U.S. Department of Energy
Technical Qualifications

Electrical Systems
Topical Area

Self-Study Guide
and
Training-to-Competency Matrices

August 1996

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The uncontrolled information contained in this text is **FOR TRAINING USE ONLY**. In no way should it be interpreted that the material contained herein may be substituted for facility procedures or SOPs. When copies of SOPs or procedures are given, they are intended as examples and information only, and the latest revision of the material in question should be obtained for actual use. If you have any questions, contact your supervisor.

READ ME FIRST!

This study guide is designed to bring together information and references related to the topical area of Electrical Systems. This document contains 34 topical competencies in 18 chapters. Each competency has the following sections: Supporting Knowledge and Skills, Self-Study Information, References, Practice Exercises, and Practice Exercise Answers. The Supporting Knowledge and Skills sections lists the applicable knowledge and skill statements that further describe the intent of the competency statements. The Self-Study Information is provided to help you refresh your knowledge of the information you need to know to be qualified in that competency. The References section lists the references for further study and information. The Practice Exercise section provides questions, practice exercise, scenarios, or case studies to assist study for the competency. Finally, the Practice Exercise Answers section provides answers to the Practice Exercise section. Additionally, an appendix provides the Training-to-Competency Matrix listing related courses and other activities that address the competency requirements.

COMPETENCIES - Which ones are mine?

The wording of the competencies found in this study guide may not exactly match those found in your Functional Area Qualification Standard. A number of similar competencies from across nine functional areas were consolidated to reduce the bulk and repetition of the material. To identify which of the 34 topical competencies in this Guide match the electrical systems related competencies from your Functional Area Qualification Standard, use the matrixes on pages xi, xii, xiii, and xiv.

PLEASE NOTE- Not all Knowledge and Skills items identified in the Functional Area Qualification Standards are addressed in the Topical Area Study Guide. Employees are not required to demonstrate competency to the knowledge and skill level in order to qualify, only to the competency level. Ensure that you refer to your Functional Area Qualification Standards and compare those required Knowledge and Skills to the Knowledge and Skills identified in this Study Guide. The Topical Area Competencies in this self study guide list the applicable Functional Area and identifies the Functional Area Competency as FAC# X.X.

WHAT REFERENCES DO I USE?

References used in this study guide are designed to be used throughout the DOE complex when possible. In some cases it is necessary to use site specific documents to provide information which more fully explains the intended knowledge and skills. For example, if a skill is to complete a report - those reports would be specific for a given site. In these situations a site specific reference will be given. In order to gain the most value from the self-study, when a site specific document is referenced, you should identify your own program/operations/field office specific reference(s) which support the requirements of knowledge and skill statement. In the event that a knowledge or skill is such that the only available references are site specific and would not necessarily change from one site to another, the reference will be identified and will accompany the study guide for your use.

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TABLE OF CONTENTS

Competency 1.5

Competency 1.6

Competency 1.7

Competency 1.8

Competency 1.9

Competency 1.10

Competency 1.11

Competency 1.12

Competency 1.13

Competency 1.14

Competency 1.15

Competency 1.16

Competency 1.17

Competency 1.18

Competency 1.19

Competency 1.20

Competency 1.21

Competency 1.22

Competency 1.23

Competency 1.28

Competency 1.29

Competency 1.30

Competency 1.34

ELECTRICAL SYSTEMSIntroduction

1. Scope and Background

The scope of this study guide is to describe requirements for understanding electrical systems within the Department of Energy (DOE) nuclear facilities. This study guide provides the participants with the required Competencies, Knowledge and Skills, Self-Study Information, and Practice Exercises necessary for the basic understanding of electrical systems and components. This study guide provides the knowledge and references for personnel to more fully understand the operation of electrical equipment for the safe and reliable operation of a facility.

This study guide has been developed to support personnel in their efforts to become more technically competent and complete the requirements of DOE's Technical Qualification Program. By providing competencies for which conduct and operation of electrical systems can be implemented, a uniform process and program can be established for defense nuclear facility technical personnel.

The competencies developed for this study guide identify a familiarity level; a working level; an expert level of knowledge or skill; or they require the individual to demonstrate the ability to perform a task or activity. These levels are defined as follows:

Familiarity level is defined as a basic knowledge of or exposure to the subject or process adequate to discuss the subject or process with individuals of greater knowledge.

Working level is defined as the knowledge required to monitor and assess operations/activities, to apply standards of acceptable performance, and to reference appropriate material and/or expert advice as required to ensure the safety of Departmental activities.

Expert level is defined as a comprehensive, intensive knowledge of the subject or process sufficient to provide advice in the absence of procedural guidance.

Demonstrate the ability is defined as the actual performance of a task or activity in accordance with policy, procedure, guidelines, and/or accepted industry or Department practices.

Due to the administrative nature of some topics of Electrical Systems, in certain cases there are no upper tier DOE related material available as reference for certain Knowledge and Skills. As a result, site specific reference material has been cited. It is the responsibility of the participating individuals to obtain their version of the referenced material used at their site/program office to assist them in understanding the Knowledge and Skills as required. To assist the participants with this study guide, a copy of the specific Savannah River Site materials have been included.

Due to the lack of appropriate technical information and documentation to support the knowledge and skills of some competency statements, some skill and knowledge statements were omitted from this version of the self study guide. Should this information become available it will be incorporated in the next revision of this document.

2. Purpose

   The purpose of this study guide is to assist personnel in preparing to demonstrate their competency in the area of knowledge of electrical systems within the Department of Energy (DOE) complex. This study guide provides the fundamentals for consistent techniques and processes, and allows the participants to focus on performance and effectiveness rather than simple compliance with requirements.

   This study guide also provides a matrix of related electrical system training courses available to the participants. The listed courses, in conjunction with the Self-Study Information can be used to satisfy and enhance the competency requirements.

3. How to Use This Guide

   a. Read this guide for those competencies you wish to satisfy through self-study. Review the associated Knowledge and Skills, Self-Study Information, and the items identified in the Reference section. Review the Self-Study Information in this guide, or in the referenced training material. For assistance or additional information, contact your supervisor or subject matter expert at your facility or site, or refer to identified resources in the Training-to-Competencies Matrix located in Appendix B.

   b. Work through the Practice Exercises provided in the document, filling your responses in the space provided. When complete, check your answers against the answers provided in the back of the competency.

   c. Refer to the Glossary (Appendix A), as needed, which contains definitions and terminology.

4. Functional Area Competencies-to-Study Guide Competencies Matrix

   a. Use the matrix on the following pages to determine which competencies in this document you should study. Identify the functional area you are assigned to in the left hand column. Go across that row until you reach a box with a number in it, that number represents the Functional Area Competency number (FAC# x.x). From that box go up the column until you reach the top of the column, the number at the top of the column represents the Topical Area Competency number. Repeat this process for each competency in your row. Locate and study those Topical Competencies in this Self Study Guide.

      Example: Locate the Project Management functional area. Notice on page xiii the matrix does not list any competencies, but on page xiv that in the second column to the right is the number 1.2. Proceeding to the Topical Area Study Guide Competencies at the top, Project Management personnel should study Competency 1.19 in this document.

   If there are no numbers in the row that contains your functional area then this document does not apply to your functional area and you are not required to complete any material in this document.

      Example: Locate the Technical Manager functional area. Notice that there are no numbers in the row to the right of the Technical Manager functional area, this means there are no competencies in this document that the Technical Manager should study.

MATRIX FUNCTIONAL AREA COMPETENCIES-TO-TOPICAL AREA STUDY GUIDE COMPETENCIES

TOPICAL AREA STUDY GUIDE COMPETENCIES

FUNCTIONAL AREA	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11	1.12	1.13	1.14	1.15	1.16	1.17
General Technical Bases																	
Facility Representative	1.8		1.9								1.10		1.10		1.10		
Technical Manager																	
Technical Training																	
Radiation Protection																	
Environmental Restoration																	
Waste Management																	
Environmental Compliance																	
Fire Protection																	
Emergency Management																	
Occupational Safety																	
Industrial Hygiene																	
Nuclear Safety																	

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MATRIX FUNCTIONAL AREA COMPETENCIES-TO-TOPICAL AREA STUDY GUIDE COMPETENCIES

FUNCTIONAL AREA	TOPICAL AREA STUDY GUIDE COMPETENCIES																
	1.18	1.19	1.20	1.21	1.22	1.23	1.24	1.25	1.26	1.27	1.28	1.29	1.30	1.31	1.32	1.33	1.34
General Technical Bases																	
Facility Representative		1.10	1.11				1.22			1.23							
Technical Manager																	
Technical Training																	
Radiation Protection																	
Environmental Restoration																	
Waste Management																	
Environmental Compliance																	
Fire Protection																	
Emergency Management																	
Occupational Safety																	
Industrial Hygiene																	
Nuclear Safety						1.12			1.13								

MATRIX FUNCTIONAL AREA COMPETENCIES-TO-TOPICAL AREA STUDY GUIDE COMPETENCIES

FUNCTIONAL AREA	TOPICAL AREA STUDY GUIDE COMPETENCIES: 1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11	1.12	1.13	1.14	1.15	1.16	1.17
Nuclear Weapons Safety																	
Civil/ Structural Engineer																	
Project Management																	
Safeguards and Security																	
Electrical Systems		1.1		1.4		1.2		1.3		1.5 1.8		1.6		1.7		1.10	
Instrumentation & Controls		1.1		1.2		1.2		1.2				1.2		1.2		1.2	
Facility Maintenance	1.8		1.9						1.9		1.9				1.9		
Construction Management			1.21		1.20 1.21		1.21				1.20 1.21		1.20 1.21		1.20 1.21		1.20
Mechanical Systems																	
EH Resident	1.7		1.8								1.9		1.9		1.9		1.35
Chemical Processing																	
Nuclear Explosives																	

CONTINUED ON NEXT PAGE

MATRIX FUNCTIONAL AREA COMPETENCIES-TO-TOPICAL AREA STUDY GUIDE COMPETENCIES

FUNCTIONAL AREA	TOPICAL AREA STUDY GUIDE COMPETENCIES																
	1.18	1.19	1.20	1.21	1.22	1.23	1.24	1.25	1.26	1.27	1.28	1.29	1.30	1.31	1.32	1.33	1.34
Nuclear Weapons Safety																	
Civil/ Structural Engineer																	
Project Management		1.2															
Safeguards and Security																	
Electrical Systems			1.9	1.11	1.12		1.15			1.15		2.1	4.1	2.10	4.3	1.14	1.16
Instrumentation & Controls	1.2		1.2					1.20			1.20						
Facility Maintenance		1.10						1.20 1.21			1.21						
Construction Management		1.20 1.21						1.8 1.9			1.9						
Mechanical Systems						1.25			1.26								
EH Resident		1.9						1.15									
Chemical Processing																	
Nuclear Explosives																	

5. DOE Orders in Transition

DOE Orders are in a stage of transition. However, Order cancellation does not necessarily mean that the Order is no longer in effect. For example, DOE Order 440.1, *Worker Safety and Health Program,* which cancels seven occupational safety-related Orders, states:

> "Cancellation of an Order does not, by itself, modify or otherwise affect any contractual obligation to comply with such an Order. Canceled Orders that are incorporated by reference in a contract shall remain in effect until the contract is modified to delete the reference to the requirements in the canceled Orders."

This study guide refers to both old and new Orders. There are three reasons for this: (1) as stated above, many facilities are contractually obligated to follow the old Orders, (2) the replacement process is dynamic and will continue for some time, and (3) the old Orders are often content-oriented and house the in-depth details regarding processes and procedures.

Rather than publish a matrix of new and old Orders within this study guide, participants should refer to the document *"Crosswalk of Old Directives Numbers to New Directives Numbering System."* This is an excellent resource. It is linked to the DOE homepage "Clearinghouse for Training, Education, and Development" or may be reached directly at the following gopher site:

gopher://VM1.HQADMIN.DOE.GOV;70/00/doemenu1/directiv/251cross.asc

Many of the referenced materials are available by accessing World Wide Web sites supported by DOE and other organizations. The constantly evolving nature of the Internet makes it impossible to guarantee the continuous existence of any referenced site, but some of the more helpful sites are included here:

- American National Standards Institute - http:www.ansi.org
- Department of Energy (DOE) Home Page - http://www.doe.gov
- DOE Clearinghouse for Training, Education and Development Home Page - http://cted.inel.gov/cted
- DOE Course Index - http://cted.inel.gov/cted/crsindex.html
- DOE Office of Training HRD, EH Training Material Page - http://cted.inel.gov/cted/eh_mat.html
- DOE OpenNet Database - http://apollo.osti.gov/html/osti/opennet1.html
- FedWorld Home Page - http://www.fedworld.gov
- U.S. House of Representatives Code of Federal Regulations - http://www.house.gov

6. Activities Following Completion of this Guide

   a. When you are ready to be evaluated on the competency(ies) applicable to your functional area, notify your supervisor, who will determine how you will be evaluated. This could include a written exam, oral checkout, or a walkdown. Note that this evaluation may be delegated by your supervisor to another DOE organization or individual (subject matter expert).

   b. Upon successfully demonstrating your competence to the evaluator, your Technical Qualification Record will be updated to document the completed competencies. The evaluator will sign off the designated competency(ies) identified on this matrix.

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U.S. Department of Energy
Technical Qualifications

Electrical Systems Topical Area

Self-Study Guide

Competencies

August 1996

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Competency 1.1

EH Residents (FAC# 1.7), Facility maintenance management (FAC# 1.8), and Facility Representatives (FAC# 1.8) personnel shall demonstrate a familiarity level knowledge of the terminology and theory of basic electrical fundamentals.

1. Supporting Knowledge and/or Skills

   a. Discuss the following terms:

      - Electrostatic force
      - Electrostatic field
      - Conductor
      - Insulator
      - Resistor

        DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter Electrical Terminology

   b. Describe the following parameters and discuss their relationship:

      - Voltage
      - Current
      - Resistance
      - Ohm's Law
      - Power
      - Inductance
      - Capacitance

        DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter Units of Electrical Measurement.

Competency 1.2

Electrical systems (FAC# 1.1) and Instrumentation and control (FAC# 1.1) personnel shall demonstrate a working level knowledge of electrical and circuit theory, terminology, theorems, laws, and analysis.

1. Supporting Knowledge and/or Skills

   a. Explain the basic law of electrostatics.

      DOE Fundamentals Handbook Electrical Science Volume 1 of 4, Chapter Atoms and Its Forces.

b. Define and discuss the following terms, including their relationship in energized circuits:

- Voltage
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter Units of Electrical Measurement.
- Current
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter Units of Electrical Measurement.
- Power
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter Units of Electrical Measurement.
- Conductor
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter Electrical Terminology.
- Insulator
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter Electrical Terminology.
- Inductance
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter Units of Electrical Measurement and Volume 2 of 4, Chapter Inductance and Chapter Inductance.
- Capacitance
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter Units of Electrical Measurement and Volume 2 of 4, Chapter Capacitance.
- Impedance
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter Impedance.
- Electromagnetic force
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter Magnetism.
- Electromagnetic field
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter Magnetism.
- Frequency
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter AC Generation Analysis.
- Resistance
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter Units of Electrical Measurement.

- Reactance
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter Inductance and Chapter Capacitance.

c. Explain the following fundamental laws of circuit analysis:

- Ohm's Law
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter Units of Electrical Measurement.
- Kirchhoff's Law
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter Kirchhoff's Law.

d. Discuss the function of the following components in an electrical circuit:

- Diode
- Rectifier
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter DC Sources.
- Transformer
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 4 of 4, Chapter Transformer Types.
- Relay
- Contact
- Fuse
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 4 of 4, Chapter System Components and Protection Devices.
- Time delay relay
- Overcurrent relay
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 4 of 4, Chapter Circuit Breakers.
- Undervoltage relay
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 4 of 4, Chapter Motor Controllers.
- Switches
- Silicon controlled rectifiers
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter DC Sources.

e. Explain the use of the following theorems in network analysis and describe their application in circuit reduction techniques:

- Thévenin's Theorem
- Norton's Theorem
- Maximum Power Transfer Theorem
- Superposition Theorem

f. Discuss the fundamental relationships in direct current (DC) circuits among voltage, current, resistance, and power.

- Voltage
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter Electrical Terminology and Units of Electrical Measurement.
- Current
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter Electrical Terminology and Units of Electrical Measurement.
- Resistance
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter Units of Electrical Measurement.
- Power
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter Units of Electrical Measurement.
- Ohm's Law
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter Units of Electrical Measurement.
- Kirchhoff's Law
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter Kirchhoff's Law.

g. Explain the treatment of inductance and capacitance values in steady-state direct current circuits.
   DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter Inductance and Chapter Capacitance.

h. Discuss the fundamental relationships in alternating current (AC) circuits among voltage, current, resistance, reactance, impedance, power, and power factor.

Ohm's Law
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter Units of Electrical Measurement.
Kirchhoff's Law
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter Kirchhoff's Law.
Reactance
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter Inductance and Chapter Capacitance.
Impedance
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter Impedance.
Power
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter Power Triangle.
Power Factor
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter Power Triangle.

i. Describe how the following methods produce a voltage:

- Electro-chemistry
- Static electricity
- Magnetic induction
- Piezo-electric effect
- Thermo-electricity
- Photoelectric effect
- Thermonic emission

DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter Methods of Producing Voltage (Electricity).

j. Using appropriate data, calculate the total resistance for a circuit containing combinations of parallel and series resistance.
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter Basic DC Circuit Calculations.

k. Using appropriate data for a circuit, calculate the reactance of that circuit.
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter Inductance and Chapter Capacitance.

2. Self-Study Information

Competency 1.1 and 1.2 address the knowledge of the basic electrical terms and theories. Competency 1.1 at a familiarity level of knowledge and Competency 1.2 at a working level of knowledge.

The supporting material for the Self-Study Information include the following documents:

- Department of Energy Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92).
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-01-LP)
- Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100).
- Bureau of Naval Personnel (1969). Basic Electricity. Washington, DC: U.S. Government Printing Office. Stock Ordering No. 0502-LP-050-4300.
- DeFrance, J. J. (1969). Electrical Fundamentals. Englewood Cliffs, NJ: Prentice-Hall, Inc. ISBN 13-247197-3. Call# TK146.D38.
- Dorf, Richard C. (editor) (1993). The Electrical Engineering Handbook. Boca Raton, FL: CRC Press Inc. ISBN 0-8493-0185-8. Call# TK145.E354.
- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Albany, NY: Delmar Publishers Inc. ISBN 0-8273-4156-3. Call# TK1141.D83.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. New York: McGraw-Hill Book Company. ISBN 0-07-020974-X. Call# TK151.S8.
- Institute of Electrical and Electronic Engineers (1990). IEEE Recommended Practice for Industrial and Commercial Power Systems Analysis (IEEE-STD-399-1990 IEEE Brown Book). New York: Institute of Electrical and Electronic Engineers Inc. ISBN 1-55937-044-0.
- Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Albany, NY: Delmar Publishers Inc. ISBN 0-8273-4146-6. Call# TK1111.L66.
- Smeaton, Robert W. (editor) (1977). Switchgear and Control Handbook. New York: McGraw-Hill Book Company. ISBN 0-07-058439-7. Call# TK2821.S88.
- Shrader, Robert L. (1977). Electrical Fundamentals for Technicians. New York: McGraw-Hill Book Company. ISBN 0-07-05714-4. Call# TK146.S557.

Superposition Theorem

This method allows more complex circuitry with multiple electrical sources to be solved using vector summation of partial circuits. The circuit is solved considering each power source individually, then the partial solutions are superimposed over one another to obtain the actual results. The results obtained would be the same as if Kirchhoff's Laws were used.

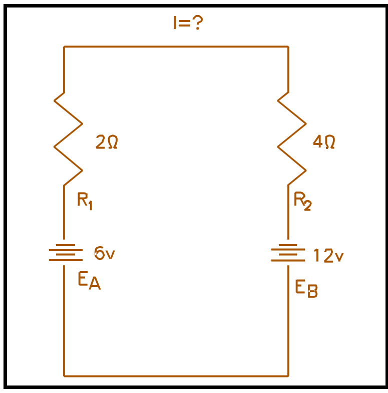


Figure 1

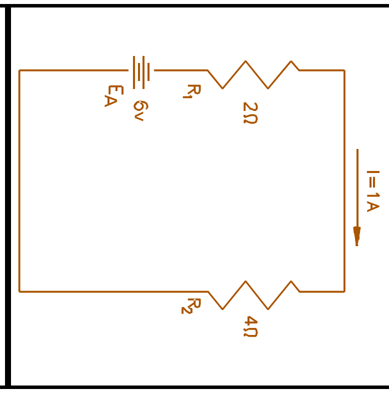


Figure 2

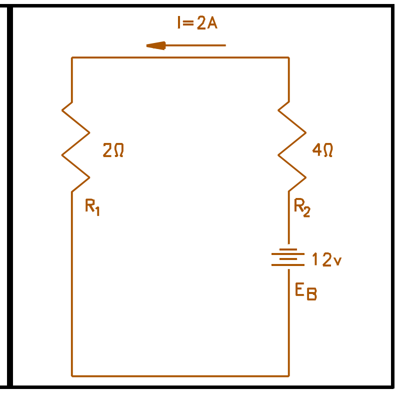


Figure 3

To solve a simple circuit problem Figure 1, imagine the circuit first without one power supply and solve the circuit with one power supply only (Figure 2). Then imagine the circuit without the second power supply and solve the circuit (Figure 3). Then combine the algebraic sum of the results and solve for the complete circuit (Figure 4).

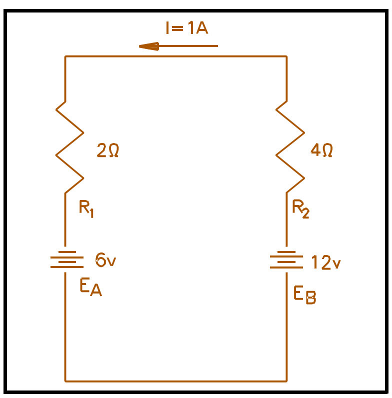


Figure 4

Example (Figure 2) with the 6 v power supply and without the 12 v power supply the circuit can be solved as a series circuit.

$R_T = R_1 + R_2$
$R_T = 2\Omega + 4\Omega$
$R_T = 6\Omega$

$$E = IR$$
$$I = \frac{E}{R}$$
$$I = \frac{6V}{6\Omega}$$
$$I = 1A\rightarrow$$

Now solve with the 12 v power supply and without the 6 V power supply (Figure 3).

$$E = IR$$
$$I = \frac{E}{R}$$
$$I = \frac{12V}{6\Omega}$$
$$I = 2A\leftarrow$$

Algebraically solving for the Total current (Figure 4):

$I_T = I_{12V} + I_{6V}$
$I_T = 2A \leftarrow + 1A \rightarrow$
$I_T = 1A \leftarrow$

In a more complex series-parallel problem (Figure 5), the same methodology is used. Solve one side first (Figure 6), then the other side (Figure 7). Then solve the algebraic sum (Figure 8 and Figure 9).

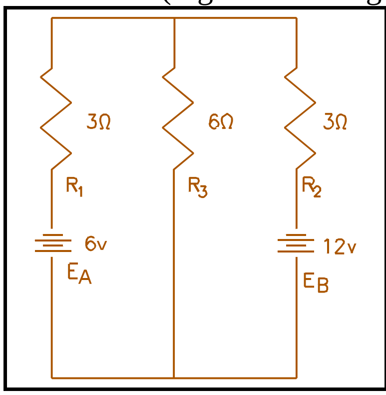


Figure 5

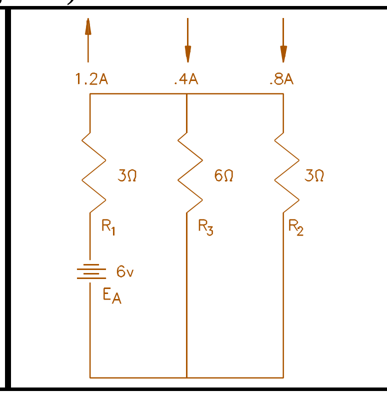


Figure 6

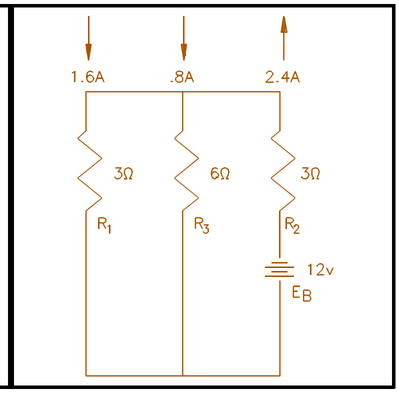


Figure 7

Given Figure 6 where R_1 is in series with the circuit and R_2 and R_3 are in parallel with one another. Solve the circuit for the 6V power supply, solve the parallel circuit resistance first.

$$R_{2,3} = \frac{R_2 \cdot R_3}{R_2 + R_3}$$

$$R_{2,3} = \frac{3 \cdot 6}{3 + 6} = \frac{18}{9} = 2\Omega$$

Solve for the total circuit resistance:

$R_T = R_1 + R_{2,3}$
$R_T = 3\Omega + 2\Omega$
$R_T = 5\Omega$

Solve for the total current:

$$E = IR$$

$$I = \frac{E}{R_T}$$

$$I = \frac{6V}{5\Omega}$$

$$I = 1.2A\uparrow$$

Solve for the voltage in the series portion and the parallel portion:
I R = E
Solve for the voltage in the series portion:
1.2A • 3Ω = 3.6 V
Solve for the voltage in the parallel portion:
1.2A • 2Ω = 2.4 V

(Reminder-check that the sum of the two equal the total voltage 3.6 + 2.4 = 6)

Now solve for the current in the series portion:

$$E = IR_1$$
$$I = \frac{E}{R_1}$$
$$I_{R_1} = \frac{3.6V}{3\Omega}$$
$$I_{R_1} = 1.2A\uparrow$$

Now solve for the current in the parallel portion:

$$E = IR$$
$$I = \frac{E}{R}$$
$$I_{R_3} = \frac{2.4V}{6\Omega}$$
$$I_{R_3} = 0.4A\downarrow$$
$$I_{R_2} = \frac{2.4V}{3\Omega}$$
$$I_{R_2} = 0.8A\downarrow$$

Given Figure 7 where R_1 is in series with the circuit and R_2 and R_3 are in parallel with one another. Solve the circuit for the 12V power supply, again solve the parallel circuit resistance first.

$$R_{1,3} = \frac{R_1 \cdot R_3}{R_1 + R_3}$$
$$R_{1,3} = \frac{3 \cdot 6}{3+6} = \frac{18}{9} = 2\Omega$$

Solve for the total circuit resistance:
$R_T = R_1 + R_{1,3}$
$R_T = 3\Omega + 2\Omega$
$R_T = 5\Omega$

Solve for the total current:

$$E = IR$$
$$I = \frac{E}{R_T}$$
$$I_{R_T} = \frac{12V}{5\Omega}$$
$$I_{R_T} = 2.4A\uparrow$$

Solve for the voltage in the series portion and the parallel portion:
I R = E
Solve for the voltage in the series portion:
2.4A • 3Ω = 7.2 V
Solve for the voltage in the parallel portion:
2.4A • 2Ω = 4.8 V

(Reminder-check that the sum of the two equal the total voltage 7.2 + 4.8 = 12)

Now solve for the current in the series portion:

$$E = IR$$
$$I = \frac{E}{R_2}$$
$$I = \frac{7.2V}{3\Omega}$$
$$I = 2.4A\uparrow$$

Now solve for the current in the parallel portion:

$$E = IR$$
$$I = \frac{E}{R}$$
$$I_{R_3} = \frac{4.8V}{6\Omega}$$
$$I_{R_3} = 0.8A\downarrow$$
$$I_{R_1} = \frac{4.8V}{3\Omega}$$
$$I_{R_1} = 1.6A\downarrow$$

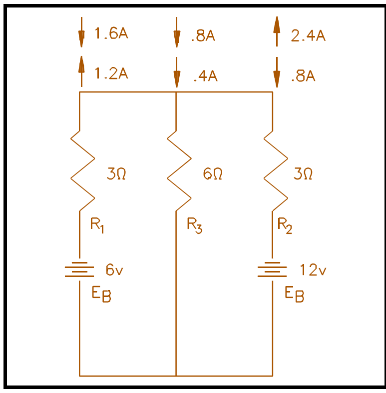


Figure 8

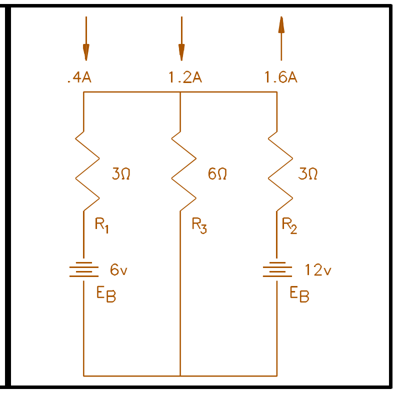


Figure 9

Now solve the algebraic sums of the current for each of the legs (Figure 8 and Figure 9);

$I_{R1} = I_{R1,6V} + I_{R1,12V}$
$I_{R1} = 1.2A\uparrow + 1.6A\downarrow$
$I_{R1} = 0.4A\downarrow$

$I_{R2} = I_{R2,6V} + I_{R2,12V}$
$I_{R2} = 0.8A\downarrow + 2.4A\uparrow$
$I_{R2} = 1.6A\uparrow$

$I_{R3} = I_{R3,6V} + I_{R3,12V}$
$I_{R3} = 0.4A\downarrow + 0.8A\downarrow$
$I_{R3} = 1.2A\downarrow$

Thévenin's Theorem

Any linear network of impedance and source, if viewed from any two points in the network can be replaced by an equivalent impedance Z_{th} in series with the equivalent voltage source E_{th}. (The term impedance means opposition to current flow and in DC circuits will be taken to mean internal resistance or R_i.)

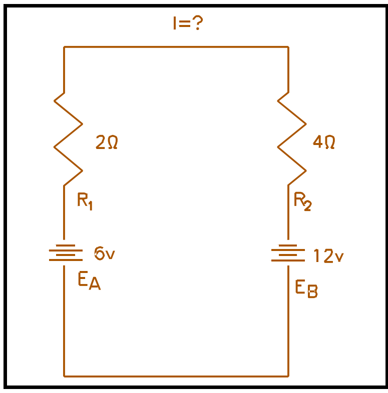


Figure 10

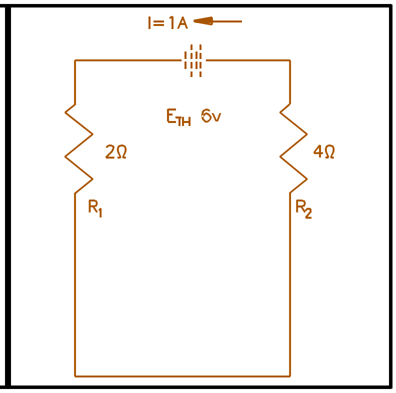


Figure 11

To solve a simple circuit problem (Figure 10), imagine the circuit first with one combined power supply and solve the circuit with one power supply only.

Example (Figure 11), by combining the two power supplies

$E_{th} = E_1 + E_2$

$E_{th} = 6V\rightarrow + 12V\leftarrow$

$E_{th} = 6V\leftarrow$

Now the circuit can be solved as a simple series circuit with a single Thévenin (E_{th}) 6V power supply with two resistors in series:

$R_T = R_1 + R_2$

$R_T = 2\Omega + 4\Omega$

$R_T = 6\Omega$

$$E = IR$$

$$I = \frac{E}{R_T}$$

$$I = \frac{6V}{6\Omega}$$

$$I = 1A\leftarrow$$

Notice that this is the same answer obtained when the similar circuit was solved using the Superposition method (Figure 4).

To solve a more complex circuit using the Thévenin Theorem requires a redrawing of the circuit to be considered. Using the same circuit we have been using (Figure 12), and solving for the load current and load voltage of R_3.

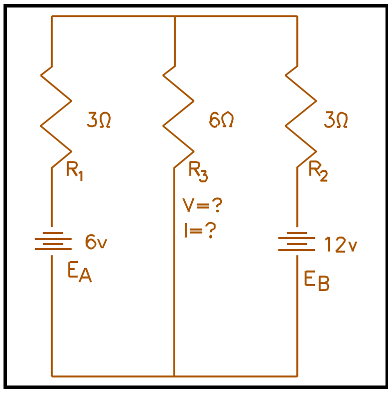


Figure 12

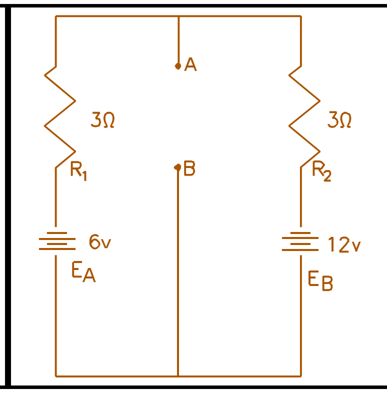


Figure 13

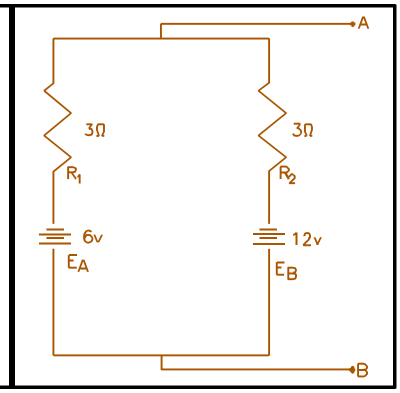


Figure 14

First disconnect the section of the circuit that is to be evaluated (Figure 13). This creates terminal ends we will refer to as A and B. Then calculate the voltage at the load terminals. With R_3 removed the circuit becomes a simple series calculation with two resistors (R_1 and R_2) and two power supplies (6V and 12V) (Figure 14).

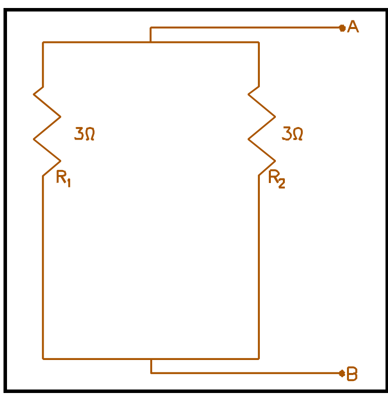


Figure 15

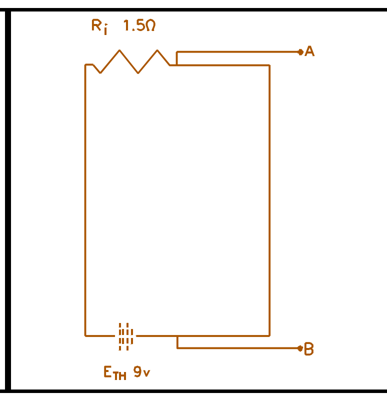


Figure 16

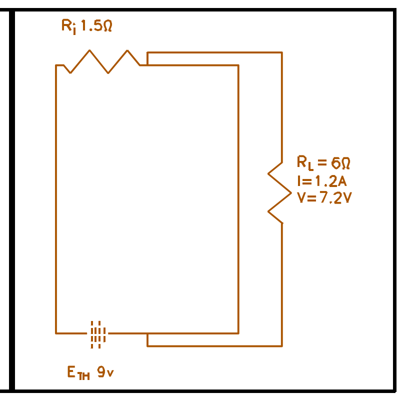


Figure 17

The net voltage (E_{net}) becomes the algebraic sum of the two power supplies, in this case 6V (Figure 16). Now solve for the voltage across the terminals (E_{AB}):

$$I = \frac{E_{net}}{R_1 + R_2} = \frac{6V}{6\Omega} = 1A$$

$$E_{AB} = E_{OC} = E_B - IR_1 = 12V - (1A \cdot 3\Omega) = 9V$$

To solve the circuit, consider both voltage sources as a short, with negligible internal resistance (Figure 15). Now consider the circuit from the point of view of the load. R_1 and R_2 now are in parallel with one another. Solve for the internal resistance (R_i) of the circuit.

$$R_i = \frac{R_1 \cdot R_2}{R_1 + R_2} = \frac{3 \cdot 3}{3 + 3} = \frac{9}{6} = 1.5\Omega$$

Now the Thévenin equivalent circuit can be drawn (Figure 16), where R_i is 1.5Ω and the E_{th} is 9V.

Solving for the load current becomes:

$$I_L = \frac{E_{OC}}{R_i + R_L} = \frac{9V}{1.5\Omega + 6\Omega} = \frac{9V}{7.5\Omega} = 1.2A$$

And solving for the load voltage is (Figure 17):
$E_L = I_L \bullet R_L$
$E_L = 1.2A \bullet 6\Omega$
$E_L = 7.2V$

These are the same values obtain when computed using either Kirchhoff's Laws or the Superposition Theorem. The benefit of solving problems using Thévenin's theorem is that if it is necessary to solve the problem for several different loads once the voltage (E_{OC}) and resistance (R_i) is solved for it is only necessary to substitute the new load value in to the final equations. Any other previous method introduced would require the entire calculation to be preformed.

Norton's Theorem

Any linear network of impedance and sources, if viewed from any two points in the network, can be replaced by an equivalent impedance Z_{th} in shunt with an equivalent current source I_{th} (or I_{sc}). (The term impedance means opposition to current flow and in DC circuits will be taken to mean shunt resistance or R_{sh}.)

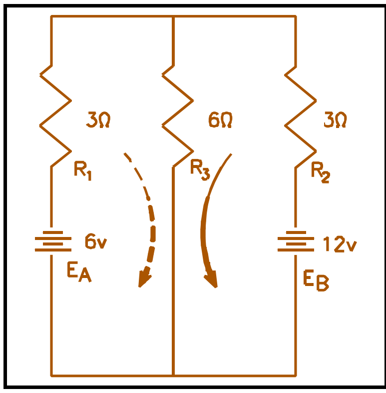


Figure 18

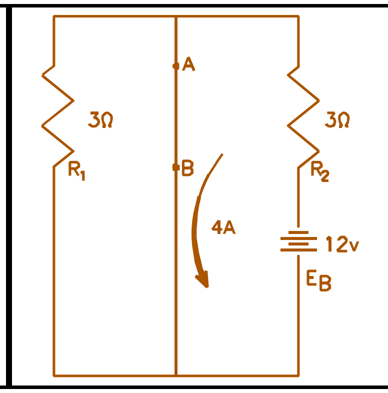


Figure 19

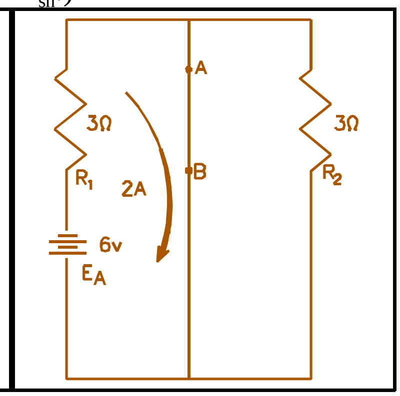


Figure 20

Using the same circuit we have been using (Figure 18), and solving for the load current and load voltage of R_3. To find the current value it is necessary to evaluate the circuit with R_3 shorted.

Then using the Superposition Theorem solve the circuit with the individual power supplies. First consider remove and replacing the 6V power supply with a negligible internal resistance (Figure 19). The current flow path is from the 12V battery through R_2, the shorted R_3 (points AB), and returning to the 12V power supply.

$$E = IR$$
$$I_{AB} = \frac{E}{R_2}$$
$$I_{AB} = \frac{12V}{3\Omega}$$
$$I_{AB} = 4A\downarrow$$

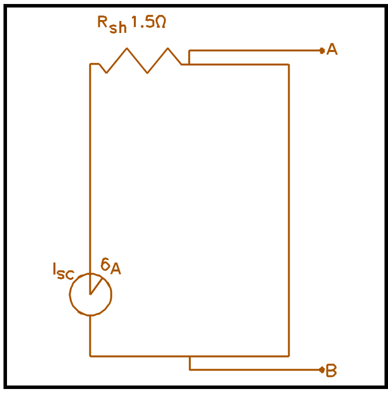
Then consider replacing the 12V power supply with a negligible internal resistance and solving for the 6V circuit (Figure 20). The current flow path then becomes from the 6V battery through R_1, the short R_3 (points AB), and returning to the 6V power supply.

$$E = IR$$
$$I_{AB} = \frac{E}{R_1}$$
$$I_{AB} = \frac{6V}{3\Omega}$$
$$I_{AB} = 2A\downarrow$$

Therefore the Norton constant-current source (I_{sc}) becomes:
$I_{sc} = I_{AB} + I_{AB} = 4A + 2A = 6A$

If the circuit is redrawn to show the load as a shunt resistance, the two resistors R_1 and R_2 become a parallel circuit. Solving for the Norton shunt resistance (R_{sh}) becomes:

$$R_{sh} = \frac{R_1 \cdot R_2}{R_1 + R_2} = \frac{3 \cdot 3}{3+3} = \frac{9}{6} = 1.5\Omega$$



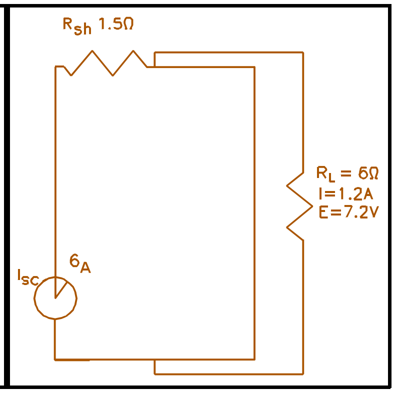


Figure 21 **Figure 22**

The Norton equivalent circuit can be drawn and the current and load solved for similarly to the process used in the Thévenin process (Figure 21).

$$I_L = I_{sc}\frac{R_{sh}}{R_{sh} + R_L} = 6A \times \frac{1.5\Omega}{1.5\Omega + 6\Omega} = \frac{9A}{7.5} = 1.2A$$

And solving for the load voltage is (Figure 22):
$E_L = I_L \bullet R_L = 1.2A \bullet 6\Omega$
$E_L = 7.2V$

3. References

NOTE: For information regarding the Supporting Knowledge and Skills refer to the Self-Study Information section of this competency.

a. For Supporting Knowledge and Skills **1.1-1.a** and **1.2-1.a** refer to:
   - Westinghouse Savannah River Company Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100) Chapter Electrical Forces, Chapter Electrical Terminology.
   - Fink, Donald G. and H. Wayne Beatty (1978). <u>Standard Handbook for Electrical Engineering</u>. Chapter Electric and Magnetic Circuits.
   - Bureau of Naval Personnel (1969). <u>Basic Electricity</u>. Chapter Fundamental Concepts of Electricity.
   - Loper, Orla E. and Edgar Tedsen (1991). <u>Direct Current Fundamentals</u>. Chapter Electrostatics.

b. For supporting Knowledge and Skills **1.1-1.b** and **1.2-1.b** refer to:
   - Westinghouse Savannah River Company Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100) Chapter Electrical Terminology, Chapter Units of Electrical Measurement, Chapter DC Circuits.
   - Fink, Donald G. and H. Wayne Beatty (1978). <u>Standard Handbook for Electrical Engineering</u>. Chapter Quantities, Units, Symbols, Constants, and Conversion Factors.
   - Bureau of Naval Personnel (1969). <u>Basic Electricity</u>. Chapter Fundamental Concepts of Electricity, Series DC Circuits, Parallel DC Circuits, Network Analysis of DC Circuits.
   - Loper, Orla E. and Edgar Tedsen (1991). <u>Direct Current Fundamentals</u>. Chapter Basic Circuit Concepts, Chapter Resistance.
   - DOE-SR Office of Training Facility Representative Advance Nuclear Course. <u>Electrical Theory, Safety, and Equipment</u> Instructor Lesson Plan (DOE-OT-FRANC-105-01-LP) Module Basic Electrical Theory.

c. For Supporting Knowledge and Skills **1.2-1.c** refer to:
   - Westinghouse Savannah River Company Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100) Chapter DC Circuits, Chapter Kirchhoff's Laws.
   - Fink, Donald G. and H. Wayne Beatty (1978). <u>Standard Handbook for Electrical Engineering</u>. Chapter Electric and Magnetic Circuits.
   - Bureau of Naval Personnel (1969). <u>Basic Electricity</u>. Chapter Series DC Circuits, Parallel DC Circuits, Network Analysis of DC Circuits.
   - Loper, Orla E. and Edgar Tedsen (1991). <u>Direct Current Fundamentals</u>. Chapter Ohm's Law, Chapter Series-Parallel Circuits and Loaded Voltage Dividers.

- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-01-LP) Module Basic Electrical Theory.

d. For Supporting Knowledge and Skills **1.2-1.d** refer to:
- Westinghouse Savannah River Company Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100) Chapter Transformers, Chapter System Components and Protective Devices, Chapter Circuit Breakers, Chapter Motor Controllers, Chapter Switches.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering.
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter series DC Circuits, Circuit Protective and Control Devices, Electrical Indicating Instruments, Alternating Current Generators and Transformers.
- Smeaton, Robert W. (editor) (1977). Switchgear and Control Handbook. Chapter Control Circuit Devices.

e. For Supporting Knowledge and Skills **1.2-1.e** refer to:
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Network Analysis of D-C Circuits, Chapter Series D-C Circuits.
- DeFrance, J. J. (1969). Electrical Fundamentals. Chapter ?
- Dorf, Richard C. (editor) (1993). The Electrical Engineering Handbook. Chapter Linear Analysis section 3.3 and 3.4.
- Shrader, Robert L. (1977). Electrical Fundamentals for Technicians. Chapter ?
- Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Solving DC Networks.
- Institute of Electrical and Electronic Engineers (1990). IEEE Recommended Practice for Industrial and Commercial Power Systems Analysis (IEEE-STD-399-1990 IEEE Brown Book). Chapter Analytical Procedures.

f. For Supporting Knowledge and Skills **1.2-1.f** refer to:
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Series DC Circuits, Parallel DC Circuits, Network Analysis of DC Circuits.
- Westinghouse Savannah River Company Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100) Chapter Electrical Terminology, Chapter Units of Electrical Measurement, Chapter DC Circuits, Chapter Kirchhoff's Laws.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Quantities, Units, Symbols, Constants, and Conversion Factors and Chapter Electric and Magnetic Circuits.
- Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Ohm's Law, Chapter Series-Parallel Circuits and Loaded Voltage Dividers.

- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-01-LP) Module Basic Electrical Theory.

g. For Supporting Knowledge and Skills **1.2-1.g** refer to:
  - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Inductance, Chapter Capacitance.
  - Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Quantities, Units, Symbols, Constants, and Conversion Factors and Chapter Electric and Magnetic Circuits.

h. For Supporting Knowledge and Skills **1.2-1.h** refer to:
  - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Series DC Circuits, Parallel DC Circuits, Network Analysis of DC Circuits, Inductive and Capacitive Reactance.
  - Westinghouse Savannah River Company Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100) Chapter Electrical Terminology, Chapter Units of Electrical Measurement, Chapter DC Circuits, Chapter Kirchhoff's Laws.
  - Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Quantities, Units, Symbols, Constants, and Conversion Factors and Chapter Electric and Magnetic Circuits.
  - Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Ohm's Law, Chapter Series-Parallel Circuits and Loaded Voltage Dividers.

i. For Supporting Knowledge and Skills **1.2-1.i** refer to:
  - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Fundamental Concepts of Electricity, Chapter Batteries.
  - Westinghouse Savannah River Company Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100) Chapter Magnetism and Magnetic Induction, Chapter DC Sources.
  - Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Alternate Sources and Converters of Power.
  - Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Electricity Production and Use.
  - DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-01-LP) Module Basic Electrical Theory.

j. For Supporting Knowledge and Skills **1.2-1.j** refer to:
  - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Series DC Circuits, Parallel DC Circuits, Network Analysis of DC Circuits.

- Westinghouse Savannah River Company Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100) Chapter DC Circuits, Chapter Kirchhoff's Laws.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Electric and Magnetic Circuits.
- Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Ohm's Law, Chapter Series Circuits, Chapter Parallel Circuits, Chapter Series-Parallel Circuits and Loaded Voltage Dividers.

k. For Supporting Knowledge and Skills **1.2-1.k** refer to:
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Series Inductive and Capacitive Reactance.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Electric and Magnetic Circuits.
- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals. Chapter Inductance in Alternating-Current Circuits, Chapter Capacitors in Alternating-Current Circuits.

4. Practice Exercise

   a. Define the term **Electrostatic force**. (K&S 1.1-1.a.)

   b. Materials with electrons that are tightly bound to their atoms and require large amounts of energy to free them from the influence of the nucleus. These materials are referred to as a: (K&S 1.1-1.a.)

      1) Conductor

      2) Insulator

      3) Semi-conductor

      4) Transformer

   c. Define the electrical parameter current, including the symbol and units of measurement. (K&S 1.1-1.b.) (K&S 1.2-1.b.)

   d. Define the electrical parameter voltage, including the symbol and units of measurement. (K&S 1.1-1.b.) (K&S 1.2-1.b.)

e. Which one of the equations below is the equation for power? (K&S 1.1-1.b.) (K&S 1.2-1.b.)

   1) P = I R

   2) P = I E

   3) P = I R^2

   4) P = I / E

f. The ability to store an electric charge is measured in: (K&S 1.1-1.b.) (K&S 1.2-1.b.)

   1) Capacity

   2) Henrys

   3) Everreadies

   4) Farads

g. Define the term **Inductance** and include its relationship in energized circuits: (K&S 1.1-1.b.) (K&S 1.2-1.b.)

h. State the Ohm's Law of circuit analysis three ways: (K&S 1.1-1.b.) (K&S 1.2-1.c.)

   1.

   2.

   3.

i. Explain the basic law of electrostatics. (K&S 1.2-1.a.)

j. The definition of **impedance** is: (Select ONE) (K&S 1.2-1.c.)

1) The amount the current flow in a circuit is reduced due to resistance.
2) The total opposition to current flow in a circuit.
3) The ability to store resistance in a circuit.
4) The ability to induce a voltage in a circuit due to resistance to a magnetic field.

k. Using Ohm's Law and given that the current flow is 5 Amps and the voltage is 120 V, calculate the circuit resistance. (K&S 1.2-1.c.)

l. Using Ohm's Law and given the voltage is 24 V and the resistance is 240 Ω, what current will flow through a circuit? (K&S 1.2-1.c.)

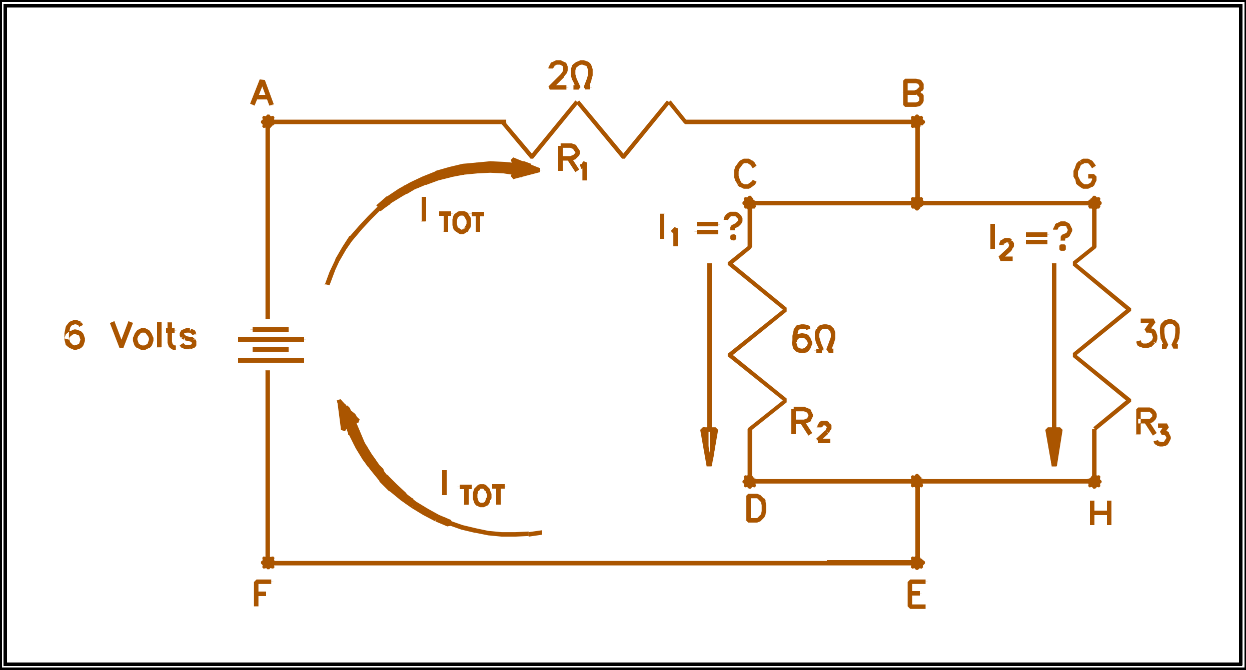
m. Using Ohm's Law and given circuit current is 25 Amps and circuit resistance is 552 ohms, calculate the applied voltage. (K&S 1.2-1.c.)

n. State Kirchhoff's Voltage and Current Laws of circuit analysis: (K&S 1.2-1.c.)

Voltage Law:

Current Law:

o. Calculate the value of current in leg 1 (I_1) in the circuit shown in below using Kirchhoff's Voltage and Current Laws. (K&S 1.2-1.c.)



p. Discuss the function of the following components in an electrical circuit: (K&S 1.2-1.d.)

- Resistor

- Diode

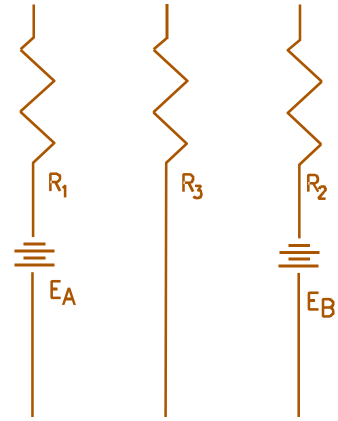
- Relay

q. Explain the use of the following theorems in network analysis and describe their application in circuit reduction techniques: (K&S 1.2-1.e.)

- Norton's Theorem

- Superposition Theorem

r. Given the following schematic with the following values: E_A is 1.5V, E_B is 12V, R_1 is 5Ω, R_2 is 15Ω, R_3 is 10Ω. Calculate the value of the current in R_3 using the following methods: (K&S 1.2-1.e.)



a. Superposition Theorem

b. Thévenin's Theorem

c. Norton Theorem

s. Discuss the fundamental relationships in direct current (DC) circuits among voltage, current, resistance, and power. (K&S 1.2-1.f.)

- Show the relationship between power and voltage.

- Show the relationship between resistance and voltage.

- Show the relationship between power and resistance.

t. State the formula(s) for inductance and capacitance in steady-state direct current circuits. (K&S 1.2-1.g.)

u. Discuss the fundamental relationships in alternating current (AC) circuits among voltage, current, resistance, reactance, impedance, power, and power factor. (K&S 1.2-1.h.)

v. Match the descriptions below in column A with the methods of producing electricity below in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.2-1.i.)

Column A	Column B
__ 1. By applying pressure to certain crystals electrons can be driven out of orbit in the direction of the force.	a. Thermo-electricity
	b. Static electricity
__ 2. Produces a voltage by rotating coils of wire through a stationary magnetic field.	c. Magnetic induction
__ 3. When the photons in a light beam strike the surface of a material, they transfer energy to the atomic electrons of the material. This energy transfer may dislodge electrons from their orbits around the surface of the substance.	d. Piezo-electric effect
	e. Electro-chemistry
	f. Photoelectric effect
__ 4. Chemicals can be combined with certain metals to cause a reaction that will transfer electrons to produce electrical energy.	

w. Describe how the following methods produce a voltage: (K&S 1.2-1.i.)

- Static electricity

- Thermo-electricity

x. A series circuit has a 50 Ω, a 100 Ω, and a 150 Ω resistor in series. Calculate the total resistance of the circuit? (K&S 1.2-1.j.)

y. A series circuit has a 300 Ω, a 50 Ω, and a 100 Ω resistor in series. Calculate the voltage necessary to produce a current of 0.25 amps. (K&S 1.2-1.j.)

z. Two resistors, each drawing 5 amps, and a third resistor, drawing 3 amps, are connected in parallel across a 115 volt source. Calculate the total current. (K&S 1.2-1.j.)

aa. Calculate the total resistance of a 5 Ω, a 5 Ω, and a 3 Ω resistor in parallel. (K&S 1.2-1.j.)

ab. Given a circuit with the following parameters, calculate the reactance of the circuit. Frequency is 60 hertz and the inductance is 15 Henrys. (K&S 1.2-1.k.)

ac. Given an AC circuit with the following parameters, calculate the reactance of the circuit. Frequency is 60 hertz and the capacitance is 5×10^{-6} farads. (K&S 1.2-1.k.)

ad. Given the circuit of an AC generator with the following parameters, calculate the reactance of the circuit. The generator has 4 poles, a speed of 750 rpm, and the inductance is 25 Henrys. (K&S 1.2-1.k.)

ae. Given an AC circuit the following parameters, calculate the reactance of the circuit. The generator has 8 poles, a speed of 900 rpm, and the capacitance is 25 μfarads. (K&S 1.2-1.k.)

5. Practice Exercise Answers

   a. Define the term **Electrostatic force**. (K&S 1.1-1.a.)

      The force that attracts the electron and the nucleus to each other. The force that holds the electron in orbit.

$$F = K\frac{q_1 \cdot q_2}{d^2}$$

   b. Materials with electrons that are tightly bound to their atoms and require large amounts of energy to free them from the influence of the nucleus. These materials are referred to as a: (K&S 1.1-1.a.)

      1) Conductor

      2) Insulator

      3) Semi-conductor

      4) Transformer

   c. Define the electrical parameter current, including the symbol and units of measurement. (K&S 1.1-1.b.) (K&S 1.2-1.b.)

      The movement or flow of electrons is called *electron current flow* or just *current*.

      The symbol for current is (I). The basic measurement for current is the ampere (A).

      To produce current, the electrons must be moved by a potential difference.

d. Define the electrical parameter voltage, including the symbol and units of measurement. (K&S 1.1-1.b.) (K&S 1.2-1.b.)

   Voltage, electromotive force (emf), or potential difference, is described as the pressure or force that causes electrons to move in a conductor.

   The symbol for voltage, electromotive force (emf), or potential difference is (E) or (V). The basic measurement unit of measurement is the volt (V).

   Applied voltage equals circuit current times the circuit resistance. E = I R (Also since written as V = I R .)

e. Which one of the equations below is the equation for power? (K&S 1.1-1.b.) (K&S 1.2-1.b.)

   1) P = I R

   2) P = I E

   3) P = $I R^2$

   4) P = I / E

f. The ability to store an electric charge is measured in: (K&S 1.1-1.b.) (K&S 1.2-1.b.)

   1) Capacity

   2) Henrys

   3) Everreadies

   4) Farads

g. Define the term **Inductance** and include its relationship in energized circuits: (K&S 1.1-1.b.) (K&S 1.2-1.b.)

The ability of a coil to store energy, induce a voltage in itself, and oppose changes in current flowing through it. The symbol used to indicate inductance in electrical formulas and equations is a capital L. The units of measurement are called henries. The unit henry is abbreviated by using the capital letter H. One henry is the amount of inductance (L) that permits one volt to be induced (V_L) when the current through the coil changes at a rate of one ampere per second. The mathematical representation of the rate of change in current through a coil per unit time is

$$\left(\frac{\Delta I}{\Delta t} \right)$$

The mathematical representation for the voltage V_L induced in a coil with inductance L is shown below. A negative sign indicates that voltage induced opposes the change in current through the coil per unit time ($\Delta I/\Delta t$).

$$V_L = -L \left(\frac{\Delta I}{\Delta t} \right)$$

h. State the Ohm's Law of circuit analysis three ways: (K&S 1.1-1.b.) (K&S 1.2-1.c.)

1. Applied voltage equals circuit current times the circuit resistance. E = I x R

2. Current is equal to the applied voltage divided by the circuit resistance.

$$I = \frac{E}{R}$$

3. Resistance of a circuit is equal to the applied voltage divided by the circuit current.

$$R \text{ (or } \Omega) = \frac{E}{I}$$

i. Explain the basic law of electrostatics. (K&S 1.2-1.a.)

The strength of the attraction or of the repulsion force depends upon two factors: (1) the amount of charge on each object, and (2) the distance between the objects. The greater the charge on the objects, the greater the electrostatic field. The greater the distance between the objects, the weaker the electrostatic field between them, and vice versa. This leads us to the law of electrostatic attraction, commonly referred to as Coulomb's Law of electrostatic charges, which states that the force of electrostatic attraction, or repulsion, is directly proportional to the product of the two charges and inversely proportional to the square of the distance between them.

$$F = K\frac{q_1 \cdot q_2}{d^2}$$

If q_1 and q_2 are both either positively or negatively charged, the force is positive and is repulsive. If q_1 and q_2 are opposite polarity or charge, the force is negative and is attractive.

j. The definition of **impedance** is: (Select ONE) (K&S 1.2-1.c.)

1) The amount the current flow in a circuit is reduced due to resistance.

2) The total opposition to current flow in a circuit.

3) The ability to store resistance in a circuit.

4) The ability to induce a voltage in a circuit due to resistance to a magnetic field.

k. Using Ohm's Law and given that the current flow is 5 Amps and the voltage is 120 V, calculate the circuit resistance. (K&S 1.2-1.c.)

$$R = \frac{E}{I} \quad R = \frac{120\ V}{5\ A} = 24\ \Omega$$

l. Using Ohm's Law and given the voltage is 24 V and the resistance is 240 Ω, what current will flow through a circuit? (K&S 1.2-1.c.)

$$I = \frac{E}{R} \quad I = \frac{24\ V}{240\ \Omega} = 0.1\ A$$

m. Using Ohm's Law and given circuit current is 25 Amps and circuit resistance is 552 ohms, calculate the applied voltage. (K&S 1.2-1.c.)

$E = I R$

$E = (25\text{ A})(552\ \Omega) = 13800\text{ V}$

n. State Kirchhoff's Laws of circuit analysis for Voltage and Current: (K&S 1.2-1.c.)

Voltage Law: The sum of the voltage drops around a closed loop is equal to the sum of the voltage sources of that loop (Kirchhoff's Voltage Law).

$E_{source} = E_1 + E_2 + E_3 + \text{etc.}$

$E_{source} = I_1 R_1 + I_2 R_2 + I_3 R_3 + \text{etc.}$

$\Sigma E_{source} = \Sigma I R$

Current Law: The current arriving at any junction point in a circuit is equal to the current leaving that junction (Kirchhoff's Current Law).

$I_{IN} - I_{OUT} = 0$ or $I_{IN} = I_{OUT}$

o. Calculate the value of current in leg 1 (I_1) in the circuit shown in below using Kirchhoff's Voltage and Current Laws. (K&S 1.2-1.c.)

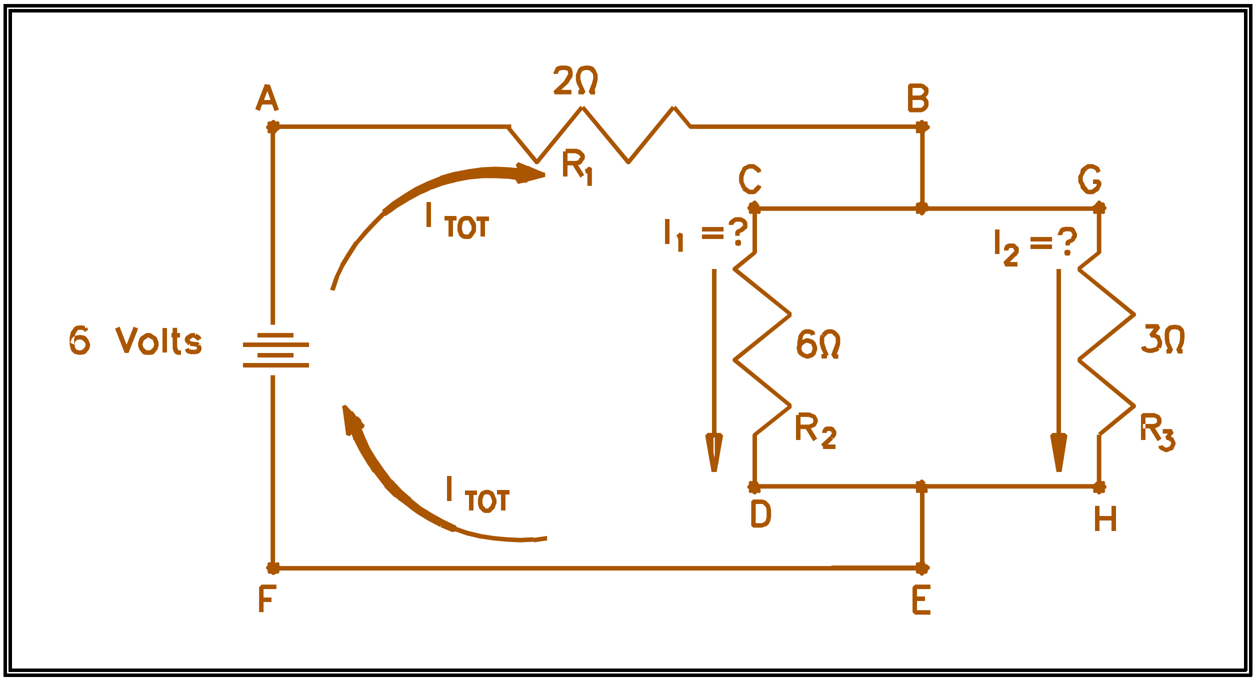
Solution: (Alternate solutions are acceptable as long as they use valid methodology.)

First, apply Kirchhoff's Voltage Law to both loops.

Loop ABCDEF	Loop ABGHEF
$\sum E_{source} = \sum I R$	$\sum E_{source} = \sum I R$
$\sum E_{source} = (I_{total})(R_1) + (I_1)(R_2)$	$\sum E_{source} = (I_{total})(R_1) + (I_2)(R_3)$
$6\text{ v} = (I_{total})(2\ \Omega) + (I_1)(6\ \Omega)$	$6\text{ v} = (I_{total})(2\ \Omega) + (I_2)(3\ \Omega)$

Since 6 v = 6 v, then Loop ABCDEF = Loop ABGHEF. Substitute in:

$(I_{total})(2\ \Omega) + (I_1)(6\ \Omega) = (I_{total})(2\ \Omega) + (I_2)(3\ \Omega)$



To solve for I_2, get I_2 as the only unknown on one side so subtract $(I_{total})(2\ \Omega)$ from the side with I_2 on it. Therefore you must subtract $(I_{total})(2\ \Omega)$ from the other side also.

$$(I_{total})(2\ \Omega) - (I_{total})(2\ \Omega) + (I_1)(6\ \Omega) = (I_{total})(2\ \Omega) - (I_{total})(2\ \Omega) + (I_2)(3\ \Omega)$$

$$(I_1)(6\ \Omega) = (I_2)(3\ \Omega)$$

Divide both sides by 3 Ω to get I_2 alone.

$$(I_1)(6\ \Omega) \div (3\ \Omega) = (I_2)(3\ \Omega) \div (3\ \Omega)$$

Therefore I_2 is equal to:

$$(I_1)2 = I_2$$

According the Kirchhoff's Current Law:

$$I_{total} = I_1 + I_2$$

$$I_{total} = I_1 + (I_1)2$$

$$I_{total} = 3(I_1)$$

Returning to Kirchhoff's Voltage Law for Loop ABCDEF

$\sum E_{source} = (I_{total})(R_1) + (I_1)(R_2)$

$6\text{ v} = (I_{total})(2\ \Omega) + (I_1)(6\ \Omega)$

$6\text{ v} = (3(I_1))(2\ \Omega) + (I_1)(6\ \Omega)$

$6\text{ v} = (I_1)(6\ \Omega) + (I_1)(6\ \Omega)$

$6\text{ v} = (I_1)(12\ \Omega)$

$6\text{ v} \div 12\ \Omega = (I_2)(12\ \Omega) \div (12\ \Omega)$

$6\text{ v} \div 12\ \Omega = I_1$

$$I_1 = \frac{E}{R}$$

$$I_1 = \frac{6\text{ V}}{12\ \Omega} = 0.5\text{ A}$$

p. Discuss the function of the following components in an electrical circuit: (K&S 1.2-1.d.)

- Resistor - electrical device whose chief characteristic is resistance; used to use the flow of electrical current.

- Diode - electrical device that allows electron flow in only one direction. Used in rectifiers. Used to convert AC to DC.

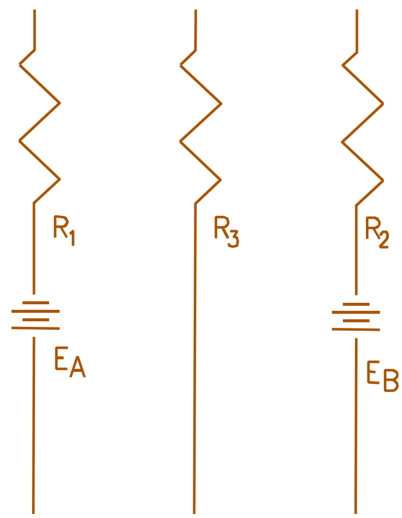
- Relay - an electromagnetic device with one or more sets of contacts which changes contact positions by magnetic attraction of a coil to an armature.

q. Explain the use of the following theorems in network analysis and describe their application in circuit reduction techniques: (K&S 1.2-1.e.)

- Superposition Theorem - This method allows more complex circuitry with multiple electrical sources to be solved using vector summation of partial circuits. The circuit is solved considering each power source individually, then the partial solutions are superimposed over one another to obtain the actual results.

- Thévenin's Theorem - Any linear network of impedance and source, if viewed from any two points in the network can be replaced by an equivalent impedance Z_{th} in series with the equivalent voltage source E_{th}.

r. Given the following schematic with the following values: E_A is 1.5V, E_B is 12V, R_1 is 5Ω, R_2 is 15Ω, R_3 is 10Ω. Calculate the value of the current in R_3 using the following methods: (K&S 1.2-1.e.)



a. Superposition Theorem

Solve the circuit for the 1.5V power supply, solve the parallel circuit resistance first.

$$R_{2,3} = \frac{R_2 \cdot R_3}{R_2 + R_3}$$

$$R_{2,3} = \frac{10 \cdot 15}{10 + 15} = \frac{150}{25} = 6\Omega$$

Solve for the total circuit resistance:
$R_T = R_1 + R_{2,3}$
$R_T = 5\Omega + 6\Omega$
$R_T = 11\Omega$

Solve for the total current:

$$E = IR$$

$$I = \frac{E}{R_T}$$

$$I = \frac{1.5V}{11\Omega}$$

$$I = 0.136A\uparrow$$

Solve for the voltage in the parallel portion:
0.136A • 6Ω = 0.818 V

Now solve for the current in the parallel portion:

$$E = IR$$

$$I = \frac{E}{R}$$

$$I_{R_3} = \frac{0.818V}{10\Omega}$$

$$I_{R_3} = 0.0818A\downarrow$$

Solve the circuit for the 12V power supply, again solve the parallel circuit resistance first.

$$R_{1,3} = \frac{R_1 \cdot R_3}{R_1 + R_3}$$

$$R_{1,3} = \frac{5 \cdot 10}{5 + 10} = \frac{50}{15} = 3.33\Omega$$

Solve for the total circuit resistance:
$R_T = R_2 + R_{1,3}$
$R_T = 15\Omega + 3.33\Omega$
$R_T = 18.33\Omega$

Solve for the total current:

$$E = IR$$

$$I = \frac{E}{R_T}$$

$$I_{R_T} = \frac{12V}{18.33\Omega}$$

$$I_{R_T} = 0.654A\uparrow$$

Solve for the voltage in the parallel portion:
.654A • 3.33Ω = 2.182 V
Now solve for the current in the parallel portion:

$$E = IR$$

$$I = \frac{E}{R}$$

$$I_{R_3} = \frac{2.182V}{10\Omega}$$

$$I_{R_3} = 0.218A\downarrow$$

Now solve the algebraic sum of the current for the R_3 leg:

$I_{R3} = I_{R3,6V} + I_{R3,12V}$
$I_{R3} = 0.0818A\downarrow + 0.218A\downarrow$
$I_{R3} = 0.3A\downarrow$

b. Thévenin's Theorem

The net voltage (E_{net}) becomes the algebraic sum of the two power supplies, in this case 6V (Figure 16). Now solve for the voltage across the terminals (E_{AB}):

$$I = \frac{E_{net}}{R_1 + R_2} = \frac{10.5V}{5\Omega + 15\Omega} = \frac{10.5V}{20\Omega} = .525A$$

$$E_{AB} = E_{OC} = E_B - IR_2 = 12V - (0.525A \cdot 15\Omega) = 4.125V$$

To solve the circuit, consider both voltage sources as a short, with negligible internal resistance. Now consider the circuit from the point of view of the load. R_1 and R_2 now are in parallel with one another. Solve for the internal resistance (R_i) of the circuit.

$$R_i = \frac{R_1 \cdot R_2}{R_1 + R_2} = \frac{5 \cdot 15}{5 + 15} = \frac{75}{20} = 3.75\Omega$$

Solving for the load current becomes:

$$I_L = \frac{E_{OC}}{R_i + R_L} = \frac{4.125V}{3.75\Omega + 10\Omega} = \frac{4.125V}{13.75\Omega} = 0.3A$$

c. Norton Theorem

First consider remove and replacing the 6V power supply with a negligible internal resistance.

$$E = IR$$
$$I_{AB} = \frac{E}{R_2}$$
$$I_{AB} = \frac{12V}{15\Omega}$$
$$I_{AB} = 0.8A\downarrow$$

Then consider replacing the 12V power supply with a negligible internal resistance and solving for the 6V circuit.

$$E = IR$$
$$I_{AB} = \frac{E}{R_1}$$
$$I_{AB} = \frac{1.5V}{5\Omega}$$
$$I_{AB} = 0.3A\downarrow$$

Therefore the Norton constant-current source (I_{sc}) becomes:
$I_{sc} = I_{AB} + I_{AB} = 0.8A + 0.3A = 1.1A$

Solving for the Norton shunt resistance (R_{sh}) becomes:

$$R_{sh} = \frac{R_1 \cdot R_2}{R_1 + R_2} = \frac{5 \cdot 15}{5 + 15} = \frac{75}{20} = 3.75\Omega$$

The Norton equivalent circuit can be drawn and the current and load solved for similarly to the process used in the Thévenin process.

$$I_L = I_{sc}\frac{R_{sh}}{R_{sh} + R_L} = 1.1A \times \frac{3.75\Omega}{3.75\Omega + 10\Omega} = \frac{4.125A}{13.75} = 0.3A$$

s. Discuss the fundamental relationships in direct current (DC) circuits among voltage, current, resistance, and power. (K&S 1.2-1.f.)

- Show the relationship between power and voltage.

  P = I E or $P = \frac{V^2}{R}$

- Show the relationship between resistance and voltage.

  E = I R
  or
  E/I = R

- Show the relationship between power and resistance.

  P = I E and E = I R therefore

  P = I I R or P = I^2 R or P = $\frac{V^2}{R}$

t. State the formula(s) for inductance and capacitance in steady-state direct current circuits. (K&S 1.2-1.g.)

$$L = \frac{\psi}{I}$$

L = inductance in webers/amp or henrys
ψ = magnetic flux in webers
I = current in amps

$$C = \frac{Q}{E}$$

C = capacitance in coulombs/voltage or Farads
Q = charge in coulombs
E = voltage in volts

u. Discuss the fundamental relationships in alternating current (AC) circuits among voltage, current, resistance, reactance, impedance, power, and power factor. (K&S 1.2-1.h.)

voltage	$E = I\,R$
current	$I = E/R$
resistance	$R = E/I$
reactance	$X_L = \frac{E_{ind}}{I} = \frac{2\pi f L I}{I} = 2\pi f L$
impedance	$Z = \sqrt{R^2 + X_L}$
power	$P = I\,E\cos\Theta$
power factor	$pf = \cos\Theta = \frac{\text{true power}}{\text{apparent power}}$

v. Match the descriptions below in column A with the methods of producing electricity below in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.2-1.i.)

Column A	Column B
_d_ 1. By applying pressure to certain crystals electrons can be driven out of orbit in the direction of the force.	a. Thermo-electricity
_c_ 2. Produces a voltage by rotating coils of wire through a stationary magnetic field.	b. Static electricity
_f_ 3. When the photons in a light beam strike the surface of a material, they transfer energy to the atomic electrons of the material. This energy transfer may dislodge electrons from their orbits around the surface of the substance.	c. Magnetic induction
_e_ 4. Chemicals can be combined with certain metals to cause a reaction that will transfer electrons to produce electrical energy.	d. Piezo-electric effect
	e. Electro-chemistry
	f. Photoelectric effect

w. Describe how the following methods produce a voltage: (K&S 1.2-1.i.)

Static electricity - Atoms with the proper number of electrons in orbit around them are in a neutral state, or have a "zero charge." A body of matter consisting of these atoms will neither attract nor repel other matter that is in its vicinity. If electrons are removed from the atoms in this body of matter, as happens due to friction it will become electrically positive. If this body of charged matter comes near, but not in contact with, another body having a normal charge, an electric force is exerted between them because of their unequal charges.

Thermo-electricity - Some materials readily give up their electrons and others readily accept electrons. For example, when two dissimilar metals like copper and zinc are joined together, a transfer of electrons can take place. Electrons will leave the copper atoms and enter the zinc atoms. The zinc gets a surplus of electrons and becomes negatively charged. The copper loses electrons and takes on a positive charge. This creates a voltage potential across the junction of the two metals. The heat energy of normal room temperature is enough to make them release and gain electrons, causing a measurable voltage potential. As more heat energy is applied to the junction, more electrons are released, and the voltage potential becomes greater. When heat is removed and the junction cools, the charges will dissipate and the voltage potential will decrease. A device like this is generally referred to as a "thermocouple."

x. A series circuit has a 50 Ω, a 100 Ω, and a 150 Ω resistor in series. Calculate the total resistance of the circuit? (K&S 1.2-1.j.)

$$R_T = R_1 + R_2 + R_3$$
$$= 50\ \Omega + 100\ \Omega + 150\ \Omega$$
$$= 300\ \Omega$$

y. A series circuit has a 300 Ω, a 50 Ω, and a 100 Ω resistor in series. Calculate the voltage necessary to produce a current of 0.25 amps. (K&S 1.2-1.j.)

Step 1: Find circuit current. As we already know, current is the same throughout a series circuit, which is already given as 0.25 amps.

Step 2: Find R_T.

$$R_T = R_1 + R_2 + R_3$$

$$R_T = 300\ \Omega + 50\ \Omega + 100\ \Omega$$

$$R_T = 450\ \Omega$$

Step 3: Find V_T. Use Ohm's Law.

$$V_T = I\ R_T$$

$$V_T = (0.25 \text{ amps})(450\ \Omega)$$

$$V_T = 112.5 \text{ volts}$$

z. Two resistors, each drawing 5 amps, and a third resistor, drawing 3 amps, are connected in parallel across a 115 volt source. Calculate the total current. (K&S 1.2-1.j.)

$$I_T = I_1 + I_2 + I_3$$
$$I_T = 5A + 5A + 3A$$
$$I_T = 13A$$

aa. Calculate the total resistance of a 5 Ω, a 5 Ω, and a 3 Ω resistor in parallel. (K&S 1.2-1.j.)

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$\frac{1}{R_T} = \frac{1}{5} + \frac{1}{5} + \frac{1}{3}$$

$$\frac{1}{R_T} = \frac{3}{15} + \frac{3}{15} + \frac{5}{15} = \frac{11}{15}$$

$$R_T = \frac{15}{11} = 1.364\Omega$$

ab. Given a circuit with the following parameters, calculate the reactance of the circuit. Frequency is 60 hertz and the inductance is 15 Henrys. (K&S 1.2-1.k.)

$X_L = 2\pi fL$

$X_L = 2 \bullet \pi \bullet 60Hz \bullet 15H$

$X_L = 5655\Omega$

ac. Given an AC circuit with the following parameters, calculate the reactance of the circuit. Frequency is 60 hertz and the capacitance is 5 x 10^{-6} farads. (K&S 1.2-1.k.)

$$X_C = \frac{1}{2 \cdot \pi \cdot f \cdot C}$$

$$X_L = \frac{1}{2 \cdot \pi \cdot 60 \cdot 5 \times 10^{-6}} = \frac{1}{1.88 \times 10^{-3}}$$

$X_L = 530.5\Omega$

ad. Given the circuit of an AC generator with the following parameters, calculate the reactance of the circuit. The generator has 4 poles, a speed of 750 rpm, and the inductance is 25 Henrys. (K&S 1.2-1.k.)

$$f = \frac{P \cdot N}{2 \cdot 60}$$

$$f = \frac{4 \cdot 750}{2 \cdot 60} = \frac{3000}{120} = 25\ \text{Hz}$$

$X_L = 2\pi fL$

$X_L = 2 \bullet \pi \bullet 25\text{Hz} \bullet 25\text{H}$

$X_L = 3927\Omega$

ae. Given an AC circuit the following parameters, calculate the reactance of the circuit. The generator has 8 poles, a speed of 900 rpm, and the capacitance is 25 μfarads. (K&S 1.2-1.k.)

$$f = \frac{P \cdot N}{2 \cdot 60}$$

$$f = \frac{8 \cdot 900}{2 \cdot 60} = \frac{7200}{120} = 60\ \text{Hz}$$

$$X_L = \frac{1}{2 \cdot \pi \cdot f \cdot C}$$

$$X_L = \frac{1}{2 \cdot \pi \cdot 60 \cdot 2.5 \times 10^{-6}} = \frac{1}{0.0009424} = 1061\ \Omega$$

Competency 1.3

Construction management and engineering (FAC# 1.21), EH Residents (FAC# 1.8), Facility maintenance management (FAC# 1.9), and Facility Representatives (FAC# 1.9) personnel shall demonstrate familiarity level knowledge of basic electrical fundamentals in the area of direct current (DC).

1. Supporting Knowledge and/or Skills

   a. Discuss the basic principle by which the following components produce direct current (DC):

      - DC Generator
        DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter DC Sources and Volume 2 of 4, Chapter DC Generators.
      - Thermocouple
        DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter DC Sources.

   b. Discuss the purpose of a rectifier.
      DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter DC Sources.

   c. Discuss the following terms:

      - Resistivity
      - Electric circuit
      - Series circuit
      - Parallel circuit
        DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter DC Circuit Terminology.

   d. Discuss the following terms:

      - Battery
        DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter DC Sources and Volume 2 of 4, Chapter Battery Terminology, Chapter Battery Theory, and Chapter Battery Operations.
      - Electrode
        DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter Battery Terminology.

- Electrolyte
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter Battery Terminology.
- Specific gravity
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter Battery Terminology.
- Ampere-hour
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter Battery Terminology.

e. Describe in basic terms what happens when a lead-acid battery is charged and discharged.
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter Battery Theory.

f. Describe the relationship between voltage and current-carrying capacity for series-connected versus parallel-connected batteries.
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter Battery Operations.

g. Other than lead-acid batteries list three additional types of batteries.
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter Types of Batteries.

h. Describe the hazards associated with lead-acid storage batteries.
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter Battery Hazards.

i. Discuss the various types of batteries used in electrical systems. Include the following elements of battery operation in the discussion:

- Capacity
- Voltage applications
- Battery life expectancy
- Environmental requirements for safe battery operation

Competency 1.4

Electrical systems (FAC# 1.4) and Instrumentation and control (FAC# 1.2) personnel shall demonstrate a working level knowledge of battery construction, voltage production, and hazards.

1. Supporting Knowledge and/or Skills

   a. Discuss the basic principle by which the following components produce direct current (DC):

      - DC Generator
        DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter DC Sources and Volume 2 of 4, Chapter DC Generators.
      - Thermocouple
        DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter DC Sources.

   b. Using a cutaway drawing of a simple multi-cell storage battery, identify the following components and discuss their function:

      - Positive terminal
      - Negative terminal
      - Electrode
      - Cell
        DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter Battery Theory.

   c. Describe the hazards associated with storage batteries.
      DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter Battery Hazards.

   d. Define the following terms:

      - Voltaic cell
        DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter Battery Terminology.
      - Battery
        DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/1-92) Volume 1 of 4, Chapter DC Sources and Volume 2 of 4, Chapter Battery Terminology, Chapter Battery Theory, and Chapter Battery Operations.

- Electrode
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter Battery Terminology.
- Electrolyte
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter Battery Terminology.
- Specific gravity
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter Battery Terminology.
- Ampere-hour
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter Battery Terminology.

e. Describe the operation of a simple voltaic cell.
   DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Battery Theory.

f. Explain the relationship between specific gravity and state of charge of a lead-acid battery.
   DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter Battery Terminology and Chapter Battery Theory.

g. Describe the relationship between total battery voltage and individual cell voltage for a series-connected battery.
   DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter Battery Terminology, Chapter Battery Theory, and Chapter Battery Operations.

h. Explain the advantage of connecting a battery in parallel with respect to current-carrying capability.
   DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter Battery Operations.

i. Describe the difference between primary and secondary cells with respect to recharge capability.
   DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter Battery Operations.

j. Discuss the various types of batteries used in electronic components.

- Carbon-zinc cell
- Alkaline cell
- Nickel-cadmium cell
- Edison cell
- Mercury cell

Include in the discussion the following elements of battery operation:

- Method by which a direct current (DC) is produced
- Current capacity
- Amp-hour capacity
- Voltage applications
- Charge and discharge characteristics
- Battery life expectancy
- Materials used in the battery construction
- Battery physical characteristics, i.e., size, weight
- Environmental requirements for safe battery operation
- Specific component applications
- Advantages of each type of battery

DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter Types of Batteries.

k. Explain how gas generation is minimized for a lead-acid battery.

DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter Battery Hazards.

l. Explain how heat is generated in a lead-acid battery.

DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter Battery Hazards.

2. Self-Study Information

Competency 1.3 and 1.4 address the knowledge of the principles associated with direct current electrical systems, components, and batteries. Competency 1.3 at a familiarity level of knowledge and Competency 1.4 at a working level of knowledge.

The supporting material for the Self-Study Information include the following documents:

- Department of Energy Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92).
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-03-LP)
- Westinghouse Savannah River Corporation. Employee Safety Manual 8Q Procedure 83 Battery Safety Rev 12/31/95.
- Westinghouse Savannah River Corporation. Safe Electrical Practices and Procedures Manual 18Q Procedure 2 Safe Practices On or Near Electrical Conductors Rev 2 12/8/95.
- DOE-SR Office of Training Facility Representative Advanced Nuclear Course Electrical Theory, Systems, and Components (DOE-OT-FRANC-105-13-LP)
- Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100).
- Bureau of Naval Personnel (1969). Basic Electricity. Washington, DC: U.S. Government Printing Office. Stock Ordering No. 0502-LP-050-4300.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. New York: McGraw-Hill Book Company. ISBN 0-07-020974-X. Call# TK151.S8.
- General Physics Corporation. Electrical Industrial Plant Maintenance. Columbia, MD: General Physics Corporation.
- Institute of Electrical and Electronic Engineers (1992). IEEE Recommended Practice for Powering and Grounding Sensitive Electronic Equipment (IEEE-STD-1100-1992 IEEE Emerald Book). New York: Institute of Electrical and Electronic Engineers Inc. ISBN 1-55937-231-1.
- Institute of Electrical and Electronic Engineers (1986). IEEE Recommended Practice for Electric Systems in Health Care Facilities (IEEE-STD-602-1986 IEEE White Book). New York: Institute of Electrical and Electronic Engineers Inc. ISBN 0-471-82747-9.
- Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Albany, NY: Delmar Publishers Inc. ISBN 0-8273-4146-6. Call# TK1111.L66.
- Smeaton, Robert W. (editor) (1977). Switchgear and Control Handbook. New York: McGraw-Hill Book Company. ISBN 0-07-058439-7. Call# TK2821.S88.

Batteries

Storage batteries are constantly electrically alive and a constant source of electrical shock. Care should be taken not contact the positive and negative terminals. Tools or equipment should never be placed on top batteries to prevent short circuits.

Battery rooms should be posted as a No Smoking and No Open Flames area. Hydrogen gas is generated during battery charging operations. Ventilation should be maintained to prevent the buildup of hydrogen gas.

The electrolyte used in batteries is an acid. The electrolyte is corrosive and dangerous if ingested. Emergency eyewash and shower facilities are required to be located nearby, ensure that you know where the closest eyewash/shower is before working around the storage batteries.

3. References

NOTE: For information regarding the Supporting Knowledge and Skills refer to the Self-Study Information section of this competency.

a. For Supporting Knowledge and Skills **1.3-1.a** and **1.4-1.a** refer to:
- Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100) Chapter DC Sources.
- Fink, Donald G. and H. Wayne Beatty (1978). <u>Standard Handbook for Electrical Engineering</u>. Chapter Direct-Current Generators and Chapter Alternate Sources and Converters of Power.
- Bureau of Naval Personnel (1969). <u>Basic Electricity</u>. Chapter Fundamental Concepts of Electricity.
- Loper, Orla E. and Edgar Tedsen (1991). <u>Direct Current Fundamentals</u>. Chapter Electricity Production and Use.

b. For Supporting Knowledge and Skills **1.3-1.b** refer to:
- Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100) Chapter DC Sources.
- DOE-SR Office of Training. Westinghouse Savannah River Corporation Facility Representative Advanced Nuclear Course Electrical Theory, Systems, and Components (DOE-OT-FRANC-105-13-LP). Chapter Emergency Power.
- Fink, Donald G. and H. Wayne Beatty (1978). <u>Standard Handbook for Electrical Engineering</u>. Chapter Power Electronics.

c. For Supporting Knowledge and Skills **1.3-1.c** refer to:
- Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100) Chapter DC Circuits.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Alternate Sources and Converters of Power.
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Series DC Circuits, Chapter Parallel DC Circuits.
- Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Series Circuits, Chapter Parallel Circuits, Chapter Series-Parallel and Loaded Voltage Dividers.

d. For Supporting Knowledge and Skills **1.3-1.d** and **1.4-1.d** refer to:
- Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100) Chapter Batteries.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Alternate Sources and Converters of Power.
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Batteries.
- Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Batteries
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-03-LP) Module Batteries.

e. For Supporting Knowledge and Skills **1.3-1.e** refer to:
- Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100) Chapter Batteries.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Alternate Sources and Converters of Power.
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Batteries.
- Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Batteries

f. For Supporting Knowledge and Skills **1.3-1.f**, **1.4-1.g** and **1.4-1.h** refer to:
- Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100) Chapter Batteries.
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Batteries.
- Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Batteries
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-03-LP). Module Batteries.

g. For Supporting Knowledge and Skills **1.3-1.g**, **1.3-1.i**, and **1.4-1.j** refer to:
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Batteries.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Alternate Sources and Converters of Power.
- Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Batteries
- Institute of Electrical and Electronic Engineers (1992). IEEE Recommended Practice for Powering and Grounding Sensitive Electronic Equipment (IEEE-STD-1100-1992 IEEE Emerald Book). Chapter Specification and Selection of Equipment and Materials
- Smeaton, Robert W. (editor) (1977). Switchgear and Control Handbook. Chapter DC Supply Considerations.

h. For Supporting Knowledge and Skills **1.3-1.h** and **1.4-1.c** refer to:
- Westinghouse Savannah River Corporation. Employee Safety Manual 8Q Procedure 83 Battery Safety Rev 12/31/95.
- Westinghouse Savannah River Corporation. Safe Electrical Practices and Procedures Manual 18Q Procedure 2 Safe Practices On or Near Electrical Conductors Rev 2 12/8/95.
- Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100) Chapter Batteries.
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Batteries.
- Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Batteries

i. For Supporting Knowledge and Skills **1.4-1.b** refer to:
- Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100) Chapter Batteries.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Alternate Sources and Converters of Power.
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Batteries.
- Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Batteries

j. For Supporting Knowledge and Skills **1.4-1.e** refer to:
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Batteries.
- Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Batteries
- Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100) Chapter Batteries.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Alternate Sources and Converters of Power.

- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-03-LP). Module Batteries.

k. For Supporting Knowledge and Skills **1.4-1.f** refer to:
   - Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100) Chapter Batteries.
   - Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Alternate Sources and Converters of Power.
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Batteries.
   - Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Batteries

l. For Supporting Knowledge and Skills **1.4-1.i** refer to:
   - Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100) Chapter Batteries.
   - Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Alternate Sources and Converters of Power.
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Batteries.
   - Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Batteries

m. For Supporting Knowledge and Skills **1.4-1.k** refer to:
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Batteries.

n. For Supporting Knowledge and Skills **1.4-1.l** refer to:
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Batteries.

4. Practice Exercises

a. Discuss the basic principle by which a thermocouple produces direct current (DC): (K&S 1.3-1.a.) (K&S 1.4-1.a.)

b. Which of the statements below describes the purpose of a rectifier. (K&S 1.3-1.b.)

1) to convert alternating current to direct current then back to alternating current.

2) to convert battery power to electromagnetic power.

3) to convert direct current to alternating current.

4) to convert alternating current to direct current.

c. Define the term **RESISTIVITY** including the factors that affect it: (K&S 1.3-1.c.)

d. Draw a simple **Series circuit** including **ALL** components necessary to have an electrical circuit. (K&S 1.3-1.c.)

e. Define the following terms: (K&S 1.3-1.d.) (K&S 1.4-1.d.)

- Ampere-Hour

- Battery

- Electrode

- Electrolyte

- Specific-Gravity

f. A lead-acid battery is being charged which of the following statements is true? (K&S 1.3-1.e.) (K&S 1.4-1.f.)

1) The electrolyte divides into H_2 and SO_4.

2) The electrolyte divides into Pb and SO_4.

3) The lead sulphate ($PbSO_4$) is driven out of the electrolyte and back into the Pb and SO_4 ions.

4) The electrolyte combines into H_2 and SO_4.

g. List three battery types other than lead-acid batteries. (K&S 1.3-1.g.) (K&S 1.4-1.j.)

h. What problem is associated with gassing of a lead-acid storage batteries. (K&S 1.3-1.h.) (K&S 1.4-1.k.)

1) The battery may not completely charge as energy goes into formation of the gas.

2) Production of phosgene, a toxic gas.

3) Production of hydrogen, a flammable gas.

4) Sulfuric gas may be formed which shortens the life span of the battery.

i. Discuss the various types of batteries used in electrical systems. Include the following elements of battery operation in the discussion: (K&S 1.3-1.i.) (K&S 1.4-1.j.)

	Capacity Ah/kg theoretical (Wh/kg Practical)	Cell voltage Theoretical (Practical)
Carbon- zinc		
Alkaline		
Nickel- cadmium		
Edison		
Mercury		

j. Define the term **Voltaic cell**: (K&S 1.4-1.d.)

k. Describe the construction of a voltaic cell. (K&S 1.4-1.e.)

l. Describe the operation of a simple voltaic cell. (K&S 1.4-1.e.)

m. Describe what happens to the specific gravity of a battery as the battery is charged. (K&S 1.4-1.f.)

   1) The specific gravity becomes more negative.

   2) The specific gravity decreases.

   3) The specific gravity increases.

   4) The specific gravity remains the same unless the temperature of the electrolyte changes.

n. Match the characteristics of a battery in column A with the type of battery in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.3-1.f.) (K&S 1.3-1.g.) (K&S 1.3-1.f.) (K&S 1.3-1.h.) (K&S 1.3-1.i.)

Column A	Column B
__ 1. The total voltage output of two batteries in this fashion is the same as that of a single cell.	a. Electrochemical
	b. Parallel
__ 2. Cells that can be recharged to nearly their original condition.	c. Primary
__ 3. Cells that cannot be recharged after their voltage output has dropped to a value that is not usable.	d. Secondary
	e. Series
__ 4. The total voltage output of the battery is equal to the sum of the individual cell voltages.	f. Wet cell

o. Discuss the various types of batteries used in electronic components. (K&S 1.4-1.j.)

BATTERY TYPE	Method by which a direct current (DC) is produced	Materials used in the battery construction	Advantages of each type of battery
Carbon- zinc		Positive - Negative - Electrolyte -	
Alkaline		Positive - Negative - Electrolyte -	
Nickel-cadmium		Positive - Negative - Electrolyte -	
Edison		Positive - Negative - Electrolyte -	
Mercury		Positive - Negative - Electrolyte -	

p. Explain how gas generation is minimized for a lead-acid battery. (K&S 1.4-1.k.)

q. Explain how heat is generated in a lead-acid battery. (K&S 1.4-1.l.)

5. Practice Exercise Answers

   a. Discuss the basic principle by which a thermocouple produces direct current (DC): (K&S 1.3-1.a.) (K&S 1.4-1.a.)

      A thermocouple is a device used to convert heat energy into a voltage output. The thermocouple consists of two different types of metal joined at a junction. As the junction is heated, the electrons in one of the metals gain enough energy to become free electrons. The free electrons will then migrate across the junction and into the other metal. This displacement of electrons produces a voltage across the terminals of the thermocouple.

   b. Which of the statements below describes the purpose of a rectifier. (K&S 1.3-1.b.)

      1) to convert alternating current to direct current then back to alternating current.

      2) to convert battery power to electromagnetic power.

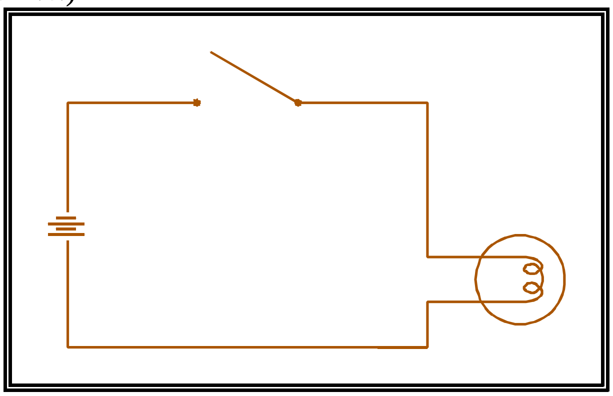
      3) to convert direct current to alternating current.

      4) to convert alternating current to direct current.

   c. Define the term **RESISTIVITY** including the factors that affect it: (K&S 1.3-1.c.)

      The measure of the resistance a material imposes on current flow. The resistance of a given length of conductor depends upon the resistivity of that material, the length of the conductor, and the cross-sectional area of the conductor, according to $R = \rho \frac{L}{A}$.

d. Draw a simple **Series circuit** including **ALL** components necessary to have an electrical circuit. (K&S 1.3-1.c.)



The circuit must contain: 1) a source of electromotive force (battery), 2) conductors, 3) load or loads (light), and 4) some means of control (switch).

e. Define the following terms: (K&S 1.3-1.d.) (K&S 1.4-1.d.)

- Ampere-Hour - a current of one ampere flowing for one hour. A unit describing the storage capacity of (amount of energy stored in) a battery (the product of the current and the time)

- Battery - a group of two or more connected voltaic cells. Device for converting chemical energy into electrical energy. Two or more primary or secondary cells connected together electrically.

- Electrode - a metallic compound, or metal, which has an abundance of electrons (negative electrode) or an abundance of positive charges (positive electrode).

- Electrolyte - a solution which is capable of conducting an electric current. The electrolyte of a cell may be a liquid or a paste. If the electrolyte is a paste, the cell is referred to as a dry cell; if the electrolyte is a solution, it is called a wet cell.

- Specific-Gravity - the ratio comparing the weight of any liquid to the weight of an equal volume of water.

f. A lead-acid battery is being charged which of the following statements is true? (K&S 1.3-1.e.) (K&S 1.4-1.f.)

1) The electrolyte divides into H_2 and SO_4.

2) The electrolyte divides into Pb and SO_4.

3) The lead sulphate ($PbSO_4$) is driven out of the electrolyte and back into the Pb and SO_4 ions.

4) The electrolyte combines into H_2 and SO_4.

g. List three battery types other than lead-acid batteries. (K&S 1.3-1.g.) (K&S 1.4-1.j.)

- Carbon-zinc cell
- Alkaline cell
- Nickel-cadmium cell
- Edison cell
- Mercury cell

h. What problem is associated with gassing of a lead-acid storage batteries. (K&S 1.3-1.h.) (K&S 1.4-1.k.)

1) The battery may not completely charge, as energy goes into formation of the gas.

2) Production of phosgene, a toxic gas.

3) Production of hydrogen, a flammable gas.

4) Sulfuric gas may be formed which shortens the life span of the battery.

i. Discuss the various types of batteries used in electrical systems. Include the following elements of battery operation in the discussion: (K&S 1.3-1.i.) (K&S 1.4-1.j.)

	Capacity Ah/kg theoretical (Wh/kg Practical)	Cell voltage Theoretical (Practical)
Carbon- zinc	230 (65)	1.6 v (1.2 v)
Alkaline	230 (65)	1.5 v (1.15 v)
Nickel- cadmium	165 (33)	1.35 v (1.2 v)
Edison	195 (29)	1.5 v (1.2 v)
Mercury	185 (80)	1.34 v (1.2 v)

j. Define the term **Voltaic cell**: (K&S 1.4-1.d.)

A combination of materials used to convert chemical energy into electrical energy. A voltaic or chemical cell consists of two electrodes of different types of metals or metallic compounds and an electrolyte solution which is capable of conducting an electric current.

k. Describe the construction of a voltaic cell. (K&S 1.4-1.e.)

A voltaic cell (or chemical cell) consists of two electrodes (positive terminal and negative terminal) of different types of metals or metallic compounds and an electrolyte solution which is capable of conducting an electric current.

l. Describe the operation of a simple voltaic cell. (K&S 1.4-1.e.)

A voltaic cell consists of two electrodes of different types of metals or metallic compounds and an electrolyte solution which is capable of conducting an electric current.

A good example of a voltaic cell is one that contains zinc and copper electrodes. When these electrodes are immersed in an electrolyte, chemical action begins. The zinc electrode will accumulate a much larger negative charge because it dissolves into the electrolyte. The atoms, which leave the zinc electrode, are positively charged and are attracted by the negatively charged ions of the electrolyte; the atoms repel the positively charged ions of the electrolyte toward the copper electrode.

m. Describe what happens to the specific gravity of a battery as the battery is charged. (K&S 1.4-1.f.)

1) The specific gravity becomes more negative.

2) The specific gravity decreases.

3) The specific gravity increases.

4) The specific gravity remains the same unless the temperature of the electrolyte changes.

n. Match the characteristics of a battery in column A with the type of battery in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.3.1.f.) (K&S 1.3-1.g.) (K&S 1.3-1.f.) (K&S 1.3-1.h.) (K&S 1.3-1.i.)

Column A	Column B
_b_ 1. The total voltage output of two batteries in this fashion is the same as that of a single cell.	a. Electrochemical
	b. Parallel
_d_ 2. Cells that can be recharged to nearly their original condition.	c. Primary
_c_ 3. Cells that cannot be recharged after their voltage output has dropped to a value that is not usable.	d. Secondary
	e. Series
_e_ 4. The total voltage output of the battery is equal to the sum of the individual cell voltages.	f. Wet cell

o. Discuss the various types of batteries used in electronic components. (K&S 1.4-1.j.)

BATTERY TYPE	Method by which a direct current (DC) is produced	Materials used in the battery construction	Advantages of each type of battery
Carbon- zinc		Positive - Carbon rod Negative - Zinc casing Electrolyte - Ammonium chloride	durable, inexpensive, variety of sizes
Alkaline	$Zn + 2Mno_2 \rightarrow ZnO + Mn_2O_3$	Positive - Manganese dioxide Negative - Zinc Electrolyte - Potassium hydroxide alkaline	extended life over that of a carbon-zinc cell of the same size
Nickel-cadmium	$Cd + 2\ Ni(OH)_3 \rightarrow CdO + 2\ Ni(OH)_2 + H_2O$	Positive - Cadmium hydroxide Negative - Nickel hydroxide Electrolyte -Potassium hydroxide	Dry cell that can be recharged. Rugged, dependable battery under extreme conditions of temperature, shock, and vibration. Long shelf life, heavy weight, large volume, minimal temperature effect
Edison		Positive - Nickel and nickel hydrate Negative - Iron/ steel Electrolyte - Potassium hydroxide alkaline	Lighter and more rugged secondary cell than a lead-acid storage battery
Mercury	$Zn + H_2O + HgO \rightarrow ZnO + H_2O + Hg$	Positive - Negative - Electrolyte -	very rugged, relatively long shelf life, constant output under varying load, highest capacity

p. Explain how gas generation is minimized for a lead-acid battery. (K&S 1.4-1.k.)

To reduce the amount of gassing, charging voltages above 2.30 volts per cell should be minimized (e.g., 13.8 volts for a 12 volt battery).

q. Explain how heat is generated in a lead-acid battery. (K&S 1.4-1.l.)

Whenever the battery is charged, the current flowing through the battery will cause heat to be generated by the electrolysis of water. The current flowing through the battery (I) will also cause heat to be generated (P) during charge and discharge as it passes through the internal resistance (R_i), as illustrated using the formula for power $P = I^2 R$.

Competency 1.5

Construction management and engineering (FAC# 1.20 & 1.21) personnel shall demonstrate a familiarity level knowledge of direct current (DC) generators.

1. Supporting Knowledge and/or Skills

   a. Discuss the applications of direct current (DC) generators.

   b. Discuss the basic operation of direct current (DC) generators.
      DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter DC Equipment Construction, Chapter DC Generator Theory, and Chapter DC Generator Construction.

Competency 1.6

Electrical systems (FAC# 1.2) and Instrumentation and control (FAC# 1.2) personnel shall have a working level knowledge of direct current (DC) generators.

1. Supporting Knowledge and/or Skills

   a. Discuss the basic operation of direct current (DC) generators. Include in the discussion the following elements of generator operation:

      - Electromagnetic force
      - Counter-electromagnetic force
        DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter DC Equipment Terminology.
      - Generator field strength vs. output voltage relationship
        DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter DC Generator Theory.
      - Field excitation
        DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter DC Generator Theory.
      - Generator voltage regulation
        DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter Voltage Regulation.
      - Generator protection circuitry and relaying
        DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter DC Generator Theory.

b. Describe the relationship between shaft speed, field flux and generated voltage.
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter DC Generator Theory.

c. Define the following:

- Electromotive force
- Excitation
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter DC Generator Theory.
- Compounding
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter DC Equipment Construction.
- Armature
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter DC Equipment Construction.
- Terminal voltage
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter DC Equipment Terminology and Chapter DC Generator Theory.
- Load current
- Shunt windings
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter DC Equipment Construction.
- Series windings
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter DC Equipment Construction.

d. State the purpose of the following components of a direct current machine:

- Armature
- Rotor
- Stator
- Field
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter DC Equipment Construction.

e. Describe self-excited and separately excited generators.
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter DC Generator Theory.

f. Describe the operation of compound-wound generators.
   DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter DC Generator Construction.

g. Describe how the terminal voltage of a direct current generator is adjusted.
   DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter DC Generator Theory.

h. State the basis behind each direct current generator rating.
   DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter DC Generator Theory.

i. Describe the internal losses found in a direct current generator.
   DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter DC Generator Theory.

j. Describe the differences in construction between a shunt-wound and a series-wound direct current generator with respect to the relationship between the field and the armature.
   DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter DC Generator Construction.

k. Describe the relationship between the shunt and series fields for cumulatively-compounded and differentially-compounded direct current generators.
   DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter DC Generator Construction.

l. Describe the voltage-versus-current characteristics for a flat-compounded, over-compounded, and under-compounded direct current generator.
   DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter DC Generator Construction.

2. Self-Study Information

Competency 1.5 and 1.6 address the knowledge associated with the construction, theory, and purpose of direct current (DC) generators. Competency 1.5 at a familiarity level of knowledge and Competency 1.6 at a working level of knowledge.

The supporting material for the Self-Study Information include the following documents:

- Department of Energy Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92).
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-03-LP)
- Bureau of Naval Personnel (1969). Basic Electricity. Washington, DC: U.S. Government Printing Office. Stock Ordering No. 0502-LP-050-4300.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. New York: McGraw-Hill Book Company. ISBN 0-07-020974-X. Call# TK151.S8.
- Institute of Electrical and Electronic Engineers (1986). IEEE Recommended Practice for Electric Systems in Health Care Facilities (IEEE-STD-602-1986 IEEE White Book). New York: Institute of Electrical and Electronic Engineers Inc. ISBN 0-471-82747-9.
- Institute of Electrical and Electronic Engineers (1986). IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (IEEE-STD-242-1986 IEEE Buff Book). New York: Institute of Electrical and Electronic Engineers Inc. ISBN 0-471-85392-5.
- Dorf, Richard C. (editor) (1993). The Electrical Engineering Handbook. Boca Raton, FL: CRC Press Inc. ISBN 0-8493-0185-8. Call# TK145.E354.
- Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Albany, NY: Delmar Publishers Inc. ISBN 0-8273-4146-6. Call# TK1111.L66.

Where possible study site specific applications and references (Technical Manuals, Procedures, Electrical Drawings, Schematics, and Logics, Vendors' Manuals, etc.)

3. References

NOTE: For information regarding the Supporting Knowledge and Skills refer to the Self-Study Information section of this competency.

a. For Supporting Knowledge and Skills **1.5-1.a** refer to:
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Direct-Current Generators.

b. For Supporting Knowledge and Skills **1.5-1.b** and **1.6-1.a** refer to:
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Direct-Current Generators.
   - Institute of Electrical and Electronic Engineers (1986). IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (IEEE-STD-242-1986 IEEE Buff Book). Chapter Generator Protection.
   - Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Direct-Current Generators.
   - Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Electromagnetic Induction, Chapter DC Generators.
   - Institute of Electrical and Electronic Engineers (1986). IEEE Recommended Practice for Electric Systems in Health Care Facilities (IEEE-STD-602-1986 IEEE White Book). Chapter Emergency Power Systems.

c. For Supporting Knowledge and Skills **1.6-1.b** refer to:
   - Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Direct-Current Generators.
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Direct-Current Generators.
   - Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Electromagnetic Induction, Chapter DC Generators.

d. For Supporting Knowledge and Skills **1.6-1.c** refer to:
   - Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Direct-Current Generators.
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Direct-Current Generators.
   - Dorf, Richard C. (editor) (1993). The Electrical Engineering Handbook. Chapter Electrical Machines section 61.1.
   - Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Electromagnetic Induction, Chapter DC Generators.

e. For Supporting Knowledge and Skills **1.6-1.d** refer to:
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Direct-Current Generators.
   - Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Direct-Current Generators.
   - Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Electromagnetic Induction, Chapter DC Generators.
   - DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-04-LP). Module DC Generators.

f. For Supporting Knowledge and Skills **1.6-1.e** refer to:
   - Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Direct-Current Generators.
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Direct-Current Generators.
   - Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Electromagnetic Induction, Chapter DC Generators.

g. For Supporting Knowledge and Skills **1.6-1.f** refer to:
   - Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Direct-Current Generators.
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Direct-Current Generators.
   - Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Electromagnetic Induction, Chapter DC Generators.

h. For Supporting Knowledge and Skills **1.6-1.g** refer to:
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Direct-Current Generators.
   - Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Electromagnetic Induction, Chapter DC Generators.
   - DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-04-LP). Module DC Generators.

i. For Supporting Knowledge and Skills **1.6-1.h** refer to:
   - DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-04-LP). Module DC Generators.

j. For Supporting Knowledge and Skills **1.6-1.i** refer to:
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Direct-Current Generators.
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Direct-Current Generators.
- Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Electromagnetic Induction, Chapter DC Generators.
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-04-LP). Module DC Generators.

k. For Supporting Knowledge and Skills **1.6-1.j** refer to:
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Direct-Current Generators.
- Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Electromagnetic Induction, Chapter DC Generators.
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-04-LP). Module DC Generators.

l. For Supporting Knowledge and Skills **1.6-1.k** refer to:
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Direct-Current Generators.
- Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Electromagnetic Induction, Chapter DC Generators.

m. For Supporting Knowledge and Skills **1.6-1.l** refer to:
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Direct-Current Generators.
- Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Electromagnetic Induction, Chapter DC Generators.
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-04-LP). Module DC Generators.

4. Practice Exercise

a. List one site specific application of direct current (DC) generators. Why is a DC system used instead of an AC system in this applications. (K&S 1.5-1.a.)

b. List the four basic components of a direct current (DC) generator. (K&S 1.5-1.b.)

1)

2)

3)

4)

c. DC generator output voltage is dependent on three factors, which of the following is **NOT** a factor that affects generator output?

1) armature speed

2) number of conductor loops in series in the armature

3) number of conductor loops in series in the field

4) magnetic field strength

d. Which of the following statements is true regarding an increase in the shaft speed of a DC generator? (K&S 1.6-1.b.)

1) The generated voltage decreases because the rotor has less time to interact with the magnetic field of the stator.

2) The generated voltage remains the same because shaft speed only affects frequency not a concern in a DC generator.

3) The generated voltage increases proportionally to the speed of the shaft.

4) The generated voltage remains the same because voltage is dependent only on the field strength.

e. Define the following: (K&S 1.6-1.c.)

- Excitation

- Terminal voltage

f. In a series-wound generator the _________ of a DC generator is connected in series with the _________. (K&S 1.6-1.c.)

g. Match the generator component in column A with the function of the component in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.6..d)

Column A	Column B
__ 1. Armature	a. Positions brushes so that the segments change brushes at the same time the armature current changes direction, to mechanically convert AC to DC.
__ 2. Commutator	b. Supplies a magnetic field for producing a voltage.
__ 3. Field	c. Converts electrical energy to mechanical energy.
	d. Converts mechanical energy to electrical energy.
	e. The moving part of a generator used is to provide the magnetic field.

h. Describe self-excited and separately excited generators. (K&S 1.6-1.e.)

Self-excited generator

Separate excited generator

i. Describe the operation of compound-wound generators. (K&S 1.6-1.f.)

j. List the two (2) items in a normally operating direct current generator that can be adjusted by an operator to change the terminal voltage **AND** identify which is the commonly used method **AND** describe how the voltage is adjusted. (K&S 1.6-1.g.)

1)

2)

k. Match the basis behind each direct current generator rating in column A with the direct current generator rating in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.6-1.h.)

Column A	Column B
__ 1. Based on the size of the conductor and the amount of heat that can be dissipated in the generator.	a. Resistance b. Current
__ 2. The upper limit is based on when mechanical damage is done to the machine. The lower rating is based on the limit for field current.	c. Heat d. Power
__ 3. Based on the insulation type and design of the machine.	e. Speed f. Voltage
__ 4. Based on the mechanical limitations of the device that is used to turn the generator and on the thermal limits of conductors, bearings, and other components of the generator.	g. Windage

l. List and describe the four (4) internal losses found in a direct current generator. (K&S 1.6-1.i.)

1)

2)

3)

4)

m. When the field winding of a generator is connected in parallel with the generator armature, the generator is called a _________ generator. (K&S 1.6-1.j.)

n. Describe the relationship between the shunt and series fields for cumulatively-compounded and differentially-compounded direct current generators. (K&S 1.6-1.k.)

o. Describe the voltage-versus-current characteristics for a flat-compounded, over-compounded, and under-compounded direct current generator. (K&S 1.6-1.l.)

5. Practice Exercise Answers

   a. List one site specific application of direct current (DC) generators. Why is a DC system used instead of an AC system in this applications. (K&S 1.5-1.a.)

      List site specific applications

   b. List the four basic components of a direct current (DC) generator. (K&S 1.5-1.b.)

      1) a magnetic field (The magnetic field may be supplied by either a permanent magnet or an electromagnet.)

      2) a single conductor, or loop

      3) a commutator

      4) brushes

   c. DC generator output voltage is dependent on three factors, which of the following is **NOT** a factor that affects generator output?

      1) armature speed

      2) number of conductor loops in series in the armature

      3) number of conductor loops in series in the field

      4) magnetic field strength

d. Which of the following statements is true regarding an increase in the shaft speed of a DC generator? (K&S 1.6-1.b.)

1) The generated voltage decreases because the rotor has less time to interact with the magnetic field of the stator.

2) The generated voltage remains the same because shaft speed only affects frequency not a concern in a DC generator.

3) The generated voltage increases proportionally to the speed of the shaft.

4) The generated voltage remains the same because voltage is dependent only on the field strength.

e. Define the following: (K&S 1.6-1.c.)

- Excitation - The magnetic fields in DC generators are most commonly provided by electromagnets. A current must flow through the electromagnet conductors to produce a magnetic field. In order for a DC generator to operate properly, the magnetic field must always be in the same direction. Therefore, the current through the field winding must be direct current.

- Terminal voltage - *Terminal voltage*, as applied to DC generators, is defined as the voltage that can be measured at the output of the generator.

f. In a series-wound generator the <u>field winding</u> of a DC generator is connected in series with the <u>armature</u>. (K&S 1.6-1.c.)

g. Match the generator component in column A with the function of the component in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.6-1.d)

Column A	Column B
_d_ 1. Armature	a. Positions brushes so that the segments change brushes at the same time the armature current changes direction, to mechanically convert AC to DC.
_a_ 2. Commutator	b. Supplies a magnetic field for producing a voltage.
_b_ 3. Field	c. Converts electrical energy to mechanical energy.
	d. Converts mechanical energy to electrical energy.
	e. The moving part of a generator used is to provide the magnetic field.

h. Describe self-excited and separately excited generators. (K&S 1.6-1.e.)

Self-excited generator - the field winding is connected directly to the generator output. The field may be connected in series with the output, in parallel with the output, or a combination of the two.

Separate excited generator - requires an external DC electrical power source, such as a battery. Provides DC electrical power to the field windings.

i. Describe the operation of compound-wound generators. (K&S 1.6-1.f.)

Series-wound and shunt-wound generators have a disadvantage in that changes in load current cause changes in generator output voltage. Many applications in which generators are used require a more stable output voltage than can be supplied by a series-wound or shunt-wound generator. One means of supplying a stable output voltage is by using a compound generator.

The compound generator has a field winding in parallel with the generator armature (the same as a shunt-wound generator) and a field winding in series with the generator armature (the same as a series-wound generator).

j. List the two (2) items in a normally operating direct current generator that can be adjusted by an operator to change the terminal voltage AND identify which is the commonly used method and describe how the voltage is adjusted. (K&S 1.6-1.g.)

1) armature speed (usually impractical to change the speed)
2) magnetic field strength
The strength of the magnetic field can be changed quite easily by varying the current through the field winding.

k. Match the basis behind each direct current generator rating in column A with the direct current generator rating in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.6-1.h.)

Column A	Column B
_b_ 1. Based on the size of the conductor and the amount of heat that can be dissipated in the generator.	a. Resistance b. Current
_e_ 2. Based at the upper limit, is determined by when mechanical damage is done to the machine. The lower rating is based on the limit for field current.	c. Heat d. Power
_f_ 3. Based on the insulation type and design of the machine.	e. Speed f. Voltage
_d_ 4. Based on the mechanical limitations of the device that is used to turn the generator and on the thermal limits of conductors, bearings, and other components of the generator.	g. Windage

l. List and describe the four (4) internal losses found in a direct current generator. (K&S 1.6-1.i.)

1) *Copper loss* is the power lost as heat in the windings; it is caused by the flow of current through the coils of the DC armature or DC field. This loss varies directly with the square of the current in the armature or field and the resistance of the armature or field coils.

2) *Eddy-Current Losses* - As the armature rotates within the field, it cuts the lines of flux at the same time that the copper coils of wire that are wound on the armature cut the lines of flux. Since the armature is made of iron, an EMF is induced in the iron, which causes a current to flow. These circulating currents within the iron core are called *eddy-currents*.

3) *Hysteresis losses* occur when the armature rotates in a magnetic field. The magnetic domains of the armature are held in alignment with the field in varying numbers, dependent upon field strength. The magnetic domains rotate, with respect to the particles not held in alignment, by one complete turn during each rotation of the armature. This rotation of magnetic domains in the iron causes friction and heat. The heat produced by this friction is called magnetic hysteresis loss.

4) *Rotational or mechanical losses* can be caused by bearing friction, brush friction on the commutator, or air friction (called windage), which is caused by the air turbulence due to armature rotation.

m. When the field winding of a generator is connected in parallel with the generator armature, the generator is called a <u>shunt-wound</u> generator. (K&S 1.6-1.j.)

n. Describe the relationship between the shunt and series fields for cumulatively-compounded and differentially-compounded direct current generators. (K&S 1.6-1.k.)

If the two fields are wound so that their flux fields oppose one another, the generator is said to be *differentially-compounded*. Due to the nature of this type of generator, it is used only in special cases and will not be discussed further in this text.

If the two fields of a compound generator are wound so that their magnetic fields aid one another, the generator is said to be *cumulatively-compounded*. As the load current increases, the current through the series field winding increases, increasing the overall magnetic field strength and causing an increase in the output voltage of the generator. With proper design, the increase in the magnetic field strength of the series winding will compensate for the decrease in shunt field strength. Therefore, the overall strength of the combined magnetic fields remains almost unchanged, so the output voltage will remain constant. In reality, the two fields cannot be made so that their magnetic field strengths compensate for each other completely. There will be some change in output voltage from the no-load to full-load conditions.

o. Describe the voltage-versus-current characteristics for a flat-compounded, over-compounded, and under-compounded direct current generator. (K&S 1.6-1.l.)

In practical compounded generators, the change in output voltage from no-load to full-load is less than 5 percent. A generator with this characteristic is said to be *flat-compounded*.

For some applications, the series winding is wound so that it overcompensates for a change in the shunt field. The output gradually rises with increasing load current over the normal operating range of the machine. This type of generator is called an *over-compounded* generator.

The series winding can also be wound so that it undercompensates for the change in shunt field strength. The output voltage decreases gradually with an increase in load current. This type of generator is called an *under-compounded* generator.

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Competency 1.7

Construction management and engineering (FAC# 1.21) personnel shall demonstrate a familiarity level knowledge of direct current (DC) motors.

1. Supporting Knowledge and/or Skills

   a. Discuss the basic operation of the various types of direct current (DC) motors. Include in the discussion the following elements of motor operation as applicable to direct current (DC) motors:

   - Starting current vs. running current
   - Current vs. load characteristics
   - Applications for different types of motors

     DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter Types of DC Motors.

Competency 1.8

Electrical systems (FAC# 1.3) and Instrumentation and control (FAC# 1.2) personnel shall have a working level knowledge of direct current (DC) motors.

1. Supporting Knowledge and/or Skills

   a. Discuss the basic operation of the various types of direct current (DC) motors. Include in the discussion the following elements of motor operation as applicable to direct current motors:

   - Electromagnetic force
   - Counter-electromagnetic force

     DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter DC Motor Theory.
   - Starting current vs. running current
   - Starting torque
   - Current vs. load characteristics
   - Variable speed operation
   - Speed control
   - Motor controller circuitry
   - Applications of different types of motors

     DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter Types of DC Motors.

b. Describe the basic construction and operation of the following four types of direct current motors:

- Shunt
- Separately excited
- Compound-wound
- Series

DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter Types of DC Motors.

c. State the function of torque in a direct current motor and how it is developed.
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter DC Motor Theory.

d. Describe the function of counter-electromotive force (CEMF) and how it is developed in a direct current motor.
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter DC Motor Theory.

e. Describe the relationship between field current and magnetic field size in a direct current motor.
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter DC Motor Theory.

f. Describe how to adjust the speed of a direct current motor.
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter DC Motor Theory.

g. Describe the relationship between armature current and torque produced in a direct current motor.
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter DC Motor Theory.

h. Describe the torque-versus-speed characteristics for a shunt-wound and a series-wound direct current motor.
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter Types of DC Motors.

i. Explain why starting resistors may be necessary for large direct current motors.
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92) Volume 2 of 4, Chapter DC Motor Operation.

2. Self-Study Information

Competency 1.7 and 1.8 address the knowledge associated with the construction, theory, and purpose of direct current (DC) motors. Competency 1.7 at a familiarity level of knowledge and Competency 1.8 at a working level of knowledge.

The supporting material for the Self-Study Information include the following documents:

- Department of Energy Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92).
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-05-LP). Module DC Motors.
- Bureau of Naval Personnel (1969). Basic Electricity. Washington, DC: U.S. Government Printing Office. Stock Ordering No. 0502-LP-050-4300.
- Dorf, Richard C. (editor) (1993). The Electrical Engineering Handbook. Boca Raton, FL: CRC Press Inc. ISBN 0-8493-0185-8. Call# TK145.E354.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. New York: McGraw-Hill Book Company. ISBN 0-07-020974-X. Call# TK151.S8.
- Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Albany, NY: Delmar Publishers Inc. ISBN 0-8273-4146-6. Call# TK1111.L66.
- Rockis, Gary and Glen Mazur, (1993). Electrical Motor Controls, Automated Industrial Systems Third Edition. Homewood, IL: American Technical Publishers, Inc. ISBN 0-8269-1666-X. Call# TK2851.R63
- Smeaton, Robert W. (editor) (1977). Switchgear and Control Handbook. New York: McGraw-Hill Book Company. ISBN 0-07-058439-7. Call# TK2821.S88.
- Werninck, E. H. (editor) (1978). Electric Motor Handbook. London: McGraw-Hill Book Company. ISBN 0-07-084488-7. Call# TK2511.E42.

3. References

NOTE: For information regarding the Supporting Knowledge and Skills refer to the Self-Study Information section of this competency.

a. For Supporting Knowledge and Skills **1.7-1.a** refer to:
   - Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Motors.
   - Dorf, Richard C. (editor) (1993). The Electrical Engineering Handbook. Chapter Electrical Machine section 61.2
   - Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Mechanical Motion From Electrical Energy, Chapter DC Motors, Chapter Starters and Speed Controllers.

- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Direct-Current Motors.
- Rockis, Gary and Glen Mazur, (1993). Electrical Motor Controls, Automated Industrial Systems. Chapter AC Reduced Voltage Starters.
- Smeaton, Robert W. (editor) (1977). Switchgear and Control Handbook. Chapter Motor Types and Characteristics, Chapter DC Motor Control.
- Werninck, E. H. (editor) (1978). Electric Motor Handbook. Chapter Application Considerations.

b. For Supporting Knowledge and Skills **1.8-1.a** refer to:
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Motors.
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Direct-Current Motors.
- Dorf, Richard C. (editor) (1993). The Electrical Engineering Handbook. Chapter Electrical Machine section 61.2.
- Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter DC Motors, Chapter Starters and Speed Controllers.
- Rockis, Gary and Glen Mazur, (1993). Electrical Motor Controls, Automated Industrial Systems. Chapter AC Reduced Voltage Starters.
- Werninck, E. H. (editor) (1978). Electric Motor Handbook. Chapter Application Considerations, Chapter Direct Current Motors, Chapter Motor Control.
- Smeaton, Robert W. (editor) (1977). Switchgear and Control Handbook. Chapter Motor Types and Characteristics, Chapter DC Motor Control.

c. For Supporting Knowledge and Skills **1.8-1.b** refer to:
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Direct-Current Motors.
- Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Mechanical Motion From Electrical Energy, Chapter DC Motors.
- Rockis, Gary and Glen Mazur, (1993). Electrical Motor Controls, Automated Industrial Systems. Chapter Reversing Circuits Applied to Single Phase, Three Phase and DC Motor Types, Chapter Accelerating and Decelerating Methods and Circuits.
- Werninck, E. H. (editor) (1978). Electric Motor Handbook. Chapter Application Considerations, Chapter Direct Current Motors, Chapter Motor Control.

d. For Supporting Knowledge and Skills **1.8-1.c** refer to:
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Direct-Current Motors.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Motors.

- Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Mechanical Motion From Electrical Energy.

e. For Supporting Knowledge and Skills **1.8-1.d** refer to:
   - Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Motors.
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Direct-Current Motors.
   - Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter DC Motors.

f. For Supporting Knowledge and Skills **1.8-1.e** refer to:
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Direct-Current Motors.
   - Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Mechanical Motion From Electrical Energy, Chapter DC Motors.

g. For Supporting Knowledge and Skills **1.8-1.f** refer to:
   - Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Motors.
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Direct-Current Motors.
   - Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter DC Motors, Chapter Starters and Speed Controllers.
   - Rockis, Gary and Glen Mazur, (1993). Electrical Motor Controls, Automated Industrial Systems. Chapter Reversing Circuits Applied to Single Phase, Three Phase and DC Motor Types, Chapter Accelerating and Decelerating Methods and Circuits.
   - DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-05-LP). Module DC Motors.
   - Smeaton, Robert W. (editor) (1977). Switchgear and Control Handbook. Chapter DC Motor Control.
   - Werninck, E. H. (editor) (1978). Electric Motor Handbook. Chapter Direct Current Motors.

h. For Supporting Knowledge and Skills **1.8-1.g** refer to:
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Direct-Current Motors.
   - Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter DC Motors.

- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-05-LP). Module DC Motors.

i. For Supporting Knowledge and Skills **1.8-1.h** refer to:
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Direct-Current Motors.
   - Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter DC Motors.

j. For Supporting Knowledge and Skills **1.8-1.i** refer to:
   - Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Motors.
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Direct-Current Motors.
   - Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Starters and Speed Controllers.
   - DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-05-LP). Module DC Motors.

4. Practice Exercise

   a. List two site specific applications of direct current (DC) motors. Why is a DC system used instead of an AC system in these applications? (K&S 1.7-1.a.)

   b. Match the characteristics of DC motors in column A with the type of DC motor in column B. The column B answers **MAY BE** used **MORE** than one time. Ignore any response in column B not identified in column A. (K&S 1.8-1.b)

Column A	Column B
__ 1. Precise control of speed and torque	a. Compound
__ 2. Good speed regulation, low torque	b. Series-wound
__ 3. Develops a large torque	c. Shunt-wound
__ 4. Constant speed motor	
__ 5. Can be operated at low speed	
__ 6. Good speed regulation, high torque	

   c. What is the relationship between starting current and running current in a DC motor? (K&S 1.7-1.a.) (K&S 1.8-1.a.)

d. Match the type of DC motor in column A with the description in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.8-1.b)

Column A	Column B
__ 1. Compounded	a. The motor armature windings are in series with the rotor field.
__ 2. Separately excited	b. Constructed so that it contains both a shunt and a series field.
__ 3. Series	c. Constructed so that it contains both a separately excited and a series field.
__ 4. Shunt	d. The motor field windings are in series with the armature.
	e. Constructed such that the field is not connected to the armature.
	f. The field is in parallel with the armature.

e. The force which tends to produce and maintain rotation is called _________. (K&S 1.8-1.c.)

f. Describe how torque is produced in a DC motor. (K&S 1.8-1.c.)

g. Describe the production of counter-electromotive force (CEMF) in a direct current motor. (K&S 1.8-1.d.)

h. Describe the effect on a direct current motor if the resistance of the field is decreased. (K&S 1.8-1.e.)

i. Describe how to decrease the speed of a direct current motor using field resistors. (K&S 1.8-1.f.)

j. Describe the relationship between armature current and torque produced in a direct current motor. (K&S 1.8-1.g.)

k. Describe the torque-versus-speed characteristics for a shunt-wound direct current motor. (K&S 1.8-1.h.)

l. The load is completely removed from a series-wound motor, this action will cause the _________. (K&S 1.8-1.h.)

   1) Speed to increase and the torque to increase

   2) Speed to increase and the torque to decrease

   3) Speed to reach stall speed and the torque to increase

   4) Speed to reach stall speed and the torque to decrease

m. Why do large DC motors have high starting current? What is done to minimize the high starting current? Why? (K&S 1.8-1.i.)

5. Practice Exercise Answers

   a. List two site specific applications of direct current (DC) motors. Why is a DC system used instead of an AC system in these applications? (K&S 1.7-1.a.)

      List site specific applications and reasons.

   b. Match the characteristics of DC motors in column A with the type of DC motor in column B. The column B answers **MAY BE** used **MORE** than one time. Ignore any response in column B not identified in column A. (K&S 1.8-1.b)

Column A	Column B
_c_ 1. Precise control of speed and torque	a. Compound
_c_ 2. Good speed regulation, low torque	b. Series-wound
_b_ 3. Develops a large torque	c. Shunt-wound
_c_ 4. Constant speed motor	
_b_ 5. Can be operated at low speed	
_a_ 6. Good speed regulation, high torque	

   b. What is the relationship between starting current and running current in a DC motor? (K&S 1.7-1.a.) (K&S 1.8-1.a.)

      Starting current is typically 5 to 7 times the normal full load current.

d. Match the type of DC motor in column A with the description in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.8-1.b)

Column A	Column B
_b_ 1. Compounded	a. The motor armature windings are in series with the rotor field.
_e_ 2. Separately excited	b. Constructed so that it contains both a shunt and a series field.
_a_ 3. Series	c. Constructed so that it contains both a separately excited and a series field.
_f_ 4. Shunt	d. The motor field windings are in series with the armature.
	e. Constructed such that the field is not connected to the armature.
	f. The field is in parallel with the armature.

e. The force which tends to produce and maintain rotation is called <u>torque</u>. (K&S 1.8-1.c.)

f. Describe how torque is produced in a DC motor. (K&S 1.8-1.c.)

When a voltage is applied to a motor, current will flow through the field winding, establishing a magnetic field. Current will also flow through the armature winding creating a current-carrying conductor in a magnetic field. This exerts a force on the conductor, tending to move it at right angles to that field. Using the left-hand rule for current-carrying conductors, the magnetic field on one side is strengthened, while it is weakened on the other side. Using the right-hand rule for motors, there is a force exerted on the armature which tends to turn the armature.

g. Describe the production of counter-electromotive force (CEMF) in a direct current motor. (K&S 1.8-1.d.)

When a conductor cuts lines of force, an EMF is induced in that conductor. Current to start the armature turning will flow in the direction determined by the applied DC power source. After rotation starts, the conductor cuts lines of force. By applying the left-hand rule for generators, the EMF that is induced in the armature will produce a current in the opposite direction. The induced EMF, as a result of motor operation, is called counter-electromotive force, or CEMF.

h. Describe the effect on a direct current motor if the resistance of the field is decreased. (K&S 1.8-1.e.)

For a constant applied voltage to the field (E), as the resistance of the field (R_f) is lowered, the amount of current flow through the field (I_f) increases as shown by Ohm's Law.

$$\uparrow I_f = \frac{\overset{\leftrightarrow}{E}}{\downarrow R_f}$$

An increase in field current will cause field flux (Φ_f) to increase. The increase of field strength increases the CEMF of the motor, since more lines of flux are being cut by the armature conductors. Thus if the field flux of a DC motor is increased, the motor speed will decrease.

$$\uparrow E_{CEMF} = \vec{K}\ \overset{\uparrow}{\Phi_F}\ \vec{N}$$

i. Describe how to decrease the speed of a direct current motor using field resistors. (K&S 1.8-1.f.)

The field of a DC motor is varied using external devices, usually field resistors. For a constant applied voltage to the field (E), as the resistance of the field (R_f) is decreased, the amount of current flow through the field (I_f) increases as shown by Ohm's Law.

$$\uparrow I_f = \frac{\overset{\leftrightarrow}{E}}{\downarrow R_f}$$

An increase in field current will cause field flux (Φ_f) to increase. The increase of field strength increases the CEMF of the motor, since more lines of flux are being cut by the armature conductors. $\uparrow E_{CEMF} = \vec{K}\ \overset{\uparrow}{\Phi_F}\ \vec{N}$ A increase of counter-EMF allows a decrease in armature current. $\downarrow I_a = \dfrac{\left(\overset{\leftrightarrow}{E_T} - \overset{\uparrow}{E_{CEMF}}\right)\downarrow}{\overset{\leftrightarrow}{R_a}}$ This decrease in armature current causes a smaller torque to be developed; the decrease in armature current more than offsets the increase in field flux. $\downarrow T = \vec{K}\ \overset{\uparrow}{\Phi_F}\ \overset{\downarrow}{I_a}$ Thus if the resistance of the field of a DC motor is decreased, the motor speed will decrease.

j. Describe the relationship between armature current and torque produced in a direct current motor. (K&S 1.8-1.g.)

When a voltage is applied to a motor, current will flow through the field winding, establishing a magnetic field. Current will also flow through the armature winding.

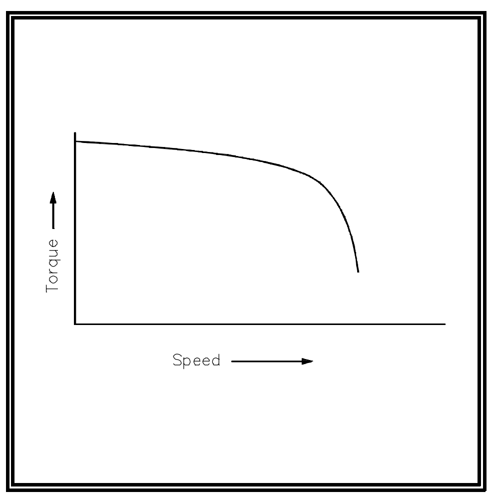
Since the armature is a current-carrying conductor in a magnetic field, the conductor has a force exerted on it, tending to move it at right angles to that field. Using the left-hand rule for current-carrying conductors, you will see that the magnetic field on one side is strengthened on one side, while it is weakened on the other side. Using the right-hand rule for motors, we can see that there is a force exerted on the armature which tends to turn the armature in the counter-clockwise direction.

The force that is developed on a conductor of a motor armature is due to the combined action of the magnetic fields. The force developed is directly proportional to the strength of the main field flux and the strength of the field around the armature conductor. The field strength around each armature conductor depends on the amount of current flowing through the armature conductor. Therefore, the torque which is developed by the motor can be determined using the equation below.

$$\uparrow T = \overset{\leftrightarrow}{K}\ \overset{\leftrightarrow}{\Phi}\ \overset{\uparrow}{I_a}$$

k. Describe the torque-versus-speed characteristics for a shunt-wound direct current motor. (K&S 1.8-1.h.)

The speed-torque relationship for a typical shunt-wound motor is shown in to the right. A shunt-wound DC motor has a decreasing torque when speed increases. The decreasing torque-vs-speed is caused by the armature resistance voltage drop and armature reaction. At a value of speed near 2.5 times the rated speed, armature reaction becomes excessive, causing a rapid decrease in field flux, and a rapid decline in torque until a stall condition is reached.



Torque versus Speed
for Shunt-Wound DC Motor

l. The load is completely removed from a series-wound motor, this action will cause the ________. (K&S 1.8-1.h.)

1) Speed to increase and the torque to increase

2) Speed to increase and the torque to decrease

3) Speed to reach stall speed and the torque to increase

4) Speed to reach stall speed and the torque to decrease

m. Why do large DC motors have high starting current? What is done to minimize the high starting current? Why? (K&S 1.8-1.i.)

Initially the only component to limit starting current is the armature resistance, which, in most DC motors is a very low value (approximately one ohm or less). At the moment a DC motor is started the armature is stationary and there is no counter-EMF being generated.

External resistors are placed in series with the armature during the starting period. Starting resistors are usually incorporated into the motor design to limit starting current to 125 to 200 percent of full load current.

Without external resistors to prevent the large current flow before the counter-EMF is established, the large current could cause severe damage to the brushes, commutator, or windings.

Competency 1.9

Facility maintenance management (FAC# 1.9) personnel shall demonstrate a familiarity level knowledge of the basic electrical fundamentals of alternating current (AC).

1. Supporting Knowledge and/or Skills

    a. Describe the relationship between apparent, true, and reactive power by definition or by using a power triangle.
    DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter Power Triangle.

    b. Discuss the reasons that three-phase power systems are used in industry.
    DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter Three-Phase Circuits.

Competency 1.10

Electrical systems personnel (FAC# 1.5 & 1.8) shall demonstrate a working level knowledge of alternating current (AC) including reactive components, inductive and capacitive reactance and phase relationships in reactive circuits.

1. Supporting Knowledge and/or Skills

    a. Define the effective value of an alternating current (AC) relative to direct current (DC).
    DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter AC Generation Analysis.

    b. Describe the relationship between maximum, average, and root-mean-square (RMS) values of voltage and current in an alternating current waveform.
    DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter AC Generation Analysis.

    c. Using a diagram of two sine waves, describe the phase relationship between the two waves.
    DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter AC Generation Analysis.

d. Define the following:

- Inductive reactance
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter Inductance.
- Capacitive reactance
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter Capacitance.
- Impedance
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter Impedance.
- Resonance
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter Resonance.
- Power factor
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter Power Triangle.
- Non-symmetrical load

e. Describe the effect of the phase relationship between current and voltage in an inductive circuit.
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter Inductance.

f. Describe the effect on phase relationship between current (I) and voltage (E) in a capacitive circuit.
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter Capacitance.

g. Determine the value for total current (IT) in a simple parallel resistance-capacitance-inductance (R-C-L) alternating current circuit.
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter Impedance.

h. Describe the relationship between apparent, true, and reactive power.
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter Power Triangle.

i. Describe the indications of an unbalanced load in a three-phase power system.
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter Three-Phase Circuits.

j. Discuss circuit considerations required for non-symmetrical loads.

2. Self-Study Information

Competency 1.9 and 1.10 address knowledge associated with the theory and operation of alternating current (AC) components. Competency 1.9 at a familiarity level of knowledge and Competency 1.10 at a working level of knowledge.

The supporting material for the Self-Study Information include the following documents:

- Department of Energy Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92).
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-07-LP)
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-08-LP)
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-06-LP)
- Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100).
- Bureau of Naval Personnel (1969). Basic Electricity. Washington, DC: U.S. Government Printing Office. Stock Ordering No. 0500-030-0010.
- Dorf, Richard C. (editor) (1993). The Electrical Engineering Handbook. Boca Raton, FL: CRC Press Inc. ISBN 0-8493-0185-8. Call# TK145.E354.
- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Albany, NY: Delmar Publishers Inc. ISBN 0-8273-4156-3. Call# TK1141.D83.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. New York: McGraw-Hill Book Company. ISBN 0-07-020974-X. Call# TK151.S8.
- Institute of Electrical and Electronic Engineers (1994). IEEE Recommended Practice for Electrical Power Distribution for Industrial Plants (IEEE-STD-141-1993 IEEE Red Book). New York: Institute of Electrical and Electronic Engineers Inc. ISBN 1-55937-333-4.
- Mablekos, Van E. (1980). Electric Machine Theory for Power Engineering. New York: Harper & Row Publishers. ISBN 0-06-044149-6. Call# TK2211.M32.
- Werninck, E. H. (editor) (1978). Electric Motor Handbook. London: McGraw-Hill Book Company. ISBN 0-07-084488-7. Call# TK2511.E42.

3. References

NOTE: For information regarding the Supporting Knowledge and Skills refer to the Self-Study Information section of this competency.

a. For Supporting Knowledge and Skills **1.9-1.a** and **1.10-1.h** refer to:
- Institute of Electrical and Electronic Engineers (1994). IEEE Recommended Practice for Electrical Power Distribution for Industrial Plants (IEEE-STD-141-1993 IEEE Red Book). Chapter Power Factors and Related Considerations.
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Introduction to Alternating-Current Electricity, Chapter Fundamental Alternating-Current Circuit Theory.
- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Inductance in Alternating Current Circuits.
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-08-LP) AC Power.

b. For Supporting Knowledge and Skills **1.9-1.b** refer to:
- Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100). Chapter Three-Phase Circuits.
- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Introduction to Alternating Current, Chapter Three-Phase Systems.
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-08-LP) AC Power.

c. For Supporting Knowledge and Skills **1.10-1.a** refer to:
- Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100). Chapter AC Generation Analysis.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Electric and Magnetic Circuits.
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Introduction to Alternating-Current Electricity, Chapter Fundamental Alternating-Current Circuit Theory.
- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Alternating-Current Circuits Containing Resistance.
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-06-LP). Module Basic AC Theory.

d. For Supporting Knowledge and Skills **1.10-1.b** refer to:
   - Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100). Chapter AC Generation Analysis.
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Introduction to Alternating-Current Electricity, Chapter Fundamental Alternating-Current Circuit Theory.
   - Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Alternating-Current Circuits Containing Resistance.
   - DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-06-LP). Module Basic AC Theory.
   - DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-08-LP) AC Power.

e. For Supporting Knowledge and Skills **1.10-1.c** refer to:
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Introduction to Alternating-Current Electricity, Chapter Fundamental Alternating-Current Circuit Theory.

f. For Supporting Knowledge and Skills **1.10-1.d** refer to:
   - Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Electric and Magnetic Circuits, Chapter Properties of Materials.
   - Institute of Electrical and Electronic Engineers (1994). IEEE Recommended Practice for Electrical Power Distribution for Industrial Plants (IEEE-STD-141-1993 IEEE Red Book). Chapter Power Factors and Related Considerations.
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Introduction to Alternating-Current Electricity, Chapter Fundamental Alternating-Current Circuit Theory.
   - Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Series Circuits - Resistance and Impedance, Chapter Inductance in Alternating-Current Circuits, Chapter Capacitors in Alternating-Current Circuits, Chapter Ac Parallel Circuits, Chapter Series-Parallel Circuits.
   - DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-07-LP). Module AC Reactive Components.
   - DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-08-LP) AC Power.

- Dorf, Richard C. (editor) (1993). The Electrical Engineering Handbook. Chapter Transmission.
- Mablekos, Van E. (1980). Electric Machine Theory for Power Engineering. Section 4.10 The Two Phase Induction Motor.
- Werninck, E. H. (editor) (1978). Electric Motor Handbook. Chapter Alternating Current Motors.

g. For Supporting Knowledge and Skills **1.10-1.e** refer to:
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Introduction to Alternating-Current Electricity, Chapter Fundamental Alternating-Current Circuit Theory.
- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Alternating-Current Circuits Containing Resistance, Chapter Inductance in Alternating-Current Circuits.
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-07-LP). Module AC Reactive Components.

h. For Supporting Knowledge and Skills **1.10-1.f** refer to:
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Inductive and Capacitive Reactance.
- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Capacitors in Alternating-Current Circuits.
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-07-LP). Module AC Reactive Components.

i. For Supporting Knowledge and Skills **1.10-1.g** refer to:
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Electric and Magnetic Circuits Table 2-1 and Table 2-2.
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Inductive and Capacitive Reactance.
- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Series Circuits: Resistance, Inductive Reactance and Capacitive Reactance, Chapter Ac Parallel Circuits, Chapter Series-Parallel Circuits.

j. For Supporting Knowledge and Skills **1.10-1.i** refer to:
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-08-LP) AC Power.

k. For Supporting Knowledge and Skills **1.10-1.j** refer to:
   - Dorf, Richard C. (editor) (1993). The Electrical Engineering Handbook. Chapter Transmission.
   - Mablekos, Van E. (1980). Electric Machine Theory for Power Engineering. Section 4.10 The Two Phase Induction Motor.
   - Werninck, E. H. (editor) (1978). Electric Motor Handbook. Chapter Alternating Current Motors.

4. Practice Exercise

a. Match the electrical power term in column A with the definition in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.9-1.a) (K&S 1.10-1.h)

Column A	Column B
__ 1. Reactive power	a. The power delivered to an electrical circuit.
__ 2. True power	b. The power consumed in a DC circuit because of the expansion and collapse of magnetic (capacitive) and electrostatic (inductive) fields.
__ 3. Apparent power	c. The power consumed by the resistive loads in an electrical circuit.
	d. The power consumed in an AC circuit because of the expansion and collapse of magnetic (inductive) and electrostatic (capacitive) fields.
	e. The power consumed by the impedance loads in an electrical circuit.

b. Describe the relationship between apparent, true, and reactive power by using a power triangle. (K&S 1.9-1.a.) (K&S 1.10-1.h.)

c. List three (3) reasons that three-phase power systems are used in industry. (K&S 1.9-1.b.)

d. Define the effective value of an alternating current (AC) relative to direct current (DC). (K&S 1.10-1.a.)

e. Describe the relationship between maximum, average, and root-mean-square (RMS) values of voltage and current in an alternating current waveform. (K&S 1.10-1.b.)

Peak value = average value x ____

Peak value = effective value (RMS) x ____

Average value = peak value x ____

Average value = effective (RMS) x ____

Effective value (RMS) = average value x ____

Effective value (RMS) = peak value x ____

f. In a sine wave at what angle, or angles, is the amplitude increasing at its fastest rate? (K&S 1.10-1.c)

1) 30°

2) 30°, 60°, and 90°

3) 0°, 180°, and 360°

4) 60°, 90°, and 120°

g. Match the electrical power term in column A with the definition in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.10-1.d)

Column A	Column B
__ 1. Resonance	a. The opposition of the inductance to the flow of an alternating current
__ 2. Power factor	b. Occurs in an AC circuit when inductive reactance and capacitive reactance are equal to one another: $X_L = X_{C.}$
__ 3. Inductive reactance	c. The total opposition to current flow in a circuit.
__ 4. Impedance	d. The ratio between apparent power and true power.
	e. The opposition by a capacitor or a capacitive circuit to the flow of current.
	f. The ratio between true power and apparent power.

h. Describe the effect of the phase relationship between current and voltage in an inductive circuit. (K&S 1.10-1.e.)

i. Describe the effect on phase relationship between current (I) and voltage (E) in a capacitive circuit. (K&S 1.10-1.f.)

j. Determine the value for total current (IT) in a simple parallel resistance-capacitance-inductance (R-C-L) alternating current circuit. (K&S 1.10-1.g.)

k. Calculate the value for total current (IT) in a simple parallel resistance-capacitance-inductance (R-C-L) alternating current circuit with the following values: a 480 Ω resistor, a 30 Ω X_L, and an 180 Ω X_C are placed in parallel across a 120 V AC source. (K&S 1.10-1.g.)

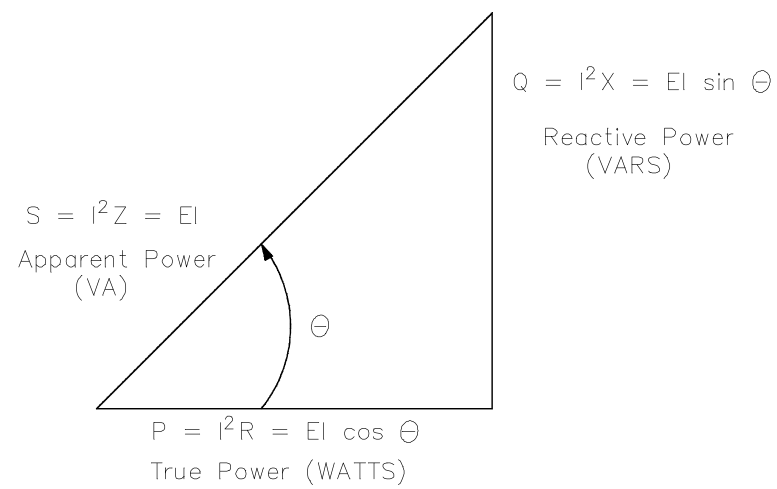
l. Describe the indications of an unbalanced load in a three-phase power system. (K&S 1.10-1.i.)

5. Practice Exercise Answers

a. Match the electrical power term in column A with the definition in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.9-1.a) (K&S 1.10-1.h)

Column A	Column B
_e_ 1. Reactive power	a. The power delivered to an electrical circuit.
_c_ 2. True power	b. The power consumed in a DC circuit because of the expansion and collapse of magnetic (capacitive) and electrostatic (inductive) fields.
_a_ 3. Apparent power	c. The power consumed by the resistive loads in an electrical circuit.
	d. The power consumed in an AC circuit because of the expansion and collapse of magnetic (inductive) and electrostatic (capacitive) fields.
	e. The power consumed by the impedance loads in an electrical circuit.

b. Describe the relationship between apparent, true, and reactive power by using a power triangle. (K&S 1.9-1.a.) (K&S 1.10-1.h.)



The power triangle equates AC power to DC power by showing the relationship between generator output (apparent power - S) in volt-amperes (VA), usable power (true power - P) in watts, and wasted or stored power (reactive power - Q) in volt-amperes-reactive (VAR). The phase angle (θ) represents the inefficiency of the AC circuit and corresponds to the total reactive impedance (Z) to the current flow in the circuit.

c. List three (3) reasons that three-phase power systems are used in industry. (K&S 1.9-1.b.)

- They have a wide range of voltages and can be used for single-phase loads.
- Three-phase equipment weighs less than single-phase equipment of the *same power rating*.
- Three-phase equipment is smaller in size than single-phase equipment of the *same power rating*.
- Three-phase equipment is more efficient than single-phase equipment of the *same power rating*.

d. Define the effective value of an alternating current (AC) relative to direct current (DC). (K&S 1.10-1.a.)

Effective value of AC is the amount of AC that produces the same heating effect as an equal amount of DC. One ampere effective value of AC will produce the same amount of heat in a conductor, in a given time, as one ampere of DC.

e. Describe the relationship between maximum, average, and root-mean-square (RMS) values of voltage and current in an alternating current waveform. (K&S 1.10-1.b.)

Peak value = average value x 1.57

Peak value = effective value (RMS) x 1.414

Average value = peak value x 0.637

Average value = effective (RMS) x 0.9

Effective value (RMS) = average value x 1.11

Effective value (RMS) = peak value x 0.707

f. In a sine wave at what angle, or angles, is the amplitude increasing at its fastest rate? (K&S 1.10-1.c)

1) 30°

2) 30°, 60°, and 90°

3) 0°, 180°, and 360°

4) 60°, 90°, and 120°

g. Match the electrical power term in column A with the definition in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.10-1.d)

Column A	Column B
_b_ 1. Resonance	a. The opposition of the inductance to the flow of an alternating current
_f_ 2. Power factor	b. Occurs in an AC circuit when inductive reactance and capacitive reactance are equal to one another: $X_L = X_C$.
_a_ 3. Inductive reactance	c. The total opposition to current flow in a circuit.
_c_ 4. Impedance	d. The ratio between apparent power and true power.
	e. The opposition by a capacitor or a capacitive circuit to the flow of current.
	f. The ratio between true power and apparent power.

h. Describe the effect of the phase relationship between current and voltage in an inductive circuit. (K&S 1.10-1.e.)

The value of the self-induced EMF varies as a sine wave and lags the current by 90°. The applied voltage must be equal and opposite to the self-induced EMF at all times; therefore, the current lags the applied voltage by 90° in a purely inductive circuit.

The memory aid, "ELI the ICE man," can be used to remember the voltage/current relationship in AC circuits. E**L**I refers to an inductive circuit (L) where voltage (E) leads (comes before) current (I).

i. Describe the effect on phase relationship between current (I) and voltage (E) in a capacitive circuit. (K&S 1.10-1.f.)

In any purely capacitive circuit, current leads applied voltage by 90°.

The memory aid, "ELI the ICE man," can be used to remember the voltage/current relationship in AC circuits. I**C**E refers to a capacitive circuit (C) where current (I) leads (comes before) voltage (E).

j. Determine the value for total current (IT) in a simple parallel resistance-capacitance-inductance (R-C-L) alternating current circuit. (K&S 1.10-1.g.)

Total current in a parallel R-C-L circuit is equal to the square root of the sum of the squares of the current flows through the resistance, inductive reactance, and capacitive reactance branches of the circuit.

$$I_T = \sqrt{I_R^2 + (I_C - I_L)^2}$$

$$I_T = \sqrt{I_R^2 + (I_L - I_C)^2}$$

(Because the difference between I_L and I_C is squared, the order in which the quantities are subtracted does not affect the answer.)

k. Calculate the value for total current (IT) in a simple parallel resistance-capacitance-inductance (R-C-L) alternating current circuit with the following values: a 480 Ω resistor, a 30 Ω X_L, and an 180 Ω X_C are placed in parallel across a 120 V AC source. (K&S 1.10-1.g.)

1. $$I_T = \sqrt{I_R^2 + (I_C - I_L)^2} \qquad I_R = \frac{V_T}{R} \qquad I_L = \frac{V_T}{X_L} \qquad I_C = \frac{V_T}{X_C}$$

$$= \sqrt{\left(\frac{V_T}{R}\right)^2 + \left(\frac{V_T}{X_L} - \frac{V_T}{X_C}\right)^2}$$

$$= \sqrt{\left(\frac{120}{480}\right)^2 + \left(\frac{120}{30} - \frac{120}{180}\right)^2}$$

$$= \sqrt{0.25^2 + (4 - .666)^2}$$

$$= \sqrt{0.25^2 + (3.333)^2}$$

$$= \sqrt{.0625 + 11.111}$$

$$= \sqrt{11.174}$$

$$I_T = 3.34 \text{ amps}$$

l. Describe the indications of an unbalanced load in a three-phase power system. (K&S 1.10-1.i.)

In a fault condition, the neutral connection in a wye-connected load will carry more current than the phase under a balanced load. Unbalanced three-phase circuits are indicated by abnormally high currents in one or more of the phases. This may cause damage to equipment if the imbalance is allowed to continue.

Competency 1.11

Construction management and engineering (FAC# 1.20 & 1.21), EH Residents (FAC# 1.9), Facility Representatives (FAC# 1.10), and Facility maintenance management (FAC# 1.9) personnel shall demonstrate familiarity level knowledge of the construction and operation of alternating current (AC) generators.

1. Supporting Knowledge and/or Skills

   a. Discuss the construction and basic theory of operation of an alternating current (AC) generator.
      DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter AC Generator Components, Chapter AC Generator Theory, and Chapter AC Generation Operation.

   b. Discuss the applications of alternating current (AC) generators.
      DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter AC Generator Components, Chapter AC Generator Theory, and Chapter AC Generation Operation.

Competency 1.12

Electrical systems (FAC# 1.6) and Instrumentation and control (FAC# 1.2) personnel shall demonstrate a working level knowledge of the construction and operation of alternating current (AC) generators.

1. Supporting Knowledge and/or Skills

   a. Describe the basic construction and basic theory of operation of an alternating current generator. Include in the discussion the following elements of generator operation:

      - Electromagnetic force
      - Counter-electromagnetic force
      - Generator speed vs. frequency relationship
      - Frequency control
      - Generator field strength vs. output voltage relationship
      - Field excitation
      - Generator voltage regulation
      - Generator protection circuitry and relaying
        DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter AC Generator Theory, Chapter Voltage Regulation.

b. Describe the development of a sine-wave output in an alternating current generator.
   DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter AC Generation.

c. Define the following terms in relation to alternating current generation:

   - Radians/second
   - Hertz
   - Period

     DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter AC Generation Analysis.

d. Using the type and application of an alternating current generator, describe the operating characteristics of that generator including methods of voltage production, advantages of each type, and methods for paralleling.
   DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter AC Generator Components, Chapter AC Generator Theory, and Chapter AC Generation Operation.

e. State the purpose of the following components of an alternating current generator:

   - Field
   - Armature
   - Prime mover
   - Rotor
   - Stator
   - Slip rings

     DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter AC Generator Components.

f. Using the speed of rotation and number of poles, calculate the frequency output of an alternating current generator.
   DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter AC Generator Theory.

g. List the three losses found in an alternating current generator.
   DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter AC Generator Theory.

h. Given the prime mover input and generator output, determine the efficiency of an alternating current generator.
   DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter AC Generator Theory.

i. Describe the basis for the kilowatt and kilovolt-amperes ratings of an alternating current generator.
   DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter AC Generator Operations.

j. Describe the conditions that must be met prior to paralleling two alternating current generators including, consequences of not meeting these conditions.
   DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter AC Generator Operations.

k. Describe the difference between a stationary field, rotating armature alternating current generator and a rotating field, stationary armature alternating current generator.
   DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter AC Generator Operations.

l. Explain the differences between a wye-connected and delta-connected alternating current generator including advantages and disadvantages of each type.
   DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter AC Generator Operations.

2. Self-Study Information

Competency 1.11 and 1.12 address knowledge associated with the construction, operation, and theory of alternating current (AC) generators. Competency 1.11 at a familiarity level of knowledge and Competency 1.12 at a working level of knowledge.

The supporting material for the Self-Study Information include the following documents:

- Department of Energy Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92).
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-09-LP)
- Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100).
- Bureau of Naval Personnel (1969). Basic Electricity. Washington, DC: U.S. Government Printing Office. Stock Ordering No. 0502-LP-050-4300.
- Bureau of Naval Personnel (1982). Electrician's Mate 3 & 2 Rate Training Manual (NAVEDTRA 10546-E). Washington, DC: U.S. Government Printing Office. Stock Ordering No. 0502-LP-052-7325.
- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Albany, NY: Delmar Publishers Inc. ISBN 0-8273-4156-3. Call# TK1141.D83.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. New York: McGraw-Hill Book Company. ISBN 0-07-020974-X. Call# TK151.S8.
- General Physics Corporation. Diesel Generator and Controls. Columbia, MD: General Physics Corporation.
- Institute of Electrical and Electronic Engineers (1986). IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (IEEE-STD-242-1986 IEEE Buff Book). New York: Institute of Electrical and Electronic Engineers Inc. ISBN 0-471-85392-5.
- Rockis, Gary and Glen Mazur, (1993). Electrical Motor Controls, Automated Industrial Systems Third Edition. Homewood, IL: American Technical Publishers, Inc. ISBN 0-8269-1666-X Call# TK2851.R63

3. References

NOTE: For information regarding the Supporting Knowledge and Skills refer to the Self-Study Information section of this competency.

a. For Supporting Knowledge and Skills **1.11-1.a** refer to:
   - Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Alternating-Current Generators.
   - Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Alternating-Current Generators.
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Introduction to Alternating-Current Electricity, Chapter Alternating-Current Generators and Transformers.
   - Bureau of Naval Personnel (1982). Electrician's Mate 3 & 2 Rate Training Manual. Chapter A-C Power Distribution Systems.
   - Rockis, Gary and Glen Mazur, (1993). Electrical Motor Controls, Automated Industrial Systems. Chapter Power Distribution Systems.
   - DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-09-LP) AC Generators.

b. For Supporting Knowledge and Skills **1.11-1.b** refer to:
   - Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Introduction to Alternating Current, Chapter Three-Phase Systems, Chapter Alternating-Current Generators.
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Introduction to Alternating-Current Electricity, Chapter Alternating-Current Generators and Transformers.
   - Bureau of Naval Personnel (1982). Electrician's Mate 3 & 2 Rate Training Manual (NAVEDTRA 10546-E). A-C Power Distribution Systems.
   - General Physics Corporation. Diesel Generator and Controls. Columbia, MD: General Physics Corporation. Chapter AC Synchronous Generators.

c. For Supporting Knowledge and Skills **1.12-1.a** refer to:
   - Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100). Chapter AC Generation.
   - Institute of Electrical and Electronic Engineers (1986). IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (IEEE-STD-242-1986 IEEE Buff Book). Chapter Generator Protection.
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Introduction to Alternating-Current Electricity, Chapter Alternating-Current Generators and Transformers.

- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Alternating-Current Generators.

d. For Supporting Knowledge and Skills **1.12-1.b** refer to:
   - Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100). Chapter AC Generation.
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Introduction to Alternating-Current Electricity, Chapter Alternating-Current Generators and Transformers.
   - Rockis, Gary and Glen Mazur, (1993). Electrical Motor Controls, Automated Industrial Systems. Chapter Power Distribution Systems.

e. For Supporting Knowledge and Skills **1.12-1.c** refer to:
   - Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Introduction to Alternating Current, Chapter Inductance in Alternating-Current Circuits.
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Introduction to Alternating-Current Electricity, Chapter Alternating-Current Generators and Transformers.
   - DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-06-LP) AC Theory.

f. For Supporting Knowledge and Skills **1.12-1.d** refer to:
   - Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Introduction to Alternating Current, Chapter Alternating Current Circuits Containing Resistance, Chapter Alternating-Current Generators.
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Alternating-Current Generators and Transformers.

g. For Supporting Knowledge and Skills **1.12-1.e** refer to:
   - Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Alternating-Current Generators.
   - Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Alternating-Current Generators.
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Alternating-Current Generators and Transformers.
   - DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-09-LP) AC Generators.

h. For Supporting Knowledge and Skills **1.12-1.f** refer to:
   - Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Introduction to Alternating Current.
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Alternating-Current Generators and Transformers.
   - DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-09-LP) AC Generators.

i. For Supporting Knowledge and Skills **1.12-1.g** refer to:
   - Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Alternating-Current Generators.
   - DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-09-LP) AC Generators.

j. For Supporting Knowledge and Skills **1.12-1.h** refer to:
   - Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Alternating-Current Generators.

k. For Supporting Knowledge and Skills **1.12-1.i** refer to:
   - DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-09-LP) AC Generators.

l. For Supporting Knowledge and Skills **1.12-1.j** refer to:
   - Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Alternating-Current Generators.
   - Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Alternating-Current Generators.
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Alternating-Current Generators and Transformers.
   - DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-09-LP) AC Generators.

m. For Supporting Knowledge and Skills **1.12-1.k** refer to:
   - Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Alternating-Current Generators.
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Alternating-Current Generators and Transformers.

n. For Supporting Knowledge and Skills **1.12-1.l** refer to:
- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Alternating-Current Generators.
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Alternating-Current Generators and Transformers.

4. Practice Exercise

    a. List the three (3) main components of an alternating current (AC) generator. (K&S 1.11-1.a.)

        1)

        2)

        3)

    b. Select the statement below that describes the magnetic field an AC generator. (K&S 1.11-1.a.)

        1) The strong electro-magnetic field is produced by an electrical current flowing through the field coil of the rotor.

        2) The strong magnetic field is produced by a permanent magnet in the rotor.

        3) The strong electro-magnetic field is produced by an electrical current flowing through the field coil of the stator.

        4) The strong magnetic field is produced by a permanent magnet in the stator.

    c. Discuss the applications of alternating current (AC) generators. (K&S 1.11-1.b.)

d. The frequency of the generated voltage is decreasing, which of the following is a possible cause? (K&S 1.12-1.a.)

1) The resistance of the armature has been increased

2) The speed of the rotor has increased

3) The strength of the field has decreased

4) The speed of the rotor has decreased

e. Describe the development of a sine-wave output in an alternating current generator. (K&S 1.12-1.b.)

f. Match the electrical generation term in column A with the definition in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.12-1.c)

Column A	Column B
__ 1. Hertz	a. The time it takes for the generator to complete one cycle.
__ 2. Period	b. The radians it takes for the generator to complete a full revolution.
__ 3. Radians/second	c. 1 cycle per second.
	d. Number of cycles per second.
	e. 60 cycle per second.
	f. Units of angular velocity.

g. Match the generator component in column A with the description of the component function in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.12-1.e)

Column A	Column B
__ 1. Slip rings and brushes	a. The part of an AC generator in which voltage is produced.
__ 2. Rotor	b. The coils of conductors within the generator that receive a voltage from a source and produce a magnetic flux.
__ 3. Field	c. The component that is used to drive the AC generator.
__ 4. Armature	d. The non-moving part of an AC generator, may be the armature or the field.
	e. The electrical connections that are used to transfer power to and from the moving portion of an AC generator.
	f. The moving part of an AC generator, may be the armature or the field.

h. Given the speed of rotation is 1800 RPM and the number of poles is 4, calculate the frequency output of an alternating current generator. (K&S 1.12-1.f.)

i. List three (3) losses found in an alternating current generator. (K&S 1.12-1.g.)

1)

2)

3)

j. Given a 15 hp motor acting as the prime mover of a generator that has an output of 2.5 kW, calculate the efficiency of the generator. (K&S 1.12-1.h.)

k. Describe the basis for the kilowatt (power) ratings of an alternating current generator. (K&S 1.12-1.i.)

l. List and describe the three (3) conditions that must be met prior to paralleling two alternating current generators including, consequences of not meeting these conditions. (K&S 1.12-1.j.)

1)

2)

3)

m. Describe the difference between a stationary field, rotating armature alternating current generator and a rotating field, stationary armature alternating current generator. (K&S 1.12-1.k.)

n. Match the characteristics of an electrical connection in column A with the type of electrical connection in column B. The column B answers **MAY BE** used **MORE** than one time. Ignore any response in column B not identified in column A. (K&S 1.12-1.l)

Column A	Column B
__ 1. Line voltage is the same as the voltage generated in any one phase.	a. Delta
__ 2. Line currents are equal to phase currents.	b. Wye
__ 3. Can be used for high voltage generation.	
__ 4. If one phase becomes damaged or open, the remaining two phases can still deliver three-phase power.	

5. Practice Exercise Answers
   a. List the three (3) main components of an alternating current (AC) generator. (K&S 1.11-1.a.)

      1) a strong magnetic field
      2) conductors that rotate through that magnetic field
      3) a means by which a continuous connection is provided to the conductors as they are rotating. (slip rings and brushes)

   b. Select the statement below that describes the magnetic filed of an AC generator. (K&S 1.11-1.a.)

      1) The strong electro-magnetic field is produced by an electrical current flowing through the field coil of the rotor.

      2) The strong magnetic field is produced by a permanent magnet in the rotor.

      3) The strong electro-magnetic field is produced by an electrical current flowing through the field coil of the stator.

      4) The strong magnetic field is produced by a permanent magnet in the stator.

   c. Discuss the applications of alternating current (AC) generators. (K&S 1.11-1.b.)

      Small AC generators usually have a stationary field and a rotating armature. The rotating field, stationary armature type AC generator is used when large power generation is involved. This type of AC generator has several advantages over the stationary field, rotating armature AC generator: 1) a load can be connected to the armature without moving contacts in the circuit; 2) it is much easier to insulate stator fields than rotating fields; and 3) much higher voltages and currents can be generated.

   d. The frequency of the generated voltage is decreasing, which of the following is a possible cause? (K&S 1.12-1.a.)

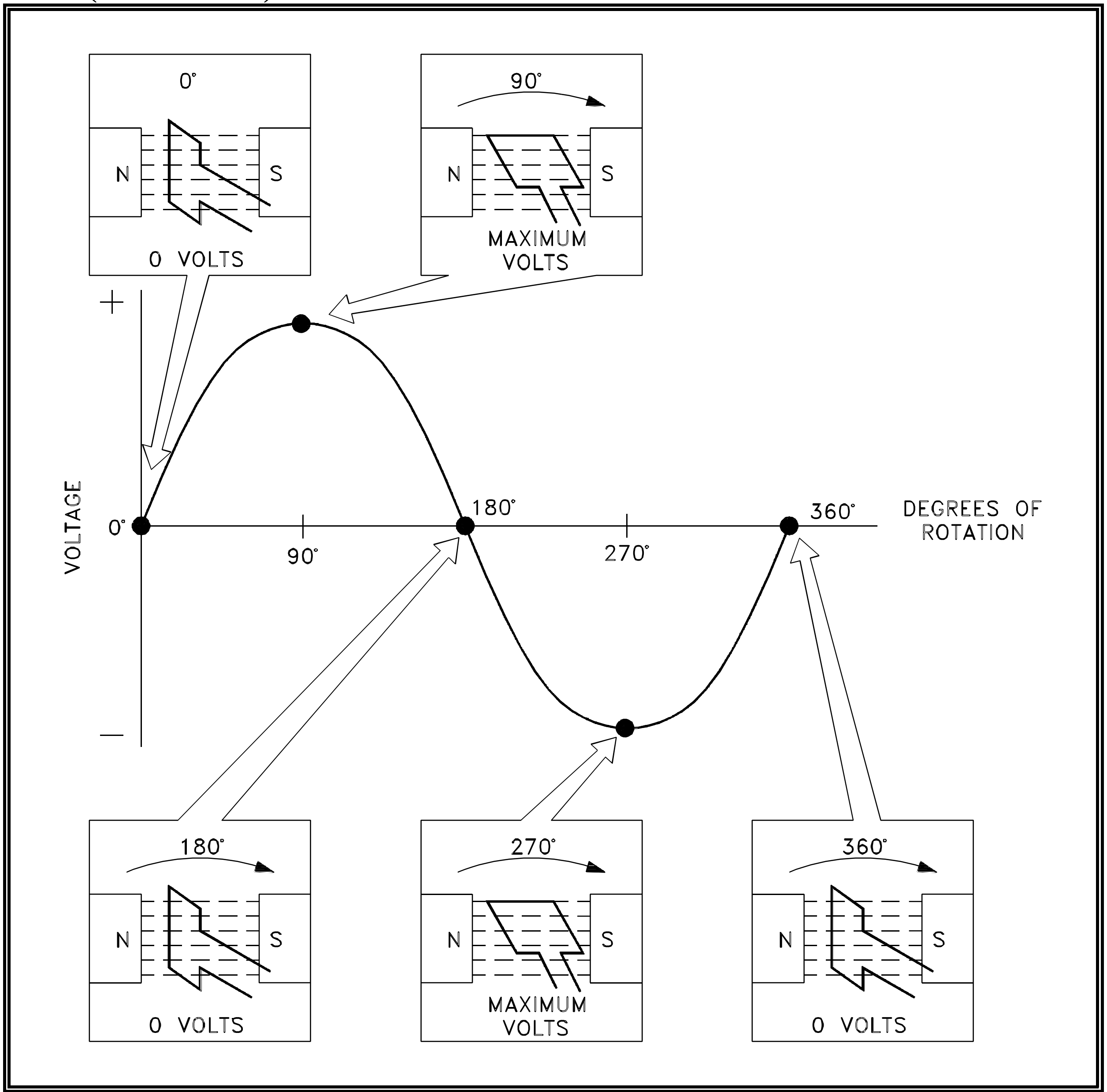
      1) The resistance of the armature has been increased

      2) The speed of the rotor has increased

      3) The strength of the field has decreased

      4) The speed of the rotor has decreased

e. Describe the development of a sine-wave output in an alternating current generator. (K&S 1.12-1.b.)



At the instant the loop is in the vertical position (0°), the coil sides are moving parallel to the field and do not cut magnetic lines of force. In this instant, there is no voltage induced in the loop. As the coil rotates in a counter-clockwise direction, the coil sides will cut the magnetic lines of force in opposite directions. The direction of the induced voltages depends on the direction of movement of the coil.

The induced voltages add in series, making slip ring X positive (+) and slip ring Y negative (-). The potential across resistor R will cause a current to flow from Y to X through the resistor. This current will increase until it reaches a maximum value when the coil is horizontal to the magnetic lines of force (90°). The horizontal coil is moving perpendicular to the field and is cutting the greatest number of magnetic lines of force. As the coil continues to turn, the voltage and current induced decrease until they reach zero, where the coil is again in the vertical position (180°). In the other half revolution, an equal voltage is produced except that the polarity is reversed (270°, 360°). The current flow through R is now from X to Y.

The periodic reversal of polarity results in the generation of an alternating voltage. The rotation of the coil through 360° results in an AC sine wave output.

f. Match the electrical generation term in column A with the definition in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.12-1.c)

Column A	Column B
_c_ 1. Hertz	a. The time it takes for the generator to complete one cycle.
_a_ 2. Period	b. The radians it takes for the generator to complete a full revolution.
_f_ 3. Radians/second	c. 1 cycle per second.
	d. Number of cycles per second.
	e. 60 cycle per second.
	f. Units of angular velocity.

g. Match the generator component in column A with the description of the component function in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.12-1.e)

Column A	Column B
_e_ 1. Slip rings and brushes	a. The part of an AC generator in which voltage is produced.
_f_ 2. Rotor	b. The coils of conductors within the generator that receive a voltage from a source and produce a magnetic flux.
_b_ 3. Field	c. The component that is used to drive the AC generator.
_a_ 4. Armature	d. The non-moving part of an AC generator, may be the armature or the field.
	e. The electrical connections that are used to transfer power to and from the moving portion of an AC generator.
	f. The moving part of an AC generator, may be the armature or the field.

h. Given the speed of rotation is 1800 RPM and the number of poles is 4, calculate the frequency output of an alternating current generator. (K&S 1.12-1.f.)

$$f = \frac{NP}{120}$$

$$f = \frac{(1800)(4)}{120}$$

$$f = 60hz$$

i. List three (3) losses found in an alternating current generator. (K&S 1.12-1.g.)

1) Hysteresis losses occur when iron cores in an AC generator are subject to effects from a magnetic field. The magnetic domains of the cores are held in alignment with the field in varying numbers, dependent upon field strength. The magnetic domains rotate, with respect to the domains not held in alignment, one complete turn during each rotation of the rotor. This rotation of magnetic domains in the iron causes friction and heat. The heat produced by this friction is called magnetic hysteresis loss.

2) Rotational or *mechanical losses* can be caused by bearing friction, brush friction on the commutator.

3) Air friction (called windage), which is caused by the air turbulence due to armature rotation.

4) Heating losses of electrical power I^2R losses.

j. Given a 15 hp motor acting as the prime mover of a generator that has an output of 2.5 kW, calculate the efficiency of the generator. (K&S 1.12-1.h.)

First, the input and output power must be in the same units.

$$\left(\frac{550\ \frac{\text{ft}-\text{lbf}}{\text{sec}}}{1\text{hp}}\right)\left(\frac{1\ \text{kW}}{737.6\ \frac{\text{ft}-\text{lbf}}{\text{sec}}}\right)\left(\frac{1000\ \text{w}}{1\ \text{kW}}\right) = 746\ \frac{\text{W}}{\text{hp}}$$

$$\text{Input Power} = 15\ \text{hp} \times 746\ \frac{\text{W}}{\text{hp}} = 11190\ \text{W}$$

$$\text{Output Power} = 2.5\ \text{kW}\left(\frac{1000\ \text{W}}{1\ \text{kW}}\right) = 2500\ \text{W}$$

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} = \frac{2500\ \text{W}}{11190\ \text{W}} = 0.223 \times 100\% = 22.3\%$$

k. Describe the basis for the kilowatt (power) ratings of an alternating current generator. (K&S 1.12-1.i.)

The kilowatt (power) ratings of an AC generator are based on the ability of the prime mover to overcome generator losses and the ability of the machine to dissipate the internally generated heat.

l. List and describe the three (3) conditions that must be met prior to paralleling two alternating current generators including, consequences of not meeting these conditions. (K&S 1.12-1.j.)

1) Their terminal voltages must be equal. If the voltages of the two AC generators are not equal, one of the AC generators could be picked up as a reactive load to the other AC generator. This causes high currents to be exchanged between the two machines, possibly causing generator or distribution system damage.

2) Their frequencies must be equal. A mismatch in frequencies of the two AC generators will cause the generator with the lower frequency to be picked up as a load on the other generator (a condition referred to as "motoring"). This can cause an overload in the generators and the distribution system.

3) Their output voltages must be in phase. A mismatch in the phases will cause large opposing voltages to be developed. The worst case mismatch would be 180° out of phase, resulting in an opposing voltage between the two generators of twice the output voltage. This high voltage can cause damage to the generators and distribution system due to high currents.

m. Describe the difference between a stationary field, rotating armature alternating current generator and a rotating field, stationary armature alternating current generator. (K&S 1.12-1.k.)

Small AC generators usually have a stationary field and a rotating armature. One important disadvantage to this arrangement is that the slip-ring and brush assembly is in series with the load circuits and, because of worn or dirty components, may interrupt the flow of current.

If DC field excitation is connected to the rotor, the stationary coils will have AC induced into them. This arrangement is called a rotating field, stationary armature AC generator. The rotating field, stationary armature type AC generator is used when large power generation is involved. In this type of generator, a DC source is supplied to the rotating field coils, which produces a magnetic field around the rotating element. As the rotor is turned by the prime mover, the field will cut the conductors of the stationary armature, and an EMF will be induced into the armature windings. This type of AC generator has several advantages over the stationary field, rotating armature AC generator: (1) a load can be connected to the armature without moving contacts in the circuit; (2) it is much easier to insulate stator fields than rotating fields; and (3) much higher voltages and currents can be generated.

n. Match the characteristics of an electrical connection in column A with the type of electrical connection in column B. The column B answers **MAY BE** used **MORE** than one time. Ignore any response in column B not identified in column A. (K&S 1.12-1.l)

Column A	Column B
_a_ 1. Line voltage is the same as the voltage generated in any one phase.	a. Delta
_b_ 2. Line currents are equal to phase currents.	b. Wye
_b_ 3. Can be used for high voltage generation.	
_a_ 4. If one phase becomes damaged or open, the remaining two phases can still deliver three-phase power.	

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Competency 1.13

Construction management and engineering (FAC# 1.20 & 1.21), EH Residents (FAC# 1.9), and Facility Representatives (FAC# 1.10) personnel shall demonstrate familiarity level knowledge of alternating current (AC) motors.

1. Supporting Knowledge and/or Skills

   a. Discuss the basic operation of the various types of alternating current (AC) motors. Include in the discussion the following elements of motor operation as applicable to alternating current (AC) motors:

      - Starting current vs. running current
      - Current vs. load characteristics
      - Applications for different types of motors

        DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter AC Motor Types.

Competency 1.14

Electrical systems (FAC# 1.7) and Instrumentation and control (FAC# 1.2) personnel shall demonstrate a working level knowledge of various types of alternating current (AC) motors, including operating characteristics, method of torque production, and the advantages of specific motor types.

1. Supporting knowledge and/or Skills

   a. Discuss the basic operation of the various types of alternating current (AC) motors. Include in the discussion the following elements of motor operation as applicable to alternating current motors:

      - Electromagnetic force
      - Counter-electromagnetic force
      - Starting current vs. running current
      - Starting torque
      - Current vs. load characteristics
      - Variable speed operation
      - Speed control
      - Motor controller circuitry
      - Applications of different types of motors

        DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter AC Motor Types.

b. Describe how an alternating current motor produces a rotating magnetic field.
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter AC Motor Theory.

c. Describe how an alternating current motor produces torque.
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter AC Motor Theory.

d. Using field speed and rotor speed, calculate percent slip in an alternating current motor.
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter AC Motor Theory.

e. Explain the relationship between speed and torque in an alternating current induction motor.
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter AC Motor Theory.

f. Describe how torque is produced in a single-phase alternating current motor.
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter AC Motor Types.

g. Explain why an alternating current synchronous motor does not have starting torque.
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter AC Motor Types.

h. Describe how an alternating current synchronous motor is started.
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter AC Motor Types.

i. Describe the effects of over and under-exciting an alternating current synchronous motor.
DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter AC Motor Types.

j. State some applications of the following types of alternating current motors:

- Induction
- Single-phase
- Synchronous

DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter AC Motor Types.

k. Describe the differences in starting and operating characteristics of premium efficiency motors.

   DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter AC Motor Types.

l. Explain the following motor terms:

   - Nameplate Revolutions Per Minute (RPM)
   - National Electrical Manufacturers Association (NEMA) frame size
   - Service factor
   - Insulation class
   - National Electrical Manufacturers Association (NEMA) design designation (letter)
   - Non-symmetrical load

2. Self-Study Information

Competency 1.13 and 1.14 address the knowledge of the principles associated with basic electrical fundamentals in the area of alternating current (AC). Competency 1.13 at a familiarity level of knowledge and Competency 1.14 at a working level of knowledge.

The supporting material for the Self-Study Information include the following documents:

- Department of Energy Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92).
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-10-LP)
- Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100).
- Bureau of Naval Personnel (1969). Basic Electricity. Washington, DC: U.S. Government Printing Office. Stock Ordering No. 0502-LP-050-4300.
- Dorf, Richard C. (editor) (1993). The Electrical Engineering Handbook. Boca Raton, FL: CRC Press Inc. ISBN 0-8493-0185-8. Call# TK145.E354.
- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Albany, NY: Delmar Publishers Inc. ISBN 0-8273-4156-3. Call# TK1141.D83.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. New York: McGraw-Hill Book Company. ISBN 0-07-020974-X. Call# TK151.S8.

- Institute of Electrical and Electronic Engineers (1994). IEEE Recommended Practice for Electrical Power Distribution for Industrial Plants (IEEE-STD-141-1993 IEEE Red Book). New York: Institute of Electrical and Electronic Engineers Inc. ISBN 1-55937-333-4.
- Institute of Electrical and Electronic Engineers (1990). IEEE Recommended Practice for Industrial and Commercial Power Systems Analysis (IEEE-STD-399-1990 IEEE Brown Book). New York: Institute of Electrical and Electronic Engineers Inc. ISBN 1-55937-044-0.
- Kenjo, Tak (1991). Electric Motors and Their Controls. Oxford, UK: Oxford University Press. ISBN 0-19-856235-7. Call# TK2511.K46
- Mablekos, Van E. (1980). Electric Machine Theory for Power Engineering. New York: Harper & Row Publishers. ISBN 0-06-044149-6. Call# TK2211.M32.
- National Electrical Manufacturers Association (1993). NEMA 1-1993. Washington, DC: National Electrical Manufacturers Association.
- Rockis, Gary and Glen Mazur, (1993). Electrical Motor Controls, Automated Industrial Systems. Homewood, IL: American Technical Publishers, Inc. ISBN 0-8269-1666-X Call# TK2851.R63.
- Say, M. G. (1976). Alternating Current Machines. New York: John Wiley & Sons. ISBN 0-470-15133-1. Call# TK2711.S3.
- Smeaton, Robert W. (editor) (1977). Switchgear and Control Handbook. New York: McGraw-Hill Book Company. ISBN 0-07-058439-7. Call# TK2821.S88.
- Schultz, George Patrick (1989). Transformers and Motors. Carmel, IN: Macmillam Computer Publishing. ISBN 0-672-30131-8. Call# TK2541.S55.
- Werninck, E. H. (editor) (1978). Electric Motor Handbook. London: McGraw-Hill Book Company. ISBN 0-07-084488-7. Call# TK2511.E42.

3. References

NOTE: For information regarding the Supporting Knowledge and Skills refer to the Self-Study Information section of this competency.

a. For Supporting Knowledge and Skills **1.13-1.a** and **1.14-1.a** refer to:
   - Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100). Chapter AC Motor Theory.
   - Institute of Electrical and Electronic Engineers (1994). IEEE Recommended Practice for Electrical Power Distribution for Industrial Plants (IEEE-STD-141-1993 IEEE Red Book). Chapter Power Switching, Transformation, and Motor Control Apparatus.
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Alternating-Current Motors.

- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Three-Phase Induction Motors, Chapter The Synchronous Motor, Chapter Single-Phase Motors, Chapter Reversing Circuits Applied to Single Phase, Three Phase and DC Motor Types, Chapter Accelerating and Decelerating Methods and Circuits.
- Kenjo, Tak (1991). Electric Motors and Their Controls. Chapter Physical Principles of Various Types of Motors, Chapter Engineering Principles in Motor Design, Chapter Classical Motor-Control Technology, Chapter Power Electronics and Modern Control Methods.
- Mablekos, Van E. (1980). Electric Machine Theory for Power Engineering. Section 6.8 Balanced Three-phase Faults on Synchronous Generators.
- Say, M. G. (1976). Alternating Current Machines. Chapter Induction Machines: Theory and Performance, Chapter Induction Machines: Construction and Design, Chapter Synchronous Machines: Theory and Performance, Chapter Synchronous Machines: Construction and Design.
- Smeaton, Robert W. (editor) (1977). Switchgear and Control Handbook. Chapter Control Standards and General Purpose Starters, Chapter Polyphase Motor Control, Chapter Variable Frequency Solid State AC Drives.
- Schultz, George Patrick (1989). Transformers and Motors. Chapter Section 6 Fundamental Concepts: Motors, Section 9 Installation, Chapter
- Werninck, E. H. (editor) (1978). Electric Motor Handbook. Chapter Application Considerations, Chapter Alternating Current Motors.

b. For Supporting Knowledge and Skills **1.14-1.b** refer to:

- Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100). Chapter AC Motor Theory.
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Alternating-Current Motors.
- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Three-Phase Induction Motors, Chapter The Synchronous Motor, Chapter Single-Phase Motors.
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-10-LP) AC Motors.
- Werninck, E. H. (editor) (1978). Electric Motor Handbook. Chapter Alternating Current Motors.

c. For Supporting Knowledge and Skills **1.14-1.c** refer to:

- Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100). Chapter AC Motor Theory.

- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Alternating-Current Motors.
- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Three-Phase Induction Motors, Chapter Single-Phase Motors.
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-10-LP) AC Motors.

d. For Supporting Knowledge and Skills **1.14-1.d** refer to:
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Motors section 51.
- Institute of Electrical and Electronic Engineers (1994). IEEE Recommended Practice for Electrical Power Distribution for Industrial Plants (IEEE-STD-141-1993 IEEE Red Book). Chapter Power Switching, Transformation, and Motor Control Apparatus section 10.7.2.2.
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Alternating-Current Motors.
- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Three-Phase Induction Motors.
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-10-LP) AC Motors.

e. For Supporting Knowledge and Skills **1.14-1.e** refer to:
- Institute of Electrical and Electronic Engineers (1990). IEEE Recommended Practice for Industrial and Commercial Power Systems Analysis (IEEE-STD-399-1990 IEEE Brown Book). Chapter System Modeling.
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Alternating-Current Motors.
- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Three-Phase Induction Motors.
- Kenjo, Tak (1991). Electric Motors and Their Controls. Chapter Engineering Principles in Motor Design.

f. For Supporting Knowledge and Skills **1.14-1.f** refer to:
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Motors.
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Alternating-Current Motors.
- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Single-Phase Motors.

- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-10-LP) AC Motors.

g. For Supporting Knowledge and Skills **1.14-1.g** refer to:
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Motors.
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Alternating-Current Motors.
- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter The Synchronous Motor.
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-10-LP) AC Motors.

h. For Supporting Knowledge and Skills **1.14-1.h** refer to:
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Motors section 37.
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Alternating-Current Motors.
- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter The Synchronous Motor.
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-10-LP) AC Motors.

i. For Supporting Knowledge and Skills **1.14-1.i** refer to:
- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter The Synchronous Motor.

j. For Supporting Knowledge and Skills **1.14-1.j** refer to:
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Motors section 41.
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Alternating-Current Motors.
- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Three-Phase Induction Motors, Chapter The Synchronous Motor.
- Rockis, Gary and Glen Mazur, (1993). Electrical Motor Controls, Automated Industrial Systems. Chapter Reversing Circuits Applied to Single Phase, Three Phase and DC Motor Types.

k. For Supporting Knowledge and Skills **1.14-1.k** refer to:
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Alternating-Current Motors.
- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Three-Phase Induction Motors, Chapter The Synchronous Motor.
- Rockis, Gary and Glen Mazur, (1993). Electrical Motor Controls, Automated Industrial Systems. Chapter Reversing Circuits Applied to Single Phase, Three Phase and DC Motor Types, Chapter Reversing Circuits Applied to Single Phase, Three Phase and DC Motor Types, Chapter Accelerating and Decelerating Methods and Circuits.

l. For Supporting Knowledge and Skills **1.14-1.l** refer to:
- National Electrical Manufacturers Association (1993). NEMA 1-1993.
- Dorf, Richard C. (editor) (1993). The Electrical Engineering Handbook. Chapter Transmission.
- Say, M. G. (1976). Alternating Current Machines. Chapter Windings.
- Mablekos, Van E. (1980). Electric Machine Theory for Power Engineering. Section 4.10 The Two-Phase Induction Motor.
- Schultz, George Patrick (1989). Transformers and Motors. Chapter Fundamental Concepts: Motors.
- Werninck, E. H. (editor) (1978). Electric Motor Handbook. Chapter Alternating Current Motors.

4. Practice Exercise

   a. What is the relationship between the current and the load on an alternating current (AC) motors during normal operations? (K&S 1.13-1.a.)

   b. Match the type of AC motor in column A with the characteristics of a motor in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.14-1.a) (K&S 1.14-1.a) (K&S 1.14-1.j)

Column A	Column B
__ 1. Induction	a. This type of motor derives its name from the fact that DC currents are induced into the rotor by a rotating magnetic field.
__ 2. Single-phase	
__ 3. Synchronous	b. Used to accommodate large loads and to improve the power factor of transformers in large industrial complexes.
	c. Used for small commercial applications such as household appliances.
	d. Used for small commercial applications such as household appliances, because it is difficult to induce enough voltage for large loads.
	e. The most commonly used AC motor in industrial applications because of its simplicity, rugged construction, and relatively low manufacturing costs.

c. You are an operator starting an AC motor that has just been placed in service after a major overhaul. As you start the motor you notice that the motor current ammeter momentarily "pegs high" then starts drifting down towards its normal expected value. Which of the following actions should you take? (K&S 1.14-1.a.)

   1) Stop the motor, the high current was due to a fault in the motor windings and the current is drifting down because the windings have shorted.

   2) Report the incident to your supervisor or the electrical supervisor and next time make sure the load is removed from the motor before starting.

   3) Nothing, the observed high current is due to a normal starting current.

d. What is the relationship between starting current vs. running current in an AC motor? (K&S 1.14-1.a.)

e. State three (3) causes for the high starting current in an AC induction motor. (K&S 1.14-1.a.)

   1)

   2)

   3)

f. What is the relationship between starting torque and full load torque? (K&S 1.14-1.a.)

g. Describe how an alternating current motor produces a rotating magnetic field. (K&S 1.14-1.b.)

h. Describe how an alternating current motor produces torque. (K&S 1.14-1.c.)

i. A four pole, 60 Hz AC induction motor has a full load speed of 1735 rpm. Calculate percent slip in an alternating current motor. (K&S 1.14-1.d.)

j. Why must an alternating current induction motor have a certain percent of **SLIP** to operate? (K&S 1.14-1.e.)

k. What is **BREAKDOWN TORQUE**? (K&S 1.14-1.e.)

l. Describe how torque is produced in a single-phase alternating current motor. (K&S 1.14-1.f.)

m. Explain why an alternating current synchronous motor does not have starting torque. (K&S 1.14-1.g.)

n. Describe how an alternating current synchronous motor is started. (K&S 1.14-1.h.)

o. What method would one use to reverse the direction of rotation of a synchronous motor? (K&S 1.14-1.i.)

p. Explain the following motor terms: (K&S 1.14-1.l.)

- Service factor

- Insulation class

5. Practice Exercise Answers

   a. What is the relationship between the current and the load on an alternating current (AC) motors during normal operations? (K&S 1.13-1.a.)

      The motor current varies directly with the load on the motor. If the load is increased the current required also increases.

   b. Match the type of AC motor in column A with the characteristics of a motor in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.14-1.a) (K&S 1.14-1.a) (K&S 1.14-1.j)

Column A	Column B
_e_ 1. Induction	a. This type of motor derives its name from the fact that DC currents are induced into the rotor by a rotating magnetic field.
_c_ 2. Single-phase	b. Used to accommodate large loads and to improve the power factor of transformers in large industrial complexes.
_b_ 3. Synchronous	c. Used for small commercial applications such as household appliances.
	d. Used for small commercial applications such as household appliances, because it is difficult to induce enough voltage for large loads.
	e. The most commonly used AC motor in industrial applications because of its simplicity, rugged construction, and relatively low manufacturing costs.

c. You are an operator starting an AC motor that has just been placed in service after a major overhaul. As you start the motor you notice that the motor current ammeter momentarily "pegs high" then starts drifting down towards its normal expected value. Which of the following actions should you take? (K&S 1.14-1.a.)

   1) Stop the motor, the high current was due to a fault in the motor windings and the current is drifting down because the windings have shorted.

   2) Report the incident to your supervisor or the electrical supervisor and next time make sure the load is removed from the motor before starting.

   3) **Nothing, the observed high current is due to a normal starting current.**

d. What is the relationship between starting current vs. running current in an AC motor? (K&S 1.14-1.a.)

   Starting current is 5 to 7 times the normal full load running current.

e. State three (3) causes for the high starting current in an AC induction motor. (K&S 1.14-1.a.)

   1) Extra power is required to buildup the rotating magnetic field in the stator

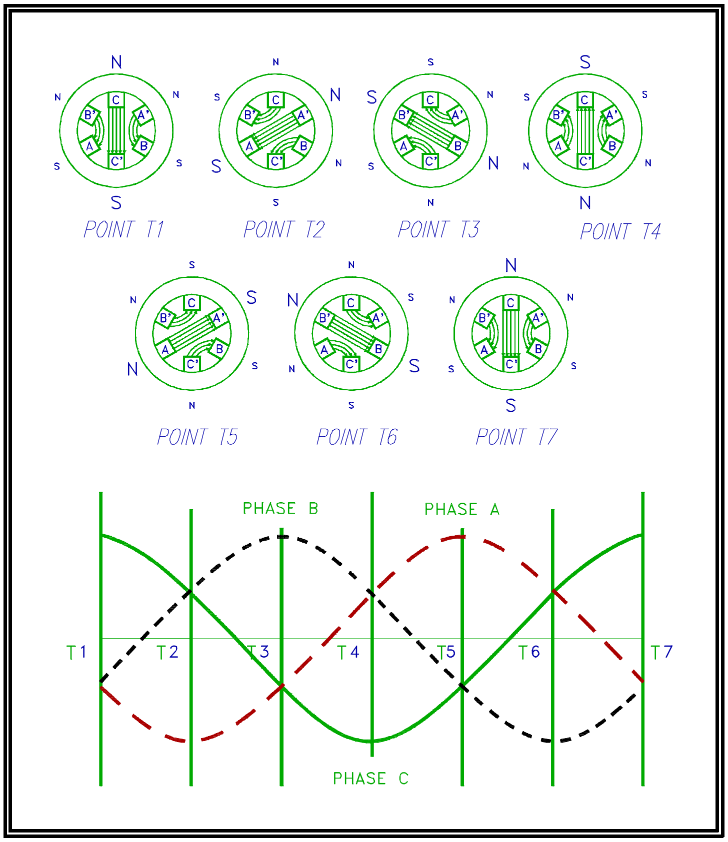
   2) Extra energy is required to overcome the inertia of the machine

   3) Interactions between the rotor currents and the stator magnetic field

f. What is the relationship between starting torque and full load torque? (K&S 1.14-1.a.)

   Starting torque is normally 150 to 200% of full-load torque.

g. Describe how an alternating current motor produces a rotating magnetic field. (K&S 1.14-1.b.)



There are three phases and the phases are electrically 120° out of phase. Electrically, the phases are connected to the windings via a wye connection. Each phase has two windings. The windings are wound in the same direction and are on opposites of the stator. When electrical current flows through a winding a magnetic field is produced. The magnetic field is directed across the diameter of the stator.

The magnetic field generated in one phase will depend on the current through that phase. If the current through that phase is zero, the resulting magnetic field is zero. If the current is at a maximum value, the resulting field is at a maximum value.
Since the currents in the three windings are 120° out of phase, the magnetic fields produced will also be 120° out of phase. When the current flow in a phase is positive, the magnetic field will develop a north pole at the poles labeled A, B, and C. When the current flow in a phase is negative, the magnetic field will develop a north pole at the poles labeled A', B', and C'. The three magnetic fields will combine to produce one field, which will act upon the rotor. At the end of one cycle of alternating current, the magnetic field will have shifted through 360°, or one revolution.

For example refer to point T1 on the figure, the current in phase C is at its maximum positive value. The resulting magnetic field is established vertically downward, with the maximum field strength developed across the C phase, between pole C (north) and pole C' (south). At the same instance, the currents in phases A and B are at half of the maximum negative value. Thus poles A' and B' are weak south poles and poles A and B are weak north poles. The strong magnetic field between poles C and C' prevents the weaker poles from connecting through the stator to their corresponding matching pole. Instead the strong magnetic field is aided by the weaker fields developed across phases A and B, with poles A' and B' being north poles and poles A and B being south poles. The weak north A' pole is magnetically coupled to the closer weak south B pole rather than coupling through the rotor and the strong C and C' magnetic field. And the weak north B' pole is magnetically coupled to the closer weak south A pole. Thus overall one side of the stator has a north pole (centered on the C pole) and the other side of the stator has a south pole (centered on the C' pole).

h. Describe how an alternating current motor produces torque. (K&S 1.14-1.c.)

When alternating current is applied to the stator windings of an AC induction motor, a rotating magnetic field is developed. The rotating magnetic field cuts the bars of the rotor and induces a current in them due to generator action. The induced current, in turn produces a magnetic field, opposite in polarity of the stator field, around the conductors of the rotor. Because opposite charges attract, the rotor's magnetic field will try to line up with the magnetic field of the stator. Since the stator field is rotating continuously, the rotor cannot line up with, or lock onto, the stator field and, therefore, must follow behind it. The torque of an AC induction motor is dependent upon the strength of the interacting rotor and stator fields and the phase relationship between them.

i. A four pole, 60 Hz AC induction motor has a full load speed of 1735 rpm. Calculate percent slip in an alternating current motor. (K&S 1.14-1.d.)

Synchronous speed:

$$N_S = \frac{120\ f}{P}$$

$$N_S = \frac{120\ (60\ \text{Hz})}{4}$$

$$N_S = 1800\ \text{rpm}$$

Slip:

$$\text{SLIP} = \frac{N_S - N_R}{N_S} \times 100\%$$

$$\text{SLIP} = \frac{1800 - 1735\ \text{rpm}}{1800\ \text{rpm}} \times 100\% = 3.6\%$$

j. Why must an alternating current induction motor have a certain percent of **SLIP** to operate? (K&S 1.14-1.e.)

It is impossible for the rotor of an AC induction motor to turn at the same speed as that of the rotating magnetic field. If the speed of the rotor were the same as that of the stator, no relative motion between them would exist, and there would be no induced EMF in the rotor. (Recall that relative motion between a conductor and a magnetic field is needed to induce a current.) Without this induced EMF, there would be no interaction of fields to produce motion. The rotor must, therefore, rotate at some speed less than that of the synchronous speed of the magnetic field in the stator if relative motion is to exist between the two.

k. What is **BREAKDOWN TORQUE**? (K&S 1.14-1.e.)

Breakdown torque is the maximum value of torque in a motor. If load is increased beyond this point, the motor will stall and come to a rapid stop. The typical induction motor breakdown torque varies from 200 to 300% of full load torque.

l. Describe how torque is produced in a single-phase alternating current motor. (K&S 1.14-1.f.)

If two stator windings of unequal impedance are spaced 90 electrical degrees apart and connected in parallel to a single-phase source, the field produced will appear to rotate. This is called phase splitting.

In a split-phase motor, a starting winding is utilized. This winding has a higher resistance and lower reactance than the main winding. When the same voltage V_T is applied to the starting and main windings, the current in the main winding (I_M) lags behind the current of the starting winding I_S. The angle between the two windings is enough phase difference to provide a rotating magnetic field to produce a starting torque. When the motor reaches 70 to 80% of synchronous speed, a centrifugal switch on the motor shaft opens and disconnects the starting winding.

m. Explain why an alternating current synchronous motor does not have starting torque. (K&S 1.14-1.g.)

Torque is only developed when running at synchronous speed; therefore, the motor needs some type of device to bring the rotor to synchronous speed.

n. Describe how an alternating current synchronous motor is started. (K&S 1.14-1.h.)

An AC synchronous motor may be started by a DC motor on a common shaft. When the motor is brought to synchronous speed, AC current is applied to the stator windings. The DC motor now acts as a DC generator and supplies DC field excitation to the rotor of the synchronous motor. The load may now be placed on the synchronous motor.

Synchronous motors are more often started by means of a squirrel-cage winding embedded in the face of the rotor poles. The DC rotor windings are de-energized and a reduced three phase voltage is applied to the stator windings. The motor is then started as an induction motor and brought to ~95% of synchronous speed, at which time direct current is applied, and the motor begins to pull into synchronism. The torque required to pull the motor into synchronism is called the pull-in torque.

o. What method would one use to reverse the direction of rotation of a synchronous motor? (K&S 1.14-1.i.)

By changing any two of the three stator connections.

p. Explain the following motor terms: (K&S 1.14-1.l.)

- Service factor - associated with an AC motor, this is a numerical multiplier applied to the rated horsepower which indicates a permissible horsepower loading which may be carried under the conditions specified for the service condition. (NEMA section 1.43)

- Insulation class - Divides the insulation systems of motors and generators into four classes based on the thermal endurance of the system for temperature rating purposes. Classes A, B, F, H. These classes have been established in accordance with IEEE Std 1, General Principles for Temperature Limits in Rating of Electric Equipment. (NEMA section 1.66)

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Competency 1.15

Construction management and engineering (FAC# 1.20 & 1.21), EH Residents (FAC# 1.9), Facility maintenance management (FAC# 1.9), and Facility Representatives (FAC# 1.10) personnel shall demonstrate familiarity level knowledge of transformers.

1. Supporting Knowledge and/or Skills

   a. Discuss the basic operation of the various types of transformers. Include in the discussion the following elements of transformer operation and design:

      - Theory of operation
      - Purpose of the transformer
      - Transformer ratings
      - Transformer cooling requirements

        DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter Transformer Theory.

Competency 1.16

Electrical systems (FAC# 1.10) and Instrumentation and control (FAC# 1.2) personnel shall demonstrate a working level knowledge of transformers.

1. Supporting Knowledge and/or Skills

   a. Discuss the purposes of a transformer.

   b. Define the following terms as they apply to transformers:

      - Mutual induction
      - Turns ratio
      - Impedance ratio
      - Efficiency

        DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter Transformer Theory.

c. Discuss the basic operation of the various types of transformers. Include in the discussion the following elements of transformer operation and design:

- Theory of operation
- Magnetic coupling
- Voltage/current relationships between primary and secondary windings
- Purposes of a transformer
- Step up vs. step down transformer design
- Multiple secondary windings
- Transformer tap changers
- Transformer ratings
- Transformer cooling requirements
- Current transformers vs. potential transformers

DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter Transformer Theory.

d. Discuss the application of specific transformer designs to the following types of electrical/electronic circuitry:

- Instrumentation power
- Voltage sensing circuits
- Current sensing circuits
- Control circuitry power
- Circuits requiring fault isolation protection

e. Describe the differences between a wye-connected and delta-connected transformer.

DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter Transformer Theory.

f. Using the type of connection and turns ratios for the primary and secondary of a transformer, calculate voltage, current, and power for each of the following types:

- Delta - Delta
- Delta - Wye
- Wye - Delta
- Wye - Wye

DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter Transformer Theory.

g. State the applications of each of the following types of transformers:

- Distribution
- Power
- Control
- Auto
- Isolation
- Instrument potential
- Instrument current

DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter Transformer Types.

h. Describe the hazardous materials that are associated with transformers.

2. Self-Study Information

Competency 1.15 and 1.16 address the knowledge of transformer construction and operation. Competency 1.15 is at a familiarity level and Competency 1.16 is at a working level.

The supporting material for the Self-Study Information include the following documents:

- Department of Energy Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92).
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-11-LP) Transformers.
- Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100).
- Bureau of Naval Personnel (1969). Basic Electricity. Washington, DC: U.S. Government Printing Office. Stock Ordering No. 0502-LP-050-4300.
- Dorf, Richard C. (editor) (1993). The Electrical Engineering Handbook. Boca Raton, FL: CRC Press Inc. ISBN 0-8493-0185-8. Call# TK145.E354.
- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Albany, NY: Delmar Publishers Inc. ISBN 0-8273-4156-3. Call# TK1141.D83.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. New York: McGraw-Hill Book Company. ISBN 0-07-020974-X. Call# TK151.S8.
- General Physics Corporation. Switchgear Maintenance. Columbia, MD: General Physics Corporation.

- General Physics Corporation. Electrical Industrial Plant Maintenance. Columbia, MD: General Physics Corporation.
- General Physics Corporation. Power Distribution and Control. Columbia, MD: General Physics Corporation.
- Institute of Electrical and Electronic Engineers (1994). IEEE Recommended Practice for Electrical Power Distribution for Industrial Plants (IEEE-STD-141-1993 IEEE Red Book). New York: Institute of Electrical and Electronic Engineers Inc. ISBN 1-55937-333-4.
- Institute of Electrical and Electronic Engineers (1994). IEEE Recommended Practice for Electrical Power Distribution for Industrial Plants (IEEE-STD-141-1993 IEEE Red Book). New York: Institute of Electrical and Electronic Engineers Inc. ISBN 1-55937-333-4.
- Institute of Electrical and Electronic Engineers (1986). IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (IEEE-STD-242-1986 IEEE Buff Book). New York: Institute of Electrical and Electronic Engineers Inc. ISBN 0-471-85392-5.
- Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Albany, NY: Delmar Publishers Inc. ISBN 0-8273-4146-6. Call# TK1111.L66.
- Pansini, Anthony J., E.E., P.E. (1992). Electrical Distribution Engineering 2nd Edition. Lilburn, GA: The Fairmount Press Inc. ISBN 0-88173-121-8. Call# TK3001.P28.
- Richardson, Donald V. (1978). Rotating Electric Machinery and Transformer Technology. Reston, VA: Reston Publishing Company Inc. ISBN 0-87909-732-9. Call# TK2181.R48.
- Rockis, Gary and Glen Mazur, (1993). Electrical Motor Controls, Automated Industrial Systems Third Edition. Homewood, IL: American Technical Publishers, Inc. ISBN 0-8269-1666-X Call# TK2851.R63
- Say, M. G. (1976). Alternating Current Machines. New York: John Wiley & Sons. ISBN 0-470-15133-1. Call# TK2711.S3.
- Smeaton, Robert W. (editor) (1977). Switchgear and Control Handbook. New York: McGraw-Hill Book Company. ISBN 0-07-058439-7. Call# TK2821.S88.
- Schultz, George Patrick (1989). Transformers and Motors. Carmel, IN: Macmillam Computer Publishing. ISBN 0-672-30131-8. Call# TK2541.S55.
- Westinghouse Electric Corporation. (1974). Westinghouse Electrical Maintenance Hints. Trafford, PA: Westinghouse Electric Corporation. Call# TK151.W156

Transformer hazardous materials.

Dikes and drainage provisions shall be built as required by the local procedures in conformance with 40CFR112.

Wet type transformers are filled with oil. Fire or explosion is a possibility if the transformer is faulted. Polychlorinated Biphenyls (PCB) or PCB contaminated electrical equipment and the treatment of PCB oil spills shall comply with 40CFR761. Oil filled transformers installed near buildings shall comply with FM 5-4/14-8. Existing PCB or PCB-contaminated equipment shall be provided with warning signs and shall not be relocated or re-used in other existing or new facilities. PCB used under the trade names of Askarel and Pyranol. Electrical equipment cooling material shall be handled in accordance with 29CFR1910.1200. See DOE 6430.1A section 1630-2.3.5.

When venting or opening gas or oil filled equipment take precautions against explosion, fire, and asphyxiation. Ensure adequate ventilation is provided.

Extreme care must be taken when dealing with transformers filled Inerteen. Inerteen fumes are toxic especially when heated. Exposure to the skin may cause skin rashes, gloves should be worn to prevent contact with the skin.

Gas given off by a selenium rectifier is toxic. The gas, hydrogen selenide, has a strong pungent odor.

Although not a material hazard, operators should be aware not to open the circuit of the secondary winding. Opening the secondary windings of a transformer will increase the flux in the core due to the high primary windings, creating excessive core loss, heating, and dangerously high voltage across the secondary windings.

An additional hazard not a material hazard is that transformers with fans for cooling may start automatically at any time. Do not place hands or tools in the fans.

3. References

NOTE: For information regarding the Supporting Knowledge and Skills refer to the Self-Study Information section of this competency.

a. For Supporting Knowledge and Skills **1.15-1.a** and **1.16-1.a** refer to:
   - Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100). Chapter Transformers.
   - Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Power System Components.
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Alternating-Current Generators and Transformers, Chapter Magnetic Amplifiers.
   - General Physics Corporation. Electrical Industrial Plant Maintenance. Chapter Transformers.
   - General Physics Corporation. Power Distribution and Control. Chapter Transformers.
   - General Physics Corporation. Switchgear Maintenance. Chapter Switchgear Equipment.
   - Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Transformers, Chapter Transformer Connections for Three-Phase Circuits.
   - Rockis, Gary and Glen Mazur, (1993). Electrical Motor Controls, Automated Industrial Systems. Chapter Power Distribution Systems.
   - DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-11-LP) Transformers.

b. For Supporting Knowledge and Skills **1.16-1.b** refer to:
   - Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100). Chapter Transformers.
   - Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Power System Components.
   - Institute of Electrical and Electronic Engineers (1994). IEEE Recommended Practice for Electrical Power Distribution for Industrial Plants (IEEE-STD-141-1993 IEEE Red Book). Chapter Electrical Conservation Through Energy Management Section 14.6. Efficiencies of electrical equipment.
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Alternating-Current Generators and Transformers, Chapter Magnetic Amplifiers.
   - General Physics Corporation. Power Distribution and Control. Chapter Transformers.
   - Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Transformers.

- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-11-LP) Transformers.

c. For Supporting Knowledge and Skills **1.16-1.c** refer to:
- Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100). Chapter Transformers.
- Dorf, Richard C. (editor) (1993). The Electrical Engineering Handbook. Chapter Power Transformers.
- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals. Chapter Transformers, Chapter Special Transformers Applications.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Power System Components.
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Alternating-Current Generators and Transformers, Chapter Magnetic Amplifiers.
- General Physics Corporation. Power Distribution and Control. Chapter Transformers.
- Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Transformers, Chapter Special Transformers Applications.
- Say, M. G. (1976). Alternating Current Machines. Chapter Transformers: Theory and Performance, Chapter Transformers: Construction and Design, Chapter Loss Dissipation.
- Schultz, George Patrick (1989). Transformers and Motors. Chapter Fundamental Concepts: Transformers, Chapter Installation.

d. For Supporting Knowledge and Skills **1.16-1.d** refer to:
- Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Special Transformers Applications.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Power System Components.
- Institute of Electrical and Electronic Engineers (1986). IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (IEEE-STD-242-1986 IEEE Buff Book). Chapter Instrument Transformers, Chapter Transformer Protection.
- Pansini, Anthony J., E.E., P.E. (1992). Electrical Distribution Engineering. Chapter Metering, Chapter Transformers, Cutouts and Surge Arresters.
- Richardson, Donald V. (1978). Rotating Electric Machinery and Transformer Technology. Chapter Alternating-Current Motor Control and Operation.

e. For Supporting Knowledge and Skills **1.16-1.e** refer to:
- Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100). Chapter Transformers.
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Alternating-Current Generators and Transformers.
- Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Transformers, Chapter Transformer Connections for Three-Phase Circuits.
- Rockis, Gary and Glen Mazur, (1993). Electrical Motor Controls, Automated Industrial Systems. Chapter Power Distribution Systems.
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-11-LP) Transformers.

f. For Supporting Knowledge and Skills **1.16-1.f** refer to:
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Alternating-Current Generators and Transformers.
- Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Transformers, Chapter Transformer Connections for Three-Phase Circuits.
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-11-LP) Transformers.

g. For Supporting Knowledge and Skills **1.16-1.g** refer to:
- Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100). Chapter Transformers.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Power System Components.
- Institute of Electrical and Electronic Engineers (1986). IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (IEEE-STD-242-1986 IEEE Buff Book). Chapter Instrument Transformers.
- Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Transformers, Chapter Special Transformers Applications.
- General Physics Corporation. Electrical Industrial Plant Maintenance. Chapter Transformers, Chapter Protective Relaying and Instrument Transformers.
- General Physics Corporation. Switchgear Maintenance. Chapter Switchgear Equipment.
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-11-LP) Transformers.

- Smeaton, Robert W. (editor) (1977). Switchgear and Control Handbook. Chapter Instrument Transformers.

h. For Supporting Knowledge and Skills **1.16-1.h** refer to:
   - Institute of Electrical and Electronic Engineers (1994). IEEE Recommended Practice for Electrical Power Distribution for Industrial Plants (IEEE-STD-141-1993 IEEE Red Book). Chapter Power Switching, Transformation, and Motor Control Apparatus Section 10.4.7.1 Insulation medium.
   - IEEE Std C57.102-1974. IEEE Guide for Acceptance and Maintenance of Transformer Askarel in Equipment.
   - 40 Code of Federal Regulation 761.
   - Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Properties of Materials section 264, Chapter Power System Components section 10 and section 47, Chapter Industrial Electronics section 41, Chapter Standards in Electrotechnology section 50.
   - Say, M. G. (1976). Alternating Current Machines. Chapter Transformers: Theory and Performance, Chapter Transformers: Construction and Design.
   - Schultz, George Patrick (1989). Transformers and Motors. Chapter Installation.
   - Westinghouse Electric Corporation (1974). Westinghouse Electrical Maintenance Hints. Chapter Tooling and Safety.

4. Practice Exercise

    a. Discuss the basic operation of a transformer. (K&S 1.15-1.a.) (K&S 1.16-1.c.)

    b. Discuss the basic requirements for transformer cooling. (K&S 1.15-1.a.) (K&S 1.16-1.c.)

    c. State the purposes of a transformer. (K&S 1.15-1.a.) (K&S 1.16-1.a.)

    d. How is the voltage step-down function of a transformer performed? (K&S 1.15-1.a.) (K&S 1.16-1.a.) (K&S 1.16-1.c.)

        1) The secondary windings are further from the primary windings.

        2) There are fewer secondary windings than primary windings.

        3) The transformer uses a core with a higher reluctance.

        4) There are fewer primary windings than secondary windings.

e. Which statement below best describes the electrical change occurring in a step-up transformer. (K&S 1.15-1.a.) (K&S 1.16-1.a.) (K&S 1.16-1.c.)

1) The secondary voltage increases, output power decreases proportionally.

2) The secondary voltage increases, secondary current decreases proportionally.

3) The secondary voltage increases, output power and secondary current remain constant.

4) The secondary voltage increases, output power and secondary current both decrease proportionally.

f. Match the transformer terms in column A with the equations in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.16-1.b)

Column A	Column B
__ 1. Efficiency	a. $\frac{N_P}{N_S}$
__ 2. Impedance ratio	b. $\frac{\text{Power Input}}{\text{Power Output}} = \frac{P_P}{P_S} \times 100$
__ 3. Turns ratio	c. $\left(\frac{N_P}{N_S}\right)^2 = \frac{Z_P}{Z_S}$
	d. $\frac{N_S}{N_P}$
	e. $\frac{\text{Power Output}}{\text{Power Input}} = \frac{P_S}{P_P} \times 100$

g. Discuss the voltage/current relationships between primary and secondary windings. (K&S 1.16-1.c.)

h. Besides varying the number of windings in a transformer, another way of obtaining different voltages is to use a _________. (K&S 1.16-1.c.)

i. Describe the differences between a wye-connected and delta-connected transformer. (K&S 1.16-1.e.)

j. Given a 3ϕ transformer bank with a line voltage of 13.8 kV, primary line current 12.5 A, and a turns ratio of 5:1 with a Delta - Delta connection. (K&S 1.16-1.f.)

- Calculate the voltage across each primary winding.

- Calculate the primary phase current.

- Calculate the secondary line current.

- Calculate the secondary phase current.

k. Given a 3ϕ transformer bank with a line voltage of 13.8 kV, primary line current 12.5 A, and a turns ratio of 5:1 with a Delta - Wye connection. (K&S 1.16-1.f.)

- Calculate the voltage across each primary winding.

- Calculate the primary phase current.

- Calculate the secondary line current.

- Calculate the secondary phase current.

l. Given a 3ϕ transformer bank with a line voltage of 13.8 kV, primary line current 12.5 A, and a turns ratio of 5:1 with a Wye - Wye connection. (K&S 1.16-1.f.)

- Calculate the voltage across each primary winding.

- Calculate the primary phase current.

- Calculate the secondary line current.

- Calculate the secondary phase current.

m. Given a 3ϕ transformer bank with a line voltage of 13.8 kV, primary line current 12.5 A, and a turns ratio of 5:1 with a Wye - Delta connection. (K&S 1.16-1.f.)

- Calculate the voltage across each primary winding.

- Calculate the primary phase current.

- Calculate the secondary line current.

- Calculate the secondary phase current.

n. Match the type of transformer in column A with the characteristics of a transformer in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.16-1.g)

Column A	Column B
__ 1. Auto	a. Low power transformers used to remove electronic noise from or to ground electronic circuits.
__ 2. Instrument current	b. Used in electrical power transmission systems. This class of transformer has the highest power, or volt-ampere ratings, and the highest continuous voltage rating.
__ 3. Isolation	c. Steps down the current of a circuit to a lower value to allow measurements of high values of current can be obtained.
__ 4. Power	d. Used in electronic circuits, normally provide power to the power supply of an electronic device.
	e. Used in low power applications where a variable voltage is required constructed by tapping or connecting at certain points along the a single winding, different voltages can be obtained.
	f. Used in electronic circuits that require constant voltage or constant current with a low power or volt-amp rating.
	g. Steps down voltage of a circuit to a low value that can be effectively and safely used for operation of instruments such as ammeters, voltmeters, watt meters, and relays used for various protective purposes.

o. List the hazards associated with transformers. (K&S 1.16-1.h.)

5. Practice Exercise Answers

   a. Discuss the basic operation of a transformer. (K&S 1.15-1.a.) (K&S 1.16-1.c.)

      A transformer works on the principle that energy can be transferred by magnetic induction from one set of coils to another set by means of a varying magnetic flux. The magnetic flux is produced by an AC source. The coil of a transformer that is energized from an AC source is called the primary winding (coil), and the coil that delivers this AC to the load is called the secondary winding (coil).

      When alternating voltage is applied to the primary winding, an alternating current will flow that will magnetize the magnetic core, first in one direction and then in the other direction. This alternating flux flowing around the entire length of the magnetic circuit induces a voltage in the secondary windings. The induced voltage will be the same frequency as the source.

      A voltage will also be induced into the primary windings, since it is also in close proximity to the changing magnetic field. The voltage opposes the voltage applied to the primary windings and is called counter-electromotive force (CEMF).

      The alternating current flowing through the primary windings establishes a primary magnetic field. The primary magnetic field will build up, collapse and change directions due to the alternating electrical current. The secondary winding is placed near the primary winding. The expanding and collapsing magnetic field of the primary winding produces relative motion and electrical current is produced in the secondary winding.

   b. Discuss the basic requirements for transformer cooling. (K&S 1.15-1.a.) (K&S 1.16-1.c.)

      The power rating of a transformer is normally determined by the type of cooling methods the transformer may use. Cooling is required because of the large amount of electrical current flowing through the transformer windings. The heat generated in a transformer is based on the power or I^2R. Smaller transformers are cooled by air flow over the windings, in larger transformers fans maybe used to increase the air flow. In still larger transformer some commonly-used methods of cooling are by using oil or some other heat-conducting material.

c. State the purposes of a transformer. (K&S 1.15-1.a.) (K&S 1.16-1.a.)

A transformer is an electrical device designed to transfer electrical energy from one circuit to another buy electromagnetic induction. Transformers can be used to step voltage up, step voltage down, or to provide electrical isolation.

d. How is the voltage step-down function of a transformer performed? (K&S 1.15-1.a.) (K&S 1.16-1.a.) (K&S 1.16-1.c.)

1) The secondary windings are further from the primary windings.

2) There are fewer secondary windings than primary windings.

3) The transformer uses a core with a higher reluctance.

4) There are fewer primary windings than secondary windings.

e. Which statement below best describes the electrical change occurring in a step-up transformer. (K&S 1.15-1.a.) (K&S 1.16-1.a.) (K&S 1.16-1.c.)

1) The secondary voltage increases, output power decreases proportionally.

2) The secondary voltage increases, secondary current decreases proportionally.

3) The secondary voltage increases, output power and secondary current remain constant.

4) The secondary voltage increases, output power and secondary current both decrease proportionally.

f. Match the transformer terms in column A with the equations in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.16-1.b)

Column A	Column B
_e_ 1. Efficiency	a. $\frac{N_P}{N_S}$
_c_ 2. Impedance ratio	b. $\frac{\text{Power Input}}{\text{Power Output}} = \frac{P_P}{P_S} \times 100$
_d_ 3. Turns ratio	c. $\left(\frac{N_P}{N_S}\right)^2 = \frac{Z_P}{Z_S}$
	d. $\frac{N_S}{N_P}$
	e. $\frac{\text{Power Output}}{\text{Power Input}} = \frac{P_S}{P_P} \times 100$

g. Discuss the voltage/current relationships between primary and secondary windings. (K&S 1.16-1.c.)

The voltage of the windings in a transformer is directly proportional to the number of turns on the coils. This relationship is expressed in $\frac{V_P}{V_S} = \frac{N_P}{N_S}$. A voltage ratio of 1:5 means that for each volt on the primary, there will be 5 volts on the secondary.

The ratio of primary voltage to secondary voltage is known as the *voltage ratio* (VR). The ratio of primary turns of wire to secondary turns of wire is known as the turns ratio (TR). The voltage ratio is equal to the turns ratio. VR = TR.

h. Besides varying the number of windings in a transformer, another way of obtaining different voltages is to use a <u>transformer tap changer</u>. (K&S 1.16-1.c.)

i. Describe the differences between a wye-connected and delta-connected transformer. (K&S 1.16-1.e.)

In the wye connection, three common ends of each phase are connected together at a common terminal (marked "N" for neutral), and the other three ends are connected to a three-phase line.

In the delta connection, all three phases are connected in series to form a closed loop.

j. Given a 3ϕ transformer bank with a line voltage of 13.8 kV, primary line current 12.5 A, and a turns ratio of 5:1 with a Delta - Delta connection. (K&S 1.16-1.f.)

- Calculate the voltage across each primary winding.

  primary voltage = V = 13800 volts

- Calculate the primary phase current.

  $$\text{primary phase current} = \frac{I}{\sqrt{3}} = \frac{12.5}{1.73} = 7.22 \text{ amps}$$

- Calculate the secondary line current.

  secondary line current = 5(12.5) = 62.5 amps

- Calculate the secondary phase current.

  $$\text{secondary phase current} = \frac{aI}{\sqrt{3}} = \frac{5\ (12.5)}{1.73} = 36.1 \text{ amps}$$

k. Given a 3ϕ transformer bank with a line voltage of 13.8 kV, primary line current 12.5 A, and a turns ratio of 5:1 with a Delta - Wye connection. (K&S 1.16-1.f.)

- Calculate the voltage across each primary winding.

  primary voltage = V = 13800 volts

- Calculate the primary phase current.

  $$\text{primary phase current} = \frac{I}{\sqrt{3}} = \frac{12.5}{1.73} = 7.22 \text{ amps}$$

- Calculate the secondary line current.

  $$\text{secondary line current} = \frac{aI}{\sqrt{3}} = \frac{5\,(12.5)}{1.73} = 36.1 \text{ amps}$$

- Calculate the secondary phase current.

  $$\text{secondary phase current} = \frac{aI}{\sqrt{3}} = \frac{5\,(12.5)}{1.73} = 36.1 \text{ amps}$$

l. Given a 3ϕ transformer bank with a line voltage of 13.8 kV, primary line current 12.5 A, and a turns ratio of 5:1 with a Wye - Wye connection. (K&S 1.16-1.f.)

- Calculate the voltage across each primary winding.

  $$\text{primary voltage} = \frac{V}{\sqrt{3}} = \frac{13800}{1.73} = 7967.4 \text{ volts}$$

- Calculate the primary phase current.

  primary phase current = I = 12.5 amps

- Calculate the secondary line current.

  secondary line current = aI = 5(12.5) = 62.5 amps

- Calculate the secondary phase current.

  secondary phase current = aI = 5(12.5) = 62.5 amps

m. Given a 3ϕ transformer bank with a line voltage of 13.8 kV, primary line current 12.5 A, and a turns ratio of 5:1 with a Wye - Delta connection. (K&S 1.16-1.f.)

- Calculate the voltage across each primary winding.

  primary voltage $= \frac{V}{\sqrt{3}} = \frac{13800}{1.73} = 7967.4$ volts

- Calculate the primary phase current.

  primary phase current = I = 12.5 amps

- Calculate the secondary line current.

  secondary line current = $\sqrt{3}$aI = (1.73)(5)(12.5) = 108.3 amps

- Calculate the secondary phase current.

  secondary phase current = aI = 5(12.5) = 62.5 amps

n. Match the type of transformer in column A with the characteristics of a transformer in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.16-1.g)

Column A	Column B
_e_ 1. Auto	a. Low power transformers used to remove electronic noise from or to ground electronic circuits.
_c_ 2. Instrument current	b. Used in electrical power transmission systems. This class of transformer has the highest power, or volt-ampere ratings, and the highest continuous voltage rating.
_a_ 3. Isolation	c. Steps down the current of a circuit to a lower value to allow measurements of high values of current can be obtained.
_d_ 4. Power	d. Used in electronic circuits, normally provide power to the power supply of an electronic device.
	e. Used in low power applications where a variable voltage is required constructed by tapping or connecting at certain points along the a single winding, different voltages can be obtained.
	f. Used in electronic circuits that require constant voltage or constant current with a low power or volt-amp rating.
	g. Steps down voltage of a circuit to a low value that can be effectively and safely used for operation of instruments such as ammeters, voltmeters, watt meters, and relays used for various protective purposes.

o. List the hazards associated with transformers. (K&S 1.16-1.h.)

- As with all electrical equipment electrical shock must be considered.
- Transformers using fans, although the fans do not run constantly, they may start suddenly without any warning.
- Transformers can explode during fault conditions.
- Some oil cooled transformers contain PCBs a known carcinogen.

Competency 1.17

Construction management and engineering (FAC# 1.20) and EH Resident (FAC# 1.35) personnel shall demonstrate a familiarity level knowledge of uninterruptible power supplies.

1. Supporting Knowledge and/or Skills

   a. Discuss the purpose of an uninterruptible power supply.

   b. Discuss the types of emergency power sources used for an uninterruptible power supply.

   c. Discuss the purpose of a static inverter.

   d. Discuss the basic operation of a static inverter.

   e. Describe how to determine the state of charge of a battery used in an uninterruptible power supply.

   f. Given an uninterruptible power supply for a computer system, identify the maintenance requirements that ensure operability of the system.

   g. Discuss application of the following as backup power supplies:

      - UPS inverters
      - Diesel generators
      - Motor generators
      - Auto transfer switches

Competency 1.18

Instrumentation and control (FAC# 1.2) personnel shall demonstrate a working level knowledge of backup power supplies.

1. Supporting Knowledge and/or Skills

   a. Discuss application of the following as backup power supplies:

      - UPS inverters
      - Diesel generators
      - Motor generators
      - Auto transfer switches

2. Self-Study Information

Competency 1.17 and 1.18 addresses backup power supply components' construction, theory, and purpose. Competency 1.17 at a familiarity level of knowledge and Competency 1.18 at a working level of knowledge.

The supporting material for the Self-Study Information include the following documents:

- Department of Energy Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92).
- Department of Energy (DOE) DOE/DP-0124T, Emergency and Backup Power Supplies at Department of Energy Facilities.
- Department of Energy (DOE) Standard Backup Power Sources for DOE Facilities (DOE-STD-3003-94)
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-13-LP)
- Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100).
- Westinghouse Savannah River Corporation High Level Waste Operator Training Electrical Science Student Study Guide (NWMOG008.H0102).
- Dorf, Richard C. (editor) (1993). The Electrical Engineering Handbook. Boca Raton, FL: CRC Press Inc. ISBN 0-8493-0185-8. Call# TK145.E354.
- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Albany, NY: Delmar Publishers Inc. ISBN 0-8273-4156-3. Call# TK1141.D83.

- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. New York: McGraw-Hill Book Company. ISBN 0-07-020974-X. Call# TK151.S8.
- General Physics Corporation. Power Distribution and Control. Columbia, MD: General Physics Corporation.
- General Physics Corporation. Uninterruptible Power Supplies. Columbia, MD: General Physics Corporation.
- Institute of Electrical and Electronic Engineers (1986). IEEE Recommended Practice for Electric Systems in Health Care Facilities (IEEE-STD-602-1986 IEEE White Book). New York: Institute of Electrical and Electronic Engineers Inc. ISBN 0-471-82747-9.
- Institute of Electrical and Electronic Engineers (1991). IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems (IEEE-STD-493-1990 IEEE Gold Book). New York: Institute of Electrical and Electronic Engineers Inc. ISBN 1-55937-066-1.
- Institute of Electrical and Electronic Engineers (1987). IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications (IEEE-STD-446-1987 IEEE Orange Book). New York: Institute of Electrical and Electronic Engineers Inc. ISBN 471-62571-X
- Institute of Electrical and Electronic Engineers (1994). IEEE Recommended Practice for Electrical Power Distribution for Industrial Plants (IEEE-STD-141-1993 IEEE Red Book). New York: Institute of Electrical and Electronic Engineers Inc. ISBN 1-55937-333-4.
- Schultz, George Patrick (1989). Transformers and Motors. Carmel, IN: Macmillam Computer Publishing. ISBN 0-672-30131-8. Call# TK2541.S55.
- Smeaton, Robert W. (editor) (1977). Switchgear and Control Handbook. New York: McGraw-Hill Book Company. ISBN 0-07-058439-7. Call# TK2821.S88.

3. References

NOTE: For information regarding the Supporting Knowledge and Skills refer to the Self-Study Information section of this competency.

a. For Supporting Knowledge and Skills **1.17-1.a** refer to:
   - Department of Energy (DOE) DOE/DP-0124T, Emergency and Backup Power Supplies at Department of Energy Facilities.
   - Department of Energy (DOE) Standard Backup Power Sources for DOE Facilities (DOE-STD-3003-94)
   - Westinghouse Savannah River Corporation High Level Waste Operator Training Electrical Science Student Study Guide NWMOG008.H0102, Chapter Uninterruptable Power Supply.
   - Institute of Electrical and Electronic Engineers (1987). IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications (IEEE-STD-446-1987 IEEE Orange Book). Chapter Stored Energy Systems.
   - Institute of Electrical and Electronic Engineers (1986). IEEE Recommended Practice for Electric Systems in Health Care Facilities (IEEE-STD-602-1986 IEEE White Book). Chapter Emergency Power Systems.
   - Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Industrial Electronics, section 22 Electronics.
   - General Physics Corporation. Power Distribution and Control. Chapter Uninterruptible Power Supplies.
   - DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-13-LP) Chapter Emergency Power.
   - Dorf, Richard C. (editor) (1993). The Electrical Engineering Handbook. Chapter Power Electronics.
   - Smeaton, Robert W. (editor) (1977). Switchgear and Control Handbook. Chapter Emergency Power-Standby or Uninterrupted, Chapter System Considerations for Switchgear, Chapter System Considerations for AC Control, System Protection and Coordination.

b. For Supporting Knowledge and Skills **1.17-1.b** refer to:
   - Westinghouse Savannah River Corporation High Level Waste Operator Training Electrical Science Student Study Guide NWMOG008.H0102, Chapter Uninterruptable Power Supply.
   - DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-13-LP) Chapter Emergency Power.

- Institute of Electrical and Electronic Engineers (1987). IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications (IEEE-STD-446-1987 IEEE Orange Book).
- Institute of Electrical and Electronic Engineers (1991). IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems (IEEE-STD-493-1990 IEEE Gold Book). Chapter Emergency and Backup Power.

c. For Supporting Knowledge and Skills **1.17-1.c** refer to:
- Westinghouse Savannah River Corporation High Level Waste Operator Training Electrical Science Student Study Guide NWMOG008.H0102, Chapter Uninterruptable Power Supply.
- General Physics Corporation. Power Distribution and Control. Chapter Uninterruptible Power Supplies.

d. For Supporting Knowledge and Skills **1.17-1.d** refer to:
- General Physics Corporation. Power Distribution and Control. Chapter Uninterruptible Power Supplies.
- Institute of Electrical and Electronic Engineers (1994). IEEE Recommended Practice for Electrical Power Distribution for Industrial Plants (IEEE-STD-141-1993 IEEE Red Book). Chapter Harmonics in Power Systems.

e. For Supporting Knowledge and Skills **1.17-1.e** refer to:
- Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100) Chapter Batteries.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Alternate Sources and Converters of Power.
- Bureau of Naval Personnel (1969). Basic Electricity. Washington, DC: U.S. Government Printing Office. Stock Ordering No. 0502-LP-050-4300. Chapter Batteries.
- Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Batteries

f. For Supporting Knowledge and Skills **1.17-1.f** refer to:

i. General Physics Corporation. Uninterruptible Power Supplies. Chapter Fundamental Components of Power Inverters, Converters, and UPS Systems, Chapter UPS Troubleshooting and Maintenance.

g. For Supporting Knowledge and Skills **1.17-1.g** and **1.18-1.a** refer to:
- Department of Energy (DOE) DOE/DP-0124T, Emergency and Backup Power Supplies at Department of Energy Facilities.

- Department of Energy (DOE) Standard Backup Power Sources for DOE Facilities (DOE-STD-3003-94)
- Westinghouse Savannah River Corporation High Level Waste Operator Training Electrical Science Student Study Guide NWMOG008.H0102, Chapter Uninterruptable Power Supply, Chapter Switches.
- Institute of Electrical and Electronic Engineers (1987). IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications (IEEE-STD-446-1987 IEEE Orange Book).
- Institute of Electrical and Electronic Engineers (1991). IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems (IEEE-STD-493-1990 IEEE Gold Book). Chapter Emergency and Backup Power.
- Institute of Electrical and Electronic Engineers (1986). IEEE Recommended Practice for Electric Systems in Health Care Facilities (IEEE-STD-602-1986 IEEE White Book). Chapter Emergency Power Systems.
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-13-LP) Chapter Emergency Power.
- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals. Chapter The Synchronous Motor.
- General Physics Corporation. Power Distribution and Control. Chapter Uninterruptible Power Supplies.
- Schultz, George Patrick (1989). Transformers and Motors. Chapter Transformers.

4. Practice Exercise

   a. State the name of the electrical device designed to maintain total electrical continuity of power to critical loads. (K&S 1.17-1.a.)

   b. Describe the electrical power flow path using an uninterruptible power supply. (K&S 1.17-1.b.)

      Normal conditions -

      Loss of normal power -

      Loss of normal power and alternate power -

   c. List the sources of power typically available to an uninterruptible power supply. (K&S 1.17-1.b.)

d. List the two (2) purposes of a static inverter. (K&S 1.17-1.c.)

1)

2)

e. Describe how to determine the state of charge of a battery used in an uninterruptible power supply. (K&S 1.17-1.e.)

f. Discuss application of the following as backup power supplies: (K&S 1.17-1.g.) (K&S 1.18-1.a.)

- Diesel generators

- Motor generators

g. State the name of the two types of automatic transfer switches **AND** describe the differences between the two switches. (K&S 1.17-1.g.) (K&S 1.18-1.a.)

1)

2)

5. Practice Exercise Answers

   a. State the name of the electrical device designed to maintain total electrical continuity of power to critical loads. (K&S 1.17-1.a.)

      Uninterruptible Power Supply (UPS)

   b. Describe the electrical power flow path using an uninterruptible power supply. (K&S 1.17-1.b.)

      Normal conditions - AC from the normal power supply is converted in to DC in the rectifier. A small trickle charge of DC electricity maintains a charge on the UPS DC battery. The majority of DC electricity from the rectifier is converted back to AC electricity in the inverter. The AC electricity passes through a static transfer switch and onto the uninterruptible power supply loads via the distribution panel.

      Loss of normal power - When the normal AC electricity power supply is lost, the static transfer switch sense the loss of electricity. The static transfer switch automatically disconnects the normal power supply and connects the alternate AC power supply. This allows the alternate power supply to provide power to the uninterruptible power supply loads.

      Loss of normal power and alternate power - When the normal AC electricity power supply is lost and the static transfer switch senses power unavailable from the alternate AC power supply, as soon as the DC electricity out of the rectifier drops below the voltage of the UPS battery, electricity flows out of the battery and to the inverter where the DC electricity is converted to AC electricity in the inverter. The AC electricity passes through a static transfer switch and onto the uninterruptible power supply loads via the distribution panel. The UPS loads will be supplied with power as long as the charge on the battery lasts. UPS batteries are sized to provide full load on the system for approximately 20 minutes.

   c. List the sources of power typically available to an uninterruptible power supply. (K&S 1.17-1.b.)

      Normally there are three power supplies associated with an uninterruptible power supply. First is the normal power supply, second is an alternate power supply, and the final source of power is a battery.

d. List the two (2) purposes of a static inverter. (K&S 1.17-1.c.)

   1) Provides a normal current path from the inverter to the loads in the uninterruptible power supply distribution panel.

   2) Disconnects the normal current path and directs an alternate power supply (internal bypass) to the uninterruptible power supply distribution panel in the event current from the inverter is out of specifications.

e. Describe how to determine the state of charge of a battery used in an uninterruptible power supply. (K&S 1.17-1.e.)

   The state of charge of a battery is determined by the specific gravity of the cells of the battery. The operator can use a hydrometer to determine the specific gravity of individual cells. The specific gravity must be temperature corrected for differences between actual temperature and standardize temperatures.

f. Discuss application of the following as backup power supplies: (K&S 1.17-1.g.) (K&S 1.18-1.a.)

   - Diesel generators - provide backup or emergency electrical power. The diesel can be automatically started or manually started upon the loss of the original electrical power. The diesels provide mechanical energy and serve as the prime mover for an electrical generator. As the shaft of the diesel turns, it is connected to the shaft of a generator. The electrical generator can be designed and constructed to be either AC or DC depending on system load requirements. The spinning shaft of the generator converts the mechanical energy of the diesel to electrical energy that can be connected to the distribution system.

   - Motor generators - provide backup or emergency electrical power. The motor generator is an arrangement that mechanically connects a motor to a generator. The motor is turned to an electrical power source, in backup power applications this electrical power typically comes from a battery source. The DC electrical power from the battery turns the motor, the motor is mechanically connected to the generator shaft. As the motor turns the shaft of the generator, electrical power is created in the generator. The electrical power can be connected to the electrical distribution system.

g. State the name of the two types of automatic transfer switches **AND** describe the differences between the two switches. (K&S 1.17-1.g.) (K&S 1.18-1.a.)

Normal seeking - on a loss of normal power the normal seeking automatic transfer switch automatically switches from the normal power source to the alternate power source. When normal power is restored a normal seeking automatic transfer switch automatically returns to the normal power source.

Power seeking - on a loss of normal power the power seeking automatic transfer switch automatically switches from the normal power source to the alternate power source. The power seeking automatic transfer switch will remain on the alternate power source until an operator manually returns the switch to the normal power source after power has been returned to the normal power source.

Competency 1.19

Construction management and engineering (FAC# 1.20 & 1.21), Facility maintenance management (FAC# 1.10), EH Residents (FAC# 1.9), Facility Representatives (FAC# 1.10), and Project management (FAC# 1.2) personnel shall demonstrate a familiarity level knowledge of the basic electrical fundamentals of electrical distribution systems.

1. Supporting Knowledge and/or Skills

   a. State the purpose of each of the following major components used in a basic electrical transmission or distribution system:

      - Generator
      - Transformer
      - Load center and motor control center
      - Circuit breakers
        DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter Circuit Breakers.
      - Fuses
        DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter System Components and Protection Devices.
      - Protective relays
        DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter System Components and Protection Devices.
      - Diesel power
        DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter System Components and Protection Devices.
      - Uninterruptable power supply (UPS)
      - Neutral grounding
        DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter System Components and Protection Devices.
      - Voltage class
        DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter System Components and Protection Devices.

   b. Describe the protection provided by fuses and circuit breakers.
      DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter System Components and Protection Devices, and Chapter Circuit Breakers.

c. Describe the purpose and functions of a motor controller.
   DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter Motor Controllers.

d. Describe the difference between single-phase loads and three-phase loads.
   DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter Three-Phase Circuits.

e. Discuss the reasons that three phase power systems are used in industry.
   DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter Three-Phase Circuits.

f. Discuss the types and function of electrical switchgear used on a construction project.

g. Identify and discuss the operation of the different types of electrical switchgear.

h. Identify and discuss the application of the different types of circuit breakers.
   DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter Circuit Breakers.

Competency 1.20

Electrical systems (FAC# 1.9), Facility Representatives (FAC# 1.11), and Instrumentation and control (FAC# 1.2) personnel shall demonstrate a working level knowledge of electrical transmission and distribution systems.

1. Supporting Knowledge and/or Skills

   a. Explain the differences between transmission and distribution systems.

   b. Identify and discuss the advantages and disadvantages associated with underground and above-ground distribution systems.

c. Describe the function and importance of the following control and protective devices:

- Circuit breakers
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter Circuit Breakers.
- Protective relays
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter System Components and Protection Devices.
- Fuses
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter System Components and Protection Devices.
- Transient protection
- Motor controllers
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter Motor Controllers.

d. Compare and contrast the characteristics of three-phase and single-phase distribution systems.
   DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/3-92) Volume 3 of 4, Chapter Three-Phase Circuits.

e. Discuss the principles associated with ensuring continual power availability during electrical outages.

f. Explain the following terms as they relate to power systems:

- Fault current
- Available fault current
- Fault duty

g. Discuss the safety considerations associated with high voltage transmission systems.

h. Discuss the principles of electromagnetic radiation.

i. Explain the requirements for and uses of alternate power supplies.

j. Discuss the effects on facility operations of failure of electrical components.

k. Explain the following terms as they apply to electrical distribution systems:

- Single-line diagram
- Diesel power
- Neutral grounding
- Protective relays

  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter System Components and Protection Devices.

l. Identify and discuss the operation of the different types of electrical switchgear.

m. Identify and discuss the operation of the different types of circuit breakers.

n. Discuss the current, voltage, and insulation ratings of a given type of electrical cable. Include in the discussion this applications for the specific type of cable.

2. Self-Study Information

Competency 1.19 and 1.20 address the knowledge of electrical transmission and distribution systems construction and operation. Competency 1.19 at a familiarity level of knowledge and Competency 1.20 at a working level of knowledge.

The supporting material for the Self-Study Information include the following documents:

- Title 29 Code of Federal Regulations 1926, Subpart V "Power Transmission and Distribution Section 950-960". Washington, DC: U.S. Government Printing Office.
- Department of Energy Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92).
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-12-LP)
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-13-LP)
- Westinghouse Savannah River Corporation. Employee Safety Manual 8Q Procedure 10 Non-Electric Work Near Overhead Power Lines and Above Process Piping Rev 0 4/1/91.
- Westinghouse Savannah River Corporation. Safe Electrical Practices and Procedures Manual 18Q Procedure 2 Safe Practices On or Near Electrical Conductors Rev 2 12/8/95.
- Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100).

- Dorf, Richard C. (editor) (1993). The Electrical Engineering Handbook. Boca Raton, FL: CRC Press Inc. ISBN 0-8493-0185-8. Call# TK145.E354.
- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Albany, NY: Delmar Publishers Inc. ISBN 0-8273-4156-3. Call# TK1141.D83.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. New York: McGraw-Hill Book Company. ISBN 0-07-020974-X. Call# TK151.S8.
- General Physics Corporation. Switchgear Maintenance. Columbia, MD: General Physics Corporation.
- General Physics Corporation. Electrical Industrial Plant Maintenance. Columbia, MD: General Physics Corporation.
- General Physics Corporation. Power Distribution and Control. Columbia, MD: General Physics Corporation.
- General Physics Corporation. Uninterruptible Power Supplies. Columbia, MD: General Physics Corporation.
- Institute of Electrical and Electronic Engineers (1994). IEEE Recommended Practice for Electrical Power Distribution for Industrial Plants (IEEE-STD-141-1993 IEEE Red Book). New York: Institute of Electrical and Electronic Engineers Inc. ISBN 1-55937-333-4.
- Institute of Electrical and Electronic Engineers (1987). IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications (IEEE-STD-446-1987 IEEE Orange Book). New York: Institute of Electrical and Electronic Engineers Inc. ISBN 471-62571-X
- Institute of Electrical and Electronic Engineers (1986). IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (IEEE-STD-242-1986 IEEE Buff Book). New York: Institute of Electrical and Electronic Engineers Inc. ISBN 0-471-85392-5.
- Pansini, Anthony J., E.E., P.E. (1992). Electrical Distribution Engineering 2nd Edition. Lilburn, GA: The Fairmount Press Inc. ISBN 0-88173-121-8. Call# TK3001.P28.
- Smeaton, Robert W. (editor) (1977). Switchgear and Control Handbook. New York: McGraw-Hill Book Company. ISBN 0-07-058439-7. Call# TK2821.S88.
- Bennet, William R. Jr. "Cancer and Power Lines" Physics Today v.47 April 1994 p.23-9.
- Edwards, Diane D. "ELF: The Current Controversy Does extremely low-frequency electromagnetic radiation harm our health, or doesn't it? No one - not even those with the latest incriminating data - knows for sure." Science News v.131 February 14, 1987 p.107-9.
- Edwards, D. D. "ELF: Under suspicion in new report." Science News v.132 July 18, 1987 p.39.

- Ezzell, Carol "Power-Line Static Debates rage over the possible Hazards of electromagnetic fields." Science News v.140 September 28, 1991 p 202-3.
- Haupt, Roy C. PhD and James R. Nolan, PhD "The Effects of High Voltage Transmission Lines on the Health of Adjacent Resident Populations" American Journal of Public Health v.74 January 1984 p.76-8.
- Savitz, David A. "Power Lines and Cancer Risks" Journal of the American Medical Association v.265 March 20, 1991 p 1458.

General Safety Information on Electrical Equipment

When in a high voltage switch yard exercise caution when walking around. Do not touch or lean on equipment support structures or guy wires, they have the potential for electrical shock. Do not reach or point (especially with an object) at electrical conductors, as you may present the path of less resistance.

Aerial Disconnects - Many disconnects are remotely operated and are opened under load. When opened the disconnect may draw an arc. The danger presented by disconnects opening under load include starting fires and splattering molten metal. Do not stand within 20 feet of a disconnect. When opened disconnects generate an unmistakable "frying" sound.

Oil Filled Circuit Breakers (OCBs) - Under faulted conditions OCBs present a hazard. The high current flow of a fault condition may cause the oil to boil or even ignite. This may cause the OCB to explode and expel the oil outward. This is must likely to occur during breaker operation, when operated the breaker creates a loud "thud". It is recommended that you not stand within 20 feet of OCBs.

Wet type transformers are filled with oil. Some models of transformers contain PCBs. PCBs are a carcinogen. Transformers containing PCBs must be labeled and all fluids must be contained and treated as hazardous waste. Control of PCBs are regulated by 40CFR761. Fire or explosion is a possibility if the transformer is faulted. Operators should be aware not to open the circuit of the secondary winding. Opening the secondary windings of a transformer will increase the flux in the core due to the high primary windings, creating excessive core loss, heating, and dangerously high voltage across the secondary windings. This may cause over heating of the oil. An additional hazard is that transformers with fans for cooling may start automatically at any time. Do not place hands or tools in the fans.

Overhead power supply lines shall be used where service is to be installed in remote, unsettled or industrial areas. Maximum use shall be made of single pole structures. Joint use for power and communication distribution shall maintain safety standards and shall limit electrical interference to communication services. Proper clearance for hot line maintenance work shall comply with ANSI C2.

In congested areas and where required for safety, for service continuity, or for conformance with local practices, primary and secondary power distribution circuits shall be placed underground. Underground distribution circuits may consists of direct-burial cable installations or of cable installed in manholes and duct.

Non-electrical Personnel whose work causes them or their materials to come with in 10 feet of overhead power lines must have written approval from their supervision , from Power and E&I supervision, and from the custodian served by the line. Additionally for lines more than 600V the line MUST be de-energized and grounded or the work shall not be done. If the line voltage is less than 600V either the line must be de-energized or a written plan must be provided. The written plan is in addition to the Work Clearance Permit (WCP). The plan will specify job details and special safety measures provided to ensure the safety of the workers. The plan must be approved by the Area Manager, the custodian, the Power Department, and the appropriate E&I group. The written plan should consider unexpected situations and instructions for handling them.

Operation of non-electrical Mobile Equipment that can come within 20 feet of overhead power lines must be authorized by written approval of the operator's supervision, Power and E&I supervision, and from the custodian served by the line. If any part of the mobile equipment must come within the following minimum clearance, the line MUST be de-energized and grounded or the work shall not be done.

Line Voltage	Minimum Clearance
13.8 kV	10 feet
115 kV	13 feet
230 kV	16 feet

Electromagnetic Radiation

Recently the press has reported a number of studies relating extremely low-frequency (ELF) fields to cancer, leukemia, and other significant health problems. Although there are some studies that indicate some measurable effects, there are an equal number or more that show no statistically significant effect. A couple of studies have shown that children living in homes with high current wiring configurations or living close to wires designed to carry high electricity currents have a higher increase in contracting childhood cancers. Although there is no proof that the extremely low-frequency (ELF) fields are the cause. Another study shows that users of electrically heated beds (heated water beds or electric blankets) are more likely to have miscarriages and longer gestation periods when the beds are electrically warmed. The Department of Energy (DOE), Electric Power Research Institute (EPRI) and Oak Ridge National Laboratory have funded addition studies. David Savitz, the researcher who's finding showed an increase in cancers is quoted as saying "There is no solid evidence that you should be worried even if you live *under* the power line, the bottom line...is that the evidence does fall short of implicating these fields as a health hazard." He adds "The other side is that there are these suspicions raised that haven't been resolved. So from a public health perspective, there is reason for concern."[1] He also says "The public interest makes the present level of knowledge a sufficient basis for some concerns...but not necessarily action."[2] A study released by the New York Public Service Commission reported that electromagnetic fields can effect laboratory animal behavior and an increase in childhood cancers. However the study failed to show a cause and effect relationship between ELF and behavior of laboratory animals and the increase of childhood cancers. Most of the studies conducted found no effects from ELF exposure. Two studies shows an increase in the chance of breast cancer in men in electrical trades. However, because the studies did not measure the actually exposure of the workers to the ELF, the relationship can not be proven. One study of telephone workers where the electromagnetic fields (EMF) were measured showed an increase of breast cancers. In another survey of telephone worker, the workers were studied to determine if there was an increase in leukemia. In this study the difference in the development of leukemia was too small to be determined statistically significant. A new larger survey of 130,000 electrical utility workers is underway. This study is looking for any relationship between the workers and leukemia.

[1]Edwards, Diane D. "ELF:The Current Controversy Does extremely low-frequency electromagnetic radiation harm our health, or doesn't it? No one - not even those with the latest incriminating data - knows for sure." Science News v.131 February 14, 1987 p. 109.

[2]Savitz, David A. "Power Lines and Cancer Risks" Journal of the American Medical Association v.265 March 20, 1991 p 1458.

3. References

NOTE: For information regarding the Supporting Knowledge and Skills refer to the Self-Study Information section of this competency.

a. For Supporting Knowledge and Skills **1.19-1.a** refer to:
   - Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100). Chapter System Components and Protection Devices.
   - Institute of Electrical and Electronic Engineers (1994). IEEE Recommended Practice for Electrical Power Distribution for Industrial Plants (IEEE-STD-141-1993 IEEE Red Book). Chapter Application and Coordination of Protective Devices.
   - Institute of Electrical and Electronic Engineers (1987). IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications (IEEE-STD-446-1987 IEEE Orange Book).
   - Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Power System Components.
   - General Physics Corporation. Electrical Industrial Plant Maintenance. Chapter Switchgear, Chapter Transformers, Chapter Circuit Breakers.
   - General Physics Corporation. Switchgear Maintenance. Chapter Introduction to Switchgear Maintenance, Chapter Types of Circuit Breakers.
   - General Physics Corporation. Power Distribution and Control. Chapter Introduction to Power Distribution Systems.
   - General Physics Corporation. Uninterruptible Power Supplies. Chapter Basic UPS Applications.
   - DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-12-LP) SRS Power Distribution System and Equipment.
   - Smeaton, Robert W. (editor) (1977). Switchgear and Control Handbook. Chapter System Protection and Coordination, Chapter Motor and Motor-branch Circuit Protection.

b. For Supporting Knowledge and Skills **1.19-1.b** refer to:
   - Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100). Chapter System Components and Protection Devices, Chapter Circuit Breakers.
   - Institute of Electrical and Electronic Engineers (1994). IEEE Recommended Practice for Electrical Power Distribution for Industrial Plants (IEEE-STD-141-1993 IEEE Red Book). Chapter Application and Coordination of Protective Devices.

- Institute of Electrical and Electronic Engineers (1986). IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (IEEE-STD-242-1986 IEEE Buff Book). Chapter Fuses, Chapter Low-Voltage Circuit Breakers.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Power System Components.
- General Physics Corporation. Switchgear Maintenance. Chapter Introduction to Switchgear Maintenance.
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-12-LP) SRS Power Distribution System and Equipment.
- Smeaton, Robert W. (editor) (1977). Switchgear and Control Handbook. Chapter System Protection and Coordination, Chapter Motor and Motor-branch Circuit Protection.

c. For Supporting Knowledge and Skills **1.19-1.c** refer to:

- Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100). Chapter Motor Controllers.
- Institute of Electrical and Electronic Engineers (1994). IEEE Recommended Practice for Electrical Power Distribution for Industrial Plants (IEEE-STD-141-1993 IEEE Red Book). Chapter Power Switching, Transformation, and Motor Control Application.
- Institute of Electrical and Electronic Engineers (1986). IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (IEEE-STD-242-1986 IEEE Buff Book). Chapter Motor Protection.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Motors.
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-12-LP) SRS Power Distribution System and Equipment.
- Smeaton, Robert W. (editor) (1977). Switchgear and Control Handbook. Chapter Control Standards and General Purpose Starters, Chapter System Protection and Coordination, Chapter Motor and Motor-branch Circuit Protection.

d. For Supporting Knowledge and Skills **1.19-1.d** and **1.20-1.d** refer to:

e. For Supporting Knowledge and Skills **1.19-1.e** refer to:

- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Introduction to Alternating Current, Chapter Three-Phase Systems.

f. For Supporting Knowledge and Skills **1.19-1.f** refer to:
- General Physics Corporation. Switchgear Maintenance. Chapter Introduction to Switchgear Maintenance, Chapter Switchgear.
- Smeaton, Robert W. (editor) (1977). Switchgear and Control Handbook. Chapter Control Standards and General Purpose Starters, Chapter System Protection and Coordination, Chapter Motor and Motor-branch Circuit Protection.

g. For Supporting Knowledge and Skills **1.19-1.g** refer to:
- General Physics Corporation. Switchgear Maintenance. Chapter Switchgear, Chapter Switchgear Equipment, Chapter Introduction to Switchgear Maintenance.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Power System Components.
- Smeaton, Robert W. (editor) (1977). Switchgear and Control Handbook. Chapter Control Standards and General Purpose Starters, Chapter System Protection and Coordination, Chapter Motor and Motor-branch Circuit Protection.

h. For Supporting Knowledge and Skills **1.19-1.h** refer to:
- Institute of Electrical and Electronic Engineers (1986). IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (IEEE-STD-242-1986 IEEE Buff Book). Chapter Low-Voltage Circuit Breakers.
- Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100). Chapter System Components and Protection Devices, Chapter Circuit Breakers.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Power System Components.
- General Physics Corporation. Switchgear Maintenance. Chapter Circuit Breaker Construction, Chapter Types of Circuit Breakers.
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-12-LP) SRS Power Distribution System and Equipment.
- Smeaton, Robert W. (editor) (1977). Switchgear and Control Handbook. Chapter Control Standards and General Purpose Starters, Chapter System Protection and Coordination.

i. For Supporting Knowledge and Skills **1.20-1.a** refer to:
- General Physics Corporation. Power Distribution and Control. Chapter Introduction to Power Distribution Systems.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Transmission Systems, Chapter Power Distribution.

j. For Supporting Knowledge and Skills **1.20-1.b** refer to:
- Title 29 Code of Federal Regulations 1926, Subpart V "Power Transmission and Distribution Section 950-960".
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Transmission Systems, Chapter Power Distribution.
- Dorf, Richard C. (editor) (1993). The Electrical Engineering Handbook. Chapter Transmission Section 58.1 and 58.2.
- Pansini, Anthony J., E.E., P.E. (1992). Electrical Distribution Engineering Chapter Distribution Considerations, Chapter Load Characteristics, Chapter Mechanical Design: Overhead, Chapter Mechanical Design: Underground.

k. For Supporting Knowledge and Skills **1.20-1.c** refer to:
- Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100). Chapter System Components and Protection Devices, Chapter Circuit Breakers, Chapter Motor Controllers.
- Institute of Electrical and Electronic Engineers (1994). IEEE Recommended Practice for Electrical Power Distribution for Industrial Plants (IEEE-STD-141-1993 IEEE Red Book). Chapter Power Switching, Transformation, and Motor Control Apparatus.
- Institute of Electrical and Electronic Engineers (1986). IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (IEEE-STD-242-1986 IEEE Buff Book). Chapter Selection and Application of Protective Relays, Chapter Fuses, Chapter Low-Voltage Circuit Breakers, Chapter Motor Protection, Chapter Substation Design, Chapter Motors.
- Dorf, Richard C. (editor) (1993). The Electrical Engineering Handbook. Chapter Transmission Section 58.6.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Power System Components.
- General Physics Corporation. Switchgear Maintenance. Chapter Circuit Breaker Construction.
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-12-LP) SRS Power Distribution System and Equipment.
- Smeaton, Robert W. (editor) (1977). Switchgear and Control Handbook. Chapter System Protection and Coordination, Chapter Motor and Motor-branch Circuit Protection.

l. For Supporting Knowledge and Skills **1.20-1.e** refer to:
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-13-LP) Chapter Emergency Power.

- Institute of Electrical and Electronic Engineers (1987). IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications (IEEE-STD-446-1987 IEEE Orange Book). Chapter Generator and Electric Utility Systems.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Substation Design, Chapter Power Distribution.
- Pansini, Anthony J., E.E., P.E. (1992). Electrical Distribution Engineering Chapter Distribution Substations.
- Smeaton, Robert W. (editor) (1977). Switchgear and Control Handbook. Chapter System Protection and Coordination.

m. For Supporting Knowledge and Skills **1.20-1.f** refer to:
   - Institute of Electrical and Electronic Engineers (1986). IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (IEEE-STD-242-1986 IEEE Buff Book). Chapter Selection and Application of Protective Relays, Chapter Fuses, Chapter Low-Voltage Circuit Breakers, Chapter Motor Protection.
   - Dorf, Richard C. (editor) (1993). The Electrical Engineering Handbook. Chapter Transmission section 58.5.
   - Pansini, Anthony J., E.E., P.E. (1992). Electrical Distribution Engineering Chapter Electrical Design.

n. For Supporting Knowledge and Skills **1.20-1.g** refer to:
   - Westinghouse Savannah River Corporation. Employee Safety Manual 8Q Procedure 10 Non-Electric Work Near Overhead Power Lines and Above Process Piping Rev 0 4/1/91.
   - Westinghouse Savannah River Corporation. Safe Electrical Practices and Procedures Manual 18Q Procedure 2 Safe Practices On or Near Electrical Conductors Rev 2 12/8/95.
   - Pansini, Anthony J., E.E., P.E. (1992). Chapter Nontechnical Considerations.

o. For Supporting Knowledge and Skills **1.20-1.h** refer to:
   - Bennet, William R. Jr. "Cancer and Power Lines" Physics Today v.47 April 1994 p.23-9.
   - Edwards, Diane D. "ELF: The Current Controversy Does extremely low-frequency electromagnetic radiation harm our health, or doesn't it? No one - not even those with the latest incriminating data - knows for sure." Science News v.131 February 14, 1987 p.107-9.
   - Edwards, D. D. "ELF: Under suspicion in new report." Science News v.132 July 18, 1987 p.39.
   - Ezzell, Carol "Power-Line Static Debates rage over the possible Hazards of electromagnetic fields." Science News v.140 September 28, 1991 p 202-3.

- Haupt, Roy C. PhD and James R. Nolan, PhD "The Effects of High Voltage Transmission Lines on the Health of Adjacent Resident Populations" American Journal of Public Health v.74 January 1984 p.76-8.
- Savitz, David A. "Power Lines and Cancer Risks" Journal of the American Medical Association v.265 March 20, 1991 p 1458.

p. For Supporting Knowledge and Skills **1.20-1.i** refer to:
- Institute of Electrical and Electronic Engineers (1987). IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications (IEEE-STD-446-1987 IEEE Orange Book). Chapter General Need Guidelines, Chapter Generator and Electric Utility Systems.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Substation Design, Chapter Power Distribution, Chapter Alternate Sources and Converters of Power.
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-13-LP) Emergency Power.
- Smeaton, Robert W. (editor) (1977). Switchgear and Control Handbook. Chapter Emergency Power Standby or Uninterrupted.

q. For Supporting Knowledge and Skills **1.20-1.j** refer to:
- Institute of Electrical and Electronic Engineers (1987). IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications (IEEE-STD-446-1987 IEEE Orange Book). Chapter General Need Guidelines, Chapter Generator and Electric Utility Systems.
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-13-LP) Emergency Power.

r. For Supporting Knowledge and Skills **1.20-1.k** refer to:
- Institute of Electrical and Electronic Engineers (1987). IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications (IEEE-STD-446-1987 IEEE Orange Book). Chapter General Need Guidelines, Chapter Generator and Electric Utility Systems, Chapter Grounding.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Substation Design, Chapter Power Distribution.
- General Physics Corporation. Switchgear Maintenance. Chapter Introduction to Switchgear Maintenance.
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-12-LP) SRS Power Distribution System and Equipment.
- Smeaton, Robert W. (editor) (1977). Switchgear and Control Handbook. Chapter

System Protection and Coordination.

s. For Supporting Knowledge and Skills **1.20-1.l** refer to:
- General Physics Corporation. Switchgear Maintenance. Chapter Introduction to Switchgear Maintenance, Chapter Switchgear, Chapter Switchgear Equipment, Chapter Circuit Breaker Construction, Chapter Types of Circuit Breakers.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Power System Components.

t. For Supporting Knowledge and Skills **1.20-1.m** refer to:
- Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100). Chapter System Components and Protection Devices, Chapter Circuit Breakers.
- Institute of Electrical and Electronic Engineers (1986). IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (IEEE-STD-242-1986 IEEE Buff Book). Chapter Low-Voltage Circuit Breakers.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Power System Components.
- General Physics Corporation. Switchgear Maintenance. Chapter Introduction to Switchgear Maintenance, Chapter Types of Circuit Breakers.
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-12-LP) SRS Power Distribution System and Equipment.

u. For Supporting Knowledge and Skills **1.20-1.n** refer to:
- Institute of Electrical and Electronic Engineers (1994). IEEE Recommended Practice for Electrical Power Distribution for Industrial Plants (IEEE-STD-141-1993 IEEE Red Book). Chapter Cable Systems.
- General Physics Corporation. Switchgear Maintenance. Chapter Switchgear.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Transmission Systems, Chapter Power Distribution.

4. Practice Exercise

a. Match the type of electrical power supply device in column A with the description in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.19-1.a) (K&S 1.20-1.c) (K&S 1.20-1.k)

Column A	Column B
__ 1. Diesel power	a. An electrical device that converts the supplied power into conditioned AC output at a specific voltage and frequency to maintain total continuity of power to critical power loads.
__ 2. Generator	b. Power generated by a diesel-driven generator, an economical and practical source of "standby power" or "emergency power".
__ 3. Transformer	c. Converts DC power from the rectifier to AC power for critical loads.
__ 4. Uninterruptable power supply (UPS)	d. A device which uses rotating electro-magnetic fields to create an electric output.
	e. Converts AC power from the rectifier to DC power for critical loads.
	f. A device that transfers electrical energy from one circuit to another by electromagnetic induction.

b. A transmission line carries 13.8 kV. Select the correct voltage group the line belongs to: (K&S 1.19-1.a.)

1) Very High

2) Low

3) Intermediate

4) High

c. Match the electrical distribution terms in column A with the definitions in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.19-1.a) (K&S 1.20-1.c) (K&S 1.20-1.k)

Column A	Column B
__ 1. Voltage class __ 2. Circuit breakers __ 3. Fuses __ 4. Protective relays	a. Protects a circuit from an overcurrent condition only, contains a current-carrying element sized so that the excessive heat caused by over current or short circuits causes the element to melt and open the circuit. b. Stops the current flow when the current exceeds a predetermined value without causing damage to the circuit or the component. c. Designed to safeguard generating equipment and electrical circuits from any undesirable condition, such as undervoltage, underfrequency, or interlocking system lineups. d. Reduces the amount of insulation required for high-voltage transmission lines. e. Starts the current flow when the current reaches a predetermined value without operator action. f. Divides voltage distribution systems into three groups: high voltage, intermediate voltage, and low voltage.

d. There are only two operating principles for protective relays: (1) electromagnetic attraction and

1) electromagnetic induction
2) fusible links
3) spring loaded contacts
4) oil filled heat sinks

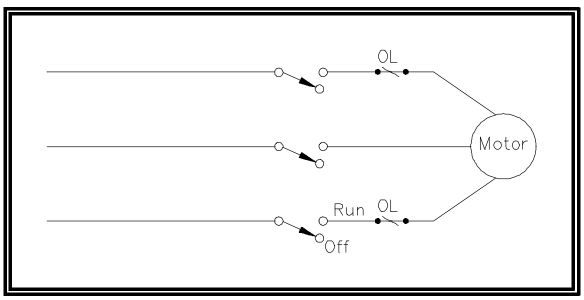
e. Describe the protection provided by fuses. (K&S 1.19-1.b.)

f. Describe the basic operation of a fuse. (K&S 1.19-1.b.)

g. A fuse circuit requires a 15 amp fuse. There are no 15 amp fuses available. Why is putting a higher rated fuse (25 amps) not allowed? (K&S 1.19-1.b.)

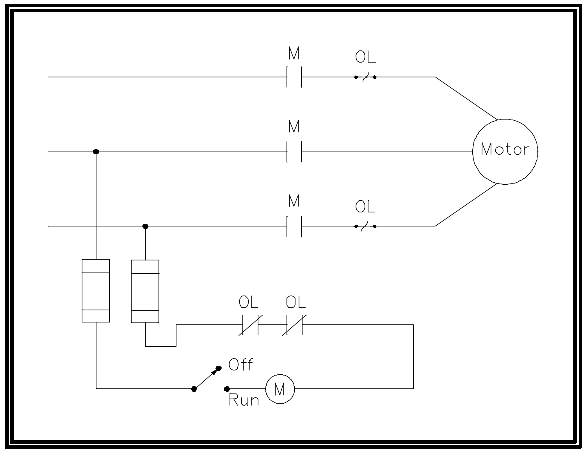
h. Describe the purpose and functions of a motor controller. (K&S 1.19-1.c.) (K&S 1.20-1.c.)

i. A motor, protected with an LVRE controller, is running. The electrical power supply to the motor is temporarily lost and then regained. Without any operator action what is the status of the motor?



j. What is the purpose of an LVRE controller?

k. A motor, protected with an LVR controller, is **NOT** running. The electrical power supply to the motor is temporarily lost and then regained. Refer to the drawing to the right, determine:

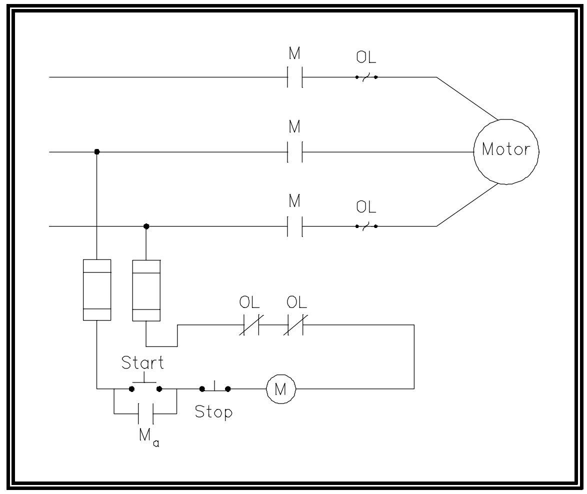


What is the status of the motor?
[energized] [de-energized]
What is the status of the M contacts?
[open] [closed]
What is the status of the M coil?
[energized] [de-energized]

l. What is the purpose of an LVR controller?

m. A motor, protected with an LVR controller, is running. The motor draws excess current due to a fault in the motor. Describe what happens to the electrical circuitry.

n. A motor, protected with an LVP controller, is running. The electrical power supply to the motor is temporarily lost and then regained. Refer to the drawing to the right, determine:



What is the status of the motor?
[energized] [de-energized]
What is the status of the M contacts?
[open] [closed]
What is the status of the M_a contacts?
[open] [closed]
What is the status of the M coil?
[energized] [de-energized]

o. A motor, protected with an LVP controller, is running. The voltage of the electrical power supply begins to drop describe what happens to the motor.

p. What is the purpose of an LVP controller?

q. Describe the difference between single-phase loads and three-phase loads. (K&S 1.19-1.d.) (K&S 1.20-1.d.)

r. List three (3) reasons that three-phase power systems are used in industry. (K&S 1.19-1.e.)

s. Electrical equipment is divided by voltage levels. The classifications are ________________, ________________, _________________, ________________, and _________________. (K&S 1.19-1.f.) (K&S 1.19-1.g.) (K&S 1.20-1.l.)

1) low, medium, high, extra high, and ultra voltage

2) very low, low, medium, high, and danger

3) 15V, 60V, 110V, 115V, and 277V

4) 60V, 110V, 210V, 408V, and 650V

t. If the circuit breaker opens under a short circuit or overload condition, the handle will go to the __________ position. (K&S 1.19-1.h.) (K&S 1.20-1.m.)

1) OFF

2) ON

3) Safe

4) Trip-free

u. Oil circuit breakers (OCBs) are circuit breakers that have _________ . (K&S 1.19-1.h.) (K&S 1.20-1.m.)

1) Oil cooled windings

2) Hydraulically operated contacts

3) Contacts immersed in oil

4) Low voltage capabilities

v. When the separable contacts of an air circuit breaker are opened, an arc develops between the two contacts. The arc is drawn into the _________, it is divided into small segments and extinguished. This action extinguishes the arc rapidly, which minimizes the chance of a fire and also minimizes damage to the breaker contacts. (K&S 1.19-1.h.) (K&S 1.20-1.m.)

1) Arc chute

2) Air blast

3) Quencher

4) Thermal trip element

w. List four (4) types of circuit breakers. (K&S 1.19-1.h.) (K&S 1.20-1.m.)

x. Explain the differences between transmission and distribution systems. (K&S 1.20-1.a.)

y. A simple and easy-to-read diagram showing power supplies, loads, and major components in the distribution system. (K&S 1.20-1.k.)

1) Logic diagram

2) Electronic schematic

3) Single-line diagram

4) Transmission line

5. Practice Exercise Answers

a. Match the type of electrical power supply device in column A with the description in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.19-1.a) (K&S 1.20-1.c) (K&S 1.20-1.k)

Column A	Column B
_b_ 1. Diesel power	a. An electrical device that converts the supplied power into conditioned AC output at a specific voltage and frequency to maintain total continuity of power to critical power loads.
_d_ 2. Generator	b. Power generated by a diesel-driven generator, an economical and practical source of "standby power" or "emergency power".
_f_ 3. Transformer	c. Converts DC power from the rectifier to AC power for critical loads.
_a_ 4. Uninterruptable power supply (UPS)	d. A device which uses rotating electro-magnetic fields to create an electric output.
	e. Converts AC power from the rectifier to DC power for critical loads.
	f. A device that transfers electrical energy from one circuit to another by electromagnetic induction.

b. A transmission line carries 13.8 kV. Select the correct voltage group the line belongs to: (K&S 1.19-1.a.)

1) Very High

2) Low

3) Intermediate

4) High

c. Match the electrical distribution terms in column A with the definitions in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.19-1.a) (K&S 1.20-1.c) (K&S 1.20-1.k)

Column A	Column B
_f_ 1. Voltage class	a. Protects a circuit from an overcurrent condition only, contains a current-carrying element sized so that the excessive heat caused by over current or short circuits causes the element to melt and open the circuit.
_b_ 2. Circuit breakers	b. Stops the current flow when the current exceeds a predetermined value without causing damage to the circuit or the component.
_a_ 3. Fuses	c. Designed to safeguard generating equipment and electrical circuits from any undesirable condition, such as undervoltage, underfrequency, or interlocking system lineups.
_c_ 4. Protective relays	d. Reduces the amount of insulation required for high-voltage transmission lines.
	e. Starts the current flow when the current reaches a predetermined value without operator action.
	f. Divides voltage distribution systems into three groups: high voltage, intermediate voltage, and low voltage.

d. There are only two operating principles for protective relays: (1) electromagnetic attraction and

1) electromagnetic induction

2) fusible links

3) spring loaded contacts

4) oil filled heat sinks

e. Describe the protection provided by fuses. (K&S 1.19-1.b.)

Fuses provide protection for excessive or over current flow only.

f. Describe the basic operation of a fuse. (K&S 1.19-1.b.)

A fuse consists of a fusible metal link that all the electrical current flows through. The metal link is sized so that normal current can flow through the strip with out any problem. If the current flow rate becomes excessive the heat generated by the excess current will cause the metal to melt, opening the circuit and preventing any electrical flow through the system.

g. A fuse circuit requires a 15 amp fuse. There are no 15 amp fuses available. Why is putting a higher rated fuse (25 amps) not allowed? (K&S 1.19-1.b.)

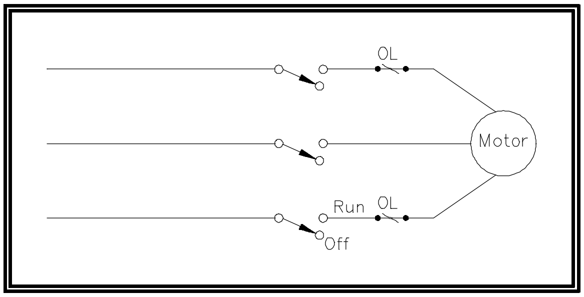
Circuitry is carefully analyzed to determine the required size fuses. If a higher rated fuse is installed the electricity flowing through the system and components may cause damage (overheating, insulation damage, or fire) to the system or component before the fusible link melts and opens the electrical circuit.

h. Describe the purpose and functions of a motor controller. (K&S 1.19-1.c.) (K&S 1.20-1.c.)

Motor controllers range from a simple toggle switch to a complex system using solenoids, relays, and timers. The basic functions of a motor controller are to control and protect the operation of a motor. This includes starting and stopping the motor, and protecting the motor from overcurrent, undervoltage, and overheating conditions that would cause damage to the motor. There are two basic categories of motor controllers: the manual controller and the magnetic controller.

i. A motor, protected with an LVRE controller, is running. The electrical power supply to the motor is temporarily lost and then regained. Without any operator action what is the status of the motor?

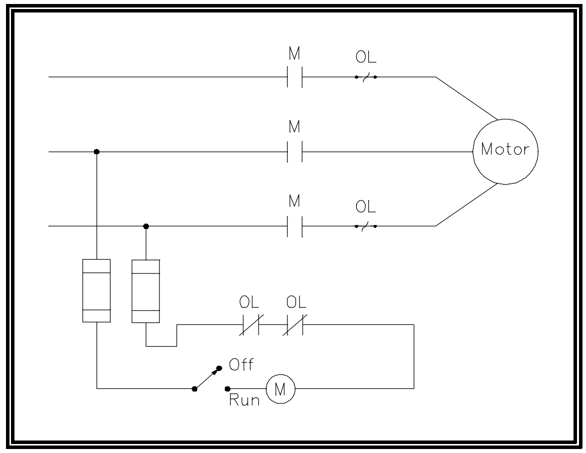
The motor is running.



j. What is the purpose of an LVRE controller?

Maintains electrical power to the motor at all time the switch is run.

k. A motor, protected with an LVR controller, is **NOT** running. The electrical power supply to the motor is temporarily lost and then regained. Refer to the drawing to the right, determine:



What is the status of the motor?
[energized] **[de-energized]**
What is the status of the M contacts?
[open] [closed]
What is the status of the M coil?
[energized] **[de-energized]**

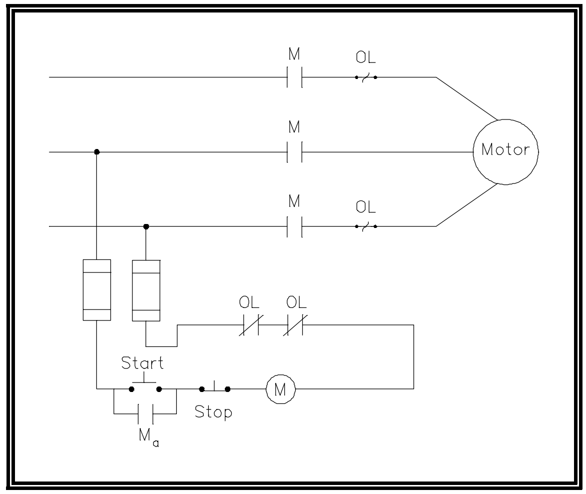
l. What is the purpose of an LVR controller?

The purpose of the LVR controller is to de-energize the motor in a low voltage condition and automatically restart the motor when normal voltage is restored.

m. A motor, protected with an LVR controller, is running. The motor draws excess current due to a fault in the motor. Describe what happens to the electrical circuitry.

The overload relay (OL) in the power supply to the pump sense the high current flow. The overload contacts (OL) in the controller circuit opens. This de-energizes the M coil, opening the M contact and the M_a contact, removing electrical power to and de-energizing the motor. (The motor will not restart without operator action.)

n. A motor, protected with an LVP controller, is running. The electrical power supply to the motor is temporarily lost and then regained. Refer to the drawing to the right, determine:



What is the status of the motor?
[energized] **[de-energized]**

What is the status of the M contacts?
[open] [closed]

What is the status of the M_a contacts?
[open] [closed]

What is the status of the M coil?
[energized] **[de-energized]**

o. A motor, protected with an LVP controller, is running. The voltage of the electrical power supply begins to drop describe what happens to the motor.

As the voltage drop below the predetermined low voltage setpoint the M coil drops out (de-energizes), the M contact and the M_a contact open, and the motor de-energizes. (The motor will not restart without operator action.)

p. What is the purpose of an LVP controller?

The main purpose of an LVP controller is to de-energize the motor in a low voltage condition and keep it from re-starting automatically upon return of normal voltage.

q. Describe the difference between single-phase loads and three-phase loads. (K&S 1.19-1.d.) (K&S 1.20-1.d.)

The source of single-phase (1ϕ) power in all facilities is by generation from a single-phase generator or by utilization of one phase of a three-phase (3ϕ) power source. Basically, each phase of the 3ϕ distribution system is a single-phase generator electrically spaced 120 degrees from the other two; therefore, a 3ϕ power source is convenient and practical to use as a source of single-phase power.

Single-phase loads can be connected to three-phase systems utilizing two methods. The first scheme provides for the connection of the load from a phase leg to any ground point and is referred to as a phase-to-ground scheme. The second scheme connects the single-phase load between any two legs of the three-phase source and is referred to as a phase-to-phase connection. The choice of schemes, phase-to phase or phase-to-ground, allows several voltage options depending on whether the source three-phase system is a delta or wye configuration.

r. List three (3) reasons that three-phase power systems are used in industry. (K&S 1.19-1.e.)

- They have a wide range of voltages and can be used for single-phase loads.
- Three-phase equipment weighs less than single-phase equipment of the *same power rating*.
- Three-phase equipment is smaller in size than single-phase equipment of the *same power rating*.
- Three-phase equipment is more efficient than single-phase equipment of the *same power rating*.

s. Electrical equipment is divided by voltage levels. The classifications are __________________, __________________, __________________, __________________, and __________________. (K&S 1.19-1.f.) (K&S 1.19-1.g.) (K&S 1.20-1.l.)

1) low, medium, high, extra high, and ultra voltage

2) very low, low, medium, high, and danger

3) 15V, 60V, 110V, 115V, and 277V

4) 60V, 110V, 210V, 408V, and 650V

t. If the circuit breaker opens under a short circuit or overload condition, the handle will go to the __________ position. (K&S 1.19-1.h.) (K&S 1.20-1.m.)

1) OFF

2) ON

3) Safe

4) Trip-free

u. Oil circuit breakers (OCBs) are circuit breakers that have _________. (K&S 1.19-1.h.) (K&S 1.20-1.m.)

1) Oil cooled windings

2) Hydraulically operated contacts

3) Contacts immersed in oil

4) Low voltage capabilities

v. When the separable contacts of an air circuit breaker are opened, an arc develops between the two contacts. The arc is drawn into the _________, it is divided into small segments and extinguished. This action extinguishes the arc rapidly, which minimizes the chance of a fire and also minimizes damage to the breaker contacts. (K&S 1.19-1.h.) (K&S 1.20-1.m.)

1) Arc chute

2) Air blast

3) Quencher

4) Thermal trip element

w. List four (4) types of circuit breakers. (K&S 1.19-1.h.) (K&S 1.20-1.m.)

- Air circuit breakers
- Magnetic air circuit breaker
- Compressed-air circuit breakers
- Air-blast circuit breakers
- Oil circuit breaker

x. Explain the differences between transmission and distribution systems. (K&S 1.20-1.a.)

Transmission refers to the transportation of bulk electrical power from generation sites to areas of use. This is accomplished by the use of transmission lines and transformers.

Distribution refers to the delivery section of the electrical power system. Power from the transmission line is delivered to the distribution substations where the voltage is transformer downward to voltages ranging from 69kV to 2,400kV.

y. A simple and easy-to-read diagram showing power supplies, loads, and major components in the distribution system. (K&S 1.20-1.k.)

1) Logic diagram

2) Electronic schematic

3) Single-line diagram

4) Transmission line

Competency 1.21

Electrical Systems (FAC# 1.11) personnel shall demonstrate a working level knowledge of electrical test instruments and measuring devices.

1. Supporting Knowledge and/or Skills

   a. Explain the following meter movements:

   - D-Arsonval
   - Electro-dynamometer
   - Moving iron vane
     DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter Meter Movements.

   b. Describe the purpose and method of operation of the following in-place measuring devices:

   - Voltmeter
     DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter Voltmeter.
   - Ammeter
     DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter Ammeter.
   - Ohmmeter
     DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter Ohm meter.
   - Wattmeter
     DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter Wattmeter.
   - Ampere-hour meter
     DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter Other Electrical Measuring Devices.
   - Power factor meter
     DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter Other Electrical Measuring Devices.
   - Ground detector
     DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter Other Electrical Measuring Devices.

- Synchroscope
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter Other Electrical Measuring Devices.
- Meggar
  DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter Test Equipment.

c. Describe safe methods for using the following portable test equipment:

- Ammeter
- Voltmeter
- Ohmmeter

2. Self-Study Information

Competency 1.21 addresses the working level knowledge of the principles associated with electrical test instruments and measuring devices.

The supporting material for the Self-Study Information include the following documents:

- Department of Energy Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92).
- Department of Energy (DOE) DOE/ID-10600, Electrical Safety Guidelines
- Westinghouse Savannah River Corporation. Safe Electrical Practices and Procedures Manual 18Q Procedure 2 Safe Practices On or Near Electrical Conductors Rev 2 12/8/95.
- Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100).
- Bureau of Naval Personnel (1969). Basic Electricity. Washington, DC: U.S. Government Printing Office. Stock Ordering No. 0502-LP-050-4300.
- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Albany, NY: Delmar Publishers Inc. ISBN 0-8273-4156-3. Call# TK1141.D83.
- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. New York, NY: McGraw-Hill Book Company. ISBN 0-07-020974-X. Call# TK151.S8.
- Institute of Electrical and Electronic Engineers (1994). IEEE Recommended Practice for Electrical Power Distribution for Industrial Plants (IEEE-STD-141-1993 IEEE Red Book). New York, NY: Institute of Electrical and Electronic Engineers Inc. ISBN 1-55937-333-4.
- Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Albany, NY: Delmar Publishers Inc. ISBN 0-8273-4146-6. Call# TK1111.L66.

A galvanometer is a type of d'Arsonval meter. An ammeter uses a d'Arsonval meter movement. These meters are used for low current flow indications, for higher current flows a shunt (a low value resistor in parallel with the circuit) must be used. Ammeters are connected in series with the circuit to be measured.

A voltmeter uses d'Arsonval or galvanometer meter movement with a resistor in series. A voltmeter is connected in parallel with the circuit to be measured.

An ohmmeter is a galvanometer with a power supply and a set of series resistors. It must be used on a dead circuit.

General precautions

If possible do not work alone when making measurements of circuits where a shock hazard can exist. At a minimum notify another person that you are or are intending to make such measurements.

Locate all voltage sources and accessible paths prior to making measurement connections. Check that the test equipment is properly grounded and the right rating and type of fuse(s) is installed. Set the instrument to the proper range before power is applied.

Voltages may appear unexpectedly in defective equipment. Turn off power and discharge all capacitors before connecting or disconnecting test leads to and from the circuit being measured.

Inspect test leads for cracks, breaks, or crazes in the insulation, prods, or connectors before each use. Replace defective leads.

DO NOT make measurements in a circuit where a corona is present. A corona is the field around a voltage of 1000V or higher. It is caused by the breakdown of air molecules. Corona can be identified by a pale blue color emanation from sharp metal points in the circuit, the odor of ozone, and its sound.

Hands, shoes, floor, and workbench must be dry. Avoid making measurements under humid, damp, or other environmental conditions that could effect the dielectric of the test leads or instrument.

DO NOT touch the test leads or instrument while power is applied to the circuit being measured.

Use extreme caution when making measurements in any RF circuit where a dangerous combination of voltages could be present.

Do not make measurement using test leads which differ from those originally furnished with the instrument.

Do not come in contact with any object which could provide a current path to the common side of the circuit under test or power line ground. Always stand on a dry insulating surface capable of withstanding the voltage being measure or that could be encountered.

The range or function switch should only be changed when the power to the circuit under measurement is turned off. This will provide maximum safety to the user and eliminate arcing the switch contacts.

Ensure the correct range meter is selected for the expected values. If multiple ranges available on meter start on high range and range down until meter indication is provided. This is to prevent damage to the meter internals.

Some meters are sensitive and require a specific set of leads, ensure the correct leads are used. This is to prevent incorrect reading.

For meters using shunts, ensure the correct shunt is properly installed. This is to prevent incorrect reading.

Ensure the proper polarity of the circuit and the meter are observed. Improper alignment may cause damage to the meter movement.

Ensure that meter are not exposed to excess moisture. The moisture can be absorbed by the insulation and reduce the insulation resistance, causing incorrect readings.

For Multimeter applications ensure the test leads are plugged into the proper jacks.

Ammeter

Current measuring instruments must be always connected in series with a circuit and never in parallel.

Always check the polarity of the ammeter. Make certain that the meter is connected to the circuit so that electrons flow into the negative lead of the meter and out of the positive lead of the meter. (Normally the negative lead is black and the positive lead is red.)

Always set the full scale deflection of the meter to be larger than the expected current. To be safe, set the full scale current several times larger than the expected current, and then slowly increase the sensitivity to the appropriate scale.

Voltmeter

Voltage measuring instruments must be always connected in parallel with (across the) a circuit and never in series.

Always set the full scale voltage of the meter to be larger than the expected voltage to be measured.

Always insure that the internal resistance of the voltmeter is much greater than the resistance of the component to be measured.

Ohmmeter

Before measuring the resistance of a circuit always short the meter test leads together and ensure the meter indicates near zero. Adjust the meter to indicate zero using the meter adjustment. When the test leads are take apart ensure that the meter reads infinite (∞) resistance.

The power supply to the circuit to be measure must always be OFF and/or disconnected. This prevents the circuits source from being applied across the meter and damaging the meter's movement.

The ohmmeter range selection switch should be positioned so that the indicator is in the middle region of the scale. This provides better accuracy.

3. References

NOTE: For information regarding the Supporting Knowledge and Skills refer to the Summary section of this competency.

a. For Supporting Knowledge and Skills **1.21-1.a** refer to:
   - Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100). Chapter Electrical Indicating Devices.
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Electrical Indicating Instruments.
   - Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Ac Instruments and Meters.
   - Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Measurement and Instruments.
   - Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Electrical Measuring Instruments.

b. For Supporting Knowledge and Skills **1.21-1.b** refer to:
   - Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. Chapter Measurement and Instruments.
   - Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100). Chapter Electrical Indicating Devices.
   - Institute of Electrical and Electronic Engineers (1994). IEEE Recommended Practice for Electrical Power Distribution for Industrial Plants (IEEE-STD-141-1993 IEEE Red Book). Chapter Instruments and Meters.
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Electrical Indicating Instruments.
   - Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Ac Instruments and Meters.
   - Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Electrical Measuring Instruments.

c. For Supporting Knowledge and Skills **1.21-1.c** refer to:
   - Department of Energy (DOE) DOE/ID-10600, Electrical Safety Guidelines
   - Westinghouse Savannah River Corporation. Safe Electrical Practices and Procedures Manual 18Q Procedure 2 Safe Practices On or Near Electrical Conductors Rev 2 12/8/95.
   - Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Ac Instruments and Meters.
   - Loper, Orla E. and Edgar Tedsen (1991). Direct Current Fundamentals. Chapter Electrical Measuring Instruments.

4. Practice Exercise

   a. Describe the construction and operation of a D-Arsonval meter movements. (K&S 1.21-1.a.)

   b. Match the type of meter movement in column A with **ALL** the types of electrical current measured in column B. The column B answers **MAY BE** used **MORE** than one time. Ignore any response in column B not identified in column A. (K&S 1.21-1.a)

Column A	Column B
__ 1. Moving iron vane	a. AC current
__ 2. Electro-dynamometer	b. AC current rectified to DC
__ 3. D-Arsonval	c. DC current

c. Match the electrical parameter measured in column A with the type of meter in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.21-1.b)

Column A	Column B
__ 1. Electrical potential	a. Ammeter
__ 2. DC power or true AC power	b. Ground detector
__ 3. Electrical current	c. Ohmmeter
__ 4. Electrical resistance	d. Power factor meter
	e. Synchroscope
	f. Voltmeter
	g. Wattmeter

d. Match the function of the meter in column A with the type of meter in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.21-1.b)

Column A	Column B
__ 1. Used to detect conductor insulation resistance to ground.	a. Meggar
	b. Three-Phase Wattmeter
__ 2. Portable instrument used to measure insulation resistance.	c. Ground detector
__ 3. Indicates when two AC generators are in the correct phase relation for connecting in parallel.	d. Power factor meter
	e. Synchroscope

e. List five (5) safety precautions should be taken concerning the test leads of portable test equipment? (K&S 1.21-1.c.)

5. Practice Exercise Answers

   a. Describe the construction and operation of a D-Arsonval meter movements. (K&S 1.21-1.a.)

      When electrical current is directed through the coils of the electromagnet it produces a magnetic field. The magnetic field produced by the electromagnetic coil opposes the field of the permanent magnet. Since the electromagnetic core is suspended between the poles of a permanent magnet it is free to rotate. The more current applied to the core, the stronger the opposing field, and the larger the deflection, up to the limit of the current capacity of the coil. The core is restrained by springs so that the needle will deflect or move in proportion to the current intensity. When the current is interrupted, the opposing field collapses, and the needle is returned to zero by the restraining springs.

   b. Match the type of meter movement in column A with **ALL** the types of electrical current measured in column B. The column B answers **MAY BE** used **MORE** than one time. Ignore any response in column B not identified in column A. (K&S 1.21-1.a)

Column A	Column B
_a,b,c_ 1. Moving iron vane	a. AC current
_a,b,c_ 2. Electro-dynamometer	b. AC current rectified to DC
_b,c_ 3. D-Arsonval	c. DC current

c. Match the electrical parameter measured in column A with the type of meter in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.21-1.b)

Column A	Column B
_f_ 1. Electrical potential	a. Ammeter
_g_ 2. DC power or true AC power	b. Ground detector
_a_ 3. Electrical current	c. Ohmmeter
_c_ 4. Electrical resistance	d. Power factor meter
	e. Synchroscope
	f. Voltmeter
	g. Wattmeter

d. Match the function of the meter in column A with the type of meter in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A.(K&S 1.21-1.b)

Column A	Column B
_c_ 1. Used to detect conductor insulation resistance to ground.	a. Meggar
	b. Three-Phase Wattmeter
_a_ 2. Portable instrument used to measure insulation resistance.	c. Ground detector
_e_ 3. Indicates when two AC generators are in the correct phase relation for connecting in parallel.	d. Power factor meter
	e. Synchroscope

e. List five (5) safety precautions should be taken concerning the test leads of portable test equipment? (K&S 1.21-1.c.)

Turn off power and discharge all capacitors before connecting or disconnecting test leads to and from the circuit being measured.

Inspect test leads for cracks, breaks, or crazes in the insulation, prods, or connectors before each use. Replace defective leads.

DO NOT touch the test leads or instrument while power is applied to the circuit being measured.

Some meters are sensitive and require a specific set of leads, ensure the correct leads are used. This is to prevent incorrect reading.

For Multimeter applications ensure the test leads are plugged into the proper jacks.

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Competency 1.22

Electrical systems (FAC# 1.12) personnel shall demonstrate a working level knowledge of safety and health fundamentals related to electrical systems and components.

1. Supporting Knowledge and/or Skills

   a. Discuss the hazards associated with the use of corrosives (acids and alkalies).
      DOE Fundamentals Handbook Chemistry (DOE-HDBK-1015/2-92) Volume 2 of 2, Chapter Corrosives (Acids and Alkalies).

   b. Describe the general safety precautions necessary for the handling, storage, and disposal of corrosives.
      DOE Fundamentals Handbook Chemistry (DOE-HDBK-1015/2-92) Volume 2 of 2, Chapter Corrosives (Acids and Alkalies).

   c. Discuss the hazards associated with:

      - Battery fluids and materials
      - Transformer oils

   d. Identify and discuss elements of an electrical safety program, including the following:

      - Two-man rule
      - Protective equipment
      - Lockout and tagout
      - Grounding
        DOE Fundamentals Handbook Electrical Science (DOE-HDBK-1011/4-92) Volume 4 of 4, Chapter Wiring Schemes and Grounding.
      - Stored energy
      - Component labelling

2. Self-Study Information

Competency 1.22 addresses the working level knowledge of the safety and health fundamentals related to electrical systems and components.

The supporting material for the Self-Study Information include the following documents:

- Title 29 Code of Federal Regulations 1910, Subpart S, "Electrical". Washington, DC: U.S. Government Printing Office.
- Title 29 Code of Federal Regulations 1926, Subpart H, "Material Handling, Storage, Use, and Disposal". Washington, DC: U.S. Government Printing Office.
- Title 29 Code of Federal Regulations 1926, Subpart K, "Electrical". Washington, DC: U.S. Government Printing Office.
- Department of Energy Fundamentals Handbook Electrical Science (DOE-HDBK-1011/2-92).
- Department of Energy (DOE) DOE/ID-10600, Electrical Safety Guidelines
- Department of Energy (DOE) Order 5480.9 Construction Safety Health Program
- Department of Energy (DOE) Standard Guide to Good Practices for Equipment and Piping Labeling (DOE-STD-1044-93)
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-14-LP)
- Westinghouse Savannah River Corporation. Employee Safety Manual 8Q Procedure 25 Basic Electrical Safety Awareness Rev 2 12/31/95.
- Westinghouse Savannah River Corporation. Employee Safety Manual 8Q Procedure 32 Hazardous Energy Control (Lockout/Tagout) Rev 5 12/22/94.
- Westinghouse Savannah River Corporation. Employee Safety Manual 8Q Procedure 61 Personal Protective Equipment Rev 2 12/12/94.
- Westinghouse Savannah River Corporation. Employee Safety Manual 8Q Procedure 83 Battery Safety Rev 12/31/95.
- Westinghouse Savannah River Corporation. Safe Electrical Practices and Procedures Manual 18Q Procedure 2 Safe Practices On or Near Electrical Conductors Rev 2 12/8/95.
- Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100).
- Bureau of Naval Personnel (1969). Basic Electricity. Washington, DC: U.S. Government Printing Office. Stock Ordering No. 0500-030-0010.
- Bureau of Naval Personnel (1982). Electrician's Mate 3 & 2 Rate Training Manual (NAVEDTRA 10546-E). Washington, DC: U.S. Government Printing Office. Stock Ordering No. 0502-LP-052-7325.

- Institute of Electrical and Electronic Engineers, Inc. (1991). National Electrical Safety Code (ANSI C2-1990). New York: Institute of Electrical and Electronic Engineers, Inc. ISBN 1-55937-011-4. Call# TK152.I132.
- Institute of Nuclear Power Operations Good Practice (OP-208) System and Component Labeling (INPO 88-009). Atlanta, GA:Institute of Nuclear Power Operations.
- National Fire Protection Association (1992). National Electric Code. Quincy, MA: National Fire Protection Association. ISBN 0-87765-383-6. Call# TK260.N464.
- Occupational Safety and Health Administration (OSHA) Article 1910.333
- Smeaton, Robert W. (editor) (1977). Switchgear and Control Handbook. New York: McGraw-Hill Book Company. ISBN 0-07-058439-7. Call# TK2821.S88.
- Westinghouse Electric Corporation (1974). Westinghouse Electrical Maintenance Hints. Trafford, PA: Westinghouse Electric Corporation. Call# TK151.W156
- U.S. Department of Labor (1983). An Illustrated Guide to Electrical Safety (OSHA 3073). Washington, DC: U.S. Government Printing Office. Call# TK152.I44.

Electrical Safety

The most important piece of safety equipment when performing work in an electrical environment is common sense. All areas of electrical safety precautions and practices draw upon common sense and attention to detail. One of the most dangerous conditions in an electrical work area is a poor attitude toward safety.

- All work on electrical equipment should be done with circuits de-energized and cleared and grounded.
- All conductors, buses, and connections should be considered energized until proven otherwise.
- Know the work to be done and how to do it.
- Check out the entire area you will be in, beyond the scope of your work.
- Use safety apparel and rubber gloves.
- Always block off your work areas, and never have your work area unattended unless everything is in a secure condition.
- Do not perform work on energized circuits/equipment without direct authorization of your supervisor.
- Always stay aware of work conditions and equipment status.
- Never directly touch an unconscious worker that may be in contact with an energized circuit.

Batteries

Storage batteries are constant alive electrically and a constant source of electrical shock. Care should be taken not contact the positive and negative terminals. Tools or equipment should never be placed on top batteries, this is to prevent short circuits.

Battery rooms should be posted as a No Smoking and No Open Flames area. Hydrogen gas is generated during battery charging operations. Ventilation should be maintained to prevent the buildup of hydrogen gas.

The electrolyte used in batteries is an acid. The electrolyte is corrosive and dangerous if ingested. Emergency eyewash and shower facilities are required to be located nearby, ensure that you know where the closest eyewash/shower is before working around the storage batteries. Review the Material Safety Data Sheet for additional information and precautions. Use Neoprene gloves and required Chemical Protection Clothing.

Fires

The best way to extinguish an electrical fire is to from the power source or opening the circuit. Proper fire extinguishers should be used to put out a fire involving electrical power. A Type "C" (ele**C**trical) extinguisher should be used. A CO_2 or dry chemical extinguisher are both rated class C. The hazard with a CO_2 extinguisher is that the carbon dioxide displaces the oxygen in the room and workers can suffocate. The dry chemical extinguisher can be corrosive to electrical circuits. The use of water to combat electrical fires should be restricted to extreme emergencies and only under the direction of trained fire fighters.

3. References

NOTE: For information regarding the Supporting Knowledge and Skills refer to the Self-Study Information section of this competency.

a. For Supporting Knowledge and Skills **1.22-1.a** refer to:
   - Westinghouse Savannah River Corporation High Level Waste Operator Training Program Chemistry (NWMOG011.H0102) Chapter Hazards of Chemicals and Gases.
   - Westinghouse Savannah River Corporation. Employee Safety Manual 8Q Procedure 83 Battery Safety Rev 12/31/95.

b. For Supporting Knowledge and Skills **1.22-1.b** refer to:
   - Title 29 Code of Federal Regulations 1926, Subpart H, "Material Handling, Storage, Use, and Disposal".
   - Westinghouse Savannah River Corporation High Level Waste Operator Training Program Chemistry (NWMOG011.H0102) Chapter Hazards of Chemicals and Gases.
   - Westinghouse Savannah River Corporation High Level Waste Operator Training Program Chemistry (NWMOG011.H0101) Chapter Chemical Safety.
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Batteries.
   - Westinghouse Savannah River Corporation. Employee Safety Manual 8Q Procedure 61 Personal Protective Equipment Rev 2 12/12/94.
   - Westinghouse Savannah River Corporation. Employee Safety Manual 8Q Procedure 83 Battery Safety Rev 12/31/95.

c. For Supporting Knowledge and Skills **1.22-1.c** refer to:
   - U.S. Department of Labor (1983). An Illustrated Guide to Electrical Safety (OSHA 3073).
   - Westinghouse Savannah River Corporation High Level Waste Operator Training Program Electrical Science (NWMOG008.H0102) Chapter Electrical Hazards.
   - Westinghouse Savannah River Corporation. Employee Safety Manual 8Q Procedure 83 Battery Safety Rev 12/31/95.
   - Title 29 Code of Federal Regulations 1926.441.
   - Bureau of Naval Personnel (1969). Basic Electricity. Chapter Batteries.
   - National Fire Protection Association (1992). National Electric Code. Section 450-23 through 450-28.
   - Institute of Electrical and Electronic Engineers, Inc. (1991). National Electrical Safety Code (ANSI C2-1990). Section 140-146, Section 150-152.
   - Smeaton, Robert W. (editor) (1977). Switchgear and Control Handbook. Chapter DC Supply Considerations.

d. For Supporting Knowledge and Skills **1.22-1.d** refer to:

- Title 29 Code of Federal Regulations 1926.100-107; 404; 416-417.
- U.S. Department of Labor (1983). An Illustrated Guide to Electrical Safety (OSHA 3073).
- Department of Energy (DOE) DOE/ID-10600, Electrical Safety Guidelines
- Department of Energy (DOE) Standard Guide to Good Practices for Equipment and Piping Labeling (DOE-STD-1044-93)
- Westinghouse Savannah River Corporation. Employee Safety Manual 8Q Procedure 25 Basic Electrical Safety Awareness Rev 2 12/31/95.
- Westinghouse Savannah River Corporation. Employee Safety Manual 8Q Procedure 32 Hazardous Energy Control (Lockout/Tagout) Rev 5 12/22/94.
- Westinghouse Savannah River Corporation. Employee Safety Manual 8Q Procedure 61 Personal Protective Equipment Rev 2 12/12/94.
- Westinghouse Savannah River Corporation. Employee Safety Manual 8Q Procedure 83 Battery Safety Rev 12/31/95.
- Westinghouse Savannah River Corporation. Safe Electrical Practices and Procedures Manual 18Q Procedure 2 Safe Practices On or Near Electrical Conductors Rev 2 12/8/95.
- Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100). Chapter Electrical Hazards.
- Bureau of Naval Personnel (1969). Basic Electricity. Chapter Safety.
- Bureau of Naval Personnel (1982). Electrician's Mate 3 & 2 Rate Training Manual (NAVEDTRA 10546-E).
- DOE-SR Office of Training Facility Representative Advance Nuclear Course. Electrical Theory, Safety, and Equipment Instructor Lesson Plan (DOE-OT-FRANC-105-14-LP) Chapter Electrical Safety.
- Smeaton, Robert W. (editor) (1977). Switchgear and Control Handbook. Chapter Safety.
- Institute of Nuclear Power Operations Good Practice (OP-208) System and Component Labeling (INPO 88-009).
- Westinghouse Electric Corporation (1974). Westinghouse Electrical Maintenance Hints. Chapter Tooling and Safety.

4. Practice Exercise

   a. What is an **ACID**? (K&S 1.22-1.a.)

   b. What acid is associated with electrical systems? (K&S 1.22-1.a.)

   c. What hazards associated with the combination of acids and metals. (K&S 1.22-1.a.)

   d. Discuss the hazards associated with the use of alkalies. (K&S 1.22-1.a.)

   e. List four (4) general safety precautions necessary for the handling corrosives. (K&S 1.22-1.b.)

f. List four (4) general safety precautions necessary for the storage of corrosives. (K&S 1.22-1.b.)

g. List the hazards and precautions associated with batteries. (K&S 1.22-1.c.)

Hazard	Precaution
	- -
	- - -
	-
	- - - - - -

h. List the hazards associated with transformers. (K&S 1.22-1.c.)

i. What is the purpose of grounding electrical equipment and grounding strips. (K&S 1.22-1.d.)

j. State the purpose of the Two-man rule concerning electrical safety. (K&S 1.22-1.d.)

k. What action must be taken by the electrical worker before using rubber safety gloves for electrical protection? (K&S 1.22-1.d.)

5. Practice Exercise Answers

   a. What is an **ACID**? (K&S 1.22-1.a.)

      A chemical substance that (dissociates to) produces hydrogen ions (hydronium, H^+ ions) when dissolved in water (or other solutions)

   b. What acid is associated with electrical systems? (K&S 1.22-1.a.)

      Sulfuric acid (H_2SO_4) is the common electrolyte in large wet cell storage batteries.

   c. What hazards associated with the combination of acids and metals. (K&S 1.22-1.a.)

      Acids and metals react together to form hydrogen which is a highly flammable gas.

   d. Discuss the hazards associated with the use of alkalies. (K&S 1.22-1.a.)

      Alkalies (bases) are more destructive to the human body than acids. The material causes chemical burns, ulcerations, and scarring. Bases soften and emulsify skin fats. May cause irritation to the eyes and respiratory tract. Can cause damage to the mucous membranes. When dissolved in water the chemical reaction releases a great deal of heat, may cause solution to boil and splatter.

   e. Describe the general safety precautions necessary for the handling corrosives. (K&S 1.22-1.b.)

      - Use personal protective equipment
      - Carefully inspect container prior to handling
      - Ensure all containers properly labeled
      - Use proper transporting, handling, and storage containers

   f. Describe the general safety precautions necessary for the storage of corrosives. (K&S 1.22-1.b.)

      - Building or storage facility should be or fire resistant construction.
      - Floors should be of chemical resistant brick or treated concrete and have adequate drainage.
      - Area should be well lit and ventilated.
      - Environment should be cool and dry, preventing extremes in temperature and humidity.
      - Electrical fixtures should be protected from corrosive mists and wiring of corrosive resistant material.

g. List the hazards and precautions associated with batteries. (K&S 1.22-1.c.)

Hazard	Precaution
Sulfuric acid (the common electrolyte in wet cell batteries) can cause chemical burns if it comes in contact with the skin or eyes.	- Wear protective clothing (goggles, face shield, rubber gloves, rubber apron, etc.) when working with batteries. - Know where the closest working eye wash and shower is located. Know how to operate eye wash and shower.
Hydrogen and oxygen gas produced during charging process can cause flammable environment.	- Ensure battery well ventilation systems operating as designed. - Observe no smoking/flames requirements. - Use sparkless tools.
Excessive charging of battery can raise temperature of electrolyte causing splattering.	- Observe proper battery charging techniques and rates.
Batteries have large electrical storage and current capacity. Batteries can not be turned off.	- Observe precautions to prevent coming in contact with electrical components of batteries. - Only qualified personnel should operate or perform maintenance on electrical equipment. - Install guards to prevent accidental contact with live conductors. - Ground electrical equipment. - Whenever possible de-energize equipment prior to working on them. - Consider electrical equipment energized until proven de-energized by qualified personnel.

h. List the hazards associated with transformers. (K&S 1.22-1.c.)

- Some transformers contain oil containing PCBs a know carcinogen. Take care not to come in contact with PCBs.
- Fans on transformers can start without warning. Stay clear of fan blades and rotating equipment.
- Transformers can explode under fault conditions. Stay clear unless work requires.

i. What is the purpose of grounding electrical equipment and grounding strips. (K&S 1.22-1.d.)

   Providing a low resistance path for electrical current to the earth. If a short develops the electrical current will take the path of least resistance, through the equipment ground to the earth and not through a person touching the equipment.

j. State the purpose of the Two-man rule concerning electrical safety. (K&S 1.22-1.d.)

   The two man rule is designed as a risk reducing policy. It requires the physical presence of at least two personnel to perform tasks where an unaccompanied individual would be at an unreasonable risk. The second person is there to ensure that if one person working on an electrical system receives an electrical shock, the second person can disconnect the power or safely remove the person, provide any required first aid, and notify other personnel.

k. What action must be taken by the electrical worker before using rubber safety gloves for electrical protection? (K&S 1.22-1.d.)

   Gloves should be stored in a canvas storage container in a clean dry area. Electrical gloves shall be examined for snags, cracks, holes, or worn areas. Air test by rolling gloves from gauntlet to hand end to test for leaks with entrapped air. Ensure inspection is current.

Competency 1.23

Mechanical systems (FAC# 1.25) and Nuclear safety system (FAC# 1.12) personnel shall demonstrate a familiarity level knowledge of reading and interpreting electrical diagrams and schematics.

1. Supporting Knowledge and/or Skills

   a. Identify the symbols and/or codes used on engineering electrical drawings. Including the following symbols:

   - Motors
   - Controllers
   - Breakers
   - Generators
   - Batteries

     DOE Fundamentals Handbook Engineering Symbology, Science (DOE-HDBK-1016/1-93), Volume 1 of 2, Chapter Electrical Diagrams and Schematics.

   b. Given the appropriate diagram, state the condition (energized/de-energized) in which all electrical devices are shown, unless otherwise noted on the diagram.
      DOE Fundamentals Handbook Engineering Symbology, Science (DOE-HDBK-1016/1-93), Volume 1 of 2, Chapter Electrical Diagrams and Schematics.

   c. Using a simple schematic and initial conditions, identify the power sources and/or loads and their status.
      DOE Fundamentals Handbook Engineering Symbology, Science (DOE-HDBK-1016/1-93), Volume 1 of 2, Chapter Electrical Wiring and Schematic Diagram Reading Examples.

   d. Using an electronic block diagram, print, or schematic, identify the basic component symbols.
      DOE Fundamentals Handbook Engineering Symbology, Science (DOE-HDBK-1016/1-93), Volume 1 of 2, Chapter Electrical Diagrams and Schematics and Chapter Electrical Wiring and Schematic Diagram Reading Examples.

Competency 1.24

Electrical systems (FAC# 1.15) and Facility representative (FAC# 1.22) personnel shall demonstrate a working level knowledge of electrical reading and interpreting electrical diagrams, prints, and schematics including:

- **One-line diagrams**
- **Schematics**
- **Construction drawings**
- **As-built drawings**
- **Wiring diagrams**

1. Supporting Knowledge and/or Skills

   a. Using a engineering electrical drawings (schematic), identify an electrical component by its symbology.
      DOE Fundamentals Handbook Engineering Symbology, Science (DOE-HDBK-1016/1-93), Volume 1 of 2, Chapter Electrical Diagrams and Schematics.

   b. Given a simple electrical schematic (one-line diagram) and initial conditions, identify the power sources and/or loads and their status.
      DOE Fundamentals Handbook Engineering Symbology, Science (DOE-HDBK-1016/1-93), Volume 1 of 2, Chapter Electrical Wiring and Schematic Diagram Reading Examples.

   c. Identify the symbols and/or codes used on engineering electrical drawings to depict the relationship between components.
      DOE Fundamentals Handbook Engineering Symbology, Science (DOE-HDBK-1016/1-93), Volume 1 of 2, Chapter Electrical Diagrams and Schematics.

   d. State the condition in which all electrical devices are shown, unless otherwise noted on the diagram or schematic.
      DOE Fundamentals Handbook Engineering Symbology, Science (DOE-HDBK-1016/1-93), Volume 1 of 2, Chapter Electrical Diagrams and Schematics.

   e. Using a one-line diagram or schematic diagram, analyze the effects of a component failure in a system.
      DOE Fundamentals Handbook Engineering Symbology, Science (DOE-HDBK-1016/1-93), Volume 1 of 2, Chapter Electrical Wiring and Schematic Diagram Reading Examples.

   f. Using a construction drawing, identify the emergency power supplies.

g. Discuss the origin and purpose of "as-built" drawings.

Competency 1.25

Construction management and engineering (FAC# 1.8 & 1.9), EH Residents (FAC# 1.15), Facility maintenance management (FAC# 1.20 & 1.21), and Instrumentation and control (FAC# 1.20) personnel shall demonstrate the ability to read and interpret electrical diagrams including:

- **One-line diagrams**
- **Schematics**
- **Printed wiring board diagrams**
- **Electronic block diagrams**

1. Supporting Knowledge and/or Skills

   a. Identify the symbols used on electrical engineering drawings.
      DOE Fundamentals Handbook Engineering Symbology, Science (DOE-HDBK-1016/1-93), Volume 1 of 2, Chapter Electrical Diagrams and Schematics.

   b. Identify the symbols and/or codes used on electrical engineering drawings to show the relationship between components.
      DOE Fundamentals Handbook Engineering Symbology, Science (DOE-HDBK-1016/1-93), Volume 1 of 2, Chapter Electrical Diagrams and Schematics.

   c. State the condition in which all electrical devices are shown, unless otherwise noted on the diagram or schematic.
      DOE Fundamentals Handbook Engineering Symbology, Science (DOE-HDBK-1016/1-93), Volume 1 of 2, Chapter Electrical Diagrams and Schematics.

   d. Given a simple electrical schematic and initial conditions, identify the power sources and/or loads and their status.
      DOE Fundamentals Handbook Engineering Symbology, Science (DOE-HDBK-1016/1-93), Volume 1 of 2, Chapter Electrical Wiring and Schematic Diagram Reading Examples.

   e. Given an electronic block diagram, print, or schematic, identify the symbols that represent the basic components.
      DOE Fundamentals Handbook Engineering Symbology, Science (DOE-HDBK-1016/2-93), Volume 2 of 2, Chapter Electronic Diagrams, Prints, and Schematics.

f. Given a one-line diagram or schematic diagram, analyze the effects of a component failure in a system.

   DOE Fundamentals Handbook Engineering Symbology, Science (DOE-HDBK-1016/1-93), Volume 1 of 2, Chapter Electrical Wiring and Schematic Diagram Reading Examples.

g. Given a construction diagram, identify the power supplies.

h. Discuss the origin and purpose of "as-built" drawings.

i. Describe printed wiring board fabrication and assembly.

   DOE Fundamentals Handbook Engineering Symbology, Science (DOE-HDBK-1016/2-93), Volume 2 of 2, Chapter Electronic Diagrams, Prints, and Schematics.

2. Self-Study Information

Competency 1.23, 1.24, and 1.25 address reading and interpreting electrical diagrams and schematics. Competency 1.23 at a familiarity level of knowledge, Competency 1.24 at a working level of knowledge, and Competency 1.25 at an ability to demonstrate level of knowledge.

The supporting material for the Self-Study Information include the following documents:

- DOE-STD-1073-93-Pt.1 (1993). Guide for Operational Configuration Management Program
- Department of Energy Fundamentals Handbook Engineering Symbology, Prints, and Drawings (DOE-HDBK-1016/1-93).
- Westinghouse Savannah River Corporation Core Fundamentals Training Electrical Science Level A Student Study Guide (TTFGEL1A.H0100).
- Baer, Charles J. and John R. Ottaway (1993). Electrical and Electronic Drawings Fifth Edition. New York: Macmillan/McGraw-Hill. ISBN 0-07-003028-6 Call# TK431.B3
- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Albany, NY: Delmar Publishers Inc. ISBN 0-8273-4156-3. Call# TK1141.D83.
- Rockis, Gary and Glen Mazur, (1993). Electrical Motor Controls, Automated Industrial Systems. Homewood, IL: American Technical Publishers, Inc. ISBN 0-8269-1666-X Call# TK2851.R63.
- Smeaton, Robert W. (editor) (1977). Switchgear and Control Handbook. New York: McGraw-Hill Book Company. ISBN 0-07-058439-7. Call# TK2821.S88.

3. References

NOTE: For information regarding the Supporting Knowledge and Skills refer to the Self-Study Information section of this competency.

a. For Supporting Knowledge and Skills **1.23-1.a**, **1.24-1.a**, **1.25-1.a**, and **1.25-1.b** refer to:
   - Baer, Charles J. and John R. Ottaway (1993). Electrical and Electronic Drawings Fifth Edition. Chapter Industrial Controls and Appendix B.
   - Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Control Circuits.
   - Rockis, Gary and Glen Mazur, (1993). Electrical Motor Controls, Automated Industrial Systems. Chapter Industrial Electrical Symbols and Line Diagrams, Chapter Logic applied to Line Diagrams and Basic Control Circuits.
   - Smeaton, Robert W. (editor) (1977). Switchgear and Control Handbook. Chapter Control Standards and General Purpose Starters.
   - General Physics Corporation. Power Distribution and Control. Chapter Introduction to Power Distribution Systems.

b. For Supporting Knowledge and Skills **1.23-1.b**, **1.24-1.d**, and **1.25-1.c** refer to:
   - Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Control Circuits.
   - Smeaton, Robert W. (editor) (1977). Switchgear and Control Handbook. Chapter Control Standards and General Purpose Starters.

c. For Supporting Knowledge and Skills **1.23-1.c**, **1.24-1.b**, and **1.25-1.d** refer to:
   - Baer, Charles J. and John R. Ottaway (1993). Electrical and Electronic Drawings Fifth Edition. Chapter Industrial Controls.
   - Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Control Circuits.
   - Rockis, Gary and Glen Mazur, (1993). Electrical Motor Controls, Automated Industrial Systems. Chapter Industrial Electrical Symbols and Line Diagrams, Chapter Logic applied to Line Diagrams and Basic Control Circuits.
   - General Physics Corporation. Power Distribution and Control. Chapter Introduction to Power Distribution Systems.

d. For Supporting Knowledge and Skills **1.23-1.d** and **1.25-1.e** refer to:
   - Baer, Charles J. and John R. Ottaway (1993). Electrical and Electronic Drawings Fifth Edition. Chapter Device Symbols, Chapter The Schematic Diagram, and Chapter Industrial Controls.

e. For Supporting Knowledge and Skills **1.24-1.c** refer to:
- Baer, Charles J. and John R. Ottaway (1993). Electrical and Electronic Drawings Fifth Edition. Chapter Device Symbols, Chapter The Schematic Diagram, and Chapter Industrial Controls.
- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Control Circuits.
- Rockis, Gary and Glen Mazur, (1993). Electrical Motor Controls, Automated Industrial Systems. Chapter Industrial Electrical Symbols and Line Diagrams, Chapter Logic applied to Line Diagrams and Basic Control Circuits.

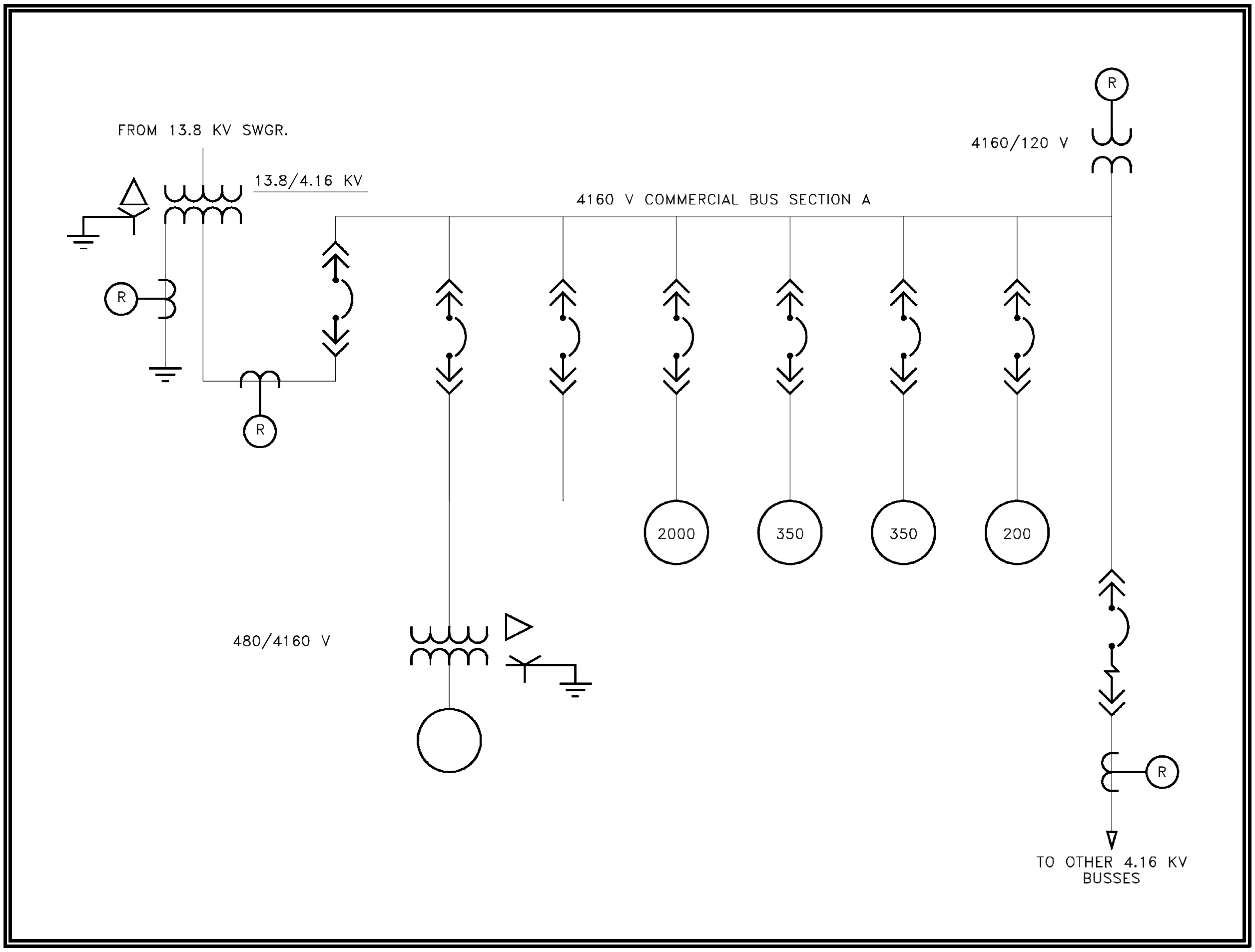
f. For Supporting Knowledge and Skills **1.24-1.e** and **1.25-1.f** refer to:
- Baer, Charles J. and John R. Ottaway (1993). Electrical and Electronic Drawings Fifth Edition. Chapter Device Symbols, Chapter The Schematic Diagram, and Chapter Industrial Controls.
- Duff, John R. and Stephen L. Herman (1991). Alternating Current Fundamentals Fourth Edition. Chapter Control Circuits.
- Rockis, Gary and Glen Mazur, (1993). Electrical Motor Controls, Automated Industrial Systems. Chapter Industrial Electrical Symbols and Line Diagrams, Chapter Logic applied to Line Diagrams and Basic Control Circuits.
- General Physics Corporation. Power Distribution and Control. Chapter Introduction to Power Distribution Systems.

g. For Supporting Knowledge and Skills **1.24-1.f** and **1.25-1.g** refer to:
- Baer, Charles J. and John R. Ottaway (1993). Electrical and Electronic Drawings Fifth Edition. Chapter Device Symbols, Chapter The Schematic Diagram, and Chapter Industrial Controls, and Appendix B.

h. For Supporting Knowledge and Skills **1.24-1.g** and **1.25-1.h** refer to:
- DOE-STD-1073-93-Pt.1 (1993). Guide for Operational Configuration Management Program

i. For Supporting Knowledge and Skills **1.25-1.i** refer to:
- Baer, Charles J. and John R. Ottaway (1993). Electrical and Electronic Drawings Fifth Edition. Chapter Wiring, Cabling, and Chassis Drawing; and Chapter Printed Circuit Boards.

4. Practice Exercise



Example Electric Drawing #1

a. Refer to Example Electric Drawing #1 above.

1. What type of diagram is Example Electric Drawing #1?

2. How many power transformers are in the diagram? Classify them. (K&S 1.23-1.a.) (K&S 1.24-1.a.)

3. How many circuit breakers are shown?

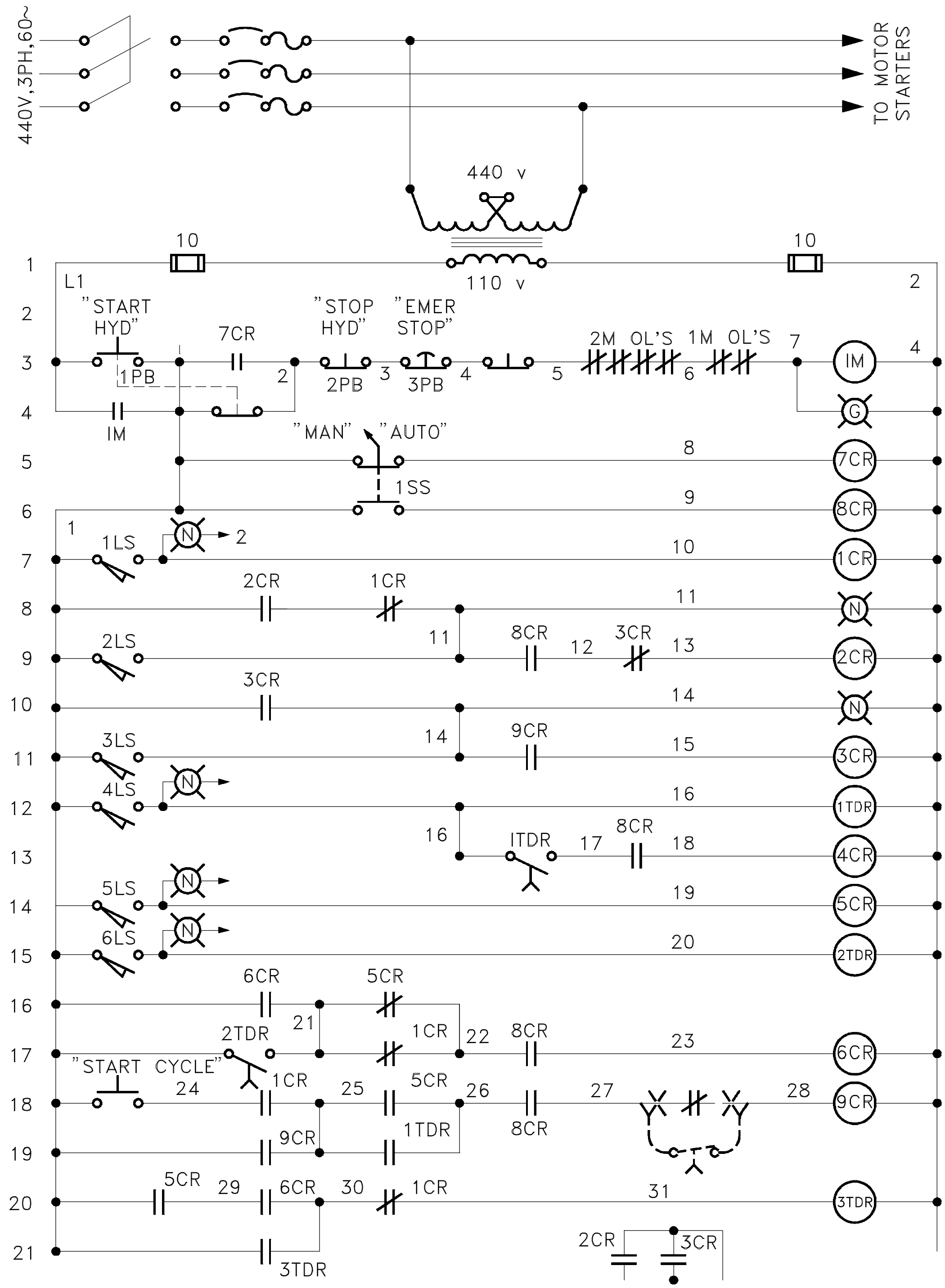
4. What voltage are shown in the diagram?

5. What do the numbers in the circles represent?

6. Classify the transformer in the upper right corner.

7. The transformer in the upper left is supplying power to the loads which breakers must closed?

8. The power supply to the 13.8 kV line is lost. The diesel generator in the lower left will be started to supply power to the vital loads. Which breakers must be operated?



Example Electric Drawing #2

b. Refer to Example Electric Drawing #2: (K&S 1.24-1.f.)

1. What type of diagram is the Example Electric Drawing #2?

2. What is the voltage rating of the motor controller circuit?

3. Where does the voltage come from?

4. Is the motor controller circuit energized now? Why? Why not? (K&S 1.23-1.c.) (K&S 1.24-1.c.)

Refer to the number at the far left to locate the following lines.

5. What is the component labeled 1TDR in line 13? (K&S 1.24-1.d.)

6. How many "a" contacts are operated from relay 1CR?

7. How many "b" contacts are operated from relay 1CR?

8. What is the status of the contacts in line 16? (K&S 1.23-1.b.) (K&S 1.24-1.e.)

9. If power were available to the circuit and "START HYD" pushbutton in line 3 is momentarily depressed and then released what would happen?

10. What is the purpose of the 3CR contact in line 10?

c. Discuss the origin and purpose of "as-built" drawings. (K&S 1.24-1.h.)

5. Practice Exercise Answers

a. <u>Answers</u> to questions on the Example Electric Drawing #1.

1. What type of diagram is Example Electric Drawing #1?

   One line electrical

2. How many power transformers are in the diagram? Classify them. (K&S 1.23-1.a.) (K&S 1.24-1.a.)

   2
   A step down 13.8 kV to 4.16 kV delta primary - grounded wye secondary
   A step up 480 volt to 4160 volt grounded wye primary - delta secondary

3. How many circuit breakers are shown?

   8

4. What voltage are shown in the diagram?

   13.8 kV; 4160 volt (4.16 kV); 480 volt; 120 volt

5. What do the numbers in the circles represent?

   Horsepower ratings of the motor (loads)

6. Classify the transformer in the upper right corner.

   A step down potential transformer 4160 volts to 120 volts

7. The transformer in the upper left is supplying power to the loads which breakers must closed?

   The transformer outlet breaker must be closed and all loads requiring power must be closed.

8. The power supply to the 13.8 kV line is lost. The diesel generator in the lower left will be started to supply power to the vital loads. Which breakers must be operated?

   The transformer outlet breaker must be opened, the diesel breaker must be closed, and all loads requiring power must be closed. Breakers for non vital loads should be opened.

b. Answers to questions on Example Electric Drawing #2.

1. What type of diagram is the Example Electric Drawing #2?

   Schematic

2. What is the voltage rating of the motor controller circuit?

   110 volt

3. Where does the voltage come from?

   Through a step down transformer from 440 volt power supply to motor starters.

4. Is the motor controller circuit energized now? Why? Why not? (K&S 1.23-1.c.) (K&S 1.24-1.c.)

   No. The ganged switch is open and the circuit breakers in the 440 volt power supply to motor starters are open.

5. What is the component labeled 1TDR in line 13? (K&S 1.24-1.d.)

   A time delay relay

6. How many "a" contacts are operated from relay 1CR?

   2

7. How many "b" contacts are operated from relay 1CR?

   3

8. What is the status of the contacts in line 16? (K&S 1.23-1.b.) (K&S 1.24-1.e.)

   6CR is open 5CR is closed

9. If power were available to the circuit and "START HYD" pushbutton in line 3 is momentarily depressed and then released what would happen?

   Power would flow through the closed 1PB pushbutton. As it is now with 7CR contact open it would go no further to the right. The power would travel down at the first junction, the pushbutton in line 4 would be open and as it is now go no further to the right. But it could continue down and through the closed "MAN" "AUTO" switch in line 5 and energize the 7CR relay. Now the 7CR contact in line 3 would close and power would continue across line 3 through the closed "STOP HYD" 2PB pushbutton, the "EMER STOP" 3PB pushbutton the unlabeled pushbutton, through the four closed 2M overload relays, and the two 1M overload relays and energize the 1M relay in line 3 and the green light in line 4. Energizing the 1M relay would close the 1M contact in line 4. So when the "START HYD" pushbutton is released the 1M relay remains energized.

10. What is the purpose of the 3CR contact in line 10?

    If the 9CR contact in line 11 is closed and limit switch 3LS in line 11 is closed then relay 3CR would energize. That would close contact 3CR in line 10. When limit switch 3LS opens relay 3CR will remain energized.

c. Discuss the origin and purpose of "as-built" drawings. (K&S 1.24-1.h.)

   The purpose of "as-built" drawings is to document the actual physical configuration of a system including piping, valves, controllers switches, gauges, etc, for example. The as-built drawing is usually done to verify that what was installed agrees with what is on the drawings. As-found drawings are similar except you are verifying what is found in the field when it is walked-down. If there are any discrepancies between the two, they are reconciled according to site standards.

Competency 1.26

Mechanical systems (FAC# 1.26) and Nuclear safety system (FAC# 1.13) personnel shall demonstrate a familiarity level knowledge of reading and interpreting electrical logic diagrams.

1. Supporting Knowledge and/or Skills

   a. Given a logic diagram, identify/interpret the symbols used on logic diagrams to represent the components.

      DOE Fundamentals Handbook Engineering Symbology, Prints, and Drawings (DOE-HDBK-1016/2-93), Chapter Engineering Logic Diagrams.

   b. Identify the symbols used to denote a logical "1" (high/on) and a logical "0" (low/off) as used in logic diagrams.

      DOE Fundamentals Handbook Engineering Symbology, Prints, and Drawings (DOE-HDBK-1016/2-93), Chapter Engineering Logic Diagrams and Chapter Truth Tables and Exercises.

   c. Given a logic diagram and appropriate information, determine the output of each component and the logic circuit.

      DOE Fundamentals Handbook Engineering Symbology, Prints, and Drawings (DOE-HDBK-1016/2-93), Chapter Engineering Logic Diagrams and Chapter Truth Tables and Exercises.

   d. Explain the operation of the three types of time delay devices.

      DOE Fundamentals Handbook Engineering Symbology, Prints, and Drawings (DOE-HDBK-1016/2-93), Chapter Engineering Logic Diagrams.

   e. Using a relay ladder, explain the logic ties.

Competency 1.27

Electrical systems (FAC# 1.15) and Facility Representatives (FAC# 1.23) personnel shall demonstrate a working level knowledge of reading and interpreting electrical logic diagrams.

1. Supporting Knowledge and/or Skills

   a. Given a logic diagram, identify/interpret the symbols used on logic diagrams to represent the components.
      DOE Fundamentals Handbook Engineering Symbology, Prints, and Drawings (DOE-HDBK-1016/2-93), Chapter Engineering Logic Diagrams.

   b. Identify the symbols used to denote a logical "1" (high/on) and a logical "0" (low/off) as used in logic diagrams.
      DOE Fundamentals Handbook Engineering Symbology, Prints, and Drawings (DOE-HDBK-1016/2-93), Chapter Engineering Logic Diagrams and Chapter Truth Tables and Exercises.

   c. Given a logic diagram and appropriate information, determine the output of each component and the logic circuit.
      DOE Fundamentals Handbook Engineering Symbology, Prints, and Drawings (DOE-HDBK-1016/2-93), Chapter Engineering Logic Diagrams and Chapter Truth Tables and Exercises.

   d. Explain the operation of the three types of time delay devices.
      DOE Fundamentals Handbook Engineering Symbology, Prints, and Drawings (DOE-HDBK-1016/2-93), Chapter Engineering Logic Diagrams.

   e. Using a logic diagram for a control circuit, identify and describe the effects of an action taken.
      DOE Fundamentals Handbook Engineering Symbology, Prints, and Drawings (DOE-HDBK-1016/2-93), Chapter Engineering Logic Diagrams and Chapter Truth Tables and Exercises.

Competency 1.28

Construction management and engineering (FAC# 1.9), Facility maintenance management (FAC# 1.21), and Instrumentation and control (FAC# 1.20) personnel shall demonstrate the ability to read and interpret electrical logic diagrams.

1. Supporting Knowledge and/or Skills

   a. Given a logic diagram, identify/interpret the symbols used on logic diagrams to represent the components.
      DOE Fundamentals Handbook Engineering Symbology, Prints, and Drawings (DOE-HDBK-1016/2-93), Chapter Engineering Logic Diagrams.

   b. Identify the symbols used to denote a logical "1" (high/on) and a logical "0" (low/off) as used in logic diagrams.
      DOE Fundamentals Handbook Engineering Symbology, Prints, and Drawings (DOE-HDBK-1016/2-93), Chapter Engineering Logic Diagrams and Chapter Truth Tables and Exercises.

   c. Given a logic diagram and appropriate information, determine the output of each component and the logic circuit.
      DOE Fundamentals Handbook Engineering Symbology, Prints, and Drawings (DOE-HDBK-1016/2-93), Chapter Engineering Logic Diagrams and Chapter Truth Tables and Exercises.

   d. Explain the operation of the three types of time delay devices.
      DOE Fundamentals Handbook Engineering Symbology, Prints, and Drawings (DOE-HDBK-1016/2-93), Chapter Engineering Logic Diagrams.

   e. Using a logic diagram for a control circuit, identify and describe the effects of an action taken.
      DOE Fundamentals Handbook Engineering Symbology, Prints, and Drawings (DOE-HDBK-1016/2-93), Chapter Engineering Logic Diagrams and Chapter Truth Tables and Exercises.

2. Self-Study Information

Competency 1.26, 1.27, and 1.28 address reading and interpreting logic diagrams. Competency 1.26 at a familiarity level of knowledge, Competency 1.27 at a working level of knowledge, and Competency 1.28 at an ability to demonstrate level of knowledge.

The supporting material for the Self-Study Information include the following documents:

- Department of Energy Fundamentals Handbook Engineering Symbology, Prints, and Drawings (DOE-HDBK-1016/1-93).
- Westinghouse Savannah River Corporation Core Fundamentals Training Instrumentation and Control Study Guide (TTFGIC1A.H0100).
- Baer, Charles J. and John R. Ottaway (1993). Electrical and Electronic Drawings Fifth Edition. New York: Macmillan/McGraw-Hill. ISBN 0-07-003028-6 Call# TK431.B3

3. References

NOTE: For information regarding the Supporting Knowledge and Skills refer to the Self-Study Information section of this competency.

a. For Supporting Knowledge and Skills **1.26-1.a**, **1.27-1.a**, and **1.28-1.a** refer to:
   - Baer, Charles J. and John R. Ottaway (1993). Electrical and Electronic Drawings Fifth Edition. Chapter Device Symbols, Chapter Flow Diagrams and Logic Diagrams, and Appendix B.

b. For Supporting Knowledge and Skills **1.26-1.b**, **1.27-1.b**, and **1.28-1.b** refer to:

c. For Supporting Knowledge and Skills **1.26-1.c**, **1.27-1.c**, and **1.28-1.c** refer to:
   - Baer, Charles J. and John R. Ottaway (1993). Electrical and Electronic Drawings Fifth Edition. Chapter Device Symbols, Chapter Flow Diagrams and Logic Diagrams, and Appendix B.

d. For Supporting Knowledge and Skills **1.26-1.d**, **1.27-1.d**, and **1.28-1.d** refer to:

e. For Supporting Knowledge and Skills **1.26-1.e** refer to:
   - Baer, Charles J. and John R. Ottaway (1993). Electrical and Electronic Drawings Fifth Edition. Chapter Device Symbols, Chapter Flow Diagrams and Logic Diagrams, and Appendix B.

f. For Supporting Knowledge and Skills **1.27-1.e** and **1.28-1.e** refer to:
- Baer, Charles J. and John R. Ottaway (1993). Electrical and Electronic Drawings Fifth Edition. Chapter Device Symbols, Chapter Flow Diagrams and Logic Diagrams, and Appendix B.

4. Practice Exercise

a. Refer to Example Logic Drawing #1 to answer the following questions. The figure illustrates a logic diagram of a simple fan start circuit.

1. Identify by number the following logic symbols: (K&S AA.1.a.) (K&S AB.1.a.) (K&S AC.1.a.)

   ________ a. AND

   ________ b. OR

   ________ c. Time delay

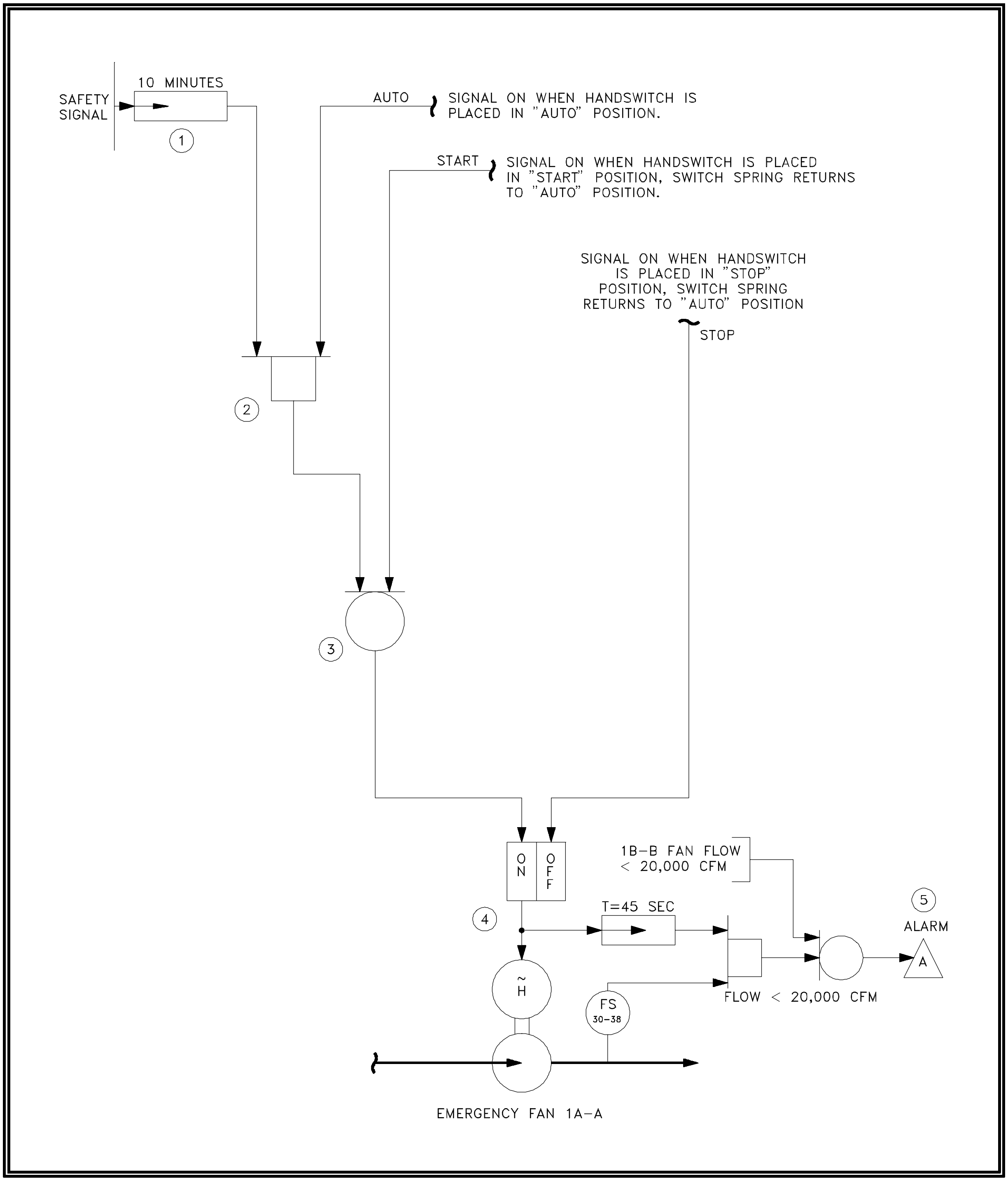
   ________ d. Retentive-Memory

2. How long must the safety signal be present before the time delay (1) will pass an output (on) signal to Gate 2? (K&S AA.1.c.) (K&S AB.1.c.) (K&S AC.1.c.)

3. Under what conditions will Gate 2 turn on? (K&S AA.1.d.) (K&S AB.1.d.) (K&S AC.1.d.)

4. Under what conditions will the low flow alarm (5) sound? (K&S AA.1.d.) (K&S AB.1.d.) (K&S AC.1.d.)

5. Since the control switch is always in the AUTO position (due to the spring return feature), what logic gate keeps the continuous on signal that is generated by the control switch being in the AUTO position from starting the fan? What signal must also be present to allow the AUTO signal to start the fan? (K&S AA.1.d.) (K&S AB.1.d.) (K&S AC.1.d.)



Example Logic Drawing #1

6. If 12 minutes after first receiving a safety signal, with the fan control switch in the AUTO position, the safety signal is removed (off), what will happen to the fan? Why? (K&S AA.1.d.) (K&S AB.1.d.) (K&S AC.1.d.)

7. How many ways can the fan be started? How many ways can the fan be stopped? (K&S AA.1.d.) (K&S AB.1.d.) (K&S AC.1.d.)

b. Refer to Example Logic Drawing #2 to answer the following questions. Example 2 illustrates a simple valve control circuit. Flow control valve (FCV) 1-147 is an air-operated valve, with its air controlled by flow solenoid valve (FSV) 1-147, which is shown in its de-energized position.

1. Identify by number the following logic symbols. (K&S AA.1.a.) (K&S AB.1.a.) (K&S AC.1.a.)

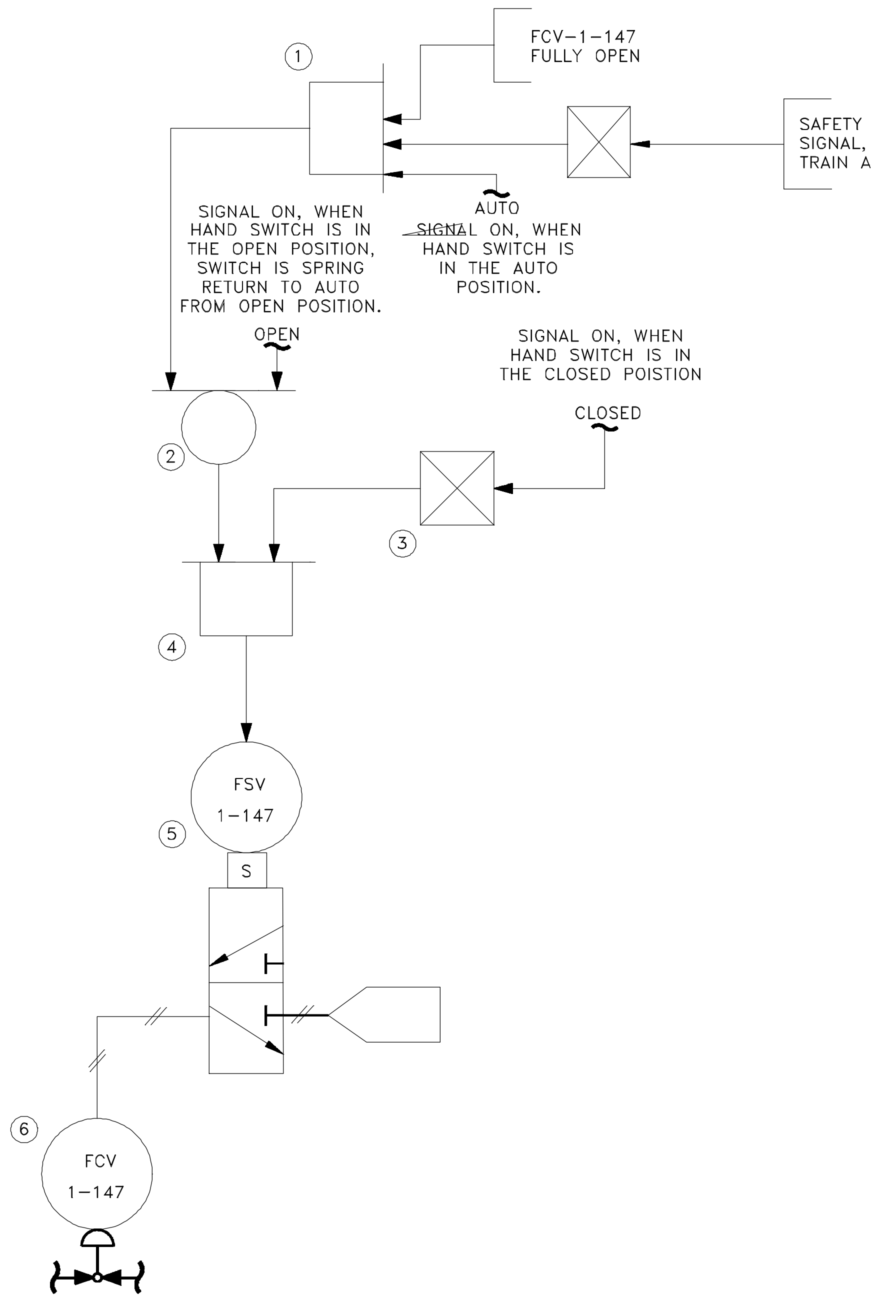
   ________ a. AND

   ________ b. OR

   ________ c. NOT

2. As drawn, with the hand switch in the AUTO position and no safety signal present, what is the status of the two inputs to Gate 4, on or off? (K&S AA.1.d.) (K&S AB.1.d.) (K&S AC.1.d.)

3. Since electrical components are drawn in their de-energized state, and using the answer from Question 2, is the flow solenoid valve (FSV-1-147) in its correct position? Why? (K&S AA.1.d.) (K&S AB.1.d.) (K&S AC.1.d.)



Example Logic Drawing #2

4. How many ways can FSV-1-147 be energized? De-energized? (K&S AA.1.d.) (K&S AB.1.d.) (K&S AC.1.d.)

5. If a safety signal is present, can FCV-1-147 (valve FSV-1-147 energized) be opened? Why? (K&S AA.1.d.) (K&S AB.1.d.) (K&S AC.1.d.)

5. Practice Exercise Answers

a. Answers to questions on Example Logic Drawing #1

1. Identify by number the following logic symbols: (K&S AA.1.a.) (K&S AB.1.a.) (K&S AC.1.a.)

   2 a. AND

   3 b. OR

   1 c. Time delay

   4 d. Retentive-Memory

2. How long must the safety signal be present before the time delay (1) will pass an output (on) signal to Gate 2? (K&S AA.1.c.) (K&S AB.1.c.) (K&S AC.1.c.)

   The safety signal must be received for greater than 10 minutes before it will pass through the time delay. If the safety signal is removed before 10 minutes has elapsed no signal will be passed to Gate 2.

3. Under what conditions will Gate 2 turn on? (K&S AA.1.d.) (K&S AB.1.d.) (K&S AC.1.d.)

   Gate 2 will turn "ON" when the hand-switch is in the "AUTO" position and a safety signal has been received for greater than 10 minutes.

4. Under what conditions will the low flow alarm (5) sound? (K&S AA.1.d.) (K&S AB.1.d.) (K&S AC.1.d.)

   If flow switch (FS) 30-38 senses less than 20,000 cfm, 45 seconds after the fan has started, or the same condition exists on the 1B-B fan, the alarm will sound.

5. Since the control switch is always in the AUTO position (due to the spring return feature), what logic gate keeps the continuous on signal that is generated by the control switch being in the AUTO position from starting the fan? What signal must also be present to allow the AUTO signal to start the fan? (K&S AA.1.d.) (K&S AB.1.d.) (K&S AC.1.d.)

   AND Gate 2 prevents the "ON" signal from passing until a safety signal is also received (>10 minutes).

6. If 12 minutes after first receiving a safety signal, with the fan control switch in the AUTO position, the safety signal is removed (off), what will happen to the fan? Why? (K&S AA.1.d.) (K&S AB.1.d.) (K&S AC.1.d.)

   Ten minutes after receiving the safety signal, the fan started. At 12 minutes, removing the safety signal only removes the continuous start signal to the fan. The fan will continue to run until the hand switch is placed in the "STOP" position. Further, with the removal of the safety signal, the fan will remain stopped when the hand switch spring returns to the "AUTO" position. Note that if the hand switch is placed in the "STOP" position while the safety signal is present, the fan will stop, but will restart as soon as the switch spring returns to the "AUTO" position.

7. How many ways can the fan be started? How many ways can the fan be stopped? (K&S AA.1.d.) (K&S AB.1.d.) (K&S AC.1.d.)

   It can be started by two signals - "START" and "AUTO" plus a safety signal.

   It can be stopped by one signal - "STOP" (but will only remain stopped if no safety signal is present or the switch is held in the stopped position).

b. Answers to questions on Example Logic Drawing #2

   1. Identify by number the following logic symbols. (K&S AA.1.a.) (K&S AB.1.a.) (K&S AC.1.a.)

      __1 & 4__ a. AND

      __2__ b. OR

      __3__ c. NOT

2. As drawn, with the hand switch in the AUTO position and no safety signal present, what is the status of the two inputs to Gate 4, on or off? (K&S AA.1.d.) (K&S AB.1.d.) (K&S AC.1.d.)

   Right input is - "ON" - this is because the hand control switch is in the "AUTO" position, and the "AUTO" switch contacts are made up, resulting in an "ON" signal. Therefore the hand-switch CLOSE position contacts are open, resulting in an "OFF" signal. The "OFF" signal is reversed in the NOT gate and becomes an "ON" signal.

   Left input is - "OFF" -. To determine this, the status of the gates feeding the left input must be determined.

   Looking at the OR gate (2) above it

   The right input to the OR gate is - "OFF" - because the hand control switch is in the "AUTO" position. The OPEN position contacts are not made up, resulting in an "OFF" signal.

   The left input to the OR gate comes from the AND gate (1) above it.

   Looking at the three inputs to the AND gate. The bottom input is - "ON" - because the hand control switch is in the "AUTO" position and the "AUTO" contacts are made up, resulting in an "ON" signal.

   The middle input to the AND gate is - "ON" - because the NOT gate reverses the "OFF" safety signal.

   The top input is - "OFF" - because the valve is not fully open, resulting in the generation of an "OFF" signal. Note this is the signal that, once the valve has traveled to the fully open position, allows the valve to remain open after the hand switch is allowed to spring return to the "AUTO" position.

   Now that all the inputs are known, we can work back through the circuit to determine the status of the left input to the AND gate (4).

   Because the one input, the top, to the AND gate (1) is "OFF", the output of the AND gate is "OFF". Therefore, the left input into the OR gate (2) is "OFF". Therefore, because both the left and right inputs to the OR gate (2) are "OFF" the output of the OR gate (1) is "OFF".

3. Since electrical components are drawn in their de-energized state, and using the answer from Question 2, is the flow solenoid valve (FSV-1-147) in its correct position? Why? (K&S AA.1.d.) (K&S AB.1.d.) (K&S AC.1.d.)

   Yes, de-energized is correct because the left input of the AND gate (4) is "OFF" and its right input is "ON". But because it is an AND gate and both its inputs are not "ON", it will not pass an "ON" signal to the solenoid to energize it.

4. How many ways can FSV-1-147 be energized? De-energized? (K&S AA.1.d.) (K&S AB.1.d.) (K&S AC.1.d.)

   It can be energized one way - the hand switch can be momentarily placed in the OPEN position.

   It can be de-energized two ways - the hand switch can be placed in the CLOSE position, or, if the valve is open and a safety signal is received, the valve will automatically close.

5. If a safety signal is present, can FCV-1-147 (valve FSV-1-147 energized) be opened? Why? (K&S AA.1.d.) (K&S AB.1.d.) (K&S AC.1.d.)

   Yes, the valve can be opened, but it will not remain open when the hand switch is allowed to spring return to the "AUTO" position. This is because the safety signal's NOT gate removes the "ON" signal that allows the AND gate (1) to output an "ON" signal and energize the solenoid.

Competency 1.29

Electrical systems (FAC# 2.1) personnel shall demonstrate a working level knowledge of the electrical systems-related sections and/or requirements of Department of Energy, DOE Order 6430.1A, General Design Criteria, Division 1, General Requirements, and Division 16, Electrical.

1. Supporting Knowledge and/or Skills

   a. Discuss the use of DOE Order 6430.1A, General Design Criteria, Division 1 in the identification of design requirements for electrical systems at Department facilities.

   b. Describe the purpose, scope, and application of the requirements detailed in DOE Order 6430.1A, General Design Criteria, Division 16.

   c. Determine contractor compliance with the applicable provisions of DOE Order 6430.1A, General Design Criteria.

   d. Discuss the relationship between the National Electric Code and Division 16 of DOE Order 6430.1A, General Design Criteria.

   e. Discuss the relationship between the American National Standards Institute (ANSI) standards and Division 16 of DOE Order 6430.1A, General Design Criteria.

   f. Discuss what constitutes a safety class item as defined in DOE 6430.1A, General Design Criteria.

   g. Discuss the application of single failure criteria to electrical systems.

   h. Discuss the environmental qualification criteria for electrical system equipment.

   i. Discuss the requirements for testing the capability of electrical systems as specified in DOE 6430.1A, General Design Criteria.

   j. Discuss the criteria for generic human factors engineering considerations in DOE 6430.1A, General Design Criteria, as they apply to electrical systems.

   k. Using a design package for an electrical system for a mechanical, civil, or structural application, determine the general design criteria requirements for the electrical system and components.

Competency 1.30

Electrical systems (FAC# 4.1) personnel shall demonstrate the ability to determine the adequacy of local compliance with the electrical systems-related sections and/or requirements of Department of Energy, DOE Order 6430.1A, General Design Criteria, Divisions 1 and 16.

1. Supporting Knowledge and/or Skills

   a. Using Divisions 1 and 16 of the DOE Order 6430.1A, General Design Criteria, prepare an action plan which adequately outlines interviews and observations to be conducted, and which details documents to review during an evaluation of contractor compliance against the requirements of the Order.

   b. Using an appropriate level of coverage, evaluate a contractor's compliance with the requirements of Division 16 of DOE Order 6430.1A, General Design Criteria. During this evaluation, demonstrate the ability to properly conduct interviews, observations, and document reviews.

   c. Using data from an evaluation, analyze the results to determine contractor compliance or noncompliance with the requirements.

   d. Using the results from an analysis of contractor compliance or noncompliance, document and communicate the results to contractor and Department line management.

   e. Using a system's terminal manuals and design drawings, inspect the system for compliance with Division 16 of DOE Order 6430.1A, General Design Criteria.

   f. Discuss conductor identification using color coding of low voltage (120-400 volt) systems in single and three-phase systems with the requirements of Division 16 of DOE Order 6430.1A, General Design Criteria.

2. Self-Study Information

Competency 1.29 and 1.30 address the knowledge associated with the electrical systems-related sections and/or requirements of Department of Energy, DOE Order 6430.1A, General Design Criteria. Competency 1.29 at a working level of knowledge and Competency 1.30 at an ability to demonstrate level of knowledge.

The supporting material for the Self-Study Information include the following documents:

- DOE Order 6430.1A, General Design Criteria

3. References

NOTE: For information regarding the Supporting Knowledge and Skills refer to the Self-Study Information section of this competency.

a. For Supporting Knowledge and Skills **1.29-1.a** refer to:
   - DOE Order 6430.1A, General Design Criteria

b. For Supporting Knowledge and Skills **1.29-1.b** refer to:
   - DOE Order 6430.1A, General Design Criteria

c. For Supporting Knowledge and Skills **1.29-1.c** refer to:
   - DOE Order 6430.1A, General Design Criteria

d. For Supporting Knowledge and Skills **1.29-1.d** refer to:
   - DOE Order 6430.1A, General Design Criteria

e. For Supporting Knowledge and Skills **1.29-1.e** refer to:
   - DOE Order 6430.1A, General Design Criteria

f. For Supporting Knowledge and Skills **1.29-1.f** refer to:
   - DOE Order 6430.1A, General Design Criteria section 0111-99.0.1,section 1300-3.2, and section 1300-3

g. For Supporting Knowledge and Skills **1.29-1.g** refer to:
   - DOE Order 6430.1A, General Design Criteria

h. For Supporting Knowledge and Skills **1.29-1.h** refer to:
   - DOE Order 6430.1A, General Design Criteria section 1300-3.4.2 and section 0110-7

i. For Supporting Knowledge and Skills **1.29-1.i** refer to:
   - DOE Order 6430.1A, General Design Criteria section 1300-3.6

j. For Supporting Knowledge and Skills **1.29-1.j** refer to:
   - DOE Order 6430.1A, General Design Criteria section 1300-12

k. For Supporting Knowledge and Skills **1.29-1.k** refer to:
   - DOE Order 6430.1A, General Design Criteria

l. For Supporting Knowledge and Skills **1.30-1.a** refer to:
   - DOE Order 6430.1A, General Design Criteria

m. For Supporting Knowledge and Skills **1.30-1.b** refer to:
   - DOE Order 6430.1A, General Design Criteria

n. For Supporting Knowledge and Skills **1.30-1.c** refer to:
   - DOE Order 6430.1A, General Design Criteria

o. For Supporting Knowledge and Skills **1.30-1.d** refer to:
   - DOE Order 6430.1A, General Design Criteria

p. For Supporting Knowledge and Skills **1.30-1.e** refer to:
   - DOE Order 6430.1A, General Design Criteria

q. For Supporting Knowledge and Skills **1.30-1.f** refer to:
   - DOE Order 6430.1A, General Design Criteria section 1605.2.3.3

4. Practice Exercise

a. Discuss the relationship between the American National Standards Institute (ANSI) standards and Division 16 of DOE Order 6430.1A, General Design Criteria. (K&S 1.29-1.e.)

b. Discuss what constitutes a safety class item as defined in DOE 6430.1A, General Design Criteria. (K&S 1.29-1.f.)

c. Discuss the application of single failure criteria to electrical systems. (K&S 1.29-1.g.)

d. Discuss the environmental qualification criteria for electrical system equipment. (K&S 1.29-1.h.)

e. Discuss the requirements for testing the capability of electrical systems as specified in DOE 6430.1A, General Design Criteria. (K&S 1.29-1.i.)

f. Discuss the criteria for generic human factors engineering considerations in DOE 6430.1A, General Design Criteria, as they apply to electrical systems. (K&S 1.29-1.j.)

g. Match the electrical wiring color code in column A with the type of electrical power conductor identified in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.30-1.f)

Column A	Column B
__ 1. Red	a. 208/120-volt, three-phase system phase "C" (ungrounded) conductor
__ 2. Orange	b. 208/120-volt, three-phase system phase "B" (ungrounded) conductor
__ 3. Yellow	c. 240/120-volt, single-phase system grounded conductor
__ 4. Blue	d. 480/277-volt, three-phase system phase "B" (ungrounded) conductor
	e. 240/120-volt, single-phase system grounded neutral
	f. 480/277-volt, three-phase system phase "C" (ungrounded) conductor

5. Practice Exercise Answers

   a. Discuss the relationship between the American National Standards Institute (ANSI) standards and Division 16 of DOE Order 6430.1A, General Design Criteria. (K&S 1.29-1.e.)

      DOE Order 6430.1A, states that all systems shall comply with American National Standards Institute (ANSI) Standards and ANSI C2. Preferred standard voltages shall be used in accordance with ANSI C84.1.

   b. Discuss what constitutes a safety class item as defined in DOE 6430.1A, General Design Criteria. (K&S 1.29-1.f.)

      Systems, components, and structures whose failure could adversely affect the environment or the safety and health of the public. The following are characteristics of safety class items (DOE Order 6430.1A section 1300-3.2):

      - Those whose failure would produce radiological exposures in excess of the guidelines at the site boundary or nearest public access.
      - Those required to maintain operating parameters within safety limits during normal operations and anticipated operational occurrences.
      - Those required for nuclear criticality safety.
      - Those required to monitor the release of radioactivity during a Design Basis Accident (DBA).
      - Those required to achieve and maintain the facility in a safe shutdown condition.
      - Those that control any safety item discussed above.

      Safety class items required to function during or following severe natural phenomena shall not be prevented from performing their required safety functions by the failure of components, systems, or structures that are not designed to the severe natural phenomena criteria.

      Safety Class Criteria (DOE Order 6430.1A section 1300-3) addresses the safety classification and required criteria for safety class structures.

c. Discuss the application of single failure criteria to electrical systems. (K&S 1.29-1.g.)

The document specifically provides guidance for several mechanical systems that are required to be safety class. Items that are safety class items shall be provided power by safety class emergency electric power systems. The design shall define the safety class electric systems required to meet the safety class system needs. They shall be provided with suitable redundancy and separation to ensure adequate capacity and capability including a single failure. IEEE 379 and IEEE 384 provide redundancy and separation criteria. Connection of non safety class loads to safety class power buses shall be minimized.

An occurrence that results in the loss of capability of a component to perform its intended safety Function(s). Multiply failures, resulting from a single occurrence are considered to be a single failure. Systems are considered to be designed against an assumed single failure if neither (1) a single failure of any active component nor, (2) a single failure of any passive component results in the loss of the systems capability to perform its safety function(s).

The document references IEEE 379, Standard Application of the Single Failure Criterion to Nuclear Power Generating Station Class 1E Systems for additional information.

d. Discuss the environmental qualification criteria for electrical system equipment. (K&S 1.29-1.h.)

Safety class items are required to be operable and perform the required safety functions under DBA conditions (DOE Order 6430.1A section 1300-3.4.2). The equipment must be able to perform a specified period of time. The limiting condition is based on the most severe postulated accident. Conditions to be considered include temperature, pressure, humidity, radiological and chemical environment.

This document also provides guidance for control and regulating the effect DOE facilities and systems have on the environment. Environmental regulation includes requirements for facility structures and systems (ventilation, cooling systems, radioactivity releases, and disposal facilities).

e. Discuss the requirements for testing the capability of electrical systems as specified in DOE 6430.1A, General Design Criteria. (K&S 1.29-1.i.)

Safety class items are required to designed to include the ability to test the monitoring, surveillance, and alarm system (DOE Order 6430.1A section 1300-3.6). The safety class items is required to be capable of being tested under simulated emergency conditions.

DOE Order 6430.1A document provides guidance for testing requirements of components and systems installed in DOE facilities. Some testing is performed for acceptance criteria while other testing is performed to ensure operability of equipment during inservice usage. Testing includes requirements for facility structures and systems (fire suppression, ventilation, cooling systems, and storage facilities).

f. Discuss the criteria for generic human factors engineering considerations in DOE 6430.1A, General Design Criteria, as they apply to electrical systems. (K&S 1.29-1.j.)

Human factors engineering is used to reduce human error, increase productivity, lower costs, better product quality, decrease equipment and property damage; improve program schedules;personal job satisfaction; and improvements in safe operation and maintenance of DOE facilities. DOE Order 6430.1A provides guidance for the incorporation of human factors engineering into the design, operation, and maintenance of DOE facilities (DOE Order 6430.1A section 1300-12). The guidance addresses work environment and man-machine interfaces. General guidance is provided for incorporating human factors engineering in system design, displays, controls, alarms, labelling, and communication. The criteria includes such matter as ventilation; lighting; noise control; work space layout; and equipment design and layout.

g. Match the electrical wiring color code in column A with the type of electrical power conductor identified in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.30-1.f)

Column A	Column B
_b_ 1. Red	a. 208/120-volt, three-phase system phase "C" (ungrounded) conductor
_d_ 2. Orange	b. 208/120-volt, three-phase system phase "B" (ungrounded) conductor
_f_ 3. Yellow	c. 240/120-volt, single-phase system grounded conductor
_a_ 4. Blue	d. 480/277-volt, three-phase system phase "B" (ungrounded) conductor
	e. 240/120-volt, single-phase system grounded neutral
	f. 480/277-volt, three-phase system phase "C" (ungrounded) conductor

Competency 1.31

Electrical systems (FAC# 2.10) personnel shall demonstrate a working level knowledge of the following Institute of Electrical and Electronic Engineers (IEEE) Color Book Series as they apply to the design, construction and operation of nuclear facilities.

- **Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE-STD-141-1976 (IEEE Red Book), Electrical Power Distribution**
- **Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE-STD-242-1975 (IEEE Buff Book), Protection and Coordination**
- **Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE-STD-399-1980 (IEEE Brown Book), Power Systems Analysis**
- **Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE-STD-142-1982 (IEEE Green Book), Grounding**
- **Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE-STD-446-1987 (IEEE Orange Book), Emergency and Standby Power**
- **Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE-STD-493-1990 (IEEE Gold Book), Power Systems Reliability**
- **Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE-STD-241-1990 (IEEE Gray Book), Commercial Building Power Systems**
- **Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE-STD-739-1984 (IEEE Bronze Book), Energy Conservation in Industrial Facilities**

1. Supporting Knowledge and/or Skills

   a. Refer to Institute of Electrical and Electronic Engineers (IEEE) Red Book and discuss electrical power distribution. Include the following in your discussion:

      - Basic design considerations and electrical distribution design
      - Voltage considerations
      - Surge voltage protection techniques
      - System protective devices
      - Power factor and its effects in electrical distribution systems
      - Power switching, transformation, and motor-control apparatus
      - Cable system basics
      - Busway design

b. Refer to Institute of Electrical and Electronic Engineers Buff Book and discuss protection and coordination. Include the following in your discussion:

- Fault calculations
- Short-circuit current calculations for single and three-phase circuits.
- Instrument transformer basics
- Protective relay selection and application
- Fuses selection and application
- Low-voltage circuit breaker fundamentals
- Ground-fault protection fundamentals
- Conductor, motor, transformer, generator, and bus and switchgear protection
- Maintenance, testing, and calibration of electrical systems

c. Refer to Institute of Electrical and Electronic Engineers Brown Book and discuss power system analysis. Include the following in your discussion:

- Power system analysis fundamentals
- Power system analysis analytical procedures
- System modeling fundamentals

d. Refer to Institute of Electrical and Electronic Engineers Green Book and discuss grounding. Include the following in your discussion:

- Electrical system grounding fundamentals
- Electrical equipment grounding fundamentals
- Static and lightning grounding fundamentals

e. Refer to Institute of Electrical and Electronic Engineers Orange Book and discuss emergency and standby power. Include the following in your discussion:

- Emergency and standby power guidelines
- Generator and electric utility system fundamentals
- Stored energy system fundamentals
- Protection device fundamentals

f. Refer to Institute of Electrical and Electronic Engineers Gold Book as a reference, discuss power systems reliability. Include the following in your discussion:

- Planning and design basics
- Improving existing electrical system reliability
- Reliability analysis basic concepts

g. Refer to Institute of Electrical and Electronic Engineers Grey Book and discuss commercial building power systems. Include the following in your discussion:

- Lighting design considerations
- Electric space heating fundamentals

h. Refer to Institute of Electrical and Electronic Engineers Bronze Book and discuss energy conservation in industrial facilities. Include the following in your discussion:

- Energy conservation program fundamentals
- Translating energy into cost
- Load management fundamentals
- Electrical machines and equipment conservation consideration fundamentals

Competency 1.32

Electrical systems (FAC# 4.3) personnel shall demonstrate an ability to assess contractor work activities against the requirements specified in the Institute of Electrical and Electronic Engineers (IEEE) Color Book Series, and American National Standards Institute (ANSI) Standards.

1. Supporting Knowledge and/or Skills

a. Describe the purpose, scope, and application of the requirements for electrical systems detailed in the Institute of Electrical and Electronic Engineers Standards.

b. Discuss what constitutes acceptable contractor performance consistent with the requirements of the Institute of Electrical and Electronic Engineers Standards.

c. Using the above codes and standards as applicable, evaluate a contractor's compliance with the requirements of the codes and standards. During the evaluation, demonstrate the ability to properly conduct interviews, observations, and document reviews.

d. Using data from an evaluation, analyze the results to determine contractor compliance or noncompliance with the requirements.

e. Using the results from an analysis of contractor compliance or noncompliance, document and communicate the results to contractor and Department line management.

f. Using a design package for an electrical system, demonstrate the ability to verify compliance with the appropriate Institute of Electrical and Electronic Engineers Standards.

2. Self-Study Information

Competency 1.31 and 1.32 address the knowledge associated with the Institute of Electrical and Electronic Engineers (IEEE) Color Book Series as they apply to the design, construction and operation of nuclear facilities. Competency 1.31 at a working level of knowledge, Competency 1.32 at an ability to demonstrate level of knowledge.

The supporting material for the Self-Study Information include the following documents:

- Institute of Electrical and Electronic Engineers (1994). IEEE Recommended Practice for Electrical Power Distribution for Industrial Plants (IEEE-STD-141-1993 IEEE Red Book). New York: Institute of Electrical and Electronic Engineers Inc. ISBN 1-55937-333-4.
- Institute of Electrical and Electronic Engineers (1986). IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (IEEE-STD-242-1986 IEEE Buff Book). New York: Institute of Electrical and Electronic Engineers Inc. ISBN 0-471-85392-5.
- Institute of Electrical and Electronic Engineers (1990). IEEE Recommended Practice for Industrial and Commercial Power Systems Analysis (IEEE-STD-399-1990 IEEE Brown Book). New York: Institute of Electrical and Electronic Engineers Inc. ISBN 1-55937-044-0.
- Institute of Electrical and Electronic Engineers (1992). IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems IEEE-STD-142-1991 (IEEE Green Book). New York: Institute of Electrical and Electronic Engineers Inc. ISBN 1-55937-141-2.
- Institute of Electrical and Electronic Engineers (1992). IEEE Recommended Practice for Powering and Grounding Sensitive Electronic Equipment IEEE-STD-1100-1992 (IEEE Emerald Book). New York: Institute of Electrical and Electronic Engineers Inc. ISBN 1-55937-231-1
- Institute of Electrical and Electronic Engineers (1987). IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications (IEEE-STD-446-1987 IEEE Orange Book). New York: Institute of Electrical and Electronic Engineers Inc. ISBN 471-62571-X
- Institute of Electrical and Electronic Engineers (1991). IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems (IEEE-STD-493-1990 IEEE Gold Book). New York: Institute of Electrical and Electronic Engineers Inc. ISBN 1-55937-066-1.

Institute of Electrical and Electronic Engineers (IEEE) Standards

- Institute of Electrical and Electronic Engineers (1991). IEEE Recommended Practice for Electric Power Systems in Commercial Building (IEEE-STD-241-1990 IEEE Gray Book). New York: Institute of Electrical and Electronic Engineers Inc. ISBN 1-55937-088-2.
- Institute of Electrical and Electronic Engineers (1984). IEEE Recommended Practice for Energy Conservation and Cost-Effective Planning in Industrial Facilities (IEEE-STD-739-1984 IEEE Bronze Book). New York: Institute of Electrical and Electronic Engineers Inc. Library of Congress Catalog Number 84-81026.
- American National Standards Institute (ANSI) Standards
- DOE Conduct of Assessment Topical Area Self Study Guide (SR-TA-COA-SSG-01)

3. References

NOTE: For information regarding the Supporting Knowledge and Skills refer to the Self-Study Information section of this competency.

a. For Supporting Knowledge and Skills **1.31-1.a** refer to:
- Institute of Electrical and Electronic Engineers (1986). IEEE Recommended Practice for Electrical Power Distribution for Industrial Plants (IEEE-STD-141-1986 IEEE Red Book).

b. For Supporting Knowledge and Skills **1.31-1.b** refer to:
- Institute of Electrical and Electronic Engineers (1986). IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (IEEE-STD-242-1975 IEEE Buff Book).

c. For Supporting Knowledge and Skills **1.31-1.c** refer to:
- Institute of Electrical and Electronic Engineers (1990). IEEE Recommended Practice for Industrial and Commercial Power Systems Analysis (IEEE-STD-399-1990 IEEE Brown Book).

d. For Supporting Knowledge and Skills **1.31-1.d** refer to:
- Institute of Electrical and Electronic Engineers (1992). IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems IEEE-STD-142-1991 (IEEE Green Book).
- Institute of Electrical and Electronic Engineers (1992). IEEE Recommended Practice for Powering and Grounding Sensitive Electronic Equipment IEEE-STD-1100-1992 (IEEE Emerald Book).

e. For Supporting Knowledge and Skills **1.31-1.e** refer to:
- Institute of Electrical and Electronic Engineers (1987). IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications (IEEE-STD-446-1987 IEEE Orange Book).

f. For Supporting Knowledge and Skills **1.31-1.f** refer to:
   - Institute of Electrical and Electronic Engineers (1991). IEEE Recommended Practice for the Design of Reliable Power Systems (IEEE-STD-493-1990 IEEE Gold Book).

g. For Supporting Knowledge and Skills **1.31-1.g** refer to:
   - Institute of Electrical and Electronic Engineers (1991). IEEE Recommended Practice for Electric Power Systems in Commercial Building (IEEE-STD-241-1990 IEEE Gray Book).

h. For Supporting Knowledge and Skills **1.31-1.h** refer to:
   - Institute of Electrical and Electronic Engineers (1984). IEEE Recommended Practice for Energy Conservation and Cost_effective Planning in Industrial Facilities (IEEE-STD-739-1984 IEEE Bronze Book).

i. For Supporting Knowledge and Skills **1.32-1.a, 1.32-1.b, 1.32-1.c, 1.32-1.d, 1.32-1.e,** and **1.32-1.f** refer to:
   - Institute of Electrical and Electronic Engineers (1994). IEEE Recommended Practice for Electrical Power Distribution for Industrial Plants (IEEE-STD-141-1993 IEEE Red Book).
   - Institute of Electrical and Electronic Engineers (1986). IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (IEEE-STD-242-1986 IEEE Buff Book).
   - Institute of Electrical and Electronic Engineers (1990). IEEE Recommended Practice for Industrial and Commercial Power Systems Analysis (IEEE-STD-399-1990 IEEE Brown Book).
   - Institute of Electrical and Electronic Engineers (1992). IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems IEEE-STD-142-1991 (IEEE Green Book).
   - Institute of Electrical and Electronic Engineers (1992). IEEE Recommended Practice for Powering and Grounding Sensitive Electronic Equipment IEEE-STD-1100-1992 (IEEE Emerald Book).
   - Institute of Electrical and Electronic Engineers (1987). IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications (IEEE-STD-446-1987 IEEE Orange Book).
   - Institute of Electrical and Electronic Engineers (1991). IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems (IEEE-STD-493-1990 IEEE Gold Book).
   - Institute of Electrical and Electronic Engineers (1991). IEEE Recommended Practice for Electric Power Systems in Commercial Building (IEEE-STD-241-1990 IEEE Gray Book).

Institute of Electrical and Electronic Engineers (IEEE) Standards

- Institute of Electrical and Electronic Engineers (1984). IEEE Recommended Practice for Energy Conservation and Cost-Effective Planning in Industrial Facilities (IEEE-STD-739-1984 IEEE Bronze Book).
- DOE Conduct of Assessment Topical Area Self Study Guide (SR-TA-COA-SSG-01)

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Competency 1.33

Electrical systems (FAC# 1.14) personnel shall demonstrate a familiarity level knowledge of the various computer applications used in electrical systems engineering.

1. Supporting Knowledge and/or Skills

   a. Identify and discuss at least one of the major computer programs used in electrical systems engineering.

   b. Describe the applications of computer-aided design (CAD) as it relates to electrical systems design functions (e.g., load analysis, breaker coordination, fault calculations, conductor sizing, or voltage drop calculations).

   c. Discuss the quality of electric power, including neutral harmonic currents, required for large computer systems.

   d. Describe the use of computers in the monitoring and control of power systems.

   e. Discuss the use of computers in circuit analysis and electrical system calculations.

2. Self-Study Information

   Competency 1.33 addresses the familiarity level of knowledge of the principles associated with the various computer applications used in electrical systems engineering.

   The supporting material for the Self-Study includes the following documents:

- Fink, Donald G. and H. Wayne Beatty (1978). Standard Handbook for Electrical Engineering. New York: McGraw-Hill Book Company. ISBN 0-07-020974-X. Call# TK151.S8.
- Institute of Electrical and Electronic Engineers (1990). IEEE Recommended Practice for Industrial and Commercial Power Systems Analysis (IEEE-STD-399-1990 IEEE Brown Book). New York: Institute of Electrical and Electronic Engineers Inc. ISBN 1-55937-044-0.
- Goetsch, David L., John A Nelson, and William S. Chalk (1989). Technical Drawing Fundamentals-CAD-Design Second Edition. Albany, NY: Delmar Publishers Inc. ISBN 0-82733-3280-7. Call #T353.G63.
- Nashelsky, Louis and Robert L Boylestad (1984). BASIC Applied to Circuit Analysis. Columbus, OH: Charles E. Merrill Publishing Company. ISBN 0-675-20161-6. Call# TKQA76.78.B3.N3.
- Vlach, Jiri (1983). Computer Methods for Circuit Analysis and Design. New York: Van

Nostrand Reinhold Company. ISBN 0-442-28108-0. Call# TK7867.V58.

The following text are suggested in IEEE Recommended Practice for Industrial and Commercial Power Systems Analysis (IEEE-STD-399-1990 IEEE Brown Book) addressing the use of computers.

- Arrillaga, J., C. P. Arnold, and B. J. Harker (1983). Computer Modeling of Electrical Power Systems. New York: John Wiley & Sons.
- Heydt, G. T. (1986). Computer Analysis Methods for Power Systems. New York: Macmillan.
- Kusic, George L. (1986). Computer Aided Power System Analysis. Englewood Cliffs, NJ: Prentice-Hall.
- Stagg, Glenn W. and Ahmed H. El-Abiad (1968). Computer Methods in Power System Analysis. New York: McGraw-Hill.
- Wallach, Y. (1986). Calculations and Programs for Power Systems Networks. Englewood Cliffs, NJ: Prentice-Hall.

3. References

NOTE: For information regarding the Supporting Knowledge and Skills refer to the Self-Study Information section of this competency.

a. For Supporting Knowledge and Skills **1.33-1.a** refer to:
   - Nashelsky, Louis and Robert L Boylestad (1984). BASIC Applied to Circuit Analysis.
   - Vlach, Jiri (1983). Computer Methods for Circuit Analysis and Design.
   - Goetsch, David L., John A Nelson, and William S. Chalk (1989). Technical Drawing Fundamentals-CAD-Design Second Edition.

b. For Supporting Knowledge and Skills **1.33-1.b** refer to:

c. For Supporting Knowledge and Skills **1.33-1.c** refer to:

d. For Supporting Knowledge and Skills **1.33-1.d** refer to:

e. For Supporting Knowledge and Skills **1.33-1.e** refer to:
   - Nashelsky, Louis and Robert L Boylestad (1984). BASIC Applied to Circuit Analysis.
   - Vlach, Jiri (1983). Computer Methods for Circuit Analysis and Design.

Competency 1.34

Electrical systems (FAC# 1.16) personnel shall demonstrate a familiarity level knowledge of maintenance management practices related to electrical activities.

1. Supporting Knowledge and/or Skills

   a. Define each of the following maintenance-related terms and explain their relationship to each other.

      - Corrective
      - Planned
      - Preventive
      - Reliability Centered
      - Predictive

   b. Describe the elements of an effective work control program and the documentation used to control maintenance.

   c. Discuss the importance of maintaining a proper balance of preventive and corrective maintenance.

   d. Define the term "life limiting component" and discuss its impact on facility operation.

   e. Identify typical maintenance performance indicators, and discuss their importance.

   f. Discuss the relationship between maintenance and Conduct of Operations, Qualify Assurance, and Configuration Management.

   g. Discuss the requirements for receiving and inspecting parts, materials, and equipment.

   h. Describe the difference between temporary and permanent repairs/work and the requirements and controls in place to prevent inadvertent modifications.

2. Self-Study Information

Competency 1.34 addresses the familiarity level of knowledge of the principles associated with maintenance management practices related to electrical activities.

The supporting material for the Self-Study includes the following documents:

- Title 10 Code of Federal Regulations 21 Reporting of Defects and Noncompliance. Washington, DC: U.S. Government Printing Office.
- ANSI/ASME NQA-1/2, Quality Assurance Program Requirements for Nuclear Facilities 1994 Edition
- Department of Energy (DOE) Order O 430.1, Life Cycle Asset Management.
- Department of Energy (DOE) Order 4330.4B, Maintenance Management Program
- Department of Energy (DOE) Order 5480.19 Conduct of Operation Requirements for DOE Facilities
- Department of Energy (DOE) Order 5480.26 Trending and Analysis of Operations Information Using Performance Indicators
- Department of Energy (DOE) Technical Standard Planning, Scheduling and Coordination of Maintenance (DOE-STD-1050-93)
- Department of Energy (DOE) Technical Standard Maintenance Organization and Administration (DOE-STD-1051-93)
- Department of Energy (DOE) Technical Standard Types of Maintenance Activities (DOE-STD-1052-93)
- Department of Energy (DOE) Technical Standard Control of Maintenance Activities (DOE-STD-1053-93)
- Department of Energy (DOE) Technical Standard Material Receipt, Inspection, Handling, Storage, Retrieval, and Issue (DOE-STD-1071-94)
- Department of Energy (DOE) Technical Configuration Management (DOE-STD-1073-93-Pt.1 & Pt.2)
- General Physics Corporation. Applying Reliability Centered Maintenance Seminar and Workshop Student Handbook. Columbia, MD: General Physics Corporation.
- General Physics Corporation. Predictive Maintenance Seminar and Workshop Student Handbook. Columbia, MD: General Physics Corporation.

Maintenance-related terms

- Maintenance - Day-to-day work that is required to sustain property in a condition suitable for it to be used for its designated purpose and includes preventive, predictive, and corrective (repair) maintenance.
- Corrective Maintenance - The repair of failed or malfunctioning equipment, system, or facilities to restore the intended function or design condition. This maintenance does not result in significant extension of expected useful life.
- Preventive Maintenance - Predictive, periodic, and planned maintenance actions taken to maintain a piece of equipment within design operating conditions and extend its life.
- Predictive Maintenance - Maintenance activities involving continuous or periodic monitoring and diagnosis to forecast equipment failure.
- Planned Maintenance - Maintenance activities performed prior to equipment failure. The activities can be initiated by predictive or periodic maintenance results, by vendor recommendations, or by experience.
- Reliability Centered Maintenance - A method for establishing a scheduled maintenance program that can effectively and economically realize the inherent reliability and safety levels of equipment.

3. References

NOTE: For information regarding the Supporting Knowledge and Skills refer to the Self-Study Information section of this competency.

a. For Supporting Knowledge and Skills **1.34-1.a** refer to:
- Department of Energy (DOE) Order 4330.4B Maintenance Management Program Section 5.2 Discussion; Section 5.3.2 Types of Maintenance; Attachment 1 Definitions
- General Physics Corporation. Applying Reliability Centered Maintenance Seminar and Workshop Student Handbook Definitions.
- Department of Energy (DOE) Technical Standard Types of Maintenance Activities (DOE-STD-1052-93)
- Department of Energy (DOE) Technical Standard Control of Maintenance Activities (DOE-STD-1053-93)

b. For Supporting Knowledge and Skills **1.34-1.b** refer to:
- Department of Energy (DOE) Technical Standard Planning, Scheduling and Coordination of Maintenance (DOE-STD-1050-93)
- Department of Energy (DOE) Technical Standard Control of Maintenance Activities (DOE-STD-1053-93)
- Department of Energy (DOE) Order O 430.1, Life Cycle Asset Management.
- Department of Energy (DOE) Order 4330.4B Maintenance Management Program

c. For Supporting Knowledge and Skills **1.34-1.c** refer to:
- Department of Energy (DOE) Order 4330.4B Maintenance Management Program
- Department of Energy (DOE) Technical Standard Types of Maintenance Activities (DOE-STD-1052-93)
- Department of Energy (DOE) Order O 430.1, Life Cycle Asset Management.

d. For Supporting Knowledge and Skills **1.34-1.d** refer to:
- Department of Energy (DOE) Order 4330.4B Maintenance Management Program
- Department of Energy (DOE) Technical Configuration Management (DOE-STD-1073-93-Pt.1 & Pt. 2)

e. For Supporting Knowledge and Skills **1.34-1.e** refer to:
- Department of Energy (DOE) Order 4330.4B Maintenance Management Program Section 3.7.3 Performance Measurement and Improvement; Section 16 Maintenance History; Section 17 Analysis of Maintenance Problems
- Department of Energy (DOE) Order 5480.26 Trending and Analysis of Operations Information Using Performance Indicators
- Department of Energy (DOE) Order 5700.6C Quality Assurance

- General Physics Corporation. Applying Reliability Centered Maintenance Seminar and Workshop Student Handbook, Chapter Effective Evaluations.
- Department of Energy (DOE) Technical Standard Control of Maintenance Activities (DOE-STD-1053-93)

f. For Supporting Knowledge and Skills **1.34-1.f** refer to:
- Department of Energy (DOE) Order 4330.4B Maintenance Management Program Section 3.1 Organization, Administration, and Training
- Department of Energy (DOE) Order 5480.19 Conduct of Operations Requirements For DOE Facilities Chapter VIII Control of Equipment and System Status; Chapter IX Lockouts and Tagouts
- Department of Energy (DOE) Order 5700.6C Quality Assurance
- ANSI/ASME NQA-1/2, Quality Assurance Program Requirements for Nuclear Facilities 1994 Edition
- Department of Energy (DOE) Order O 430.1, Life Cycle Asset Management.
- Department of Energy (DOE) Technical Configuration Management (DOE-STD-1073-93-Pt.1 & Pt.2)

g. For Supporting Knowledge and Skills **1.34-1.g** refer to:
- Title 10 Code of Federal Regulations 21 Reporting of Defects and Noncompliance.
- Department of Energy (DOE) Order 4330.4B Maintenance Management Program Section 3.5 Maintenance Facilities, Equipment, and Materials Control System; Section 4 Maintenance Facilities, Equipment, and Tools; Section 10 Procurement of Parts, Materials and Services; Section 11 Material Receipt, Inspection, Handling, Storage, Retrieval and Issuance.
- Department of Energy (DOE) Order O 430.1, Life Cycle Asset Management.
- Department of Energy (DOE) Technical Standard Material Receipt, Inspection, Handling, Storage, Retrieval, and Issue (DOE-STD-1071-94)

h. For Supporting Knowledge and Skills **1.34-1.h** refer to:
- Department of Energy (DOE) Order 4330.4B Maintenance Management Program Section 8.3.5 Temporary Repairs; Section 18.3.2 Temporary Repairs/Temporary Modifications.
- Department of Energy (DOE) Order 5480.19 Conduct of Operations Requirements For DOE Facilities Chapter VIII Control of Equipment and System Status
- Department of Energy (DOE) Technical Standard Control of Maintenance Activities (DOE-STD-1053-93)

4. Practice Exercise

a. Match the definition in column A with the term in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.34-1.a.)

Column A	Column B
__ 1. The repair of failed or malfunctioning equipment, system, or facilities to restore the intended function or design condition. This maintenance does not result in significant extension of expected useful life.	a. Planned
	b. Maintenance
	c. Corrective
__ 2. Periodic, and planned maintenance actions taken to maintain a piece of equipment within design operating conditions and extend its life.	d. Reliability Centered
	e. Preventive
__ 3. Activities performed prior to equipment failure. The activities can be initiated by predictive or periodic maintenance results, by vendor recommendations, or by experience.	f. Predictive
__ 4. Activities involving continuous or periodic monitoring and diagnosis to forecast equipment failure.	

b. Identify typical maintenance performance indicators, and discuss their importance. (K&S 1.34-1.e.)

c. Describe the difference between temporary and permanent repairs/work and the requirements and controls in place to prevent inadvertent modifications. (K&S 1.34-1.h.)

5. Practice Exercise Answers

a. Match the definition in column A with the term in column B. Use the column B answers one time only. Ignore any response in column B not identified in column A. (K&S 1.34-1.a.)

Column A	Column B
_c_ 1. The repair of failed or malfunctioning equipment, system, or facilities to restore the intended function or design condition. This maintenance does not result in significant extension of expected useful life.	a. Planned
	b. Maintenance
	c. Corrective
_e_ 2. Periodic, and planned maintenance actions taken to maintain a piece of equipment within design operating conditions and extend its life.	d. Reliability Centered
	e. Preventive
_a_ 3. Activities performed prior to equipment failure. The activities can be initiated by predictive or periodic maintenance results, by vendor recommendations, or by experience.	f. Predictive
_f_ 4. Activities involving continuous or periodic monitoring and diagnosis to forecast equipment failure.	

b. Identify typical maintenance performance indicators, and discuss their importance. (K&S 1.34-1.e.)

- Post-Maintenance test results.
- Periodic surveillance test results.
- Ratio of preventive maintenance costs to total corrective cost.
- Maintenance work request backlog.
- Time to restore component function after failure discovery.
- Frequency of maintenance rework.
- Corrective maintenance backlogged over three months.
- Preventive maintenance items overdue.
- Maintenance overtime worked.
- Ratio of preventive maintenance to total maintenance.
- Maintenance related radiation exposure.
- Maintenance caused trips.
- Actual PM manhours versus estimated PM manhours.
- Equipment caused equivalent unavailability.
- Ratio of preventive maintenance costs to total maintenance cost.
- Actual maintenance costs versus budgeted maintenance costs.

- Actual preventative maintenance costs versus budgeted costs.
- Top contributors to unavailability - PM to total maintenance cost.
- Percent of reworked PMs.
- Equivalent unavailability due to performing PMs.
- Aged PM backlog by priority (using current system of prioritizing).
- Equipment failures versus backlogged PMs.
- Unavailability versus PM cost.

Performance Indicators should:

- Easy to calculate.
- Data presently available or easily gathered.
- Directly related to PM Program Performance.
- Related to a specific PM problem.
- Accurately calculated promptly at end of the period of concern.
- Diagnose problems and recommend actions to correct.
- Sensitive to change (outside normal variability), and is not sensitive to non-PM program changes.
- Applicable/useful to multiple levels of the organization.

Performance indicator show over a period of time possible problems. The analysis of the PI is required to positively identify the problem.

c. Describe the difference between temporary and permanent repairs/work and the requirements and controls in place to prevent inadvertent modifications. (K&S 1.34-1.h.)

Temporary repairs are temporary modifications to the facility that allow equipment to remain in or be returned to service in a condition that is not the same as the original design specification. Prior to implementation, temporary repairs should receive a safety review in accordance with the facility temporary modification program to ensure the adequacy of the repair and its effect on personnel and equipment safety and reliability. Temporary repairs should be tracked after their completion for consideration of permanent repairs. Permanent corrective action should be taken as soon as practicable.

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U.S. Department of Energy
Technical Qualifications

Electrical Systems Topical Area

Self-Study Guide
Glossary

Appendix A

August 1996

Appendix A Glossary

An additional reference for definitions is the following:

- Institute of Electrical and Electronic Engineers (1992). The New IEEE Standard Dictionary of Electrical and Electronic Terms (IEEE-STD-100-1992). New York: Institute of Electrical and Electronic Engineers Inc. ISBN 1-55937-240-0.

Ammeter	instrument used to measure the amount of electron flow. Units - amperes.
Ampere	basic unit of electrical current flow. Symbol - A.
Ampere-hour	unit describing the storage capacity of a battery (the product of the current and the time). Symbol - Ah.
Anode	positive electrode of an electrochemical device towards which negatives ions are drawn.
Apparent Power	the power that is apparently available for use in an AC circuit containing reactive elements. It is the product of the effective voltage times the effective current. Units - voltamperes. Must be multiplied by the power factor to obtain true power available. Also the product (volt-amperes) of the rms (root mean square) exciting current and the applied rms terminal voltage in an electrical circuit containing inductive impedance.
Armature	rotating part of an electric generator or motor. The moving part of a relay or vibrator.
Autotransformer	transformer in which the primary and secondary windings are connected together in one winding.
Battery	device for converting chemical energy into electrical energy. Two or more primary or secondary cells connected together electrically.
Breakdown Torque	maximum amount of torque that can be developed by a motor at rated frequency and voltage before an abrupt change in speed occurs.
Bus Bar	primary power distribution point connected to the main power source.

Capacitance	electrical size of a capacitor. Unit - farad. Symbol - C.
Capacitive Reactance	force of a capacitor that act as a resistor to limit the flow of current. Capacitive reactance is inversely proportional to the capacitance of the capacitor and the frequency. Units - ohms. Symbol - X_C.
Capacitor	two electrodes or sets of electrodes in the form of plates, separated from each other by an insulating material called a dielectric. A capacitor stores electrical energy, blocks the flow of alternating current and permits the flow of alternating current depending on the capacitance and frequency.
Cathode	general name for any negative electrode\device.
Cell	single unit of a battery that produces direct current voltage by converting chemical energy into electrical energy.
Circuit	complete path of an electrical current.
Circuit Breaker	(600 volts nominal or less) device designed to open and close a circuit by nonautomatic means and to open the circuit automatically on a predetermined overcurrent without injury to itself when properly applied within its rating (29CFR449). (over 600 volts, nominal) A device capable of making, carrying, and breaking currents under normal circuit conditions and also making, carrying for a specified time, and breaking currents under specified abnormal circuit conditions, such as a short circuit (29CFR449). Typically an electromagnetic or thermal device that opens a circuit when the current in the circuit exceeds a predetermined amount. Circuit breakers can be reset and reused with out damage to the device. Rated for voltage, current and horsepower.
Compound-wound	a generator or motor employing a series field and a shunt field.
Conductance	the ability of a material to conduct or carry an electrical current. It is the reciprocal of the resistance of a material. Units - mhos or siemens.
Conductivity	the eases with which a material transmits electricity.
Conductor	a material, usually in the form of a wire, cable, or bus bar, suitable for carrying an electric current. A material with a large number of free electrons or a material which easily permits electric current to flow.

Contact	conducting part of a relay that acts as a switch that is closed or opened by the magnetic pull of an energized relay coil of a circuit or a component.
Control Relay	electrically operated switch that uses relatively small amounts of electrical power to either signal or control a large amount of power.
Copper Losses	power, or I^2R, losses of a resistor, dissipated in the form of heat.
Coulomb	a measure of the quantity of electricity. One coulomb is equal to 6.28 x 10^{18} electrons. Also the quantity of electrical charge that passes any cross section of a conductor in one second when the current is equal to 1 ampere. Symbol - C.
Coulombs Law	(or law of electric charges or law of electrostatic attraction) states that charged particles attract or repel each other with a force that is directly proportional to the product of their individual charges and inversely proportional to the square of the distances between the particles.
Counter-electromagnetic force (CEMF)	the electromotive force induced in a coil or armature that opposes the applied voltage.
Current	the flow of electrons past a reference point or the passage of electrons through a conductor. Units - amperes.
D'Arsonval Meter Movement	name of the permanent-magnet moving-coil movement used in many meters.
Dielectric	an insulator; term that refers to the insulating material between the plates of a capacitor.
Diode	electrical device that allows electron flow in only one direction. Used in rectifiers. Used to convert AC to DC.
Direct Current (DC)	electrical current that flows in one direction only.
Dry Cell	an electrical cell that has an electrolyte that is not a liquid, typically the electrolyte is a paste.
Eddy Current	induced circulating currents in a conducting material that are caused by

	a varying magnetic field.
Eddy Current Loss	Losses caused by random current flowing in the core of a transformer. Power is lost in the form of heat.
Efficiency	the ratio of the output power to the input power, generally expressed as a percentage.
Electric Current	the flow of electrons
Electrical Charge	electrical energy stored on or in an object. The negative charge is caused by an excess of electrons; the positive charge is caused by a deficiency of electrons. Symbol - Q or q.
Electrochemical	the action of converting chemical energy into electrical energy.
Electrode	terminal use to emit, collect, or control electrons and ions. A terminal at which electricity passes from one medium into another, such as an electrical cell where the current leaves or returns to the electrolyte.
Electrodynamic Meter Movement	a meter movement using a fixed field coil and a moving coil; usually used in wattmeters.
Electrolyte	a solution of a material capable of conducting electricity, may be a liquid or paste.
Electromagnet	an electrically excited magnet capable of exerting mechanical force or of performing mechanical work.
Electromagnetic	term describing the relationship between electricity and magnetism. Having both electrical and magnetic properties.

Electromagnetic Induction	the production of an electrical voltage in a coil due to the change in the number of magnetic lines of force passing through a coil.
Electron	the elementary negative charge that revolves around the nucleus of an atom. One of the three major parts of an atom.
Electron Shell	a group of electrons which have a common energy level that forms part of the outer structure of an atom.
Electrostatic	pertaining to electricity at rest, such as charges on an object.
Electrostatic (force or field)	term referring to the force field that surrounds a stationary, charge object.
Electromotive Force (EMF)	the force which causes electricity to flow between two points with different electrical charges or when there is a difference of potential between the two points. Units - volts.
Farad	unit of capacitance. A charge of 1 coulomb produces 1 volt potential difference between the terminals. Symbol - F.
Field	the space containing electric or magnetic lines of force.
Field Winding	coil mounted within the frame of a generator or motor used to provide or produce the magnetizing field or force.
Flux	term used to designate the electric or magnetic lines of force in a region.
Frequency	number of complete cycles per second existing in any form of wave motion.
Full Load Torque	amount of torque necessary to produce the full horsepower of a motor at rated speed.
Fuse	overcurrent protective device inserted in series with a circuit. It contains a metal that will break or melt when the current exceeds a specific value for a specific time. Not reusable.

Generator	machine that converts mechanical energy into electrical energy.
Ground	conducting connection, whether intentional or accidental, between an electrical circuit or equipment and the earth, or to some conducting body that services the place of the earth (29CFR449). A metallic connection to earth to establish ground potential, a common return to a point of zero potential.
Henry	the electromagnetic unit of inductance or mutual inductance. The inductance in a circuit is equal to one henry when a current variation of one ampere per second induces one volt. The basic unit of inductance. Symbol - H. (plural is Henrys)
Hertz	unit of frequency equal to one cycle per second. Symbol - Hz.
Horsepower	unit of power or work done equal to 550 foot pounds force per second. Equal to 746 watts of electrical power. Symbol - hp.
Impedance	the total opposition to flow of an alternating current. It may consist of any combination of resistance, inductive reactance, and capacitive reactance. Units - ohms.
Inductance	the property of a circuit which tends to oppose a change in the existing current.
Induced Current	(or induced electromotive force) current flow due to the relative motion between a conductor and a magnetic field.
Inductive Reactance	the opposition to the flow of current of an alternating current (AC) circuit caused by the inductance of a circuit. Units - ohms. Symbol - X_L.
Insulation	material used to prevent the leakage of electricity from a conductor and to provide mechanical spacing or support to protect against accidental contact. Use of a material in which current flow is negligible to surround or separate a conductor to prevent loss of current flow.

Insulator	insulating material in a form designed to support a conductor physically and electrically separate it from another conductor or object. NOTE: it is understood to be insulated for the normally expected conditions.
Interlock	device used to prevent the operation of some other device or circuit until another action has taken place.
I^2R loss	the power lost in a generator because of the current (I) flowing through the resistance (R) of the conductors.
Isolation Transformer	transformer with a secondary winding electrically isolated from the primary winding.
Joule	unit of energy or work. A joule of electrical energy is liberated by one ampere flowing for one second through a resistance of one ohm.
Kirchhoff's Laws	(1) the algebraic sum of the current flowing toward any point in an electric network is zero. (2) The algebraic sum of the products of the current and resistance in each of the conductors in any closed path in a network is equal to the algebraic sum of the electromotive forces in the path.
Ladder Diagram	(ladder relay or line diagram) industry standard for representing control systems.
Lag	the amount one wave is behind another in time; express in electrical degrees.
Lead	the amount one wave is ahead another in time; express in electrical degrees. Also, a wire or connection.
Lead-acid Cell	a cell in which the electrodes are grids of lead and the electrolyte is a sulfuric acid.
Load	device through which an electric current flows and which changes electrical energy into another form. Power consumed by a device or circuit in performing its function.

Load center	the service entrance, the point from which branch circuits originate.
Locked Rotor Current	amount of current produced when voltage is applied to a motor and the rotor is not turning.
Locked Rotor Torque	amount of torque produced by a motor at the time it of starting.
Logic	arrangement of circuitry designed to accomplish certain objectives.
Magnetism	the property of certain materials by which mechanical force is exerted on neighboring magnetic materials. Can cause electrical currents to be induced in conducting materials moving relative to the magnetized material.
Megger (meggar)	a test instrument used to measure insulation resistance and other high resistances. It is a hand operated DC generator used as an ohmmeter.
Mho	unit of conductance. It is the reciprocal of the resistance (ohm).
Motor	device that converts electrical energy into rotating mechanical energy.
Motor control center (MCC)	as assembly of one or more enclosed sections having a common power bus and principally containing motor control units.
Motor-Generator	a motor and a generator on a common shaft used to convert line voltages to other voltages or frequencies.
Moving Vane Meter Movement	name of the meter movement that uses the magnetic repulsion of like poles created in two iron vanes by electric current flowing through a coil. Commonly used in many AC meters.
Multimeter	a single meter which serves several functions (ammeter, voltmeter, and ohmmeter).
Mutual induction	the production of an electrical voltage in a coil due to the relative position of two inductors causes the magnetic lines of force to link with the turns of the other.
Neutral	in a normal condition, neither positive nor negative, contains a normal number of electrons.

Neutral grounding	conductor grounded to the earth.
Ohm	unit of electrical resistance. It is the value of electrical resistance through which a constant potential difference of one volt across a resistance will maintain a current flow of one ampere. Symbol - Ω.
Ohm's Law	the current in an electrical circuit is directly proportional to the electromotive force in the circuit. Common form of the law is E = I R. Where E is the electromotive force or voltage across the circuit, I is the current flowing in the circuit, and R is the resistance of the circuit.
Ohmmeter	instrument used to directly measure resistance in ohms.
Overcurrent	any current in excess of the rated current of equipment or ampacity of a conductor. It may result from overload, short circuit, or ground fault.
Overload	operation of equipment in excess of normal, full load rating, or of a conductor in excess of rated ampacity which, when it persists for a sufficient length of time would cause damage or dangerous overheating.
Parallel circuit	two or more electrical devices connected to the same pair of terminals so separate current flows through each. Electrons have more than one path to travel from the negative terminal to the positive terminal.
Permeability	measure of the ability of a material to act as a path for magnetic lines of force.
Phase	the angular relationship between two alternating currents or voltages when the voltage or current is plotted as a function of time. When the two are in phase, the angle is zero.
Phase angle	the number of electrical degrees of lead or lag between the voltage or current waveforms in an AC circuit.
Polarity	the condition in an electrical circuit by which the direction of the flow of electrons current can be determined. Usually applied to batteries and other direct voltage power sources. Two opposite charges, one positive, one negative. A quality of having two opposite magnetic poles, one north, one south.
Polyphase	circuit that uses more than one phase of alternating current.

Potential	the amount of charge held by a body as compared to another point or body. Units - volts.
Potential Energy	Energy due to the position of one body relative to another body.
Potentiometer	a three terminal resistor with one or more sliding contacts, which functions as an adjustable voltage divider.
Power	the rate of doing work or rate of expending energy. Unit - watt (W). Symbol - P.
Power Factor	the ratio of the actual power of an alternating or pulsating current to the apparent power. The actual power is determined using a wattmeter and the apparent power is determined using a voltmeter and an ammeter. The power factor is an expression of the losses of the load, inductor, capacitor, or insulator.
Primary Cell	cell that cannot be recharged after it has been discharged.
Primary Winding	winding of a transformer electrically connected to an electrical power supply or source.
Printed Circuit	circuit in which wires are replaced by conductive strips on an insulated board. (Abbreviated PC)
Reactance	the opposition offered to the flow of alternating current by inductance, capacitance, or both in any circuit. Symbol X. Also seen as the imaginary part of impedance.
Reactive Power	product of the rms current, the voltage, and the sine function of the angular phase difference between the current and the voltage, in an electric circuit. $P = E\ I \sin \Theta$.
Rectifier	electrical device used to convert alternating current (AC) to pulsating direct current (DC).
Relay	an electromagnetic device with one or more sets of contacts which changes contact positions by magnetic attraction of a coil to an armature.
Reluctance	a measure of the opposition that a material offers to magnetic lines of force.

Repulsion	the mechanical force tending to separate bodies having like electrical charges or like magnetic polarity.
Resistance	the opposition to flow of electrical current caused by the nature and physical dimensions of a conductor.
Resistor	electrical device whose chief characteristic is resistance; used to use the flow of electrical current.
Resonance	condition existing in a circuit in which the inductive and capacitive reactance cancel each other out.
Rheostat	a resistor whose value can be varied. A variable resistor which is used for the purpose of adjusting the current flow in a circuit.
RLC Circuit	an electrical circuit which has the properties of resistance, inductance, and capacitance.
Root Mean Square (RMS)	the equivalent heating value of an alternating current or voltage, as compared to a direct current or voltage. It is 0.707 times the peak value of a sine wave.
Rotor	portion of an electrical generator or motor that is attached to the central shaft and rotates.
Secondary Cell	cell that can be recharged after it has been discharged.
Secondary Winding	winding or output coil of a transformer.

Self-Induction	the production of counter-electromotive force (cemf) in a conductor when its own magnetic field collapses and expands with a change in the current in a conductor.
Series Circuit	arrangement where electrical devices are connect so that the total electrical current must flow through all the devices. Electrons have one path to travel from the negative terminal to the positive terminal.
Series-Parallel Circuit	a circuit that consists of both series and parallel networks.
Series-Wound	motor or generator in which the armature is wired in series with the field.
Shunt windings	windings in a generator or motor in which the field coil is connected in parallel to the armature.
Shunt	device connected in parallel to some other device.
Short Circuit	electrical circuit that contains no resistance to limit the flow of current.
Silicon controlled rectifiers	three junction semiconductor device that is normally an open circuit until a signal is applied to the gate terminal, at which time it rapidly switches to the conducting state.
Sine Wave	(sinusoidal wave) the curve traced by the projection on a uniform time scale of the end of a rotating arm or vector.
Slip	difference between the rotating magnetic field and the speed of the rotor in an induction motor.
Slip rings	metallic band mounted to but insulated from the shaft of a generator or motor. Used to connect current to or from the rotating coil.
Solenoid	electromagnetic device that changes electrical energy into mechanical motion; based on the attraction of a moveable iron plunger to the core of an electromagnet.

Specific gravity	the ratio between the density of a material and the density of pure water at a standard temperature.
Speed regulation	number indicating the amount of change in speed of a motor as it goes from a condition of no load to full load. Generally expressed in percent.
Stator	portion of an electrical generator or motor that is attached to the housing and remains stationary.
Switch	device used in electrical circuits for making, breaking, or changing connections under conditions for which the switch is rated (normally rating of amperes and volts).
Switchboard	large single panel, frame, or assembly of panels r\which have switches, buses, instruments, overcurrent and other protective devices mounted on the face or back or both.
Synchroscope	an instrument used to indicate a difference in frequency between two alternating current sources.
Tachometer	an instrument for indicating revolutions per minute (rpm).
Thermal-magnetic Trip Element	single circuit breaker trip element that combines the action of a thermal and magnetic trip element.
Thermocouple	the junction of two dissimilar metals that produces a voltage when heated.
Torque	turning or twisting force developed by a motor.
Transformer	electrical device composed of two or more coils linked by magnetic lines of force, used to transfer energy from one circuit to another.
Transmission Lines	any conductor or system of conductors used to carry electrical energy from its source to a load.
Trip-Element	part of a circuit breaker that senses any overload condition and causes the circuit breaker to open the circuit.

Trip-Free Circuit Breaker	a circuit breaker that will open a circuit even if the operating mechanism is held in the ON position.
True Power	the power dissipated in the resistance of a circuit, or power actually used in the circuit.
Turns Ratio	the ratio of the number of turns in the primary winding to the number of turns in the secondary windings of a transformer.
Uninterruptible Power supply (UPS)	system designed to automatically provide power, without delay or transients, during any period when the normal power supply is incapable of performing acceptably.
VARs	abbreviation for volt-amperes, reactive.
Volt	unit of electromotive force or electrical pressure. One volt is the pressure required to send one ampere of current through a resistance of one ohm. Symbol - V.
Voltage	(of a circuit) the greatest root-mean-square (effective) difference of potential between any two conductors of the circuit concerned (29CFR449). Also term used to signify electrical pressure or electromotive force (emf). Voltage is a force which causes current to flow through an electrical conductor.
Voltage Divider	a series circuit in which desired portions of the source voltage may be tapped off for use in equipment.
Voltage Drop	the difference in voltage between two points. It is the result of loss of electrical pressure as current flows through a resistance.
Voltage Regulation	number expressing the change in voltage as a generator or motor goes from a condition of no load to full load. Generally expressed in percent.
Voltmeter	an instrument designed to measure a difference in electrical potentials in volts.

Watt — unit of electrical power. It is the amount of power used when one ampere of direct current (DC) flows through a resistance of one ohm. Symbol - w.

Watt-Hour — unit of electrical energy equal to one watt of power for one hour.

Wattmeter — an instrument for measure electrical power in watts.

FORMULAS

$$F = K\frac{q_1 \cdot q_2}{d^2}$$

$E = I\,R$

$P = I\,E$

$R_T = R_1 + R_2 + R_3 + ... + R_n$

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_n}$$

$$R_T = \frac{R_1 \cdot R_2}{R_1 + R_2}$$

$\Sigma E_{source} = \Sigma\, I\,R$

$\Sigma\, I_{in} = \Sigma\, I_{out}$

$E_{ind} = N \bullet B \bullet V$

$E_{ind} = 2\,\pi\,f\,L\,I$

$$X_L = \frac{E_{ind}}{I} = \frac{2\pi f L I}{I} = 2\pi f L$$

$$Z = \sqrt{R^2 + X_L} = \sqrt{R^2 + 2\pi f L}$$

$P = I\,E\cos\Theta$

$$pf = \cos\Theta = \frac{\text{true power}}{\text{apparent power}}$$

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U.S. Department of Energy
Technical Qualifications

Electrical Systems Topical Area

Training-to-Competency Matrix

Appendix B

TO BE DEVELOPED

August 1996

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U.S. Department of Energy
Technical Qualifications

Electrical Systems Topical Area

Self-Study Guide
References

Appendix C

August 1996

Appendix C References

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[3] Change Control is a proceduralized process which ensures all changes are properly executed, from initiation of the change request through the approval, implementation, and incorporation into the next document revision.

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