Electrical Tech Note — 225B

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Electric Power Transmission & Distribution

Electrical power is generated as 60 Hz alternating current (60 cycles per second) at multiple locations around the country and a delivery system is needed to transport this power from the generation facilities to communities where it can be distributed to customers. An electrical *transmission system* like a super highway moves bulk power from the generating plants to the points of distribution. Transmission systems across North America are interconnected to form a ***power grid*** to allow utilities to buy and sell electrical power. If a power plant is taken out of service at one utility that utility can purchase power from another supplier who has excess capacity available. The transmission system is used to transport that bulk electrical power. *Distribution lines are used to deliver power to customers*. Distribution lines get their power from the transmission system or sometimes from local generating facilities. Distribution systems operate at lower voltages than the transmission system. Transformers are used to change the voltage. *These transformers are placed in small areas within a chain-link fence with other control equipment.* These facilities are called ***substations***.

Transmission System: Transmission lines operate at very high voltage and are usually run overhead supported on tall poles or steel structures. A transmission line is shown in *Figure 225.1.* The amount of electrical power to be transported is proportional to the voltage times the current. The transmission wire size must be adequate to carry the current. Current is the quantity that limits the capacity of the transmission line. By *increasing the operating voltage of the transmission line, more electrical energy can be delivered with minimal loss of power by reducing the level of current to deliver the power.*

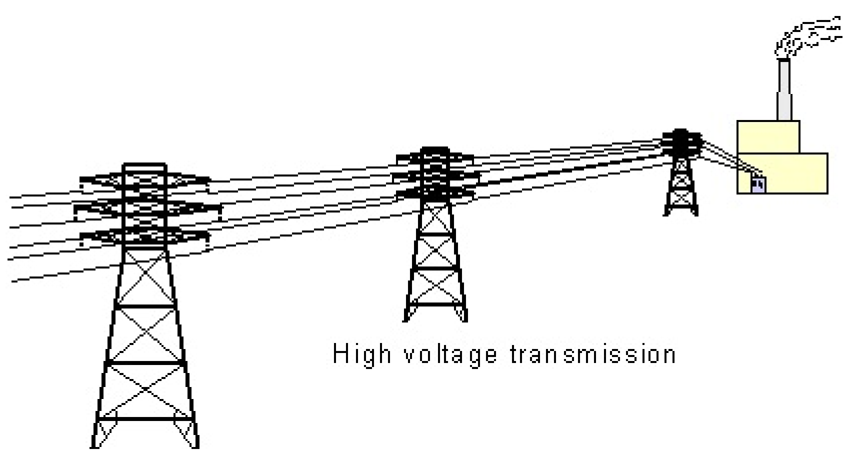

Figure 225.1 *High voltage transmission lines are necessary to transport large quantities of bulk electrical power from the power plants to points of use with minimal current and power losses.*

The following example illustrates the need for high voltage for electrical power transmission. Assume that a small community has 100 homes each drawing 50 amperes at 240 volts at the same time. The total current being drawn by the homes is 5000 amperes at 240 volts. If these homes are supplied by a single-phase distribution line operating at 7200 volts, the current flow on the distribution line to supply these homes will be 167 amperes. If power is delivered to this community by a 365,000 volt transmission line, the transmission line current required to supply the homes will only be 3.3 amperes. *It is necessary to increase the voltage of the utility electrical lines to lower the current to deliver power over long distances without excessive losses*.

When electrical power is transported, losses will occur as the current flow experiences the resistance of the wires. By increasing the voltage, the same amount of power can be delivered by the line with less current and lower losses. The fact is that transmission systems must operate at high voltage in order to effectively transport electrical power long distances between power plants sometimes located in adjacent states. Most transmission lines operate as 3-phase alternating current lines. These lines have three sets of circuit conductors. Some transmission lines in North America operate at up to 765,000 volts. There are a number of direct current transmission lines operating in North America and they may operate at as high as one million volts. Direct current transmission lines have two conductors, one with a positive voltage and one with a negative voltage. *The advantage of direct current transmission over alternating current lines is lower losses*. *Underground transmission lines* are used, but construction costs are usually higher. Underground transmission lines are generally limited to congested urban areas with limited space. Maintenance and repairs are usually more difficult with underground lines

Concerns About Transmission Lines: One concern about overhead transmission lines is their unsightliness. Another concern is whether there are health effects. High voltage transmission lines produce *electric fields*, and *magnetic fields* close to the lines. Research has not shown any adverse effects to humans, plants or animals. *High voltages will cause the breakdown of air molecules near the insulators resulting in charged particles called ions. This phenomenon is called* ***corona*** which is harmless. Audible noise from corona generally increases in wet weather. See *Tech Note 229* for an explanation of electric fields and magnetic fields near transmission lines.

Distribution Lines: Transmission system high voltage is reduced by transformers at a ***substation*** for distribution to customers. A *substation* may have from one to several distribution circuits serving customers. Most distribution circuits from a *substation* start out as 3-phase circuits usually with three high voltage wires and a neutral wire grounded to the earth. One high voltage wire and a grounded neutral wire are needed to supply single-phase 120/240 volt power to customers such as dwellings and businesses. Three wires or four wires of a distribution line are needed for 3-phase power. Single-phase power requires two wires.There are some distribution lines that do not have a grounded neutral wire.

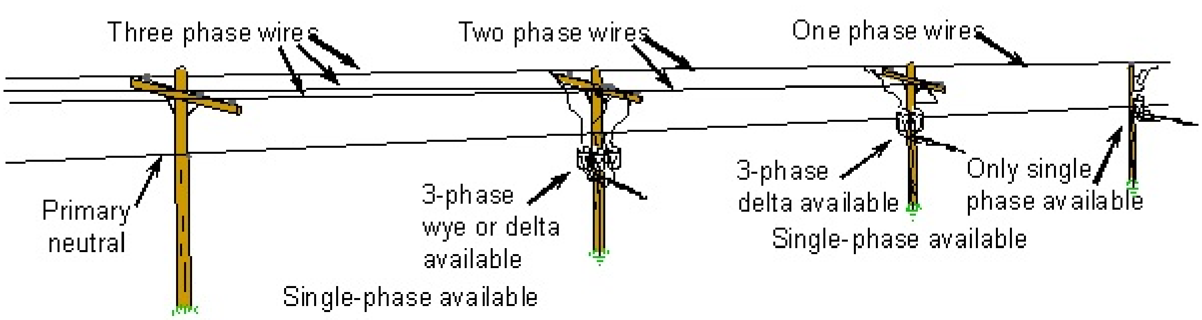

Figure 225.2 *A multi-grounded primary distribution line can have up to three phase wires and one grounded neutral wire. Some only have one phase wire and the grounded neutral wire.*

Electrical Substations: An electrical substation is shown in *Figure 225.3* which serves as a connection between a transmission line and distribution lines that deliver power to customers. The transformer in a typical substation in the Eastern U.S. has three windings connected in a radial manner called a wye configuration. The common point where the three windings are joined is connected *to the earth usually by ground rods and bare copper wires in the earth beneath the substation*. A typical 3-phase circuit leaves the substation consisting of four wires. One wire connects to the end of each transformer winding (three wires total) and the fourth wire (neutral) connects to the common point and ground rods beneath the substation. *This neutral wire is frequently connected to the earth with grounding rods along the distribution line*. This grounding can provide safety from storm damage and also acts to reduce the effects of lightning striking near the line. Under normal distribution line operation this grounding to earth will allow a small amount of power line neutral current to flow through the earth back to the substation

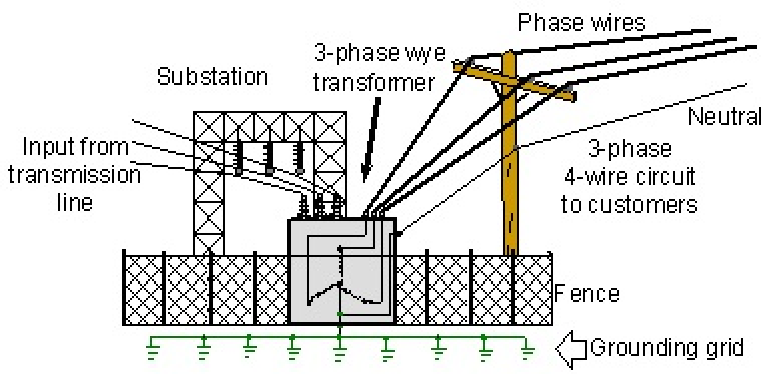

Figure 225.3 *Simplified diagram of a distribution substation with a wye connected transformer lowering the transmission voltage to a typical distribution voltage. One 4-wire circuit with a grounded neutral wire is shown leaving the substation along with three high voltage wires..*

The circuit wires leaving the substation are frequently called primary wires. They connect to the primary side of the customer transformer. Most residential and many farm and small commercial customers only use single-phase power. It takes one transformer with one wire connected to the primary neutral and one wire connected to a primary high voltae wire to supply single-phase power to a customer as shown in *Figure 225.4*.

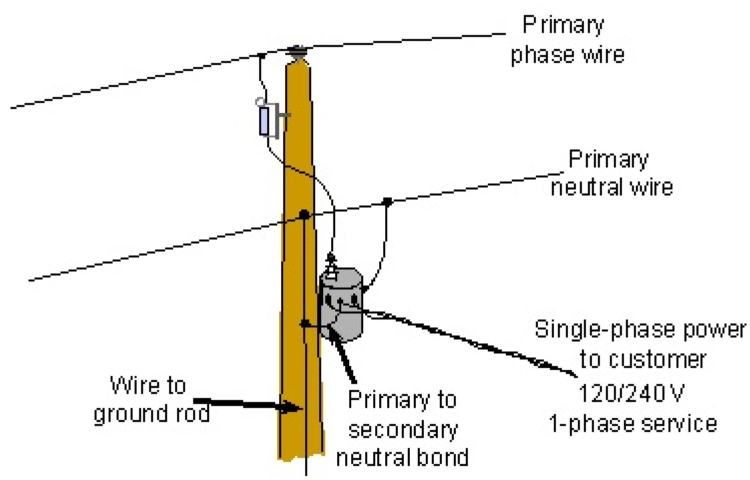

Figure 225.4 *One high voltage wire and a grounded neutral wire provide single-phase power to a customer.*

Typical 3-phase power provided to a customer requires three high voltage wires and a grounded neutral wire from the distribution line. If mounted on a pole three transformers are required. The transformers can be connected in a 3-phase four wire "wye" configuration or they can be connected in a 3-phase "delta" configuration which may or may not require the grounded neutral wire. To provide a customer with 3-phase 4-wire wye power at 480/277 volts or at 208/120 volts requires all four of the distribution line wires as shown in *Figure 225.5*.

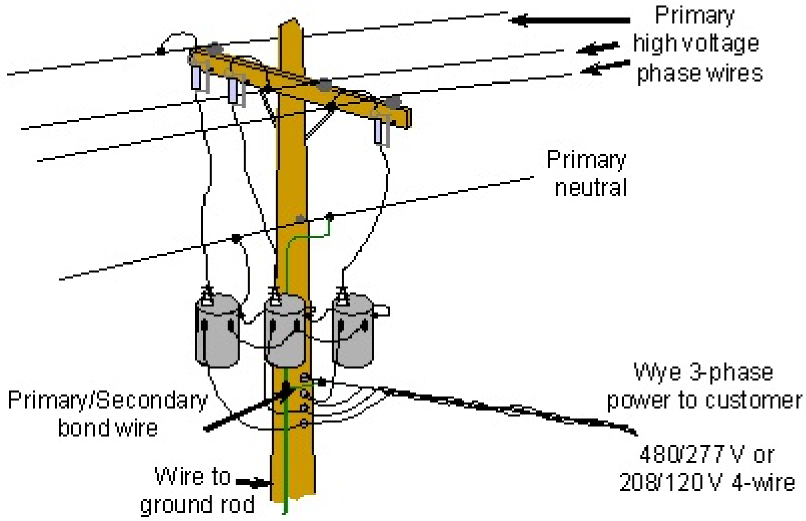

Figure 225.5 *Power for a customer requiring 3-phase wye power requires three transformers and all four distribution line wires. Delta power at 240/120 V or 480/240 V can also be provided.*

Three-phase power can be provided to a customer even if there are only two high voltage phase wires and the grounded neutral wire, but power can only be provided as a delta 3-phase configuration to the customer. For this type of connection only two transformers are needed. This type of service is called an ***open delta*** to the customer because it uses two transformers instead of three transformers.

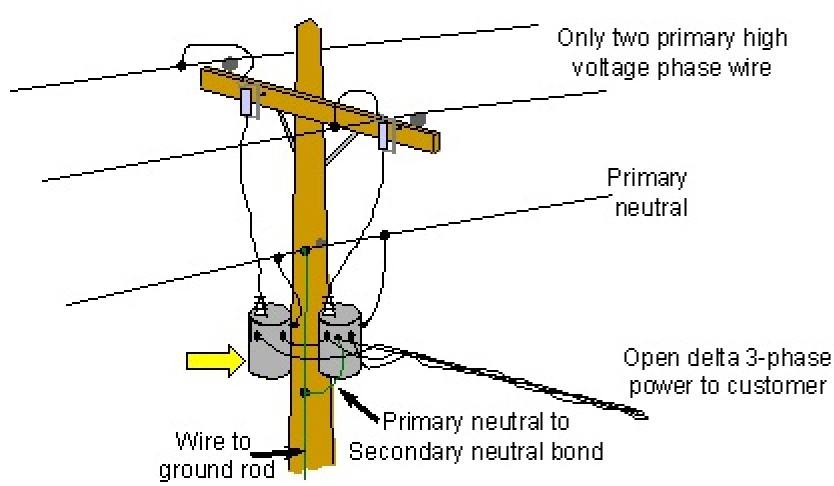

Figure 225.6 *If only two high voltage primary wires and the grounded neutral wire are available at a location 3-phase power is also available but using the delta configuration.*

The *National Electrical Safety Code* which is used as a construction guideline for utilities requires the primary neutral wire to be grounded a minimum of *four times per mile*. In most cases these grounds are at customer transformers, but sometimes a ground is placed at a pole without a transformer. *This is called a multi-grounded, 4-wire, wye primary distribution line.*

Earth Current: When power distribution lines are supplied by a grounded wye substation transformer there are three high voltage distribution lines and a one grounded neutral line supplying power to customers. *At every customer transformer installation the neutral wire is grounded to the earth*. This grounding of the neutral wire helps provide maximum electrical safety to customers from lightning and other issues that may cause damage to the primary electrical line. But the connections between the neutral wire and the earth cause the earth to become a parallel path for neutral current that flows back to the substation. This small earth current can create what is known as neutral-to-earth voltage at a customer's property. To learn more about this issue refer to *Tech Note 337* and *Tech Note 338. Figure 225.7* illustrates a section of a distribution line and shows how a small electrical neutral current can flow to the earth and flows back to the substation.

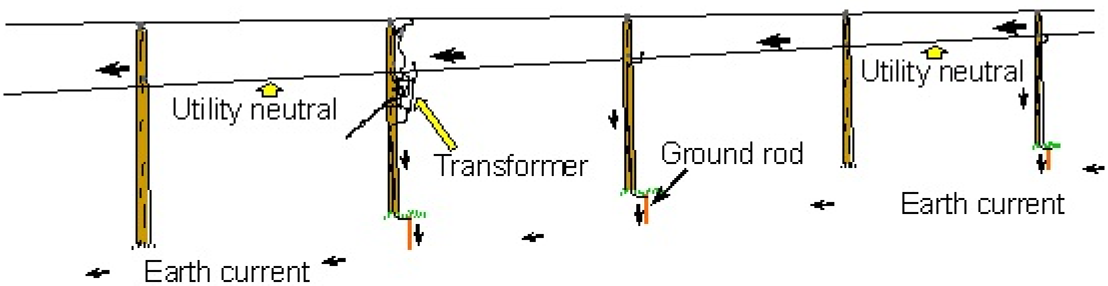

Figure 225.7 *This is a single-phase section of an electrical distribution line where the neutral wire is grounded to the earth. At each transformer location the utility neutral and the customer neutral are connected to earth and a small current can flow into the earth or from the earth to the neutral wire.*

Transformer Grounding: To protect customers from distribution line issues such as lightning, windstorm damage, or some other accidental damage, *the utility neutral wire and the customer neutral wire are connected at the utility transformer* with a connection called the primary to secondary neutral bond illustrated in *Figure 225.8.* This is a safety procedure that can be provided with a multi-grounded utility distribution line that cannot be provided by an ungrounded electrical distribution line.

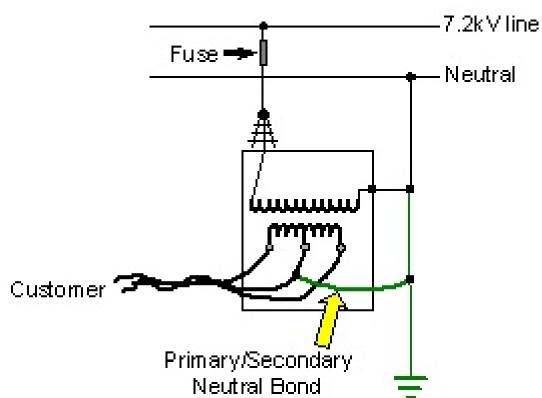

Figure 225.8 *In most cases the secondary neutral wire to the customer service is bonded with a wire to the utility primary neutral wire at the customer transformer.*

Electric Power Reliability: Electric utilities are required to have access to adequate generating capacity to provide power to customers at peak periods of electrical use. Utilities provide discount electrical rates to customers for power use during low demand periods of the day. This tends to lower peak electrical demands which helps provide economical power to all customers.

Issues can arise that make it difficult for a utility to meet the demand for power. Natural and other disasters can cause an unusual increase need for electric power or damage to the utility system which results in the inability to meet the power demand. Under these circumstances utilities must take steps to provide a continuous source to all customers. The utility may be able to purchase excess power from the "*power* grid." The utility can shut-off customer loads that by agreement are interruptible. An extreme measure is a "*brown-out*" where the *system voltage is reduced* by a small percentage. This is kind-of like adding water to the soup to be able to feed more people. If these techniques cannot keep all of the customers in power, the utility may resort to "*rolling black-outs.*" A rolling black-out is where power is shut off to an area for a specified period of time. Then that power is restored and another area is blacked-out. These are extreme measures that are seldom necessary.

Electric Utilities: In the early 1900s electric power was only available to homes and businesses in highly populated areas. It was too expensive to extend electric distribution lines out into sparsely populated rural areas. In the early years there were privately owned electric utilities, investor owned electric utilities, and municipal electric utilities. These utilities seldom extended electrical distribution lines outside of towns and cities. In 1935 the U.S. Congress passed the *Rural Electrification Act* which authorized the establishment of member owned Rural Electric Cooperatives for the purpose of extending electrical power lines out into rural areas. The Rural Electric Administration of the USDA. made low interest loans available to finance electrical line development in rural areas. By the 1940s utility electric power was available in most rural and urban areas of the U.S.

Electric utilities serving local areas take power from the transmission system or from generating facilities and distribute it to customers in that local area. These may be *investor-owned utilities, member owned rural electric cooperatives, municipal utilities, and in some cases privately owned electric utilities*. Customers such as homes, farms, commercial businesses, and small and moderate sized manufacturing companies receive their electrical power from the distribution system. Large factories and complexes such as some shopping malls use such a large amount of power they are served by a transmission line and sometimes operate and maintain their own substation.

Conclusions: Most of the electrical power is produced by large generating plants in locations often long distances from the customers to be served. A network of transmission lines is needed to transport this power to communities where it can be distributed to individual customers. Resistance of the wire is a limiting factor when moving electrical power through wires. A relationship known as Ohm's law quantifies the power loss when a high level of current flows against this wire resistance. Electrical power can be transported at a lower current if the voltage is increased resulting in a large reduction in power loss. High voltage is essential for transporting electrical power long distances.

A reliable source of electrical power to customers can be maintained when different utilities cooperate and share their facilities. Individual utility transmission lines in large regions of the country are interconnected at strategic points to form what is known as an electric ***power grid***. Utilities are constantly buying and selling electrical power to each other to maintain a reliable source of electrical power to customers .

For explanation of 3-phase wye and delta connections see *Tech Note 220.*