ANSI/IEEE Std 141-1986

IEEE Recommended Practice for Electric Power Distribution for Industrial Plants

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An American National Standard

IEEE Recommended Practice for Electric Power Distribution for Industrial Plants



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An American National Standard

IEEE Recommended Practice for Electric Power Distribution for Industrial Plants

Sponsor

**Power Systems Engineering Committee
of the
IEEE Industry Applications Society**

Approved December 12, 1985

IEEE Standards Board

Approved June 4, 1986

American National Standards Institute

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Foreword

(This Foreword is not a part of ANSI IEEE Std 141-1986, IEEE Recommended Practice for Electric Power Distribution for Industrial Plants.)

This publication was prepared by the Systems Design Subcommittee of the IEEE Power Systems Engineering Committee, which is a technical committee of the IEEE Industry Applications Society. It has been approved by the IEEE Standards Board as an IEEE standards document to provide current information and recommended practices for the design, construction, operation, and maintenance of electric power systems in industrial plants.

It was forty-one years ago that *Electric Power Distribution for Industrial Plants* was first published by the AIEE. It was given the nickname the "Red Book" because of the color of its cover, and it became the first of the present IEEE Color Book series.

The second edition of the Red Book was produced in 1956, and identified as AIEE Std 952-1956. This was followed by the third edition in 1964; it was also identified as IEEE Std 141-1964. The fourth edition was produced in 1969; it was approved as a Recommended Practice of the Institute and identified as IEEE Std 141-1969. The fifth edition was produced in 1976 and identified as IEEE Std 141-1976. This, the sixth edition, is identified as ANSI/IEEE Std 141-1986. It was initiated in 1970 with the participation of more than fifty electrical engineers from industrial plants, consulting firms, and equipment manufacturers.

This IEEE Recommended Practice continues to serve as a companion publication to the following other Recommended Practices prepared by the IEEE Power Systems Engineering Committee:

Recommended Practice for Grounding of Industrial and Commercial Power Systems (IEEE Green Book), ANSI/IEEE Std 142-1982.

Recommended Practice for Electric Power Systems in Commercial Buildings (IEEE Gray Book), ANSI/IEEE Std 241-1983.

Recommended Practice for Industrial and Commercial Power System Analysis (IEEE Brown Book), ANSI/IEEE Std 399-1980.

Recommended Practice for Emergency and Standby Power for Industrial and Commercial Applications (IEEE Orange Book), ANSI/IEEE Std 446-1980.

Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems (IEEE Gold Book), ANSI/IEEE Std 493-1980.

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Recommended Practice for Electric Systems in Health Care Facilities (IEEE White Book), ANSI/IEEE Std 602-1986.

Recommended Practice for Energy Conservation and Cost-Effective Planning in Industrial Facilities (IEEE Bronze Book), ANSI/IEEE Std 739-1984.

Comments, corrections, and suggestions for the next revision of this standard are welcome and should be submitted to:

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W. P. Burt
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A. Freund
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L. E. Griffith
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M. W. Migliaro
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Electric Power Distribution for Industrial Plants

Sixth Edition

Working Group Members and Contributors

Lucas G. Ananian, *Working Group Chairman*

Chapter 1—Introduction: Donald T. Michael, *Chairman*; Daniel L. Goldberg, R. Gerald Irving

Chapter 2—System Planning: Donald W. Zipse, *Chairman*; Lucas G. Ananian, Graydon M. Bauer, Barry L. Christen, Arthur B. Gospel, Richard H. Kaufmann (deceased), Carl Noel

Chapter 3—Voltage Considerations: Donald T. Michael, *Chairman*; Walter C. Bloomquist, Arthur B. Gospel, Ralph H. Lee

Chapter 4—Surge Voltage Protection: David S. Baker, *Co-Chairman*; M. Shan Griffith, *Co-Chairman*; Richard L. Nailen, George W. Walsh, Glenn E. Word

Chapter 5—Application and Coordination of System Protective Devices: David S. Baker, *Chairman*; M. Shan Griffith, Richard H. Kaufmann (deceased), Clifton A. LaPlatney

Chapter 6—Fault Calculations: Walter C. Huening, *Chairman*; M. Shan Griffith, William R. Haack, Richard H. Kaufmann (deceased), Bal K. Mathur

Chapter 7—Grounding: Bal K. Mathur, *Chairman*; Barry L. Christen, K. V. Patel, Donald W. Zipse

Chapter 8—Power Factor and Related Considerations: Walter C. Bloomquist, *Chairman*; Lucas G. Ananian, Graydon M. Bauer, Kao Chen, M. Shan Griffith, Bal K. Mathur, William J. Moylan, Ray P. Stratford, George W. Walsh, Myron Zucker

Chapter 9—Power Switching, Transformation, and Motor-Control Apparatus: Harold C. Miles, *Chairman*; Lucas G. Ananian, J. Michael Boyd, William P. Burt, Kao Chen, Jerome Frank, Paul W. Gulick, Douglas R. Kanitz, Steven A. Larson, Joseph F. McCormick, Edward F. Troy, Jr

Chapter 10—Instruments and Meters: William J. Moylan, *Chairman*; Kao Chen, James R. Harvey

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Chapter 11—Cable Systems: James M. Daly, *Chairman*; Alex Banes, Graydon M. Bauer, Raymond F. Bilinski, James R. Carey, David N. Hunder, Ralph H. Lee, Milton D. Robinson, Barry Schuster, Clarence P. Tsung, Dale E. Wagner

Chapter 12—Busways: Russell O. Ohlson, *Chairman*; Lucas G. Ananian, Robert W. Ingham, Frank C. Johnston, Robert H. Wood

Chapter 13—Electrical Energy Conservation: Carl E. Becker, *Chairman*; Charles S. Claar, Wayne L. Stebbins

Chapter 14—Cost Estimating of Industrial Power Systems: Erling C. Hesla, *Chairman*; Dan Agustin, Lucas G. Ananian, James M. Daly, Robert D. Giese, William L. Holveck, Douglas R. Kanitz, Harold C. Miles, Russell O. Ohlson

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1. Introduction

1.1 Institute of Electrical and Electronics Engineers (IEEE). ANSI/IEEE Std 141-1986, IEEE Recommended Practice for Electric Power Distribution for Industrial Plants, commonly called the IEEE Red Book, is published as a recommended practice by IEEE, a nonprofit, transnational professional society divided into 36 societies and councils covering the various sectors of electrical engineering. One of these is the Industry Applications Society, comprising 27 technical committees involved in the application of electric systems to industry. Of these, the Power Systems Engineering Committee is concerned with electric systems for industrial plants and is responsible for the development and maintenance of this recommended practice. Approval as an IEEE standard is conferred by the IEEE Standards Board.

1.2 IEEE Meetings and Publications. The IEEE and its constituent societies hold more than 100 technical conferences each year for the presentation of technical papers. Most of these are published in the *IEEE Transactions* or in conference records. Local sections of the IEEE and local chapters of the component societies hold meetings on various subjects of interest to members. Electrical engineers find these meetings and publications invaluable in keeping up-to-date on the latest technical developments in their particular areas of specialization. Many of these papers are referred to in this document, and copies may be obtained from the IEEE.[1]

1.3 Standards, Recommended Practices, and Guides. Electrical engineers use standards, recommended practices, and guides extensively in designing, installing, operating, and maintaining electric systems for industrial plants. Standards establish specific requirements such as definitions of electrical terms, methods of measurement and test procedures, and dimensions and ratings of equipment. Recommended practices suggest the best method of accomplishing an objective for

[1] All IEEE publications are available from Publication Sales, IEEE Service Center, 445 Hoes Lane, Piscataway, NJ 08854.

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specified conditions. Guides specify the factors that must be considered in accomplishing a specific objective. All are grouped together as standards documents.

All standards carry the year of publication as a part of their title. If a copy of a standard referred to in this document is obtained, the year should always be checked. If it is older than five years, the standard may be obsolete; the publisher should be consulted to see if a more recent edition exists and, if so, a copy should be obtained. If the standard has been updated, the material referred to in the reference may have been revised and should be checked. If the date on a standard is followed by a later date preceded by the letter *R*, the standard has been reaffirmed as of the *R* date without change and the standard, therefore, is still in effect.

1.4 IEEE Standards Documents. The IEEE publishes several hundred standards documents covering various fields of electrical engineering. Appropriate IEEE standards are routinely submitted to the American National Standards Institute (ANSI) for consideration as American National Standards. Those that have been approved by ANSI carry the ANSI letters in their designation. A few that have also been approved by the Canadian Standards Association carry CSA letters. Basic standards of general interest include the following:

(1) ANSI/IEEE Std 91-1984, IEEE Standard Graphic Symbols for Logic Diagrams.
(2) ANSI/IEEE Std 100-1984, IEEE Standard Dictionary of Electrical and Electronics Terms.
(3) ANSI/IEEE Std 260-1978, IEEE Standard Letter Symbols for Units of Measurement.
(4) ANSI/IEEE Std 268-1982, American National Standard Metric Practice.
(5) ANSI/IEEE Std 280-1985, IEEE Standard Letter Symbols for Quantities Used in Electrical Science and Electrical Engineering.
(6) ANSI/IEEE Std 315-1975 (CSA Z99-1975), Graphic Symbols for Electrical and Electronics Diagrams.

The IEEE publishes several standards documents of special interest to electrical engineers involved with industrial plant electric systems, which are sponsored by the Power Systems Engineering Committee of the IEEE Industry Applications Society:

(1) ANSI/IEEE Std 142-1982, IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems (IEEE Green Book).
(2) ANSI/IEEE Std 241-1983, IEEE Recommended Practice for Electric Power Systems in Commercial Buildings (IEEE Gray Book).
(3) ANSI/IEEE Std 242-1986, IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (IEEE Buff Book).
(4) ANSI/IEEE Std 446-1980, IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications (IEEE Orange Book).
(5) ANSI/IEEE Std 399-1980, IEEE Recommended Practice for Power Systems Analysis (IEEE Brown Book).
(6) ANSI/IEEE Std 493-1980, IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems (IEEE Gold Book).

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(7) ANSI/IEEE Std 602-1986, IEEE Recommended Practice for Electric Systems in Health Care Facilities (IEEE White Book).
(8) ANSI/IEEE Std 739-1984, IEEE Recommended Practice for Energy Conservation and Cost-Effective Planning in Industrial Facilities (IEEE Bronze Book).

1.5 National Electrical Manufacturers Association (NEMA) Standards. NEMA[2] prepares standards that establish dimensions, ratings, and performance requirements for electric equipment for manufacturers. Their standards are widely used in the preparation of purchase specifications.

1.6 National Fire Protection Association (NFPA) Standards Documents. NFPA[3] publishes standards documents specifying requirements for fire protection and safety. Of interest to industrial plant electrical engineers are the following:
(1) ANSI/NFPA 70-1984, National Electrical Code (NEC).
(2) The NFPA Handbook of the National Electrical Code, sponsored by the NFPA and published by McGraw-Hill, contains the complete NEC text plus explanations edited to correspond with each edition of the NEC.
(3) ANSI/NFPA 70B-1983, Recommended Practice for Electrical Equipment Maintenance.

1.7 Underwriters Laboratories, Inc (UL) Standards. UL[4] prepares safety standards for electric equipment including appliances and tests equipment for compliance with these standards. Manufacturers who have their products approved by UL as meeting the standards are authorized to use the UL label on the equipment. UL periodically publishes lists of approved equipment.

1.8 American National Standards Institute (ANSI). ANSI[5] does not write standards. It promotes and coordinates the development of American National Standards and approves as American National Standards those documents that have been prepared in accordance with ANSI regulations.

Standards that have been approved by other organizations and then approved as American National Standards carry the identification numbers of both organizations and may be purchased from either. The sponsoring organization retains the responsibility for keeping the standard up-to-date. Standards carrying only an ANSI number were prepared by American National Standards committees organized and administered by other organizations in accordance with ANSI regulations. These ANSI committees are generally used to coordinate participation by a large number of organizations.

ANSI standards of interest to industrial plant electrical engineers include the following:
(1) ANSI Y1.1-1972, American National Standard Abbreviations for Use on Drawings and in Text.

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[2] 2101 L Street, NW, Washington, DC 20037.
[3] Batterymarch Park, Quincy, MA 02269.
[4] 333 Pfingsten Road, Northbrook, IL 60020.
[5] 1430 Broadway, New York, NY 10018.

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(2) ANSI Y32.9-1972, American National Standard Graphic Symbols for Electrical Wiring and Layout Diagrams Used in Architecture and Building Construction.

1.9 Occupational Safety and Health Administration (OSHA). Legislation by the US Federal Government has had the effect of giving standards, such as those of ANSI, the impact of law. The Occupational Safety and Health Act, administered by the US Department of Labor, permits federal enforcement of codes and standards. OSHA established *Design Safety Standards for Electrical Systems*, published in the Federal Register as 29CFR Part 1910, Subpart S. The regulations became effective April 16, 1981, and some articles and sections apply to all electrical installations and utilization equipment, and thus are retroactive.

1.10 Environmental Considerations. In all branches of engineering, an increasing emphasis is being placed on social, ecological, and environmental concerns. Today's engineer should consider air, water, noise, and all other items that have an environmental impact. The limited availability of energy sources and the steadily increasing cost of electric energy require a concern with energy conservation on the part of the engineer.

The electrical engineer may participate in studies such as total energy required compared to utility power available, electric heating versus fossil fuel, a comparison of boilers, purchased steam, and the heat pump. The use of steam turbines compared to absorption units and electric drives for air-conditioning may be evaluated. In these studies the effects of noise, vibration, exhaust gases, cooling methods, and energy requirements must be considered in relationship to the immediate and sometimes general environment.

1.11 Edison Electric Institute (EEI). The Edison Electric Institute,[6] the trade association of the privately owned electric utilities, publishes the following handbooks:

(1) *Electric Heating and Cooling Handbook*
(2) *A Planning Guide for Architects and Engineers*
(3) *Electric Space-Conditioning*
(4) *Industrial and Commercial Power Distribution*
(5) *Industrial and Commercial Lighting*
(6) *Underground Systems Reference Book*

1.12 Handbooks. The following handbooks have, over the years, established reputations in the electrical field. This list is not intended to be all-inclusive; other excellent references are available, but are not listed here because of space limitations.

(1) CROFT, T., CARR, C., and WATT, J. *American Electricians' Handbook* (McGraw-Hill, 1970). The practical aspects of equipment, construction, and installation are covered.

[6] 1111 19th Street, NW, Washington, DC 20036.

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(2) *ASHRAE Handbook* (American Society of Heating, Refrigerating, and Air Conditioning Engineers[7] [ASHRAE]). This series of reference books in four volumes, which are periodically updated, details the electrical and mechanical aspects of space conditioning and refrigeration.
(3) *Electrical Transmission and Distribution Reference Book* (Westinghouse Electric Corporation,[8] 1964). The design and application of electric systems are outlined.
(4) *Electric Utility Engineering Reference Book, vol 3: Distribution Systems* (Westinghouse Electric Corporation, 1965). The application of high-voltage equipment and the design of high-voltage and network systems are covered in detail.
(5) McPARTLAND, J. and the editors of *Electrical Construction and Maintenance* magazine. *How to Design Electrical Systems* (McGraw-Hill, 1968); McPARTLAND, J. and NOVAK, W. *Electrical Design Details* (McGraw-Hill, 1960). These references offer the younger engineer an insight into the systems approach to electrical design.
(6) BEEMAN, D.L., editor. *Industrial Power Systems Handbook* (McGraw-Hill, 1955). A text on electrical design with emphasis on equipment, including that which is applicable to commercial buildings.
(7) *IES Lighting Handbook* (Illuminating Engineering Society[9] [IES]: Application Volume, 1981; Reference Volume, 1984). All aspects of lighting, including seeing, recommended lighting levels, lighting calculations, and design, are included in extensive detail in this comprehensive text.
(8) FINK, D.G. and CARROLL, J.M., editors. *Standard Handbook for Electrical Engineers* (McGraw-Hill, 1968). Virtually the entire field of electrical engineering is treated, including equipment and systems design.
(9) *Transformer Connections, Including Auto-transformer Connections*, Publication GET-2G (General Electric Company, 1960).
(10) *Underground Systems Reference Book* (Edison Electric Institute, 1957). The principles of underground construction and the detailed design of vault installations, cable systems, and related power systems are fully illustrated; cable splicing design parameters are thoroughly covered. Unfortunately, it has not been updated for some time.
(11) *Electrical Maintenance Hints* (Westinghouse Electric Corporation, 1975).
(12) SHAW, E.T. *Inspection and Test of Electrical Equipment* (Westinghouse Electric Corporation, 1967).

1.13 Periodicals. *Spectrum*, the basic monthly publication of the IEEE, covers all aspects of electrical and electronic engineering. It contains references to IEEE books and other publications, technical meetings and conferences, IEEE group, society, and committee activities, abstracts of papers and publications of the IEEE

[7] Publication Sales, 1791 Tullie Circle, NE, Atlanta, GA 30329.
[8] Printers' Division, Forbes Road, Trafford, PA 15085.
[9] 345 East 47 Street, New York, NY 10017.

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and other organizations, and other material essential to the professional advancement of the electrical engineer.

Following are some other well-known periodicals:

(1) *Actual Specifying Engineer*, 205 East 42 Street, New York, NY 10017
(2) *Electrical Construction and Maintenance*, 1221 Avenue of the Americas, New York, NY 10020
(3) *Electrical Consultant*, 1760 Peachtree Road NW, Atlanta, GA 30309
(4) *Lighting Design and Application*, Illuminating Engineering Society, 345 East 47 Street, New York, NY 10017
(5) *Plant Engineering*, 1301 South Grove Avenue, Barrington, IL 60010
(6) *Power*, 1221 Avenue of the Americas, New York, NY 10020
(7) *Power Engineering*, 1301 South Grove Avenue, Barrington, IL 60010

1.14 Manufacturers' Data. The electrical industry, through its assocations and individual manufacturers of electrical equipment, issues many technical bulletins and data books. While some of this information is difficult for the individual to obtain, copies should be available to each major design unit. The advertising sections of electrical magazines contain excellent material, usually well-illustrated and presented in a clear and readable form, concerning the construction and application of equipment. Such literature may be promotional; it may present the advertiser's equipment or methods in a *best light* and should be carefully evaluated. Manufacturers' catalogs are a valuable source of equipment information. Some of the larger manufacturers' complete catalogs are very extensive, covering dozens of volumes; however, these companies may issue abbreviated or condensed catalogs that are adequate for most applications. Data sheets referring to specific items are almost always available from the sales offices. Some technical files may be kept on microfilm at larger design offices for use either by projection or by printing. Manufacturers' representatives, both sales and technical, can do much to provide complete information on a product.

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2. System Planning

2.1 Introduction. The continuity of production in an industrial plant is only as reliable as its electric power distribution system. This chapter outlines the procedures for system planning and presents a guide to the use of the succeeding chapters.

No standard electric distribution system is adaptable to all industrial plants because two plants rarely have the same requirements. The specific requirements must be analyzed qualitatively for each plant and the system designed to meet its electrical requirements. Due consideration must be given to both the present and future operating and load conditions.

2.2 Basic Design Considerations. Any approach to the problem should include several basic considerations that will affect the overall design.

2.2.1 Safety. Safety of life and preservation of property are two of the most important factors in the design of the electric system. Safety to personnel involves no compromise; only the safest system can be considered. Following established codes in the selection of material and equipment is imperative.

2.2.2 Reliability. The continuity of service required is dependent on the type of manufacturing or process operation of the plant. Some plants can tolerate interruptions while others require the highest degree of service continuity. The system should be designed to isolate faults with a minimum disturbance to the system and should have features to give the maximum dependability consistent with the plant requirements and justifiable cost.

The majority of utilities today are supplying energy at 34.5, 69, and 138 kV. Some industrial plants accept supplies directly from utility distribution voltage substations at 4.16, 12.5, 13.8 kV, etc. In most instances, the utility substations also serve other customers so that there are usually several distribution lines connected to the same bus as the plant supply line(s).

For the most part, plant personnel feel secure with this type of supply, especially if the supply substation is nearby and if multiple supply lines are provided to meet *firm power* requirements. However, this tends to be a false sense of security when the facts are known regarding the reliability of distribution lines and the impact

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this has on plant operations. For example, when a fault occurs on the supply system near the plant there is an accompanying voltage dip on all of the plant primary distribution and utilization voltage buses. This lowered voltage persists while the utility relays operate and until the utility breaker trips, at which point the voltage will be reduced to zero on the faulted line and will be restored to near normal on the unfaulted portions of the system. Experience has shown that these short time voltage dips are severe enough and persist long enough to cause motor starter contactors to open automatically. When this occurs in a plant there will be parts spoilage, tool breakage, etc, all of which cause major disruptions in plant operations even though the supply may be lost only temporarily. Furthermore, new customers added to the supply substation could reduce the quality and reliability of the service.

Statistically, 138 kV lines may have outage rates of four or five outages per hundred miles per year. On the other hand, distribution lines in the 8-23 kV voltage range may have outage rates of 100 or more outages per hundred miles per year. Thus the probability of damaging voltage dips is at least 20 times as great on low voltage lines as on transmission voltage lines. This difference in probabilities is magnified even more when it is realized that the exposure to voltage dip incidents is not limited to only the plant supply line that may be extremely short. Instead, because distribution lines are not looped from substation to substation, the exposure is represented by the total miles of all lines connected to the utility substation.

2.2.3 System Reliability Analysis. One of the questions often raised during the design of the power distribution system is how to make a quantitative comparison of the failure rate and the forced downtime in hours per year for different circuit arrangements including radial, primary-selective, secondary-selective, simple spot network, and secondary-network circuits. This quantitative comparison could be used in tradeoff decisions involving the initial cost versus the failure rate and forced downtime per year. The estimated cost of power outages at the various distribution points could be considered in deciding which type circuit arrangement to use. The decisions could thus be based upon total owning cost over the useful life of the equipment rather than the first cost.

2.2.4 Reliability Data for Electrical Equipment. In order to calculate the failure rate and the forced downtime per year, it is necessary to have reliability data on the electric utility supply and each piece of electrical equipment used in the power distribution system. One of the best sources for this type of data are the extensive IEEE surveys on the reliability of electrical equipment in industrial plants and commercial buildings. See ANSI/IEEE Std 493-1980 [3].[10]

2.2.5 Reliability Analysis and Total Owning Cost. Statistical analysis methods involving probability of failure may be used to make calculations of the failure rate and the forced downtime for the power distribution system. The methods and formulas used in these calculations are given in ANSI/IEEE Std 493-1980 [3]. This includes the minimum revenue requirements method for calculating the total own-

[10] The numbers in brackets correspond to those of the references listed at the end of this chapter; when preceded by B, they correspond to the bibliography at the end of this chapter.

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ing cost over the useful life of the equipment. Data on the cost of power outages are also given in ANSI/IEEE Std 493-1980 [3].

2.2.6 Simplicity of Operation. Simplicity of operation is very important in the safe and reliable operation and maintenance of the industrial power system. The operation should be as simple as possible to meet system requirements.

2.2.7 Voltage Regulation. Poor voltage regulation is detrimental to the life and operation of electrical equipment. Voltage at the utilization equipment must be maintained within equipment tolerance limits under all load conditions.

2.2.8 Maintenance. The distribution system should include preventive maintenance requirements in the design. Accessibility and availability for inspection and repair with safety are important considerations in selecting equipment. Space should be provided for inspection, adjustment, and repair in clean, well-lighted, and temperature-controlled areas.

2.2.9 Flexibility. Flexibility of the electric system means the adaptability to development and expansion as well as to changes to meet varied requirements during the life of the plant. Consideration of the plant voltages, equipment ratings, space for additional equipment, and capacity for increased load must be given serious study.

2.2.10 First Cost. While first costs are important, safety, reliability, voltage regulation, maintenance, and the potential for expansion should also be considered in selecting the best from alternate plans.

2.3 Planning Guide for Distribution Design. The following procedure will guide the engineer in the design of an electric distribution system for any industrial plant. The system designer should have or acquire knowledge of the plant's processes in order to select the proper system and its components.

2.3.1 Load Survey. Obtain a general layout, mark it with the major loads at various locations, and determine the approximate total plant load in kilowatts or kilovolt-amperes. Initially the amount of accurate load data may be limited. Some loads such as lighting and air conditioning may be estimated from generalized data. The majority of industrial plant loads are a function of the process equipment, and such information will have to be obtained from process and equipment designers. Since their design is often concurrent with power system design, initial information will be subject to change. It is therefore important that there be continuing coordination with the other design disciplines. For example, a change from electric powered to absorption refrigeration or a change from electrostatic to high-energy scrubber air-pollution control can change the power requirements for these devices by several orders of magnitude. The power system load estimates will require continual refinement until job completion.

2.3.2 Demand. The sum of the electrical ratings of each piece of equipment will give a total connected load. Because some equipment operates at less than full load and some intermittently, the resultant demand upon the power source is less than the connected load.

Standard definitions for these load combinations and their ratios have been devised.

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demand. The electric load at the receiving terminals averaged over a specified interval of time.

NOTE: Demand is expressed in kilowatts, kilovolt-amperes, amperes, or other suitable units. The interval of time is generally 15 min, 30 min, or 1 h.

peak load. The maximum load consumed or produced by a unit or group of units in a stated period of time. It may be the maximum instantaneous load or the maximum average load over a designated period of time.

maximum demand. The greatest of all demands that have occurred during a specified period of time.

NOTE: For utility billing purposes the period of time is generally one month.

demand factor. The ratio of the maximum demand of a system to the total connected load of the system.

diversity factor. The ratio of the sum of the individual maximum demands of various subdivisions of the system to the maximum demand of the complete system.

load factor. The ratio of the average load over a designated period of time to the peak load occurring in that period.

coincident demand. Any demand that occurs simultaneously with any other demand, also the sum of any set of coincident demands.

Information on these factors for the various loads and groups of loads is useful in designing the system. For example, the sum of the connected loads on a feeder, multiplied by the demand factor of these loads, will give the maximum demand that the feeder must carry. The sum of the individual maximum demands on the circuits associated with a load center or panelboard, divided by the diversity factor of those circuits, will give the maximum demand at the load center and on the circuit supplying it. The sum of the individual maximum demands on the circuits from a transformer, divided by the diversity factor of those circuits, will give the maximum demand on the distribution transformer. The sum of the maximum demand on all distribution transformers, divided by the diversity factor of the transformer loads, will give the maximum demand on their primary feeder. By the use of the proper factors, as outlined, the maximum demands on the various parts of the system from the load circuits to the power source can be estimated.

2.3.3 Systems. Investigate the various types of distribution systems and select the system or systems best suited to the requirements of the plant.

A variety of basic circuit arrangements is available for industrial plant power distribution. Selection of the best system or combination of systems will depend upon the needs of the manufacturing process. In general, system costs increase with system reliability if component quality is equal. Maximum reliability per unit investment will be secured by using properly applied and well-designed components.

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The first step is the analysis of the manufacturing process to determine its reliability need and potential losses in the event of power interruption. Some processes are little affected by interruption. Here a simple radial system may be satisfactory. Other processes may sustain long-term damage by even a brief interruption. Here a more complex system with an alternate power source for critical load may be justified.

A need for circuit redundancy may exist in continuous-process industries to allow equipment maintenance. Although the reliability of electric power distribution equipment is high, optimum reliability and safety of operation require routine maintenance. A system that cannot be maintained because of the needs of a continuous process is improperly designed.

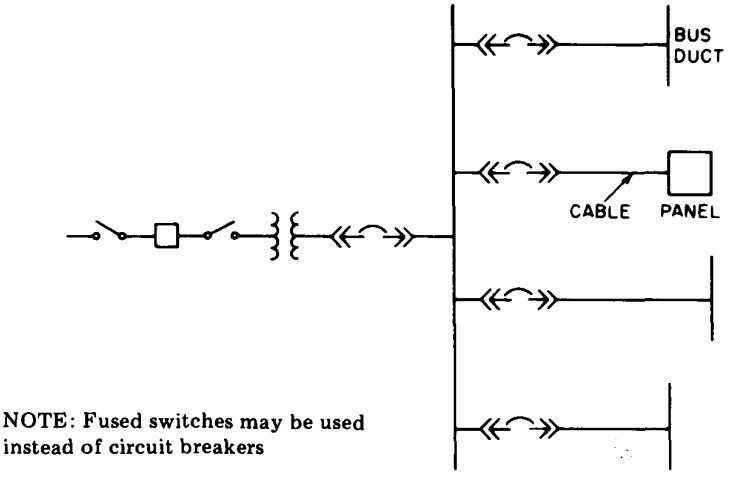
Far more can be accomplished by the proper selection of the circuit arrangement than by economizing on equipment details. Cost reductions should never be made at the sacrifice of safety and performance by using inferior apparatus. Reductions should be obtained by using a less expensive distribution system with some sacrifice in reserve capacity and reliability.

2.3.3.1 Simple Radial System (Fig 1). Distribution is at the utilization voltage. A single primary service and distribution transformer supply all the feeders. There is no duplication of equipment. System investment is the lowest of all circuit arrangements.

Operation and expansion are simple. If quality components are used, reliability is high. Loss of a cable, primary supply, or transformer will cut off service. Equipment must be shut down to perform routine maintenance and servicing.

This system is satisfactory for small industrial installations where process allows

Fig 1
Simple Radial System



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sufficient down time for adequate maintenance and the plant can be supplied by a single transformer.

2.3.3.2 Expanded Radial System (Fig 2). The advantages of the radial system may be applied to larger loads by using a radial primary distribution system to supply a number of unit substations located near the centers of load supplying the load through radial secondary systems.

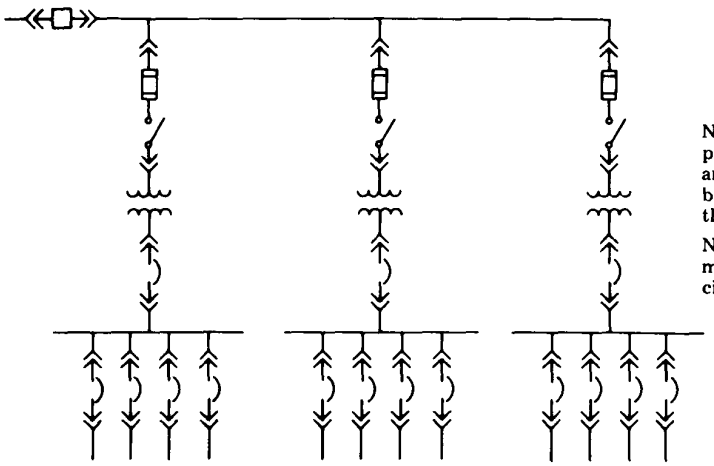
The advantages and disadvantages are the same as those described for the simple radial system.

2.3.3.3 Primary Selective System (Fig 3). Protection against loss of a primary supply can be gained through use of a primary selective system. Each unit substation is connected to two separate primary feeders through switching equipment to provide a normal and an alternate source. Upon failure of the normal source, the distribution transformer is switched to the alternate source. Switching can be either manual or automatic, but there will be an interruption until load is transferred to the alternate source.

If the two sources can be paralleled during switching, some maintenance of primary cable and, in certain configurations, switching equipment may be performed with little or no interruption of service. Cost is somewhat higher than that for a radial system because of duplication of primary cable and switchgear.

2.3.3.4 Primary Loop System (Fig 4). This system offers the same advantages and disadvantages as the primary selective system. The failure of the normal source of a primary cable fault can be isolated and service restored by sectionalizing. However, finding a cable fault in the loop may be difficult. The system may be dangerous because the quickest way to find a fault is to sectionalize the loop and

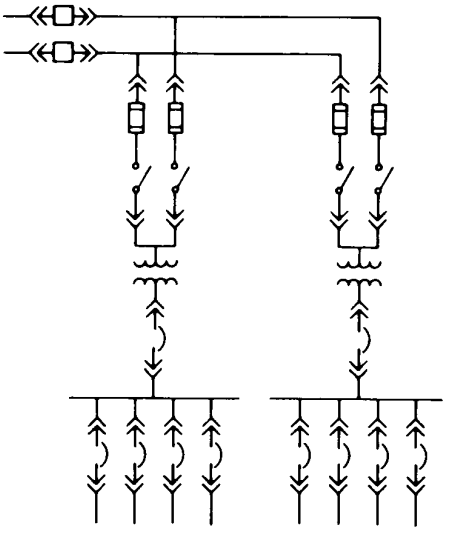
Fig 2
Expanded Radial System



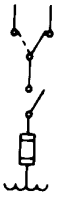
NOTE: If non-draw-out primary fused switches are used, the fuse should be on the load side of the switch.

NOTE: Fused switches may be used instead of circuit breakers.

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NOTE: If non-draw-out fused switches are used, the fuse should be on the load side of the switch.



NOTE: An alternate arrangement uses a primary selector switch with a single fused interrupter switch (which may not have certified current-switching ability).

Fig 3
Primary Selective System

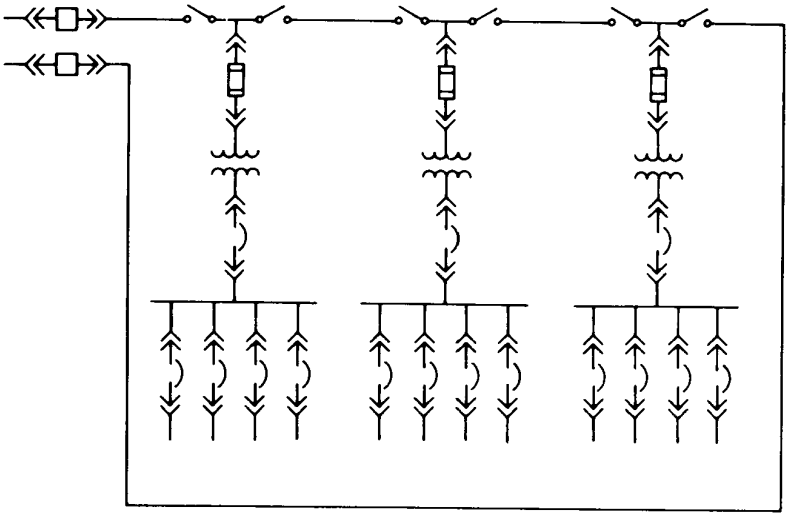


Fig 4
Primary Loop System

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reclose. This may involve several reclosings on the fault. Also potentially dangerous is the fact that a section may be energized from both ends.

Cost may be somewhat less than for the primary selective system. However, it is doubtful that the savings are justified in view of the disadvantages.

2.3.3.5 Secondary Selective System [Fig 5(a)]. If pairs of unit substations are connected through a normally open secondary tie circuit breaker, the result is a secondary selective system. If the primary feeder or a transformer fails, the main secondary circuit breaker on the affected transformer is opened and the tie circuit breaker closed. Operation may be manual or automatic. Normally the stations operate as radial systems. Maintenance of primary feeders, transformer, and main secondary circuit breakers is possible with only momentary power interruption or no interruption if the stations may be operated in parallel during switching, although complete station maintenance will require a shutdown. With the loss of one primary circuit or transformer, the total substation load may be supplied by one transformer. To allow for this condition, one (or a combination) of the following should be considered.

(1) Oversizing both transformers so that one transformer can carry the total load

(2) Providing forced-air cooling to the transformer in service for the emergency period

(3) Shedding nonessential load for the emergency period

(4) Using the temporary overload capacity in the transformer and accepting the loss of transformer life

A distributed secondary selective system has pairs of unit substations in different locations connected by a tie cable and a normally open circuit breaker in each substation. The designer should balance the cost of the additional tie circuit breaker and the tie cable against the cost advantage of putting the unit stations nearer the load center.

The secondary selective system may be combined with the primary selective system to provide a high degree of reliability. This reliability is purchased with additional investment and addition of some operating complexity.

In Fig 5(a), while adhering to the *firm* capacity concept, it is seen that the total load allowable to the substation must be equal to or less than the capability of one transformer or one low side breaker, whichever is the least. By contrast, the arrangement of Fig 5(b), using a sparing transformer, can be developed for a firm capacity equal to $(n-1)$ transformers or low side breakers.

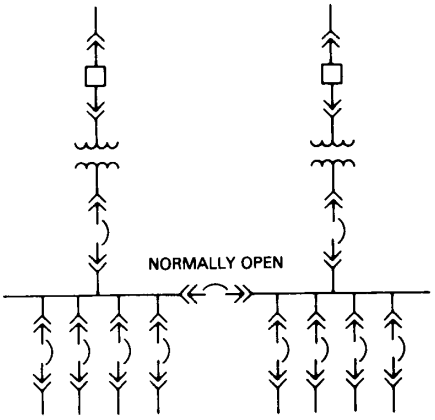
Operations, protection, etc, for configurations shown by Fig 5(a) and (b) are the same with two exceptions:

(1) Automatic transfer initiated by loss of voltage on a low side bus is not applicable in the sparing transformer scheme.

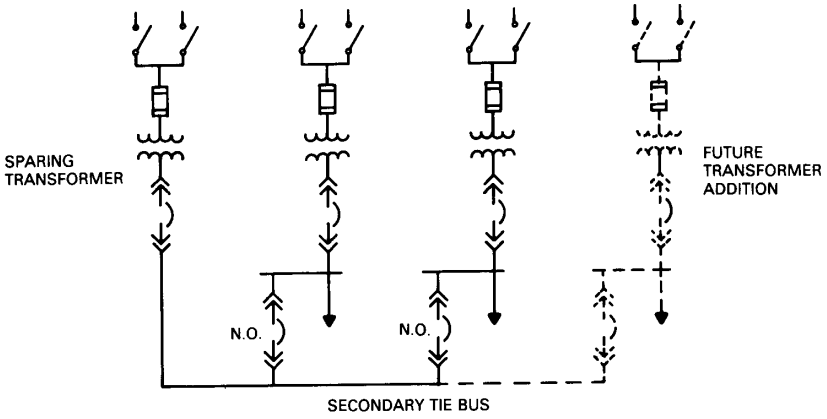
(2) Feeder breaker fault duties are almost always greater in the double-end scheme due to emergency condition when the tie is closed and one main is open.

2.3.3.6 Secondary Spot Network (Fig 6). In this system two or more distribution transformers are each supplied from a separate primary distribution feeder. The secondaries of the transformers are connected in parallel through a special

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(a) Secondary Selective System



(b) Sparing Transformer Scheme

Fig 5
Typical Configurations Load Center Substations

type of circuit breaker, called a network protector, to a secondary bus. Radial secondary feeders are tapped from the secondary bus to supply utilization equipment.

If a primary feeder fails, or a fault occurs on a primary feeder or distribution transformer, the other transformers start to feed back through the network pro-

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