PDHonline Course E184 (1 PDH)

Power Plant Electrical Distribution Systems

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2020

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Power Plant Electrical Distribution Systems

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Course Description

This one hour course provides an introduction to the design of electrical distribution systems found in electrical power generation plants. The type of equipment utilized in the electrical distribution systems is discussed in terms of its design, function, role and backup capabilities. A short quiz follows the end of the course material.

Learning Objectives

Upon completion of this course one should be able to understand the role of the following equipment in a power plant distribution system: Main electrical generator, isolated phase bus duct, step-up transformer, station auxiliary transformer, non-segregated phase bus duct, station startup transformer, medium voltage switchgear, secondary unit substations, and motor control centers. Along with the role of each type of equipment, one should understand how the equipment is utilized to provide reliable power to the station.

Introduction

Modern power plants have an extensive electrical distribution system to provide reliable power to all of the support equipment in the power plant. The utility operating the power plant is in the business of generating electrical power twenty four hours a day, seven days a week. Since electrical power can not be economically stored the plants must be online to produce power when the electrical demand is present. In this regard, the power plants must be highly reliable. Backup power sources within the plant must be ready to supply needed power within moments. This course will provide an overview of these systems and the relationships between the different systems.

Course Content

Large electrical generation power plants (power stations) today come in all varieties. Some of the plants utilize fossil fuels such as coal, oil and natural gas to fire boilers as tall as a twenty five story building. The boilers produce the massive amounts of steam necessary to spin large turbines connected to electrical generators. Nuclear plants produce the same large amounts of steam but use a nuclear reactor as the source of heat. Regardless of the type of plant,

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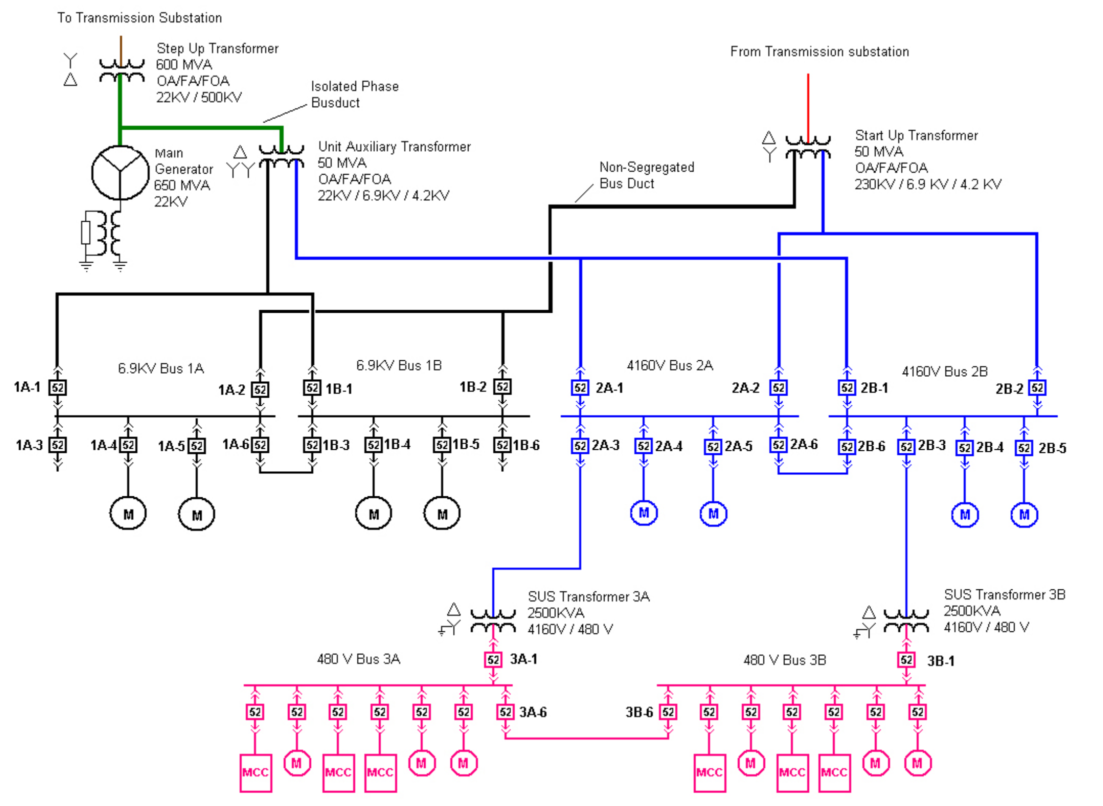
the stations auxiliary components require substantial electrical distribution systems to provide reliable power. In the fossil plant these components include large circulating water pumps that provide cooling water to the turbine condenser, large fans that move the combustion air through the boiler and feedwater pumps that circulate the water through the boiler. Nuclear plants have similar circulating water pumps and feedwater pumps. In addition, the nuclear plants have emergency equipment that supports safe operation of the reactor. Both nuclear and fossil plants have large battery banks that provide backup DC power to the plant controls. These batteries are kept charged by large battery chargers.

The designs of the electrical distribution systems are quite similar from plant to plant. Even the nuclear plants systems are somewhat similar although they have much more redundancy built into the designs. The reason the plant designs are generally the same is because utilities have perfected these plant design over the last century and continue to use what is a proven approach. When the nuclear plants came along in the 1960s and 70s, the existing proven electrical designs were simply modified slightly and used in the nuclear plant designs.

The following one-line diagram shows a typical power plant electrical distribution system.



POWER PLANT ELECTRICAL DISTRIBUTION ONE - LINE DIAGRAM

The one-line diagram shows a simplified arrangement of the primary electrical components. A more detailed discussion of each component follows this narrative.

Starting at the upper left corner of the diagram, a circle symbol with a Y in the center represents the plant main electrical generator. The output of the generator is connected to the isolated phase bus duct shown as a green line. The isolated phase bus duct connects the output of the main generator to two other components: the step-up transformer and the station auxiliary transformer.

The Step-up Transformer increases the generator voltage from 22,000 Volts or 22KV (Kilo-volts) to the transmission voltage of 500KV in this example. The transmission voltage varies from utility to utility and from plant to plant and is really a function of the transmission design that already exists (i.e. if a plant is built near an existing transmission line of a certain voltage, typically that will be the voltage chosen for the step-up transformer).

The Unit Auxiliary Transformer is the power transformer that provides power to the station's auxiliaries during normal operation. This transformer is connected directly to the Main Generator and as such will provide the cheapest power for the station use since any power from the transmission lines has losses associated with it due to the line losses and transformer losses from whatever step-up transformer provided that power. This Unit Auxiliary Transformer (UAT) is a three winding transformer having one primary winding rated 22KV and two secondary windings rated 6.9KV and 4.2KV. This allows the transformer to power two different voltage level buses in the plant.

The UAT's secondary windings are connected to the Non-segregated Phase Bus Duct or (Non-seg Bus). This bus work conveys the power to the different medium voltage switchgears located in the plant. In this plant design there are two sets of switchgear buses rated at 6.9KV and 4160V. Each 6.9KV bus (shown in black) can be energized from the Unit Auxiliary Transformer. The same is true for the 4160V switchgear.

There is another transformer shown in the drawing. The Start-up Transformer is energized from an incoming transmission line rated at 230KV. This transformer is also a three winding transformer and can feed all four of the switchgear lineups. This transformer is used to power the plant equipment while starting the unit up from cold conditions (i.e. no fire in the boiler).

All plants utilize a numbering scheme for their switchgear and circuit breakers. The scheme utilized here is as follows: The first digit of the number refers to the voltage level of the bus. A 1 is for 6.9KV, a 2 is for 4160V, and a 3 is for 480V. The second character of the numbering scheme is a letter, either A or B and stands for which bus you are connected to, of the two buses at that voltage. A breaker with the characters 2B would be on the B bus of the 4160V switchgear. The next character in the designator is simply the breaker number. Notice that similar functioning breakers are usually assigned the same breaker numbers. Breaker 1A-1 and 1B-1 are both the incoming supply breakers from the Unit Aux Transformer and Breakers 1A-2 and 1B-2 are the incoming supply breakers from the Startup Transformer.

The remainder of the one-line diagram reflects the low voltage system which is operated at 480V. This system is supplied by breakers from the 4160V bus and the voltage is stepped down to 480V by the 4160V/480V transformers shown on the drawing as SUS Transformer (Secondary Unit Substation).

The electrical distribution system shown on the one-line diagram is typical for most plants for the configuration as shown. The number of switchgear buses will vary along with the voltages. The reasons for this will become more clear as the text continues with the detailed system descriptions.

1. Main Generator

The generator produces the electrical power the utility is in business to produce and sell. The three primary components of the generator are the rotor, exciter, and stator.

Rotor: The rotor on the main generator is composed of a steel shaft to which a field winding has been added. This shaft connects to the main turbine shaft and rotates at the same rotational speed as the turbine. The field winding is located in slots machined into the rotor. When DC current is passed through the field windings, the rotor forms an electromagnet with North and South poles. The resultant magnetic flux rotates through the coils of the armature (in the stator) inducing a voltage. The number of North and South poles depends upon the machine design. Some rotors have two pole designs (a single North pole and South pole) while others have a four pole design (two North and two South poles).

The rotor has a fan mounted on each end of the shaft. This fan is used to force gas into the generator for cooling. The gas used is hydrogen due to its heat transfer capability.

Exciter: The exciter provides the DC current which is provided to the field windings. The exciter output can be varied to control the armature voltage. This is done by varying the amount of DC current to the field windings and thus varying the power of the rotor field; thus, the amount of voltage induced in the armature windings (stator) is changed.

The exciter is typically a self-excited AC generator mounted on the same shaft as the rotor and turbine. Its output is rectified through a series of power diodes providing a DC current for the rotor field windings. Depending on the manufacturer, the exciter either uses collector rings and brushes to pass the DC current to the rotor (General Electric machines). Westinghouse generators use a brushless exciter system.

Stator: The Stator has two primary parts: the stator core and the armature windings.

> The core is constructed out of donut shaped laminated iron alloy sheets that have slots around the inner circumference. The stator core has a dual purpose of supporting the armature windings and concentrating the magnetic flux around the conductors of the armature.
>
> The armature windings for the generator are located in the stator core slots. The induced voltage from the rotating field produces current in the conductors. This current is large in magnitude creating significant heating due to I^2R losses (the heat produced in a conductor is equal to the current times itself times the resistance of the conductor). In order to remove this heat the conductors are hollow and cooled with either hydrogen gas or water depending upon the machine design.

Utilities generate three phase power so there are three armature windings in the machine producing three voltages which are 120 degrees apart in phase.

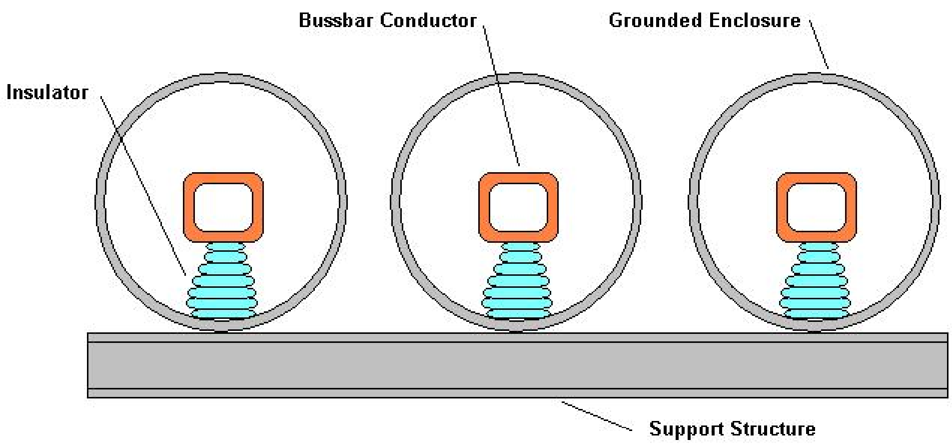
The armature leads exit the generator at the bottom and pass through cubicles with potential transformers (PT) and current transformers (CT) for metering and protective relays   In addition, the generator neutral is brought out of the machine into a separate cubicle. In the neutral grounding cubicle the grounding equipment and protective relays are located. There are a variety of ways to ground a generator neutral. In this example a ground transformer and resister are used. The purpose of the grounding equipment is to provide a means for monitoring the current in the neutral with protective relays.

From the PT and CT cubicle the generator output connects to the Isolated Phase Bus Duct.

2. Isolated Phase Bus Duct

Isolated Phase Bus Duct (Iso-Phase) is used to connect the high voltage and high current output of the generator to transformers that either transform the voltage higher for the transmission of the power over the utility transmission grid or steps the voltage down for use in the station. The picture below shows a section of Iso-Phase Bus where it is connects to an auxiliary transformer.

The sketch below shows a cross section of this equipment.



ISOLATED PHASE BUS DUCT CROSS SECTION DRAWING

The Isolated Phase Bus Duct is comprised of large aluminum tubes approximately 18 inches in diameter. The tubes form a protective enclosure to house the actual energized bus bar which is mounted on insulators. Each phase of the three phase system is isolated from the other two phases. This isolation minimizes the possibility of a short circuit (fault) involving all three phases.

The bus bars are constructed out of a tubular material that is usually aluminum. The shape may be a square tube as shown or a round tube shape. The isolated bus duct and supporting structure is custom designed for each installation. The inner and outer tubes have field welded connections with expansion joints that allow for the thermal expansion and contraction of both the conductors and housing tubes.

Large ampacity bus ducts have cooling systems that circulate cooling air through the tubes to remove heat from the I^2R losses.

3. Step-up transformer

The Step-up transformer transforms the voltage from the generator to a higher voltage necessary for the transmission of the generator's power over the utility's electric grid (transmission network). These large power transformers come in two basic configurations: Single three phase transformer or three single phase individual transformers. The photo below shows one of the three single phase transformers at a generating station.

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Utilities were forced to use single phase transformers for step-up transformer applications as the size of the generators grew. Manufacturers of transformers were limited by the size of a transformer that could be shipped by the railroads. Once this limit was reached, single phase transformers were the only economically option for increase the size of transformer. As the practice grew, utilities grasped the benefit of this configuration because a spare single phase transformer provided economically backup protection for a transformer failure.

4. Station Startup Transformer

The Station Startup Transformer is a power transformer used to connect the power station to the transmission system so that power is available for the plant equipment when the plant is being started. Power plants are routinely brought down for servicing of major pieces of equipment or when the demand for power is low such as in the spring and fall. This transformer provides the so called "Startup" power. The Start-up transformer is also used when the plant is being shutdown to power the station equipment that operates regardless of whether the plant is producing power. Finally, the Start-up transformer is used when ever the Station Auxiliary Transformer is un-available such as planned maintenance or repair.

Power plants usually have a transmission substation close to the plant. Here several transmission lines, sometimes at different voltages, come together and a line will be brought to the plant startup transformer for startup power.

The transformer shown in the one-line diagram is a three winding transformer. The purpose of the three windings is discussed in the next article on Unit Auxiliary Transformers. The photo below shows a typical startup transformer.

5. Station or Unit Auxiliary Transformer

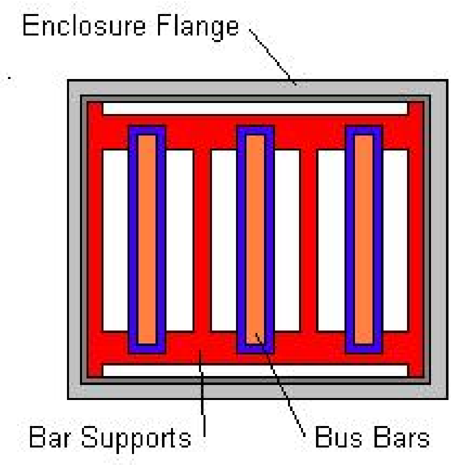
The Station Auxiliary Transformer is connected to the generator output by a tap off of the Isolated Phase Bus Duct. The high voltage winding of the transformer is designed to match the generator output voltage which is 22,000 Volts or 22KV in this example. This particular transformer is shown as a three winding transformer. It has a primary winding and two separate secondary windings at different voltages. This allows the station to have two different voltage levels one at 6900 Volts or 6.9kV and the other at 4160 Volts or 4.16KV. The higher voltage afforded by the 6.9KV windings allows for the use of similar higher voltage motors for large pumps or fans. The higher voltage motors offer several advantage over 4.16KV motors such as higher starting torques and lower full load currents.

This transformer and the station startup transformer have to be specified and connected in a configuration so that the output voltages will be in phase. The bus voltages need to be in phase so that live bus transfers can be facilitated. This is accomplished by the internal connections of the transformer phases, as specified, as either delta or wye connected. This will assure that the incoming voltage from the transmission line is in phase with the voltage from the generator (after being transformed by the auxiliary transformer).

The Unit Auxiliary Transformer is the normal power source for the station equipment when the plant is operating. Once the generator is brought on line and is connected to the transmission grid, the station loads can be transferred from the Start-up transformer. This would normally be done by closing the feed breakers from the Auxiliary Transformer (the 1A-1 and !B-1 Breakers on the A 6.9KV Bus) while the feed breakers from the Start-up Transformer (Breakers 1A-2 and 1B-2 in this example) are still closed. The two transformers are now operating in parallel. As soon as the Auxiliary feed breakers are closed the plant operators open the feed breakers from the Start-Up Transformer as parallel operation of the transformers is not a desired operating mode. This is because having two transformers connected to the switchgear provides two sources of fault current should a short circuit occur in the switchgear or downstream of the switchgear. The resulting total fault current may exceed the switchgear's short circuit rating and a catastrophic failure of the switchgear could occur.

6. Non-segregated Phase Bus Duct

Non-segregated Phase Bus Duct (Non-seg Bus) is typically used to connect the station auxiliary transformers low voltage windings to the station switchgear. Some stations use parallel runs of cable or more isolated phase bus duct in lieu of Non-seg Bus; however, the author's experience has been with Non-seg bus designs. The drawing below shows a cross section of Non-segregated Bus Duct.



Non Segregated Bus Duct

Non-seg bus duct is comprised of copper bus bars which are insulated (shown here with a blue insulation) and held in place with a support system made of fiberglass or some other non-conducting material. All three bus bars are surrounded by a grounded metal enclosure.

Non-seg bus is custom designed for each installation. It is built in sections at the factory and bolted together in the plant. Insulating boots cover the bolted bus bars. The enclosure on each section is flanged so that each enclosure section can be bolted together. Once installed and tested, non-segregated bus duct is a highly reliable component providing years of service with little maintenance required.

7. Medium Voltage Switchgear

The 6.9KV and 4.16KV Buses shown in the one-line diagram represent the plant medium voltage switchgear. Switchgear refers to a line-up of equipment to house circuit breakers, protective relays and control wiring. The switchgear is completely enclosed in a metal structure that prevents individuals from coming in contact with the lethal voltages within this equipment.

Switchgear is made up of a series of cubicles which are bolted together in a row. Each cubicle contains a rear section where the bus bars are located, a lower compartment where the circuit breaker resides, and an upper compartment where the protective relays and breaker control wiring is located. Typically, the incoming or feed breakers are located on the ends of the switchgear line-up.

As shown on the one-line diagram the pairs of switchgear can be connected together via tie breakers (one 6.9KV Bus A and B these are breakers 1A-6 and 1B-3). These breakers are normally open; however, in the event of a problem with the non-segregated bus duct or incoming feed breaker, the tie breakers can be closed and both buses energized on the same feed breaker.

Each circuit breaker is mounted on a rack and the breaker is rolled or jacked into various positions such as all the way in which is the connected or in-service position, partially withdrawn which is the test position, and fully withdrawn which is the disconnected position. While in the test position, the circuit breaker can be operated but it is not connected to the live bus bars. This allows functional tests to be performed on the breaker.

Each cubicle contains protective relays in the top portion. The type of relay varies depending upon the breaker application. Typically, each breaker will have as a minimum some type of over-current relay and ground fault relay.

8. Secondary Unit Substations

Secondary Unit Substations (SUSs) are essentially a repeat of the configuration of the station auxiliary transformer and the Medium Voltage Switchgear but at a lower voltage. Breakers from one of the plant switchgear will feed a transformer (in the one-line diagram the feed breakers is the 2A-3 breaker on the 2A 4160 Volt Bus) that will reduce the voltage to 480 Volts. This transformer is an integral part of a line-up of 480 Volt Switchgear. Sometimes the Unit Substations are designed with a transformer at each end of the switchgear. These are referred to as “double ended” secondary unit substations. The configuration shown in the one-line above is single ended substations with tie breakers which provides essentially the same reliability as a double ended substation.

Secondary Unit Substations are used to feed the large majority of components in a power plant by further distributing power to load centers, motor control centers, and battery chargers. In addition, medium range motors 200 to 300 horsepower are fed by individual 480 V SUS circuit breakers.

9. Motor Control Centers

Based upon shear numbers of components fed, Motor Control Centers feed to most components in the power plant. These include motor operators for valves, small to medium motors, lighting panels, receptacle power panels to name a few. Motor control centers are comprised of vertical sections of cubicles or buckets. Each bucket contains a molded case circuit breaker, motor starter, control transformer, control fuses and wiring. In the rear of the MCC buckets, vertical bus bars distribute power to the different buckets. The vertical sections of buckets are bolted together to form the MCC. Below is a picture of an outdoor Motor Control Center.

Motor Control Centers are located throughout the power plant and are placed near groups of loads for convenience. Outdoor MCCs are located in an additional enclosure for weather protection. A door opens to reveal each vertical section as shown in the photo above.

Glossary of Terms

CT – Current Transformer – An instrument transformer that provides a fractional current value proportional to the current it is monitoring.
Exciter - The exciter provides the DC current which is provided to the field windings of the generator.

Grounding Systems – several different techniques of construction all related to personnel safety and the proper functioning of protective devices.
Isolated Phase Bus Duct –Bus bars on insulators, surround by a metal tube, that connect the output of the station generator to the step-up transformer low voltage bushing.
Main Generator- Machine composed of the rotor, stator, and exciter that produces electricity by rotating a magnetic field through an armature winding.
Medium Voltage Switchgear
Motor Control Centers – Modular electrical panels housing the breakers and controls for numerous motors.
Non-seg Bus – see Non-segregated Phase Bus Duct
Non-segregated Phase Bus Duct – equipment designed to conduct large amounts of current through insulated bus bars surrounded by a grounded metal enclosure
PT – Potential Transformer – An instrument transformer that provides a fractional voltage value proportional to the voltage it is monitoring.
Station or Unit Auxiliary Transformer – the power transformer connected to the main generator output-used when the plant is operating
Station Startup Transformer – the power transformer connected to outside source of power used when the plant is starting up from cold conditions
Secondary Unit Substations – Low voltage switchgear with integral step down transformers
Step-up transformer – the transformer(s) that is connected to the generator output and transforms the voltage to transmission voltage levels
SUT – Start-up Transformer- the power transformer connected to outside source of power used when the plant is starting up from cold conditions
UAT – Unit Auxiliary Transformer - – the power transformer connected to the main generator output-used when the plant is operating

Conclusions

This course has provided an overview of the major electrical distribution equipment in an electric generating power plant. The role of the generator, main transformers, medium voltage, and low voltage switchgear was explained. Although each power plant is different in its design, they are surprisingly very similar in their electrical distribution systems. Hopefully, this course has provided a sense of the magnitude of the scope in providing electricity to the consumer every day of the year.

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