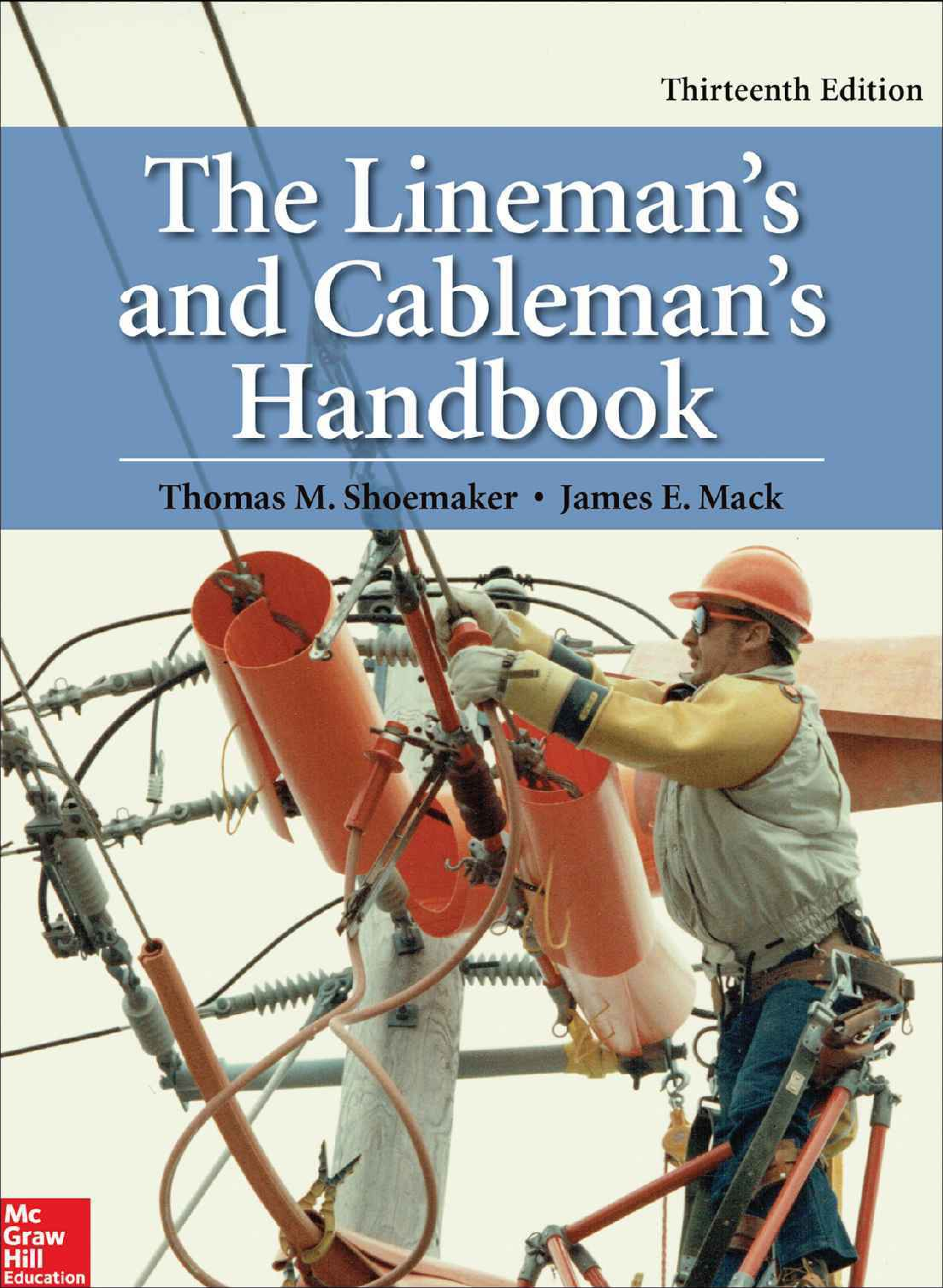
Thirteenth Edition

The Lineman's and Cableman's Handbook

Thomas M. Shoemaker • James E. Mack



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About the Editors

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The Lineman's and Cableman's Handbook

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In Memoriam

Sadly, Thomas M. Shoemaker died on April 6, 2014. Tom was a mentor, editor and author, and close friend. In 1970, he joined Professor Edwin B. Kurtz (University of Iowa) as co-author of *The Lineman's and Cableman's Handbook*. Following Dr. Kurtz' retirement, Tom was the editor and author for the 5th through the 8th editions of this work. He transferred the principal duties of editing and authorship to me for the 9th and subsequent editions of this work. Tom was inducted into the International Lineman's Museum Hall of Fame, Shelby, North Carolina, in 2008.

JEM

Contents

Preface

This Handbook is written for the apprentice, the lineman, the cableman, the foreman, the supervisor, and other employees of electric line construction contractors and transmission and distribution departments of electric utility companies. It is primarily intended to be used as an apprenticeship textbook and a home-study book to supplement daily work experiences. This Handbook has 50 chapters; 11 chapters are devoted to a general understanding of electricity, electrical terms, and electric-power systems; 31 chapters are devoted to actual construction of overhead and underground distribution and transmission lines and to maintenance procedures; and 7 chapters are expressly devoted to safety guidelines. The final chapter can be used by the reader as a self-examination of the information presented.

All chapters in this Thirteenth Edition have been revised where necessary to be consistent with the newest equipment, techniques, and procedures. A special effort was made to present all discussions clearly and in simple language. As in previous editions, a large number of illustrations showing the construction and maintenance processes are provided to assist the reader in a better understanding of the text. The illustrations clarify many details that would require additional words to express. Many of the photographs were taken specifically for use in this edition. They portray the practices in use by some of the foremost electric utility and contracting companies in the United States.

Methods of transmission-, distribution-, and rural-line construction have become quite standardized since the First Edition of the Handbook was published in 1928. The construction procedures described and illustrated are in most instances representative of general practice. While each operating company has its own standards of construction to which its linemen and cablemen must adhere, the procedures described explain why things are done in a given way. Such basic knowledge will be helpful to the lineman or cableman who is interested in learning the whys and wherefores of doing things one way or another.

Safety is emphasized throughout this book. Of course, understanding the principles involved in any operation and knowing the reasons for doing things a given way are the best aids to safety. The opinion has become quite firmly established that a person is not a good lineman unless he does his work in accordance with established safety procedures and without injury to himself or others. It is necessary for those engaged in electrical work to know the safety rules and the precautions applicable to their trades, as specified in the *National Electrical Safety Code*, Occupational Safety and Health Act (OSHA) standards, and their employers' safety manuals and standards, and to make the observance of safety rules and procedures an inseparable part of their working habits.

This Handbook places emphasis on the *National Electrical Safety Code*, OSHA standards, American National Standards Institute (ANSI) standards, and ASTM International (formerly known as the American Society for Testing and Materials) standards. Important requirements of all of these are discussed, and all of these should be studied for detailed work procedures. Many applicable codes and standards are referenced throughout the text to assist the reader.

The lineman and the cableman must become acquainted with the minimum construction requirements and maintenance and operating procedures in the various codes and standards to ensure the safety of the public and all workers. It is necessary that all linemen and cablemen know the information in the *National Electrical Safety Code* (ANSI C2) and that they adhere to the rules and procedures while performing their work assignments.

The *National Electrical Code* details the rules and regulations for electrical installations, except those under the control of an electric utility. It excludes any indoor facility used and controlled exclusively by a utility for all phases from generation through distribution of electricity and for communication and metering, as well as outdoor facilities on a utility's own or a leased site or on public or private (by established rights) property.

Reference material for the interested reader includes *Standard Handbook for Electrical Engineers*, edited by Donald G. Fink and H. Wayne Beaty and published by McGraw-Hill; *National Electrical Safety Code (NESC) Handbook*, by David J. Marne, P.E., published by McGraw-Hill; *IEEE Standard Dictionary of Electrical and Electronic Terms; Powerlineman*

Magazine; and the Electric Power Research Institute's (EPRI) publications.

The editor is well aware that one cannot become a competent lineman or cableman from a study of the pages of this book alone. However, diligent study along with daily practical experience and observation should give the apprentice an understanding of construction and maintenance procedures—and a regard for safety—that should make his progress and promotion rapid.

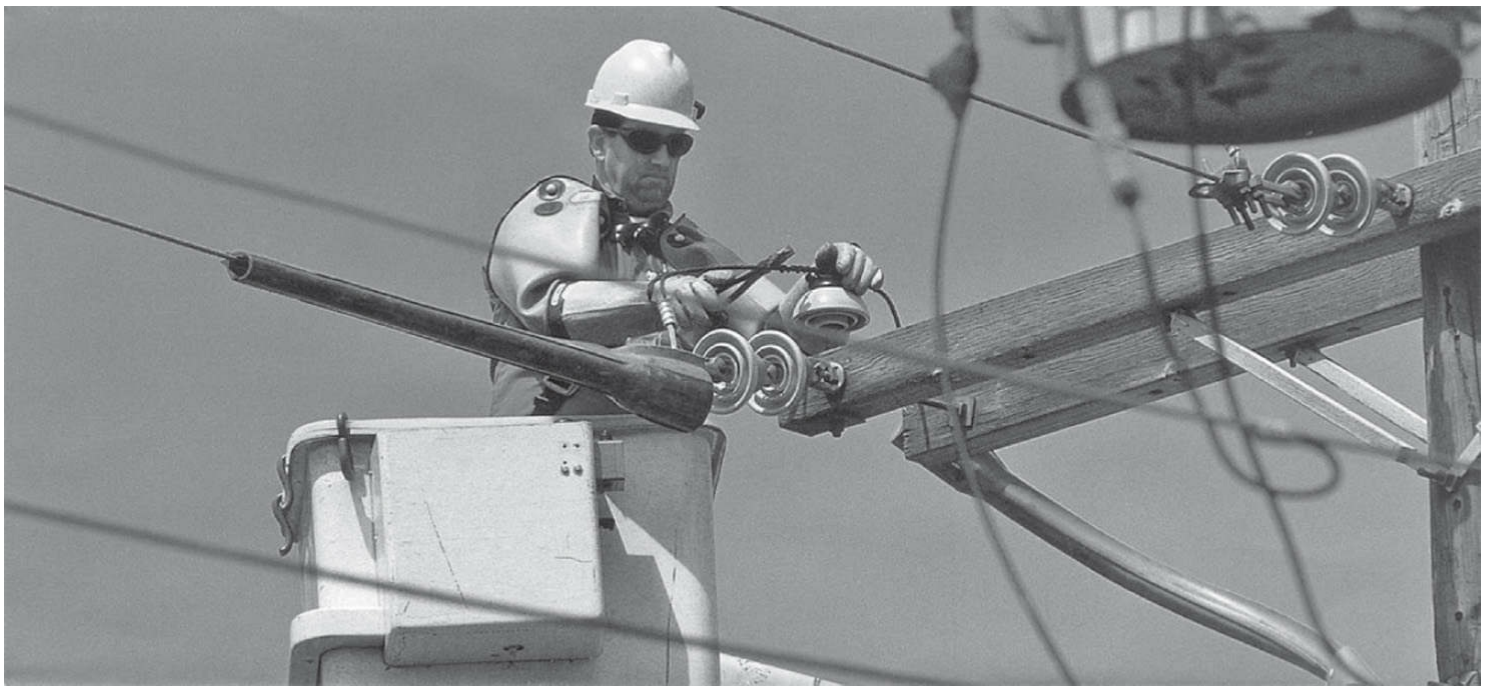
In conclusion, the lineman occupation has been properly recognized and chronicled in the film documentary series *Storm Soldiers I* and *Storm Soldiers II*. In 2006, the International Lineman's Museum, Shelby, North Carolina, established the Lineman's Hall of Fame.

James E. Mack

Acknowledgments

I wish to express my sincere appreciation to the many companies and their representatives who kindly cooperated in supplying illustrations, data, permissions to publish, and valuable suggestions. I am especially grateful to David J. Marne of Marne and Associates, Inc.; Dan Snyder of the American Iron and Steel Institute; Brian Schaaf of the Cordage Institute; Austin Henry, Ryan Norlin, Andrew McNamara, Derek Wahlheim, and Dave Litterst of MidAmerican Energy Company; Connie Hartline of the American Public Works Association; Andy Price and Murray Walker of the International Lineman's Museum & Hall of Fame; Dave Bezesky of Merchant Job Training and Safety; and numerous unnamed others.

James E. Mack



Lineman working from insulated bucket. The energized primary line conductor is covered with line hose. The lineman has positioned himself for convenient access to the work being completed. (*Courtesy Pepco Technologies*.)

The terms *lineman* and *cableman*, long-established and still current in the industry, are beginning to be replaced by non-gender-specific titles in official documents and government publications. Both men and women are employed in these capacities in the military and in the industry. To avoid awkwardness, this Handbook uses the masculine pronoun, but it in no way implies that the jobs involved are held only by men.

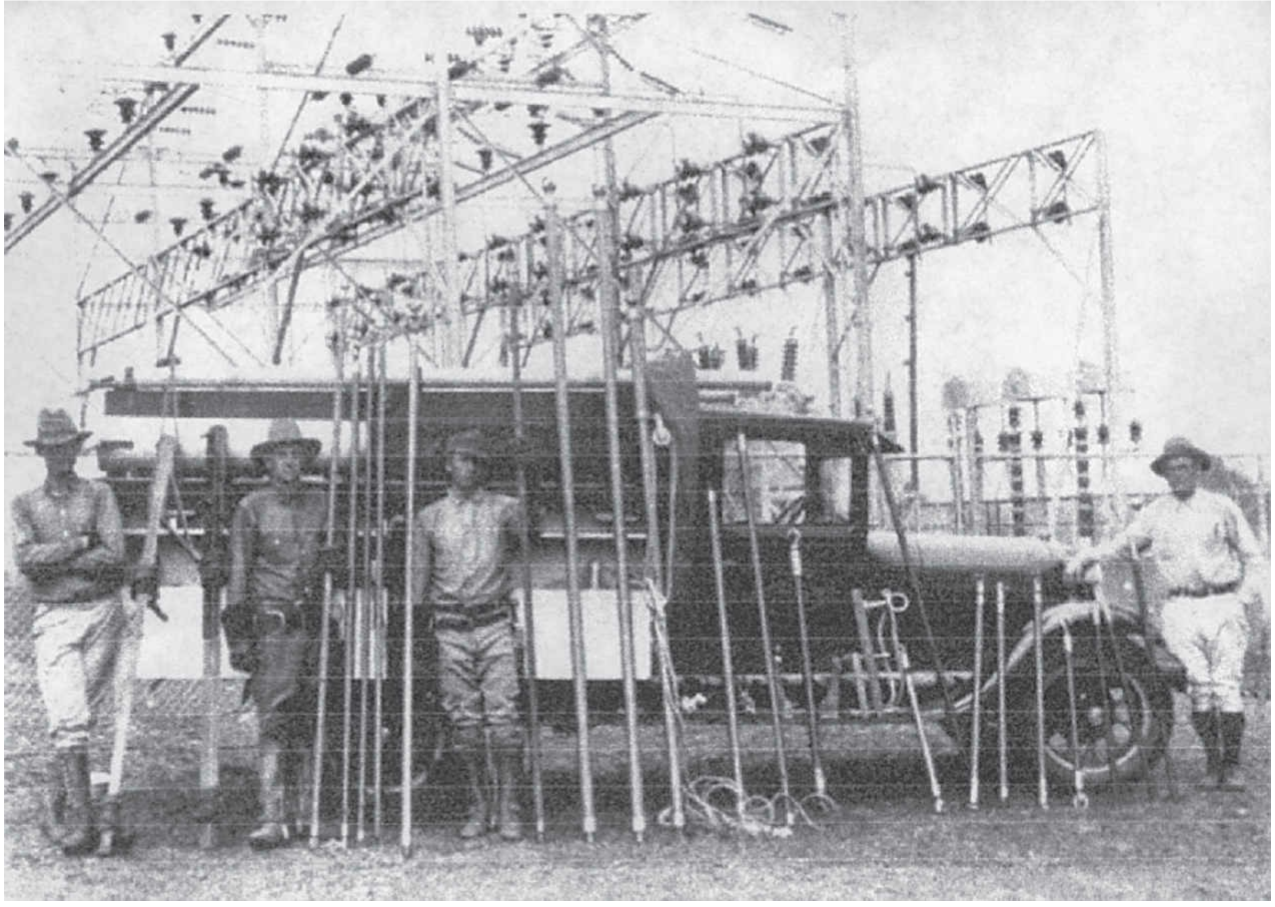
Introduction

Linemen and cablemen construct and maintain the electric transmission and distribution facilities that deliver electrical energy to our homes, factories, and commercial establishments. They provide important skilled services to the electrical industry—important because the health and welfare of the public are dependent on reliable electric service.

When emergencies develop as a result of lightning, wind, or ice storms, linemen and cablemen respond to restore electric service at any time of the day or night.

An understanding of electrical principles and their application in electrical construction and maintenance work is essential to completing the work safely, efficiently, and reliably. New equipment and the public's increased dependence on continuous electric service require that all linemen and cablemen be highly skilled.

The time and effort spent studying these pages will increase the reader's knowledge of electric distribution and transmission facilities and improve his skills. Every lineman, cableman, and groundman should develop the highest possible level of skills so that he will be able to meet the challenges of the work and be qualified for promotion when the opportunity becomes available.



A hot crew with their hot wagon. This photograph is from the 1930s when live line work was in its infancy and was specialized at many companies. Lineman working on these crews developed many effective methods and tools that are still used today.

As a testament to the significance of the role that the lineman has had in the United States, the following summary was submitted by Alan Drew, Northwest Lineman College, author of *The American Lineman*.

Evolution of the Lineman

In the 1840s, the use of the telegraph as a means of communication started in the United States. To obtain the benefits of this enhanced method of communication, lines would have to be constructed and maintained. It was found that telegraph lines could be strung on trees if they were available but that wood poles provided the best method of supporting the lines. The expansion of the telegraph system required men who could set poles and then climb them to string the wire. The term "lineman" quickly evolved as a title for those who worked on telegraph lines.

In the late 1870s the telephone was invented, and it began to replace the telegraph as a means of communication. The telephone also needed lines to be constructed, which were similar to the telegraph lines except they utilized more wires for the needed circuits. The term "lineman" was well established and carried on into the telephone era.

In the late 1890s electric power started to become a useful form of energy, and power plants and lines were built. This new form of energy immediately proved to be considerably more hazardous than the telegraph and telephone systems. A new breed of the “lineman” was now needed to work on these lines. These linemen took, and were expected to take, many risks in working on power lines and equipment. A high level of injuries occurred because of the limited training, and lack of proper equipment, construction standards, and safety rules. Although records are sketchy, in some areas it has been said that one of every three linemen was killed on the job, and mostly from electrocution.

As the power system evolved across the country there were many large line building projects, which resulted in linemen “booming around” from project to project. These early linemen quickly established a reputation as individuals who worked hard, took many risks, played hard, and took pride in their work.

In the late 1930s, the complexity of the lineman’s job was recognized as a good fit for apprenticeship training. This resulted in the establishment of the apprentice lineman, and soon programs started to evolve across the country. This was a significant step in the establishment of more formalized training to develop competent linemen.

The use of electricity brought with it a higher quality of life at home and the ability to be more productive for businesses. When power outages occurred, the impact on customers started to become significant. Linemen would quickly respond to these outages and make Herculean efforts in all types of weather to restore power. They soon established a reputation as “heroes” in the eyes of many customers.

The early linemen established their reputation while working mainly on wood pole lines. In the late 1950s, underground started to evolve as a popular and reliable way to deliver power, and it soon became part of the lineman’s work. This added a new dimension and more complexity to the lineman’s job.

Today’s linemen face challenges similar to those of the past; however, today’s customers rely heavily on the continuous delivery of power and are less tolerant of outages. This results in considerably more work on energized lines than in the past. The lineman of today has a wide array of enhanced vehicles, tools, equipment, and training to meet these challenges.

In addition, OSHA rules, standards, and procedures have greatly improved.

Linemen of today take pride in their work and remain heroes in the eyes of many customers when their power is restored after a long outage. As we look back at the vast amount of experience and knowledge that has been gained from the efforts of the pioneering linemen, it is appropriate to commit to maintaining their legacy.

CHAPTER 1

Elementary Electrical Principles

Electron Theory

The basis of our understanding of electricity is the electron theory. This theory states that all matter, that is, everything that occupies space and has weight, is composed of tiny invisible units called atoms. Atoms in turn are subdivided into still smaller particles called protons, neutrons, and electrons. The protons and neutrons make up the central core, or nucleus, of the atom, while the electrons spin around this central core in orbits as illustrated in Fig. 1.1.

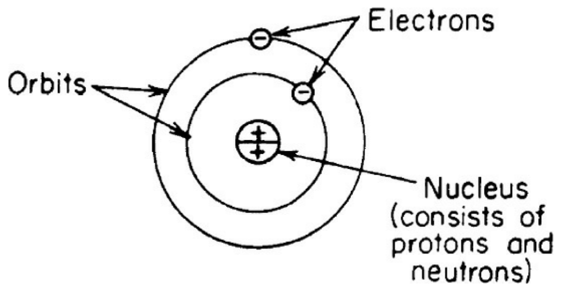


FIGURE 1.1 An atom consisting of the nucleus and revolving electrons. The nucleus is composed of protons and neutrons. The protons carry a positive electrical charge, the electrons carry a negative electrical charge, and the neutrons are neutral; that is, they carry neither a positive nor a negative charge.

The protons and electrons are charged with small amounts of electricity. The proton always has a positive charge of electricity on it, while the electron has a small negative charge of electricity on it. The magnitude of the total positive charge is equal in amount to the sum of all the negative charges on all the electrons. The neutron has no charge on it, either positive or negative, and is therefore neutral and hence called neutron.

Atoms differ from one another in the number of electrons encircling the nucleus. Some atoms have as many as 100 electrons spinning around the nucleus in different orbits. The atom of hydrogen gas has only 1 electron. The atom of lead has 82 electrons.

Positive and negative charges of electricity attract each other; that is, protons attract electrons. But the atom does not collapse because of this attraction. The spinning of the electron around the nucleus causes a centrifugal force that just balances the force of attraction and thus keeps them apart.

Electric Current

The electrons in the outermost orbit of an atom are usually not securely bound to the nucleus and therefore may fly off the atom (Fig. 1.2) and move into an outer orbit of another atom. These relatively free electrons normally move at random in all directions. However, when an electrical pressure (voltage) is applied across a length of wire, the free electrons in the wire give up their random motion and move or flow in one general direction. This flow of free electrons in one general direction, shown in Fig. 1.3, is called an electric current or simply current.[1]

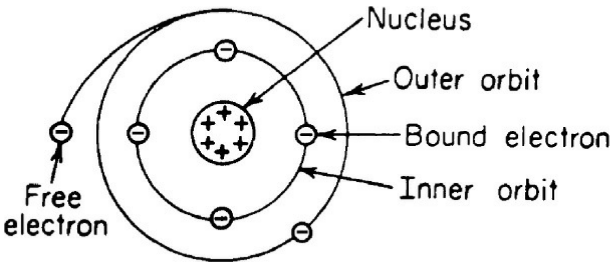


FIGURE 1.2 Atom showing electron in outer orbit leaving atom. The atom then has more positive charge than negative charge. The nucleus will therefore attract some other free electron that moves into its vicinity.

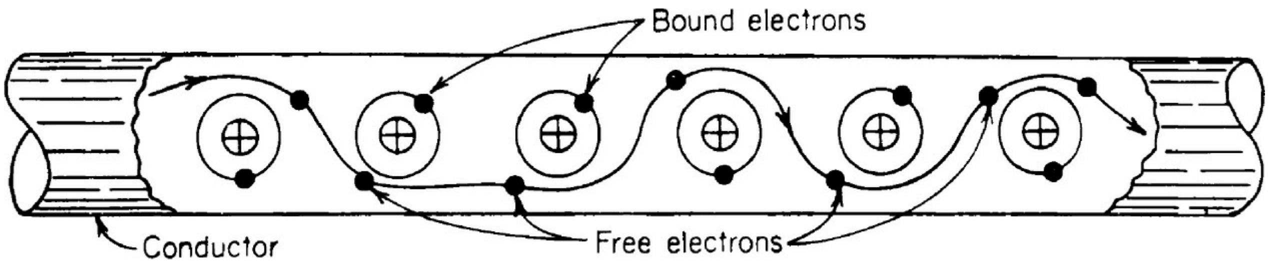


FIGURE 1.3 Flow of free electrons in a conductor. Only electrons in the outer orbit are free to move from one unbalanced atom to another unbalanced atom. This flow or drift of free electrons is called an electric current.

Conductors and Insulators

Materials having many free electrons, therefore, make good conductors of electricity, while materials having few free electrons make poor conductors. In fact, materials that have hardly any free electrons can be used to insulate electricity and are called insulators. Samples of good conductors are copper and aluminum. Samples of good insulators are glass, porcelain, rubber, paper, polyethylene, and fiberglass.

Electric Circuit Compared with Water Circuit

An electric circuit is the path in which the electric current flows. The flow of electricity in a wire is actually the simultaneous motion of countless free electrons in one direction. It is often compared with the flow of a liquid like water. Electricity can then be said to flow in a wire as water flows in a pipe. A simple water circuit, like the one shown in Fig. 1.4, has a resemblance to a typical electric circuit, shown in Fig. 1.5. The similarity between the water circuit and the electric circuit can give one an understanding of the flow of electric currents.

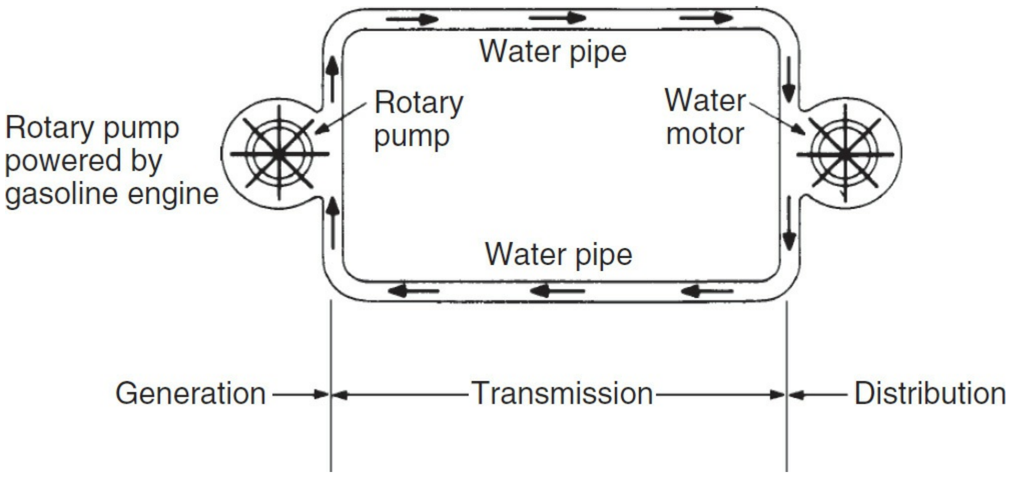


FIGURE 1.4 The water system.

Figure 1.4 illustrates water that is flowing in the pipe circuit in the direction shown by the arrows. It is evident that this current of water flows because of a pressure exerted on it. This pressure is produced by the rotary pump, often called the centrifugal pump, which is driven by an engine. A water motor is connected on the end of the pipeline, and therefore, all the water that flows around the circuit must pass through the motor. It is plain that it will cause the motor to revolve and, therefore, deliver power to the shaft and the rotating equipment connected by the shaft. Similarly, when an electric current flows in a wire, it flows because an electric pressure causes it to flow. Thus, the current in Fig. 1.5 is made to flow because of the electric pressure produced by the dynamo, or electric generator, which is driven by an engine. As the electric current flows along the wire, it will be forced to flow through the electric motor. This motor will begin to revolve as the electricity begins to flow through it and will deliver power to the shaft and the rotating equipment connected to the shaft.

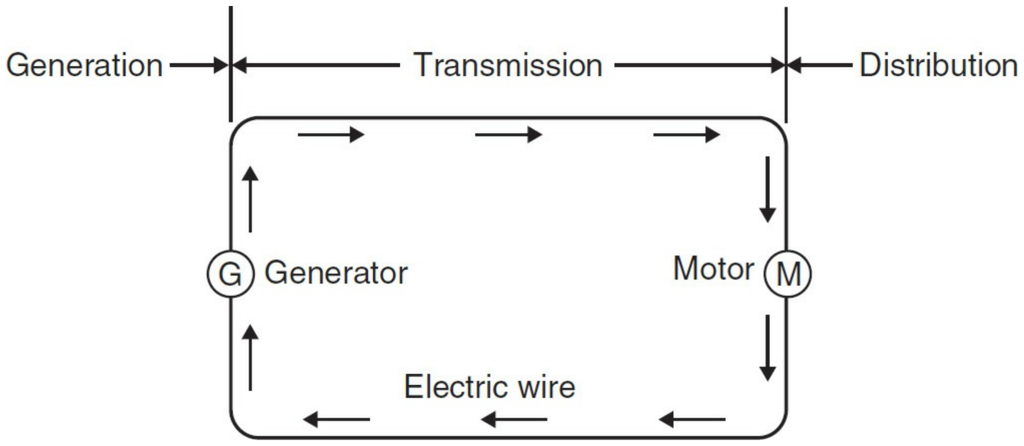


FIGURE 1.5 The electric system.

Series Circuit

An electric circuit can be arranged in several ways, as long as the path for the electric current is closed. The simplest arrangement is the so-called series circuit. The series circuit has all the elements of the circuit connected onto each other, end to end, as illustrated in Fig. 1.6. The same current from the battery flows through all the resistors.

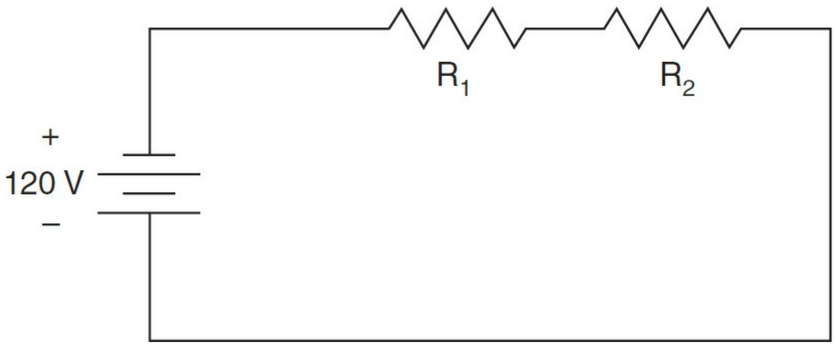


FIGURE 1.6 A series circuit. The same current flows through all the resistors.

Parallel Circuit

Another arrangement is the so-called parallel or multiple connection. Each resistor is individually connected across the battery, as shown in Fig. 1.7, instead of all the resistors being connected onto each other, end to end, and then onto the battery. The resistors are now said to be in parallel with each other.

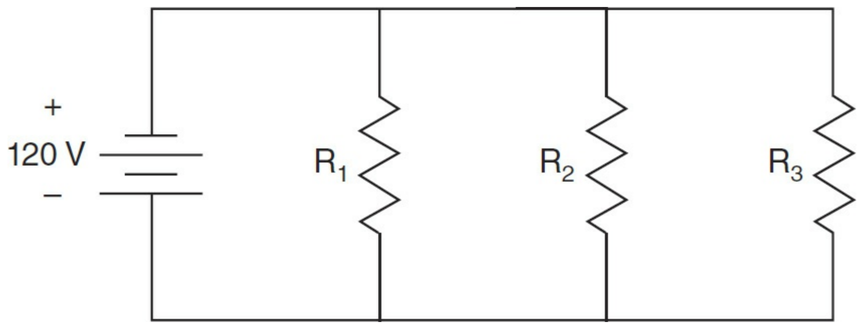


FIGURE 1.7 A parallel circuit. Each resistor is independent of the other resistors and draws its own current.

Series-Parallel Circuit

A third arrangement is the combination of the series and the parallel circuits. Part of the circuit is in series and part in parallel, as shown in Fig. 1.8. The same current flows through each element of the series portion of the circuit. The current in the parallel part of the circuit divides, and only a portion of the current flows through each of the parallel paths.

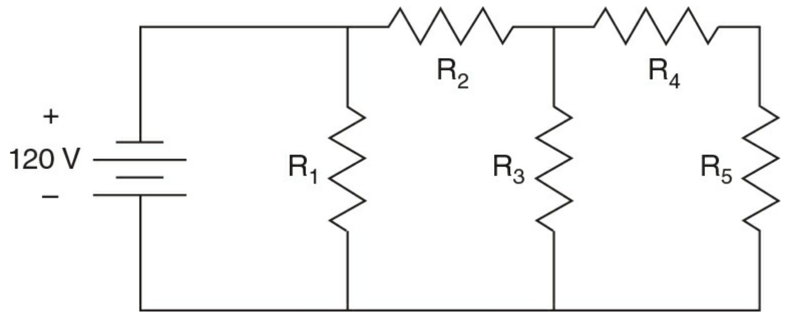


FIGURE 1.8 A series-parallel circuit.

Electric System

The circuits in Figs. 1.4 and 1.5 can be seen to consist essentially of three main divisions. The section where the electricity is produced is called the generator section. That part of the circuit which furnishes the path for the current from the place where it is generated to where it is ultimately used is the transmission section, and the section where the electricity is distributed and used is the distribution division. In the distribution division, electricity is used to light, heat, cool, and power. An actual electric circuit has three parts: a generating station, a transmission line, and a distribution system. An electric circuit with the different components is called an electric system.

The wires of the system serve to carry the electricity just as highways carry automobiles and railroad tracks carry trains. The reason one does not see the electricity moving along the wire is because it is invisible. The wires and transformers appear lifeless; however, they are very much alive and ready to do almost any work for us.

One should look on the generation, transmission, and distribution of electrical energy as one does on the manufacture, shipment, and delivery of goods. Electricity is different from a manufactured product, like shoes. The manufacturer of shoes can estimate the demand for shoes and then manufacture them in advance and put them in a warehouse. Electricity has to be manufactured or generated at the very instant when it is wanted. The customer flips a light switch to the on position or turns on the electric range and an order is flashed back through the distribution system (the retail outlet), the substation (the warehouse), the transmission line (bulk transportation), to the generator (the factory), and delivery of electricity must be made immediately.

It is important to observe that the current path or the transmission line must have a return wire just as water must have a return pipe. The water passes out along the pipe in one side of the circuit, through the water motor, where it does its work, and then returns to the rotary pump in the other pipe (Fig. 1.4). The electricity passes out along one wire to the motor, does its work, and then returns to the generator in the other wire (Fig. 1.5), a path similar to the water circuit.

Electric Current

It has been pointed out that the flow of electricity in a wire is similar to the flow of water in a pipe. When water flows in a pipe, one speaks of a current of water or a water current. Similarly, when electricity flows in a wire, it is called an electric current.

Ampere (Amp)

Generally, we want to know how much water is flowing in the pipe, and we answer by saying “10 gal/sec.” In the same way, we can express how much electricity is flowing in a wire by saying “25 amperes.” The ampere (amp) is the unit of electric current. One can learn how much an ampere is by watching what it can do. An ordinary 60-watt, 120-volt incandescent lamp will require ½ amp. This means that ½ amp is flowing through it all the time that it is glowing.

Ammeter

If we wish to measure the current of water flowing through a pipe, we place a meter right in the pipeline. A meter for measuring the flow of water in a pipe is called a flow-meter. When such a meter is placed in the line, water flows through it, and the meter indicates the number of gallons per second which pass through it. It is clear that the meter must be inserted in the pipe so that the water flows through it. The number of amperes of electric current flowing in a circuit can be measured by connecting a current meter or an ampere meter in the circuit, as shown in Fig. 1.9. Since such a meter is to read amperes, it is called an ampere meter or an ammeter. It should be noted that the ammeter is inserted in the line in order that all the current taken by the motor may pass through the meter.

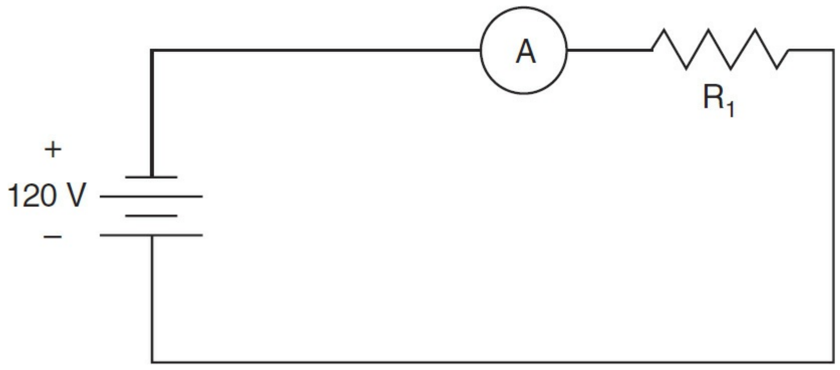


FIGURE 1.9 Ammeter in an electric circuit.

Electric Pressure

We know that a pressure causes a current of water to flow in a pipe. Likewise, in order for current to flow in a circuit, an electric pressure must be present. Voltage is the electric force or pressure that is required. Voltage is determined by the potential difference between any two points in a circuit. Generators and batteries are devices that supply voltage to circuits.

A hand valve in the water circuit will stop the flow of water if it is closed. The water pressure would still be there, but water would not flow through the water motor or the pipe. This can be demonstrated by turning off the water faucet in the kitchen sink. The water flow ceases, but the pressure is still there. A switch placed in the electric circuit will likewise prevent the flow of current if it is in the open position. The electric pressure will still be there with the switch open if the generator is being driven by the engine. Thus, there can be pressure and no current.

Volt

One must be able to talk of its strength to learn something about electrical pressure. This requires a unit with which to measure it; that unit is the volt. One volt will cause 1 amp to flow when impressed across a 1-ohm resistor. We can learn how much a volt is by observing what it can do. We can note, for example, how much pressure or how many volts are required, in general, to force a current through a doorbell, an iron, a washing-machine motor, an electric range, a small factory motor, and a large factory motor. The most common values are as follows:

An electric doorbell requires 2 volts to 5 volts.
An electric iron requires 120 volts.
A washing-machine motor requires 120 volts.
An electric range requires 240 volts.
A small factory motor requires 208 volts, 240 volts, or 480 volts.
A large factory motor requires 2,400 volts to 7,200 volts.

These values simply mean that so many volts are required to push or force the working current through the devices or machines.

One can gain an idea of the strength of electric pressure by observing how much of a shock is received when one puts one's hands across the two wires of a circuit. Under dry conditions, a person cannot detect or feel as little as 5 volts of electrical pressure but can feel 50 volts. At 120 volts, nearly everyone will get a very unpleasant shock, even when a very light and brief contact is made with the wires. It may prove fatal if a firm contact is made with the wires energized at 120 volts. If the hands should be moist or wet and if a firm grasp is made across 120 volts, death is likely to result. All voltages should be considered as dangerous and handled with great care. All higher voltages should be well guarded, and no one except an authorized, fully trained, and qualified person has any business getting near them. System voltages of 600 volts or less are classified as low voltages or utilization voltages in the *American National Standards Institute* (ANSI) standard C84.1 for Electric Power Systems and Equipment—Voltage Ratings (60 Hz). System voltages of over 600 volts to 69,000 volts are classified as medium voltages, distribution voltages, or subtransmission voltages. System voltages of over 69,000 volts to 230,000 volts are classified as high voltages or transmission voltages. System voltages of over 230,000 volts to 1 million volts are classified as extra-high voltages (EHV) or transmission voltages. Voltages of 1 million volts or more are classified as ultra-high voltages (UHV) or experimental voltages.

Voltmeter

If we wish to measure the pressure in a water circuit, all we do is tap a pressure gauge onto the pipeline. Everyone is familiar with such a gauge. The few points to be noted are that the gauge is simply tapped on the pipeline at the point at which the pressure is wanted so that the pressure at that place can get up into the gauge and make it indicate. It is also evident that flow of water in the pipe is not disturbed by insertion of the gauge.

In the same manner, we can measure electric pressure. Electric pressure or voltage is measured utilizing the voltmeter. The voltmeter measures in volts the potential difference between two points in an electric circuit. We simply connect the two leads from a voltmeter across the line, as shown in Fig. 1.10. The current through the voltmeter will then vary directly with the voltage, and the meter can be made to read volts. It is to be noted that the current which flows to the motor does not flow through the voltmeter. This is because the voltmeter is not a part of the circuit as the ammeter is. Figure 1.11 shows the two meters, the ammeter and voltmeter, properly connected. The ammeter reads the flow of current, and the voltmeter reads the pressure which causes the current to flow.

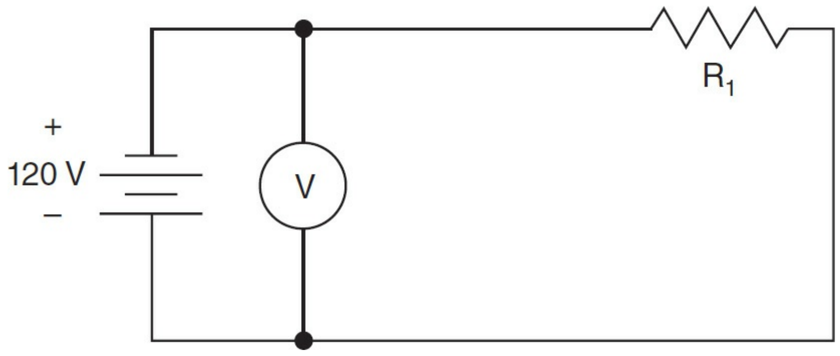


FIGURE 1.10 Voltmeter in an electric circuit.

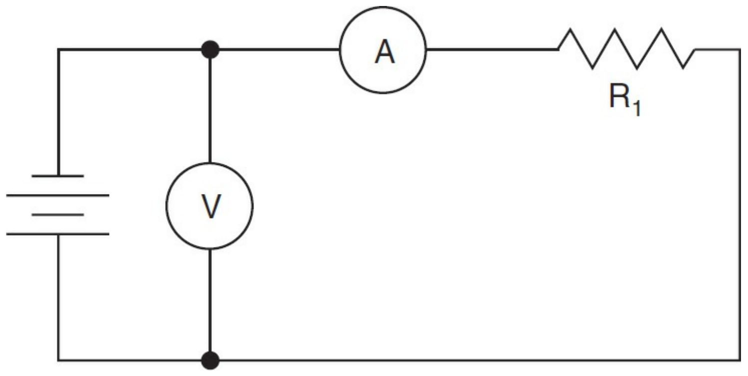


FIGURE 1.11 Ammeter and voltmeter correctly connected.

Water Power

We have likened an electric current to a current of water. When a current of water flows in a pipe in a simple circuit, as shown in Fig. 1.4, power is delivered to the water motor. We know this because the water motor revolves and can do work. The power delivered depends on the amount of water flowing and the pressure under which it flows. This is self-evident, for more power will be developed if 50 gal/sec flows through the water motor than if only 25 gal/sec flows through it. Furthermore, more power will be developed with 100 lb of pressure than with only 50 lb of pressure. The power delivered in the pipeline to the motor thus depends on the amount of water flowing and on the pressure.

Electric Power

The amount of power delivered by an electric circuit to an electric motor depends on the number of amperes flowing and the number of volts of pressure in exactly the same way as in water power. The greater the current, the larger the number of amperes, the greater will be the amount of power developed by it; and the greater the pressure, the more effect the current will have. The actual value of power in a direct-current circuit (not true for an alternating-current circuit) is equal to the product of volts times amperes; thus,

$$\text{Power} = \text{volts} \times \text{amperes}$$

Watt

The unit of power in an electric circuit is the watt. An ordinary incandescent electric lamp, when connected to an electric circuit, as in Fig.

1.12, will draw about 150 watts from the circuit. An ordinary iron, when connected to a circuit, will draw about 550 watts of power from it. The motor shown schematically in Fig. 1.13 will draw about 5,600 watts of power. It is plain that when we come to large machines, the number of watts runs up quickly. Thus, the utilization of decimal system units to quantify amounts is preferred. The decimal system is based on units and powers of 10. The unit for 1,000 is called kilo; therefore, 1,000 watts is called 1 kilowatt. This unit is abbreviated kW. A kilowatt is equal to about 1-1/3 hp. The motor in Fig. 1.13 thus draws 5.6 kW of power, or

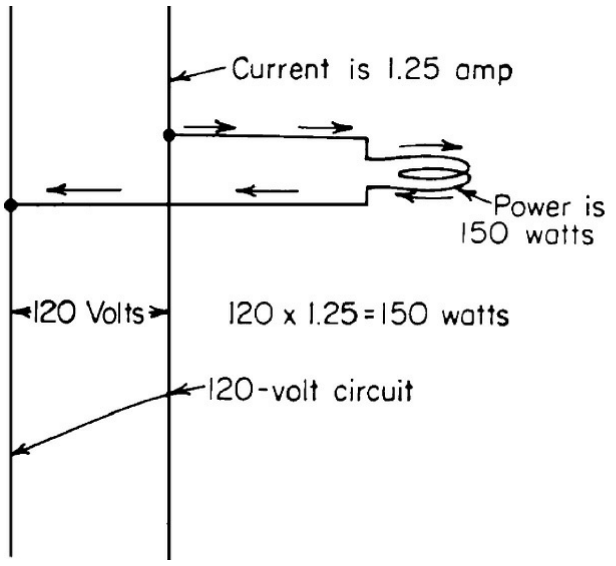


FIGURE 1.12 Electric lamp taking 1.25 amps and 150 watts from 120-volt circuit.

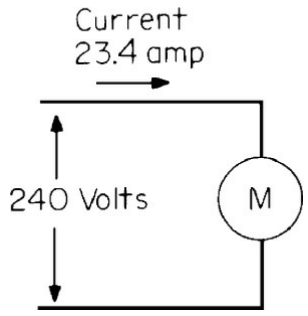


FIGURE 1.13 Motor drawing 23.4 amps of current and 5,600 watts of power.

$$5.6 \text{ kW} \times 1\text{-}1/3 \text{ hp/kW} = 7\tfrac{1}{2} \text{ hp}.$$

Wattmeter

We have to measure electric power to know how much power any device or apparatus is drawing from the line. A wattmeter registers watts or kilowatts, and by reading it one can tell how much power any piece of apparatus is consuming. The amount of electric power delivered by a