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# Electrical Distribution Systems

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# **Electrical Distribution Systems**

# Preface

*Electrical Distribution Systems* is intended as an introductory guidebook for self study or for use as a textbook in technical programs in electrical technology at vocational-technical schools, industrial training programs or college technical programs. The book uses a “systems” format to teach electrical distribution and associated power system concepts. Key concepts are presented by stressing applications-oriented theory. Through this approach, the student is not burdened with an abundance of information needed only for engineering design. “Real world” applications and operations are stressed throughout the book. Mathematical problems are solved by basic algebraic and trigonometric applications.

There are few texts on the market dealing with the topic of electrical distribution systems which are applications-oriented. Some texts are available which cover engineering design of systems; however, the two-year vocational-technical and college market has been neglected. There seems to be a demand for a text dealing with electrical distribution and associated power system operation from a user’s or technician’s point of view.

Concepts are presented in this book through an “electrical power systems” model which includes power distribution as a key element. The other subsystems of this model are important associated systems for a comprehensive understanding of electrical distribution systems. The five subsystems of the “electrical power systems” model include: Electrical Power Production, Electrical Power Distribution, Electrical Power Control, Electrical Power Conversion, and Electrical Power Measurement.

A limited understanding of basic electrical terms is assumed in the organization of this book. However Appendix A—Important Terms—is included to provide assistance in defining basic electrical terms which may be used when dealing with electrical power systems.

Through this comprehensive “systems” approach, the reader will gain a more complete understanding of electrical distribution systems. The authors have used this instructional method in teaching classes dealing with electrical power systems for over 25 years in a large university technical program.

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## Chapter I

# Power System Fundamentals

**O**ne of the most important areas of electrical knowledge is the study of electrical power systems. Complex transmission and distribution systems supply the vast need of our country for electrical power. Due to this tremendous power requirement, we must constantly be concerned with the efficient operation of our power distribution and associated systems.

### BRIEF HISTORY OF ELECTRICAL POWER SYSTEMS

Electrical power systems have been in existence for many years. The applications of power systems have expanded rapidly since their development. At the present time, applications continue to increase, placing additional requirements on power production, distribution systems and associated systems.

Thomas Edison is given credit for developing the concept of widespread generation and distribution of electrical power. He performed developmental work on direct-current (DC) generators which were driven by steam engines. Edison's work with electrical lights and power production led the way to development of electric motors, distribution systems and associated control equipment.

Most early discoveries related to electrical power dealt with direct-current (DC) systems. Alternating-current power generation became widespread a short time later. The primary reason for converting to AC power production and distribution was that *transformers* could be used to increase AC voltage levels for long-distance distribution of electrical power. Thus the discovery of transformers allowed the conversion of electrical power from DC to AC systems. Presently, almost all electrical power systems produce and distribute *three-phase* alternating current. Transformers allow the voltage produced by AC generators to be increased while decreasing current level by a corresponding amount. This

allows long-distance electrical power distribution at a reduced current level, reduces power losses, and increases overall power system efficiency. The increased use of electrical motors for home appliances and industrial and commercial equipment has increased the need for electrical power to be distributed to various locations.

In the early days of electrical power, the distribution systems were only an extension of the power generating plant. There was little planning for the efficient transfer of energy from the generating plant to the limited number of consumers. The expansion of electrical energy use has placed greater demands on the distribution system. Not only are more customers served, but today's equipment requires closer attention to voltage variation and little toleration of service interruption.

The design and operation of electrical power distribution systems has become a very important science. Well-engineered power systems of today are connected together in such a way that if a problem occurs in one system, it can be supplemented by another system. Electrical loads can be transferred easily from one system to another. The United States has a very reliable "grid" system which maintains electrical power to customers at the proper voltage level without interruption. It is extremely rare for "blackouts" or "brownouts" to occur. These conditions are avoided by proper planning for situations of extremely high demand. A blackout is a complete interruption of electrical power, while a brownout is a reduction of voltage level to the consumer. A brownout could be purposely done in order to deliver available power at a reduced voltage to avoid a blackout during a problem of extremely high demand. High demand usually occurs during abnormally hot or cold temperatures over an extended period of time.

Early power distribution systems supplied direct current (DC) at low voltage levels over relatively short distances. The invention of the transformer and the problems associated with delivering power over long distances brought about a change to the use of alternating current (AC) power systems. Today, greater electrical power demand can be supplied with long-distance, high voltage transmission. Voltage levels may be easily increased and reduced by transformers in order to supply electrical energy.

Not only has the efficiency of the electrical power distribution system been improved, but also the materials, equipment, and associated control systems have been continually updated. Examples of such improvement include the quality of steel towers, wood poles of long-last-

ing design, better conductors and insulators, and more reliable computer systems for monitoring and controlling the electrical distribution system.

## THE SYSTEM CONCEPT

For a number of years, people have worked with jigsaw puzzles as a source of recreation. A jigsaw puzzle contains a number of discrete parts that must be placed together properly to produce a picture. Each part then plays a specific role in the finished product. When a puzzle is first started, it is difficult to imagine the finished product without seeing a representative picture.

Studying a complex field such as electrical power systems by discrete parts poses a problem that is somewhat similar to the jigsaw puzzle. In this case, it is difficult to determine the role that a discrete part plays in the operation of a complex system. A picture of the system divided into its essential parts therefore becomes an extremely important aid in understanding its operation.

The system concept will serve as the “big picture” in the study of electrical power systems. In this approach, a system will first be divided into a number of essential blocks. The role played by each block then becomes more meaningful in the operation of the overall system. After the location of each block has been established, discrete component operation related to each block then becomes more relevant. Through this approach, the way in which some of the “pieces” of electrical systems fit together should be more apparent.

## BASIC SYSTEM FUNCTIONS

The word *system* is commonly defined as an organization of parts that are connected together to form a complete unit. There are a wide variety of electrical systems used today. Each system has a number of unique features, or characteristics, that distinguish it from other systems. More importantly, however, there is a common set of parts found in each system. These parts play the same basic role in all systems. The terms *energy source*, *transmission path*, *control*, *load*, and *indicator* are used to describe the various system parts. A block diagram of these basic parts

of the system is shown in Figure 1-1.

Each block of a basic system has a specific role to play in the overall operation of the system. This role becomes extremely important when a detailed analysis of the system is to take place. Hundreds and even thousands of discrete components are sometimes needed to achieve a specific block function. Regardless of the complexity of the system, each block must still achieve its function in order for the system to be operational. Being familiar with these functions and being able to locate them within a complete system is a big step toward understanding the operation of the system.

The *energy source* of a system converts energy of one form into something more useful. Heat, light, sound, chemical, nuclear, and mechanical energy are considered as primary sources of energy. A primary energy source usually goes through an energy change before it can be used in an operating system.

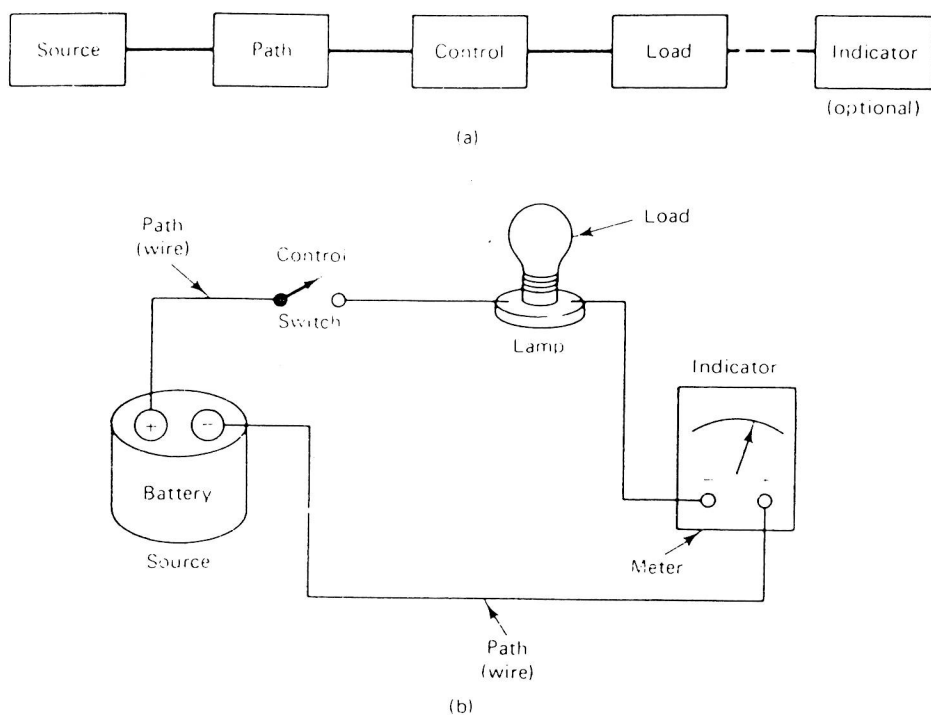


Figure 1-1. Electrical system: (a) block diagram; (b) pictorial diagram.

The *transmission path* of a system is somewhat simplified when compared with other system functions. This part of the system simply provides a path for the transfer of energy. It starts with the energy source and continues through the system to the load. In some cases, this path may be a single electrical conductor, light beam, or other medium between the source and the load. In other systems, there may be a supply line between the source and the load and a return line from the load to the source. There may also be a number of alternate or auxiliary paths within a complete system. These paths may be *series* connected to a number of small load devices or *parallel* connected to many independent devices.

The *control* section of a system is by far the most complex part of the entire system. In its simplest form, control is achieved when a system is turned on or off. Control of this type can take place anywhere between the source and the load device. The term *full control* is commonly used to describe this operation. In addition to this type of control, a system may also employ some type of *partial control*. Partial control usually causes some type of an operational change in the system other than an on or off condition. Changes in electric current or light intensity are examples of alterations achieved by partial control.

The *load* of a system refers to a specific part or number of parts designed to produce some form of work. Work, in this case, occurs when energy goes through a transformation or change. Heat, light, chemical action, sound, and mechanical motion are some of the common forms of work produced by a load device. As a general rule, a very large portion of all energy produced by the source is consumed by the load device during its operation. The load is typically the most prevalent part of the entire system because of its obvious work function.

The *indicator* of a system is primarily designed to display certain operating conditions at various points throughout the system. In some systems the indicator is an optional part, whereas in others it is an essential part in the operation of the system. In the latter case, system operations and adjustments are usually critical and are dependent upon specific indicator readings. The term *operational indicator* is used to describe this application. *Test indicators* are also needed to determine different operating values. In this role, the indicator is only temporarily attached to the system to make measurements. Test lights, meters, oscilloscopes, chart recorders, and digital display instruments are some of the common indicators used.

## A SIMPLE ELECTRICAL SYSTEM EXAMPLE

A flashlight is a device designed to serve as a light source in an emergency or as a portable light source. In a strict sense, flashlights can be classified as portable electrical systems. They contain the four essential parts needed to make this classification. Figure 1-2 is a cutaway drawing of a flashlight, with each component part shown associated with its appropriate system block.

The battery of a flashlight serves as the primary *energy source* of the system. Chemical energy of the battery must be changed into electrical energy before the system becomes operational. The flashlight is a synthesized system because it utilizes two distinct forms of energy in its operation. The energy source of a flashlight is an expendable item. It must be replaced periodically when it loses its ability to produce electrical energy.

The *transmission path* of a flashlight is commonly achieved via a metal case or through a conductor strip. Copper, brass, and plated steel are frequently used to achieve this function.

The *control* of electrical energy in a flashlight is achieved by a slide switch or a push-button switch. This type of control simply interrupts the transmission path between the source and the load device. Flashlights are primarily designed to have full control capabilities. This type of control is achieved manually by the person operating the system.

The *load* of a flashlight is a small incandescent lamp. When electrical energy from the source is forced to pass through the filament of the lamp, the lamp produces a bright glow. Electrical energy is first changed into heat and then into light energy. A certain amount of work is achieved by the lamp when this energy change takes place.

The energy transformation process of a flashlight is irreversible. It starts at the battery when chemical energy is changed into electrical energy. Electrical energy is then changed into heat and eventually into light energy by the load device. This flow of energy is in a single direction. When light is eventually produced, it consumes a large portion of the electrical energy coming from the source. When this energy is exhausted, the system becomes inoperative. The battery cells of a flashlight require periodic replacement in order to maintain a satisfactory operating condition.

Flashlights do not ordinarily employ a specific *indicator* as part of the system. Operation is indicated when the lamp produces light. In a

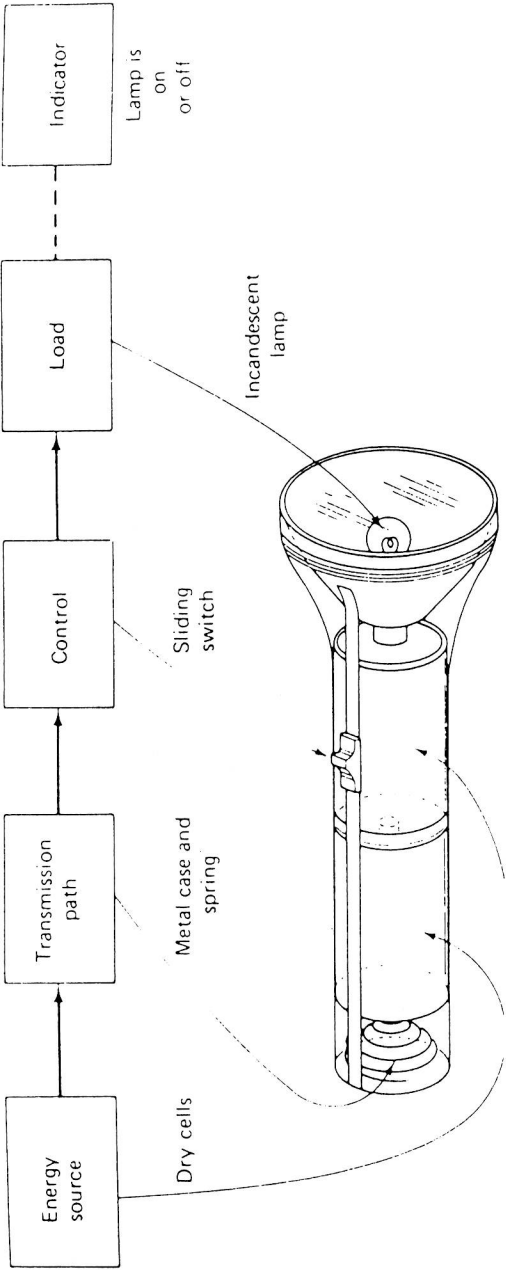


Figure 1-2. Cutaway drawing of a flashlight.

strict sense, we could say that the load of this system also serves as an indicator. In some electrical systems the indicator is an optional system part.

## THE ELECTRICAL POWER SYSTEM

The block diagram of an electrical power system is shown in Figure 1-3. The first block or the *electrical power production* section is an important part of the complete electrical power system. However, once electrical power is produced, it must be distributed to the location where it will be used, so electrical *power distribution* systems (block 2) transfer electrical power from one location to another. Electrical *power control* systems (block 3) are probably the most complex of all the parts of the electrical power system as there are unlimited types of devices and equipment used to control electrical power. Then, the electrical *power conversion* systems (block 4), also called *loads*, convert the electrical power into some other form of energy, such as light, heat, or mechanical energy. Thus, conversion systems are an extremely important part of the electrical power system. Another part of the electrical power system is *power measurement* (block 5). Without electrical power measurement systems, control of electrical power would be almost impossible.

Each of the blocks shown in Figure 1-3 represents one important part of the electrical power system. Thus, we should be concerned with each part of the electrical power system rather than only with isolated parts. In this way, we can develop a more complete understanding of how electrical power systems operate. This type of understanding is needed to help us solve our energy problems that are related to electrical power. We cannot consider only the distribution aspect of electrical power systems. We must understand and consider each part of the system. The “Electrical Power System” model will be used in this book to help understand electrical distribution systems. Refer to Figure 1-3 as a reference as you study the chapters of this book.

Figure 1-4 shows the generation and transmission of electrical power as an example. Power is produced at a generating plant (*source*). *Distribution* occurs between the plant and the consumer by power lines. Transformers are used to *control* the voltage and current levels. *Conversion* of electrical power to another form (light, heat, mechanical) occurs at the home.



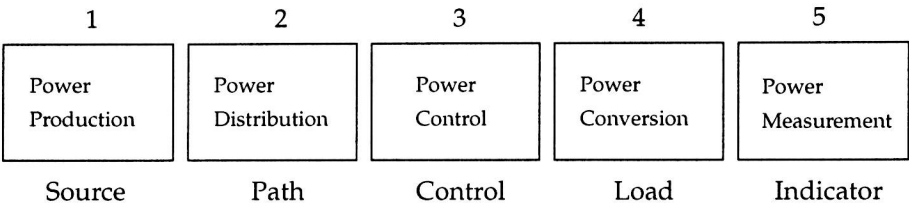


Figure 1-3. The Electrical power system model.

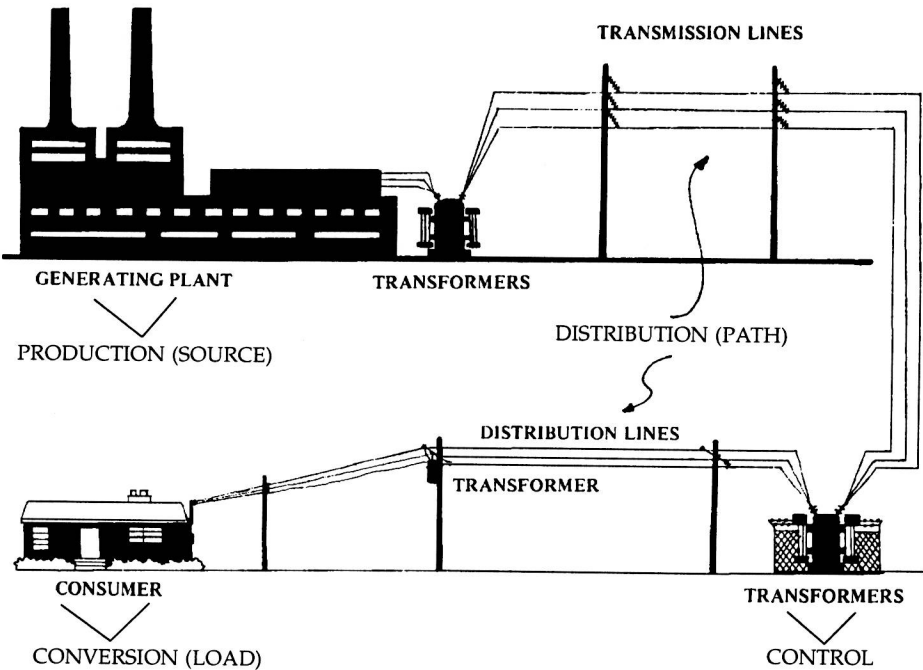


Figure 1-4. The generation and transmission of electrical power.

ENERGY, WORK, AND POWER

An understanding of the terms energy, work, and power is necessary in the study of electrical power systems. The first term, *energy*, means the capacity to do work. For example, the capacity to light a light bulb, to heat a home, or to move something requires energy. Energy ex-