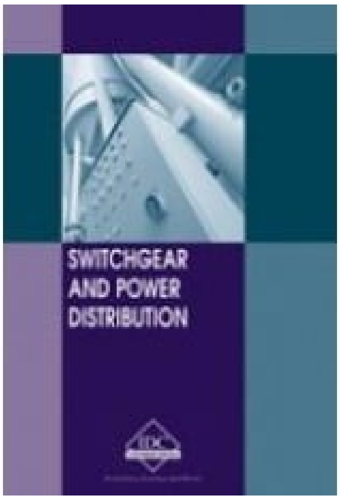
SW-E - Switchgear and Distribution Systems



Availability: In Stock

Price: $65.95

Ex Tax: $59.95

Short Description

Electrical supply is important in any industry. It is necessary to protect power distribution systems, equipment, motors, generators, etc. from dangerous fault conditions in an electrical supply. Hence, it is necessary to arrange the equipment so it can be switched ON or OFF under different conditions such as, no load or load conditions, or even under fault conditions. The collection of equipment used for switching and protecting purposes in a power system is called switchgear.

Description

Electrical supply is important in any industry. It is necessary to protect power distribution systems, equipment, motors, generators, etc. from dangerous fault conditions in an electrical supply. Hence, it is necessary to arrange the equipment so it can be switched ON or OFF under different conditions such as, no load or load conditions, or even under fault conditions. The collection of equipment used for switching and protecting purposes in a power system is called switchgear.

The most important element of good power system design is the proper selection of the distribution equipment. The purpose of this manual is to familiarise the reader with the basic concepts of a power distribution system, switchgear design and the principles of operation and applications of protection systems for the industrial electrical distribution systems. The manual provides an overview of the basics of industrial power distribution systems, the various components in the distribution systems, components of power system protection schemes and concludes with safety and maintenance aspects. This manual should be helpful for engineers and technicians in the field of electrical design or maintenance.

Table of Contents

Download Chapter List

Table of Contents

First Chapter

Switchgear and Distribution Systems - An Overview

1 Overview

In this overview, we will briefly discuss the requirements of an industrial power distribution system, its main components and the equipment and subsystems that form a part of any typical industrial power distribution system. These will form the basis of detailed discussions in the subsequent chapters.

Learning objectives

- History and growth of power distribution
- Typical characteristics of a power distribution system
- Main components of a distribution system
- Main equipments in a distribution system
- Electrical safety and power security

1.1 Introduction

Power is a critical input to any industry and availability of uninterrupted, good quality power is essential for production. It is therefore necessary that an engineer regardless of his or her function must understand the basics of electrical power distribution. This text is an attempt to explain the methodology of power distribution in industrial plants in simple, easy-to-understand terms and discuss the important subsystems that go to make a complete distribution system.

No two industries are alike. The power requirement can vary from less than 100 kilowatts for small manufacturing units to several hundreds of megawatts in the case of large facilities such as an integrated steel plant or an aluminium smelter plant. Correspondingly, the complexities of power distribution systems within the facility may vary considerably. However, the basic governing principles are valid for all cases:

- Ensuring safety of operating personnel and plant assets
- Ensuring reliable power supply (continuity of power)
- Ensuring adequate quality of power
- Ensuring that a load does not interfere with or cause problems to other consumers internal or external to the plant

One may ask how continued power supply can be a governing principle, when the responsibility of power supply is with an external agency (variously called as Utility, Supplier, Power Grid, etc.). The answer to this is as follows. Interruption of external power supply is always a possibility that cannot be discounted. By knowing the history of power supply behaviour for a particular supply system and by evaluating the tolerance of the plant equipment to power outages, one can take adequate precautions in the design of the systems and sizing of equipment to ensure that an interruption of power does not have any undesirable impact on the operation of the industrial plant. The other fact to be noted is that many interruptions may happen due to local reasons such as incorrect selection of equipment, inadequate sizing, improper operation and poor maintenance practices that do not match the needs of installed equipment and thus result in failures. This is the reason why a practicing engineer must have a clear idea of how an electrical distribution system functions and about the probable problem-areas. This is what this text will attempt to explain.

1.2 History and growth of power distribution

As we are aware, all modern power distribution is done using 3-phase alternating current (AC) supply systems. For the benefit of those interested in a bit of history, the acceptance of ac as the choice of electrical generation and distribution is only a little over 100 years old. After a bitter struggle between proponents of direct current (DC) systems, mainly Thomas Edison and of poly-phase AC systems (George Westinghouse using the patents of Nicola Tesla), the first practical AC system came up in Niagara Falls in USA using hydroelectric generators supplying power to industries situated in Buffalo and became operational in 1896. Thus, Tesla by his invention of the concepts of poly-phase ac and ac induction motors made ac systems the undisputed distribution standard all the world over. Supply frequency of 60Hz now adopted in North America as the standard today was also Tesla’s idea.

When the quantity of power to be handled increases, the conductors which carry this power have to operate at higher and higher currents (as per the formula Power =Voltage x Current assuming a pure resistance to be the load) the voltage being a constant value decided by the consuming appliances.

Any electrical conductor has a critical value of current beyond which the power loss in the conductor (computed by the formula P = I x I x R, I being the current and R the resistance of the conductor) will cause the conductor to attain excessive temperatures. The equilibrium temperature that the conductor attains is decided by the following factors:

- Power loss as calculated above converted to heat. (It is worth noting that the resistance of the conductor material is not constant but will increase with temperature according to the temperature coefficient of resistance for the material).
- Heat dissipation from the conductor to the environment through conduction, convection and radiation decided by the conductor geometry. In the case of insulated conductors and cables, the heat dissipation will have to be done through the layers of insulation.
- Capacity of the conductor to store the heat (decided by the specific heat of the material and the mass of the conductor).

The temperature attained by the conductor is limited by the value which, the insulating material used to insulate the conductor (or in the case of bare conductors to support it) can tolerate without suffering failure of insulation. An insulating material has a negative coefficient of resistance and beyond a critical temperature the insulation can become conductive. It may also lose mechanical strength in the process of heating up. The resulting fault would cause much higher currents due to the short-circuit faults which will result. In extreme cases, the conductor itself can attain temperatures close to its melting point and melt away.

Another factor to be considered is the efficiency of transmission; more the loss in transmission/distribution, the lower the overall system efficiency. One way to prevent excessive conductor heating is to increase the conductor size and put a number of conductors in parallel. This again has physical limits beyond which the conductor capacity cannot be increased. Alternatively, the system voltage can be increased so that the current value for a given quantum of power transmitted will reduce in inverse proportion. This will necessitate use of thicker insulation in the appliances sufficient to withstand the higher voltage, which in turn will make the appliances more expensive. This method also has practical limits beyond which voltage cannot be increased without compromising economy and safety. The ideal solution is therefore to use a mix of voltages so that transmission, distribution and consumption, each with an optimum value decided by economic considerations appropriate to the application.

AC systems give us an easy way to achieve this using a transformer, which can either step up or step down the voltage as required. Transformers step up the voltage for transmission of power over long distances and near the loads, the voltage can be stepped down again to a value convenient for consuming appliances.

The sinusoidal waveform is transforms in the transformer into another sinusoidal wave although with a phase shift. The sinusoidal primary current produces a sinusoidal magnetic field within the transformer which induces an emf in the secondary which is proportional to the rate of change of the magnetic field (i.e. the differential). The differential of a sine wave is another sine wave – just shifted by 90 degrees.

1.3 Benefits of the three-phase AC power system

A three phase system has thus the following advantages:

- For a given size of a motor power output is higher than a single phase system.
- Similarly, when a given amount of power is transmitted by a three system at a given voltage over a given distance, the least amount conductor material is used for achieving the same efficiency.
- Single phase motors are not self starting but three phase motors are. Also three phase motors produce uniform torque which is ideal for the loads being run from such a system.
- It is difficult to operate single-phase alternators in parallel since the synchronizing torque is much lower.

Two types of connections are possible in a three-phase system as illustrated in Figure 1.1. This is applicable both for a source and a load. Possible combinations of source and load are shown in Figure 1.2.

Figure 1.1

Star and Delta Configurations

Figure 1.2

Three Phase System Connections

Most systems use the star connection at the source, which gives them a flexibility to feed both three phase and single-phase loads. This is a de-facto distribution system standard in most parts of the world for low voltage distribution systems and unless otherwise stated, will be the one that will figure in our discussions further. A 3-phase 4-wire system is necessary when single-phase loads (loads across one phase and neutral) are supplied by the system. In this case the neutral of the source and the load will have to be connected by a neutral conductor. When the current in each of the phases have equal magnitude and phase angles the system is said to have a balanced load. In a balanced 3-phase 4-wire system the neutral current is zero. In case only three-phase equipment such a motors are fed from the system the middle conductor can be dispensed with, in which case, the system becomes a 3-phase 3-wire system. A source may feed a combination of loads requiring a 3-wire and four wire system.

1.4 Typical characteristics of an industrial distribution system

In this text, we are going to discuss industrial distribution systems. This is not the only type of distribution system that one comes across. We have other types of systems such as:

- Utility distribution systems
- Residential distribution
- Domestic/commercial building distribution

Each type of system is quite characteristic and differs considerably from the others. For example, the distribution system of utilities typically covers a large geographical area where supply lines may extend to a few km distances and cater to a number of small consumers and perhaps a few large consumers scattered within the area. Distribution lines are of overhead type in rural and suburban areas and of underground type in urban areas.

A residential consumer usually represents a small electrical load. The distribution system within a residence is naturally very small. Often the service is through a single-phase incoming feeder. The demand varies widely in the course of a day and often also varies with seasons. Some of the loads may even be supplied only during specific periods of the day whereas the others will need consistent supply without interruptions. The distribution equipment must be simple enough to be operated by persons with no special knowledge and also designed with absolute safety in mind. Overheating, sparking and fire must be absolutely prevented in the interest of safety of life and property.

Buildings housing commercial loads have a different behaviour altogether with the load cycle following the business timings quite different from the load cycle of a typical residential supply. The distribution system may have to cater to a number of individual consumers each of whom may consume very little power, but taken as a whole may amount to that of a medium sized industry. Both horizontal and vertical distribution is necessary in large buildings that have a number of floors.

Industrial distribution in a medium or large facility deals with distances far longer than a large building complex but much shorter than a utility distribution system. Distribution is invariably by cables with all equipment housed in metal clad enclosures. Load behaviour depends on the process requirement and may contain a mix of fairly steady loads and those of fluctuating type (welders being a typical example). The loads can be a mix of several units with small ratings and a few large rated loads. The latter type can cause severe problems to the rest of the system while being switched on or even during their normal operation.

1.5 Main components of an industrial distribution system

We will now briefly discuss the main components of an industrial distribution system as it applies to a large facility. It is normal for any industrial plant to receive power at a voltage higher than the standard utilization voltage. This means that the incoming voltage may have to be stepped down by a transformer at either the receiving location or elsewhere. The details may vary from facility to facility. A general case is discussed below.

A large industrial facility will have:

- An incoming section where power is received from an external supplier
- In-plant emergency/standby generation (applicable for facilities with critical loads) and associated distribution system
- A primary distribution system, usually medium/high voltage, to major loads/load centers of the facility (applicable for large industries)
- A step down transformer section
- A secondary low voltage distribution system
- Controlgear for individual loads
- Supervisory control system for centralized monitoring and control of plant

distribution system (not applicable for small facilities)

Some of the industries may have systems with more voltage levels depending on the types and characteristics of the loads.

We will discuss the above subsystems briefly here and in detail in later chapters.

1.5.1 Incoming section

This is where power from the external source is received and further distributed to plant loads. The voltage at which power is received will depend on the power demand and local regulations/voltage levels. The receiving section usually (but not always) has one or more transformers as a part of the station depending upon the quantum of demand and downstream distribution requirements.

1.5.2 In-plant emergency/standby generation

Some of the industrial units with critical loads or those fed from power supply systems with a history of unreliable operation, may choose to install generators to meet a part of the demand. The integration of the generating sets with the rest of the plant systems needs to be planned carefully.

1.5.3 Primary distribution system

A primary distribution system is meant to distribute the power from the receiving section to downstream load centers, which will step down the voltage and feed power into the secondary distribution system. There can be more than one primary distribution level in large industries.

1.5.4 Step down transformer section

Often power is received at a higher voltage and distributed to loads at low voltage. In such a case step down transformers are located at various load centers (feeding to one or more plant sections). Alternatively, a single step down transformer may be located at the receiving section and distributes power to load centers at the voltage at which loads operate. A second level of step down may sometimes be necessary at individual plant units.

1.5.5 Secondary distribution system

This is the distribution system, which feeds the supply to individual loads from the main load centers. Again, the voltage levels can be more than one. Smaller loads are usually fed at low voltage whereas some of the larger motors or DC drives may be fed from a medium voltage system such as 3300 or 6600 Volts or any other standard voltages prevailing in the country of installation.

1.5.6 Controlgear

The majority of loads in any plant usually consist of motor drives and electrical heating devices. These loads may need to be controlled from a remote panel and sometimes through a Distributed Control System (DCS) or a Programmable Logic Controller (PLC). Such loads are fed from a motor control center, which is essentially a distribution panel but equipped with devices for remote control. In case of AC or DC variable speed drives, each drive may be fed from its own drive panel or sometimes a group of drives may be fed from a single variable speed drive system.

1.5.7 Supervisory control

Large industrial plants may be provided with supervisory control system, which is a centrally located facility, which gives an overview of what is happening in the power distribution system. Most such facilities also provide for centralized switching of the distribution system.

1.6 Main equipment types in an industrial distribution system

The above components incorporate various individual equipment types each with a specific function. Examples of such equipments are:

- Circuit isolation devices
- Circuit switching devices (circuit breakers)
- Transformers
- HV and LV distribution equipment
- Motor control panels
- DC supply system
- Power system protection
- Cable (or overhead line based) distribution systems
- Earthing system
- Power quality improvement equipment

We will discuss these equipments/systems in detail in the ensuing chapters.

1.7 Electrical safety and power security

It is often said that electricity is a useful servant but a dangerous master. Improper handling of electricity and electrical equipment invites accidents. Electrical safety is governed by several statutory regulations in each country, the primary purpose of which is the safety of personnel. The regulations are further supplemented by various national and international standards for the design of equipment, their installation, maintenance and testing. In addition to the objective of safety, they also ensure trouble-free operation of equipment and subsystems during their expected service life and thus achieve the goals of continuity of power and quality of power supplied to the loads as well as limit the potential for interference with other consumers. We will discuss the issue of safety in a later chapter.

As we said earlier, reliability of power supply is a critical factor in any industry and must be ensured by appropriate steps in design and installation conforming to regulations, standards and well-proven operational and maintenance practices. One of the important aspects of distribution system management is proper upkeep of equipment. We will devote a chapter to the maintenance of distribution system equipment and the modern practices adopted in maintenance. Use of these practices will ensure that power supply security as appropriate to the installation can be achieved at an optimal cost.

1.8 Summary

Power is a critical input to any industry and availability of uninterrupted, good quality power is essential for production. The complexities of power distribution systems within the facility may vary considerably depending on the industry. The four guiding principles of any system are the same however: viz., reliability, quality, safety and non-interference with other consumers of the system. An industrial distribution system consists of several important component parts and each part is made up of several equipments and subsystems. Statutory regulations supplemented by various national and international standards ensure safety, trouble-free service, continuity of power, quality of power supplied to the loads and interference with other consumers. Another important aspect of distribution system management is proper upkeep of equipment. Adoption of modern maintenance practices will ensure that power supply security as appropriate to the installation can be achieved at an optimal cost.