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ELECTRICIAN'S EXAM QUESTIONS & ANSWERS

ALL NEW 14TH EDITION

Paul Rosenberg

Audel™

Questions and Answers for Electrician's Examinations

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Introduction

Tips on Taking Tests

It is the author's experience that, for most electricians, knowing how to take a test is almost as important as knowing the technical information, as far as obtaining a passing grade is concerned. A great number of electricians fear tests more than they fear 480 volts.

Really, there is no good reason why this should be so. After all, if hundreds of thousands of men and women can pass these tests, anyone interested who gives a real effort and pays particular attention to some basic rules can succeed. Some basic rules for taking tests are these:

1. Know the material being covered.
2. Know the format of the test.
3. Be physically and mentally prepared on the exam day.
4. RELAX!
5. Work the test the smartest way you can.

The first point—knowing the material being covered—is a mandatory prerequisite. Most test failures come from violating this rule. No, it isn't always easy to learn all the material on a test. It requires hours, sometimes many hours, of studying when you'd rather be doing other things. It means that you have to make your brain work harder than it wants to, going over the material again and again. Sorry, but unless you have an exceptional aptitude for learning, there are no shortcuts for hard, intense study. A good study guide (like this book) is about as much help as you can get.

The second rule for taking tests is that you need to *know the format of the test*. Some of the things you need to know are:

How many questions are on the test?
How many questions are open-book?
How many are closed-book?
Do all questions count for the same number of points?
Is there a penalty for wrong answers?
How much time is allowed for each section of the test?
Who wrote the test?
How will the test be graded?

By knowing the answers to these questions, you can plan your efforts intelligently. For example, if certain questions will count for more points than others, you should be ready to spend more time and effort on those questions. By knowing the time limits, you can calculate how much time you have for each question, etc. Get answers to all of these questions and consider all of these facts as you prepare for the exam.

Now, as for *being physically and mentally prepared*, I think most readers are familiar with the way athletes prepare for an event. They make sure they eat the right kinds of food so that they have enough energy. They get plenty of sleep, and they come to the event planning on winning. The same thing should be done in preparation for a test.

The most important factor is what was mentioned above—planning on winning. Psychologists have found that the results one achieves are directly related to what one expects to receive. If you believe that you will do well, you are quite likely to do well; if you believe that you will do poorly, you probably will. Remember, it does not matter what you wish for; what matters is what you actually expect to happen. I'll pass on to you one of my favorite quotes along these lines. It comes from Robert J. Ringer: "The results you produce in life are inversely proportional to the degree to which you are intimidated."

If you want to improve your confidence (expectations) in your test-taking abilities, picture yourself as having aced the test. Refuse to imagine yourself failing, and spend as much time studying as is necessary for you to believe in yourself.

On the day of a test, you want to walk in well rested (but not still groggy), having been well fed (but not full), and with a subdued confidence. Generally, heavy studying the night before the test is not a good idea. Do a light review and leisurely go over a difficult part of the information if you like, but the night before is not the time to get intense. You should have been intense two weeks ago. The night before the test is a time to eat well and to go to bed early. Try not to eat within two or three hours of the test, as it tends to bog you down. It has been said that mental efficiency is highest on an empty stomach.

Confidence is built on a good knowledge of the material to be covered and the ability to pass with style.

Upon entering the test location, *relaxing* is very important. If you choke up during the test, you are automatically taking five points off your score, possibly more. You should have the same attitude as the runner who shows up for a race he knows he will win. He is ready to run his fastest, but he is not nervous because he knows that his fastest is good enough.

Before taking the test, clear your mind, don't get involved with trivial conversations, and then, when it is time to answer the questions, dig into the test with your full strength.

During the test, first answer all of the easy questions; pass up the hard questions for now, and *do only the ones you know for sure*. Then, once you have answered these questions, don't go over them again; just move on to the next group of questions. Next, do the questions that will require some work, but don't do the most difficult questions; save them for last. It is silly to waste half of your time on one difficult question. Do the 47 easier questions, and then come back to the three especially difficult ones.

Work the test in the smartest possible way. Pay attention to time requirements, books allowed during open-book tests, etc. For your electrical exam, you should definitely put tabs on your Code book. Bring an electronic calculator with you and some scratch paper (as long as you are allowed to). Rather than buying a set of Code book tabs, I recommend that you do your own. Tab the index and the sections of the Code that you most commonly use. I generally put tabs on the following:

Tables 250.66 & 250.122 (Sizes of ground wires)
Table 310.16 (Wire ampacities)
Appendix C (Conduit fill tables)
Article 230 (Services)
Table 300.5 (Burial depths)
Table 370.6 (Number of wires in boxes)
Article 430 (Motors)
Article 450 (Transformers)
Article 490 (Over 600 volts)
Article 500 (Hazardous location wiring)
Article 700 (Emergency systems)

Remember

If hundreds of thousands of other people have passed these tests, you can too—if you prepare.

Business Competency Examinations

In recent years, many municipalities have added business competency examinations to their standard Master Electrician examinations. In reality, they didn't have much choice. Since 1980, the number of licensed electrical contractors has skyrocketed, causing a great number of problems. Most of these problems were the result not of a lack of technical knowledge but of bad business practices. After some study, the various State Departments of Professional Regulation found out that while the newly licensed electrical contractors were proficient at trade skills they were woefully inadequate in business skills.

In an effort to ensure that newly licensed contractors are knowledgeable in business, new sections have been added to many competency examinations. Typically, 25 percent of a Master Electrician exam is dedicated to business skills and knowledge. The following are the topics usually covered:

1. Taxes
2. Unemployment and worker's compensation
3. OSHA and safety
4. Lien laws
5. Business skills

To help familiarize you with the various requirements and reference sources, each of these topics will be briefly discussed and then followed with questions and answers.

The *Taxes* section of such tests covers withholding of employee taxes. The information needed to answer these questions can be found in various IRS publications. (The easiest way to obtain these publications is to download them from the IRS's web site—http://www.irs.ustreas.gov/businesses/index.html.) Knowing the proper rules for withholding federal income tax, social security, federal unemployment, and state taxes is critical, not only for your test but also in order to operate a business. Let me state this clearly: The IRS is neither understanding nor compassionate, and it won't cut you even a little bit of slack for an ignorant infraction of its rules. The business of the IRS is to collect as much of your money as it is entitled to. Learn the rules for the test, and if and when you open a business, engage the services of a good accountant.

Unemployment compensation is paid directly to the state by the employer. It is not deducted from the employee's wages. Rates vary, and there are a number of requirements for anyone receiving this compensation. All of the required information can be found in a booklet called "Unemployment Compensation Handbook," which is available through various sources, including your public library.

Worker's compensation is handled on the state level, and the requirements vary from state to state; because of this, you will have to get local requirements from your state government. The people who administer your local test should be able to guide you to the right place.

OSHA (Occupational Safety and Health Administration) establishes rules to ensure that no employee is subjected to dangers to his or her safety or health. The OSHA regulations can be found in "OSHA Standard 2207, Part 1926." There are too many regulations to memorize, but one must be familiar enough with the book to be able to find the answer to any question easily.

Each state has its own *lien laws*. Copies of the regulations must be obtained through your own state government, although the testing agency administering your test can probably tell you exactly how to get them. Liens are very important in the construction business and have been developed primarily for the benefit of the contractor.

The *business skills* part of the test deals mostly with banks, financing, and basic management skills. As a reference source for the exam, "Tax Guide for Small Business" is recommended. This book, published by the IRS Division of the Treasury Department, is available from your local office of the Small Business Administration (SBA). There are many, many other business books available (and I would hope that anyone going into business would read several), but this handbook addresses the material in the test more directly.

You should remember, however, that the business skills covered by these tests are not enough to ensure success in business. In addition to these skills, you will need skill in dealing with people, the ability to analyze a market, and the ability to make and follow through on decisions. This test covers only academic business skills; to actually make money, you will need other skills also.

I-1 If a certain employee spends less than half of his time during a pay period performing services that are subject to taxation, how much of his or her pay is taxable?

All employees are taxable.

I-2 If an employer fails to make federal income tax deposits when they are due, how large a penalty will they be assessed?

10 percent.

I-3 A self-employed person is considered an employee. True or false?

False.

I-4 What form must be used to correct errors in withholding taxes?

941C.

I-5 What would be the take-home pay of a worker who claims one deduction, is married, and who earns $500.00 per week (without state or local taxes)?

500.00	
(56.00)	Federal Income Tax Withholding
(31.00)	Social Security
(7.25)	Medicare
$405.75	

I-6 For unemployment taxation, the term "employer" includes any person or organization that paid ________ or more in wages in any quarter or had employees at any time in 20 weeks of the year.

$1,500.00.

I-7 If an employee is paid $325.00 per week, how much Social Security and Medicare tax should be deducted from his or her wages?

$325.00 \times 7.65\% = \$24.86$.

I-8 What form is used to get an Employer Identification Number?

SS-4.

I-9 What form must a new employee sign before beginning work?

W-4.

I-10 If an employer has _____ or more employees in 20 or more weeks, the employer must file a Form 940 Federal Unemployment Act.

1.

I-11 On what portion of his or her wages must an employee contribute for state unemployment compensation?

The first $9,000.00 of wages.

I-12 Casual labor is labor that is occasional, incidental, and not exceeding ___ working days in duration.
10.

I-13 Does a temporary light fixture with a reflector that deeply recesses its bulb require a guard?
No.

I-14 How long may double cleat ladders be?
15 feet.

I-15 What is the angle of repose for average soil?
45 degrees.

I-16 How many gallons of flammable liquid can be stored in a room outside of an approved storage cabinet?
25.

I-17 When an interior-hung scaffold is suspended from the beams of a ceiling, what percentage of the rated load must the suspending wire be capable of supporting?
600 percent (six times the rated load).

I-18 What is the proper maintenance procedure for an "ABC" dry-chemical stored-pressure fire extinguisher?
Check the pressure gauge and the condition of the chemical annually.

I-19 Workers should not be exposed to impulsive or impact noises louder than _____ decibels.
140.

I-20 What is the standard height for a guardrail?
42 inches.

I-21 What is the minimum size (OSHA requirement) of a conductor to a ground rod?
#2 AWG copper.

I-22 For a scaffold with a working load of 75 pounds per square feet, what is the maximum span for a 2″ × 12″ plank?
7 feet.

I-23 Loaded powder-activated tools may not be left _______.
Unattended.

I-24 What should be the predominant color of caution signs?
Yellow.

I-25 For 225 employees on a construction site, how many toilets must be provided?
Five toilet seats and five urinals.

I-26 When safety belts are used, the maximum distance of fall must be ______.
6 feet.

I-27 What is the minimum lighting level in a field construction office?
30 foot-candles.

I-28 Manually handled lumber cannot be stacked higher than ______.
16 feet.

I-29 What is the term for the claims of a creditor against the assets of a business?
Liabilities.

I-30 Small Business Administration loans can be guaranteed up to ______.
90 percent.

I-31 Would taxes be considered a liability?
Yes.

I-32 The assets of a business, minus its liabilities, are called its _______.
Equity.

I-33 Accounts receivable financing is normally based on receivables that are how old?
70 to 90 days.

I-34 If your company has gross sales of $210,000.00 and expenses of $198,500.00, what percentage of profit did it make?
5.5 percent.

I-35 An agreement by which you get exclusive use of a certain item for a stated period of time is called a ______.
Lease.

I-36 What is the minimum rate of return sought by most venture capitalists?

It is currently around 10 percent (or higher), but this figure can be modified by changes in interest rates, inflation, etc.

I-37 A one-year line of credit refers to a note that is renewable for one year at ___-day intervals.

90.

I-38 What is the term for a plan of cash receipts and expenditures for a certain period of time?

A cash budget.

I-39 What is the term for the money required to carry accounts receivable, cover payrolls, and buy products?

Working capital.

I-40 Is an 18-year-old boy, employed by his parents, exempt from Social Security tax?

Yes.

I-41 Is a wife, employed by her husband, subject to Social Security tax?

No.

I-42 What are the two primary account methods?

Cash accounting and accrual.

I-43 Are all types of business activities voluntary?

No, the payment of taxes is enforced. Almost every other type of business activity is voluntary between the parties involved.

I-44 What type of law covers the awarding of damages for accidental injuries and the like?

Torts.

I-45 Define "overhead."

"Overhead" is the money necessary to keep a company operating, even if there is no one working in the field. It includes everything except material, labor, and job expenses. Office expenses, office salaries, sales expenses, office equipment, vehicles, and similar expenses are considered to be overhead.

I-46 What does the term "Net 30" indicate?

"Net 30" indicates a payment procedure. In general, it means that if one party to a transaction presents a valid invoice, it will be paid by the other party within 30 days.

I-47 What is "cash flow," and why is it important?

"Cash flow" is a general term describing the flow of cash within a company. It is important because electrical construction work is almost always done on credit, sometimes leaving the contractor in a situation in which he or she is making a lot of money but hasn't collected it yet and therefore has no cash with which to pay bills. Insufficient cash has been the ruin of many construction firms.

I-48 What are the functions of profit in a company?

There are two. The first is to offset risks. Without some extra money in a contract, even a small difficulty would cause the project to go over budget. The second is to give the owners of the company a return on their investment. If the owners did not get a return on their money, they would have no reason to put it to use in the company.

I-49 What are job expenses?

Expenses—such as storage trailer rental, tool rentals, and job telephones—that are caused by the project and not by continuing operations.

I-50 How does OSHA make sure that their rules are followed?

By imposing fines on companies that are judged to be in violation.

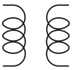
Electrical Symbols

To avoid confusion, ASA policy requires that the same symbol not be included in more than one Standard. If the same symbol were used in two or more Standards and one of these Standards were revised, changing the meaning of the symbol, considerable confusion could arise over which symbol was correct, the revised or unrevised.

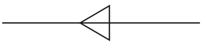
The symbols in this category include, but are not limited to, those listed below. The reference numbers are the American Standard Y32.2 item numbers.

46.3 *Electric motor*

46.2 *Electric generator*



86.1 *Power transformer*



82.1 *Pothead (cable termination)*

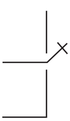
48 *Electric watthour meter*

12.2 *Circuit element, e.g., circuit breaker*

11.1 *Circuit breaker*

36 *Fusible element*

76.3 *Single-throw knife switch*



76.2 *Double-throw knife switch*

13.1 *Ground*

7 *Battery*

Electrical Symbols.

List of Symbols

1.0 Lighting Outlets

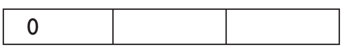
Ceiling Wall

1.1 *Surface or pendant incandescent, mercury vapor, or similar lamp fixture*

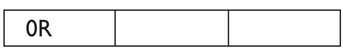
1.2 *Recessed incandescent, mercury vapor, or similar lamp fixture*

1.3 *Surface or pendant individual fluorescent fixture*

1.4 *Recessed individual fluorescent fixture*



1.5 *Surface or pendant continuous-row fluorescent fixture*



1.6 *Recessed continuous-row fluorescent fixture**

1.7 *Bare-lamp fluorescent strip***

1.8 *Surface or pendant exit light*

1.9 *Recessed exit light*

(continued)

*In the case of combination continuous-row fluorescent and incandescent spotlights, use combinations of the above Standard symbols.

**In the case of a continuous-row bare-lamp fluorescent strip above an area-wide diffusion means, show each fixture run, using the Standard symbol; indicate area of diffusing means and type of light shading and/or drawing notation.

1.10 Blanked outlet

1.11 Junction box

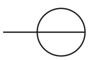
1.12 Outlet controlled by low-voltage switching when relay is installed in outlet box

Lighting Outlets.

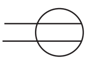
2.0 Receptacle Outlets

Unless noted to the contrary, it should be assumed that every receptacle will be grounded and will have a separate grounding contact.

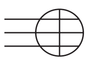
Use the uppercase subscript letters described under Section 2 item a-2 of this Standard when weatherproof, explosion-proof, or some other specific type of device will be required.



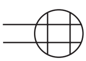
2.1 Single receptacle outlet



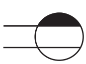
2.2 Duplex receptacle outlet



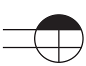
2.3 Triplex receptacle outlet



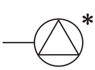
2.4 Quadruplex receptacle outlet



2.5 Duplex receptacle outlet—split wired



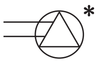
2.6 Triplex receptacle outlet—split wired



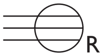
*2.7 Single special-purpose receptacle outlet**

(*continued*)

*Use numeral or letter, either within the symbol or as a subscript alongside the symbol keyed to explanation in the drawing list of symbols, to indicate type of receptacle or usage.

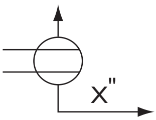


*2.8 Duplex special-purpose receptacle outlet**



2.9 Range outlet

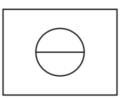
2.10 Special-purpose connection or provision for connection. Use subscript letters to indicate function (DW—dishwasher; CD—clothes dryer, etc.)



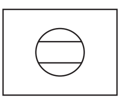
2.11 Multioutlet assembly. Extend arrows to limit of installation. Use appropriate symbol to indicate type of outlet. Also indicate spacing of outlets as x inches.

2.12 Clock Hanger Receptacle

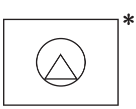
2.13 Fan Hanger Receptacle



2.14 Floor Single Receptacle Outlet



2.15 Floor Duplex Receptacle Outlet



*2.16 Floor Special-Purpose Outlet**

(*continued*)

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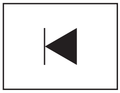
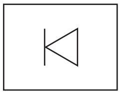
*Use numeral or letter, either within the symbol or as a subscript alongside the symbol keyed to explanation in the drawing list of symbols, to indicate type of receptacle or usage.

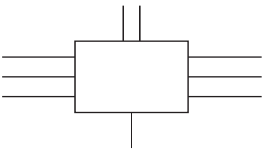


2.17 Floor Telephone Outlet—Public

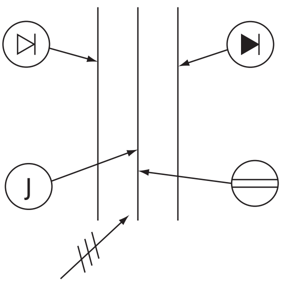


2.18 Floor Telephone Outlet—Private

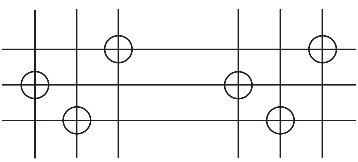
Not a part of the Standard: example of the use of several floor outlet symbols to identify a 2-, 3-, or more-gang floor outlet



2.19 Underfloor Duct and Junction Box for Triple, Double or Single Duct System as indicated by the number of parallel lines



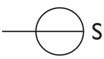
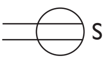
Not a part of the Standard: example of use of various symbols to identify location of different types of outlets or connections for underfloor duct or cellular floor systems



2.20 Cellular Floor Header Duct

Receptacle Outlets.

3.0 Switch Outlets

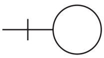
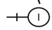
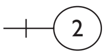
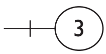
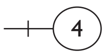
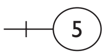
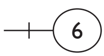
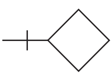
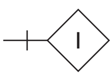
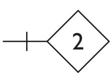
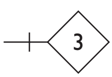
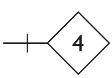
S	*3.1*	*Single-pole switch*
S_2	*3.2*	*Double-pole switch*
S_3	*3.3*	*Three-way switch*
S_4	*3.4*	*Four-way switch*
S_K	*3.5*	*Key-operated switch*
S_P	*3.6*	*Switch and pilot lamp*
S_L	*3.7*	*Switch for low-voltage switching system*
S_{LM}	*3.8*	*Master switch for low-voltage switching system*
	*3.9*	*Switch and single receptacle*
	*3.10*	*Switch and double receptacle*
S_D	*3.11*	*Door switch*
S_T	*3.12*	*Time switch*
S_{CB}	*3.13*	*Circuit-breaker switch*
S_{MC}	*3.14*	*Momentary contact switch or pushbutton for other than signaling system*

Switch Outlets.

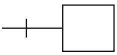
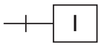
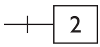
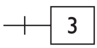
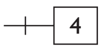
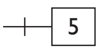
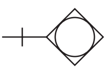
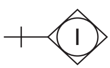
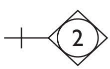
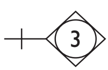
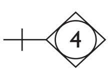
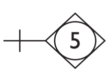
Signaling System Outlets

4.0 Institutional, Commercial, and Industrial Occupancies

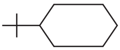
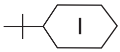
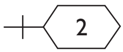
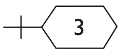
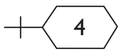
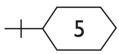
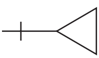
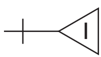
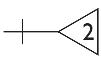
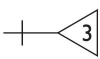
These symbols are recommended by the American Standards Association but are not used universally. The reader should remember not to assume that these symbols will be used on any certain plan and should always check the symbol list on the plans to verify whether these symbols are actually used.

Basic Symbol	Examples of Individual Item Identification (Not a part of the Standard)	
		4.1 I. Nurse Call System Devices (and type)
		*Nurses' Annunciator (can add a number after it as*  *24 to indicate number of lamps)*
		*Call station, single cord, pilot light*
		*Call station, double cord, microphone speaker*
		*Corridor dome light, 1 lamp*
		*Transformer*
		*Any other item on same system—use numbers as required.*
		4.2 II. Paging System Devices (any type)
		*Keyboard*
		*Flush annunciator*
		*2-face annunciator*
		*Any other item on same system—use numbers as required.*

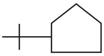
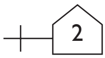
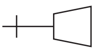
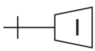
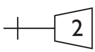
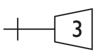
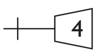
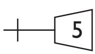
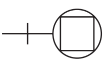
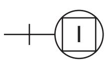
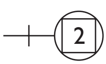
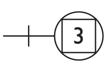
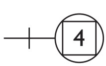
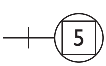
(continued)

Basic Symbol	Examples of Individual Item Identification (Not a part of the Standard)		
		4.3	**III. Fire Alarm System Devices (any type) including Smoke and Sprinkler Alarm Devices**
			*Control panel*
			*Station*
			*10″ Gong*
			*Pre-signal chime*
			*Any other item on same system—use numbers as required.*
		4.4	**IV. Staff Register System Devices (any type)**
			*Phone operators' register*
			*Entrance register—flush*
			*Staff room register*
			*Transformer*
			*Any other item on same system—use numbers as required.*

(continued)

Basic Symbol	Examples of Individual Item Identification (Not a part of the Standard)	
		4.5 V. Electric Clock System Devices (any type)
		*Master clock*
		*12″ Secondary—flush*
		*12″ Double dial—wall-mounted*
		*18″ Skeleton dial*
		*Any other item on same system—use numbers as required.*
		4.6 VI. Public Telephone System Devices
		*Switchboard*
		*Desk phone*
		*Any other item on same system—use numbers as required.*
		4.7 VII. Private Telephone System Devices (any type)
		*Switchboard*
		*Wall phone*
		*Any other item on same system—use numbers as required.*

(*continued*)

Basic Symbol	Examples of Individual Item Identification (Not a part of the Standard)	
		4.8 VIII. Watchman System Devices (any type)
		*Central station*
		*Key station*
		*Any other item on same system—use numbers as required.*
		4.9 IX. Sound System
		*Amplifier*
		*Microphone*
		*Interior speaker*
		*Exterior speaker*
		*Any other item on same system—use numbers as required.*
		4.10 X. Other Signal System Devices
		*Buzzer*
		*Bell*
		*Pushbutton*
		*Annunciator*
		*Any other item on same system—use numbers as required.*

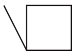
Institutional, Commercial, and Industrial Occupancies.

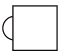
Signaling System Outlets

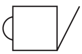
5.0 Residential Occupancies

When a descriptive symbol list is not employed, use the following signaling system symbols to identify standardized, residential-type, signal-system items on residential drawings. Use the basic symbols with a descriptive symbol list when other signal-system items are to be identified.

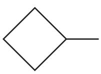

5.1 *Pushbutton*


5.2 *Buzzer*


5.3 *Bell*

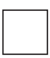

5.4 *Combination bell-buzzer*

5.5 *Chime*


5.6 *Annunciator*

5.7 *Electric door opener*

5.8 *Maid's signal plug*


5.9 *Interconnection box*

5.10 *Bell-ringing transformer*


5.11 *Outside telephone*


5.12 *Interconnecting telephone*

5.13 *Radio outlet*

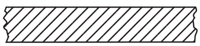
5.14 *Television outlet*

Residential Occupancies.

6.0 Panelboards, Switchboards, and Related Equipment

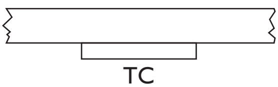
6.1 *Flush-mounted panelboard and cabinet**

6.2 *Surface-mounted panelboard and cabinet**

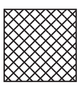


6.3 *Switchboard, power control center, unit substations*—should be drawn to scale*

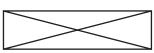
6.4 *Flush-mounted terminal cabinet.* In small-scale drawings the TC may be indicated alongside the symbol.*



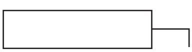
6.5 *Surface-mounted terminal cabinet.* In small-scale drawings the TC may be indicated alongside the symbol.*



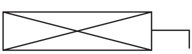
6.6 *Pull box (identify in relation to wiring section and sizes)*



6.7 *Motor or other power controller**



6.8 *Externally-operated disconnection switch**



6.9 *Combination controller and disconnection means**

Panelboards, Switchboards, and Related Equipment.

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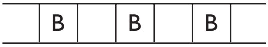
*Identify by notation or schedule.

7.0 Bus Ducts and Wireways

*7.1 Trolley duct**



*7.2 Busway (service, feeder, or plug-in)**

*7.3 Cable trough ladder or channel**

*7.4 Wireway**

Bus Ducts and Wireways.

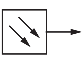
8.0 Remote Control Stations for Motors or Other Equipment*

8.1 Pushbutton station

8.2 Float switch—mechanical

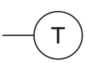
8.3 Limit switch—mechanical

8.4 Pneumatic switch—mechanical



8.5 Electric eye—beam source

8.6 Electric eye—relay



8.7 Thermostat

Remote Control Stations for Motor or Other Equipment.

*Identify by notation or schedule.

9.0 Circuiting

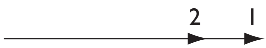
Wiring method identification by notation on drawing or in specification.

9.1 Wiring concealed in ceiling or wall

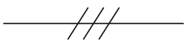
9.2 Wiring concealed in floor

9.3 Wiring exposed

Note: *Use heavyweight line to identify service and feeders. Indicate empty conduit by notation CO (conduit only).*

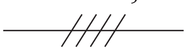


3 wires



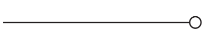
9.4 Branch-circuit home run to panel-board. Number of arrows indicates number of circuits. (A numeral at each arrow may be used to identify circuit number.) Note: Any circuit without further identification indicates two-wire circuit. For a greater number of wires, indicate with cross lines, e.g.:

4 wires, etc.



Unless indicated otherwise, the wire size of the circuit is the minimum size required by the specification.

Identify different functions of wiring system, e.g., signaling system by notation or other means.



9.5 Wiring turned up

9.6 Wiring turned down

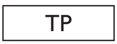
Circuiting.

10.0 Electric Distribution or Lighting System, Underground

*10.1 Manhole**

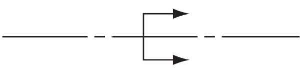
*10.2 Handhole**

*10.3 Transformer manhole or vault**

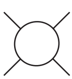


*10.4 Transformer pad**

10.5 Underground direct burial cable. Indicate type, size, and number of conductors by notation or schedule.



10.6 Underground duct line. Indicate type, size, and number of ducts by cross-section identification of each run by notation or schedule. Indicate type, size, and number of conductors by notation or schedule.



*10.7 Streetlight standard feed from underground circuit**

Electric Distribution or Lighting System, Underground.

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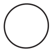
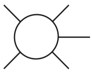
*Identify by notation or schedule.

11.0 Electric Distribution or Lighting System, Aerial

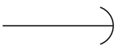

*11.1 Pole**


*11.2 Streetlight and bracket**

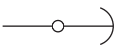

*11.3 Transformer**

*11.4 Primary circuit**

*11.5 Secondary circuit**


11.6 Down guy


11.7 Head guy

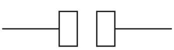

11.8 Sidewalk guy


*11.9 Service weather head**

Electrical Distribution or Lighting System Aerial.

4 Arrester, Lighting Arrester (Electric surge, etc.) Gap


4.1 General


4.2 Carbon block

Block, telephone protector

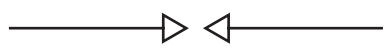
The sides of the rectangle are to be approximately in the ratio of 1 to 2, and the space between rectangles shall be approximately equal to the width of a rectangle.

(continued)

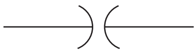
*Identify by notation or schedule.

4.3 Electrolytic or aluminum cell
This symbol is not composed of arrowheads.

4.4 Horn gap



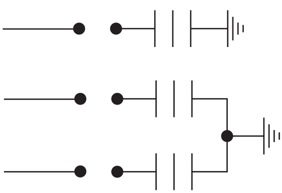
4.5 Protective gap
These triangles shall not be filled.



4.6 Sphere gap

4.7 Valve or film element

4.8 Multigap, general

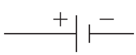


4.9 Application: gap plus valve plus ground, 2-pole4.9 Application: gap plus valve plus ground, 2-pole

Arrester, Lighting Arrester (Electric surge etc.) Gap.

7 Battery

The long line is always positive, but polarity may be indicated in addition. Example:



IEC

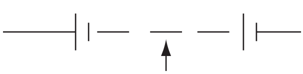
7.1 Generalized direct-current source

7.2 One cell

IEC

7.3 Multicell

7.3.1 Multicell battery with 3 taps



7.3.2 Multicell battery with adjustable tap

Battery.

11 Circuit Breakers

If it is desired to show the condition causing the breaker to trip, the relay-protective-function symbols in item 66.6 may be used alongside the break symbol.

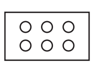
11.1 General

11.2 Air circuit breaker, if distinction is needed; for alternating-current breakers rated at 1,500 volts or less and for all direct-current circuit breakers.

11.2.1 Network protector

See **Note 11.3A**

11.3 Circuit breaker, other than covered by item 11.2. The symbol in the right column is for a 3-pole breaker.

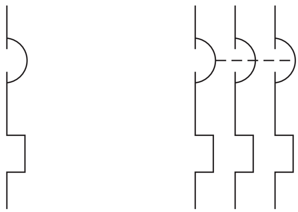


See **Note 11.3A**

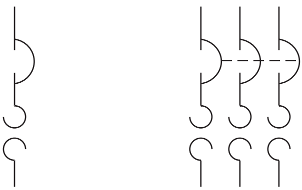
11.3.1 On a connection or wiring diagram, a 3-pole single-throw circuit breaker (with terminals shown) may be drawn as shown.

(*continued*)

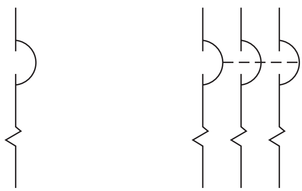
Note 11.3A—On a power diagram, the symbol may be used without other identification. On a composite drawing where confusion with the general circuit element symbol (item 12) may result, add the identifying letters CB inside or adjacent to the square.



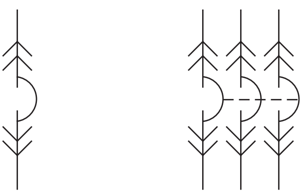
11.4 Applications



11.4.1 3-pole circuit breaker with thermal overload device in all 3 poles



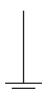
11.4.2 3-pole circuit breaker with magnetic overload device in all 3 poles



11.4.3 3-pole circuit breaker, drawout type

Circuit Breakers.

13 Circuit Return

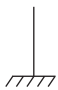


13.1 Ground

(A) A direct conducting connection to the earth or body of water that is a part thereof

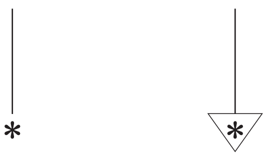
(continued)

(B) A conducting connection to a structure that serves a function similar to that of an earth ground (that is, a structure such as a frame of an air, space, or land vehicle that is not conductively connected to earth)



IEC

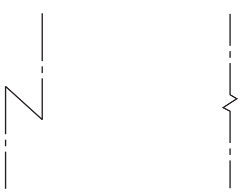
13.2 Chassis or frame connection
A conducting connection to a chassis or frame of a unit. The chassis or frame may be at a substantial potential with respect to the earth or structure in which this chassis or frame is mounted.



13.3 Common connections
*Conducting connections made to one another. All like-designated points are connected. *The asterisk is not a part of the symbol. Identifying valves, letters, numbers, or marks shall replace the asterisk.*

Circuit Return.

15 Coil, Magnetic Blowout*

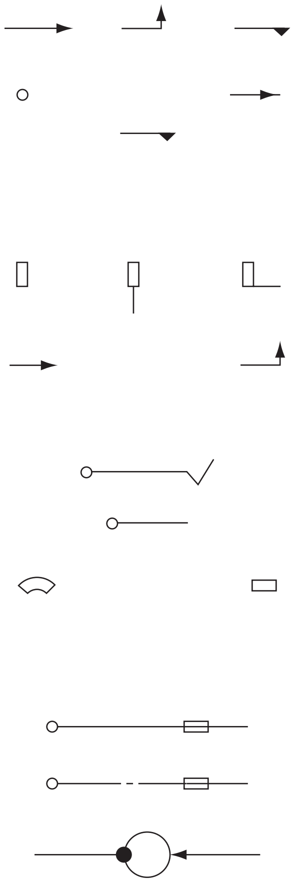


Coil, Magnetic Blowout.

*The broken line (— - —) indicates where line connection to a symbol is made and is not a part of the symbol.

23 Contact, Electrical

For buildups or forms using electrical contacts, see applications under CONNECTOR (item 19), RELAY (item 66), and SWITCH (item 76). See DRAFTING PRACTICES (item 0.4.6).



23.1.1 Fixed contact for jack, key, relay, etc.

23.1.2 Fixed contact for switch

23.1.3 Fixed contact for momentary switch
See SWITCH (item 76.8 and 76.10).

23.1.4 Sleeve

23.2.1. Adjustable or sliding contact for resistor, inductor, etc.

23.2.2 Locking

23.2.3 Segment; bridging contact

23.2.4 Nonlocking
See SWITCH (items 76.12.3 and 76.12.4).

23.2.5 Vibrator reed

23.2.6 Vibrator split reed

23.2.7 Rotating contact (slip ring) and brush

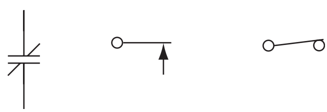
A. Contact, Electrical.

It is standard procedure to show a contact by a symbol that indicates the circuit condition produced when the actuating device is in the nonoperated, or deenergized, position. It may be necessary to add a clarifying note explaining the proper point at which the contact functions—the point where the actuating device (mechanical, electrical, etc.) opens or closes due to changes in pressure, level, flow, voltage, current, etc. When it is necessary to show contacts in the operated, or energized, condition—and where confusion would otherwise result—a clarifying note shall be added to the drawing. Contacts for circuit breakers, auxiliary switches, etc., may be designated as shown below:

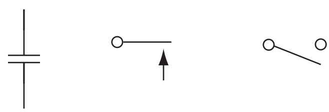
- **(a)** Closed when device is in energized or operated position.
- **(b)** Closed when device is in deenergized or nonoperated position.
- **(aa)** Closed when operating mechanism of main device is in energized or operated position.
- **(bb)** Closed when operating mechanism of main device is in deenergized or nonoperated position.

[See American Standard C37.2-1962 for details.]

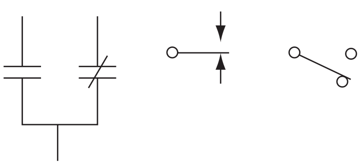
In the parallel-line contact, symbols showing the length of the parallel lines shall be approximately $1\frac{1}{4}$ times the width of the gap (except for item 23.6).



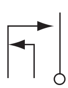
23.3.1 Closed contact (break)
See also SWITCHING FUNCTION (item 77).



23.3.2 Open contact (make)
See also SWITCHING FUNCTION (item 77).



23.3.3 Transfer
See also SWITCHING FUNCTION (item 77).

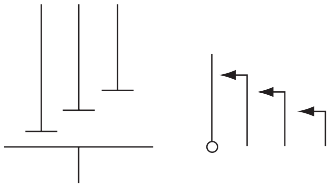


23.3.4 Make-before-break

23.4 Application: open contact with time closing (TC) or time delay closing (TDC) feature

(*continued*)

23.5 Application: closed contact with time opening (TO) or time delay opening (TDO) feature



23.6 Time sequential closing

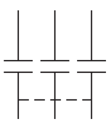
B. Contact, Electrical.

24 Contactor

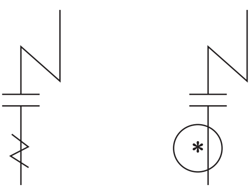
See also RELAY (item 66).

Contactor symbols are derived from fundamental contact, coil, and mechanical connection symbols and should be employed to show contactors on complete diagrams. A complete diagram of the actual contactor device is constructed by combining the abovementioned fundamental symbols for mechanical connections, control circuits, etc.

Mechanical interlocking should be indicated by notes.



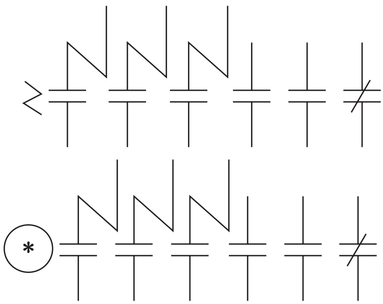
24.1 Manually operated 3-pole contactor



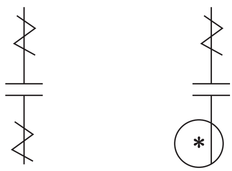
24.2 Electrically operated 1-pole contact or with series blowout coil See Note 24.2A.

(*continued*)

Note 24.2A—The asterisk is not a part of the symbol. Always replace the asterisk by a device designation.



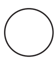
24.3 *Electrically operated 3-pole contactor with series blowout coils; 2 open and 1 closed auxiliary contacts (shown smaller than the main contacts)*



24.4 *Electrically operated 1-pole contactor with shunt blowout coil*

Contactor.

46 Machine, Rotating



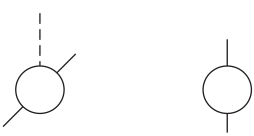
46.1 *Basic*

46.2 *Generator (general)*

46.3 *Motor (general)*

46.4 *Motor, multispeed*

USE BASIC MOTOR SYMBOL AND NOTE SPEEDS



46.5 *Rotating armature with commutator and brushes**

(*continued*)

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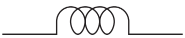
*The broken line (–––) indicates where line connection to a symbol is made and is not a part of the symbol.

46.6 Field, generator or motor
Either symbol of item 42.1 may be used in the following items.

46.6.1 Compensating or commutating

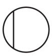
46.6.2 Series



46.6.3 Shunt, or separately excited

46.6.4 Magnet, permanent
See item 47.

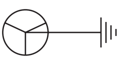
46.7 Winding symbols
Motor and generator winding symbols may be shown in the basic circle using the following representation.



46.7.1 1-phase

46.7.2 2-phase

46.7.3 3-phase wye (ungrounded)



46.7.4 3-phase wye (grounded)

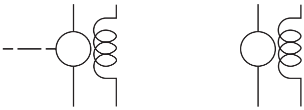
46.7.5 3-phase delta

46.7.6 6-phase diametrical

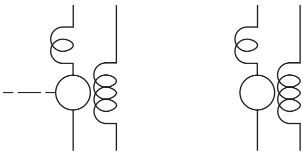
46.7.7 6-phase double-delta

46.8 Direct-current machines; applications

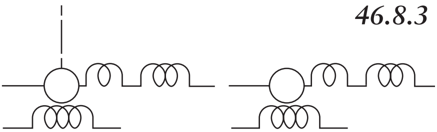
(continued)



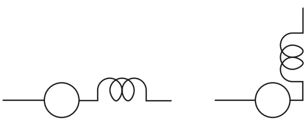
46.8.1 Separately excited direct-current generator or motor*



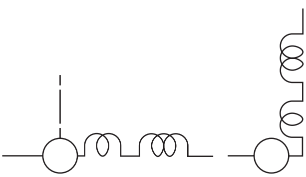
46.8.2 Separately excited direct-current generator or motor; with commutating or compensating field winding or both*



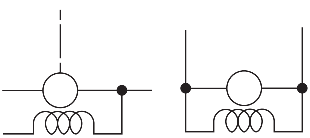
46.8.3 Compositely excited direct-current generator or motor; with commutating or compensating field winding or both*



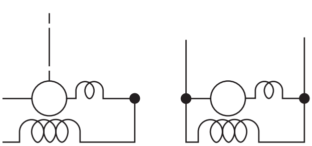
46.8.4 Direct-current series motor or 2-wire generator*



46.8.5 Direct-current series motor or 2-wire generator; with commutating or compensating field winding or both*



46.8.6 Direct-current shunt motor or 2-wire generator*

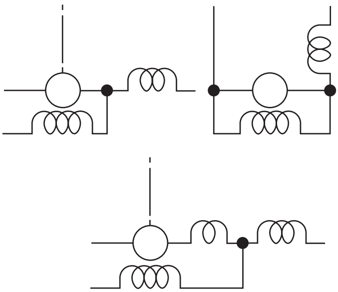


46.8.7 Direct-current shunt motor or 2-wire generator; with commutating or compensating field winding or both*

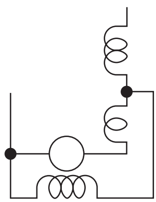
(continued)

*The broken line (- — -) indicates where line connection to a symbol is made and is not a part of the symbol.

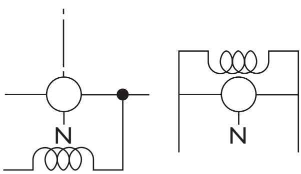
*46.8.8 Direct-current, permanent-magnet field generator or motor**



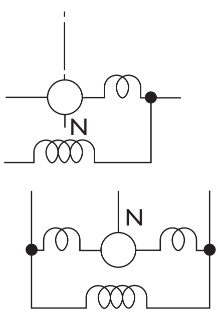
*46.8.9 Direct-current, compound motor or 2-wire generator or stabilized shunt motor**



*46.8.10 Direct-current compound motor or 2-wire generator or stabilized shunt motor; with commutating or compensating field winding or both**



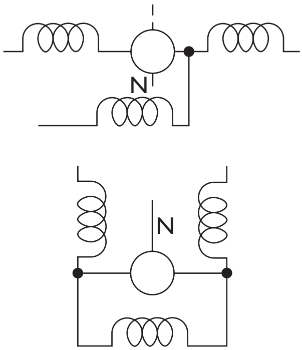
*46.8.11 Direct-current, 3-wire shunt generator**



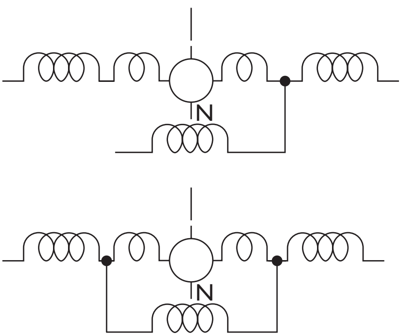
*46.8.12 Direct-current, 3-wire shunt generator; with commutating or compensating field winding or both**

(continued)

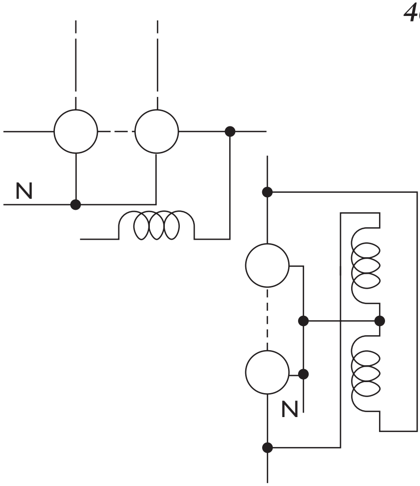
*The broken line (- — -) indicates where line connection to a symbol is made and is not a part of the symbol.



*46.8.13 Direct-current, 3-wire compound generator**



*46.8.14 Direct-current, 3-wire compound generator; with commutating or compensating field winding or both**

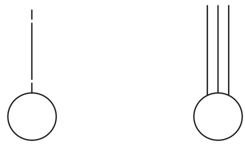


*46.8.15 Direct-current balancer, shunt wound**

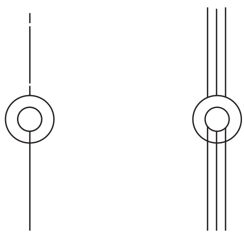
(*continued*)

*The broken line (- — -) indicates where line connection to a symbol is made and is not a part of the symbol.

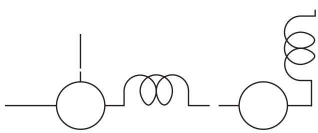
46.9 Alternating-current machines; application



46.9.1 Squirrel-cage induction motor or generator, split-phase induction motor or generator, rotary phase converter or repulsion motor.*



*46.9.2 Wound-rotor induction motor, synchronous induction motor, induction generator, or induction frequency converter**



*46.9.3 Alternating-current series motor**

Machine, Rotating.

48 Meter Instrument

As indicated in Note 48A, the asterisk is not part of the symbol and should always be replaced with one of the letter combinations listed below, according to the meter's function. This is not necessary if some other identification is provided in the circle and described in the diagram.

A	*Ammeter*
AH	*Ampere-hour*
CMA	*Contact-making (or breaking) ammeter*

(*continued*)

*The broken line (- — -) indicates where line connection to a symbol is made and is not a part of the symbol.

CMC	*Contact-making (or breaking) clock*
CMV	*Contact-making (or breaking) voltmeter*
CRO	*Oscilloscope or cathode-ray oscillograph*
DB	*DB (decibel) meter*
DBM	*DBM (decibels referred to 1 milliwatt) meter*
DM	*Demand meter*
DTR	*Demand-totalizing relay*
F	*Frequency meter*
G	*Galvanometer*
GD	*Ground detector*
I	*Indicating*
INT	*Integrating*
μA or UA	*Microammeter*
MA	*Milliammeter*
NM	*Noise meter*
OHM	*Ohmmeter*
OP	*Oil pressure*
OSCG	*Oscillograph string*

(*continued*)

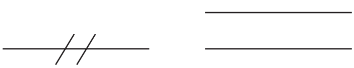
PH	*Phasemeter*
PI	*Position indicator*
PF	*Power factor*
RD	*Recording demand meter*
REC	*Recording*
RF	*Reaction factor*
SY	*Synchroscope*
TLM	*Telemeter*
T	*Temperature meter*
THC	*Thermal converter*
TT	*Total time*
V	*Voltmeter*
VA	*Volt-ammeter*
VAR	*Varmeter*
VARH	*Varhour meter*
VI	*Volume indicator; meter, audio level*
VU	*Standard volume indicator; meter, audio level*
W	*Wattmeter*
WH	*Watthour meter*

Meter Instrument.

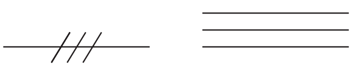
58 Path, Transmission, Conductor, Cable, Wiring

58.1 Guided path, general
The entire group of conductors, or the transmission path required to guide the power or symbol, is shown by a single line. In coaxial and waveguide work, the recognition symbol is employed at the beginning and end of each type of transmission path as well as at intermediate points to clarify a potentially confusing diagram. For waveguide work, the mode may be indicated as well.

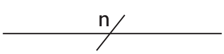
58.2 Conductive path or conductor; wire



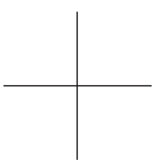
58.2.1 Two conductors or conductive paths of wires



58.2.2 Three conductors or conductive paths of wires



58.2.3 “n” conductors or conductive paths of wires



58.5 Crossing of paths or conductors not connected
The crossing is not necessarily at a 90-degree angle.

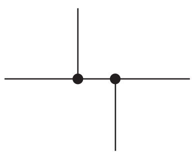
(continued)

58.6 Junction of paths or conductors

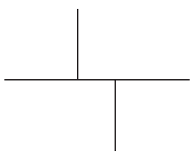
58.6.1 Junction of paths or conductors

58.6.1.1 Application: junction of paths, conductor, or cable. If desired, indicate path type or size.

Splice

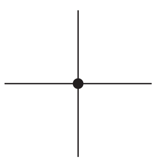


58.6.1.2 Application: splice (if desired) of same size cables. Junction of conductors of same size or different size cables. If desired, indicate sizes of conductors.



58.6.2 Junction of connected paths, conductors, or wires

OR ONLY IF REQUIRED BY SPACE LIMITATION



Path, Transmission, Conductor, Cable, Wiring.

63 Polarity Symbol

+	*63.1*	*Positive*
–	*63.2*	*Negative*

Polarity Symbol.

76 Switch

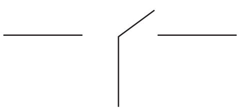
See also FUSE (item 36); CONTACT, ELECTRIC (item 23); and DRAFTING PRACTICES (items 0.4.6 and 0.4.7).

Switch symbols may be constructed using the fundamental symbols for mechanical connections, contacts, etc.

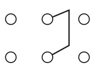
In standard procedure, a switch is represented in the nonoperating, or deenergized, position. In the case of switches that have two or more positions in which no operating force is applied and for those switches (air-pressure, liquid-level, rate-of-flow, etc.) that may be actuated by a mechanical force, the point at which the switch functions should be described in a clarifying note.

In cases where the basic switch symbols (items 76.1–76.4) are used in a diagram in the closed position, the terminals must be included for clarity.

76.1 Single throw, general



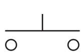
76.2 Double throw, general



76.2.1 Application: 2-pole double-throw switch with terminals shown

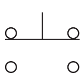
76.3 Knife switch, general

76.6 Pushbutton, momentary or spring return



76.6.1 Circuit closing (make)

76.6.2 Circuit opening (break)

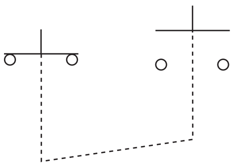


76.6.3 Two-circuit

(*continued*)

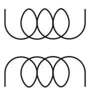
76.7 Pushbutton, maintained or not spring return

76.7.1 Two-circuit



Switch.

86 Transformer

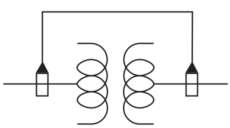


86.1 General

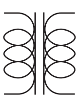
Either winding symbol may be used. In the following items, the left symbol is used. Additional windings may be shown or indicated by a note. For power transformers use polarity markingH_1, X_1, etc., from American Standard C6.1-1956.

For polarity markings on current and potential transformers, see items 86.16.1 and 86.17.1

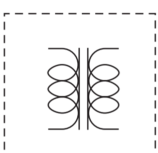
In coaxial and waveguide circuits , this symbol will represent a taper or step transformer without mode change



86.1.1 Application: transformer with direct-current connections and mode suppression between two rectangular waveguides

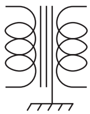


86.2 If it is desired especially to distinguish a magnetic-core transformer

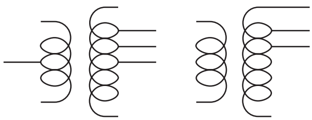


86.2.1 Application: shielded transformer with magnetic core shown

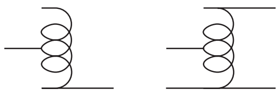
(continued)



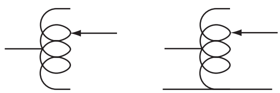
86.2.2 *Application: transformer with magnetic core shown and with a shield between windings. The shield is shown connected to the frame.*



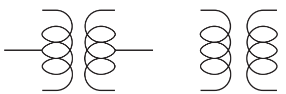
86.6 *With taps, 1-phase*



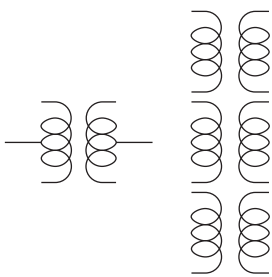
86.7 *Autotransformer, 1-phase*



86.7.1 *Adjustable*

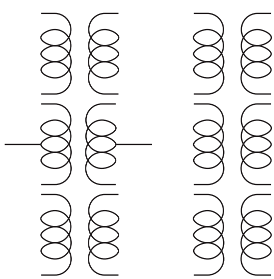


86.13 *1-phase, 2-winding transformer*



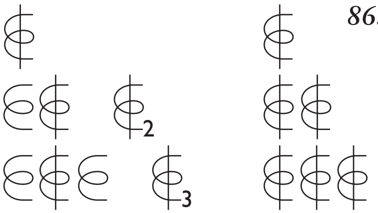
86.13.1 *3-phase bank of 1-phase, 2-winding transformer*

See American Standard C6.1-1965 for interconnections for complete symbol.

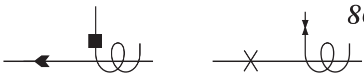


86.14 *Polyphase transformer*

(continued)

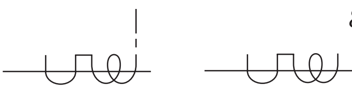


86.16 Current transformer(s)

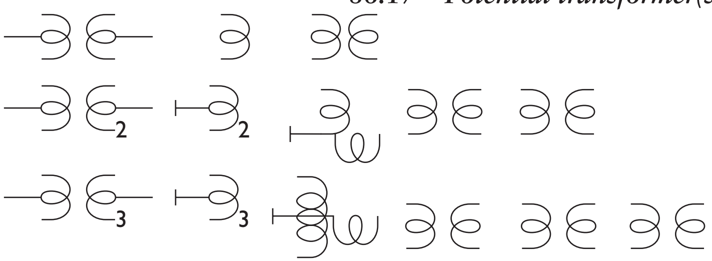


86.16.1 Current transformer with polarity marking. Instantaneous direction of current into one polarity mark corresponds to current out of the other polarity mark.

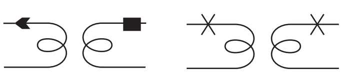
Symbol used shall not conflict with item 77 when used on same drawing.



*86.16.2 Bushing-type current transformer**



86.17 Potential transformer(s)

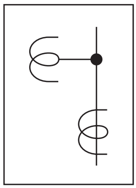


86.17.1 Potential transformer with polarity mark. Instantaneous direction of current into one polarity mark corresponds to current out of the other polarity mark.

(*continued*)

*The broken line (- — -) indicates where line connection to a symbol is made and is not a part of the symbol.

Symbol used shall not conflict with item 77 when used on same drawing.

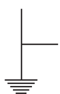


86.18 *Outdoor metering device*

86.19 *Transformer winding connection symbols*

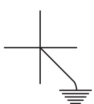
For use adjacent to the symbols for the transformer windings.

86.19.1 *2-phase 3-wire, grounded*

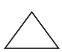


86.19.1.1 *2-phase 3-wire, grounded*

86.19.2 *2-phase 4-wire*



86.19.2.1 *2-phase 5-wire, grounded*

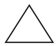


86.19.3 *3-phase 3-wire, delta or mesh*

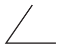
86.19.3.1 *3-phase 3-wire, delta, grounded*

86.19.4 *3-phase 4-wire, delta, ungrounded*

(continued)



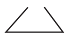
86.19.4.1 *3-phase 4-wire, delta, grounded*



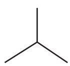
86.19.5 *3-phase, open-delta*

86.19.5.1 *3-phase, open-delta, grounded at common point*

86.19.5.2 *3-phase, open-delta, grounded at middle point of one transformer*



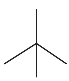
86.19.6 *3-phase, broken-delta*



86.19.7 *3-phase, wye or star, ungrounded*

86.19.7.1 *3-phase, wye, grounded neutral*

The direction of the stroke representing the neutral can be arbitrarily chosen.



86.19.8 *3-phase 4-wire, ungrounded*

Transformer.

Chapter 1

Review Definitions

Definitions are covered in Article 100 of the NEC (National Electrical Code). The questions that follow won't cover all of the definitions but only the more pertinent ones. The answers given here are the author's. Refer to Article 100 of the NEC for the official definitions. Some definitions appear in the *Code* elsewhere than Article 100 (see NEC, *Index*).

1-1 What is "accessible" as applied to wiring methods?

Wiring that is readily available to inspection, repair, removal, etc., without disturbing the building structure or finish. Not permanently enclosed by the structure or finish of buildings.

1-2 What is "accessible" as applied to equipment?

Equipment that may be readily reached without climbing over obstacles or that is not in locked or other hard to reach areas. For example, panelboards in kitchen cabinets that are mounted in or on the walls above washers and dryers, or in closets or bathrooms, are not accessible. Service-entrance equipment that can be reached only by going into a closet, behind a stairway, or around some other obstacle would not be considered accessible.

1-3 What does "ampacity" mean?

The amount of flowing current (in amperes) that a conductor can carry continuously for specific use conditions and not exceed the temperature rating of the conductor (see NEC *Section 310.10*).

1-4 What is a building?

A building may be a structure that stands by itself, or one that is separated from another by a fire wall.

1-5 What does "dead front" mean?

No live (energized) parts are exposed where a person operates electrical equipment.

1-6 What does "approved" mean?

Any appliance, wiring material, or other electrical equipment that is acceptable to the enforcing authorities. Underwriters Laboratory is (by far) the most acceptable authority to inspectors.

A note of caution: Don't be fooled by a UL label on the motor or cord of an appliance if there is no such label on the entire article (see NEC, *Section 110.2*). The entire appliance must be approved, not just the cord or motor.

1-7 What does "identified" mean as applied to equipment?

It means that the equipment will be suitable for the particular use or environment, that it has been evaluated by a qualified electrical testing organization, and that it features a product listing or label indicating its suitability.

1-8 What is a branch circuit?

A branch circuit is the portion of a wiring system that extends beyond the last overcurrent-protective device. In interpreting this, you must not consider the thermal cutout or the motor overload protection as the beginning of the branch circuit. The branch circuit actually begins at the final fusing or circuit-breaker point where the circuit breaks off to supply the motor.

1-9 What is a small appliance branch circuit?

This is the circuit supplying one or more outlets connecting appliances only. There is no permanently connected lighting on this circuit, except the lighting that may be built into an appliance. This term is most often used in connection with *Sections 210.11(C)(1)* and *210.52(B)* of the NEC, which refer to outlets for small appliance loads in kitchens, laundries, pantries, and dining and breakfast rooms of dwellings.

1-10 What is a general purpose circuit?

This is a branch circuit to which lighting and/or appliances may be connected. It differs from the small appliance branch circuit in question 1-9, where lighting cannot be connected.

1-11 What is a multiwire branch circuit?

A multiwire branch circuit has two or more ungrounded conductors with a potential difference between them and also has a grounded (neutral) conductor with an equal potential difference between it and each of the other wires. Examples are a three-wire 120/240-volt system or a 120/208-volt wye system, using two- or three-phase conductors and a grounded conductor. However, in either case, the "hot" wires must not be tied to one phase but must be connected to different phases to make the system a multiwire circuit (see NEC, *Section 210.4*).

1-12 What is a circuit breaker?

A device that is designed not only to open and close a circuit nonautomatically but also to open the circuit automatically at a predetermined current-overload value. The circuit breaker may be thermally or magnetically operated. However, ambient temperatures affect the operation of the thermally operated type, so that the trip value of the current is not as stable as with the magnetic type.

1-13 What is a current-carrying conductor?

A conductor that is expected to carry current under normal operating conditions.

1-14 What is a noncurrent-carrying conductor?

One that carries current only in the event of a malfunction of equipment or wiring. An equipment grounding conductor is a good example. It is employed for protection and is quite a necessary part of the wiring system, but it is not used to carry current except in the case of faulty operation, where it aids in tripping the overcurrent-protective device.

1-15 What is a pressure connector (solderless)?

A device that establishes a good electrical connection between two or more conductors by some means of mechanical pressure. A pressure connector is used in place of soldering connections and is required to be of an approved type.

1-16 What is meant by "demand factor"?

This is the ratio between the maximum demand on a system or part of a system and the total connected load on the same system or part of the system.

1-17 What is meant by "dust-tight"?

The capacity to keep dust out of an enclosure (e.g., a case or cabinet) so that dust cannot interfere with the normal operation of equipment. This is discussed further in connection with *Articles 500* and *502* of the NEC, which cover hazardous (classified) locations.

1-18 What is meant by "explosionproof apparatus"?

Apparatus enclosed in a case that is able to sustain an explosion that may occur within the case and is also able to prevent ignition of specified gases or vapors surrounding the enclosure caused by sparks, flashes, or explosion of the gases or vapors within. It must also operate at a temperature that won't ignite any inflammable atmosphere or residue surrounding it. If an explosion does occur within the equipment, the gases are allowed to escape either by a ground joint or by threads, and the escaping gases are thereby cooled to a temperature low enough to inhibit the ignition of any external gases.

1-19 What is a feeder?

The circuit conductors between the service equipment, or the source of a separately derived system, and the final branch-circuit overcurrent device or devices. Generally, feeders are comparatively large in size and supply a feeder panel, which is composed of a number of branch-circuit overcurrent devices (see *Article 215* of the NEC.)

1-20 What is a fitting?

A mechanical device, such as a locknut or bushing, that is intended primarily for a mechanical, rather than an electrical, function.

1-21 What is meant by a "ground"?

An electrical connection, either accidental or intentional, that exists between an electrical circuit or equipment and the earth, or some other conducting body that serves in place of the earth.

1-22 What does "grounded" mean?

Connected to the earth or to some other conducting body that serves in place of the earth.

1-23 What is a grounded conductor?

A system or circuit conductor that has been intentionally grounded.

1-24 What is a grounding conductor?

A conductor that is used to connect equipment, devices, or wiring systems with grounding electrodes.

1-25 What is a grounding conductor (equipment)?

The conductor used to connect noncurrent-carrying metal parts of equipment, raceways, and other enclosures to the system grounding conductor at the service and/or the grounding electrode conductor.

1-26 What is a grounding electrode conductor?

A conductor used to connect the grounding electrode to the equipment grounding conductor and/or to the grounded conductor of the circuit at the service.

1-27 What is a dwelling unit?

A dwelling unit includes one or more rooms used by one or more persons, with space for sleeping, eating, living, and a permanent provision for cooking and sanitation.

1-28 What is an outlet?

A point in the wiring system at which current is taken to supply some equipment.

1-29 What is meant by "rain-tight"?

Capable of withstanding a beating rain without allowing water to enter.

1-30 What is a receptacle?

A receptacle is a contact device installed at the outlet for the connection of a single attachment plug. A single receptacle is a single device with no other contact device on the same yoke. A multiple receptacle is a single device containing two or more receptacles.

1-31 What does "rainproof" mean?

So constructed, protected, or treated as to prevent rain from interfering with the successful operation of the apparatus.

Note

Pay particular attention to the following questions; they involve **services** and are probably among the most misused of any definitions in the NEC.

1-32 What is meant by the term "service"?

The conductors and equipment for delivering electrical energy from the secondary distribution system—the street main, the distribution feeder, or the transformer—to the wiring system on the premises. This includes the service-entrance equipment and the grounding electrode.

1-33 What are service conductors?

The portion of the supply conductors that extend from the street main, duct, or transformers to the service-entrance equipment of the premises supplied. For overhead conductors, this includes the conductors from the last line pole (not including the service pole) to the service equipment.

1-34 What is a service cable?

A service conductor manufactured in the form of a cable and normally referred to as SE cable, or USE cable (see the NEC, *Article 338*).

1-35 What is meant by "service drop"?

The overhead conductors from the last pole or other aerial support to and including the splices, if any, connecting to the service-entrance conductors at the building or other structure. If there is a service pole with a meter on it, such as a farm service pole, the service drop does not stop at the service pole; all wires extending from this pole to a building or buildings are service drops, as well as the conductors from the last line pole to the service pole (see the NEC, *Article 100* and *Article 230, II*).

1-36 What are service-entrance conductors (overhead system)?

That portion of the service conductors between the terminals of service equipment and a point outside the building, clear of building walls, where they are joined by a splice or tap to the service drop, street main, or other source of supply.

1-37 What are service-entrance conductors (underground system)?

The service conductors between the terminals of the service equipment and the point of connection to the service lateral. Where service equipment is located outside the building walls, there may be no service-entrance conductors, or they may be entirely outside the building.

1-38 What are sets of service-entrance conductors?

Sets of service-entrance conductors are taps that run from main service conductors to service equipment.

1-39 What is meant by "service equipment"?

The necessary equipment, usually consisting of circuit breakers or switches and fuses and their accessories, located near the point of where supply conductors enter a building, structure, or an otherwise defined area, and intended to constitute the main control and means to cut off the supply.

1-40 What is meant by "service lateral"?

The underground service conductors between the street main, including any risers at the pole or other structure, or from transformers, and the first point of connection to the service-entrance conductors in a terminal box. The point of connection is considered to be the point where the service conductors enter the building.

1-41 What is meant by "service raceway"?

The rigid metal conduit, electrical metallic tubing, or other raceway that encloses service-entrance conductors.

1-42 What is meant by "special permission"?

The written consent of the authority enforcing the NEC. Under most circumstances, this is a local electrical inspector.

1-43 What is meant by a "general-use switch"?

A device intended for use as a switch in general distribution and branch circuits. It is rated in amperes and is capable of interrupting its rated current at its rated voltage.

1-44 What is meant by a "T-rated switch"?

An AC general-use snap switch that can be used (a) on resistive and inductive loads that don't exceed the ampere rating at the voltage involved, (b) on tungsten-filament lighting loads that don't exceed the ampere rating at 120 volts, and (c) on motor loads that don't exceed 80% of their ampere rating at the rated voltage.

1-45 What is meant by an "isolating switch"?

A switch that is intended to isolate an electric circuit from its source of power. It has no interrupting rating and is intended to be operated only after the circuit has been opened by some other means.

1-46 What is meant by a "motor-circuit switch"?

A switch, rated in horsepower, that is capable of interrupting the maximum operating overload current of a motor of the same horsepower rating as the switch, at the rated voltage.

1-47 What is meant by "watertight"?

So constructed that moisture won't enter the enclosing case.

1-48 What is meant by "weatherproof"?

So constructed or protected that exposure to the weather won't interfere with successful operation. Raintight or watertight may fulfill the requirements for "weatherproof." However, weather conditions vary, and consideration should be given to conditions resulting from snow, ice, dust, and temperature extremes.

1-49 What is meant by the "voltage" of a circuit?

This is the greatest effective difference of potential (root-mean-square difference of potential) that exists between any two conductors of a circuit. On various systems, such as 3-phase 4-wire, single-phase 3-wire, and 3-wire direct current, there may be various circuits with a number of voltages.

Chapter 2

Ohm's Law and Other Electrical Formulas

When a current flows in an electric circuit, the magnitude of the current is determined by dividing the electromotive force (volts, designated by the letter E) in the circuit by the resistance (ohms, designated by the letter R) of the circuit. The resistance is dependent on the material, cross section, and length of the conductor. The current is measured in amperes and is designated by the letter I. The relationship between an electric current (I), the electromotive force (E), and the resistance (R) is expressed by Ohm's law. The following equations take into consideration only pure resistance (i.e., not inductance or capacitance); therefore, they are customarily known as the dc formulas for Ohm's law. However, in most calculations for dc circuits, which is the ordinary wiring application, these formulas are quite practical to use. Later in this book, other forms of Ohm's law that deal with inductive and capacitive reactance will be discussed.

2-1 What are the three equations for Ohm's law and what do the letters in the formulas mean?

$$I = \frac{E}{R} \quad R = \frac{E}{I} \quad E = IR$$

where I is the current flow in amperes, E is the electromotive force in volts, and R is the resistance in ohms.

2-2 A direct-current circuit has a resistance of 5 ohms. If a voltmeter connected across the terminals of the circuit reads 10 volts, how much current is flowing?

From Ohm's law, the current is:

$$I = \frac{E}{R} = \frac{10}{5} = 2 \text{ amperes}$$

2-3 If the resistance of a circuit is 25 ohms, what voltage is necessary for a current flow of 4 amperes?

From Ohm's law:

$$E = I \times R = 4 \times 25 = 100 \text{ volts}$$

2-4 If the potential across a circuit is 40 volts and the current is 5 amperes, what is the resistance?

From Ohm's law:

$$R = \frac{E}{I} = \frac{40}{5} = 8 \text{ ohms}$$

Series Circuits

A series circuit may be defined as one in which the resistive elements are connected in a continuous run (i.e., connected end to end) as shown in Figure 2-1. It is evident that since the circuit has only one pathway (no branches), the amount of current flowing must be the same in all parts of the circuit. Therefore, the current flowing through each resistance is also equal. The total potential across the entire circuit equals the sum of potential drops across each individual resistance, or:

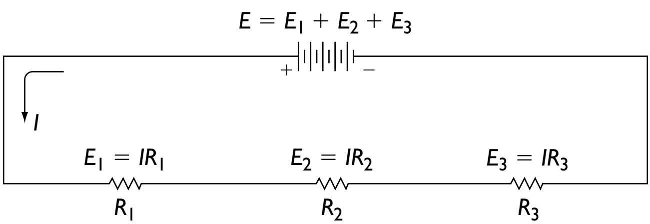


Figure 2-1 Resistances in series.

$$E_1 = IR_1$$
$$E_2 = IR_2$$
$$E_3 = IR_3$$
$$E = E_1 + E_2 + E_3$$

and

$$R = R_1 + R_2 + R_3$$

The equation for the total potential of the circuit is:

$$E = IR_1 + IR_2 + IR_3 = I(R_1 + R_2 + R_3)$$

and

$$I = \frac{E}{R_1 + R_2 + R_3} = \frac{E}{R}$$

2-5 If the individual resistances shown in Figure 2-1 are 5, 10, and 15 ohms, respectively, what potential must the battery supply to force a current of 0.5 ampere through the circuit?

The total resistance is:

$$R = 5 + 10 + 15 = 30 \text{ ohms}$$

Hence, the total voltage is:

$$E = 0.5 \times 30 = 15 \text{ ohms}$$

As a check, calculate the individual voltage drop across each part:

$$\begin{aligned} E_1 &= 0.5 \times 5 = 2.5 \text{ volts} \\ E_2 &= 0.5 \times 10 = 5.0 \text{ volts} \\ E_3 &= 0.5 \times 15 = 7.5 \text{ volts} \end{aligned}$$

and,

$$E = E_1 + E_2 + E_3 = 2.5 + 5.0 + 7.5 = 15 \text{ volts}$$

2-6 In order to determine the voltage of a dc source, three resistance units of 10, 15, and 30 ohms are connected in series with this source. If the current through the circuit is 2 amperes, what is the potential of the source?

$$\begin{aligned} E &= I(R_1 + R_2 + R_3) \\ &= 2(10 + 15 + 30) = 2 \times 55 \\ &= 110 \text{ volts} \end{aligned}$$

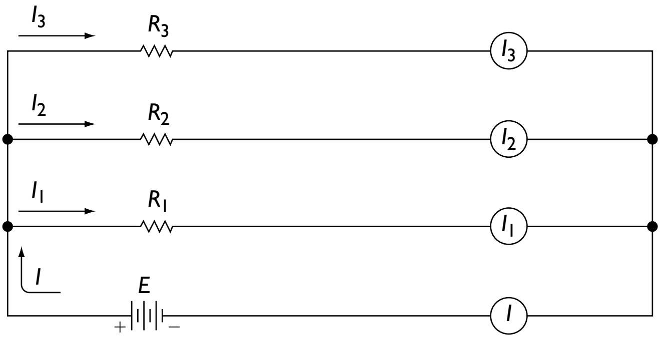
Parallel Circuits

In a parallel, or divided, circuit such as that shown in Figure 2-2, the same voltage appears across each resistance in the group; the current flowing through each resistance is inversely proportional to the value of the resistance. The sum of all the currents, however, is equal to the total current leaving the battery. Thus:

$$E = I_1R_1 = I_2R_2 = I_3R_3$$

and,

$$I = I_1 + I_2 + I_3$$



$I_T = I_1 + I_2 + I_3$ $\qquad R_T = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$ $\qquad E_T = I_T + \frac{1}{R_T}$

Figure 2-2 Resistances in parallel.

When Ohm's law is applied to the individual resistances, the following equations are obtained:

$$I_1 = \frac{E}{R_1} \quad I_2 = \frac{E}{R_2} \quad I_3 = \frac{E}{R_3}$$

Hence,

$$I_1 = \frac{E}{R_1} + \frac{E}{R_2} + \frac{E}{R_3}$$

or

$$I = E\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

and since $I = E/R$, the equivalent resistance of the several resistances connected in parallel is:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

You've found, then, that any number of resistances in parallel can be replaced by an equivalent resistance whose value is equal to the reciprocal of the sum of the reciprocals of the individual resistances. You will find that the sum of resistances in parallel will always be smaller than the value of the smallest resistor in the group.

The value $1/R$, or the reciprocal of the value of the resistance, is expressed as the conductance of the circuit; its unit is mho (ohm spelled backward) and is usually expressed by g or G.

Where there are only two resistances connected in parallel,

$$R = \frac{R_1 \times R_2}{R_1 + R_2} \text{ ohms}$$

Where there are any number of equal resistances connected in parallel, you may divide the value of one resistance by the number of equal resistances.

2-7 A resistance of 2 ohms is connected in series with a group of three resistances in parallel, which are 4, 5, and 20 ohms, respectively. What is the equivalent resistance of the circuit?

The equivalent resistance of the parallel network is:

$$\frac{1}{R} = \frac{1}{4} + \frac{1}{5} + \frac{1}{20} = 0.25 + 0.20 + 0.05 = 0.50$$

$$R = \frac{1}{0.50} = 2 \text{ ohms}$$

The circuit is now reduced to two series resistors of 2 ohms each, as shown in Figure 2-3. The equivalent resistance of the circuit is 2 + 2, or 4 ohms.

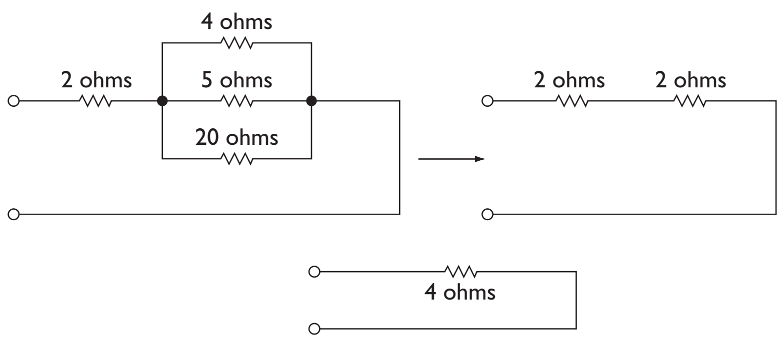


Figure 2-3 Equivalent resistance of the series-parallel circuit of question 2-7.

2-8 Two parallel resistors of 2 and 6 ohms are connected in series with a group of three parallel resistors of 1, 3, and 6 ohms, respectively. If the two parallel-resistance groups are connected in series

by means of a 1.5-ohm resistor, what is the equivalent resistance of the system?

Replace the 2- and 6-ohm resistors by a resistance of R_1, where:

$$R_1 = \frac{2 \times 6}{2 + 6} = \frac{12}{8} = 1.5 \text{ ohms}$$

Replace the group of three resistors by R_2, where:

$$\frac{1}{R} = \frac{1}{1} + \frac{1}{3} + \frac{1}{6} = 1.0 + 0.33 + 0.17 = 1.50$$

$$R = \frac{1}{1.50} = 0.67 \text{ ohms}$$

The circuit is now reduced to three series resistances, the values of which are 1.5, 1.5 and 0.67 ohms, as shown in Figure 2-4. Their combined values are:

$$R_T = R + R_1 + R_2$$
$$R_T = 1.5 + 1.5 + 0.67 = 3.67 \text{ ohms}$$

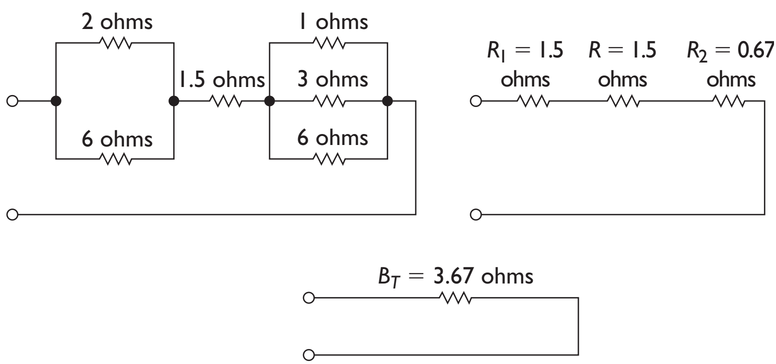


Figure 2-4 Equivalent resistance of the series-parallel circuit of question 2-8.

Units of Area and Resistance

The circular mil is the unit of cross section used in the American wire gauge (AWG) or the B&S wire gauge systems (see NEC, *Chapter 9, Table 8*). The term *mil* means one thousandth of an inch (0.001 inch). A circular mil is the area of the cross-sectional surface of a cylindrical wire with a diameter of 1 mil (0.001 inch).

The circular mil area of any solid cylindrical wire is equal to the wire's diameter (expressed in mils) squared. For example, the area in circular mils (written CM or cir. mils) of a wire having a diameter of ⅜ inch (0.375) equals $375 \times 375 = 375^2 = 140{,}625$ CM. The diameter in mils of a solid circular wire is equal to the square root of its circular mil area. Assuming that a conductor has an area of 500,000 CM, its diameter in mils is the square root of 500,000, which is equal to 707 mils, or 0.707 inch (approximately). The area in square inches of a wire whose diameter is 1 mil is:

$$\frac{\pi}{4} = 0.7845 \times 0.001^2 = 0.0000007854 \text{ sq. in.}$$

The square mil is the area of a square whose sides are each 1 mil (0.001 inch). Hence, the area of a square mil is 0.001^2, or 0.000001 square inch. With reference to the previous definitions of the circular mil and the square mil, it is obvious that in order to convert a unit of circular area into its equivalent area in square mils, the circular mil must be multiplied by $\pi/4$, or 0.7854, which is the same as dividing by 1.273. Conversely, to convert a unit area of square mils into its equivalent area in circular mils, the square mil should be divided by $\pi/4$, or 0.7854, which is the same as multiplying by 1.273.

The above relations may be written as follows:

$$\text{Square mils} = \text{circular mils} \times 0.7854 = \frac{\text{circular mils}}{1.273}$$

$$\text{Circular mils} = \frac{\text{square mils}}{0.7854} = \text{square mils} \times 1.273$$

Thus, any circular conductor may be easily converted into a rectangular conductor (a bus bar, for example) containing an equivalent area of current-carrying capacity.

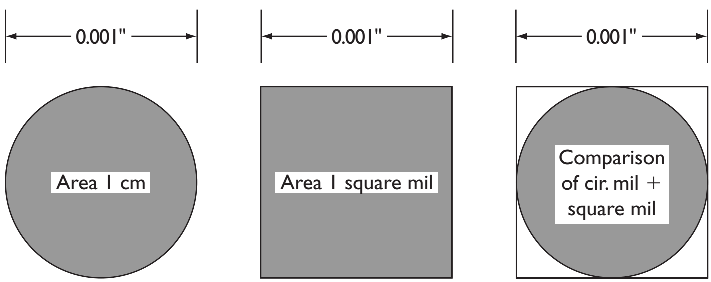


Figure 2-5 Enlarged view of one circular mil and one square mil, with a comparison of the two.

2-9 If a No. 10 wire (B&S or AWG) has a diameter of 101.9 mils, what is its circular mil area?

$$\text{Area} = 101.9^2 = 10{,}383.6 \text{ CM}$$

Referring to Table 2-1, you will find this to be approximately true. If you concentrate on remembering the CM area of No. 10 wire as 10,380 CM, you will find this invaluable in arriving at the CM area of any size wire without the use of a table. For practical purposes, if you do not have a wire table such as Table 2-1 readily available, you may find the circular mil area of any wire size by juggling back and forth as follows, and the answer will be close enough for all practical purposes.

Every three sizes removed from No. 10 doubles or halves the area in CM.

Every ten sizes removed from No. 10 is 1/10 or 10 times the area in CM.

Example: Ten sizes smaller than No. 10 is No. 0 wire. No. 10 wire has a circular mil area of 10,380 CM; therefore, No. 0 would be 103,800 CM. Table 2-1 shows an area of 105,600 CM for No. 0 wire, or about a 1.7% error.

Example: Ten sizes smaller than No. 10 is No. 20 wire. Number 20 wire should then have a circular mil area of 1038.1 CM.

You can see from the examples above that for quick figuring, the percentage of error is quite small. However, you should always have a wire table nearby. (You can find a pretty good one in *Chapter 9*, *Table 8* of the NEC.)

2-10 Number 000 wire (AWG) has an area of 167,800 CM. If it were solid copper (not made of strands), what would its diameter be?

The diameter is:

$$\sqrt{167{,}800} = 409.6 \text{ mils, or } 0.4096 \text{ inch}$$

2-11 A certain switchboard arrangement necessitates conversion from a circular conductor to a rectangular bus bar having an equivalent area. If the diameter of the solid conductor measures 0.846 inch, calculate (a) the width of an equivalent bus bar, if the thickness of the bus bar is ¼ inch; (b) the bus bar area in circular

mils; (c) the current-carrying capacity, if 1 square inch of copper carries 1000 amperes.

The area, in square inches, of the circular conductor is:

$$\begin{aligned} A &= 0.7854 \times D^2 = 0.7854 \times 0.846^2 \\ &= 0.562 \text{ square inch} \end{aligned}$$

The area, in square inches, of the bus bar is:

$$A' = 0.25 \times W$$

where W is the width of the bus bar.

Since,

$$A' = A\,0.562 = 0.25W$$

(a) $W = 0.562/025 = 2.248$ inches

(b) The area of the conductor $= 846^2 = 715{,}716$ CM

(c) The current-carrying capacity of the conductor $= 0.562 \times 1000 = 562$ amps.

2-12 A certain 115-volt, 100-horsepower dc motor has an efficiency of 90% and requires a starting current that is 150% of the full-load current. Determine (a) the size of fuse needed, in amps; (b) the copper requirements of the switch. Assume that 1 square inch of copper carries 1000 amperes.

Motor current:

$$I_M = \frac{\text{hp} \times 746}{E \times \text{efficiency}} = \frac{100 \times 746}{115 \times 0.9} = 721 \text{ amperes}$$

(a) The amperage of the fuses is, therefore, $721 \times 1.5 = 1081.5$, or 1200 amperes, which is the rating of the closest manufactured fuse.

(b) Since the motor required a current of 721 amperes, the copper of each switch blade must be $^{721}\!/_{1000}$, or 0.721 square inch. Therefore, if $^3\!/_8$-inch bus copper is used, its width must be:

$$W = \frac{0.721}{0.375} = 1.92 \text{ inches}$$

The mil-foot is a unit of cross-sectional area of a cylindrical conductor that is one foot in length and one mil in diameter. The resistance of such a unit of copper has been found experimentally to be 10.37 ohms at 20°C; this is normally thought of as 10.4 ohms (Figure 2-6).

A mil-foot of copper at 20°C offers 10.4 ohms resistance; at 30°C, it is 11.2 ohms; at 40°C, it is 11.6 ohms; at 50°C, it is 11.8 ohms; at 60°C, it is 12.3 ohms; and at 70°C, it is 12.7 ohms. Thus, in voltage-drop calculations, 12 is generally used as the constant *K*, unless otherwise specified, to allow for higher temperatures and to afford some factor of safety.

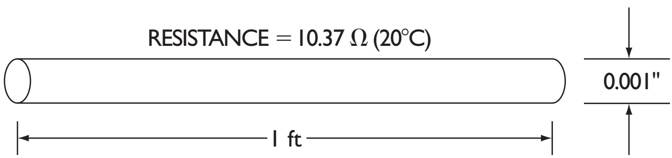


Figure 2-6 Dimensions and resistance of one circular mil-foot of copper.

The resistance of a wire is directly proportional to its length and inversely proportional to its cross-sectional area. Therefore, if the resistance given in ohms of a mil-foot of wire is multiplied by the total length in feet (remember that there are practically always two wires, so if the distance is given in feet, multiply it by two to get the total resistance of both wires; this is a common error when working examination problems) and divided by its cross-sectional area in circular mils, the result will be the total resistance of the wire in ohms. This is expressed as:

$$R = \frac{K \times L \times 2}{A}$$

where: R is the resistance in ohms
K is the constant (12) for copper
L is the length in feet one way
A is the area in circular mils

K for copper was given, so it will be well to give *K* for commercial aluminum:

20°C(68°F): $K = 17.39$	50°C (122°F): $K = 19.73$
30°C(86°F): $K = 18.73$	60°C (140°F): $K = 20.56$
40°C(104°F): $K = 19.40$	70°C (158°F): $K = 21.23$

$K = 12$ was used for copper, because in most instances it provides a safety factor in figuring voltage drop. Thus, with a correction factor of 1.672 for aluminum, as opposed to copper, it would be well to use a K factor of 20 for aluminum.

Should you have other conditions, K factors have been given for both copper and aluminum at various degrees Celsius. To change Celsius to Fahrenheit, use the following formula:

$$\text{Degrees C} \times 1.8 + 32 = \text{Degrees F}$$

Thus:

$$30°\text{C} \times 1.8 + 32 = 54 + 32 = 86°\text{F}$$

2-13 What is the resistance of a 500-foot line of No. 4 copper wire?

From *Chapter 9, Table 8* of the NEC, No. 4 wire has a cross-sectional area of 41,740 CM. Therefore,

$$R = \frac{12 \times 500 \times 2}{41{,}740} = \frac{12{,}000}{41{,}740} = 0.29 \text{ ohms}$$

Table 8 lists a value of 0.2480 ohm for 1000 feet of No. 4 wire at 20°C. The difference is that a K of 12 was used instead of 10.4; 20°C is 68°F, and the 12 value is for slightly over 50°C, or 122°F.

2-14 Suppose it is desired to have a copper wire of 0.5-ohm resistance whose total length is 2000 feet, or 1000 feet one way. What must its cross-sectional area be? What size wire is necessary?

$$A = K\frac{L}{R} = \frac{12 \times 2000}{0.5} = 48{,}000 \text{ CM}$$

According to *Chapter 9, Table 8* of the NEC, No. 4 wire has a cross-sectional area of 41,740 CM and No. 3 wire has an area of 52,620 CM, so use the larger size No. 3 wire. Also, notice that the equation did not use the factor 2 because the 2000-foot length was the total and not just the length of one wire.

2-15 If the resistance of a copper wire whose diameter is ⅛ inch is measured as 0.125 ohm, what is the length of the wire?

$$L = \frac{RA}{K} = \frac{0.125 \times 125^2}{12} = 163 \text{ feet}$$

Here again, this is the total length; one way would be 81.5 feet.

2-16 A copper line that is 5 miles in length has a diameter of 0.25 inch. Calculate: (a) the diameter of the wire in mils; (b) the area of the wire in circular mils; (c) the weight in pounds; (d) the resistance at 50°C. Assume that the weight in pounds per cubic inch is 0.321.

(a) The diameter in mils = 1000 × 0.25 = 250 mils

(b) The area in CM = 250^2 = 62,500 CM

(c) Cross-sectional area = 0.7854 × D^2 = 0.7854 × 0.25^2 = 0.0491 sq. in. Length of wire = 5280 × 5 × 2 × 12 = 633,600 in. Weight of wire = 0.0491 × 633,600 × 0.321 = 9,986.23, or about 10,000 lb.

(d)
$$\begin{aligned} R &= \frac{K \times 2 \times (5 \times 5280)}{62{,}500} \\ &= \frac{12 \times 2 \times 26{,}400}{62{,}500} \\ &= 10.14 \text{ ohms} \end{aligned}$$

Skin Effect

When alternating current flows through a conductor, an inductive effect occurs, which tends to force the current to the surface of the conductor. This produces a voltage loss and also affects the current-carrying capacity of the conductor. For open wires or wires in nonmetallic-sheathed cable, this "skin effect" is neglected until the No. 0 wire size is reached. In metallic-sheathed cables and metallic raceways, the skin effect is neglected until size No. 2 is reached. At these points, there are multiplying factors for conversion from dc resistance to ac resistance (Table 2-1). Note that there is a different factor for aluminum than for copper cables.

2-17 The dc resistance of a length of 250,000-CM copper cable in rigid metal conduit was found to be 0.05 ohm. What would its ac resistance be?

From Table 2-1, the multiplying factor is found to be 1.06; therefore, R_{AC} = 0.05 ohm × 1.06 = 0.053 ohm.

Table 2-1 Multiplying Factors for Converting dc Resistance to 60-Cycle ac Resistance

	Multiplying Factor			
Size	***For Nonmetallic-Sheathed Cables in Air or Nonmetallic Conduit***		***For Metallic-Sheathed Cables or All Cables in Metallic Raceways***	
	Copper	***Aluminum***	***Copper***	***Aluminum***
Up to 3 AWG	1.000	1.000	1.00	1.00
2	1.000	1.000	1.01	1.00
1	1.000	1.000	1.01	1.00
0	1.001	1.000	1.02	1.00
00	1.001	1.001	1.03	1.00
000	1.002	1.001	1.04	1.01
0000	1.004	1.002	1.05	1.01
250 kcmil	1.005	1.002	1.06	1.02
300 kcmil	1.006	1.003	1.07	1.02
350 kcmil	1.009	1.004	1.08	1.03
400 kcmil	1.011	1.005	1.10	1.04
500 kcmil	1.018	1.007	1.13	1.06
600 kcmil	1.025	1.010	1.16	1.08
700 kcmil	1.034	1.013	1.19	1.11
750 kcmil	1.039	1.015	1.21	1.12
800 kcmil	1.044	1.017	1.22	1.14
1000 kcmil	1.067	1.026	1.30	1.19
1250 kcmil	1.102	1.040	1.41	1.27
1500 kcmil	1.142	1.058	1.53	1.36
1750 kcmil	1.185	1.079	1.67	1.46
2000 kcmil	1.233	1.100	1.82	1.56

Voltage-Drop Calculations

The methods for finding the resistance of wire have been discussed. Now you can use Ohm's law to find the voltage drop for circuits loads. Use the form

$$E = I \times R$$

Under *Section 215.2(A)(4), FPN 2* of the NEC, find the prescribed maximum allowable percent of voltage drop permitted for feeders and branch circuits. In *Section 210.19(A), FPN 4* of the NEC, the maximum allowable percent of voltage drop for branch circuits is given.

2-18 What is the percentage of allowable voltage drop for feeders that are used for power and heating loads?

Maximum of 3%.

2-19 What is the percentage of allowable voltage drop for feeders that are used for lighting loads?

Maximum of 3%.

2-20 What is the percentage of allowable voltage drop for combined lighting, heating, and power loads?

A maximum 3% voltage drop for feeders and 5% for feeders and branch circuits is allowable. The following formula is used for voltage drop calculations.

Since,

$$R = \frac{K \times L \times 2}{A}$$

then,

$$E_d = I \times R = \frac{K \times 2L \times I}{A}$$

where E_d is the voltage drop of the circuit
$2L$ is the total length of the wire
K is a constant (12)
I is the current, in amperes, of the circuit
A is the area, in circular mils, of the wire in the circuit

By transposing the formula above, determine the circular mil area of a wire for a specified voltage drop:

$$A = \frac{K \times 2L \times I}{E_d}$$

2-21 A certain motor draws 22 amps at 230 volts, and the feeder circuit is 150 feet in length. If No. 10 copper wire is desired, what would the voltage drop be? Would No. 10 wire be permissible to use?

$$\begin{aligned} E_d &= \frac{12 \times 2 \times 150 \times 22}{10{,}380} \\ &= \frac{79{,}200}{10{,}380} \\ &= 7.63 \text{ volts} \end{aligned}$$

However, $230 \times 0.03 = 6.90$ volts, which is the voltage drop permissible under *Section 215.2* of the NEC, so No. 10 wire would not be large enough.

2-22 In question 2-21, a voltage drop of 7.63 volts was calculated; however, the maximum permissible voltage drop is 6.9 volts. What size wire would have to be used?

According to *Chapter 9, Table 8* of the NEC, No. 10 wire has an area of 10,380 CM, and No. 9 wire has an area of 13,090 CM. Therefore, No. 9 would be the proper size, except that you cannot purchase No. 9 wire; you will have to use No. 8 wire, which has an area of 16,510 CM.

2-23 If No. 8 copper wire were used in question 2-22, what would the voltage drop be? What percentage would this drop be?

$$E_d = \frac{12 \times 2 \times 150 \times 22}{16{,}509} = \frac{79{,}200}{16{,}509} = 4.80 \text{ volts}$$

$$\frac{4.80}{2.30} \times 100 = 2.09\%$$

$$A = \frac{K \times 2L \times I}{E_d}$$

$$= \frac{12 \times 2 \times 150 \times 22}{6.9}$$

$$= 11{,}478.3 \text{ CM}$$

Formulas for Determining Alternating Current in Alternating-Current Circuits

In the formulas of Figure 2-7:

R is the resistance in ohms

X_L is the inductive reactance in ohms $= 2\pi fL$

X_C is the capacitive reactance in ohms $= 2\pi fC$

f is the frequency

L is the inductance in henrys

C is the capacity in farads

Z is the impedance in ohms

I is the current in amperes

E is the pressure in volts

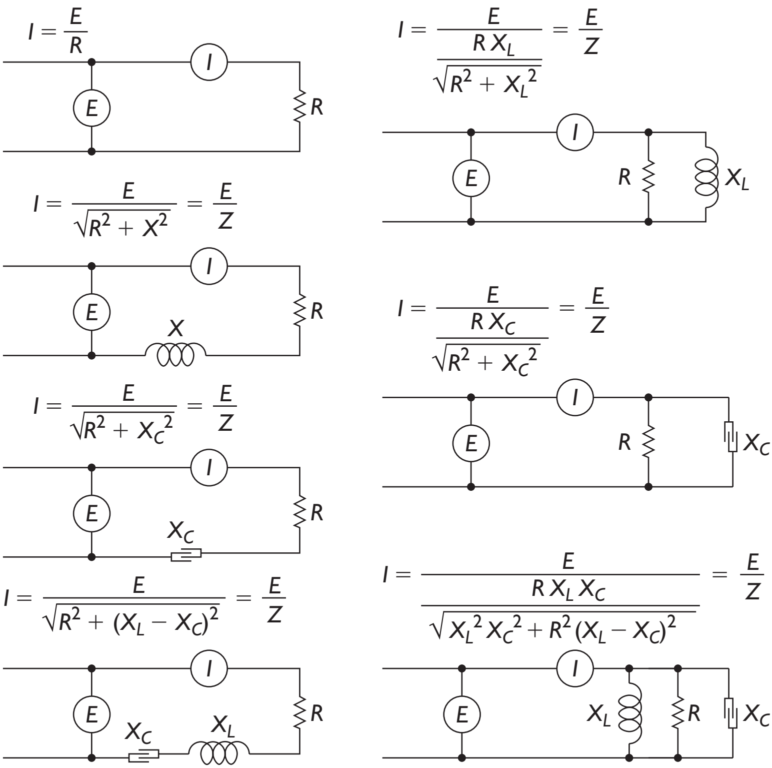


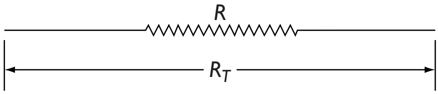
Figure 2-7 Fundamental forms of ac circuits, with the method of determining current when voltage and impedance are known.

Formulas for Combining Resistance and Reactance

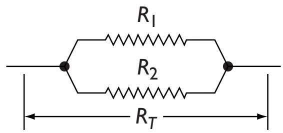
In the following formulas of Figure 2-8:

R is the resistance in ohms
X_L is the inductive reactance in ohms = $2\pi fL$
X_C is the capacitive reactance in ohms = $1/2\pi fC$
f is the frequency
L is the inductance in henrys
C is the capacity in farads
Z is the impedance in ohms
I is the current in amperes
E is the pressure in volts

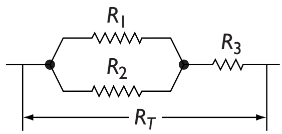
$$R_T = R$$



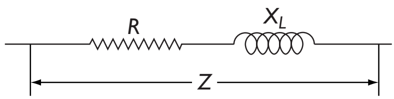
$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}} = \frac{R_1 R_2}{R_2 + R_2}$$



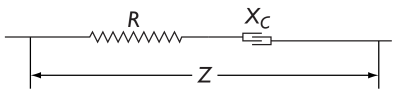
$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}} + R_3 = \frac{R_1 R_2}{R_2 + R_2} + R_3$$



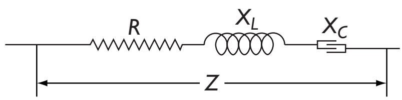
$$Z = \sqrt{R^2 + X_L{}^2}$$



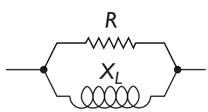
$$Z = \sqrt{R^2 + X_C{}^2}$$



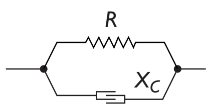
$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$



$$Z = \frac{1}{\sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{X_L}\right)^2}} = \frac{RX_L}{\sqrt{R^2 + X_L{}^2}}$$



$$Z = \frac{1}{\sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{X_C}\right)^2}} = \frac{RX_C}{\sqrt{R^2 + X_C{}^2}}$$



$$Z = \frac{1}{\sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{X_L} - \frac{1}{X_C}\right)^2}} = \frac{R\,X_L\,X_C}{\sqrt{X_L{}^2 X_C{}^2 + R^2(X_L - X_C)^2}}$$

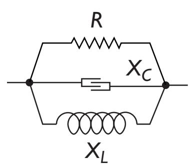


Figure 2-8 Methods of impedance determination in ac circuits when resistance, inductive reactance, and capacitive reactance (in ohms) are known.

2-24 A coil has a resistance of 10 ohms and an inductance of 0.1 henry. If the frequency of the source is 60 hertz, what is the voltage necessary to cause a current of 2 amperes to flow through the coil?

With reference to the previously derived formula,

$$E_R = IR = 2 \times 10 = 20 \text{ volts}$$
$$X_L = 2\pi fL = 2\pi \times 60 \times 0.1 = 37.7 \text{ ohms}$$
$$E_L = IX_L = 2 \times 37.7 = 75.4 \text{ volts}$$

The applied voltage must therefore be:

$$E = \sqrt{E_R^2 + E_L^2} = \sqrt{20^2 + 75.4^2} = 78 \text{ volts}$$

2-25 A coil with a negligible resistance requires 3 amperes when it is connected to a 180-volt, 60-hertz supply. What is the inductance of the coil?

$$X_L = \frac{E}{I} = \frac{180}{3} = 60 \text{ ohms}$$

and,

$$X_L = 2\pi fL$$

therefore,

$$L = \frac{60}{2\pi \times 60} = 0.159 \text{ henry}$$

2-26 An alternating current of 15 amperes with a frequency of 60 hertz is supplied to a circuit containing a resistance of 5 ohms and an inductance of 15 millihenrys. What is the applied voltage?

$$X_L = 2\pi fL = 2\pi \times 60 \times 0.015 = 5.65 \text{ ohms}$$
$$Z = \sqrt{R^2 + X_L^2} = \sqrt{5^2 + 5.65^2} = 7.54 \text{ ohms}$$
$$E = IZ = 15 \times 7.54 = 113.1 \text{ volts}$$

2-27 A coil contains 5 ohms resistance and 0.04 henry inductance. The voltage and frequency of the source are 100 volts at 60 cycles. Find (a) the impedance of the coil; (b) the current through the coil; (c) the voltage drop across the inductance; (d) the voltage drop across the resistance.

$$X_L = 2\pi fL = 2\pi \times 60 \times 0.04 = 15 \text{ ohms}$$

(a) $Z = \sqrt{5^2 + 15^2} = \sqrt{250} = 15.8 \text{ ohms}$

(b) $I = \dfrac{E}{Z} = \dfrac{100}{\sqrt{5^2 + 15^2}} = 6.3 \text{ amperes}$

(c) $E_L = IX_L = 6.3 \times 15 = 94.5 \text{ volts}$

(d) $E_R = IR = 6.3 \times 5 = 31.5 \text{ volts}$

2-28 An alternating-current contains 10 ohms resistance in series with a capacitance of 40 microfarads. The voltage and frequency of the source are 120 volts at 60 cycles. Find (a) the current in the circuit; (b) the voltage drop across the resistance; (c) the voltage drop across the capacitance; (d) the power factor; (e) the power loss.

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi \times 60 \times 0.00004} = 66.67 \text{ ohms}$$

$$Z = \sqrt{10^2 + 66.7^2} = 67 \text{ ohms}$$

(a) $I = \dfrac{E}{Z} = \dfrac{120}{67} = 1.8 \text{ amperes}$

(b) $E_R = IR = 1.8 \times 10 = 18 \text{ volts}$

(c) $E_C = IX_C = 1.8 \times 66.3 \times 119.3 \text{ volts}$

(d) $\cos\phi = \dfrac{R}{Z} = \dfrac{10}{67} = 0.15, \text{ or } 15\%$

(e) $P = E \times I \times \cos\phi$

$= 120 \times 1.8 \times 0.15$

$= 32.4 \text{ watts}$

2-29 A coil of 3 ohms resistance and 20 millihenrys inductance is connected in series with a capacitance of 400 microfarads. If the voltage and frequency are 120 volts at 60 hertz, find (a) the impedance of the circuit; (b) the current in the circuit; (c) the power loss; (d) the power factor.

$$X_L = 2\pi fL = 2\pi \times 60 \times 0.020 = 7.54 \text{ ohms}$$

$$X_C = \frac{1}{2\pi \times 60 \times 0.0004} = 6.67 \text{ ohms}$$

(a) $Z = \sqrt{R^2 + (X_L - X_C)^2}$

$= \sqrt{3^2 + (7.54 - 6.67)^2}$

$= 3.12 \text{ ohms}$

(b) $I = \frac{E}{Z} = \frac{120}{3.12} = 38.5$ amperes

(c) $P = I^2R = 38.5^2 \times 3 = 4{,}447$ watts

(d) $\cos\phi = \frac{R}{Z} = \frac{3}{3.12} = 0.961$, or 96% (approx.)

As a check for the power loss in part (c), use the information obtained in part (d), the power factor. Then:

$$P = EI\cos\phi = 120 \times 38.5 \times 0.961 = 4{,}440 \text{ watts}$$

2-30 A certain series circuit has a resistance of 10 ohms, a capacitance of 0.0003 farad, and an inductance of 0.03 henry. If a 60-hertz, 230-volt Electromotive force (emf) is applied to this circuit, find (a) the current through the circuit; (b) the power factor; (c) the power consumption.

$$X_L = 2\pi fL = 2\pi \times 60 \times 0.03 = 11.30 \text{ ohms}$$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi \times 60 \times 0.0003} = 8.85 \text{ ohms}$$

$$\begin{aligned} Z &= \sqrt{R^2 + (X_L - X_C)^2} \\ &= \sqrt{10^2 + (11.30 - 8.85)^2} \\ &= 10.3 \text{ ohms} \end{aligned}$$

(a) $I = \frac{E}{Z} = \frac{230}{10.3} = 22.3$ amperes

(b) $\cos\phi = \frac{10}{10.2} = 0.97$, or 97%

(c) $P = I^2R = 22.3^2 \times 10 = 4.97$ kilowatts

2-31 The circuit in Figure 2-9 contains a resistance of 30 ohms and a capacitance of 125 microfarads. If an alternating current of 8 amperes at a frequency of 60 hertz is flowing in the circuit, find (a) the voltage drop across the resistance; (b) the voltage drop across the capacitance; (c) the voltage applied across the circuit.

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi \times 60 \times 0.000125} = 21.3 \text{ ohms}$$

$$Z = \sqrt{R^2 + X_C^2} = \sqrt{30^2 + 21.3^2} = 36.8 \text{ ohms}$$

(a) $E_R = IR = 8 \times 30 = 240$ volts

(b) $E_C = IX_C = 8 \times 21.3 = 170$ volts

(c) $E = IZ = 8 \times 36.8 = 294$ volts

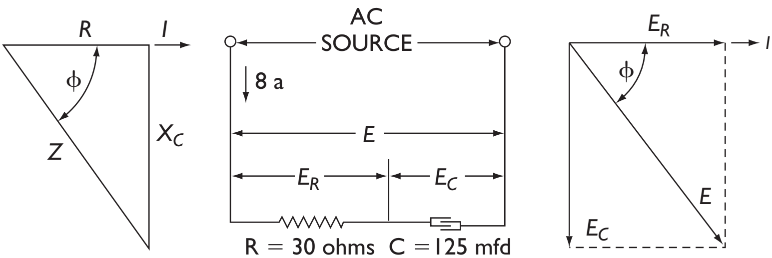


Figure 2-9 Resistance and capacitance in series, with appropriate vector diagrams.

2-32 A resistance of 15 ohms is connected in series with a capacitance of 50 microfarads. If the voltage of the source is 120 volts at 60 hertz, find (a) the amount of current in the circuit; (b) the voltage drop across the resistance; (c) the voltage drop across the capacitance; (d) the angular difference between the current and the applied voltage; (e) the power loss in the circuit.

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi \times 60 \times 0.00005} = 53.0 \text{ ohms}$$

$$Z = \sqrt{R^2 + X_C^2} = \sqrt{15^2 + 53.0^2} = 55.1 \text{ ohms}$$

(a) $I = \dfrac{E}{Z} = \dfrac{120}{55.1} = 2.18$ amperes

(b) $E_R = IR = 2.18 \times 15 = 32.7$ volts

(c) $E_C = IX_C = 2.18 \times 53.0 = 115.5$ volts

(d) $\cos\phi = \dfrac{E_R}{E} = \dfrac{32.7}{120} = 0.272$, and $\phi = 74.2°$

(e) $P = I^2R = 2.18^2 \times 15 = 71$ watts

2-33 A resistance of 20 ohms and a capacitance of 100 microfarads are connected in series across a 200-volt, 50-hertz ac supply. Find (a) the current in the circuit; (b) the potential drop across the resistance; (c) the potential drop across the capacitance; (d) the phase

difference between the current and the applied voltage; (e) the power consumed; (f) the power factor.

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi \times 50 \times 0.0001} = 31.8 \text{ ohms}$$
$$Z = \sqrt{R^2 + X_C^2} = \sqrt{20^2 + 31.8^2} = 37.6 \text{ ohms}$$

(a) $I = \frac{E}{Z} = \frac{200}{37.6} = 5.32$ amperes

(b) $E = IR = 5.32 \times 20 = 106.4$ volts

(c) $E_C = IX_C = 5.32 \times 31.8 = 169.2$ volts

(d) $\cos\phi = \frac{R}{Z} = \frac{20}{37.6} = 0.532$, and $\phi = 57.9°$

(e) $P = I^2R = 5.32^2 \times 20 = 566$ watts

(f) $\cos\phi = 0.532$, or 53.2%

2-34 What is the total capacitance of four parallel capacitors rated 10, 15, 25, and 30 microfarads, respectively?

$$\begin{aligned} C &= C_1 + C_2 + C_3 + C_4 \\ &= 10 + 15 + 25 + 30 \\ &= 80 \text{ microfarads} \end{aligned}$$

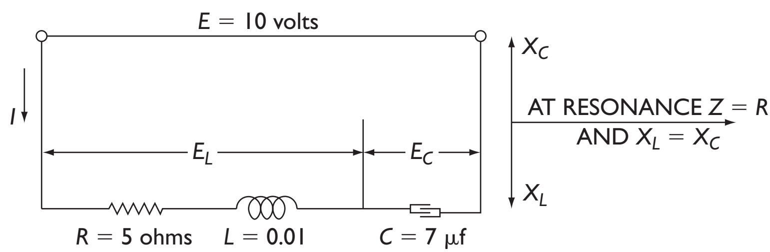


Figure 2-10 Resistance, inductance, and capacitance in series, with a vector diagram illustrating their relationship to each other.

2-35 A certain coil (shown in Figure 2-10) with a resistance of 5 ohms and an inductance of 0.01 henry is connected in series with a capacitor across a 10-volt supply, which has a frequency of 800 cycles per second. Find (a) the capacitance that will produce resonance; (b) the corresponding value of the current; (c) the potential

drop across the coil; (d) the potential drop across the capacitor; (e) the power factor of the circuit; (f) the power consumption.

The inductive reactance of the coil is:

$$X_L = 2\pi \times 800 \times 0.01 = 50.24 \text{ ohms}$$

Therefore,

$$X_C = 50.24 = \frac{10^6}{2\pi \times 800 \times C}$$

$$C = \frac{10^4}{50.24^2}$$

$$= 3.96 \text{ microfarads}$$

(a) Since resonance occurs when $X_L = X_C$, X_C must also be equal to 50.24 ohms.

(b) At resonance, the current is:

$$I = \frac{E}{R} = \frac{10}{5} = 2 \text{ amperes}$$

(c) The potential drop across the coil is:

$$E_L = IX_L = 2 \times 50.24 = 100.5 \text{ volts}$$

(d) The potential drop across the capacitor is:

$$E_C = IX_C = 2 \times 50.24 = 100.5 \text{ volts}$$

(e) The power factor is:

$$\cos\phi = \frac{R}{Z}$$

but since resonance $Z = R$,

$$\cos\phi = \frac{R}{R} = 1, \text{ and } \phi = 0°$$

(f) The power consumed is:

$$P = I^2R = 4 \times 5 = 20 \text{ watts}$$

2-36 The field winding of a shunt motor has a resistance of 110 ohms, and the emf applied to it is 220 volts. What is the amount of power expended in the field excitation?

The current through the field is:

$$I_f = \frac{E_t}{R_f} = \frac{220}{110} = 2 \text{ amperes}$$

The power expended $= E_t I_f = 220 \times 2 = 440$ watts. The same results can also be obtained directly by using the following equation:

$$P_f = \frac{E_f^2}{R_f} = \frac{220^2}{110} = 440 \text{ watts}$$

2-37 A shunt motor whose armature resistance is 0.2 ohm and whose terminal voltage is 220 volts requires an armature current of 50 amperes and runs at 1500 rpm when the field is fully excited. If the strength of the field is decreased and the amount of armature current is increased, both by 50%, at what speed will the motor run?

The expression for the counter-emf of the motor is:

$$E_a = E_t = I_a R_a$$

and,

$$E_{a^1} = 220 - (50 \times 0.2) = 210 \text{ volts}$$

Similarly,

$$E_{a^2} = 220 - (75 \times 0.2) = 205 \text{ volts}$$

also,

$$E_a = NfK$$

and,

$$\frac{E_{a^1}}{E_{a^2}} = \frac{N_1 \phi_1 K_1}{N_2 \phi_2 K_2}$$

Since the field is decreased by 50%,

$$\phi_1 = 1.5\phi_2, \text{ and } Z_1 = Z_2$$

it follows that:

$$\frac{210}{205} = \frac{1500 \times 1.5}{N_2}$$

$$N_2 = \frac{1500 \times 205 \times 1.5}{210} = 2196 \text{ rpm}$$

2-38 A 7.5-hp, 220-volt interpole motor has armature and shunt-field resistances of 0.5 ohm and 200 ohms, respectively. The current input at 1800 rpm under no-load conditions is 3.5 amperes. What are the current and the electromagnetic torque for a speed of 1700 rpm?

Under no-load conditions (at 1800 rpm),

$$I_a = I_L - I_f = 3.5 - \frac{220}{200} = 2.4 \text{ amperes}$$

$$\phi K_{NL} = \frac{E_t - (I_a R_a)}{N} = \frac{220 - (2.4 \times 0.5)}{1800} = 0.1216$$

$$\phi K_{NL} = \phi K_{FL}$$

At 1700 rpm,

$$\begin{aligned} I_a &= \frac{E_t - (N\phi K)}{R_a} \\ &= \frac{220 - (1700 \times 0.1216)}{0.5} \\ &= 26.6 \text{ amperes} \\ I_L &= I_a + I_f = 26.6 + 1.1 = 27.7 \text{ amperes} \\ T_a &= 7.05\phi K I_a = 7.05 \times 0.1216 \times 26.6 = 22.8 \text{ ft-lb} \end{aligned}$$

2-39 The mechanical efficiency of a shunt motor whose armature and field resistances are 0.055 and 32 ohms, respectively, is to be tested by means of a rope brake. When turning at 1400 rpm, the longitudinal pull on the 6-inch-diameter pulley is 57 lb. Simultaneous readings on the line voltmeter and ammeter are 105 volts and 35 amperes, respectively. Calculate (a) the counter-emf developed;(b) the copper losses;(c) the efficiency.

$$I_a = I_L - I_f = 35 - \frac{105}{32} = 31.7 \text{ amperes}$$

(a) $E_a = E_t - (I_a R_a) = 105 - (31.7 \times 0.055)$
$= 103.26$ volts

(b) $P_c = I_f^2 R_f + I_a^2 R_a$
$= (3.3^2 \times 32) + (31.7^2 \times 0.055)$
$= 404$ watts

(c) $$\text{Output} = \frac{3p \times 1400 \times \frac{3}{12} \times 57}{33{,}000} = 3.8 \text{ hp}$$

$$\text{Input} = \frac{105 \times 35}{746} = 4.93 \text{ hp}$$

$$\eta_m = \frac{3.8}{4.93} = 0.771, \text{ or } 77\%$$

2-40 A copper transmission line that is 1.5 miles in length is used to transmit 10 kilowatts from a 600-volt generating station. The voltage drop in the line is not to exceed 10% of the generating station voltage. Calculate (a) the line current;(b) the resistance of the line;(c) the cross-sectional area of the wire.

(a) $$IL = \frac{10{,}000}{600} = 16.67 \text{ amperes}$$

The permissible voltage drop $= 600 \times 0.1 = 60$ volts

(b) $$R = \frac{60}{16.67} = 3.6 \text{ ohms}$$

(c) $$3.6 = \frac{10.4 \times 3 \times 5280}{A}$$

$$A = \frac{10.4 \times 3 \times 5280}{3.6} = 45{,}760 \text{ CM}$$

2-41 A trolley system 10 miles long is fed by two substations that generate 600 volts and 560 volts, respectively. The resistance of the trolley wire and rail return is 0.3 ohm per mile. If a car located 4 miles from the 600-volt substation draws 200 amperes from the line, what is the voltage between the trolley collector and the track? How much current is supplied by each substation?

With reference to Figure 2-11, the following equation can be written:

Equation (1) $\quad I_1 + I_2 = 200$ amperes

That is, the arithmetical sum of the current drain from each substation must equal the current drawn by the trolley car. Similarly, the equations for the voltage drop in each branch of the trolley wire are:

Equation (2) $\quad I_1(1.2) = 600 - E$
Equation (3) $\quad I_2(1.8) = 560 - E$

Subtracting equation (3) from equation (2),

Equation (4) $\quad 40 = 1.2I_1 - 1.8I_2$

According to equation (1),

$$I_1 = 200 - I_2$$

Therefore, equation (4) becomes:

$$40 = 1.2(200 - I_2) - 1.8I_2$$
$$I_2 = 66.67 \text{ amperes}$$
$$I_1 = 200 - 66.67 = 133.33 \text{ amperes}$$

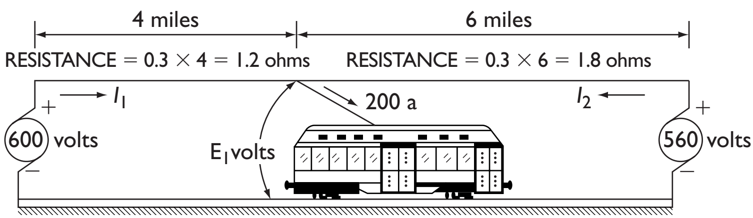


Figure 2-11 Current and potential drop in a trolley feeder system.

By inserting the value of I_2 in equation (3), obtain the voltage between the trolley collector and the track:

$$E = 560 - (1.8 \times 66.67) = 440 \text{ volts}$$

The same result can be obtained by inserting the value of I_1 in equation (2).

2-42 It is desired to supply power from a 220-volt source to points C and D in Figure 2-12 by means of the feeder arrangement indicated. The motor at point C requires 120 amperes, and the motor

at point D requires 80 amperes. With the length of the wires as indicated and a maximum voltage drop of 10%, calculate (a) the cross-sectional area of feeder AB;(b) the cross-sectional area of feeder BC;(c) the cross-sectional area of feeder BD;(d) the power loss in each section.

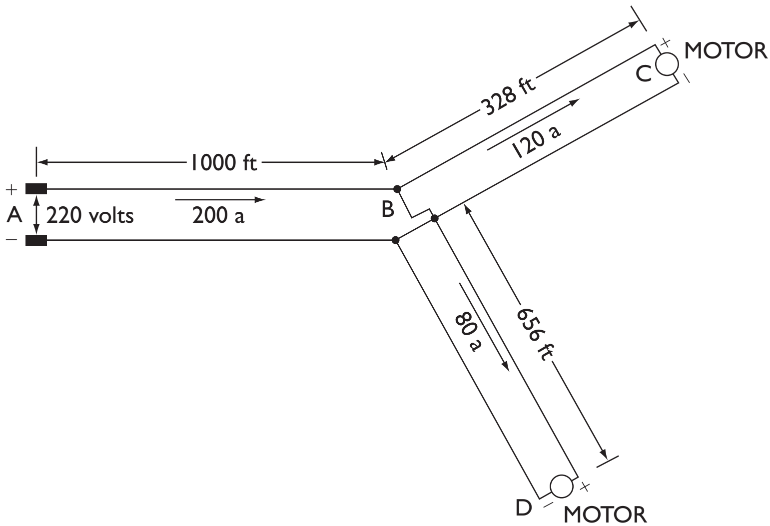


Figure 2-12 Branch feeder calculations.

The voltage drop across AC and AD is:

$$E' = 220 \times 0.1 = 22 \text{ volts}$$

To simplify our calculation, the voltage drop across BC and BD can be arbitrarily set at 10 volts. The voltage drop across AB is, therefore, 22.10, or 12 volts.

(a) $A = \left(\dfrac{10.4 \times 2}{12}\right) \times 200 \times 1000 = 346{,}667 \text{ CM}$

(b) $A = \left(\dfrac{10.4 \times 2}{10}\right) \times 120 \times 328 = 81{,}869 \text{ CM}$

(c) $A = \left(\dfrac{10.4 \times 2}{10}\right) \times 80 \times 656 = 109{,}158 \text{ CM}$

(d) $P_{AB} = 200 \times 12 = 2400$ watts
$P_{BC} = 120 \times 10 = 1200$ watts
$P_{BD} = 80 \times 10 = 800$ watts

2-43 The motor illustrated in Figure 2-13 is located at a distance of 500 feet from the generator and requires 40 amperes at 220 volts. No. 4 AWG wire is used. Calculate (a) the voltage at the generator; (b) the voltage-drop percentage in the line; (c) the power loss in the line; (d) the power-loss percentage; (e) the cost of power losses per year. Assume that the motor operates 8 hours per day, 300 days per year, at a cost of 3 cents per kilowatt-hour.

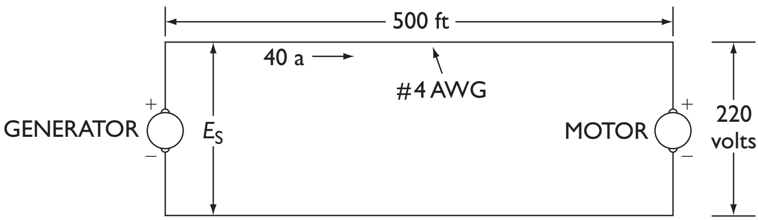


Figure 2-13 Calculations for a 220-volt motor.

With reference to Table 2-1, the cross-sectional area of No. 4 wire = 41,740 CM.

$$R = \frac{10.4 \times 1000}{41,740} = 0.25 \text{ ohms}$$

(a) $E_G = 220 + (40 \times 0.25) = 230$ volts

(b) $\dfrac{(230 - 220)100}{220} = 4.55\%$

(c) $P_G - P_R = 40^2 \times 0.25 = 400$ watts

(d) $\dfrac{(P_G - P_R)100}{P_R} = \dfrac{400 \times 100}{40 \times 220} = 4.55\%$

(e) Yearly cost of power losses $= 0.4 \times 8 \times 300 \times 0.03$
$= \$28.80$

2-44 Energy is transmitted from a switchboard to the combined load shown in Figure 2-14. The lamp group requires 20 amperes, and the motor requires 30 amperes from the line. Number 2 wire

(resistance = 0.156 ohm per 1000 ft) is used throughout the circuit. Calculate (a) the power drawn by the lamps; (b) the power drawn by the motor; (c) the power loss in the line; (d) the total power supplied by the switchboard.

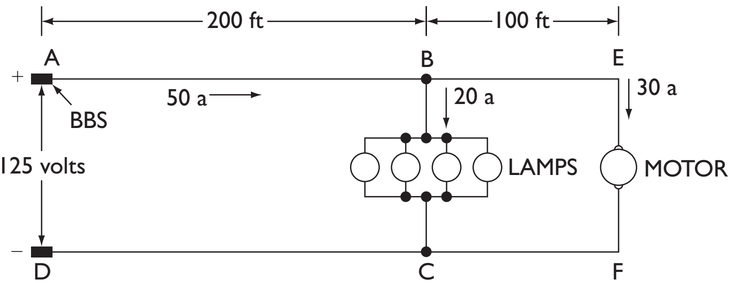


Figure 2-14 Voltage-drop calculations in a feeder circuit that is supplying a motor and lamp load.

The resistance in line ABCD is:

$$\frac{0.162 \times 200 \times 2}{1000} = 0.065 \text{ ohm}$$

(a) $P = 20 \times 121.8 = 2.436$ kilowatts

The resistance in line BEFC is:

$$\frac{0.162 \times 100 \times 2}{1000} = 0.0324 \text{ ohm}$$

$$\text{Voltage at the motor} = 121.8 - (30 \times 0.0324)$$
$$= 120.83 \text{ volts}$$

(a) $P_M = 30 \times 120.83 = 3.62$ kw

(b) $P_L = (50 \times 125) - (2436 + 3630) = 184$ watts

(c) $P_t = 125 \times 50 = 6.25$ kilowatts

Relative Conductivity

2-45 What is the comparison of electrical conductivity between silver, copper, and aluminum?

Of the three, silver is the best conductor of electricity and is considered to possess 100% conductivity. Copper is next, at approximately 94% of the conductivity of silver. Aluminum is considered to be last with approximately 61% of the conductivity of silver.

2-46 What are the advantages and disadvantages of silver as a conductor?

The price of silver makes it generally prohibitive to use for a conductor. It is used only in special cases for its high conductivity and where the price is a minor factor.

2-47 What are the advantages of copper as a conductor? What are its disadvantages?

Copper is plentiful, relatively inexpensive, a good conductor, and it has a high tensile strength. It can be corroded under certain circumstances.

2-48 What are the advantages and disadvantages of aluminum as a conductor?

Aluminum is inexpensive, lightweight, and readily available. It corrodes more easily than copper, so its use is limited to some degree; it also has less tensile strength than copper.

Chapter 3

Power and Power Factor

The unit of *work* is the foot-pound (ft-lb). This is the amount of work done when a force of one pound acts through a distance of one foot. The amount of work done is equal to the force in pounds times the distance in feet:

$$W \text{ (work)} = \text{force} \times \text{distance}$$

Thus, if an object weighing 10 pounds is lifted a distance of 4 feet, the work done is equal to 40 ft-lb.

Time becomes involved when performing work, so you use the quantity known as *power*, which is the rate of doing work. Power is directly proportional to the amount of work done and is inversely proportional to the time in which the work is done. For example, more power is required if an object weighing 10 pounds is lifted through a distance of 4 feet in 1 minute than if the same 10-pound object is lifted a distance of 4 feet in 5 minutes. From this statement, you may arrive at the formula for power:

$$\text{Power (foot-pounds per minute)} = \frac{\text{work done (foot-pounds)}}{\text{time (minutes)}}$$

A more common unit of power is the *horsepower* (hp), which is equivalent to 33,000 ft-lb of work per minute. Remember this figure and its relationship to time and horsepower; it will be used quite often when working problems that deal with power.

In electricity, the unit of power is the watt. However, since the watt is a relatively small unit, the kilowatt is more commonly used as the unit of power. One kilowatt is equivalent to 1000 watts.

A good working knowledge of the electrical formulas that are used to determine power is a *must* for the electrician. When using electrical formulas to determine power, it is a universal practice to use the following notations:

P is the power in watts

I is the current in amperes

R is the resistance in ohms

E is the potential difference in volts

Thus, the power P expended in a load resistance R when a current I flows due to a voltage pressure E can be found by the following relationships:

$$P = IE$$
$$P = \frac{E^2}{R}$$
$$P = I^2R$$

Remember, IR equals a potential, in volts, and I^2R equals power, in watts.

When dealing with large amounts of electrical power, you may be required to determine the cost of the power consumed. You will be dealing with kilowatts and also with kilowatt-hours (kwh), which are the number of kilowatts used per hour. Thus, 25 kwh is 25 kilowatts used for 1 hour. To find the cost of electricity usage on a bill, use the following formula:

$$\text{Cost} = \frac{\text{watts} \times \text{hours used} \times \text{rate per kwh}}{1000}$$

For example, an electric heater that draws 1350 watts is used for 4 hours, and the cost of electricity for that particular location is 3 cents per kilowatt-hour. What is the cost of using the heater?

$$\text{Cost} = \frac{1350 \times 4 \times 0.03}{1000} = 16.2 \text{ cents}$$

Energy can be changed from one form to another but can never be destroyed. Therefore, you may readily change electrical power into mechanical power, and the converse is also true. The usual method of referring to mechanical power is in terms of horsepower: one horsepower is equal to 746 watts. This wattage value for the horsepower unit assumes that the equipment used to produce one horsepower operates at 100% efficiency. That, of course, is not possible, because there is always some power lost in the form of friction or other losses, which will be covered later in this text.

3-1 A motor draws 50 amperes and is fed by a line of No. 6 copper wire that is 125 feet long. What is the I^2R loss of the line?

In *Chapter 9, Table 8* of the NEC, No. 6 copper has a resistance of 0.410 ohm per 1000 feet at 25°C. The line is 125 feet long, so the amount of wire used will be 2×125, or 250 feet.

This is 25% of 1000 feet, so the resistance of the wire will be 0.410×0.25, or 0.1025 ohm. Therefore,

$$\begin{aligned} P &= I^2R = (50)^2 \times 0.1025 \\ &= 2500 \times 0.1025 = 256.25 \text{ watts} \end{aligned}$$

3-2 The line loss of the line in question 3-1 is 256.25 watts. If the motor is operated for 100 hours and the rate of electricity is 3 cents per kwh, what would be the cost of the I^2R loss of the line?

$$\text{Cost} = \frac{256.25 \times 100 \times 0.03}{1000} = 76.875 \text{ cents}$$

3-3 A 1-hp motor draws 1000 watts. What is its efficiency?

$$\text{Efficiency} = \frac{\text{output}}{\text{input}}$$

Therefore,

$$\text{Efficiency} = \frac{746}{1000} = 0.746, \text{ or } 74.6\%$$

3-4 An electric iron draws 11 amperes at 120 volts. How much power is used by the iron?

$$P = 11 \times 120 = 1320 \text{ watts} = 1.32 \text{ kw}$$

3-5 A motor must lift an elevator car weighing 2000 pounds to a height of 1000 feet in 4 minutes. (a) What is the theoretical size, in horsepower, of the motor required? (b) At 50% efficiency, what is the size, in horsepower, of the motor required?

(a) $W = 2000 \times 1000 = 2{,}000{,}000$ ft-lb

$$\frac{2{,}000{,}000}{4} = 500{,}000 \text{ ft-lb per minute}$$

$$\frac{500{,}000}{33{,}000} = 15.15 \text{ hp}$$

(b) $\text{Input} = \dfrac{\text{output}}{\text{efficiency}} = \dfrac{15.15}{0.50} = 30.3 \text{ hp}$

A 30-hp motor will carry this load nicely.

3-6 A lamp operating at 120 volts has a resistance of 240 ohms. What is the wattage of the lamp?

$$P = \frac{E^2}{R} = \frac{120^2}{240} = \frac{14{,}400}{240} = 60 \text{ watts}$$

3-7 What is the overall efficiency of a 5-hp motor that draws 20 amperes at 240 volts?

$$\begin{aligned} \text{Input} &= 240 \times 20 = 4800 \text{ watts} \\ \text{Output} &= 5 \times 746 = 3730 \text{ watts} \\ \text{Efficiency} &= \frac{3750}{4800} = 0.777, \text{ or } 77.7\% \end{aligned}$$

3-8 What is the cost of operating a 2-watt electric clock for one year at 2 cents per kwh?

$$\begin{aligned} \text{Cost} &= \frac{2 \text{ watts} \times 24 \text{ hours} \times 365 \text{ days} \times 0.02}{1000} \\ &= 35.04 \text{ cents} \end{aligned}$$

3-9 The primary of a transformer draws 4 amperes at 7200 volts. A reading at the secondary shows 110 amperes at 240 volts. What is the efficiency of the transformer at this load?

$$\begin{aligned} \text{Efficiency} &= \frac{\text{output}}{\text{input}} = \frac{110 \times 240}{4 \times 7200} \\ &= \frac{26{,}400}{28{,}800} = 91.67\% \end{aligned}$$

3-10 What instrument is used to measure voltage?

A voltmeter.

3-11 How is a voltmeter connected in a circuit? (explain and illustrate)

A voltmeter is always connected in shunt, or parallel, across the load or the source whose voltage is being measured. This is illustrated in Figure 3-1.

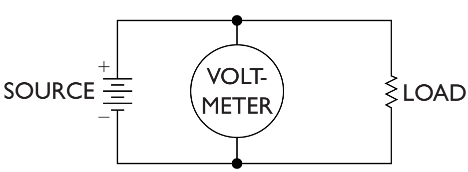


Figure 3-1 Voltmeter connections in a circuit.

3-12 With what instrument do you measure current?
An ammeter.

3-13 How is an ammeter connected in a circuit? (explain and illustrate)

An ammeter is connected in series with the circuit being tested. This is illustrated in Figure 3-2. Clamp-on ammeters, however, operate by measuring the magnetic field around conductors. These meters, though less accurate, are not wired into the circuit at all. Rather, they are simply clamped around the conductor whose current is to be measured.

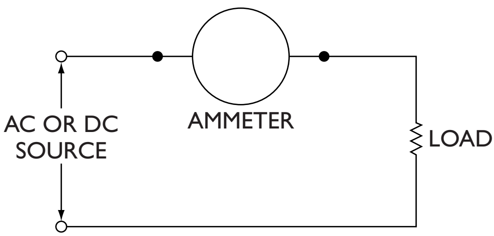


Figure 3-2 Ammeter connections in a circuit.

3-14 Give two methods of measuring large currents. Explain why they must be used.

It is impractical to construct a meter that is capable of carrying the large currents. Therefore, when measuring large currents in ac or dc circuits the electrician uses a shunt, which consists of a low-resistance load connected in series with the load and connected in parallel with a high-resistance meter. The meter then receives only a small fraction of the current passing through the load. This method is illustrated in Figure 3-3.

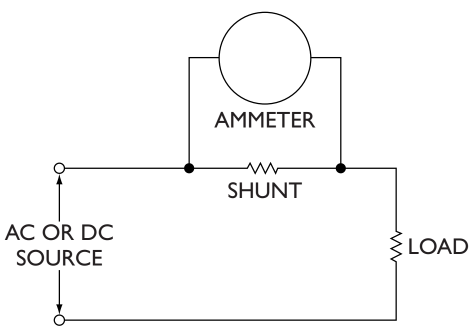


Figure 3-3 One common method used to measure large current.

Another method for measuring large currents in an ac circuit makes use of a current transformer (Figure 3-4), which is described in Chapter 6. You may also use the wire that carries the load current as the primary of a current transformer, in conjunction with a clip-on ammeter. The secondary of the transformer is incorporated into the ammeter, so the meter has no actual physical connection in the circuit (Figure 3-4).

3-15 When using an ammeter, what precautions must be taken?

Know whether the current is ac or dc, and use the appropriate ammeter. Be sure that the rating of the meter is large enough for the current being measured to prevent the meter from being damaged.

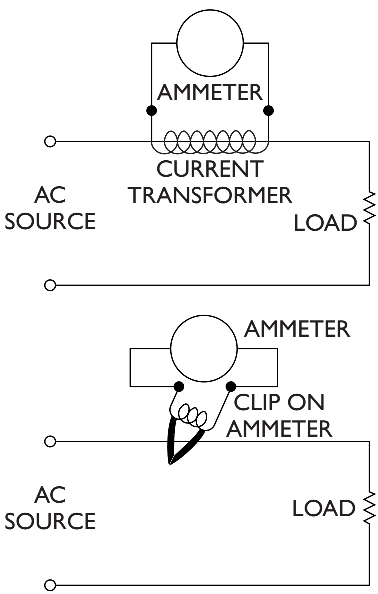


Figure 3-4 Measurement of large currents in an AC circuit.

3-16 What is a wattmeter?

A wattmeter is an instrument that is designed to measure directly the active power in an electric circuit. It consists of a coil connected in series with the circuit, such as in an ammeter, and a coil connected in parallel with the circuit, such as in a voltmeter. Both coils actuate the same meter, thereby measuring both the current and the voltage affecting one meter, which may be calibrated in watts, kilowatts, or megawatts.

3-17 How is a wattmeter connected in a circuit? Illustrate.
See Figure 3-5.

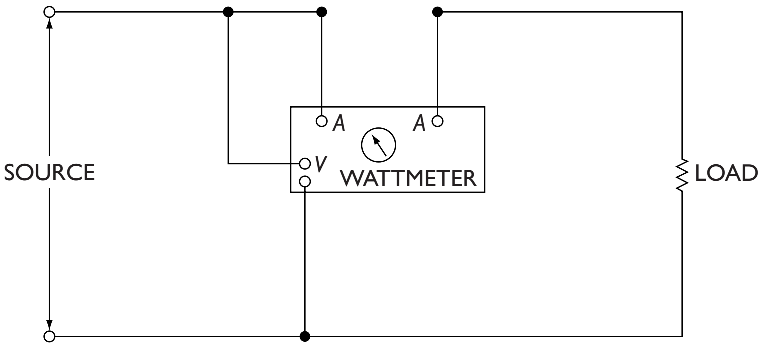


Figure 3-5 Wattmeter connections in a circuit.

3-18 Can the principles used in dc circuits be applied to all ac circuits?
The fundamental principles of dc circuits may also apply to ac circuits that are strictly resistive in nature, such as incandescent lighting and heating loads.

3-19 What causes inductive reactance?
Inductive reactance is caused by opposition to the flow of alternating current by the inductance of the circuit.

3-20 Give some examples of equipment that causes inductive reactance.
Motors, transformers, choke coils, relay coils, ballasts.

3-21 When only inductive reactance is present in an ac circuit, what happens to the current in relation to the voltage?
The current is said to *lag* behind the voltage.

3-22 What is the reason for current lagging the voltage in an inductive circuit?
In an ac circuit, the current is continually changing its direction of flow (60 times a second in a 60-hertz circuit). Any change of current value is opposed by the inductance within the circuit involved.

3-23 Draw sine waves of voltage and current in a circuit containing only inductive reactance when 60-hertz ac is applied to the circuit.
See Figure 3-6.

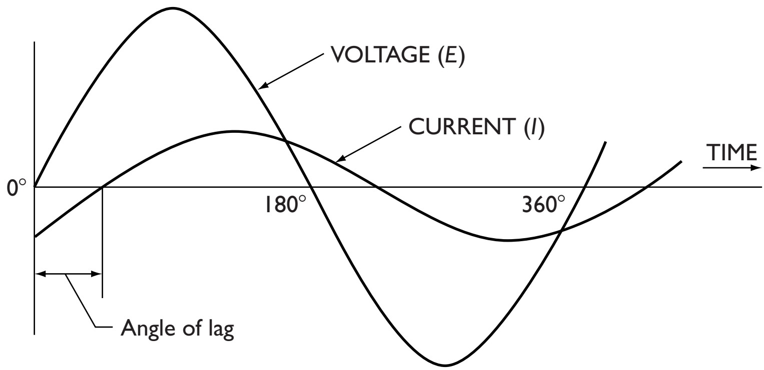


Figure 3-6 Voltage and current sine waves in a circuit containing only inductive reactance, with a frequency of 60 hertz.

3-24 When only capacitive reactive is present in an ac circuit, what happens to the relationship that exists between the voltage and the current?

The current is said to *lead* the voltage.

3-25 Draw sine waves of current and voltage in a circuit containing only capacitive reactance when 60-hertz ac is applied to the circuit.

See Figure 3-7.

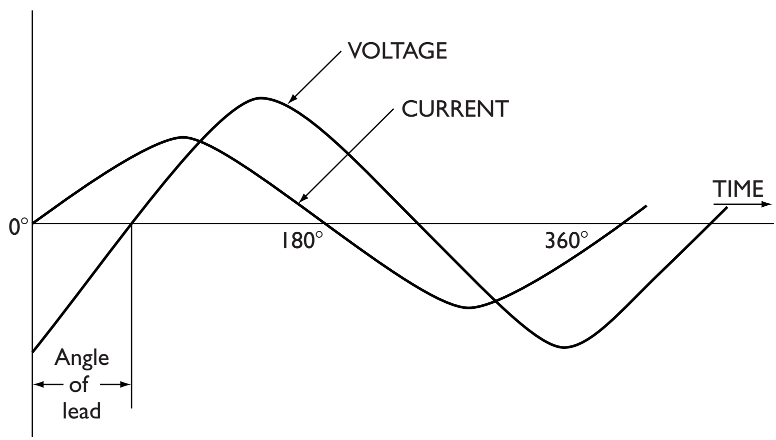


Figure 3-7 Voltage and current sine waves in a circuit containing only capacitive reactance, with a frequency of 60 hertz.

3-26 In a purely resistive circuit with an applied 60-hertz ac voltage, what is the relationship between the current and voltage?

The current and voltage will be in phase, as illustrated in Figure 3-8.

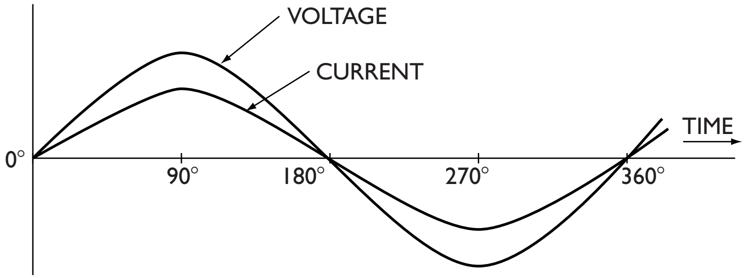


Figure 3-8 Voltage-current relationship in a resistive circuit at a frequency of 60 hertz.

3-27 Is it possible to have a circuit with only inductive reactance?

Under ordinary circumstances this is not possible, since all metal conductors have a certain amount of resistance. It is, however, possible for circuits that employ superconductors. At present, this can be done only in laboratory situations.

3-28 If it were possible to have only inductive reactance in an ac circuit, by what angle would the current lag the voltage?

The current would lag the voltage by 90°. When the voltage was at its maximum value in one direction, the current would be zero and would be just getting ready to increase in the direction of maximum voltage.

3-29 If it were possible to have only capacitive reactance in an ac circuit, by what angle would the current lead the voltage?

The current would lead the voltage by 90°. When the current was at its maximum value in one direction, the voltage would be zero and would be just getting ready to increase in the direction of maximum current.

3-30 Draw vectorially the current and voltage 90° out of phase in an inductive circuit.

See Figure 3-9.

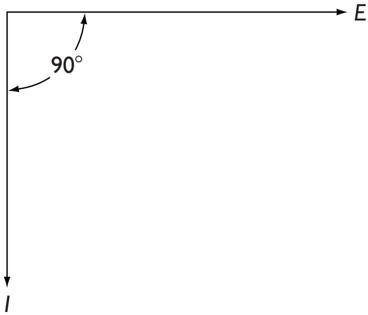


Figure 3-9 Vector relationship between voltage and current in an inductive circuit.

3-31 Draw vectorially the current and voltage 90° out of phase in a capacitive circuit.

See Figure 3-10.

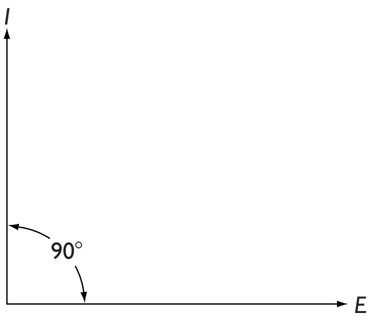


Figure 3-10 Vector relationship between voltage and current in a capacitive circuit.

3-32 What is meant by power factor?

Power factor is the phase displacement of current and voltage in an ac circuit. The cosine of the phase angle of displacement is the power factor; the cosine is multiplied by 100 and is expressed as a percentage. The cosine of 90° is 0; therefore, the power factor is 0%. If the angle of displacement were 60°, the cosine of which is 0.500, the power factor would be 50%. This is true whether the current leads or lags the voltage.

3-33 How is power expressed in dc circuits and ac circuits that are purely resistive in nature?

In dc circuits and ac circuits that contain only resistance,

$$P\ (\text{watts}) = E \times I$$

$$P\ (\text{kilowatts}) = \frac{E \times I}{1000}$$

3-34 How is power expressed in ac circuits that contain inductive and/or capacitive reactance?

$$\text{VA (volt-amperes)} = E \times I$$
$$\text{KVA (kilovolt-amperes)} = \frac{E \times I}{1000}$$
$$P \text{ (watts)} = E \times I \times \text{power factor}$$

3-35 In a 60-Hz ac circuit, if the voltage is 120 volts, the current is 12 amperes, and the current lags the voltage by 60°, find (a) the power factor; (b) the power in volt-amperes (VA); (c) the power in watts.

(a) The cosine of 60° is 0.500; therefore, the power factor is 50%.
(b) 120 × 12 = 1440 VA, which is called the *apparent* power.
(c) 120 × 12 × 0.5 = 720 watts, which is called the *true* power.

3-36 Show vectorially a 12-ampere line current lagging the voltage by 60°; indicate that the in-phase current is 50%, or 6 amperes.
See Figure 3-11.

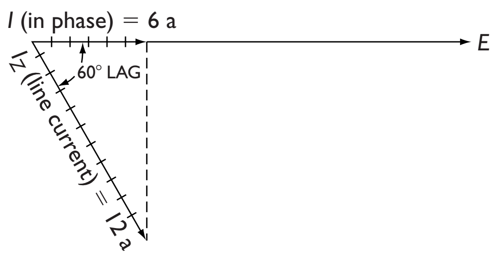


Figure 3-11 A 12-ampere line current lagging the voltage by 60°; the in-phase current is 50% of the line current, or 6 amperes.

3-37 Why is a large power factor of great importance?
As can be seen in questions 3-35 and 3-36, there is an apparent power of 1440 VA and a true power of 720 watts. There are also 12 amperes of line current and 6 amperes of in-phase, or effective, current. This means that all equipment from the source of supply to the power-consumption device must be capable of handling a current of 12 amperes, while actually the device is only utilizing a current of 6 amperes. A 50% power factor was used intentionally to make the results more pronounced. The I^2R loss is based on the 12-ampere current, whereas only 6 amperes are really effective.

3-38 How can power factor be measured or determined?

There are two easy methods: (1) by the combined use of a voltmeter, ammeter, and wattmeter (all ac instruments, of course), and (2) by the use of a power-factor meter.

3-39 How is the voltmeter-ammeter-wattmeter method used to determine the power factor?

The voltmeter, ammeter, and wattmeter are connected properly in the circuit. Then the readings of the three meters are simultaneously taken under the same load conditions. Finally, the following calculations are made:

$$\begin{aligned} \text{Power factor} &= \frac{\text{true power (watts)}}{\text{apparent power } (E \times I)} \\ &= \frac{\text{w}}{E \times I} \\ &= \frac{\text{kw}}{\text{KVA}} \end{aligned}$$

3-40 What is a power-factor meter?

A power-factor meter is a wattmeter calibrated to read the power factor directly, instead of in watts. It is connected in the circuit in the same manner as a wattmeter.

3-41 In a circuit that contains an inductance, such as a motor, will the current lead or lag the voltage? What steps can be taken to correct the power factor?

The current will lag the voltage. The power factor can be corrected by adding capacitance to the circuit. This can be done either by introducing capacitors to the circuit, or by using synchronous motors and overexciting their fields.

3-42 What is the ideal power transmission condition, as far as the power factor is concerned?

Unity power factor, or a power factor of 1, which means that the current is in phase with the voltage.

3-43 Which is the best condition, a leading or a lagging current?

They both have the same effect, so one is as good as the other. In an overall picture, there are usually more lagging currents than leading currents, because most of the loads used in the electrical field are of an inductive nature.

3-44 In an ac voltage or current, there are three values that are referred to. What are they?

The *maximum* value of current or voltage, the *effective* value of current or voltage, and the *average* value of current or voltage.

3-45 What is meant by the *maximum* ac voltage?

This is the maximum, or peak, voltage value of an ac sine wave.

3-46 What is meant by the *average* ac voltage?

This is the average of the voltages taken at all points on the sine wave.

3-47 What is meant by the *effective* ac voltage?

This is the value of the useful voltage that is indicated on a voltmeter. It is the voltage that is used in all normal calculations in electrical circuits.

3-48 What percentage of the peak voltage is the effective voltage?

70.7% of the peak value.

3-49 What percentage of the peak voltage is the average voltage?

63.7% of the peak voltage.

3-50 What is the effective voltage most commonly called?

Effective voltage is usually called rms voltage. (The term rms means rootmean-square.)

3-51 How could the rms voltage be arrived at vectorially?

An infinite number of lines could be drawn from the base line to the one-half amplitude value of the sine wave. These voltage values would then be squared, the sum of the squares would be averaged (added together and divided by the number of squares), and the square root of this figure would be the rms value of the voltage in question.

3-52 Does the peak voltage have to be considered?

Yes. In design, the peak voltage must be considered, because this value is reached twice in every cycle.

3-53 Draw a sine wave showing the effective value and the peak value of a standard 120-volt ac line.

See Figure 3-12.

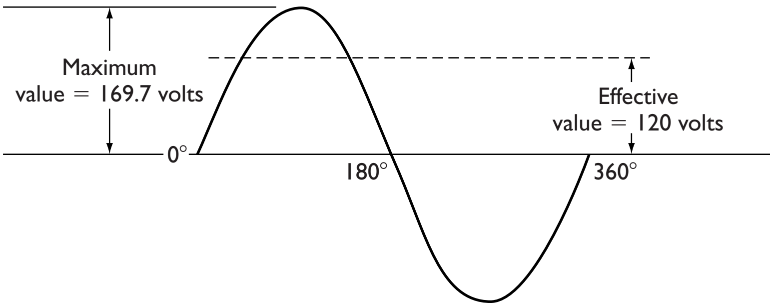


Figure 3-12 The effective and peak values of a standard 120-volt line.

Chapter 4

Lighting

4-1 What is a grounded (neutral) conductor?

A white or natural gray conductor or a conductor with three longitudinal white stripes, which indicates that it is the grounded circuit conductor.

4-2 May a grounded conductor ever be used as a current-carrying conductor? Explain.

It is permissible to use a white or natural gray conductor as a current-carrying conductor, if the conductor is permanently re-identified by painting or other effective means at each location where the conductors are visible and accessible [see *Section 200.7(A)* of the NEC]. Note, however, that when used as just described, the white or gray conductor is removed from ground and is no longer a grounded conductor.

4-3 Draw a diagram of the proper connections for a two-wire cable, one white wire and one black, to supply a light from a single-pole switch.

See Figure 4-1.

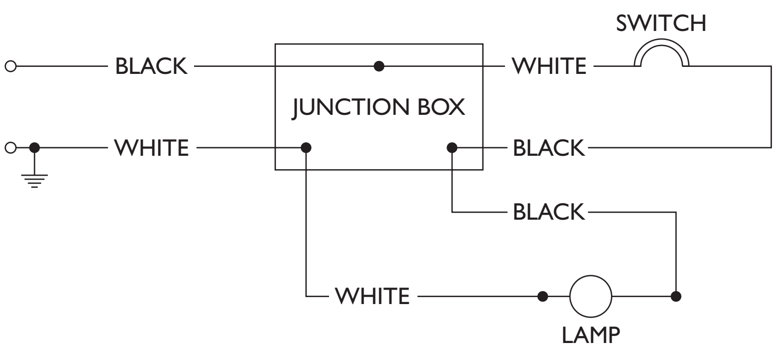


Figure 4-1 A two-wire cable supplying a lamp from a single-pole switch.

4-4 When must the neutral, or grounded, conductor be provided with a switch?

A lamp or pump circuit on a gasoline dispensing island *must* provide both the neutral and the hot wires, which supply the light or the pump, with a switch (see NEC, *Section 514.11(A)*).

4-5 Draw a three-way switch system and a lamp, using cable; show the colors and connections.
See Figure 4-2.

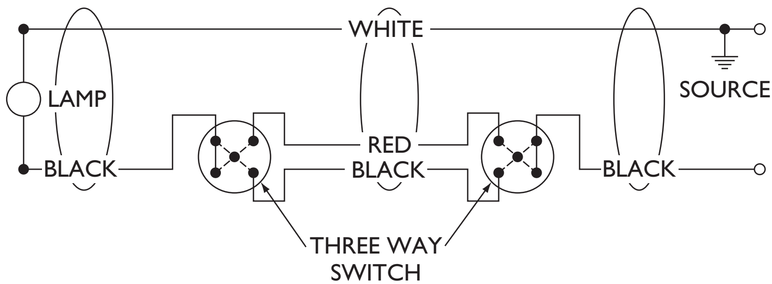


Figure 4-2 A three-way switch system with a lamp.

4-6 Draw a circuit supplying a lamp that is controlled by two three-way switches and one four-way switch (use cable).
See Figure 4-3.

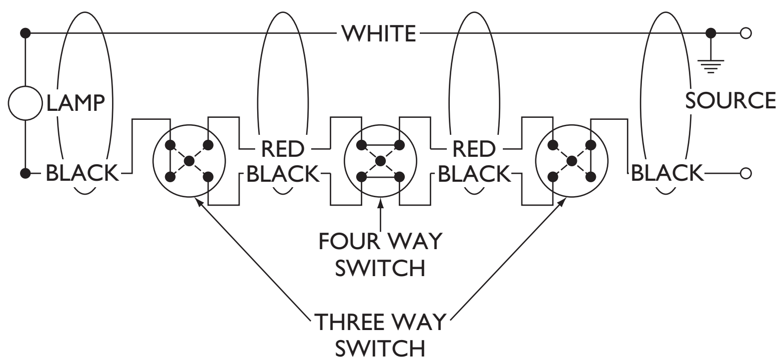


Figure 4-3 A lamp circuit that is controlled by two three-way switches and one four-way switch.

4-7 Draw a master-control lighting system.
See Figure 4-4.

4-8 Draw an electrolier switching circuit for controlling lights.
See Figure 4-5.

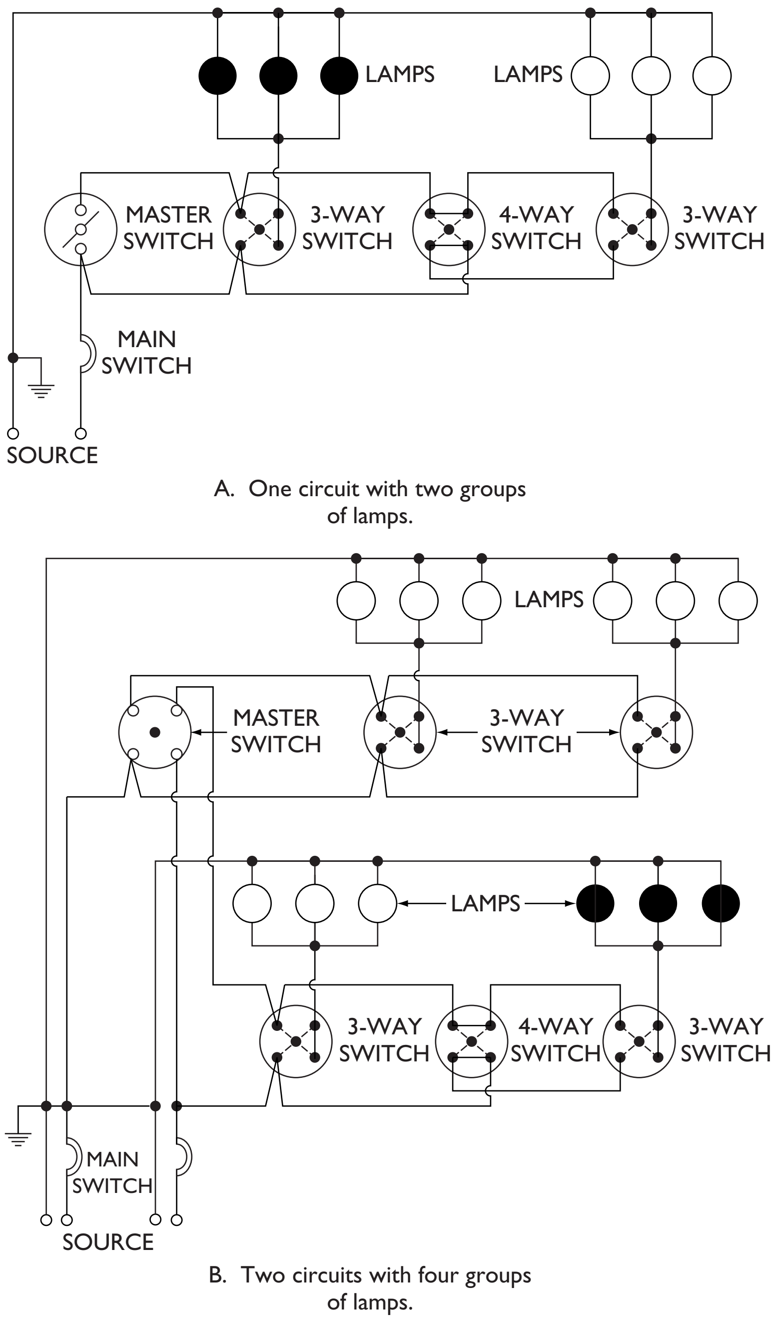


Figure 4-4 A master-control lighting system.

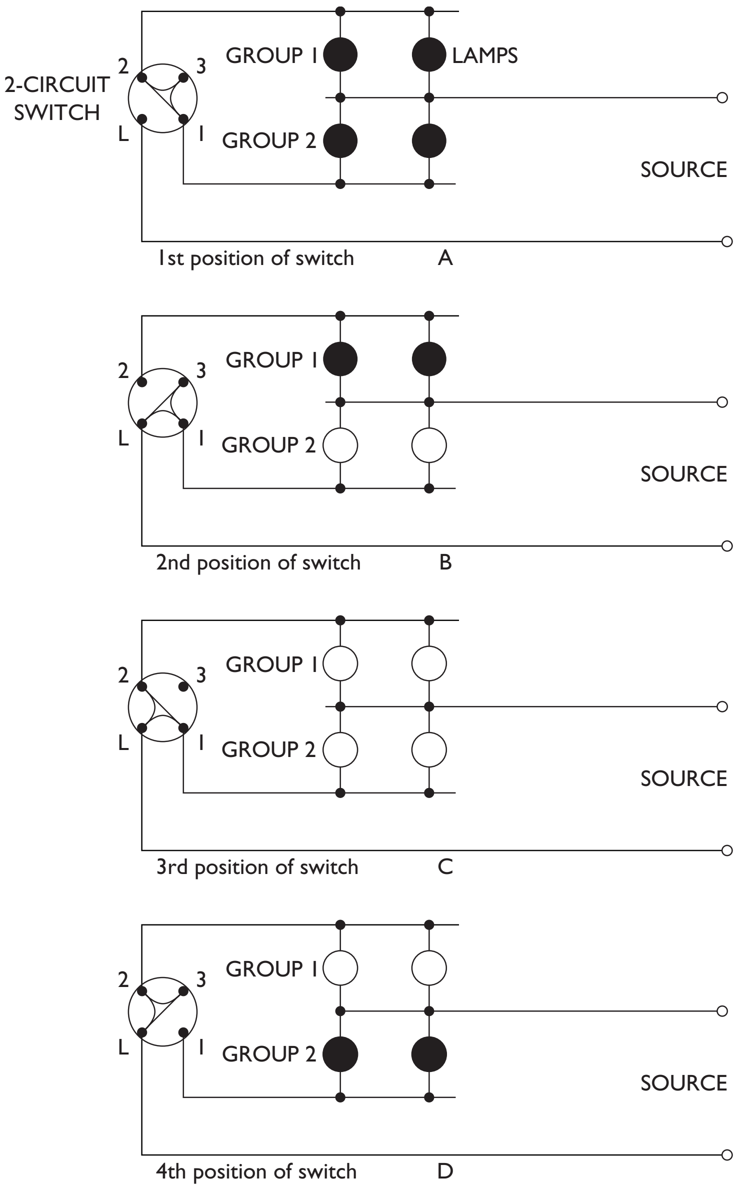


Figure 4-5 An electrolier switch arrangement for control of lamp circuits.

4-9 Draw an electrolier switching circuit to control three sets of lamps.

See Figure 4-6.

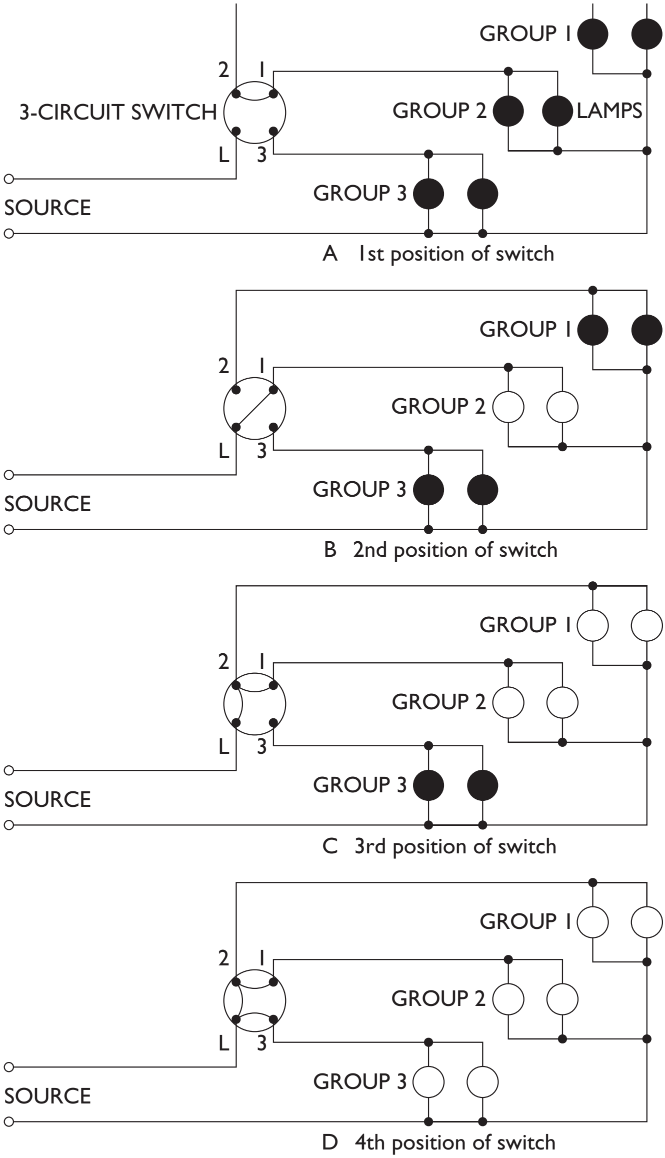


Figure 4-6 An electrolier switch arrangement for control of three groups of lamps. The sequence of operation is depicted diagrammatically.

4-10 What is a preheated-type fluorescent tube?

There are two external contacts at each end of a glass tube. Each set of contacts is connected to a specially treated tungsten filament. The inside of the tube is coated with a fluorescent powder, the type of powder used controls the color output of the tube. The tube is filled with an inert gas, such as argon, and a small drop of mercury to facilitate starting.

4-11 What kind of light does the fluorescent bulb produce within the bulb itself?

Ultraviolet light.

4-12 Do the filaments stay lit during the operation of a fluorescent bulb? Explain.

No. They remain lit only at the start to vaporize the mercury; they are then shut off by the starter. Current is supplied to one contact on each end, thereby sustaining the mercury arc within the tube.

4-13 Draw a simple circuit of a fluorescent lamp and fixture.

See Figure 4-7.

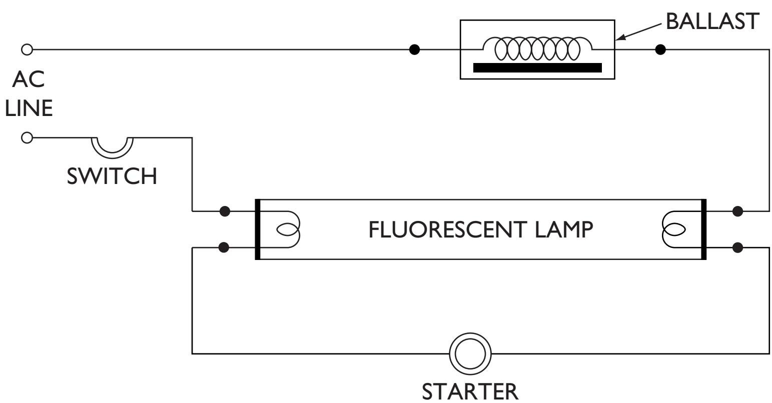


Figure 4-7 A fluorescent lamp and fixture circuit.

4-14 Explain the action of the glow-type starter.

When the switch is closed, the high resistance in the glow bulb of the starter produces heat, which causes the bimetallic U-shaped strip to close the contacts, thereby lighting the filaments in the fluorescent bulb. When the contacts close, the glow bulb cools and allows the contacts to open, thus disconnecting one side of the filaments. The arc within the fluorescent bulb is sustained without keeping the filaments heated, and the bulb lights.

4-15 Is the power factor of the circuit in Figure 4-7 good or bad? Is the current leading or lagging the voltage?

The power factor is bad; the current is lagging the voltage because of the inductive reactance of the ballast.

4-16 How can the power factor of the circuit in Figure 4-7 be corrected?

By the addition of capacitors in the ballast to counteract the lagging power factor.

4-17 What is the fixture in question 4-16 called?

A power-factor-corrected fixture.

4-18 What is a trigger-start fluorescent fixture?

This fixture uses a special trigger-start ballast that automatically preheats the filaments without the use of a starter.

4-19 Is a fluorescent fixture more efficient than an incandescent fixture?

Yes. However, no fixed efficiency can be quoted because it varies with the size of the bulb, the ballast, etc. As a rule of thumb, a 40-watt fluorescent bulb is generally considered to put out about the same amount of light as a 100-watt incandescent bulb.

4-20 What is an instant-start Slimline fluorescent lamp?

This lamp has a single terminal at each end. The ballast is normally of the autotransformer type, which delivers a high voltage at the start and a normal voltage after the arc is established.

4-21 Does room temperature affect the operation of fluorescent lamps?

Yes. The normal fluorescent lamp is designed for operation at 50°F or higher.

4-22 If the operating temperature is expected to be below 50°F, what measures should be taken when using fluorescent lamps?

Use special lamps and starters that are designed for lower temperatures.

4-23 Do fluorescent lamps produce a stroboscopic effect? Explain.

Yes. This effect is due to the fact that at 60 hertz the current passes through zero 120 times a second.

4-24 How can the strobe effect be compensated for in a two-bulb system?

When the power factor is corrected, the capacitor is so connected that at the instant the current in one bulb is passing through zero, the current in the other bulb is not at zero, and the strobe effect goes unnoticed.

4-25 What is another way to minimize the strobe effect?

By using a higher frequency, such as 400 hertz.

4-26 Does a 400-hertz frequency have any other advantages?

Yes. Smaller and lighter ballasts can be used. This makes it feasible to use simple capacitance-type ballasts, which produce an overall gain in efficiency.

4-27 Does frequent starting and stopping of fluorescent lighting affect the bulb life?

The life of fluorescent bulbs is affected by starting and stopping. A bulb that is constantly left on will have a much longer life than one that is turned on and off frequently.

4-28 When lighting an outdoor activity area with large incandescent bulbs, how can the light output of the bulbs be increased?

By using bulbs of a lower voltage rating than that of the source of supply. For example, by using a bulb that is rated at 105 volts on a 120-volt supply, the output can be increased by roughly 30%, but the life of the bulb will be cut by about 10%.

4-29 How is the light output of lamps rated?

In lumens.

4-30 How are light levels rated?

In foot-candles.

4-31 What is a foot-candle?

The amount of direct light emitted by one international candle on a square foot of surface, every part of which is one foot away.

Chapter 5

Branch Circuits and Feeders

5-1 Is the NEC a law?

It is not a law, but it is adopted into laws that are established by governmental agencies; it may be adopted in its entirety, in part, or with amendments.

5-2 Who has the responsibility for Code interpretations?

The administrative authority that has jurisdiction over endorsement of the Code has the responsibility for making Code interpretations (see NEC, *Section 90.4* and *Section 80.2*). Usually, this is a local electrical inspector.

5-3 When are rules in the NEC mandatory and when are they advisory?

When the word "shall" is used, the rules are mandatory. Fine Print Notes (FPN) explain the intent of Code rules (see *Section 9.5* of the Code).

5-4 According to the NEC, what are voltages?

Throughout the Code, the voltage considered shall be that at which the circuit operates. This is often expressed as, for example, 600 volts, nominal (see NEC, *Section 220.2*).

5-5 When wire gage or size is referred to, what wire gage is used?

The American Wire Gage (AWG) or in circular mils (CM).

5-6 When referring to conductors, what material is referred to?

Copper, unless otherwise specified. When other materials are to be used, the wire sizes must be changed accordingly (see NEC, *Section 110.5*).

5-7 In what manner must the work be executed?

All electrical equipment must be installed in a neat and workmanlike manner (see NEC, *Section 110.12*).

5-8 May wooden plugs be used for mounting equipment in masonry, concrete, plaster, etc.?

No (see NEC, *Section 110.13*).

5-9 How must conductors be spliced or joined together?

They must be spliced or joined together by approved splicing devices or by brazing, welding, or soldering with a fusible metal or alloy (see NEC, *Section 110.14*).

5-10 When soldering, what precautions must be used?

All joints or splices must be electrically and mechanically secure before soldering and then soldered with a noncorrosive flux (see NEC, *Section 110.14*). This does not apply to conductors for grounding purposes; soldering is not allowed on these conductors.

5-11 How should splices or joints be insulated?

They must be covered with an insulation that is equivalent to the original conductor insulation (see NEC, *Section 110.14*).

5-12 Can an autotransformer be used on an ungrounded system?

The autotransformer must have a grounded conductor that is common to both primary and secondary circuits and tied into a grounded conductor on the system supplying the autotransformer (see NEC, *Section 210.9*).

An autotransformer may be used to extend or add an individual branch circuit in an existing installation for equipment load without the connection to a similar grounded conductor when transforming from a nominal 208-volt supply or similarly from 240 volts to 208 volts.

5-13 On No. 6 or smaller conductors, what means must be used for the identification of the grounded conductors?

Insulated conductors of No. 6 or smaller, when used as grounded conductors, must be white, natural gray, or colored (but never green) with three longitudinal white stripes. On Type MI cable, the conductors must be distinctively marked at the terminal during installation (see NEC, *Section 200.6*).

5-14 How should conductors larger than No. 6 be marked to indicate the grounded wire?

By the use of white, natural gray, or colored (but never green) insulation with three longitudinal white stripes, or by identifying with a distinctive white marking at the terminals during installation (see NEC, *Section 200.6*).

5-15 How is the high-leg conductor of a 4-wire delta identified?

When the midpoint of one phase is grounded to supply lighting and similar loads on a 4-wire delta-connected secondary, the phase conductor with the higher voltage to ground shall be orange in color or be indicated by tagging or other effective means at the point where a connection is to be made if the neutral conductor is present (see *Section 110.15* of the NEC).

5-16 On a grounded system, which wire must be connected to the screw shell of a lampholder?

The grounded conductor [see NEC, *Section 200.10(C)*].

5-17 What will determine the classification of branch circuits?

The maximum permitted setting or rating of the overcurrent-protective device in the circuit (see NEC, *Section 210.20*).

5-18 What color-coding is required on multiwire branch circuits?

The grounded conductor of a branch circuit shall be identified by a continuous white or natural gray color. Whenever conductors of different systems are installed in the same raceway, box, auxiliary gutter, or other types of enclosures, one system grounded conductor, if required, shall have an outer covering of white or natural gray. Each other system grounded conductor, if required, shall have an outer covering of white with an identifiable colored stripe (not green) running along the insulation or another means of identification. Ungrounded conductors of different voltages shall be a different color or identified by other means (see NEC, *Section 200.6(D)*).

5-19 How must a conductor that is used only for equipment and grounding purposes be identified?

By the use of a green color, or green with one or more yellow stripes, or by being bare (only grounding conductors may be bare).

5-20 Can green-colored wire be used for circuit wires?

No. Green is intended for identification of equipment-grounding conductors only (see NEC, *Sections 210.5(B)* and *250.119*).

5-21 What voltage is used between conductors that supply lampholders of the screw-shell type, receptacles, and appliances in dwellings?

Generally speaking, a voltage of 120 volts between conductors is considered the maximum. There are, however, some exceptions (see NEC, *Section 210.6*).

5-22 What are the exceptions to the 120-volt maximum between conductors?

Listed high-intensity discharge lighting fixtures with medium base lampholders, fixtures with mogul base lampholders, other types of lighting equipment (without screw-shell lampholders), utilization equipment that is either permanently connected or cord-and-plug connected (see NEC, *Section 210.6(C)* and *Section 80.2*).

5-23 How must you ground the grounding terminal of a grounding-type receptacle?

By the use of an equipment-grounding conductor of green covered wire, green with one or more yellow stripes, or bare conductors. However, the armor of Type AC metal-clad cable, the sheath of MI cable, or a metallic raceway is acceptable as a grounding means. *Section 250.118* does not permit the general use of flexible metal conduit as a grounding means unless it and the connectors are listed.

5-24 How can you ground the grounding terminal on a grounding-type receptacle on extensions to existing systems?

Run the grounding conductor to a grounded water pipe near the equipment (see NEC, *Sections 250.130* and *250.130(C)*).

5-25 What is the minimum size for branch-circuit conductors?

They cannot be smaller than No. 8 for ranges of 8¾ kW or higher rating and not smaller than No. 14 for other loads (see NEC, *Section 210.19(A)* and *(B)*).

5-26 What is the requirement concerning all receptacles on 15- and 20-ampere branch circuits?

All receptacles on 15- and 20-ampere branch circuits must be of the grounding type. A single receptacle installed on an individual branch circuit must have a rating of not less than the rating of the branch circuit. (For complete details, see NEC, *Section 210.7(A)* and *(B)*.)

5-27 What are the requirements for spacing receptacles in dwelling occupancies?

All receptacles in kitchens, family rooms, dining rooms, living rooms, parlors, libraries, dens, sun rooms, recreation rooms, and bedrooms must be installed so that no point along the wall space, measured horizontally, is more than 6 feet from a receptacle. This includes wall space that is 2 feet or wider and any space occupied by sliding panels on exterior walls. Sliding glass panels are excepted. At least one outlet must be installed for the laundry. (See

NEC, *Section 210.52*.) The wall space afforded by fitted room dividers, such as freestanding bar-type counters, must be included in the 6-foot measurement.

In the kitchen and dining areas, a receptacle outlet must be installed at each counter space that is 12 inches wide or more. Countertop spacers separated by range tops, refrigerators, or sinks must be considered as separate countertop space. Receptacles rendered inaccessible by the installation of appliances fastened in place or appliances occupying dedicated space won't be considered as the required outlets.

At least one wall receptacle outlet must be installed in the bathroom adjacent to each basin location.

5-28 In residential occupancies, will ground-fault circuit interrupters be required?

Yes, for all 125-volt, 15- and 20-ampere receptacle outlets installed out-of-doors for residential occupancies and also for receptacle outlets in bathrooms, basements, kitchens, and garages (see NEC, *Section 210.8*).

5-29 A bedroom has one wall that contains a closet 8 feet in length, with sliding doors and a wall space of 2 feet. The bedroom door opens into the room and back against this wall space. Where are receptacles required on this wall?

One receptacle is required in the 2-foot space (Figure 5-1). (See NEC, *Section 210.52(A)*.)

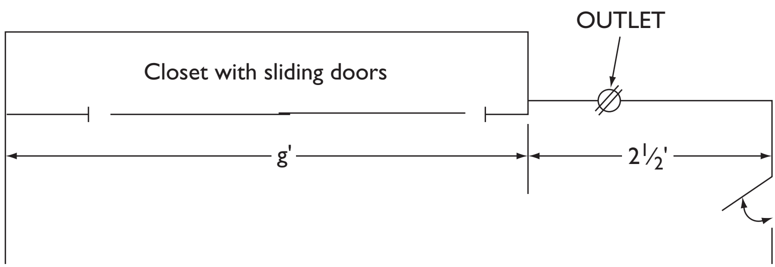


Figure 5-1 Receptacle requirements on a wall containing a closet with sliding doors.

5-30 Sketch a typical living room with sliding panels on the outside wall. Locate receptacles and show the room dimensions (Figure 5.2).

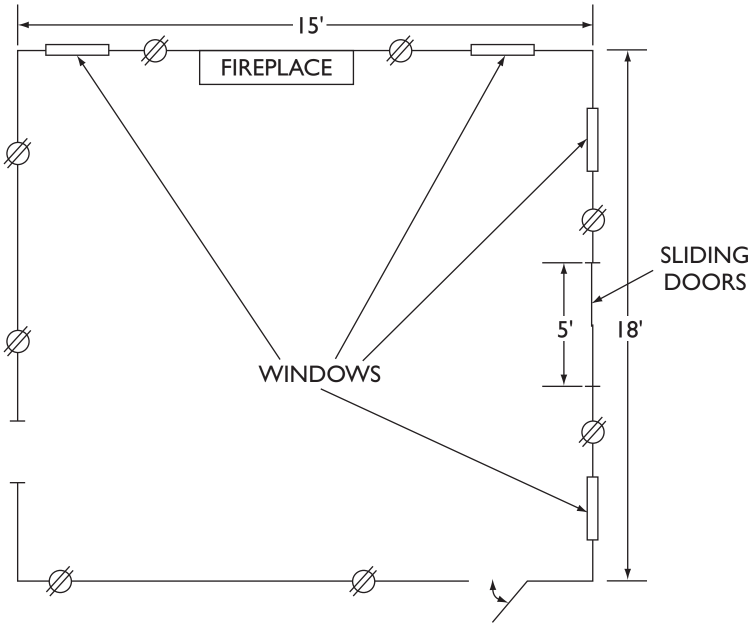


Figure 5-2 Receptacle requirements in a living room that has sliding doors on the outside wall.

5-31 A fastened-in-place appliance is located on a 15- or 20-ampere branch circuit on which there is a lighting fixture. What is the maximum rating that would be permitted on the appliance?

50 percent of the branch circuit rating (see NEC, *Section 210.23(A)*).

5-32 A cord-and-plug-connected appliance is used on a 15- or 20-ampere branch circuit. What is the maximum rating permitted for the appliance?

80 percent of the branch circuit rating (see NEC, *Section 210.23(A)*).

5-33 What is the smallest size wire permissible for a feeder circuit?

No. 10 wire (see NEC, *Section 215.2(B)*).

5-34 What are the permissible voltage drops allowable on feeders and branch circuits?

On feeders, not more than 3 percent for power, heating, and lighting loads or combinations thereof, and a total maximum voltage drop not to exceed 5 percent for conductors and for combinations of feeders and branch circuits (see NEC, *Section 215.2(D)*).

5-35 What is the basis for figuring the general lighting loads in occupancies?

They are figured on a volt-amperes-per-square-foot basis, using NEC. *Table 220.3(A)* can be used to determine the unit load per square foot in volt-amperes for the types of occupancies listed.

5-36 What measurements are used to determine the number of watts per square foot?

The outside dimensions of the building and the number of floors, not including open porches or garage (see NEC, *Section 200.3(A)*).

5-37 What is the unit load per square foot (in volt-amperes) for a hospital?

2 volt-amperes (see NEC, *Table 220.3(A)*).

5-38 What is the unit load per square foot (in volt-amperes) for a school?

3 volt-amperes (see NEC, *Table 220.3(A)*).

5-39 How many volt-amperes per square foot are required to be included for general-purpose receptacle outlets when a set of plans does not show their locations in an office building?

1 volt-ampere per square foot (see NEC, *Table 220.3(A)*** note).

5-40 What is the unit load per square foot (in volt-amperes) for a warehouse used for storage?

¼ volt-ampere (see NEC, *Table 220.3(A)*).

5-41 What voltages are used for purposes of computing feeder and branch-circuit loads when other voltages are not specified?

120, 120/240, 208Y/120, 240, 480Y/277, 480, and 600 volts (see NEC, *Section 220.2*).

5-42 How are continuous and noncontinuous loads for feeder ratings calculated?

Branch circuits must be rated no less than the noncontinuous load, plus at least 125 percent of the continuous load (see NEC, *Section 215.2*).

5-43 Are unfinished basements of dwellings used in figuring watts per square foot?

Yes, if adaptable for future use. If these spaces are not adaptable, they are not used (see NEC, *Section 220.3(A)*).

5-44 What loads are used in figuring outlets for other than general illumination?

Outlets supplying specific loads and appliances must use the ampere rating of the appliance. Outlets supplying heavy-duty lampholders must use 600 volt-amperes; calculations for other outlets must use 180 volt-amperes (see NEC, *Section 220.3(C)*).

5-45 What load must be figured for show-window lighting?

Not less than 200 volt-amperes for each linear foot measured horizontally along the base (see NEC, *Section 220.12*).

5-46 What are the receptacle requirements in dwelling occupancies for kitchen, family room, laundry, pantry, dining room, and breakfast room?

There shall be a minimum of two 20-ampere small-appliance circuits for the kitchen, family room, pantry, dining room, and breakfast room. There should also be a minimum of one 20-ampere circuit for the laundry (see NEC, *Section 220.16*).

5-47 What is the unit load per square foot (in volt-amperes) for a store?

3 volt-amperes (see NEC, *Table 220.3(A)*).

5-48 Outlets for heavy-duty lampholders are to be based on a load of how many volt-amperes?

600 (see NEC, *Section 220.3(B)(5)*).

5-49 How is the load for a household electric clothes dryer computed?

See NEC, *Section 220.18*.

5-50 Are demand factors permitted in determining feeder loads?

Yes, they are given in NEC, *Table 220.11*.

5-51 What size feeders must be installed in dwelling occupancies?

The computed load of a feeder must not be less than the sum of all branch circuit loads supplied by the feeder. The demand factors can be used in the calculation of feeder sizes.

5-52 When figuring the neutral load to electric ranges, what is the maximum unbalanced load considered to be?

The maximum unbalanced load for electric ranges is considered to be 70 percent of the load on the ungrounded conductors (see NEC, *Section 220.22*).

5-53 How is the neutral load on a 5-wire, 2-phase system determined?

It is figured at 140 percent of the load on the ungrounded conductors (see NEC, *Section 220.22*).

5-54 How may the neutral-feeder load on a 3-wire dc or single-phase 3-wire ac system be determined?

The 70 percent demand factor may be used on range loads, and a further demand factor of 70 percent may be used on that portion of the unbalanced load in excess of 200 amperes (see NEC, *Section 220.22*).

5-55 How do you calculate the unbalanced load on a 4-wire, 3-phase system?

The 70 percent demand factor may be used on range loads, and a further demand factor of 70 percent may be used on that portion of the unbalanced load in excess of 200 amperes (see NEC, *Section 220.22*).

5-56 Can you make a reduction on the neutral feeder load where discharge lighting, data processing, or similar equipment is involved?

No reduction can be made on the neutral capacity for the portion of the load that consists of electric discharge lighting, data processing, or similar equipment. The load on the neutral feeder must be taken at 100 percent of the ungrounded conductors (see NEC, *Section 220.22*).

5-57 Why do discharge lighting loads require no reduction in neutral feeder capacity?

Because of the effect of the third harmonic on the current value in the neutral feeder. In fact, it's sometimes necessary to oversize the neutral in such circuits. The same effect occurs when a great deal of data processing equipment is connected to the circuits.

5-58 Are demand factors applicable to electric ranges?

Yes. *Table 220.19* of the NEC can be used in determining demand factors for electric ranges.

5-59 Can demand factors be used on electric-clothes-dryer loads in the same manner as they are used on electric ranges?

Yes (see NEC, *Table 220.18*).

5-60 Are feeder demand factors permitted for commercial ranges and other commercial kitchen equipment?

Yes (see NEC, *Table 220.20*).

5-61 There are 2500 square feet of floor area in a house that contains an electric range rated as 12 kW and an electric dryer rated at 5000 watts. Calculate (a) the general lighting required, (b) the minimum number and sizes of branch circuits required, and (c) the minimum size of feeders (service conductors) required.

(a) 2500 square feet at 3 volt-amperes per square foot equals 7500 watts.

(b) 7500 watts divided by 120 volts equals 62.5 amperes; this would require a minimum of five 15-ampere circuits with a minimum of No. 14 wire, or a minimum of four 20-ampere circuits with a minimum of No. 12 wire.

Small-appliance load: A minimum of two small-appliance circuits (see NEC, *Section 220.4(B)*) of 1500 volt-amperes each. These will require 20-ampere 2-wire circuits with No. 12 wire.

A 12-kW range has a demand of 8 kW, according to NEC, *Table 220-19*, and 8000 watts divided by 240 volts equals 33 amperes. Therefore, a minimum of No. 8 wire with a 40-ampere service would be required, although good practice would indicate the use of No. 6 wire with a 50-ampere circuit breaker.

The dryer: 5000 watts divided by 240 volts equals 21 amperes. Therefore, you would use No. 10 wire with a 30-ampere circuit.

Laundry circuit: 1500 watts.

(c) Minimum size of service.

General lighting	7500	volt-amperes
Small appliance load	3000	volt-amperes
Laundry circuit	1500	volt-amperes
	12,000	volt-amperes
3000 volt-amperes @ 100 percent	3000	volt-amperes
9000 volt-amperes @ 35 percent	3150	volt-amperes
Net computed (without range and dryer)	6150	volt-amperes
Range load	8000	volt-amperes
Dryer load	5000	volt-amperes
	13,000	volt-amperes
Net computed (with range and dryer)	19,150	volt-amperes

Loads of over 10 kW must have a minimum of 100-ampere service; therefore, the minimum service will be 100 amperes. You can use No. 4 copper THW conductors with a 100-ampere main disconnect (see NEC, *Note 3* to *Tables 310.16* through *310.31*).

5-62 What are the demand factors for nondwelling receptacle loads?

See NEC, *Table 220.13*.

5-63 How are motor loads computed?

In accordance with *Sections 430.24*, *430.25*, and *430.26* (see NEC, *Section 220.14*).

5-64 How are fixed electric space heating loads computed?

At 100 percent of the total connected load, but in no case is a feeder load current rating to be less than the rating of the largest branch-circuit supplied (see NEC, *Section 220.15*).

5-65 What percentage is permitted to be applied as a demand factor to the nameplate rating load for four or more appliances fastened in place and served by the same feeder in a one-family, two-family, or multifamily dwelling?

Seventy-five percent for all appliances except electric ranges, clothes dryers, space heating equipment, or air-conditioning equipment (see NEC, *Section 220.17*).

5-66 The demand factor for five household electric clothes dryers is calculated at what percentage?

80 percent (see NEC, *Table 220.18*).

5-67 Where two or more single-phase ranges are supplied by a 3-phase, 4-wire feeder, how is the total load computed?

On the basis of twice the maximum number connected between any two phases (see NEC, *Section 220.19*).

5-68 What is the maximum demand for two household electric ranges, wall-mounted ovens, counter-mounted cooking units, and other household cooking appliances rated at over 1¾ kW?

11 kW for ratings not over 12 kW (see NEC, *Section 220.19*).

5-69 What computations are required for commercial cooking equipment?

See NEC, *Table 220.20*.

5-70 When computing the total load of a feeder for an electric heating system and an air-conditioning system that won't be used simultaneously, must both loads be added?

No. The smaller of the two can be omitted (see NEC, *Section 220.21*).

5-71 A store building is to be wired for general illumination and show-window illumination. The store is 40 feet by 75 feet, with 30 linear feet of show window. With a density of illumination of 3 watts per square foot for the store and 200 volt-amperes per linear foot for the show-window, calculate (a) the general store load, (b) the minimum number of branch circuits required and sizes of wire, and (c) the minimum size of feeders (or service conductors) required.

(a) General lighting load. 3000 square feet at 3 volt-amperes per square foot equals 9000 volt-amperes. However, this load will be required most of the time, so you must multiply 1.25 by 9000, which yields 11,250 volt-amperes.

Show window: 30 linear feet at 200 volt-amperes per foot equals 6000 volt-amperes. Therefore, the general store load is 11,250 volt-amperes.

(b) Minimum number of branch circuits and wire sizes. 11,250 volt-amperes divided by 240 volts equals 47 amperes. For three-wire service, this current will require four 15-ampere circuits using No. 14 wire (minimum) or three 20-ampere circuits using No. 12 wire (minimum).

Show window: 6000 volt-amperes divided by 240 volts equals 25 amperes. Therefore, two 15-ampere circuits with No. 14 wire or two 20-ampere circuits with No. 12 wire will be required.

(c) Minimum size service conductors required. The ampere load for three-wire service would be 47 amperes plus 25 amperes, which equals 72 amperes. Therefore, a 100-amp service would be used with No. 3 THW conductors in 1¼-inch conduit or No. 3 THHN conductors in 1-inch conduit.

If the service is 120 volts instead of 120/240 volts (which is highly improbable because the utility serving would require the 120/240 volts), then you would have to use 120 volts when finding the current. These currents would then be doubled; entrance-wire capacities would double as well as the main disconnect on the service entrance.

5-72 Determine the general lighting and appliance load requirements for a multifamily dwelling (apartment house). There are 40 apartments, each with a total of 800 square feet. There are two banks of meters of 20 each, and individual subfeeders to each apartment. Twenty apartments have electric ranges; these apartments

(with ranges) are evenly divided, 10 on each meter bank, and the ranges are 9 kW each. The service is 120/240 volts. Make complete calculations of what will be required, from the service entrance on.

Computed load for each apartment (see NEC, *Article 220*).

General lighting load:		
800 square feet @ 3 volt-amperes per square foot	2400	volt-amperes
Small-appliance load	3000	volt-amperes
Electric range	3000	volt-amperes

Minimum number of branch circuits required for each apartment (see NEC, *Section 220.4*).

2400 volt-amperes divided by 120 volts equals 20 amperes. This current will require two 15-ampere circuits using No. 14 wire or two 20-ampere circuits using No. 12 wire.

Small-appliance load: Two 20-ampere circuits using No. 12 wire (see NEC, *Section 220.4(B)*).

Range circuit: 8000 watts divided by 240 equals 33 amperes. A circuit of two No. 8 wires or one No. 10 wire is required (see NEC, *Section 210.19(B)*).

Minimum size subfeeder required for each apartment (see NEC, *Section 215.2*).

Computed load:		
General lighting load	2400	volt-amperes
Small-appliance load (two 20-ampere circuits)	3000	volt-amperes
Total computed load (without ranges)	5400	volt-amperes
Application of demand factor:		
3000 watts @ 100 percent	3000	volt-amperes
2400 watts @ 35 percent	840	volt-amperes
Net computed load (without ranges)	3840	volt-amperes
Range load	8000	volt-amperes
Net computed load (with ranges)	11,840	volt-amperes

For 120/240 volt, 3-wire system (without ranges):

Net computed load: 3840 volt-amperes divided by 240 volts equals 16 amperes.

Minimum feeder size could be No. 10 wire with a two-pole, 30-ampere circuit breaker.

For 120/240 volt, 3-wire system (with ranges):

> Net computed load: 11,840 volt-amperes divided by 240 volts equals 49 amperes.
>
> Minimum feeder size would be No. 6 wire with two 60-ampere fuses or No. 4 wire with a two-pole, 70-ampere circuit breaker.

Neutral subfeeder:

Lighting and small-appliance load	3840	volt-amperes
Range load (8000 watts @ 70 percent) (see NEC, *Section 220-22*)	5600	volt-amperes
Net computed load (neutral)	9440	volt-amperes

9400 watts divided by 240 volts equals 41 amperes. Size of neutral subfeeder would be No. 6 wire. There would also be two main disconnects needed ahead of the meters.

Minimum size feeders required from service equipment to meter bank (for 20 apartments—10 with ranges).

> Total computed load: Lighting and small-appliance load—20 multiplied by 5400 volt-amperes equals 108,000 volt-amperes.

Application of demand factor:

3000 volt-amperes @ 100 percent	3000	volt-amperes
105,000 volt-amperes @ 35 percent	36,750	volt-amperes
Net computed lighting and small-appliance load	39,750	volt-amperes
Range load (10 ranges, less than 12 kW)	25,000	volt-amperes
Net computed load (with ranges)	64,750	volt-amperes

For 120/240 volt, 3-wire system: Net computed load—64,750 divided by 240 equals 270 amperes. Size of each ungrounded feeder to each meter bank would be 500,000 CM.

Neutral feeder:

Lighting and small-appliance load	39,750	volt-amperes
Range load (25,000 watts @ 70 percent)	17,500	volt-amperes
Computed load (neutral)	57,250	volt-amperes

57,250 volt-amperes divided by 240 volt equals 239 amperes.

Further demand factor:

200 amperes @ 100 percent	200	amperes
39 amperes @ 70 percent	27	amperes
Net computed load (neutral)	227	amperes

Minimum size main feeder (service conductors) required (for 40 apartments—20 with ranges).

Total computed load: Lighting and small-appliance load—40 multiplied by 5400 volt-amperes equals 216,000 volt-amperes.

Application of demand factor:

3000 volt-amperes @ 100 percent	3000	volt-amperes
117,000 volt-amperes @ 35 percent	40,950	volt-amperes
96,000 volt-amperes @ 25 percent	24,000	volt-amperes
Net computed lighting and small-appliance load	67,950	volt-amperes
Range load (20 ranges, less than 12 kW)	35,000	volt-amperes
Net computed load	102,950	volt-amperes

For 120/240 volt, 3-wire system:

Net computed load—102,950 volt-amperes divided by 240 volts equals 429 amperes.

Size of each ungrounded main feeder would be 1,000,000 CM.

Neutral feeder:

Lighting and small appliance load	67,950	volt-amperes
Range load (35,000 volt-amperes @ 70 percent)	24,500	volt-amperes
Computed load (neutral)	92,450	volt-amperes

92,450 volt-amperes divided by 240 volts equals 385 amperes.

Further demand factor:

200 amperes @ 100 percent	200	amperes
185 amperes @ 70 percent	130	amperes
Net computed load (neutral)	330	amperes

Size of neutral main feeder would be 6,000,000 CM.

5-73 There is to be a current of 100 amperes per phase on a 4-wire 120/208-volt wye system. What size neutral would you need? The phase wires are No. 2 THHN.

Since in this case neutrals are not allowed to be derated and must be the same size as the phase conductors, you would need to use a No. 2 THHN conductor.

5-74 Is there a demand factor for feeders and service-entrance conductors for multifamily dwellings?

Yes (see NEC, *Table 220.32*).

Chapter 6

Transformer Principles and Connections

6-1 What is induction?

The process by which one conductor produces, or induces, a voltage in another conductor, even though there is no mechanical coupling between the two conductors.

6-2 What factors affect the amount of induced electromotive force (emf) in a transformer?

The strength of the magnetic field, the speed at which the conductors are cut by the magnetic field, and the number of turns of wire being cut by the magnetic field.

6-3 What is inductance?

The property of a coil in a circuit to oppose any change of existing current flow.

6-4 What is self-inductance?

The inducing of an emf within the circuit itself, caused by any change of current within that circuit. This induced emf is always in a direction opposite to the applied emf, thus causing opposition to any change in current within the circuit itself.

6-5 What is mutual inductance?

The linkage of flux between two coils or conductors, caused by the current flowing within one or both of the coils or conductors.

6-6 Draw a diagram of two coils, such as the coils of a transformer winding, and indicate the self-inductance and the mutual inductance.

Self-inductance is produced within the primary coil, and mutual inductance exists between the two transformer coils, as shown in Figure 6-1.

6-7 Name several methods by which an emf can be generated.

By conductors being cut by a magnetic field (as in generators), by chemical reactions (as in batteries), by heat (as in thermocouples), by crystal vibration (as in piezoelectricity), and by friction (as in static electricity).

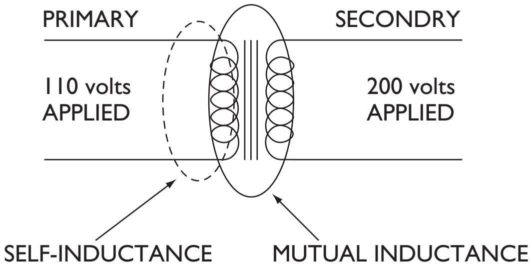


Figure 6-1 Self-inductance and mutual inductance in the coils of a transformer.

6-8 What is direct current (dc)?
Current that flows in one direction only.

6-9 What is alternating current (ac)?
Current that continually reverses its direction of flow.

6-10 What is pulsating direct current?
An unidirectional current that changes its value at regular or irregular intervals.

6-11 What is a cycle?
One complete alternation, or reversal, of alternating current. The wave rises from zero to maximum in one direction, falls back to zero, then rises to maximum in the opposite direction, and finally falls back to zero again.

6-12 What always surrounds a conductor when a current flows through it?
A magnetic field.

6-13 What is the phase relation between the three phases of a three-phase circuit?
They are 120 electrical degrees apart.

6-14 Draw sine waves for three-phase voltage; show polarity, time, and phase angle (in degrees).
See Figure 6-2.

6-15 What is the phase relation between phases in two-phase circuit?
They are 90 electrical degrees apart.

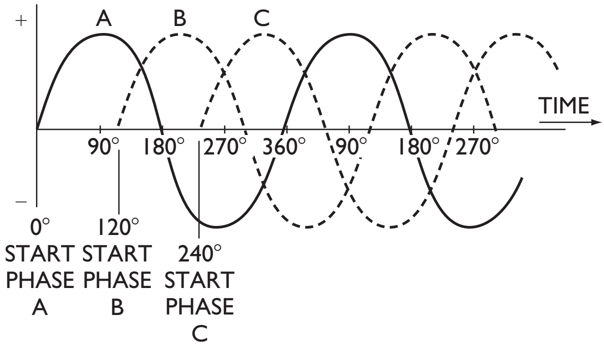


Figure 6-2 Three-phase voltage sine waves.

6-16 What is a transformer?

A device that transforms electrical energy from one or more circuits to one or more other circuits at the same frequency but usually at a different voltage and current. It consists of a core of soft-iron laminations surrounded by coils of copper-insulated wire.

6-17 There are two basic types of transformers. What are they?

The isolation type, in which the two windings are physically isolated and electrically insulated from each other, and the autotransformer type, in which there is only one coil with a tap or taps taken off it to secure other voltages (the primary is part of the secondary and the secondary is part of the primary).

6-18 What is an oil-immersed transformer?

The core and coils are immersed in a high-grade mineral oil, which has high dielectric qualities.

6-19 Why is oil used in a transformer?

To increase the dielectric strength of the insulation, to keep down the possibility of arcing between coils, and to dissipate heat to the outer case so that the transformer can carry heavier loads without excessive overheating.

6-20 What is an air-core transformer?

A transformer that does not contain oil or other dielectric compositions but is insulated entirely by the winding insulations and air.

6-21 What are eddy currents?

Circulating currents induced in conductive materials (usually the iron cores of transformers or coils) by varying magnetic fields.

6-22 Are eddy currents objectionable?

Yes, they represent a loss in energy and also cause overheating.

6-23 What means can be taken to keep eddy currents at a minimum?

The iron used in the core of an alternation-current transformer is laminated, or made up of thin sheets or strips of iron, so that eddy currents will circulate only in limited areas.

6-24 What is hysteresis?

When iron is subjected to a varying magnetic field, the magnetism lags the magnetizing force due to the fact that iron has reluctance, or resistance, to changes in magnetic densities.

6-25 Is hysteresis objectionable?

Yes, it is a loss and affects the efficiency of transformers.

6-26 Are transformers normally considered to be efficient devices?

Yes, they have one of the highest efficiencies of any electrical device.

6-27 What factors constitute the major losses produced in transformers?

Power loss of the copper (I^2R losses), eddy currents, and hysteresis losses.

6-28 Is there a definite relationship between the number of turns and voltages in transformers?

Yes, the voltage varies in exact proportion to the number of turns connected in series in each winding.

6-29 Give an illustration of the relationship between the voltages and the turns ratio in a transformer.

If the high-voltage winding of a transformer has 1000 turns and a potential of 2400 volts is applied across it, the low-voltage winding of 100 turns will have 240 volts induced across it; this is illustrated in Figure 6-3.

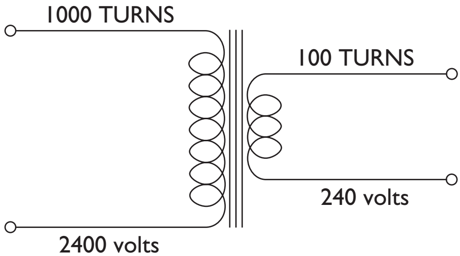


Figure 6-3 Relationship between voltages and the turns ratio in a transformer.

6-30 What is the difference between the primary and the secondary of a transformer?

The primary of the transformer is the input side of the transformer and the secondary is the output side of the transformer. On a step-down transformer, the high-voltage side is the primary and the low-voltage side is the secondary; on a step-up transformer, the opposite is true (Figure 6-4).

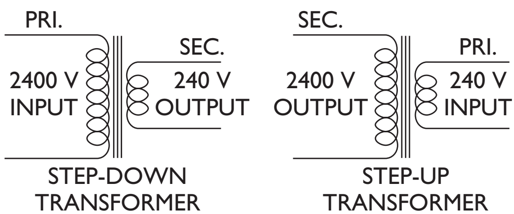


Figure 6-4 The primary and secondary windings of a step-down and a step-up transformer.

6-31 Ordinarily, what is the phase relationship between the primary and secondary voltages of a transformer?

They are 180° out of phase.

6-32 Is it possible to have the primary and secondary of a transformer in phase?

Yes, by changing the connections on one side of the transformer.

6-33 How are the leads of a transformer marked, according to ANSI (American National Standards Institute)?

The high side of the transformer is marked H_1, H_2, etc. The low side of the transformer is marked X_1, X_2, etc.

6-34 What is the purpose of the markings on transformer leads?

They are there for standardization, so that transformer polarities are recognizable for any type of use.

6-35 Draw a diagram of a transformer with additive polarity, using ANSI markings.

See Figure 6-5.

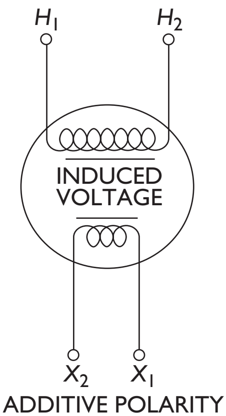


Figure 6-5 A transformer with additive polarity.

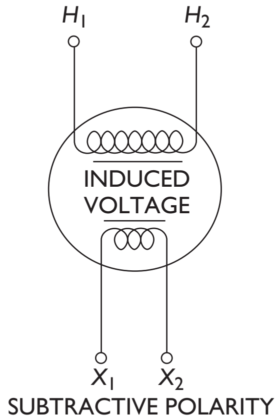


Figure 6-6 A transformer with subtractive polarity.

6-36 Draw a diagram of a transformer with subtractive polarity, using ANSI markings.

See Figure 6-6.

6-37 If a transformer is not marked, how could you test it for polarity?

Connect the transformer as shown in Figure 6-7. If it has subtractive polarity, *V* will be less than the voltage of the power source; if it has additive polarity, *V* will be greater than the voltage of the power source.

6-38 What is a split-coil transformer?

A transformer that has the coils on the low or high side in separate windings so that they can be connected in series or parallel for higher or lower voltages, as desired.

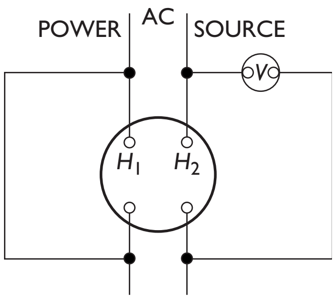


Figure 6-7 Testing a transformer for polarity.

6-39 Draw a diagram of a split-coil transformer with the low side having split coils for dual voltages; draw an additive polarity transformer, and mark the terminals with ANSI markings. Show the voltages that you use.

See Figure 6-8.

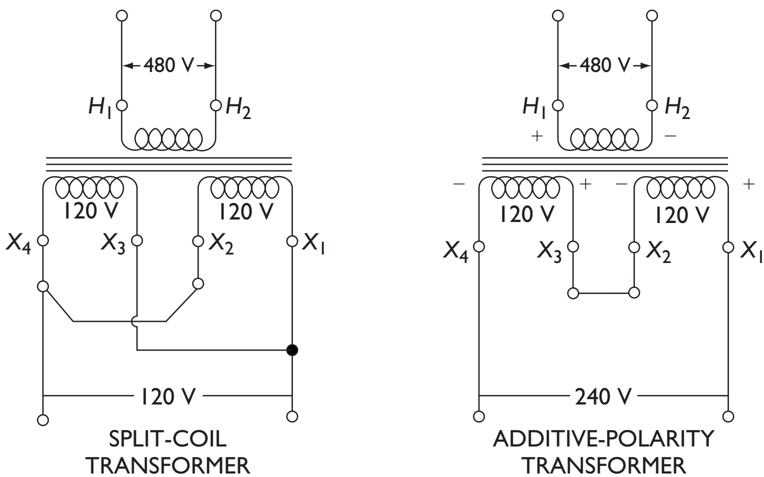


Figure 6-8 A split-coil transformer and an additive-polarity transformer.

6-40 Draw a diagram of an autotransformer.

See Figure 6-9.

6-41 Where may autotransformers be used?

(a) Where the system being supplied contains an identified grounded conductor that is solidly connected to a similar identified grounded conductor of the system supplying the autotransformer (see NEC, *Sections 210.9* and *450.4*); (b) where an autotransformer is used for starting or controlling an induction motor (see NEC, *Section 430.82(B)*); (c) where an autotransformer is used as a dimmer, such as in theaters (see NEC, *Section 520.25(C)*); (d) as part of a ballast for supplying lighting units (see NEC, *Section 410.78*). For voltage bucking and boosting, see NEC, *Section 210.9 exception 1*.

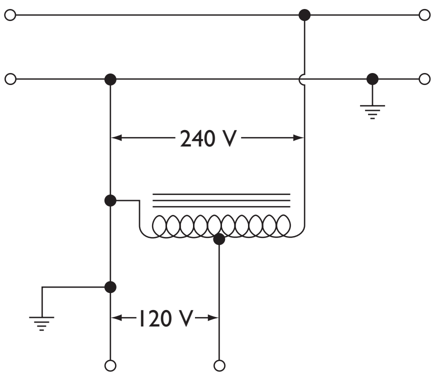


Figure 6-9 An autotransformer.

6-42 What is the relationship between the current and voltage in the high side of a transformer and the current and voltage in the low side of a transformer? Draw a diagram showing this relationship.

With respect to the turns ratio, the current in one side of a transformer is inversely proportional to the current in the other side, whereas the voltage across one side of a transformer is directly proportional to the voltage across the other side. These are illustrated in Figure 6-10.

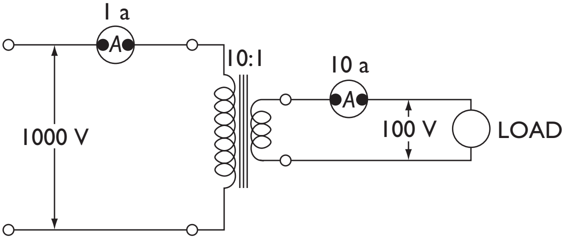


Figure 6-10 Current-voltage relationship between the high side and the low side of a transformer.

6-43 When an induction coil is connected in a dc circuit, as in Figure 6-11, what happens when the switch is closed? When the switch is opened?

When the switch is closed, the current slowly rises to a maximum (point *A* in this example). The retarding of current flow is due to self-inductance. After reaching the maximum at point *A*, the current will remain constant until the switch is opened (point *B*). When the switch is opened, the flux around the coil collapses, thereby causing an opposition to the current discharge; however, this discharge-time collapse is extremely short when compared to the charging time. The discharge causes a high voltage to be applied across the switch, which tends to sustain an arc; this voltage often reaches large values. The principles of this type of circuit have many applications, such as ignition coils and flyback transformers.

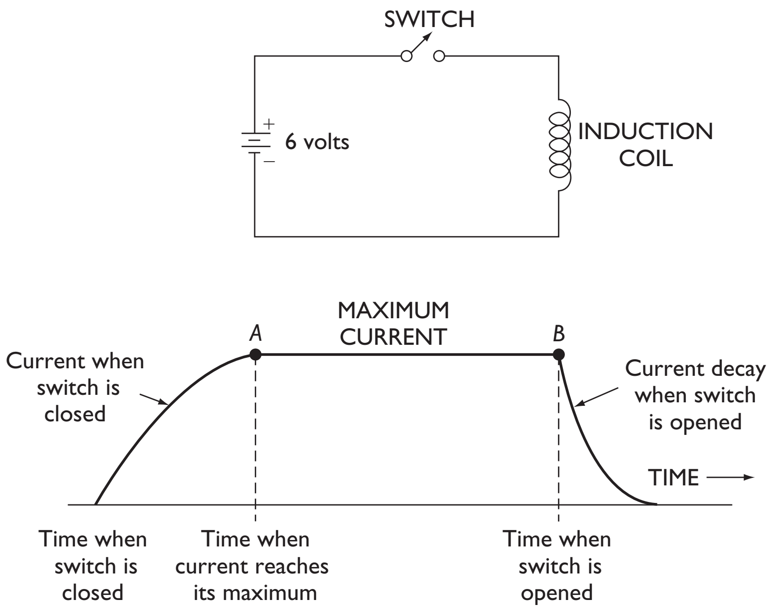


Figure 6-11 An induction coil in a dc circuit with the switch being opened and closed.

6-44 Draw a schematic diagram of the high-side windings of three single-phase transformers connected in a delta arrangement. Show the ANSI markings.

Note that in a delta arrangement, as shown in Figure 6-12, H_1 is connected to H_2 of the next transformer, and so on.

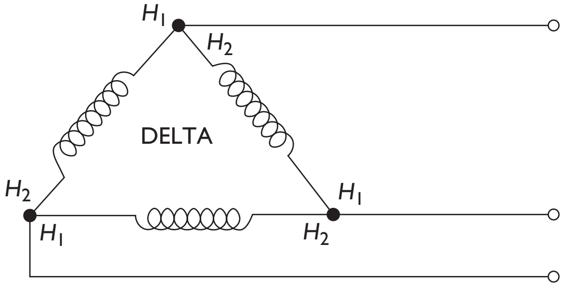


Figure 6-12 Three single-phase transformer windings connected in a delta arrangement.

6-45 Draw a schematic diagram of the high-side windings of three single-phase transformers connected in a wye (Y) arrangement. Show the ANSI markings.

Note that in a wye arrangement, as shown in Figure 6-13, all of the H_2s are connected in common, and the H_1s each supply one phase wire.

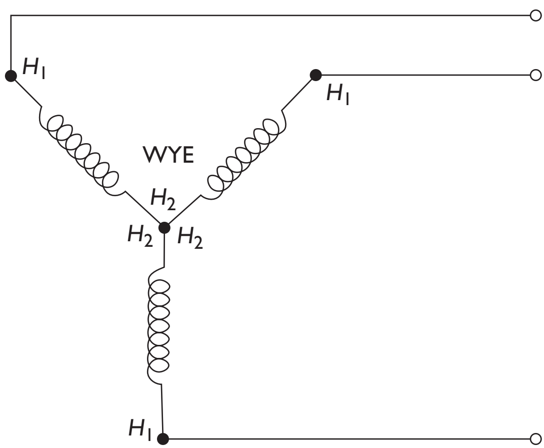


Figure 6-13 Three single-phase transformer windings connected in a wye arrangement.

6-46 If the polarity of one transformer is reversed on a delta bank of single-phase transformers that are connected for three-phase operation, what would be the result?

Instead of zero voltage on the tie-in point, there would be a voltage that is twice the proper value.

6-47 Show with diagrams how you would test to be certain that the polarities on a delta bank of three single-phase transformers are correct.

See Figure 6-14.

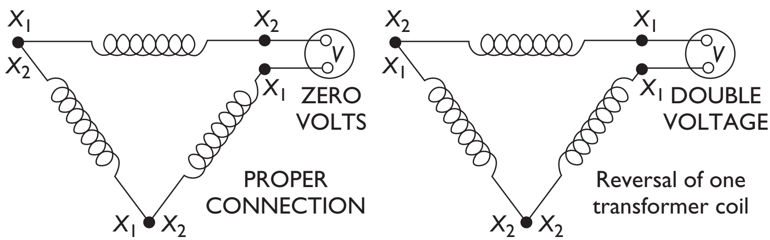


Figure 6-14 Polarity tests on a delta bank of three single-phase transformer windings.

6-48 In a bank of three single-phase transformers that are connected in a delta, each transformer delivers 240 volts at 10 amperes. What are the line voltages and line currents?

The line voltages are each equal to 240 volts; however, the line current in each phase would be the current of each transformer multiplied by 1.732 (the square root of 3), or 17.32 amperes.

6-49 Draw a schematic diagram showing all the currents and voltages on a bank of three single-phase transformers that are connected in a delta arrangement. Assume a voltage across each transformer of 240 volts and a current through each transformer of 10 amperes.

See Figure 6-15.

6-50 Draw a schematic diagram for a bank of three single-phase transformers that are connected in a wye. Show all voltages and currents; assume a voltage across each transformer of 120 volts and a current in each winding of 10 amperes.

See Figure 6-16.

6-51 Draw a bank of three single-phase transformers that are connected in a delta-delta bank with one side connected to 2400 volts, three-phase, and with the other side delivering 240 volts, three-phase. Show voltages and ANSI markings on all transformers.

See Figure 6-17.

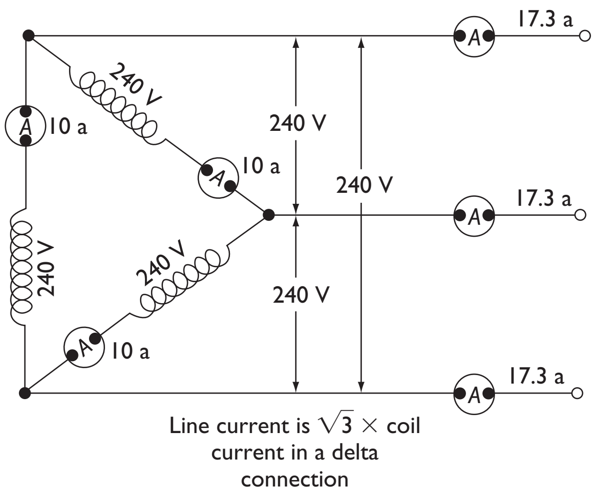


Figure 6-15 Current and voltage values on a delta bank of three single-phase transformer windings. A voltage of 240 volts and a current of 10 amperes are assumed.

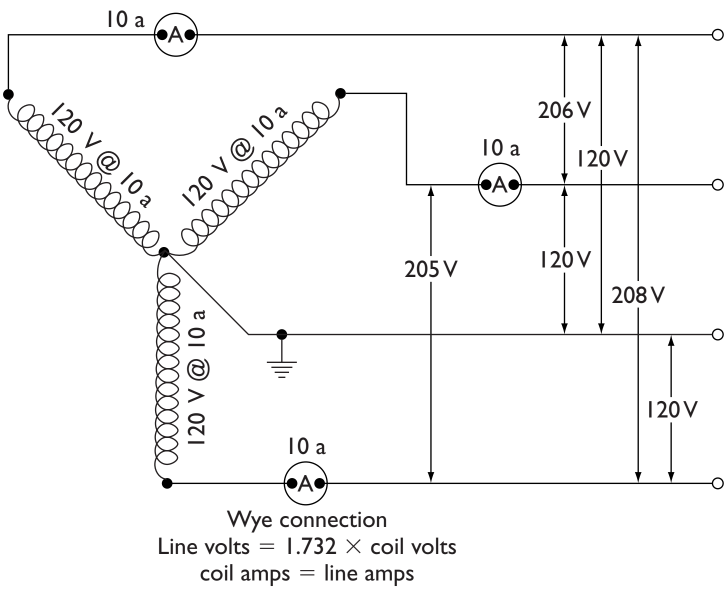


Figure 6-16 Current and voltage values on a wye bank of three single-phase transformer windings. A voltage of 120 volts and a current of 10 amperes are assumed.

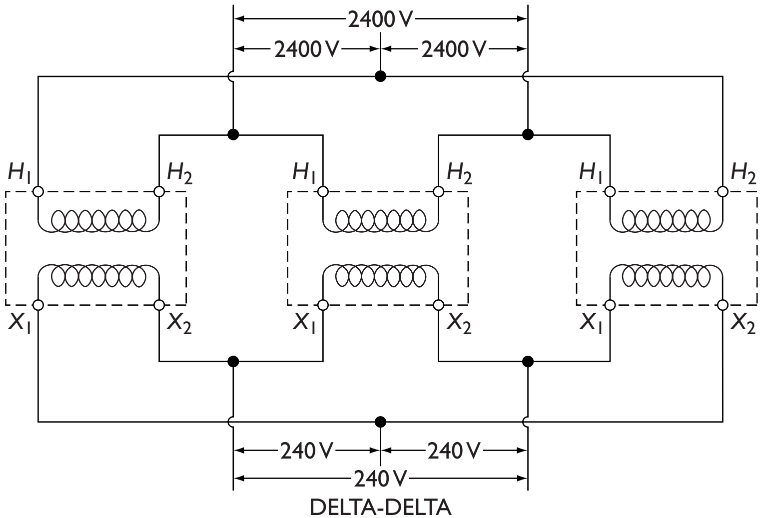


Figure 6-17 Three single-phase transformers connected in a delta-delta bank; the high side is connected to 2400 volts, three-phase, and the low side delivers 240 volts, three phase.

6-52 Is it possible to connect two single-phase transformers to secure a three-phase output from a three-phase input?

Yes, they would have to be connected in an open delta.

6-53 If you have a bank of three single-phase transformers that are connected in a closed delta arrangement, and one transformer burns up, how would you continue operation on the remaining two transformers?

By merely disconnecting the leads to the disabled transformer.

6-54 When you use a bank of two single-phase transformers in an open delta arrangement, do they supply their full output rating?

No. Each transformer is only capable of supplying 86.6 percent of its output rating.

6-55 If you have a bank of three single-phase transformers, each with a 10-kVA rating, that are connected in a closed delta arrangement, you would have a capacity of 30 kVA. If one transformer is taken out of the bank, what would be the output capacity of the remaining 10-kVA transformers?

Each transformer would deliver 8.66 kVA, and you would have a bank capacity of 17.32 kVA.

6-56 Draw a schematic diagram of two transformers that are connected in an open delta arrangement. Show transformer voltages and the three-phase voltages.

See Figure 6-18.

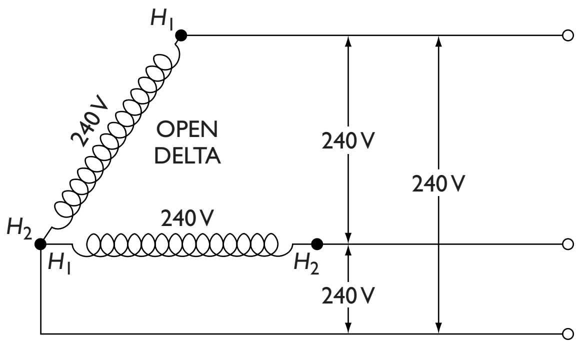


Figure 6-18 Two transformers in an open delta arrangement.

6-57 Draw a schematic diagram of three transformers that are connected in a delta arrangement on both sides, fed from a 2400-volt source on the high side, and connected for a 240-volt, three-phase, and a 120/240-volt, single-phase output on the low side. Show all voltages.

See Figure 6-19.

6-58 Draw a schematic diagram of three single-phase transformers that are connected in a wye-wye arrangement. Show the neutral on both high and low sides.

See Figure 6-20.

6-59 Draw a schematic diagram of three single-phase transformers that are connected in a wye arrangement on the high side and a delta arrangement on the low side.

See Figure 6-21.

6-60 What are instrument transformers?

In the measurement of current, voltage, or kilowatt-hours on systems with high voltage or high current, it is necessary to use a device known as an instrument transformer, which reproduces in its secondary circuit the primary current or voltage while preserving the phase relationship to measure or record at lower voltages or lower amperages, and then to use a constant to multiply the readings to obtain the actual values of voltage or current. Current transformers (CTs) are used to measure the current, and potential transformers (PTs) are used to register the potential.

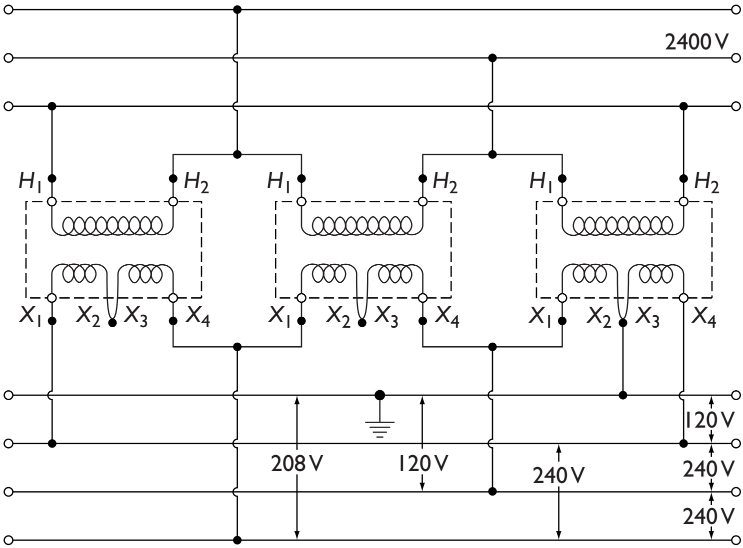


Figure 6-19 Three transformers connected in a delta-delta bank. The high side is connected to 2400 volts, three-phase, and the low side delivers 240 volts, three-phase, and 120/240 volts, single-phase.

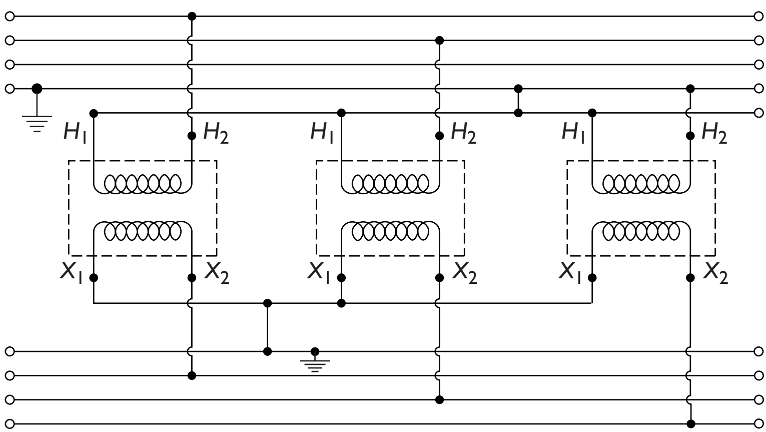


Figure 6-20 Three single-phase transformer windings connected in a wye-wye arrangement.

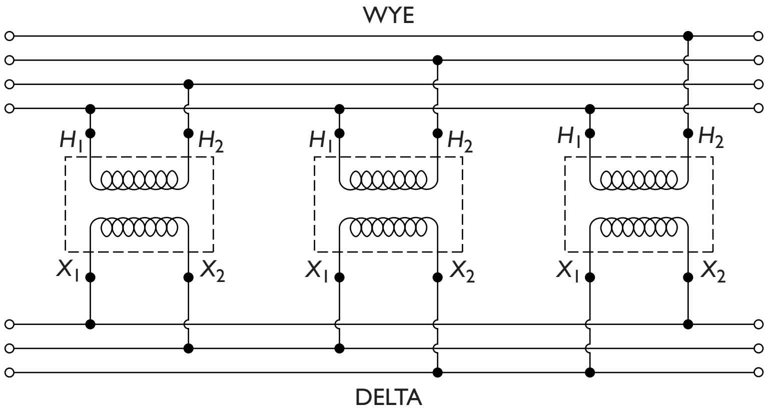


Figure 6-21 Three single-phase transformer windings connected in a wye arrangement on the high side and a delta arrangement on the low side.

6-61 Describe a potential transformer.

A potential transformer is built like the ordinary isolation transformer, except that extra precautions are taken to ensure that the winding ratios are exact. Also, the primary winding is connected in parallel with the circuit to be measured.

6-62 Describe a current transformer.

A current transformer has a primary of a few turns of heavy conductor capable of carrying the total current, and the secondary consists of a number of turns of smaller wire. The primary winding is connected in series with the circuit carrying the current that is to be measured.

6-63 How are current transformers rated?

They are rated at 50 to 5, 100 to 5, etc. The first number is the total current that the transformer is supposed to handle, and the second figure is the current on the secondary when the full-load current is flowing through the primary. For example, a 50-to-5 rating would have a multiplier of 10 ($K = 10$).

6-64 What precautions must be taken when working with current transformers? Why?

The secondary must never be opened when the primary circuit is energized. If it is necessary to disconnect an instrument while the circuit is energized, the secondary must be short-circuited. If the secondary is opened while the circuit is energized, the potential on the secondary might reach dangerously high values. By short-circuiting the secondary, damage is avoided and the voltage on the secondary is kept within safe limits.

6-65 Draw a schematic diagram of a current transformer.

As shown in Figure 6-22, the primary consists of a single conductor; it may be a single conductor or only a few turns.

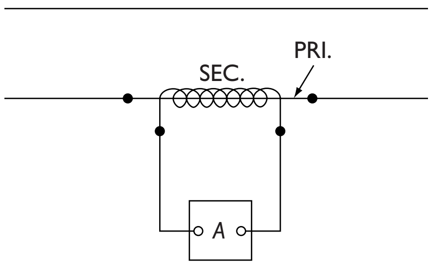


Figure 6-22 A current transformer.

6-66 What is a booster transformer?

A transformer arrangement that is often used toward the end of a power line in order to raise the voltage to its desired value. These are often called “Buck-boost” transformers.

6-67 May an ordinary transformer be used as a booster transformer?

Yes.

6-68 When connecting an ordinary transformer as a booster transformer, what important factors must be considered?

The high side of the transformer must be able to handle the approximate voltage of the line; the low side must have a voltage of approximately the value by which you wish to boost the line voltage and must also have a current capacity that is sufficient to carry the line current.

6-69 What special precaution must be taken when using a booster transformer?

There must be no fusing in the high side, or primary. Because the booster transformer is similar to a current transformer, an extremely high voltage could be built up on the secondary side if the fuse should blow.

6-70 Draw a schematic diagram of an ordinary transformer that is connected as a booster transformer.

See Figure 6-23.

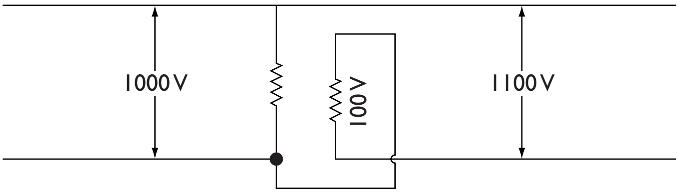


Figure 6-23 A voltage-booster transformer.

6-71 What is an induction regulator?

This device is similar to a booster transformer. It has a primary and a secondary winding, which are wound on separate cores. The primary can be moved in either direction; this is usually done by an electric motor. In turning, the primary bucks or boosts the line voltage, as required. The amount of bucking or boosting is anticipated by the current being drawn by the line.

6-72 Draw a schematic diagram showing how an induction regulator is connected into the line.

See Figure 6-24.

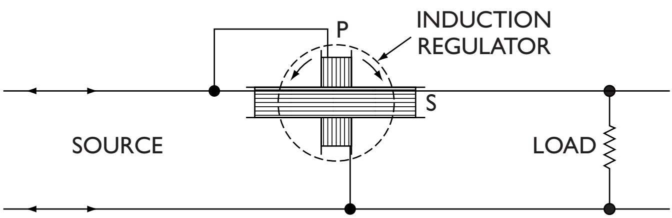


Figure 6-24 The connection of an induction regulator to the line.

6-73 What is a three-phase transformer?

A transformer that is the equivalent of three single-phase transformers, which are all wound on one core and enclosed within one common case.

6-74 When connecting transformers in parallel, what factors must be taken into consideration?

Their electrical characteristics, such as voltage ratio, impedance percentage, and voltage regulation.

6-75 If transformers with different electrical characteristics are connected in parallel, what will happen?

They won't distribute the load equally; one transformer will tend to assume more of the load than the other. This leads to overheating and, in severe cases, the destruction of the transformer(s).

Chapter 7

Wiring Design and Protection

7-1 What are the minimum requirements for service-drop conductors?

They must be of sufficient size to carry the load that is required of them, but they musn't be smaller than No. 8 copper wire or No. 6 aluminum, except under limited load conditions where they may not be smaller than No. 12 hard-drawn copper (see NEC, *Section 230.23*).

7-2 What is the minimum clearance for service drops over buildings?

They shall have a minimum clearance of 8 feet (see NEC, *Section 230.24(A)*). However, if the voltage does not exceed 300 volts between conductors and the roof has a slope of not less than 4 inches in 12 inches, the clearance may be a minimum of 3 feet (see NEC, *Section 230.24(A)*, Exception No. 2).

7-3 What is the minimum height of point of attachment of service drops?

10 feet, provided the clearance in the NEC, *Section 230.24(B)* is met (see also NEC, *Section 230.26*).

7-4 What is the minimum clearance of service drops over commercial areas, parking lots, agricultural areas, and other areas subject to truck traffic?

18 feet (see NEC, *Section 230.24(B)*).

7-5 What is the minimum clearance of service drops over sidewalks?

12 feet (see NEC, *Section 230.24(B)*).

7-6 What is the minimum clearance of service drops over driveways, alleys, and public roads?

18 feet (see NEC, *Section 230.24(B)*).

7-7 What is the minimum clearance of service drops over residential driveways?

12 feet (see NEC, *Section 230.24(B)*).