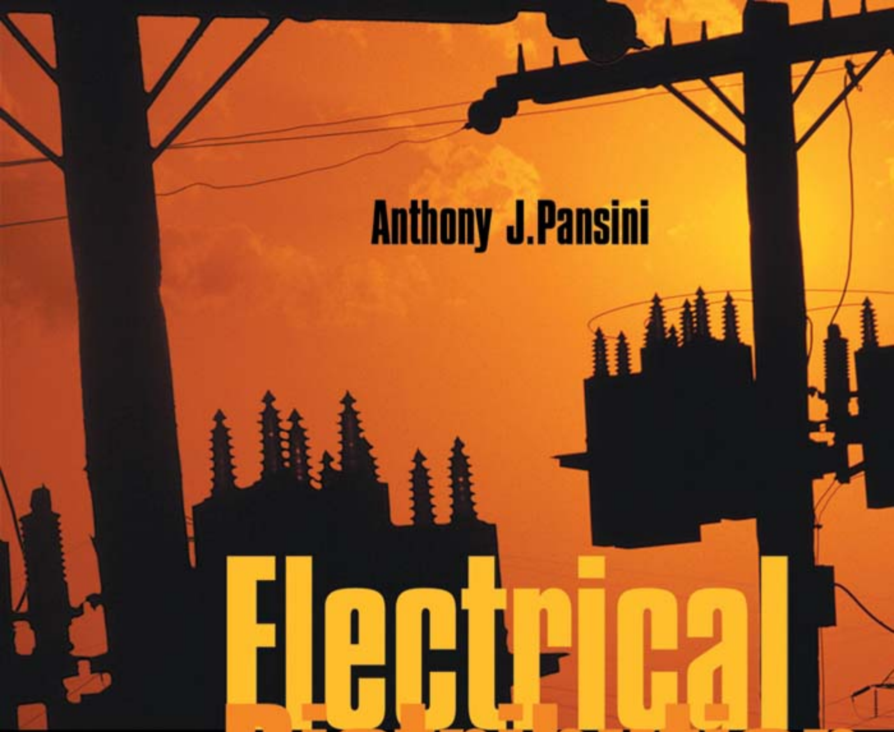

Anthony J. Pansini

Electrical Distribution Engineering

Third Edition

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3rd Edition

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Contents

Preface to the Third Edition

The steady improvements to the electric distribution systems have been joined by new concepts that include generation, conservation and storage of electricity, part of the Energy Policy Act dictated by Congress in 2005. The act recognizes changes in factors affecting the generation of electric energy and now includes the field of its distribution. These include increasing concerns for the environment (global warming, etc.), the ever widening gap in the supply and demand for fossil fuels (mostly oil, brought about in part by the modernization and industrialization of such countries as China and India), reflected by the rising prices of these commodities as well as by the declining availability of capital for their required development.

The act spells out in some detail plans for the use of replenishible "green" fuels and for conservation of existing ones. Involved are such "exotic" fuels as wind, sunshine (solar energy), geothermal (volcanic hot springs, etc.) hydro plants, and natural gas (methane). The last is actually a non-replenishible fossil fuel, but as its emissions are relatively clean, it is included as a preference to coal and oil. The act also includes suggestions and regulations as well as incentives and penalties for its compliance, especially as they pertain to the so-called "green" fuels.

Relatively new modes of operation as cogeneration and distributed generation are included in furthering the goals of the Energy Policy Act that will more fully engage the cooperation and coordination of the distribution engineer with the requirements of the consumer.

And so, the distribution engineer, while keeping his weather eye on innovations and improvements in materials and methods, now enters solidly into the field of power generation from "green" fuels added to those of cogeneration and distributed generation. What next?

A Texas-size thank you is extended to friends and former colleagues Richard E. Gibbons and Kenneth W. Smalling, and to The Fairmont Press for their aid and encouragement. And no less for her patience and understanding to my beloved wife of sixty years.

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History and Development

While much attention is focused on electric power generating plants, their necessary adjuncts, electrical distribution systems, receive relatively scant attention from the public and investors—a phenomenon reflected in many engineering schools and among managements of many utility companies. This may perhaps be because electric lines on poles in streets and alleys and along rear property lines often go unnoticed; indeed, they are sometimes installed out of sight beneath the ground.

In comparison with power plants, expenditures for distribution systems are usually made in relatively small increments—another reason for the rather meager treatment sometimes accorded them. Until a decade ago, of every dollar spent by utility companies for electric facilities, 50 cents was spent for the distribution systems. Escalating costs for generation and reduced costs of distribution equipment have lowered this proportion to 30 cents, still a substantial amount.

With society, in all walks of life, becoming more dependent for its successful functioning on a good supply of electric energy, the link between the source and the consumer, the distribution system, assumes an ever more critical role. It is not only called upon to deliver ever greater quantities of electric energy, but the demand for ever higher standards of quality imposes on it requirements that become ever more stringent.

Higher quality is not limited to better regulation of voltage, to narrower bands of almost flickerless voltage variations. Though not closely associated with electrical distribution, a very high degree of maintaining alternating current frequencies has been sought. The awareness of faults and other contingencies, their identification and location, and the means of service restoration are important factors involved. These may be accomplished by the installation of additional devices operating automatically or manually.

These objectives may also be affected by such "nonrelated" items as better-trained personnel; improved transportation and communication facilities, including tools and equipment; quicker access to records, including use of computers; adequate stocks of materials; liaison with other sources of assistance; preventive maintenance programs; and various continually updated procedures for handling a variety of contingencies. All of these are reflected in carrying charges and operating expenses, and ultimately in the consumers' bills. These "nonrelated" items will not be explored further in this presentation; they are mentioned generally to illustrate other important subjects that should be given consideration in arriving at overall solutions to problems affecting electric distribution systems.

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In the early days of the electric power industry, the distribution systems were often mere appendages to the power generating plants. Their designs, if such they may be called, sometimes were predicated almost entirely on expediency and practicality. With little study, their installation and operation were considered more of an art than a science. The areas served and the number of consumers were relatively small; individual usages were not very large, generally limited to few applications. Quality, in terms of voltage regulation and service reliability, was almost nonexistent. Other means of taking care of people's lighting and power needs were readily available.

With the expansion in the use of electricity, the demands on the distribution systems became greater and more complex. They not only had to serve greater numbers of consumers, but had to supply their greater individual loads that now required closer supervision of voltage variations at the consumers' terminals. Further, consumers demanded a reliability in their service that could tolerate only fewer interruptions of shorter duration.

At this point, the design, construction, maintenance, and operation of distribution systems became a science involving technical and economic disciplines not only in the field of electrical engineering, but in mechanical, civil, chemical, and almost all other fields of engineering as well.

From the early, simple, "radial" circuit, i.e., a feeder supplied from one source, other more sophisticated designs evolved. Radial circuits were provided with sectionalizing points which enabled a faulted section of the circuit to be disconnected. This enabled the remainder of the circuit beyond the faulted section to be reenergized by connecting it to other sources, usually adjacent circuits. These "emergency" tie points, specifically provided for this purpose, also enabled loads to be transferred conveniently from one circuit to another.

Other designs provided for duplicate feeds, with manual or automatic throw-over from one circuit to another. Circuits were formed into loops, operating open at some point or as a closed loop. In areas of more important and greater load densities, circuits were interconnected into a mesh or network.

Original distribution systems supplied direct current at the low distribution voltages. The advent of the transformer and the economics of serving larger and larger loads more and more distant from the sources of supply soon had alternating current systems supplant the direct current distribution systems almost universally, although some declining ones still survive. Larger loads could now be supplied over longer distances at higher voltages and then lowered to utilization voltages to supply a consumer or group of consumers.

Requirements for electric service became geared to the different types of consumers served: residential, including urban, suburban, and rural; commercial, including individual stores, shopping centers, and office buildings; and industrial, including manufacturing and service plants of varying sizes. Further, other considerations sometimes made the underground installation of distribution systems desirable; such systems present problems very different from the simpler overhead systems.

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Parallel with the development of the electric distribution circuits was the development of more suitable materials, electric apparatus, tools, and equipment, which permitted new and more efficient methods of construction, maintenance, and operation, a process that continues to this day.

Rough-hewn raw-wood poles have given way to well-turned, well-shaped, well-preserved poles of selected woods, including hard, strong wallaba for special applications. These, in turn, may give way to reinforced concrete, steel, and aluminum alloys. Experimentation continues with poles made of other suitable materials.

Conductors, originally always made of copper, now also include those made of aluminum and copper-clad steel; during World War II, steel and silver were also used to replace scarce materials needed for the war effort. More recently, experimental conductors made of sodium and other materials have been installed for test purposes.

Porcelain insulators, originally made in one piece and almost exclusively used, are now also made as modular suspension-type units capable of being added together to accommodate almost any voltage. Glass and Pyrex have also been used extensively, while work now progresses with insulators made of plastic compounds.

Similarly, rubber insulation for cables, the initial material almost solely used, with limited ability to withstand higher voltages as well as age, has given way for the higher voltage ratings to varnished cambric, oil-impregnated paper, and plastic compounds. Research, which has extended the use of plastic compounds to voltages in the 138-kV category, continues.

Transformers have become smaller and more efficient, as well as less costly. New forms and kinds of steel cores have materially reduced magnetizing losses, while new types of insulation have not only affected their life spans, but noticeably increased their capacity size for size. Further, associated protective devices are now included within the same enclosure, making for improved appearance, easier handling, and better coordination of such devices. For some smaller sizes, epoxy-encapsulated units to replace oil-filled tanked transformers are in widespread use. Research continues for better cores and insulation.

Secondary mains have been streamlined into cabled conductors, or completely eliminated; and fewer cross arms are being installed in many areas. Capacitors have been applied to improve voltage and reduce losses, complementing or supplanting voltage regulators. Mechanical connectors have almost completely replaced manually constructed splices; better electrical contacts result as well as more uniform, safer, and more easily made installations. Street lighting now employs photoelectric cell-actuated relays for control.

Underground cables, formerly using lead almost exclusively for waterproof sheathing, now employ plastic compound coverings for that purpose as well as for insulation. Fiber, tile, wood, concrete, steel, and asbestos-based and plastic ducts are, in many cases, dispensed with and cables buried directly in the ground.

Sufficient examples have been cited to indicate changes and progress in the development of materials, methods, and equipment. The greatest development, however, has been in the realm of standardization, notably in transformer ratings, voltages, types, etc., but extending also to poles, conductors, fuses, and almost every element of electric distribution systems.

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Concurrent with progress in the development of the several elements making up the electrical distribution system has been the improvement in means of transportation, communication, and tools and equipment.

The horse-drawn truck has been replaced by specially designed and constructed vehicles powered by internal combustion engines capable of speeds limited only by safety considerations and local speed laws. Messenger, mail, and telegraph services have been replaced by telephones, to which later were added shortwave two-way mobile radio units, making for very rapid communication with personnel and crews in the field. More recently, such radio and telephone communications have included the installation of cathode ray tubes (CRTs) in both field vehicles and operating offices, made possible by developments in electronics and miniaturization. These enable data recorded in the computer to be made almost instantly available to those people.

Bucket-type line trucks are making the lineman's work safer and easier. Vibrating plows and horizontal boring machines make possible the relatively deep burial of cable; in many instances, this is accomplished by one unit in one operation. These developments represent significant factors in preventing or holding down the duration of interruptions and other contingencies, resulting in overall greater reliability of electric service.

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Despite some prevailing views, distribution engineers have always been conscious of appearance and other environmental factors. It is true that a pole line can really look beautiful only to distribution engineers, though it must never be forgotten that the use of such construction made possible the rather inexpensive supply of electric energy to almost everyone, not only in this country, but in most other countries as well.

It is equally true, however, that the distribution engineer has given recognition to those environmental factors even earlier than recent local ordinances would suggest.

Designs were adopted in many cases that attempted to make the appearance of such lines less obtrusive. From locations in the street, many were placed out of sight along rear property lines. The shapes, sizes, and color of poles were designed to be more pleasing to the eye, and their numbers, as well as the number of prominent cross arms, were reduced as much as practical. Often such lines were built through trees, even though continual tree trimming and the use of covered and insulated conductors resulted in additional expense. Agreements were reached to place power, communication, and other facilities on a common pole line to avoid cluttering the landscape with too many pole lines. In many cases, facilities were placed underground at much greater cost to allay objections in certain particular areas. All of these were done in the interest of better public relations, all without benefit of a host of rules and regulations.

Changes in labor practices have also greatly influenced the design of distribution systems (as well as other utility operations). Where in earlier days (the 1920s) the labor component of an installation accounted for only some 20 (or less) percent compared to 80 percent for material, today that ratio has been reversed with labor constituting some 80 percent of the cost and material only 20 percent. Thus in designing an economical distribution system, the engineer could now make more ample use of material, e.g., by calling for larger-size conductors, insulators, transformers, and other components. The net result is a more reliable system requiring fewer emergency operations because of overloads, installations generally providing for larger (and longer) future demands, and a reduction in losses on such systems.

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The problem of losses in the distribution system assumes greater importance with the price of fuels no longer a relatively minor factor in the supply of electric energy. It is difficult to measure the actual energy losses in such a system, as many other factors are included in the difference between the energy consumed by each of the consumers connected to it and the energy sent out by the power plant. Educated estimates, however, place these losses at from 10 to 20 percent of the energy sent out.

Since the losses, in general, vary with the square of the current flowing through the conductors, whether in a line or in electrical equipment, holding down the value of such current will reduce losses. Many means have been employed to achieve this, the principal one being that of raising the voltages of circuits, thereby reducing current values for given loads. Increasing conductor sizes and shortening circuit lengths, by reducing resistance values, have also been employed. In alternating current systems, the installation of capacitors at strategic locations, by improving the power factor and thereby reducing the current flow for given loads, has also been used.

Since current flow is a measurement of the demand for electric energy by a consumer, efforts have been directed toward holding down the *demand* for electricity by attempting to even out more uniformly the consumption of energy. This has been termed *energy management*. Devices, mostly electronically controlled, cut off and on electric supply to the various loads and appliances connected to separate circuits, so that while the same end results are accomplished, peaks and valleys are reduced and load curves tend toward a continuously uniform flow. Special metering arrangements and rate schedules are provided to encourage and police such arrangements. Designs of distribution systems can also contribute to the realization of this goal.

In addition, the reduction of demands and currents can also result in the same facilities' carrying greater amounts of energy, delaying, if not making unnecessary, additional installations of power generating and transmission facilities (including substations), as well as of distribution facilities. This can have important impacts on the financial requirements of a utility.

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Many of the features described for improving the quality of electric service as well as for reducing losses lend themselves to automatic operation of the distribution systems. Advances in electronics and miniaturization (much of it fallout from the space program) now make such controls feasible, both technically and economically. A simple example is the control of street lighting through relays actuated by photoelectric cells. Instead of being turned on and off on some time schedule, streetlights are permitted by such relays to operate when they are needed because of darkness. Not only are circuits simplified and a smaller investment made, but losses can be minimized and better public relations achieved.

Through other types of electronically controlled relays, switches can be remotely operated automatically (opened and closed) as desired, capacitors switched on and off, loads divided more equitably between circuits as demands vary, and, during contingencies, emergency switching-off of faulted portions and re-energization of unfaulted portions from other sources accomplished quickly and automatically without manual intervention.

Remote reading and billing of consumer meter readings has been in the experimental stage for some time. Moreover, more rapid and positive operation of relays that can accommodate more sensitive settings can result in substantial savings in the installation of protective and control equipment.

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There are many other factors that influence the design, construction, and operation of distribution systems, many not of a technical