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Designing medium-voltage electrical systems

Engineers should know how nominal system voltages were established, what constitutes a medium-voltage electrical system, and what range of systems are considered appropriate for medium voltage.

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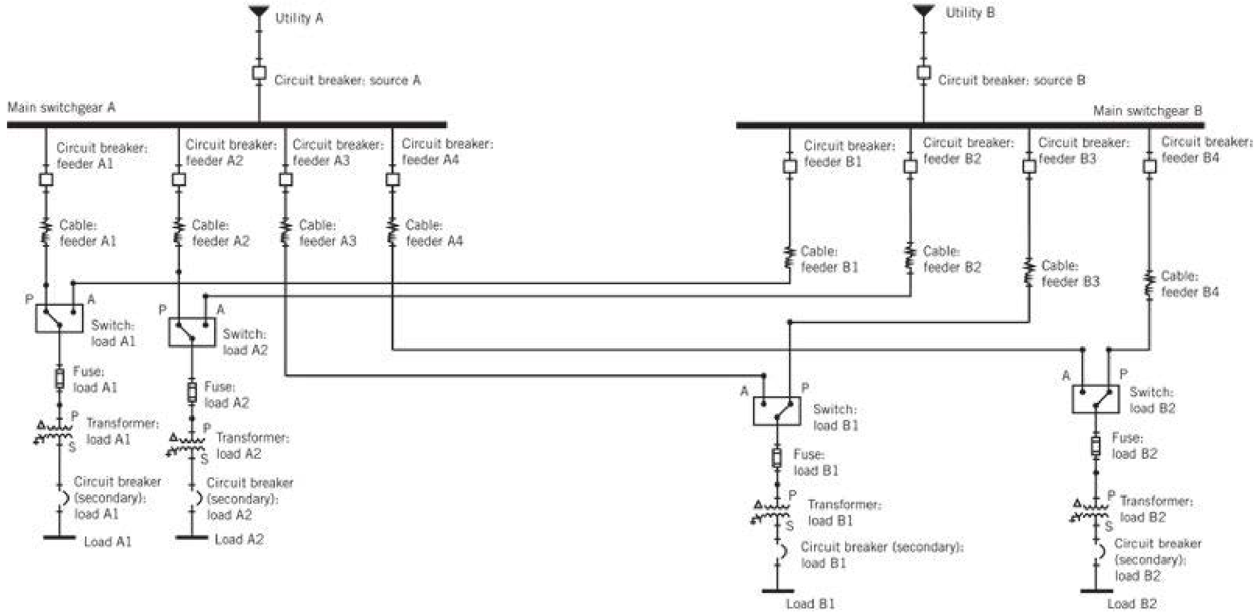
Learning objectives

- Analyze how and why a certain medium-voltage (MV) system is chosen for a given design.
- Assess the applicable codes and standards and how they affect the design of electrical systems.
- Recall what to consider when designing MV power distribution systems.

PEER REVIEWED

We are used to viewing electrical power just like any other utility delivered to our home or business. And that is the right way to look at it. Just like water and natural gas, electrical power is transmitted and distributed for general use. Just as pressure (or the pressure difference between two points) moves water and gas, voltage "moves" electrical current. For electrical power to be delivered to end users, it must go through a few iterations.



Sources, distribution of electrical power

Electrical power is produced using magnetic and kinetic energy. When a magnetic field created by permanent magnets is interrupted by a moving coil, electrical current is induced into that coil. This process is how most electrical energy is produced today. For example, a nuclear plant uses nuclear energy to produce high-pressure steam that moves the blades of a turbine. This movement is then transmitted to the turbine's rotor. The magnetic field of the generator connected to the shaft of the turbine is used by the moving rotor to create electric current in the armature winding. Coal plants also use the heat of the burning coal to create steam and produce energy through the steam turbine, but with much less efficiency than nuclear plants. A hydroelectric plant uses the potential energy of falling water to move the turbine blades. Similarly, a wind turbine uses the kinetic energy of the wind to rotate the blades. Solar cell plants do not use a turbine, but they use the energy of the sun to stimulate the electrons of the specially made photovoltaic modules, thereby creating direct current (dc). This dc is then converted to alternating current (ac) via inverters.

Even though there are so many sources of energy that can be converted to electrical power, it is not practical and often not feasible to build a power plant everywhere power is needed. To overcome this challenge, electrical power is transmitted from the source to where it is needed. To transition from utility transmission lines to the end user, utility companies use power substations. These substations reduce the transmission-level voltage to a distribution-level voltage. From these substations—called utility substations—power is delivered (distributed) to residential, commercial, and industrial users.

Types of current

Electrical power can be transmitted via dc or ac. The first power station was Pearl Street Station (built by the Edison Illuminating Co., which was headed by Thomas Edison) in New York City. This station delivered dc power to customers in the vicinity of the station. However, the problem with dc is that it can't be transported long distances because it can't be transformed to higher voltages. Nikola Tesla was convinced that the way to overcome the distance barrier was to alternate and

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then transmit the power at higher voltages using transformers. Westinghouse patented Tesla's idea and built the first ac transmission line in New York State, transporting power from Niagara Falls to Buffalo. Today's technological advances make it possible to transmit dc at high voltage economically—and that could very well be the way of the future.

The first ac-power transmission line was built in 1886 in Cerchi, Italy, which transmitted for 17 miles at 2,000 V. To avoid the high cost of conductors needed to transmit high current and the losses associated with high current flow, higher voltage transmission lines were developed. In 1936, a 287-kV transmission line was put in place in the U.S.: The Hoover Dam to Los Angeles line. Currently in the United States, voltages as high as 345 kV are commonly used for transmitting power. Using higher voltages is possible, but careful analyses are done on the economics because the price of the equipment increases substantially when going to a higher voltage level.

Voltage levels

There are several reasons to choose one voltage level over another for electrical transmission. A major reason is the cost. With higher voltage comes less copper for wiring, but more money for electrical equipment—it's a balancing act. Another reason is the length of the lines. For longer power lines, it makes sense to use higher voltages, but that comes with greater wire spacing. Often, the decision is affected by the existing transmission lines in the specific area. Using the same voltage system makes it easier to interconnect different lines into a grid, and that could make a certain voltage level very attractive, even if immediate costs are higher.

Voltage levels have been standardized so that manufacturers can concentrate on developing certain types of equipment. ANSI C84.1 defines medium voltage (MV) as being "a class of nominal system voltages greater than 1,000 V and less than 100 kV." IEEE 141 (the Red Book) references ANSI C84.1 in recognizing the same voltage levels associated with the MV range. Of all the possibilities of voltage levels between 1 kV and 100 kV, the standard voltages most often used in the United States are 4,160 V, 12,470 V, 13,200 V, 13,800 V, 24,940 V, and 34,500 V for four-wire systems and 69,000 V for three-wire systems. Other voltage systems also are used, such as 2,400 V, 4,800 V, 6,900 V, 8,320 V, 12,000 V, 20,780 V, 22,860 V, 23,000 V, and 46,000 V. Certain voltages, such as 4.1 kV, 6.9 kV, and 13.8 kV, coincide with standard motor voltages, therefore, they are preferred.

Depending on the size of the campus, the end user will have to choose what level of voltage to distribute the power. When choosing the level of voltage, several decisions must be made. Besides the cost of the project, one of the most important aspects is safety. Years ago, electricians routinely worked on energized equipment, and not only low-voltage (LV; 1,000 V or less) equipment but also on MV equipment. This practice has been very much limited because it is very dangerous. Where maintenance activity is still performed on energized gear, safety is the primary concern. To address safety, NFPA: National Electrical Code (NEC) Article 110: Requirements for Electrical Installations, requires certain working space clearances around the electrical equipment—the higher the nominal voltage, the greater the required clearance. Equipment maintenance is another factor when deciding the electrical system voltage level. If the maintenance team is already trained in certain voltage-type equipment, it makes sense to continue using that same voltage level. Otherwise, additional training will be necessary.

Using an MV distribution system has several advantages as compared with LV distribution. Voltage and current have an inverse relationship. Given a certain demand for power, the higher the voltage, the lower the current, based on the equation:

$$P = V \times I$$

Where P = power, V = voltage, and I = current.

Sometimes the distance is not the issue, but rather, the amount of power to be distributed. Residential buildings do not have a great need for power, so the use of LV suits them well. But commercial clients routinely ask for great amounts of power. Assume that a certain client needs 10 MW of power (or 12 MVA). If distributing this power at LV (480 V, for example), the facility would need to accommodate almost 14,450 amps. That's an enormous amount of current, which requires an enormous amount of wiring. In comparison, the same 12 MVA would only produce about 500 amps at 13.8 kV. This lower-current solution gives the owner the flexibility of delivering the power through the building as close to the load as possible and then stepping the power down to LV for consumption. Choosing to distribute the electrical power via MV also helps minimize power losses, which adds to operation savings.The inverse is true as well: the lower the voltage, the higher the current. The MV system delivers the same power quantity via a smaller amount of current in comparison with LV. A lower amount of current affords smaller conductors and/or fewer sets of conductors to distribute the power, which results in significant savings. Lower current levels also result in lower power losses, and as a consequence, lower voltage drop. Lower voltage drop makes power distribution to greater distances possible. It is very common for a campus arrangement to have a 13.8-kV distribution system with the voltage step-down to 480 V at the building and 4,160 V and 480 V at the central utility building. If the distances from the main utility substation of the campus to the individual buildings are great, higher voltages could be used, but the 13.8-kV distribution system is very common. Other common voltages are 12.47 kV, 24 kV, and 24.9 kV (nominally 25 kV).

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Gary , MN, United States, 07/21/16 11:34 AM:

I would be interested in hearing Mr. Pacuku's comments on protection strategy for emergency generators vs. normal power portions of a medium voltage system. It seems to me there should be two different strategies, since the normal power is always on; and the generators nearly never run, and have different characteristics than a utility-powered service.

Anonymous , 08/02/16 12:50 PM:

Well thought out and explained .

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