ELECTRICAL WIRING INDUSTRIAL

Based on the 2014 National Electrical Code®

15TH EDITION

STEPHEN L. HERMAN

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Contents

CHAPTER 19

CHAPTER 20

Preface

INTENDED USE AND LEVEL

Electrical Wiring—Industrial is intended for use in industrial wiring courses at two-year community and technical colleges. The text walks the reader step by step through an industrial building, providing the basics on installing industrial wiring systems. An accompanying set of plans at the back of the book allows the student to proceed step by step through the wiring process by applying concepts learned in each chapter to an actual industrial building, in order to understand and meet requirements set forth by the *National Electrical Code*® (*NEC*®).

SUBJECT AND APPROACH

The fifteenth edition of *Electrical Wiring—Industrial* is based on the 2014 *NEC*. The *NEC* is used as the basic standard for the layout and construction of electrical systems. To gain the greatest benefit from this text, the learner must use the *NEC* on a continuing basis.

> In addition to the *NEC*, the instructor should provide the learner with applicable state and local wiring regulations as they may affect the industrial installation.

In addition to the accurate interpretation of the requirements of the *NEC,* the successful completion of any wiring installation requires the electrician to have a thorough understanding of basic electrical principles, a knowledge of the tools and materials used in installations, familiarity with commonly installed equipment and the specific wiring requirements of the equipment, the ability to interpret electrical construction drawings, and a constant awareness of safe wiring practices.

Electrical Wiring—Industrial builds upon the knowledge and experience gained from working with the other texts in the Delmar Cengage Learning electrical wiring series and related titles. The basic skills developed through previous applications are now directed to industrial installations. The industrial electrician is responsible for the installation of electrical service, power, lighting, and special systems in new construction; the changeover from old systems to new in established industrial buildings; the provision of additional electrical capacity to meet the growth requirements of an industrial building; and periodic maintenance and repair of the various systems and components in the building.

FEATURES

An introduction to *plans and sitework* is the topic of the first chapter in the book, providing explanations of identifying symbols and interpreting the plans in order to help orient the student to the industrial job site. *Examples* are integrated into the text and take the student step by step through problems, to illustrate how to derive solutions using newly introduced mathematical formulas and calculations. *Industrial building drawings* are included in the back of the book, offering students the opportunity to apply the concepts that they have learned in each chapter as they step through the wiring process. *Review questions* at the end of each chapter allow students to test what they have learned and to target any sections that require further review.

NEW TO THIS EDITION

- Updated to the 2014 *National Electrical Code*
- New information concerning grounding and bonding
- Extended coverage of service-entrance connections
- New information concerning the maintenance of transformers
- New information on timing relays
- Additional coverage of multispeed squirrel-cage motors
- Added information concerning motor nameplate data
- Additional coverage of power factor
- New information concerning 3-phase power and connections

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This edition of *Electrical Wiring—Industrial* was completed after all normal steps of revising the *NEC* NFPA 70 were taken and before the actual issuance and publication of the 2014 edition of the *NEC*. These steps include the following:

- The National Fire Protection Association (NFPA) solicits proposals for the 2014 *NEC*.
- Interested parties submit proposals to the NFPA.
- Proposals are sent to Code-Making Panels (CMPs).
- CMPs and the Technical Correlating Committee review proposals.
- Report on Proposals document is published.
- Interested parties submit comments on the proposals to the NFPA.
- CMPs and Technical Correlating Committee review comments.
- Report on comments document is published.
- Review of all Proposals and Comments is conducted at the NFPA Annual Meeting.
- New motions are permitted to be made at the NFPA Annual Meeting.
- Finally, the Standard Council meets to review actions made at the NFPA Annual Meeting and to authorize publication of the *NEC*.

Every effort has been made to be technically correct, but there is the possibility of typographical errors or appeals made to the NFPA board of directors after the normal review process that could result in reversal of previous decisions by the CMPs.

If changes in the *NEC* do occur after the printing of this book, these changes will be incorporated in the next printing.

The NFPA has a standard procedure to introduce changes between *Code* cycles after the actual *NEC* is printed. These are called *Tentative Interim Amendments,* or TIAs. TIAs and corrected typographical errors can be downloaded from the NFPA website, http://www.nfpa.org, to make your copy of the *Code* current.

SUPPLEMENTS

The Instructor Resources CD contains an Instructor Guide as a PDF with answers to all review questions included in the book, as well as an ExamView test-bank, chapter presentations, and a topical presentation in PowerPoint. (order #: 978-1-2850-5440-7).

Visit us at http://www.delmarelectric.com, now LIVE for the 2014 Code cycle!

This newly designed website provides information on other learning materials offered by Cengage Learning, as well as industry links, career profiles, job opportunities, and more!

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ABOUT THE AUTHOR

Stephen L. Herman has been both a teacher of industrial electricity and an industrial electrician for many years. He received his formal education at Catawba Valley Technical College in Hickory, North Carolina. After working as an industrial electrician for several years, he became the Electrical Installation and Maintenance instructor at Randolph Technical College in Asheboro, North Carolina. After nine years, he returned to industry as an electrician. Mr. Herman later became the lead Electrical Technology instructor at Lee College in Baytown, Texas. After serving 20 years at Lee College, he retired from teaching and now lives with his wife in Pittsburg, Texas. Mr. Herman has received the Halliburton Education Foundation's award for excellence in teaching. He has been a guest speaker at professional organizations and has three times been a judge for the national motor control competition at Skills USA.

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CHAPTER 1

Plans and Sitework

OBJECTIVES

After studying this chapter, the student should be able to

- read site plans to determine the location of the specific items.
- select materials for electrical sitework.
- identify underground wiring methods.
- perform International System of Units (SI) to English and English to SI conversions.
- calculate metric measurements.

CONSTRUCTION PLANS

An electrician who has previously wired a residence or a commercial building is familiar with electrical floor plans and symbols. Although the electrical plans and symbols are basically similar for an industrial building project, additional emphasis is often placed on the sitework. The electrician must continually coordinate and work with the general foreman who is employed by the general contractor.

After the contract for the project is awarded, the electrical contractor must inspect the site plans to determine the approximate location of the industrial building on the site, as well as the locations of underground wiring, raceways, and manholes. The contractor then moves a trailer to the site and locates it so that it will require a minimal amount of relocation during construction. This trailer is used to store materials and tools during the construction of the building.

Building Location

The building location is given on the site plan by referring to existing points such as the centerline of a street. If the electrical contractor and the crew arrive on the site before the general contractor arrives, they are not required to "stake out" (locate) the building. However, they should be able to determine its approximate location. A site plan, such as the one given on Sheet Z-1 of the industrial building plans included in this text, shows the property lines and the centerlines of the street from which the electrician can locate the building and other site improvements.

EXPLANATION OF PLAN SYMBOLS

Contour Lines

Contour lines are given on the site plan to indicate the existing and the new grading levels. If the required underground electrical work is to be installed before the grading is complete, trenches must be provided with enough depth to ensure that the installations have the proper cover after the final grading. The responsibility of who does the ditch-work (general contractor or electrician) is usually agreed upon before the contract is awarded.

Figure 1-1 gives the standard symbols used on construction site plans for contour lines and other features.

Benchmark

The benchmark (BM), as given on the site plan, is the reference point from which all elevations are located. The benchmark elevation is established by the surveyor responsible for the preliminary survey of the industrial site. This BM elevation is related to a city datum or to the mean sea level value for the site. The elevation is usually given in feet and tenths of a foot. For example, an elevation of 123.4 ft is read as "one hundred twenty-three and four-tenths feet." Table 1-1 is used in making conversions from tenths of a foot to inches.

Elevations

The electrician must give careful attention to the elevations of the proposed building. These details are shown on Sheet Z-1 of the enclosed plans for the industrial building. These drawings provide valuable information concerning the building construction. Measurements on the elevations may be a plus or a minus reference to the BM elevation as given on the site plan.

Invert Elevation (INV)

When an invert elevation (INV) is given, this quantity indicates the level of the *lower* edge of the inside of a conduit entering the manhole (this conduit is usually the lower one in an installation). Refer ahead to Figure 1-19.

Site Plan Scales

Residential site plans generally are drawn to the same scale as is used on the building plans; that is, $\frac{1}{8}'' = 1'\text{-}0''$ or $\frac{1}{4}'' = 1'\text{-}0''$. However, industrial building site

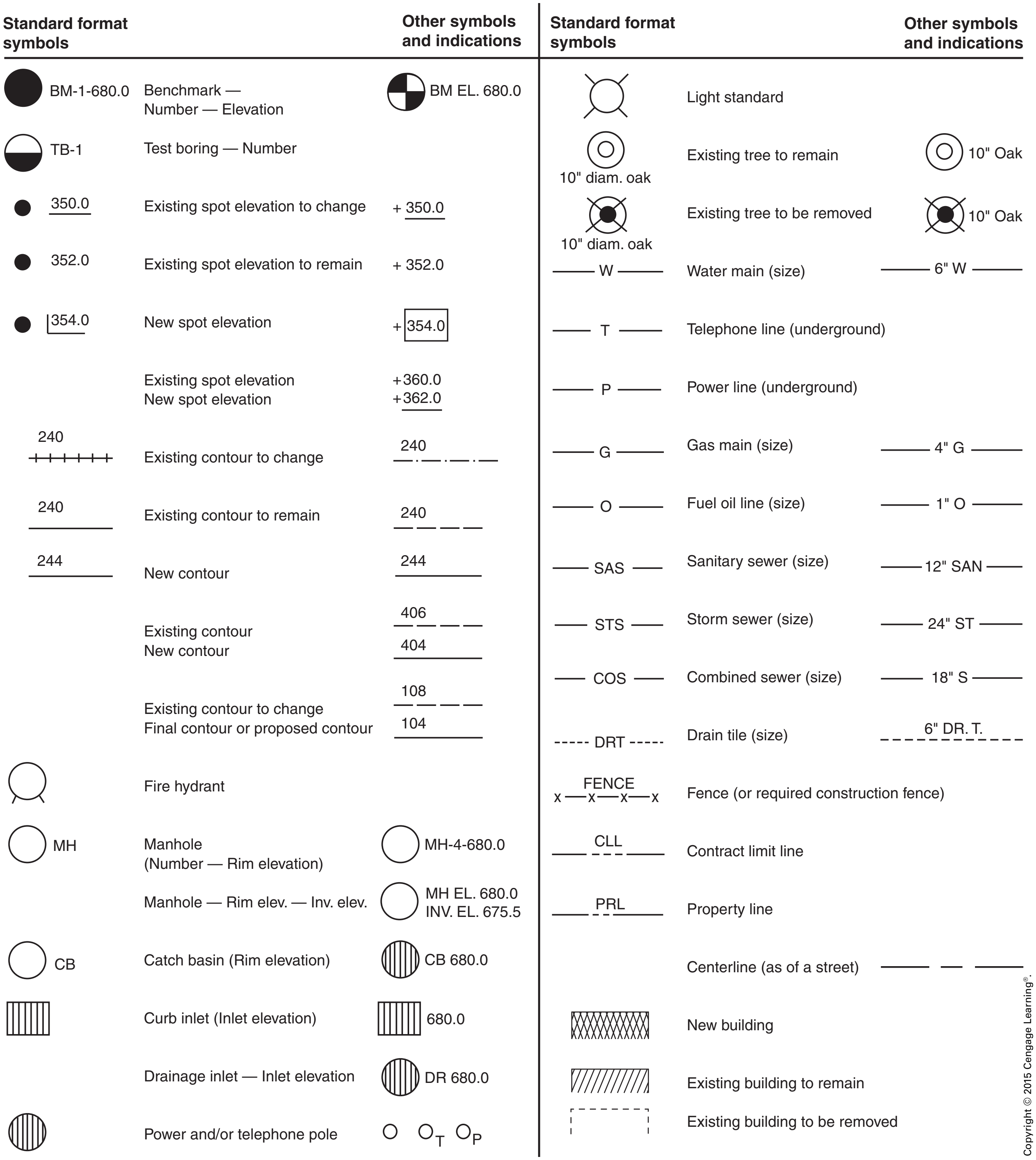

FIGURE 1-1 Site plan symbols.

TABLE 1-1

Conversions of tenths of a foot to inches.

TENTHS	DECIMAL	FRACTIONAL
0.1 ft	1.2 in.	1³⁄₁₆ in.
0.2 ft	2.4 in.	2⅜ in.
0.3 ft	3.6 in.	3⅝ in.
0.4 ft	4.8 in.	4¹³⁄₁₆ in.
0.5 ft	6 in.	6 in.
0.6 ft	7.2 in.	7³⁄₁₆ in.
0.7 ft	8.4 in.	8⅜ in.
0.8 ft	9.6 in.	9⅝ in.
0.9 ft	10.8 in.	10¹³⁄₁₆ in.

plans typically use scales ranging from 1″ = 20′ and 1″ = 30′ up to 1″ = 60′. It is recommended that the electrician use a special measuring device, called a scale, to measure the site plans, Figure 1-2.

SITEWORK

There may be requirements for several different types of electrical systems to be installed on the site apart from the building itself. The electrician should review the plans and specifications carefully to be aware of all requirements. It is then the responsibility of the electrical contractor/electrician to ensure that these requirements are met and that installations are made at the most advantageous time and in a fashion that will not conflict with sitework being carried out by other trades.

TESTING THE SITE FOR GROUNDING REQUIREMENTS

When determining the site for a building, one of the most important considerations is the system ground. Proper grounding helps protect against transient currents, electrical noise, and lightning strikes. Several methods can be used to test the electrical grounding system. The effectiveness of the grounding system greatly depends on the resistivity of the earth at the location of the system ground. The resistivity of the earth varies greatly throughout the world and even within small areas. Many factors affect the earth's resistivity such as soil type (clay, shell, sand, etc.), moisture content, electrolyte content (acids, salts, etc.), and temperature.

In theory, the system ground is considered to have a resistance of zero because it is connected to system grounds everywhere, via the neutral conductor, Figure 1-3. In actual practice, however, the current carrying capacity of the grounding system can vary greatly from one area to another.

Testing

There are different methods for determining the resistivity of the grounding system. An old method used by electricians for many years is to connect a 100-watt lamp between the ungrounded (hot) conductor and the grounding conductor, Figure 1-4. To perform this test, the grounding conductor must be disconnected from the neutral bus in the panel. The brightness of the lamp gives an indication of the effectiveness of the grounding system. Although this

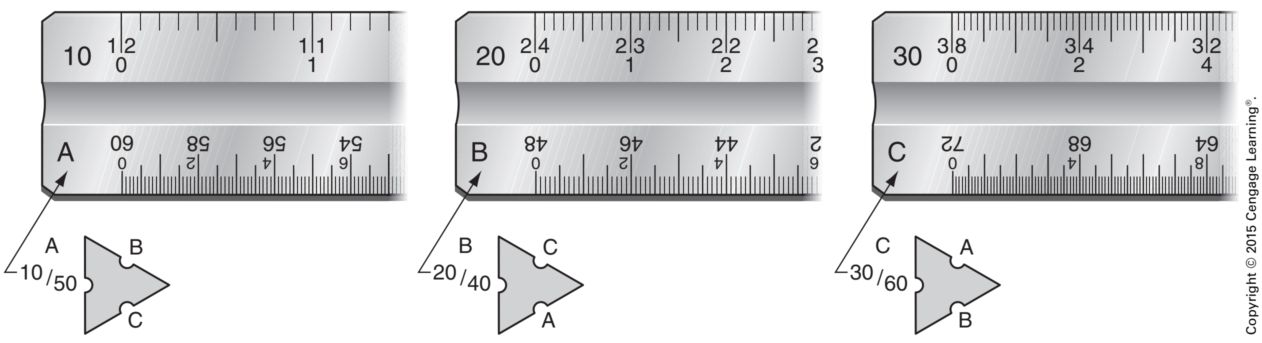

FIGURE 1-2 Scale.

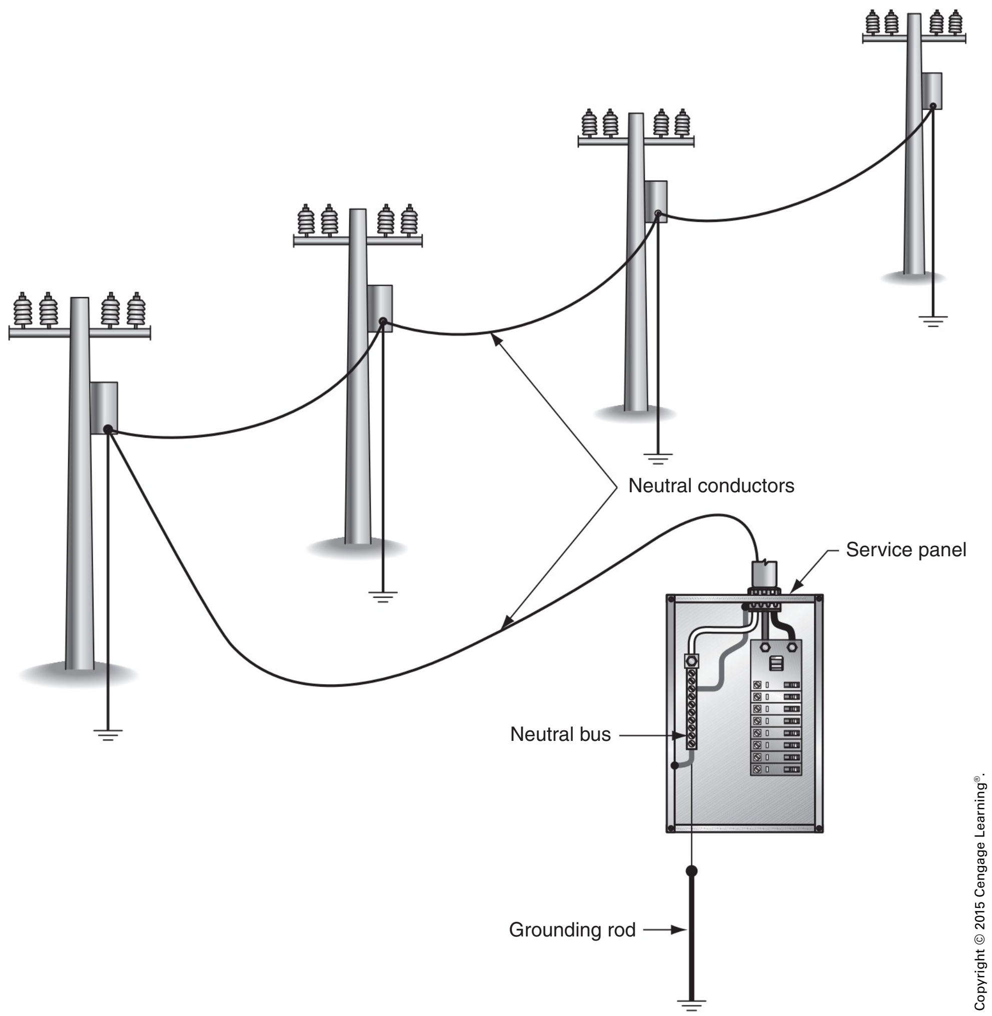

FIGURE 1-3 All neutral conductors are bonded together, forming a continuous grounding system.

test indicates whether the grounding system works, it does not indicate the actual resistance of the system. To measure the actual resistance of the grounding system requires the use of special equipment such as a ground resistance tester, Figure 1-5. There are three main tests used to measure ground resistance: the Wenner four-point test, the three-point fall-of-potential test, and the clamp-on ground resistance test.

The Wenner Four-Point Method

The Wenner four-point test is generally performed before building construction begins. This method measures the ground resistance over a wide area. The results are used in designing the grounding system to ensure that it performs properly. This test requires the use of a 4-pole ground resistance meter, four metal rods, and conductors. The four rods are driven into the ground in a straight line, with equal space between each rod, Figure 1-6. To perform this test, the ground resistance tester produces a known amount of current between rods C1 and C2, producing a voltage drop across rods P1 and P2. The amount of voltage drop is proportional to the amount of current and ground resistance. Readings are generally taken with probes C1 and C2 spaced 5, 10, 15, 20, 30, 40, 60, 80, and 100 feet apart. If possible, it is recommended to perform the test with the probes spaced 150 feet apart.

The calculated soil resistance is the average of the soil resistance from the surface to a depth equal to the space between the probes. If the probes are set 30 feet apart, for example, each probe will provide an average resistance measurement from the surface to a depth of 30 feet. The tests should not only be made with the

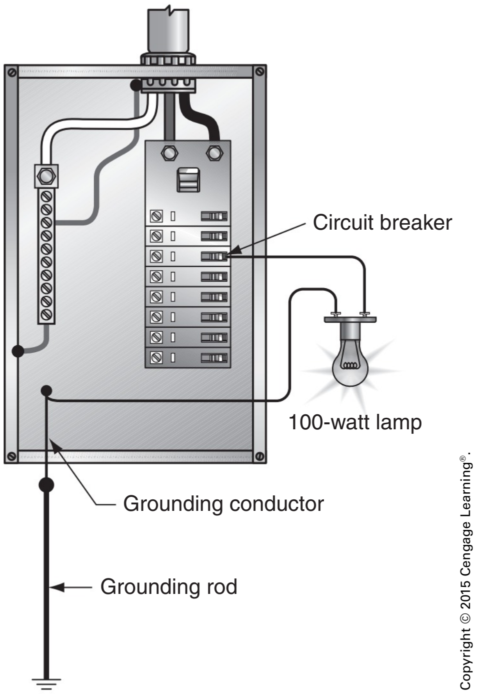

FIGURE 1-4 A 100-watt lamp is used to test the grounding system.

FIGURE 1-5 Ground resistance tester.

probes spaced different distances apart but also with the probes in different directions from a central point. If the site is large enough, it is generally recommended to perform the test along at least two sides, generally from one corner to the other. It should be noted that underground structures such as metal water pipes can influence the readings. The best results will be obtained by gathering as much data as possible.

Three-Point Fall-of-Potential Test

The fall-of-potential test requires the use of a ground resistance meter. It is performed after the installation of the grounding system and should be done annually to ensure the quality of the grounding system. Annual testing provides protection against the degradation of the system before damage to equipment and performance problems occur.

In the three-point fall-of-potential test, the three points of ground contact are

1. the system ground (grounding rod) (point A);
2. a current probe placed some distance from the grounding rod (point B); and
3. a voltage probe that is inserted at various distances between the grounding rod and the current probe (C). The voltage probe is placed in a straight line between the grounding rod and the current probe.

Ideally, the current probe (B) should be placed at a distance that is at least 10 times the length of the grounding rod (A), Figure 1-7. If the grounding rod is 8 feet in length, the current probe should be placed at least 80 feet from the grounding rod.

To perform this test, the grounding rod must be disconnected (electrically isolated) from the neutral bus in the service panel. Failure to do so will completely invalidate the test. The meter provides a known amount of current that flows from the current probe and back to the meter through the system grounding rod. The resistance of the earth causes a voltage drop that is measured between the current probe and the voltage probe. The amount of voltage drop is proportional to the amount of current flow and the ground resistance. Resistance readings should be taken at several locations by moving the voltage probe a distance equal to 10% of the distance between the system grounding rod and the current probe. If performed properly, the

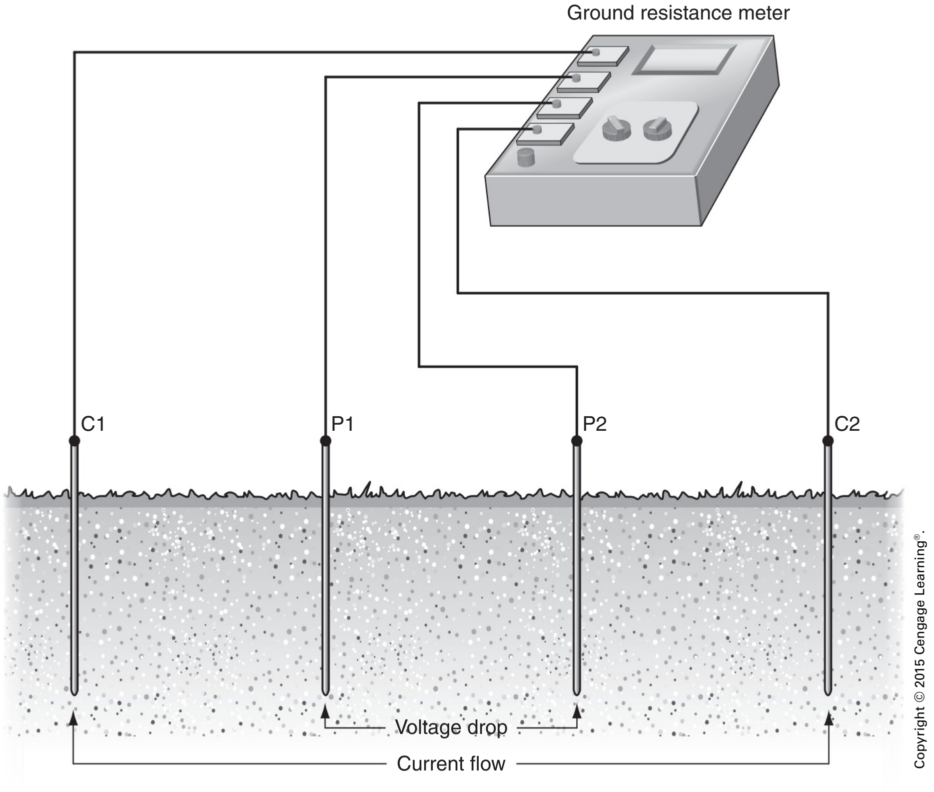

FIGURE 1-6 The Wenner four-point test.

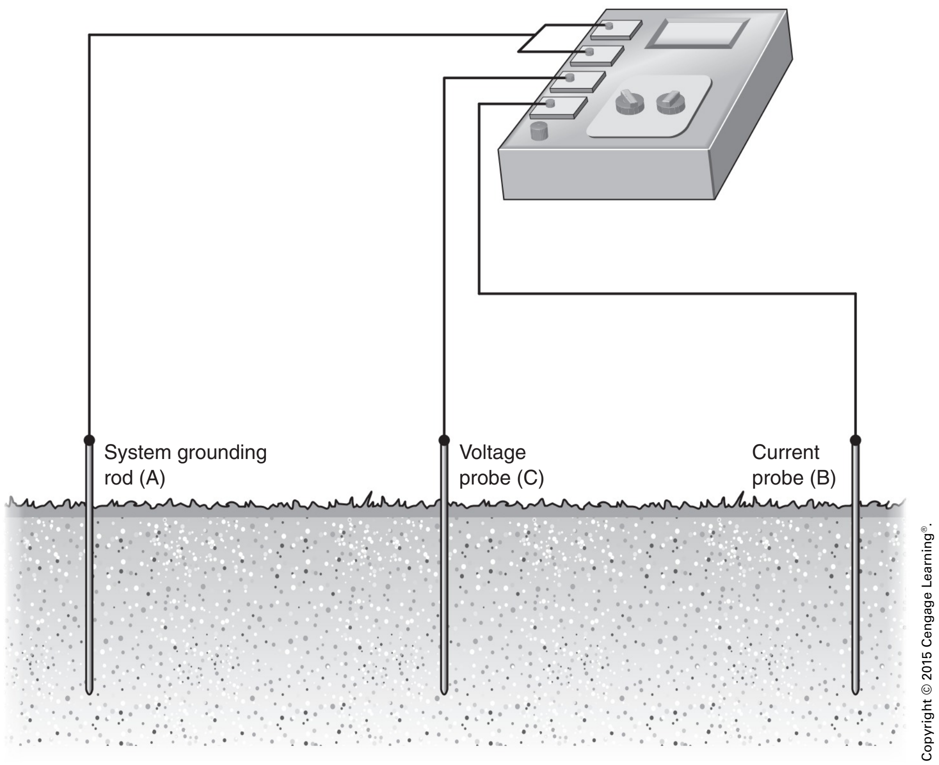

FIGURE 1-7 The three-point fall-of-potential test.

three-point ground resistance test is the most accurate method of determining ground resistance.

The Clamp-On Ground Resistance Test

The clamp-on ground resistance test requires the use of a special clamp-on ground resistance meter. This test has several advantages over the three-point fall-of-potential test.

1. The service grounding system does not have to be disconnected and isolated from the neutral bus.
2. There are no probes that have to be driven into the ground or long connecting conductors.
3. The neutral conductor supplied by the utility company ties innumerable grounds together in parallel. The clamp-on ground tester measures the effective resistance of the entire grounding system.
4. Because this test is performed by a clamp-on meter, there are no connections that have to be broken or reconnected, resulting in a safer procedure, Figure 1-8.

The clamp-on ground resistance tester, Figure 1-9, contains two transformers. One transformer induces a small fixed voltage at approximately 2 kHz on the grounding conductor. If a path exists, the voltage will result in a current flow. The path is provided by the grounding system under test, the utility neutral, and the utility grounding system. The second transformer inside the meter senses the amount of current at the unique frequency provided by the first transformer. The amount of current is proportional to the induced voltage and the resistance of the grounding system. The meter uses the two known electrical quantities to calculate the resistance of the grounding system.

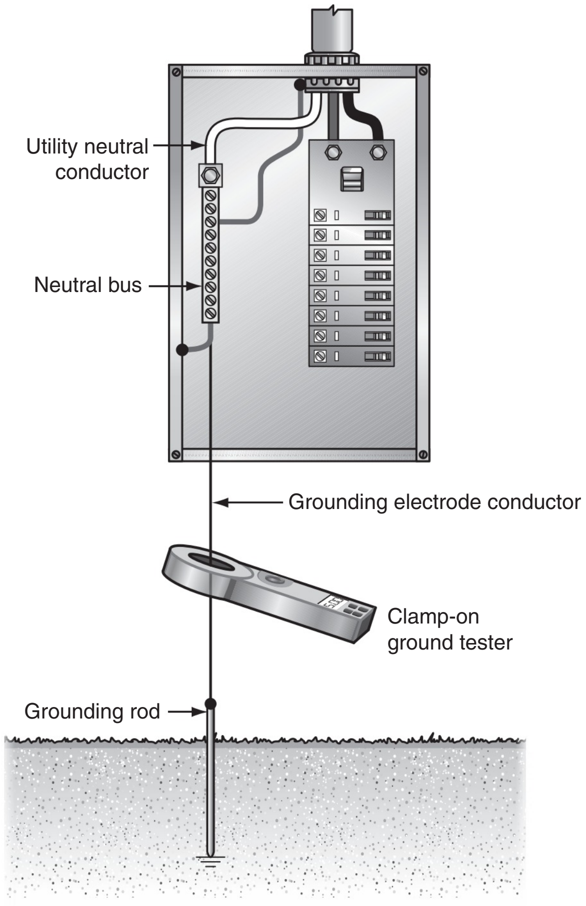

FIGURE 1-8 The clamp-on ground resistance test.

Courtesy of AEMC® Instruments

FIGURE 1-9 Ground resistance tester.

Grounding and Bonding Considerations

Many technicians and electricians pay little attention to grounding and know only the basic requirements specified by the *National Electrical Code*. However, grounding is one of the most important parts of any electrical installation. Proper grounding protects circuits and equipment from destruction and personnel from injury. Grounding is generally thought of as connecting a system to earth via a grounding electrode, as shown in Figure 1-8. In reality, grounding is connecting a circuit to a common point of reference. Almost all grounded systems are connected to earth, which is a common point of reference, but the earth generally does not provide the low-impedance path necessary to protect against ground-fault currents. *NEC 250.4(A)(5)* states, The earth shall not be considered an effective ground-fault current path.

Grounding not only provides a low-impedance path for fault currents, but it also provides a common point of reference for different electrical systems and voltages, Figure 1-10. A low-impedance path exists from the alternator supplying power to the last device connected to the circuit. The alternator has an output of 13.8 kV, which is stepped up to 138 kV for transmission. The voltage is stepped back down to 13.8 kV at a unit substation. The plant substation steps the voltage down to 480 volts to feed the plant bus system. Other 3-phase and single-phase transformers are powered by the plant bus. A battery backup system is used by an uninterruptable power supply. All of these different power systems and voltages are connected together via grounding conductors. Grounding is also used to protect against lightning, static electricity, and the influence of high frequency. It should be noted, however, that the grounding requirements listed in the *National Electrical Code* are intended for direct current and 60-hertz AC systems. These requirements may not provide an effective ground for high frequency. Alternating current systems are subject to skin effect, which is the tendency of electrons to move toward the surface of a conductor, Figure 1-11.

The higher the frequency, the greater the skin effect. At a frequency of 10 MHz, a 6 AWG copper conductor may exhibit a resistance of several thousand ohms. High-frequency circuits must be grounded with a conductor that contains a large surface area, such as braided cable or wide copper tape.

Safety

Besides providing a common point of connection for different systems and voltages, grounding plays

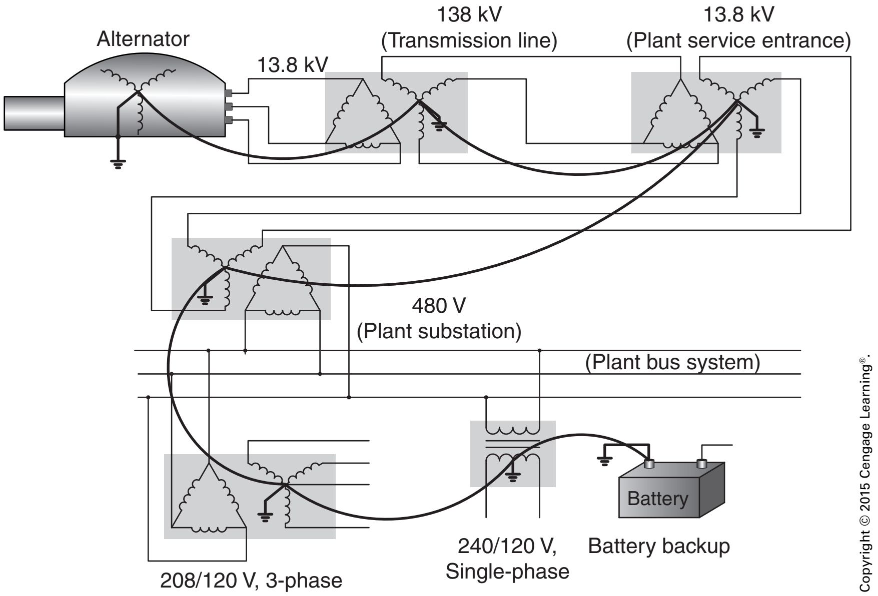

FIGURE 1-10 A low-impedance ground is connected throughout the system.