ELECTRICAL TRAINING ALLIANCE SUBSTATION APPRENTICESHIP

Second Year
Lesson Learning Objectives

SUBSTATION APPRENTICESHIP

2ND YEAR – LEVEL 1

LESSON LEARNING OBJECTIVES

Level I opens with lessons that introduce the student to blueprints and specifications. Electrical drawings and diagrams, along with civil drawings, also are reviewed. Other lessons discuss what blueprint symbols mean and how drawings are scaled and dimensioned. This course also contains a lesson dealing with substation steel erection and a lesson that introduces measuring and leveling devices. The course concludes with a lesson on measuring and drawing angles and another on right triangles.

Lesson 1: Symbols, Conventions, and Abbreviations

Introduction:

The symbols, conventions and abbreviations form part of the language of electrical work that all Qualified Electrical Workers should know. This knowledge will also help them to communicate with fellow Qualified Electrical Workers. On-the-job training will provide the needed experience to become better acquainted with the language.

Objectives:

1. State the purpose of symbols, conventions, and abbreviations used on blueprints.
2. Describe what various symbols, conventions, and abbreviations represent.
3. Explain what information is available on the various drawings discussed.
4. Describe the difference between standard and one-line electrical diagrams.

Lesson 2: Scaling and Dimensioning Drawings

Introduction:

When constructing an electrical substation, the blueprints may come from several disciplines, including civil and electrical engineers. For a Qualified Electrical Worker, it is important to understand the scaling and dimensioning terms used by different schools of engineering. Having the knowledge of basic principles of scaling and dimensioning the blueprints will prepare the Qualified Electrical Worker for such encounters throughout his or her career.

Objectives:

1. State the difference between extension and dimension lines.
2. List three types of scales used on blueprints.
3. State how dimensions are inserted into a blueprint.

Lesson 3: Single-Line Drawings

Introduction:

Single-line diagrams are commonly used in the electrical industry to provide workers with a basic understanding of the components of a system. It is common to use basic symbols in a single-line diagram to explain the components shown; it is up to the worker to develop the knowledge needed to interpret such symbols. There is no industry standard that defines what must be included on a single-line diagram, and some diagrams may include control circuits. All single-line diagrams are to be looked at as merely providing a broad overview and should not be used as a guide for installing equipment.

Objectives:

1. Interpret some of the symbols used in a single-line diagram.
2. Explain the purpose of a single-line diagram.
3. Read and understand single-line diagrams.

Lesson 4: Schematic Diagrams

Introduction:

Substation workers will encounter schematic diagrams that may be very simple or extremely complex. Qualified Electrical Workers will be called on to study and follow various schematic diagrams throughout their careers. As various diagrams are encountered, all it takes is a little patience and any piece of equipment can be wired to operate properly.

Objectives:

1. Interpret the symbols used in a schematic diagram.
2. Discuss why different color wires are used in a schematic diagram.
3. Identify various components used in schematic diagrams.

Lesson 5: Electrical Drawings and Diagrams

Introduction:

The symbols that have been introduced previously will now start to come together. Electrical drawings in blueprints and specification books are the drawings that will be used the most. Keep in mind that all changes should be reported, and, as a Qualified Electrical Worker, be sure to make every effort to build it as called for. With time and on-the-job training, it will be second nature to look at a blueprint and visualize the entire circuit and pieces of equipment as they will appear in their final arrangements and relationships. Keep in mind that the engineer wants the system to look and perform in a certain way, and knowing how to read all symbols, conventions, and abbreviations is part of the job.

Objectives:

1. Identify the symbols for transformer connections and associated electrical equipment.
2. List the types of drawings and diagrams used to illustrate an electrical system or circuit.
3. Describe what type of information is available in each kind of drawing and diagram discussed in this lesson.

Lesson 6: Introduction to Blueprints and Specifications

Introduction:

Blueprints and specification sheets are documents that lay out every aspect of a job as the engineer wants it done. A Qualified Electrical Worker will need a firm understanding of the types of maps, drawings, and specification sheets that will be used throughout his or her career. Knowledge of the tools used by engineers to communicate with Qualified Electrical Workers is also useful.

Objectives:

1. Describe the information contained in construction drawings.
2. Describe the information that would be found on a specification sheet.
3. List the types of drawings used in electrical construction.
4. State the primary uses of blueprints and specification sheets.

Lesson 7: Civil Drawings

Introduction:

This series of lessons deals with reading the instruments engineers use to convey their view of what a job should look like when it is completed. As Qualified Electrical Workers, be sure to learn how to correctly interpret the information given. Civil engineering, the "grandfather" of all engineering practices, is introduced as an important point of study. Most prints used will not specify that a civil engineer drew part of it, but it is important to know how different engineering disciplines come together to provide the field information needed.

Objectives:

1. State three methods an engineer uses to provide additional information other than the drawings.
2. Find specific information on various civil engineering drawings.
3. Recognize and identify the maps used to place a structure.
4. Describe the difference between a note and a specification sheet.

Lesson 8: Steel Erection Drawings

Introduction:

Constructing an electrical substation or, in this case, a switching station is a complex project that requires extensive prints and material lists. The steel super structures are the largest and most visible parts of a switching/substation, and are also the pieces that can stop overall construction if they are not precisely manufactured or if some parts are missing. It is the responsibility of Qualified Electrical Workers to double check material lists and drawings so that the project will be brought in on time and within budget.

Objectives:

1. Associate the list of materials with a substation blueprint.
2. Understand how substation blueprints are laid out from overview to detail.
3. Identify major station components from the blueprints.

Lesson 9: Introduction to Measuring and Leveling Devices

Introduction:

Qualified Electrical Workers will be working with or around surveying equipment for the rest of their careers. Using surveying levels and transits requires formal training and hands-on practice but learning about the instruments that lay out the blueprints on the ground is an important place to start.

Objectives:

1. State the function of the various tools and equipment used in surveying.
2. Define the different types of measurements that are taken during a survey.
3. List the proper procedures to follow when setting up measuring instruments.

Lesson 10: Measuring and Drawing Angles

Introduction:

Working with angles is a key part of turning plans and specifications on paper into something real. Learning how to draw and measure angles with a protractor is an invaluable skill. However, it is also invaluable to know how to calculate the size of an angle without the aid of a protractor.

Anyone who works in the building trades will find that they are often working with shapes and figures that are part of geometry. Therefore, a knowledge and understanding of geometry are essential to becoming a competent Qualified Electrical Worker. Understanding the concepts of angles is a key part of geometry and provides the foundation for understanding triangles.

Objectives:

1. Name and understand the different types of angles.
2. Measure and draw angles with a protractor.
3. Calculate the measure of angles without the use of a protractor.

Lesson 11: Right Triangles

Introduction:

In a right triangle, there are special relationships among the angles and sides of the triangle. One of these relationships is stated in the Pythagorean Theorem, which shows the mathematical relationship between the hypotenuse (the side opposite the right angle) and the other two sides of a right triangle. This theorem has been used by mathematicians for thousands of years and is one of the most-used mathematical formulas in existence today.

The properties of triangles and the special attributes of right triangles will help significantly in the work of a Qualified Electrical Worker. The calculations involved allows one to determine lengths and angles without actually measuring them. Some applications that may require knowledge of triangles and specifically right triangles include conduit bending, power factor correction, and the theories involved with AC circuits. Therefore, it is very important to understand the basics of triangles and learn how to put them to work in day-to-day work activities. These concepts also provide the foundation of trigonometry, or triangle measurements.

Objectives:

1. Calculate the unknown lengths and angles of a right triangle.
2. Understand and use the Pythagorean Theorem.
3. Identify different types of triangles.

Level II deals with the groundwork needed when constructing a substation, from site layout and preparation to building an oil spill prevention containment system as required by the EPA. Lessons expand on previous lessons dealing with ground grids, equipment grounding, and the types of ground connectors available to the substation technician. The student will also learn about boom capacities, load charts, steel superstructure assembly, and erection. The last four lessons deal with installing insulators, bus/jumper types, and wire bus types.

Lesson 1: Site Layout and Preparation

Introduction:

Qualified Electrical Workers are not ordinarily involved in selecting a substation site or preparing the ground for the substation. However, every worker should have a basic knowledge of what is involved. Workers normally come to a worksite weeks or months after the site has been prepared, after nature has had a chance to affect the site. Any drainage problems or environmental concerns noticed by workers must be brought to the attention of the supervisor so they can be addressed.

Objectives:

1. List three factors that should be considered when picking a site for a substation.
2. List the three types of rollers available.
3. Discuss how a rammer type soil compactor works.

Lesson 2: Equipment Foundations

Introduction:

There are different types of foundations that substation workers may be working with throughout their careers. It is important to the success of every substation worker to have background information on how and why foundations for substation equipment are built the way they are built, and on the importance of building them correctly.

Objectives:

1. List three things that should be checked on rebar prior to installation.
2. State the two most common types of foundations used in substation construction.
3. Discuss the proper way to install a template and anchor bolts prior to pouring a drilled foundation.

Lesson 3: Substation Construction---Spill Prevention, Containment, and Countermeasure Plans

Introduction:

Federal law, specifically the Code of Federal Regulations, 40 CFR, Chapter 1, Parts 110 and 112, requires the containment of potential oil spills for any facility that contains oil stored above ground in excess of 1,320 gallons, or any single container with a capacity greater than 660 gallons.

Since most electrical substation transformers meet the standards for oil capacity, each substation must have a spill prevention, control, and countermeasure (SPCC) plan in place. The electrical industry is deeply concerned about preventing oil from reaching prohibited areas, including the groundwater table and any navigable waters. Workers should be acquainted with methods used to implement an SPCC plan at a typical substation.

Objectives:

1. Discuss specific reasons a substation must have an SPCC plan.
2. State two methods used to contain an oil spill in a substation.
3. List two requirements of an SPCC plan.

Lesson 4: Substation Construction---Grounding/Ground Grids

Introduction:

A substation ground grid is a critical component needed to provide quality power and worker and public safety. Workers should understand what a ground grid is, what role it plays, and how it is constructed.

Objectives:

1. Understand the purpose of a substation ground grid.
2. Construct a ground grid.
3. Understand how a ground grid contributes to worker and public safety.

Lesson 5: Type of Ground Connectors

Introduction:

There are three main types of connectors used in making substation ground connections. Each of the connections is approved for use in a substation ground grid, with exothermic welding becoming the preferred method. Due to the high currents that a substation grid may be exposed to, each of the connectors used must be properly installed. Qualified Electrical Workers must be properly trained in the techniques and safety procedures related to substation ground connections.

Objectives:

1. State the IEEE standard, which rates the maximum allowable temperatures for connectors.
2. List two items of PPE that must be worn when installing exothermic connectors.
3. List the three most common types of connectors used on substation ground grids.

Lesson 6: Boom Capacities and Load Charts

Introduction:

The introduction of fiberglass booms into electrical line work has revolutionized the industry. Because fiberglass is lighter than steel and has insulating properties, bucket trucks and digger derricks can reach higher, faster, and safer than a steel boom. However, despite the modern boom's enormous power, it is not indestructible. Mandatory maintenance, inspection programs, and operator training must all be in place.

Every Qualified Electrical Worker needs to be familiar with and know how to use the capacity charts as posted on equipment to ensure that every lift is a safe one. Get into the habit of consulting the load charts and calculating every lift prior to making it.

Objectives:

1. Use the load charts to calculate a safe lift for a given weight.
2. Discuss the set-up procedures for a truck with a mounted boom.
3. Discuss how a truck may tip over with little or no weight at the boom tip.
4. Understand the procedures for the safe operation of booms.

Lesson 7: Insulated Platforms and the Second Point of Contact

Introduction:

It is important to be familiar with the types of insulated platforms available to Qualified Electrical Workers, and the concept of the second point of contact and how an insulated platform can insulate a Qualified Electrical Worker from it. If a mistake is made while working on an insulated platform, there may be a second chance. In other words, an insulated platform is like personal protective equipment. It may provide backup protection when things go wrong.

Objectives:

1. Introduce the concept of the second point of contact.
2. Discuss the insulated platform and its purpose.
3. Discuss methods used for protection from the second point of contact.

Lesson 8: Superstructure Assembly and Erection Part 1

Introduction:

A substation's superstructure is the installation's skeleton; it holds the various components together and is expected to last for the life of the installation. Substation workers are expected to install each piece of the superstructure where it belongs and to torque each nut to specifications. There are several manufacturers of substation superstructures and their specifications must be closely followed to assure the substation or switchyard will provide good service to customers.

Lesson 9: Superstructure Assembly and Erection Part 2

Introduction:

Most substation superstructures weigh 1,000 pounds or less and are set using a digger derrick. Cranes are brought in for heavy loads, such as power transformers, or for tall structures, such as A-Frames anchoring incoming transmission lines. The superstructures may seem small but can still cause injury or damage to other equipment if not properly handled. Every Qualified Electrical Worker should have a good understanding of rigging and the proper bolting procedures associated with handling and landing structures.

If the substation site has been compacted before the superstructures are set, pads should be used under the digger derrick outriggers to avoid punching holes in the earth. If the structures are being set near energized lines or equipment, the minimum approach distance must be maintained at all times.

Objectives:

1. State the proper way to connect onto a load using shackles and slings.
2. Discuss how to properly bolt structures together.
3. List the items that need to be considered on every lifting job.

Lesson 10: Insulators

Introduction:

Insulators are used to insulate and separate line conductors from the pole or tower and from each other. The voltage of the line largely determines the type and size of insulators used. This condition makes it possible for a knowledgeable Qualified Electrical Worker to determine the voltage class of a line simply by looking at it. This is important because it may alter the work procedure to ensure safety.

The material that is used to make an insulator can have a direct effect on its performance. For example, porcelain can withstand heavy compression, but fails quickly under tension.

Design plays an important role as well. Pin insulators are often selected over the suspension type for lower voltages, due to cost and the fact that the same conductor height can be achieved with shorter poles.

Objectives:

1. Identify different types of insulators.
2. Explain how insulators are made and list individual characteristics.
3. Determine where specific types of insulators should be used.

Lesson 11: Bus/Jumpers – Types

Introduction:

Depending on the purpose, the current carrying requirements, and the environment, buses in substations and switching yards may be of several different types. Rigid, hollow tube aluminum has become the preferred material for bus work, but Qualified Electrical Workers may be called on to install buses made from solid copper or ordinary line conductors. It is therefore important for Qualified Electrical Workers to have knowledge of buses, jumpers, and the connectors that are used with them.

Objectives:

1. List three types of substation bus arrangements.
2. State two methods used to stop bus vibration.
3. State the common size of aluminum hollow tube used for substation buses.

Lesson 12: Bus/Jumpers – Proper Handling, Installations

Introduction:

Substation bus and substation jumpers must be properly handled and installed in the substation to function as designed. In many parts of the country, ice loading and movement due to wind are factors that must be considered when installing substation bus and jumpers. Properly handling bus work and jumpers during installation helps prevent damage that may lead to a structural failure in the future.

Objectives:

1. Discuss how a Deutsch compression type connector is applied.
2. State the two types of welding that are used to join aluminum bus work.
3. Discuss the advantages of welding substation bus work.

Lesson 13: Wire Bus Type

Introduction:

Substation and switching equipment are normally connected to the rigid electrical bus with flexible copper or aluminum wire. The reason for using wire instead of rigid bus work is that equipment moves due to wind, temperature changes, or earthquake activity. The movements may be small, but after several years, rigid bus work connected to equipment bushings would cause damage to the equipment. Copper and aluminum wire will flex under stress, thereby protecting equipment bushings. Qualified Electrical Workers must become proficient in the techniques required to make proper connections from wire buses to rigid bus and to equipment bushings.

Objectives:

1. Discuss the techniques used to prepare a wire bus before crimping on a spade terminal.
2. State two types of aluminum wire that are used for buses.
3. Discuss the proper way to warm up a torque wrench.

Level III covers equipment specific to substations. The first two lessons are an overview of substation equipment and each of the remaining lessons concentrates on specific pieces of substation equipment beginning with the power transformer and ending with lightning arrestors. The lessons explain the function of each piece of equipment and point out the hazards associated with them. Besides the equipment mentioned, this course covers capacitors, reactors, rectifiers, voltage regulators, and switches.

Lesson 1: Substation Equipment Overview

Introduction:

With approximately 100,000 substations in the United States, every line worker should have a solid understanding of substations, their function, their equipment, and the safety procedures involved. A careful study of lessons pertaining to substations will be beneficial to the Qualified Electrical Workers who will be working in substations at some point in their careers.

Objectives:

1. List two methods used in substations to interrupt an arc and thereby protect a feeder.
2. List two types of substations.
3. Discuss three types of equipment found in substations.

Lesson 2: Substations---Equipment Identification

Introduction:

Due to the complexity and diversity, it is difficult to discuss every type of equipment that might be found in an electrical substation. By studying the reference materials, workers should be able to identify most of the major electrical equipment they will encounter in substations.

Objectives:

1. Discuss two safety factors associated with substations.
2. State how two pieces of substation electrical equipment perform their functions.
3. Discuss an electrical line inside a substation yard and two pieces of equipment attached to it.

Lesson 3: Power Transformers

Introduction:

The specific electrical tests and certification process required to take a substation power transformer from the manufacturer to online are many and varied. Substation workers are encouraged to learn the various tests it takes to certify a transformer in order to enhance their résumés.

Substation power transformers are typically the heaviest, largest, and most expensive pieces of equipment in an electrical substation and are expected to provide decades of quality service. Qualified Electrical Workers are expected to ensure that all equipment installed on the power transformer works properly.

Objectives:

1. State one test of a substation transformer's oil.
2. List two methods for cooling transformer oil.
3. Discuss how cooling the transformer oil allows for greater capacity.
4. Discuss the different voltages of substation power transformers.

Lesson 4: Substation --- Air Switches

Introduction:

There are several types of high-voltage air switches used in substations. The function of an air switch is stated in ANSI/IEEE Standard C37.100 as "a switching device designed to close and open one or more electrical circuits by means of guided separable contacts that separate in air." As the name implies, air, at atmospheric pressure, is the insulating medium between contacts when the switch is in the open position.

There are a variety of air switches developed to fulfill special requirements. The manufacturer's sheet provided with each type of switch should be consulted for proper installation.

The name "air-break switch" is interpreted by many Qualified Electrical Workers to mean that the switch is designed to open a circuit under full load; in fact, the opposite is true. All procedures should be followed prior to opening a switch to take the load off the circuit, and even then, some switches draw spectacular arcs due to the length of line or the size of transformer coil that is being isolated.

Objectives:

1. State three types of switches used in substations for isolating or grounding a line.
2. Discuss the method used by sulfur hexafluoride switches to open a circuit.
3. List three safety factors associated with operating switches in a substation yard.

Lesson 5: Voltage Regulators

Introduction:

Maintaining good voltage to the customer is important. Voltage fluctuates; therefore, equipment on the system is needed to regulate the voltage.

Objectives:

1. Understand the importance of maintaining good voltage.
2. Understand how voltage is affected by electrical system changes.
3. Explain how the voltage on a line can be regulated.

Lesson 6: Capacitors

Introduction:

Installing a capacitor on an electrical system has numerous benefits, mainly decreasing losses. However, installing a capacitor is not as simple as just putting it on the system. Improperly placing capacitors may result in adding to losses.

Understanding how capacitors work and why they are an important component of an electrical system is knowledge every Qualified Electrical Worker should have. The theory of capacitors is explained in the *AC Theory* textbook, accompanied by a discussion on reducing power factor explained in the Reference.

Objectives:

1. State two causes of system low power factor.
2. List the ways a capacitor functions.
3. Describe how a capacitor reduces power factor.

Lesson 7: Reactors

Introduction:

Reactors are used to improve the quality of power supplied to customers. Reactors limit inrush current that takes place during faults and when switches are opened and closed. By limiting inrush current, the customer is spared voltage swings, such as dimming and flickering lights. Reactors also protect substation equipment by keeping the current and voltage within their operating specifications.

Objectives:

1. List the application of reactors in substations.
2. State which type of reactor would be used on the end of a lightly loaded transmission line.
3. State the three major types of reactors used in substations.

Lesson 8: Rectifiers

Introduction:

Converting alternating current (AC) to direct current (DC) is a technology that is over 100 years old and is still used in applications from railroads to computers. However, in the electrical industry, using high voltage direct current (HVDC) for bulk power transmission has always been rare. There are over 70 HVDC systems worldwide but only 13 systems in the United States. The cost of building a converter (link) station is several times the cost of a conventional substation, which makes tapping off of a DC transmission line very expensive. However, the cost of acquiring new right-of-way and upgrading existing lines to meet demand is making DC transmission lines and converter stations more attractive to the industry.

The time will come when DC lines and stations will become commonplace. Substation technicians should be familiar with the history, uses, and future of rectifiers as used in the electrical industry.

Objectives:

1. List three reasons HVDC may become the preferred way of transmitting large amounts of power.
2. Discuss the function of a valve hall.
3. State one advantage of using DC instead of AC for transmission lines.

Lesson 9: Protective Equipment

Introduction:

A substation's power transformer is the largest and most expensive piece of equipment in a substation. Protecting a transformer that is meant to operate under all weather conditions for decades requires a variety of protective equipment ranging from electronic to a bare wire suspended between supports. Going into detail on any one of these protective devices is a lesson by itself. The four basic systems that can be found in almost every substation are presented with a brief overview as to purpose and function of each. Learning how different systems interconnect to protect the power transformer and how to maintain these systems is a large part of a substation technician's trade. A power transformer may cost several hundred thousand dollars and may be one of a kind, but the relay that protects the transformer can be quickly replaced and may only cost a few dollars.

Objectives:

1. List the two most common types of lightning protection used for substations.
2. State the three classes of lightning arresters used in substations.
3. State three mediums used in substation breakers to extinguish an arc.

Lesson 10: Lightning Protection

Introduction:

According to the National Weather Service, approximately 22 million cloud-to-ground lightning strikes occur every year in the United States, causing over $2 billion in property damage. A study conducted from 1959–1994 by the National Oceanic and Atmospheric Administration (NOAA) found the states with the highest number of cloud-to-earth lightning strikes are Pennsylvania, Kansas, New York, North Carolina, and Oklahoma, but all states were found to have their share of lightning strikes.

When lightning strikes a transmission or distribution line, the overvoltage lightning produces must be drained from the system to prevent damage. Lightning has the power to explode concrete, tear poles apart, explode transformers, and shatter insulators unless the line is properly protected. Properly installed lightning protection, in the form of lightning arrestors, helps direct the lightning safely to the ground, sparing equipment and customers the damage. There are several different types of lightning protection used in the industry to dissipate the excess voltage and current from the system.

Objectives:

1. Describe two characteristics of a lightning strike.
2. State three characteristics of lightning arrestors.
3. List two types of lightning arrestors used in different applications.

Level IV starts with a review of the applications of DC theory and is followed by lessons dealing with resistance, current, voltage, and power in combination circuits. The student will then compare DC to AC and be introduced to generators and the fundamentals of AC. The course concludes with a lesson on inductance and another on the causes and effects of voltage drop.

Lesson 1: Reviewing the Applications of DC Theory

Introduction:

Electrical theory principles and their functions will be reviewed. Understanding the basic principles and concepts learned in the study of DC theory are applied to the study of AC theory.

Basic DC theory calculations are reviewed, and there should not be any problems continuing with the study of AC theory. If difficulties are encountered in solving problems, a review of the information dealing with DC theory should help solve them.

Objectives:

1. Define voltage, current, resistance, and power.
2. Describe how voltage, current, and resistance function in series and parallel circuits.
3. State the basic Ohm's Law formulas as they apply to DC Theory.
4. Work a variety of DC Theory mathematical problems correctly, which will aid in the study of AC Theory.

Lesson 2: Understanding Resistance in DC Combination Circuits

Introduction:

The third type of circuit is the combination, or series-parallel circuit. In these circuits, there are components that are connected in series, as well as components that are connected in parallel. In these types of circuits, it is occasionally necessary to know how to use the rules that apply to "series-only circuits" as well as the rules that apply to "parallel-only circuits," depending on how the components are connected in the circuit.

In order to correctly understand combination circuits, each part of the circuit must be analyzed. A determination is made as to whether a part of the circuit is connected in series or in parallel, and then, the correct rules are applied to determine the operational characteristics of that part of the circuit. Many times, a combination circuit that appears to be quite complicated can easily be understood when it is redrawn. Advancing through the equivalency process may require redrawing the circuit more than once. Each time it becomes simpler, until finally, there is just one resistive source connected in series with the voltage source.

In combination circuits, the rules for resistance in series and in parallel may be applied to reduce the circuit to an equivalent resistance, which will have the same total current and resistive value as the original circuit. Additionally, branches of the combination circuit may be reduced in the same way to allow for proper analysis of the different parts of the circuit. To solve unknown values in a combination circuit, use series circuit rules for those sections of the circuit that are connected in series and parallel circuit rules for those sections connected in parallel.

There are four basic steps in reducing a combination circuit to its simplest form:

1. Redraw the circuit to show parallel and series combinations.
2. Solve for each simple parallel or series circuit.

3. Substitute the equivalent values for each simple parallel or series circuit into the original circuit.
4. Solve for the resulting series circuit.

Objectives:

1. Identify circuits that are classified as combination or series-parallel circuits.
2. Analyze components in a combination circuit to determine whether they are connected in series or parallel with other components.
3. Apply the rules learned for series and parallel resistors to reduce a circuit to its equivalent resistance.

Lesson 3: How Current Reacts in Combination Circuits

Introduction:

In series circuits, the current is the same in every component, while in parallel circuits, the current splits and follows two or more different paths through the circuit. In combination circuits, both types of currents are present.

It is important to know how to determine branch and circuit currents, as well as solve for unknowns in combination circuits. Remember to apply a systematic approach, using the principles of series and parallel circuits.

Objectives:

1. Apply Ohm's Law to determine the current through any branch or component of a combination circuit.
2. Determine which components will carry total circuit current in combination circuits.
3. Identify alternative current paths in combination or series-parallel circuits.

Lesson 4: How Voltage Functions in DC Combination Circuits

Introduction:

The current is the same in every component in series circuits, while in parallel circuits, the current splits and follows two or more different paths through the circuit. In combination circuits, it is easy to see that there are both types of currents.

It is important to know how to determine branch and circuit currents, as well as how unknowns are solved in combination circuits. Remember to apply a systematic approach, using the principles of series and parallel circuits.

Objectives:

1. Apply Ohm's Law to determine the voltage drop across components in combination circuits.
2. Calculate the total or equivalent resistance of groups of components in combination circuits.
3. Calculate current flow through components or through complete combination circuits.

Lesson 5: How to Calculate Power in DC Combination Circuits

Introduction:

As with the other types of circuits studied, the total power utilized in a combination circuit is the sum of the power dissipated in each of the individual components in that circuit, and it is also equal to the power developed by the "equivalent resistance" of the circuit.

Try to relate the problems solved here, involving power in series-parallel circuits, to on-the-job experiences. These principles are at work day in and day out.

And what about "wasted energy"? Energy that is lost or dissipated in the components of wiring systems (which are not designed to use power) is wasted energy. Heat generated in an undersized extension cord, or by a bad connection on a motor, is not only an indication of power lost in the system, but it is also a potentially dangerous condition. The principles that will be studied here are very important to the foundational understanding of how power reacts in combination circuits.

Objectives:

1. Calculate the total power consumed in a DC combination circuit.
2. Calculate the power consumed by a component, or group of components, in a DC combination circuit.
3. When given the power consumption, determine each circuit component's current, voltage, and resistance value.

Lesson 6: Comparing Direct Current to Alternating Current

Introduction:

Direct current (DC) is current that flows in only one direction. Current that changes direction periodically is known as alternating current (AC). Practical applications for each type of current are seen on the jobsite every day. The convenience of battery operated drills is courtesy of direct current. In addition, alternating current is what powers the temporary lighting so that work is not completed in the dark.

Both AC and DC have distinct advantages. However, when there is a need to transmit large amounts of power over long distances, AC is the preferred choice. The reason for this has to do with money. Transformers can step up AC voltages to very high levels. Knowing that power is equal to voltage times current, it is easy to see that by using a higher voltage, the same amount of power can be delivered at a lower current. The lower current results in less heat loss, which permits the use of smaller conductors for the transmission lines. Using smaller wires results in a significant cost benefit for the supplier which in turn makes electricity more affordable for the consumer.

The biggest single advantage of AC is that it can be transformed from one voltage to another; that is, a transformer can step voltage up or down. Higher voltages are better for transmitting electricity over long distances. This is because the higher voltage can transmit the same amount of power at a lower current value (remember that $P = EI$). Consequently, there is less heat loss (I^2R), and smaller, less expensive wire may be used. Higher voltages would be dangerous inside the home or the workplace; therefore, transformers are used to step the voltage down to lower, safer levels. DC also has some advantages; however, AC is used for the overwhelming majority of major electrical energy supply systems.

Objectives:

1. Identify the distinct characteristics of alternating and direct current.
2. Apply Ohm's Law to understand the advantage of using alternating current for power distribution.
3. Know the definition of terms used to express the characteristics of AC waveforms.
4. Understand how the values of AC waveforms are represented by the sine wave.

Lesson 7: Fundamentals of Alternating Current

Introduction:

An understanding of the principles of alternating current is necessary if one is to understand the operation of distribution equipment.

As an apprentice and as a Qualified Electrical Worker, most work is with the use of the sine wave, which is only a graph of instantaneous values of voltage in an alternating-current system. These values are what they are because a rotating machine generates the voltage.

Remember, the current created by a generator is the result of the electromotive force (EMF) developed by the generator. Voltage is defined as electromotive force. It is force that pushes the electrons through a wire and is often referred to as the electrical pressure.

Objectives:

1. Describe how an AC waveform can be represented graphically as a sine wave.
2. Define the terms cycle, frequency, period, alternation, sine wave, and instantaneous values.
3. Mathematically calculate values of AC parameters including effective value/voltage, average value/voltage, maximum value/voltage, and peak-to-peak values/voltages.

Lesson 8: An Introduction to 3-Phase Systems

Introduction:

In the power generation, transmission, and distribution field, there is no such thing as a single-phase system. All power is generated and handled as 3-phase power. Often in distribution work, Qualified Electrical Workers will work with one phase and a neutral and refer to this as single-phase, but this is really part of a 3-phase system. Three-phase systems are utilized due to their efficiency and economy. Understanding 3-phase systems and their current and voltage relationship is essential to working with 3-phase systems.

Objectives:

1. Describe the relationship between the voltages or currents in different phases of a 3-phase power system.
2. Explain the physical differences between wye and delta 3-phase connections.
3. Calculate current and voltage parameters of both wye and delta 3-phase systems.

Lesson 9: Understanding How a DC Generator Works

Introduction:

Due to its nature, direct current has some applications that make it superior to alternating current. DC can be used to drive motors for precise control. DC motors are used for many industrial applications, such as the drives for manufacturing equipment, printing presses, metro car propulsion, and locomotives.

Alternating current is normally available at most sites. When DC is required, Qualified Electrical Workers will often encounter DC generators to provide the desired power.

Objectives:

1. Identify the major parts of the DC generator.
2. Describe the principles and operation of the DC generator.
3. List the different types of losses in a generator.

Lesson 10: Understanding the Design and Function of AC Generators

Introduction:

A review of the DC generator explains that all rotating machinery used for generation produces a sine wave and alternating current. The DC generator uses a commutator, so that the current is always removed from the windings, and so that the polarity remains the same. The commutator is also a limiting factor in DC generation in that it cannot commute very large currents necessary for modern society.

Most electrical power produced today for the world economies is alternating current. Most of this electricity is produced as 3-phase power.

Objectives:

1. Describe the operation of AC generators.
2. Identify key parts of the AC generators and their functions.
3. Mathematically determine the relationships between RPM, frequency, and the number of poles.

Lesson 11: Introduction to Inductance

Introduction:

Note that alternating current behaves differently than direct current, and Qualified Electrical Workers need to know why. For example, a transformer with no load on the secondary draws some current in the primary. This is because of the inductance of the transformer coil.

It is important to understand inductance from the standpoint of its physical characteristics as well as how these characteristics affect electrical properties. This knowledge lays the groundwork for solving problems in AC circuits and understanding the operation of transformers and other inductive devices.

Objectives:

1. Understand the principles of electromagnetic induction.
2. Define inductance, self-inductance, and mutual induction.
3. Discuss the physical factors that affect inductance.

Lesson 12: Voltage Drop

Introduction:

Customers who receive electrical energy must receive power at an acceptable voltage for their equipment. This is not as simple as it may seem, because every foot of wire and every piece of apparatus between the generating station and the customer represents a line loss or voltage drop. In order for one to comprehend how to compensate for voltage drop, voltage drop and its effects must first be understood.

Not all voltage drops are undesirable. A 120-volt drop across an incandescent lamp is necessary to heat the lamp to a temperature that causes light to be emitted; this is a useful voltage drop. However, if there is a five-volt drop caused by the wires leading to the lamp, the customer still pays for the five-volt drop but derives no benefit from it. Excessive voltage drops are undesirable because they are considered a loss and may be harmful if heat is produced and weakens the insulation.

Objectives:

1. Identify the variety of conditions that can affect voltage drop.
2. Make calculations concerning line loss.
3. Discuss how wire size affects voltage drop.

Level V begins with a general safety awareness lesson, which is followed by a lesson on substation applications of lock-out/tag-out. The next lessons are on single-phase transformers and cover an introduction to transformers, their construction and characteristics, and how they operate. Single-phase connections are also reviewed. The lessons dealing with the installation of transformers help the students understand some of the pit-falls they may face when working with single-phase transformers. This course concludes with two lessons on the use of test instruments.

Lesson 1: Safety Awareness – On the Job

Introduction:

The subject matter provided in the references for this lesson is intended to develop safety awareness on the job, which should help to shape proper working attitudes that are positive and safety oriented. It is not intended to replace or conflict with an employer's safety directives or work rules. It is to be used as a reference to broaden views of the subject and to assist those who may not be exposed to organized safety programs.

Objectives:

1. State the need for everyone on a job site to work in an alert and safety-conscious manner.
2. Identify positive, safe attitudes as well as negative, dangerous ones.
3. Explain common safety practices employed in the line building industry.
4. Discuss the possible negative repercussions of an accident.

Lesson 2: Lockout/Tagout – Substation Applications

Introduction:

Qualified Electrical Workers are frequently required to work on apparatus that is necessary to be de-energized before work begins. As studied previously, a formal approach may be used by electrical utilities. In addition, it is necessary to review OSHA lockout/tagout requirements and how they apply to the electrical industry to protect workers from the unexpected startup or release of electrical energy. These regulations also apply to other energy sources such as pneumatic, hydraulic, mechanical, thermal, and chemical.

Objectives:

1. Describe the requirements for training under the lockout/tagout program.
2. Identify the elements necessary for all lockout/tagout programs.
3. Differentiate between lockout and tagout in use and in application.

Lesson 3: Introduction to Transformers

Introduction:

Electrical distribution transformers and Qualified Electrical Workers have a history that goes back over 110 years. Given this long history, improper transformer connections and difficulty troubleshooting transformers remains the most often-cited reasons for damage to customer property.

The transformer makes the electrical industry possible with its ability to step up voltage at the power plant and step it down at a substation or at the customer's location. To understand transformer connections and the voltages taken from them, it is important to understand the basic principles that make a transformer work.

Objectives:

1. Identify different types of transformers.
2. Explain how a transformer coils and core function.
3. Describe the basic theory of electromagnetic induction.

Lesson 4: Transformer Construction

Introduction:

Memorizing which wire goes to which transformer bushing for a certain voltage adds to the mystery of transformers and can sometimes lead to Qualified Electrical Workers being hurt when a different method of wiring is encountered. A careful study is needed to dispel any misunderstandings surrounding transformer installations and connections. An understanding of what is inside a transformer tank is fundamental in giving a Qualified Electrical Worker the necessary information to be able to work with transformers in a safe and skillful manner.

Objectives:

1. Describe factors that contribute to transformer heating.
2. Draw and explain the internal leads brought out from transformer coils.
3. State factors that contribute to transformer losses.
4. Describe, identify, and explain the material and components used in a transformer.

Lesson 5: Transformer Information Characteristics

Introduction:

Knowing what the information on a transformer nameplate means can be the difference between a routine job and a disaster. Manufacturers and electric companies keep extensive records on every transformer, but it is up to the Qualified Electrical Worker to properly interpret the information given to him or her. Transformers may look identical, but only by looking at the nameplate can one be sure of what is in the can.

Objectives:

1. Describe five items found on transformer nameplates.
2. State coil capacity of transformers connected in series and parallel.
3. Differentiate between internal transformer coils in series or parallel.

Lesson 6: Vectors

Introduction:

Knowing how to draw a 3-phase bank using vectors (also called phasors in some parts of the industry) is an essential tool every Qualified Electrical Worker should have. The terms *wye* and *delta* and the combination of connections in which transformers can be arranged represent the banks Qualified Electrical Workers will be working with throughout their careers. With a firm understanding of vectors, one can use the vector drawings as a wiring diagram when troubleshooting a 3-phase bank.

Most apprentices draw a 3-phase bank using rectangles to represent transformers. With a good understanding of vectors, it will not be long before a simple statement such as, “wye-delta, corner grounded, 480-volt, 30° displacement” will provide a Qualified Electrical Worker with all the information needed to build the required bank.

Objectives:

1. State the purpose of vectors as used in electrical drawings.
2. Figure the phase-to-phase voltage on a Wye connected bank.
3. Draw a vector diagram for a 3-phase bank connected wye-delta 0° displacement.

Lesson 7: Transformer Operation

Introduction:

Electrical transformers are a key piece of equipment used to provide electrical power to customers. To have a long, safe, and successful career as a Qualified Electrical Worker, it is important to have a firm understanding of how transformers operate.

Get into the habit of inspecting every transformer the crew takes out or removes from a job. The Foreman and Qualified Journeyman Electrical Worker are valuable resources in all aspects of training, but especially in learning to understand transformers.

When properly selected and installed, transformers will deliver many years of effective service. It is only when Qualified Electrical Workers become complacent about transformers that accidents happen and the customer’s equipment is damaged.

Objectives:

1. Differentiate between the functions of a potential and a current transformer.
2. Describe and apply transformer ratios.
3. Discuss Michael Faraday’s contribution to the invention of the transformer.
4. State why the transformer will not work on direct current systems.
5. Discuss transformer winding taps.

Lesson 8: Transformer Polarity/Connections

Introduction:

Qualified Electrical Workers should have learned about transformer operation in regard to winding ratios as they affect voltage and current. Next, it is necessary to learn about another characteristic of AC transformers: polarity.

Transformer manufacturers perform extensive tests to ensure that a transformer nameplate shows the correct polarity. Keep in mind there are older transformers in the field, which may be either additive or subtractive polarity or may have a nameplate that is missing or damaged.

This topic may be brief but it is still vitally important. Knowing the polarity of a transformer will prevent damage to equipment and injury to personnel.

Remember: Transformer windings work both ways between primary and secondary windings. Ordinary transformers can either step-down or step-up voltage, depending on which side of the transformer voltage is applied. Polarity tests should only be performed after a careful review of the safety procedures involved.

As always, nothing takes the place of hands-on training. Foremen and Journeymen Electrical Workers are invaluable resources in all aspects of training, but especially in learning the importance of knowing the polarity of a transformer.

Objectives:

1. Explain safety procedures prior to paralleling single-phase transformers.
2. Describe the internal polarity of a single-phase transformer.
3. Diagram the proper way to set up equipment to check polarity on a single-phase transformer.
4. State industry standards as they apply to transformer polarity.

Lesson 9: Tap Changers and Tap Changer Operation

Introduction:

When 2,400 volts was the average distribution primary voltage, transformers usually had taps to compensate for primary voltage drop. Due to the low primary voltage, almost every transformer was adjusted to meet a particular customer's need. This worked well for many years until demand grew and customers demanded power quality as well as quantity. To meet the demand, electrical systems have been converted so that 7,200 volts phase to ground and above are now common. Today, distribution transformers with taps are a rarity, as higher voltages and better voltage regulators, capacitors, and relays have met the demand for power quality.

There are still older transformers in the field with taps. For example, an engineer may order a new transformer with taps because of a customer's location, and every substation transformer is equipped with taps. Qualified Electrical Workers need to have an understanding of tap operation for the sake of their own safety and in case their company still uses tapped transformers.

The confusion that arises when dealing with taps is that most Qualified Electrical Workers assume that the lower the percentage of primary taps, the lower the secondary voltage will be. In fact, the closer the number of turns between the primary and the secondary, the higher the secondary voltage. If one has a 1:1 ratio, voltage in is equal to voltage out. So, when the primary windings are reduced from 100% to 95%, the secondary voltage is raised by 5% because the ratio between the windings is now closer.

Objectives:

1. Explain how a transformer's output voltage is changed using taps.
2. Describe the equipment needed to check load.
3. Demonstrate how to figure load on a single-phase transformer.

Lesson 10: Installing Transformers

Introduction:

One of the most common tasks assigned to a line crew is changing out or building new transformer stations. A quick check of the transformer prior to leaving the yard will avoid embarrassing situations such as hanging a 240/480-volt transformer when a 120/240-volt transformer was required. Knowing the employer's standards for building a transformer station is another aspect of the work one should strive to be an expert at. A transformer station built incorrectly can be dangerous to the Qualified Electrical Worker who has to troubleshoot it at a later date.

On-the-job training is fundamental to learning about transformer installations. Foremen and Qualified Journeymen Electrical Workers are always valuable resources in all aspects of training, but especially in correctly selecting, fusing, and installing transformers.

Objectives:

1. Draw secondary terminal connections for a single-phase transformer.
2. State the pre-installation checks to be performed prior to installing a transformer.
3. Describe bird-guard function as used on transformers.
4. Discuss transformer fusing as it relates to the protection of a transformer.

Lesson 11: Single-Phase Transformer Connections

Introduction:
The single-phase transformer is not only the most commonly used transformer in the electrical industry but is also the most versatile. It is important to the career of a Qualified Electrical Worker that he or she not only learn which wire goes where, but what is going on inside the transformer. The coils release the voltage they are designed for, and the arrangement of the leads on the secondary bushings allows one to utilize that voltage. Transformer coils can work while using very few wiring diagrams. The reason fewer wiring diagrams are used is that many companies have their own way of making transformer connections. If Qualified Electrical Workers do not have a clear understanding of coil function, they might be at a loss when faced with wires coming out of secondary bushings in a fashion other than they may be used to.

Objectives:
1. Diagram three connections that can be made with a single-phase transformer.
2. Explain the difference between series and parallel coils.
3. Name safety checks to be made prior to paralleling transformers.

Lesson 12: Transformer Protection

Introduction:

Knowing the way a system is coordinated related to transformer protection is essential for a Qualified Electrical Worker. Proper transformer fusing not only protects the transformer but also coordinates with tap fuses, which coordinate with all other system equipment. The various methods used to protect a transformer range from proper fusing to an awareness of how loading affects transformer capabilities. Knowing how a transformer operates and how to connect a transformer is useless unless the Qualified Electrical Worker knows how to protect it.

Although CSP transformers are seldom encountered by most Qualified Electrical Workers, they are extensively used by rural electric cooperatives, and may prove beneficial to Qualified Electrical Workers to know how a CSP protects itself.

Objectives:

1. Describe the function of fuses as they relate to protecting a transformer.
2. Discuss underground transformer fuse protection.
3. Discuss the effects of transformer overheating.
4. Explain the effects of transformer loading on the operation of a transformer.

Lesson 13: Introduction to Test Instruments

Introduction:

Measuring quantities is not new technology. People have been developing standards and methods for taking measurements for thousands of years. Modern culture uses a sophisticated system of benchmarks and test instruments to describe the physical world. Today, almost any task requires the use of measurement concepts, although some trades, particularly the electrical trade, use measuring tools in nearly every procedure. Qualified Electrical Workers must be knowledgeable in the applications, safety considerations, procedures, potential errors, proper maintenance, and standards and procedures of the test instruments they use.

Although Qualified Electrical Workers can use test instruments ranging from relatively simple to very complex, all demand a thorough understanding of the instrument and its safety requirements.

Objectives:

1. State several precautions required to properly care for test instruments.
2. Discuss the historical development of measuring standards and methods.
3. Discuss the use of safety labels, procedures, equipment, and standards as they apply to the use of test instruments.
4. Identify the causes of common measurement errors and the techniques used to reduce them.

Lesson 14: General Use Test Instruments

Introduction:

Many test instruments are highly specialized pieces of equipment that are used only by those trained in specific fields. However, there are several types of common test instruments that can be used safely by anyone and can provide useful information in a wide variety of situations. These include various types of instruments to indicate or measure voltage, current, resistance, or a combination of these and other quantities.

Technicians must be knowledgeable of the general procedures on how to safely use voltage, current, and resistance test instruments by themselves as tools for diagnosing relatively simple electrical problems, and as a starting point in complex situations before more specialized equipment is required. The relative advantages and disadvantages of each test instrument are important for the technician to understand when selecting the right instrument for a particular job.

These general use test instruments are so fundamental to most types of electrical and maintenance work that they can be found almost anywhere. Understanding what they are and how they are used is important to solving problems in the field.

Objectives:

1. Identify the different types of voltage and current test instruments and their relative advantages and disadvantages.
2. Understand how to safely use various voltage or current test instruments to identify electrical power problems.
3. Understand the different types of voltage and current and the terminology used to describe them.
4. Identify the different types of multimeters and understand how their features are useful in troubleshooting.
5. Understand the concepts of resistance and continuity and safely use an ohmmeter or megohmmeter.

Level VI starts with a review on how to conduct transformer load checks. Three-phase connections and voltages are covered and the lessons on single-phase transformers wrap up with information on ferroresonance and the specific hazards a substation technician may encounter when working with transformers. The next lessons include topics on step and touch potentials, equipotential zone grounding, and how to test ground (earth) resistance. This course concludes with two lessons that discuss subjects that substation technicians will be dealing with on a regular basis: power factor and power harmonics.

Lesson 1: Conducting Transformer Load Checks

Introduction:

Understanding how transformers work is not only a safety issue, but can also save employers a lot of the money they spend on equipment, wages, and benefits. One reason so many transformers are brought into the warehouse is because many crews do not know how to troubleshoot a transformer station. They decide it is easier to change out a transformer than to take the time to pinpoint the problem. Unfortunately, the problem with the transformer remains after the change-out, and it is left for another crew or a troubleshooter to solve.

One skill that separates one Qualified Electrical Worker from another Qualified Electrical Worker is his or her ability as a craftsman to solve problems in the field. Knowing how to conduct transformer load checks will allow the worker and the engineer to make intelligent decisions and will distinguish them from the Electrical Workers who repair by replacing.

An apprentice should get into the habit of figuring load on every transformer he or she installs or troubleshoots. The method for checking a load is something Qualified Electrical Workers will use throughout their careers.

Objectives:

1. Determine the equipment needed to check load on a single-phase transformer.
2. Demonstrate how to figure load on a single-phase transformer.
3. Calculate the kilovolt-amperes being drawn from a single-phase transformer.

Lesson 2: Transformers – 3-phase Connections

Introduction:

Single-phase transformers can be banked to provide 3-phase power. Three of the six basic transformer bank types will be analyzed: the wye-wye, delta-delta, and open-delta–open-delta bank types. The wye and delta laws will be used to calculate voltages across points in transformer banks and to determine currents through various transformer bank components. An introduction to banking with phasors is presented. Electrical vector line drawings of transformer banks are included with the schematics to deepen an understanding of bank connections.

Objectives:

1. Apply the wye and delta voltage and current laws to banking single-phase transformers.
2. Calculate full load currents at various points in wye-wye and delta-delta banks.
3. Identify angular displacements and vector line drawings of wye-wye and delta-delta banks.

Lesson 3: Transformers – 3-phase Voltages

Introduction:

The higher voltages available on the modern distribution grid are the result of greater load density and reach. The evolution from single-phase to delta three-phase, and finally the four-wire wye systems common today will be presented. The advantages and disadvantages of system types and voltages are a part of this lesson.

An understanding of the various voltages and circuit system types is the foundation of transformer training. Transformer banks can only be properly installed or maintained by trained professionals like you.

Objectives:

1. Explain voltages across and currents through transformer coils and lines in delta systems.
2. Explain voltages across and currents through transformer coils and lines in wye systems.
3. Discuss the advantages and disadvantages of higher voltage distribution systems.
4. Explain the advantages of poly-phase systems.

Lesson 4: Specific Hazards Working with Transformers

Introduction:

A careful check prior to entering a work zone and knowledge of some of the dangers involved can eliminate injuries to Qualified Electrical Workers while working on transformers. A careful study of the hazards involved will provide some of the tools needed to stay safe while still doing a quality, craftsman-like job.

Objectives:

1. Explain safety procedures prior to working on transformers.
2. Describe how to avoid back-feed.
3. List several items to look for prior to energizing a transformer.

Lesson 5: Ferroresonance

Introduction:

The term ferroresonance (ferro-iron, resonance-intensifying sound) first appeared in the industry in 1920. Most substation technicians will never deal directly with ferroresonance, but they will probably deal with the effect of ferroresonance: overvoltage. Ferroresonance refers to an overvoltage that occurs in distribution networks that contain transformers (inductive component) and power cables (capacitive component), and usually occurs during switching of 3-phase banks. The resulting overvoltage, as much as five to ten times primary voltage, may appear at the open point and can cause failures in transformers, cables, and arresters. Ferroresonance has been known to occur at substation power transformers when an isolating switch malfunctions, but this is rare.

There have been cases when a substation technician has been called in because it is assumed that the overvoltages are coming from the substation. It is important that every substation technician be familiar with ferroresonance in case he or she is called in to help troubleshoot a problem of overvoltage. Anytime there is overvoltage damage and there are ungrounded wye-connected 3-phase banks in conjunction with underground cable, suspect ferroresonance. It is important to be familiar with the phenomenon of ferroresonance, its cause, its effects, the conditions under which it occurs, and how to prevent it from happening.

The word "neutral" is used in the reference materials to mean the wire that ties the three H_2 terminals on the high side of a floated wye 3-phase bank. Other names for this wire include: primary tie, floater, ungrounded phase, common, and floating phase.

Objectives:

1. Discuss what conditions must be present for ferroresonance to occur.
2. State one measure that can be taken on an existing transformer bank to prevent ferroresonance.
3. List two pieces of equipment that might fail because of ferroresonance overvoltage.

Lesson 6: PPG – Grounding in Substations

Introduction:

Substations present a unique grounding situation. Substations contain many objects that can be used for connecting personal protective grounding equipment. However, seldom is an entire substation deenergized. Because of the closeness of the spacing between energized and de-energized items, induced voltages and currents are common, and the fault current levels are typically much larger than at a remote work site. These larger fault current levels require larger clamps and cables, which are heavier and more difficult to use than ordinary grounding equipment used by Qualified Electrical Workers.

In substations, the magnitude of fault current is a major consideration. The mechanical forces that result from such currents may physically break the clamps before any adverse effect from the heating due to current flow is seen.

Objectives:

1. Recognize the different grounding requirements between substation work and remote site work.
2. Know the importance of placing the grounds close to the worker.
3. Be able to recognize the hazards from the current and voltages present.

Lesson 7: PPG – Step and Touch Potential

Introduction:

Step and touch potential are two different, yet similar hazards. They both involve a Qualified Electrical Worker's body bridging across a hazardous difference of potential. Step potential involves the worker's feet making the connection. Touch potential involves the worker making the connection from hand to foot. Both hazards result from a current flow through the earth, and the related voltage drop across that part of the earth's resistance.

Step potential may be large or small. Touch potential is often quite large and very hazardous. Both are a result of the worker's position in relation to the point of contact where the current enters the earth.

Objectives:

1. Understand both step potential and touch potential, and the difference between them.
2. Understand the protection methods available for these hazards.
3. Understand that contact with the earth is not always $V = 0$.

Lesson 8: PPG – Equipotential Zone Grounding

Introduction:

Qualified Electrical Workers are closest to the work done in the electrical industry, and they are the ones most likely to come into contact with a line that can become energized. It is up to every Qualified Electrical Worker to maintain focus and to remember the things that they have been taught that will help protect them as they work.

Bracket grounding is used as part of equipotential grounding, but these grounds are trip grounds that protect a worker by making sure that protective devices operate in case the line is energized. The equipotential method (personal ground) of grounding has been shown to be the method that offers the best protection. Equipotential grounding uses a cluster bar, which is connected to the grounding scheme by providing an electrical contact around the pole. If the line should become energized, the cluster bar maintains the equipotential voltage difference above the bar.

When using personal grounds, a connection to earth makes no difference if the grounding equipment is sized correctly and a cluster bar is properly connected. If an earth connection is to be established, do not use the pole ground because it might fuse (fail) under fault current. The equipotential method of grounding is the recommended method to use whenever possible.

Objectives:

1. Define an equipotential zone.
2. Recognize the benefits of an equipotential zone over other methods of grounding.
3. Use your equipment to establish an equipotential zone of protection.

Lesson 9: Testing Ground (Earth) Resistance

Introduction:

There is an old saying about electrical grounds: All electrical grounds are earth, but not all earth is an electrical ground. This can be verified by any Qualified Electrical Worker who has found a primary phase lying on the ground, still energized. Because of high ground resistance or poor system grounding, not enough current is flowing to operate the protective equipment. Good system grounding has many benefits, such as reduction in system noise, lightning protection, personnel safety, and helping to control unwanted voltages, currents, and power surges. Without proper low-resistance grounds, protective devices will not sense the current flow involved when a phase does hit the ground.

It is important to be familiar with the subject of testing ground (earth) resistance and the two testing methods most commonly used in the electrical industry.

Objectives:

1. State three factors that influence the resistivity of the earth.
2. State two regulations or standards pertaining to ground rods.
3. List two methods used to measure or improve resistivity of ground rods.

Lesson 10: Substation Inspection

Introduction:

Electrical substations and switching yards are some of the most expensive installations in the electrical grid. One of the most effective ways to safeguard these installations is to conduct thorough periodic inspections. There is not one form that can cover every piece of equipment in all substations or switching yards. Each installation should have an inspection form that has been developed specifically for that installation. Substation technicians are normally the workers that perform periodic inspections on these installations and every technician should become an expert at this vital task.

It is a common practice in the electrical industry to refer to substations and switching yards as stations, installations, or substations. For the purposes of this discussion, *substation* is used to mean any yard that is to be inspected.

Objectives:

1. State two items associated with substation fences that should be checked.
2. State the maximum temperature allowed for a substation main transformer.
3. List three items that should be checked in a substation battery room.

Lesson 11: Substation CTs, VTs, and PTs

Introduction:

Properly metering and controlling the voltage and current in a substation requires many sensory instruments that change a condition, such as voltage or current, to a value or signal that can be measured. Potential transformers (PTs), also called voltage transformers (VTs) change or transform line voltage to a proportionally lower voltage for measurement. Current transformers (CTs) transform line current to a proportionally lower current for measurement.

The signals from CTs and PTs are typically sent to measuring equipment and controlling equipment. When controlling equipment detects a signal that is different from a preset value, it provides a signal that operates to protect or correct the system. A CT signal may cause a circuit breaker to open while a signal from a PT may cause a tap changer to operate, bringing the voltage back to an acceptable value.

The reference materials in this lesson cover transformer-rated meters that would be used for individual customers. Substation technicians may not normally deal with transformer-rated meters, but the principles involved with these meters are basic to understanding substation CTs and PTs. Having a clear understanding of voltage and current sensory devices is an important part of training as a substation technician.

Objectives:

1. List three types of current transformers in common use.
2. State the function of CTs and PTs in a substation.
3. State the main safety issue when working with CTs.

Lesson 12: Power Factor

Introduction:

An electrical system works most efficiently when the power factor is high. Qualified Electrical Workers should be familiar with what is meant by a high power factor and with the efforts made to control the power factor in an electrical system.

Objectives:

1. Understand the electrical influences that make up a power factor.
2. Explain the benefits of keeping the power factor of a circuit high.
3. Understand the measures taken to control the power factor in a circuit.

Lesson 13: Power Harmonics

Information:

To supply quality power, an electric utility must deliver a constant sinusoidal voltage and current at a constant magnitude throughout the power supply system. With the increased popularity of electronic and other non-linear loads, there are a lot of interfering waveforms of different frequencies (harmonics) distorting the fundamental 60-hertz sinusoidal waveform. These harmonics result in distorting voltages and currents that adversely affect the distribution electrical system.

Harmonic currents can create problems such as equipment heating, communications interference, nuisance fuse and breaker operations, and conductor heating.

Objectives:

1. Understand the basics of harmonic interference.
2. Recognize harmonics as a possible source of customer complaints.