Introduction to AC Power Systems

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Robert Krug, P.E.

Continuing Education and Development, Inc.

P: (877) 322-5800
info@cedengineering.ca

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1. History and Importance of Reliable Electric Power

We live in times where reliable electric power is expected but few are familiar with how electricity is generated, transmitted and distributed to customers. Power systems began as a need to replace wood, coal and gas as sources of energy and light. These energy sources required local delivery of the fuel source and had emission issues on a wide scale. Gas lighting and heating were the first demonstration of a distribution system to multiple customers simultaneously.

When light bulbs were invented by Thomas Edison electric lighting proved feasible. But these bulbs needed electric current and batteries at the time were not practical. So, Edison and others invented and built direct current (DC) dynamos.

Before power distribution systems were developed only wealthy households had electric lighting as DC dynamos were installed on the property.

The dawn of power systems had begun, and Edison realized electric power could be generated, transmitted and distributed to multiple customers. He even designed an electric meter to measure and bill for his power stations and sold the bulbs. His first power stations and distribution system was built in New York City in 1882.

But a growing and dispersed population and technical issues which we will go over limited the practicality of DC transmission and distribution.

A young engineer who worked for Edison named Nickola Tesla saw the issues with DC power and made the case for alternating current (AC) that would solve most of the DC issues. A "current" war ensued between Edison and Tesla and his engineers and investors notably George Westinghouse.

AC was proven to be more effective and the grid as we know it today would be built. Today electric power is needed for our homes, smart phones, the internet, car charging stations, lighting, computers, factories, HVAC, major appliances and many more applications. How this essential energy source gets produced, transmitted and controlled will now be discussed.

2. Differences between Alternating and Direct Current

Electric power requires a current for it to be transmitted and consumed. The current requires a pressure source which is analogous to water pressure. As with water systems the source and sink must be connected. One can think of wire is analogous to pipe in water systems. Any transmission system will encounter some source of loss due to friction and heating.

To calculate power, we need to start with Ohms' law:

$$V = I * R$$

For DC the following formulas apply:

$$I = V/R$$

$$P = I * V$$

Where:

I = Current
R= Resistance
P = Power (units are watts, kw, or MW)
V= Voltage

Therefore:

$$P = I^2 * R$$

$$P = V^2 / R$$

Note that the resistance encountered is from the wires. Wire resistance increases with length so the amount of DC power will decrease the further customers are from the source. This is lost to energy conversion of electric power to heat and can be measured as $I^2 R$. Resistance is generally a fixed parameter based on cross section, material, and length. This limits DC for transmission. But looking at the above formulas, if voltage can be greatly increased and current reduced the power of transmission could be improved.

These relationships can be considered linear. This means the DC current is a constant value and power flow would be directionally from source to load, and voltage and current are always in phase.

AC is different as current is time varying and obeys a design frequency (60 Hz in the United States). Voltage and current can be out of phase. Nickola Tesla realized that these relationships could be leveraged to produce a multiphase machine that was more efficient than a DC machine.

Another difference is that AC can be converted to higher/lower voltage (and lower/higher current) efficiently. A transformer does his by utilizing coils and magnetism properties.
So, with AC it is possible to increase the voltage and decrease the current. If this is done between source and load the power transmission is more efficient and practical at the point use.

Power in DC systems is calculated:

$$\text{Power} = P = V * I = I^2 * R = V^2/R$$

In AC systems a phase angle (θ) is involved. This is the angle between the voltage and the current.

$$P = V * I * \cos\theta$$

More on this in the next section.

3. AC systems Real and Reactive Power Flow

To understand AC systems the concepts of real power flow and reactive power need to be introduced. AC devices work on the principals of capacitance, resistance and reactance. DC cannot flow through a capacitor and both reactors and capacitors introduce a phase shift between voltage and current in AC circuits.

In AC systems some of the current will be utilized for magnetic effects and the rest of the current for useful work (ex: light, heat, motion). Magnetic effects are necessary for transformers and motors to work.

The current component required for useful work is called real power.

$$\text{Real Power} = P = V * I * \cos\theta \text{ (units are kW or MW)}$$

Current used for magnetizing is called reactive power.

$$\text{Reactive Power} = Q = V * I * \sin\theta \text{ (units are kVAR or MVAR)}$$

But in AC systems equipment current carrying capability must be based on both current components.

So the concept of Apparent power (S) was introduced.

$$S= V * I^*$$

Note I* is the mathematical conjugate of current.

Apparent power can also be expressed as:

$$S= P + jQ$$

Apparent power is a complex number where the j above indicates the imaginary component Q, the units would be volt-amps but in power systems we need much larger base units namely Mega Volt*Amps (MVA). Equipment ratings are usually specified by the apparent power (MVA or kVA) capability, but amperes are used for breakers and switches.

4. Single Phase vs Three Phase Power

The design of a 2 phase AC motor came to Nikola Tesla in a vision. He used two different out of phase circuits to cause rotation in a motor. Basically, this is letting two opposite arranged magnetic poles to chase each other on a freely rotating shaft but never can catch each other so the rotation of the shaft goes on while the power is supplied. Tesla was granted the first US patent for a polyphase induction motor in 1888.

But the effect showed some pulsating motion/power so what was needed was a system where the real power would be constant while still satisfying the reactive power requirements.

It was proven that if three electromagnets were placed 120 degrees apart in construction the total instantaneous three phase real power would be constant. This is why today we transmit power with three phase power. Transmission tower space is used efficiently as three wires are mounted on one tower and in some cases 2 circuits on each side of a tower.

In three phase circuits three conductors are used one per phase and voltage between phases is called the line voltage. If voltage is measured between phase and ground, it is called the phase voltage.

They relate by:

$$V_L = \sqrt{3} * V_p$$

Where:
V_L= Line Voltage (measured in volts or kilovolts)
V_P= Phase Voltage

The total three phase power of the circuit to a balanced load would be calculated by:

$$P_{3p} = 3 * V_p * I_p * \cos\theta$$

And

$$P_{3p} = \sqrt{3} * V_L * I_L * \cos\theta$$

Where:
V_L= Line Voltage
V_P= Phase Voltage
I_L= Line Current
I_P= Phase Current
P_{3p} = Total 3 phase power

Power is measured in kilowatts or megawatts.
When specifying kV level of transmission equipment line voltages are used.

5. Power System Components

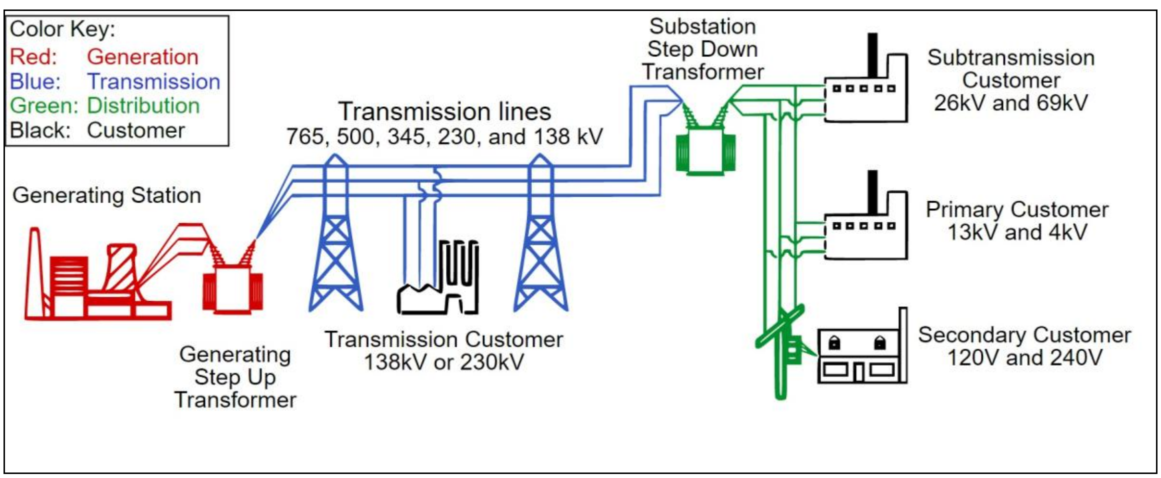
To build a power system we need a way of creating electricity through some means of generation through energy conversion, a point of use (load), means to connect the two (transmission and distribution) and a way to step up the voltage (transmission) from source and step down (distribution) at the load. The system will also need a way to protect itself from external factors and be able to be switched on and off for maintenance and when loads need to be used.

Another factor to consider is voltage control. All devices are designed to operate in some range and there are always losses in conductors so all through the system voltage must be controlled. This is done by generators, transformers with tap changers, and shunt reactors (inductors) and capacitors.

Generators can produce or absorb reactive power. Capacitors are a source of reactive power and when switched on raise voltage. Reactors absorb reactive power and lower the voltage when switched on.

Note at the point of use (distribution) in most cases it is single phase. Therefore, smaller transformers are used connected to one phase and ground or between two phases. For larger commercial or industrial loads power is supplied as three phases at higher voltages.

Below is a simplified diagram of a 3 phase system.



6. Energy Conversion and Power Generation

The first step is to produce electric power. This must be done through energy conversion. Electricity is a unique form of energy as it is not naturally occurring other than lightning which would be difficult to harness. Electricity also cannot be easily stored on a large scale.

Today electricity is produced from fossil fuels such as coal, natural gas and oil, nuclear fission, hydro and renewable resources such as solar, wind and geothermal.

For three phase AC generators, a DC magnetic field is rotated inside a core of wound coils. This is called excitation. Each coil in the stationary core will have am electro motive force (EMF) and hence produce current. The coils are positioned around the core 120 degrees apart. Each coil is wired out for the outputs.

6.1 Steam Generators

Steam generators require a heat source to convert water into steam. The heat source is a boiler using the burning of fossil fuels or the heat produced from nuclear fission or someday a fusion reaction. Fusion reactors produce no radiation but at present no suitable reactor has been developed for commercial operation.

The steam produced is piped to flow over the blades of a turbine causing it to rotate. The turbine and generator are mounted on a single shaft, so the generator armature rotates. The armature is supplied with DC from a generator or self-excitation after the generator is started. The armature coils excited by the Direct Current produce a rotating magnetic field which induces the AC in the stator coils.

Typically, large scale three phase generators produce the electric power at 13-24 kV.

Generating units can range from ten to thousands of megawatts.

Steam generators are connected to the grid and have a reserve capacity based on the inertia of the machines. If a steam generator trips off the grid its lost power output is made up by the spinning reserve of all other connected units.

6.2 Combustion Turbines

Combustion turbines (CT's) differ from steam generators in the generator shaft is spun by a diesel engine or a combustor turbine and they can be and are used for quick start.
CT's usually use Number 2 or 4 fuel oil and are typically 10-100 MW in size and generate at 4 or 13 kV.

Steam generator start times can take hours to bring on line where CT's start in minutes. They are used as peak units to supply quick power at peak load times. CT's are more expensive to run than steam units.

Special CT's called black start are installed in case the grid goes down. They are used to supply cranking power to steam units.

6.3 Hydro Power

Hydro power units utilize the flow of water to spin a turbine. They are efficient and economical to operate but limited as to where they can be sited. A dam needs to be constructed which is expensive and has environmental impact to the river and aquatic life. Another type of hydro power generation diverts the flow of a river to turbines. These are called run of river units,

Hydro units operate on the head which is the distance between the top and bottom levels of the fall of water. Some hydroelectric units can be quite large producing over 600 MW.

Another type of hydro units uses pumps to move water to a higher level at times of low electric load on the grid. When load is high the water is released to the lower level of the facility and led to spin turbines. This type of generation provides quick reserve capacity. These are called pump storage units.

6.4 Solar and Wind Power

Solar and wind are the most common forms of renewable energy. Both require site selections to take advantage of good sun exposure or reliable wind speed.
Both are built up from smaller units combined to make the total plant output.

In the case of solar energy, the sun's energy is converted to DC electricity via the photo electric effect. Panels are cascaded to build up the output. Since the output is DC, it must be converted to AC by an inverter before connection to the grid.

The other type of solar power is to use mirrors to concentrate the heat from the sun's energy to heat a focal point that is filled with a liquid to generate steam to drive a turbine.
For wind power a series of wind turbines are used to produce the output of a wind farm.

The wind blows across the turbine blades to spin a generator. The generator output is usually AC, but other devices are needed to ensure grid connection frequency and phase requirements are met.

7. Substations

Substations contain the necessary equipment to change the voltage of the generated power for transmission and distribution. Substations also contain equipment for switching and protection of the system as well as devices to regulate voltage.

Below is typical substation.

7.1 Transformers

High voltage transmission is required to bring electric power from remote locations to the load centers. When generator voltages are stepped up the current is stepped down by the inverse winding ratio of the transformer. The reduced current means the I^2R heating loss is reduced.

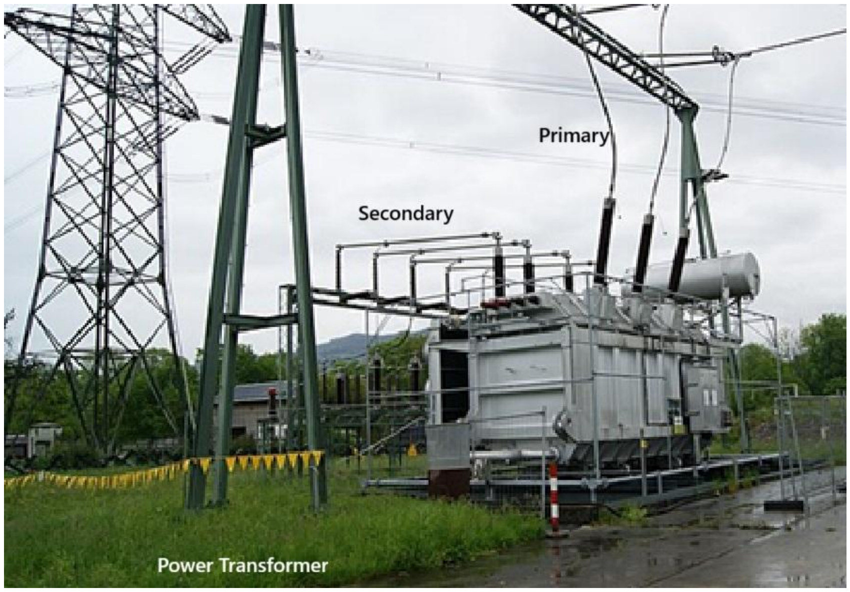
The windings are immersed in oil for cooling and insulation. Transformers generate a lot of heat and must be cooled. This is done by cooling fans and circulating the oil.

Typical transmission voltages are 115 kV, 138 kV, 230 kV, 345 kV, and 500 kV.
Once the power gets closer to the load it is stepped down by transformer to an intermediate voltage called subtransmission. Typical voltages at this level are 69 and 34 kV.

These voltages are routed to distribution substations where they are stepped down again for the level of the distribution wires on streets and neighborhoods.

Transformers are rated by their MVA or kVA capability. They usually are built as one three phase tank unit except at higher voltages where there is one tank per phase.

Transformers can be fixed ratio or load tap changing. Tap changing is used to adjust system voltages. A phase shifting transformer uses a tap changer to adjust MW flow in a networked system.



7.2 Breakers and Disconnect Switches

High and medium voltage circuit breakers are installed on the ends of connecting lines or on the primary or secondary of a transformer. They are used to switch and route power. They are operated manually or automatically.

Circuit breakers use a variety of arc extinguishing mediums such as air, vacuum, oil or SF6 gas. Circuit breakers can be one three phase tank or individual tanks per phase

Circuit breakers are open and closed automatically by a variety of protective relays. The relays use sensing devices to detect short circuits, over or under voltage, overloads and many other applications.

Substations also have a variety of disconnect switches. These are needed for equipment maintenance and safety. The difference between breakers and disconnects is disconnect switches cannot be operated underloaded.

Disconnects are usually operated manually but there are motor operated disconnects that can be operated remotely.

7.3 Ground Switches and Lightning Arrestors

Substations also have ground switches. They are used for personnel safety. Once a piece of equipment is isolated (ex: line, bus, transformer) its connections are grounded. This is to protect personnel in case equipment is accidentally energized.

Lightning arrestors are used to reduce the effects of a lighting strike. They are installed in substations and on lines to provide a path to ground for the high lightning surge current.

7.4 Capacitors and Reactors

As discussed previously reactive power is an important component in power transmission as it requires to magnetize motor type loads and help control voltage. Recall that capacitors supply reactive power and reactors consume electric power. Capacitors raise the voltage and reactors reduce it. The transformer taps do fine tuning of voltage.

Capacitor banks at substations are made of many smaller capacitor units that are connected in series and parallel to satisfy the kV level at the connection point. Each individual unit is internally fused for safety and to allow the bank to operate if one unit fails. Series capacitors are installed on some overhead transmission lines to improve system stability. System stability would be a course on its own.

Reactors are a large coil (inductor) and connected in parallel phase to ground.

Capacitors and reactors are operated by breakers.

7.5 Substation Bus

A substation bus is a heavy duty bar or wires where common connections are made. These connections are made through breakers and disconnects. Typically, 2-4 transformer secondaries need to have the power flow through routed out to 4-12 feeders.

Substations require many heavy duties steel structures to bring in and out lines and support bus equipment.

7.6 Metering Devices

Substations have many metering devices to measure MW and MVAR flow, voltage, current, transformer tap positions and frequency. These are sent to a centralized control center for monitoring and analysis. These analog values are also used as inputs to protective relays.

It is not practical to measure the high values of voltage and current in power systems so current transformers and voltage or potential transformers are used. Current transformers have ratios to step large value of current to a standard value typically 0-5 amps. Potential transformers step large values of voltage down to 120 volts.

MW and MVAR values are determined by connecting the measurement level current and voltage values to a modern smart relay or a transducer.

Breaker and switch status measurements are obtained by external contacts mounted to determine when the breaker or switch is open or closed.

Both analog and status measurements are wired to a data concentrator or remote terminal unit (RTU) and the data is sent via communications system to a centralized control center.

7.7 Batteries and Chargers

Circuit breakers are controlled by DC voltage typically 125 volts. Battery banks are installed in case the normal AC supply is lost. Chargers are installed to make sure the batteries are ready if needed.

8. Transmission

Transmission lines can be overhead or underground or a combination of both. Transmission lines must have components to insulate the conductors from each other and ground.

8.1 Overhead Transmission

Overhead transmission requires tall towers in a right of way. Towers usually support two 3 phase circuits and shield wires. The shield wires are grounded and installed above the transmission circuits to protect against lightning.

The wires are made of strands of aluminum conductor wrapped around steel carriers to hold the large weight. Since the towers are grounded the conductors must be mounted on insulators.

Overhead transmission is more economical then underground and easier to maintain and repair. But it is exposed to weather, vandalism like insulator damage from gunshots, damage from weather and corrosion and trees falling into the right of way.
Adequate ground clearance and between conductors are specified for safety and to prevent flashovers.

8.2 Underground Transmission

Underground transmission circuits are cables normally encased in steel pipes and use oil or SF6 gas for insulation. Oil insulated conductors require oil circulation and cathodic protection. There are also underground cables with solid dielectric insulation.

The underground line is usually installed in sections with concrete vault access to allow maintenance and repairs. The distance between vaults is dictated by the maximum length of cable section sold by the manufacturer. Replacing and diagnosing the sections of the line is easier and less expensive than one single line section.

Underground lines take longer to repair than overhead lines but also encouraged for aesthetics. While Underground lines are sheltered from the weather, they do suffer from accidental dig ins. Underground lines cost approximately 10 times more than overhead.

Underground cables produce a charging current from the capacitance characteristics of the cable. This causes high voltage at the end of the cable. This effect increases with voltage and distance. The increased voltage is compensated with a shunt reactor.

8.3 DC Transmission

It is sometimes desirable to control the direction of power flow. To do this DC transmission is used. To do this, inverters need to be installed at each connection point to the AC grid. The direction of power flow is accomplished by adjustment of DC voltage. Power will flow from the high voltage side to the lower voltage side.

DC transmission towers differ from AC in that they only have 1 conductor and ground return or 2 conductors per circuit one for the positive and one for the negative DC poles. AC circuits have 3 conductors, one for each phase to create a circuit.

Underground DC transmission avoids the charging and end voltage rise issues that affect underground AC transmission lines. DC underground transmission is used on long lines since the AC charging effect increases with distance.

DC transmission is used connect two systems where the frequency may be different. This is case for major and minor interconnections in the US which will be discussed later.

DC transmission lines are typically rated from 200-500 kV.

9. Types of AC loads

There are three types of electrical loads.

- Constant Power

  Constant power is the largest load type on the electric system. Constant power basically means if the voltage is increased the current will be reduced or vice versa. The most common example are electric motors designed to operate at constant speed or torque, machinery and data center UPS supplied loads.

- Constant Current

  Constant current loads draw equivalent current regardless of changes to its power supply. Constant current load examples are battery chargers, arc lamps, LED light controllers, welders, and electroplating equipment.

- Constant Impedance

  Constant impedance loads adjust their characteristics to maintain a constant impedance or admittance. Examples of constant impedance loads are incandescent lighting, heaters and electric furnaces and ovens.

Load type characteristics are important to make sure the load is supply designed, modeled and operated properly without an adverse impact on the supply system. For example, constant power motors are more efficient if shunt capacitors are located near the balance reactive power loads.

10.Distribution Systems

Once the electric power arrives from transmission or subtransmission circuits at a distribution station the voltage must be reduced and fanned out distribution feeders. Distribution feeders can be 34, 25, 13, 12 or 4kV. These are typically on poles and can be three phase or single phase circuits with a ground conductor. Distribution loads can be 3 phases or more commonly single phase. Usually, three phase is used by commercial o or industrial customers where load magnitude if higher and where more efficient 3 phase motors can be used. Single phase is used for residential customers.

Each distribution feeder is connected to the substation bus by a distribution breaker. Distribution feeders also have fuses installed at various points to isolate feeder sections. There are also several sectionalizing switches used to isolate sections. If the feeder breaker trips due to a fault (pole strike, tree limb contact, etc) the trouble can be isolated so upstream customers can be restore while repairs are made.

Distribution systems are classified as radial, network, or loop (Underground Residential Distribution).

10.1 Radial

In radial distribution the conductors are fed out from the substation down streets and loads are tapped at various customer points. At these locations distribution transformer are connected to take the primary voltage and step it down for the service entrance. The distribution feeders have 3 conductors, and each has a neutral conductor connected to ground at various points. The main trunk of the feeder need to be sized for all the connected load. As loads are tapped off smaller conductors can be used.

Where only one or two phases are required down a street the feeder will have smaller conductors.

For residential loads each distribution transformer would be connected to one phase or two phases of the distribution primary feeder. The distribution engineer’s goal is try to connect the same amount of load to each phase for the most efficient transfer of power down the line and to minimize losses. Balancing the load reduces the current in the neutral conductor and hence lowers losses.

At various point in line voltage regulators are used so voltage will stay within public service commission requirements. Voltage regulators are small tap changing transformers inserted at various points along the feeder.

Reliability of distribution feeders is improved by installing tie switches that connect 2 feeders. This way some of the load lost by a substation breaker trip can be transferred to a backup feeder. Switches are also used to isolate a section of a feeder for repairs or maintenance.

10.2 Network

In network distribution special transformers called network transformers are used to connect multiple loads to multiple feeders. This is done on the secondary of each transformer to form a grid like a city block. This improves reliability and is usually done at the 480 volt secondaries. A device called a network protector on each transformer prevents any undesirable back feed through any network transformer.

Network distribution is used for high load density areas and installed in underground vaults. The loss of a feeder does not result in any loss of load. Network distribution is very reliable as load is not lost if a supply feeder trips.

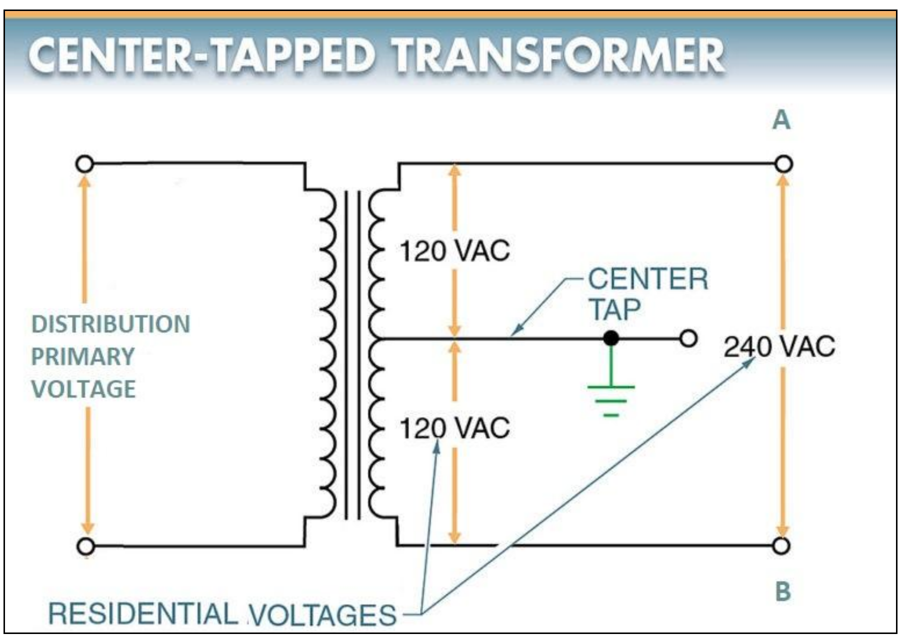
10.3 Underground Residential Distribution

Underground Residential Distribution (URD) is widely used in neighborhoods. It uses direct buried cable to supply the primary URD transformers. This type of transformer allows primary isolation or switching. URD uses two half loops with a normally open middle point. If one half loop fails it is isolated and then load can be restored from the other loop.

URD is more aesthetically pleasing and reliable. Each URD half loop is connected to one phase of the primary feeder.

10.4 Distribution Transformers

At this point we need a way to step down primary voltage to the 120/240 volt service voltage. The diagram below shows a typical distribution transformer connection.



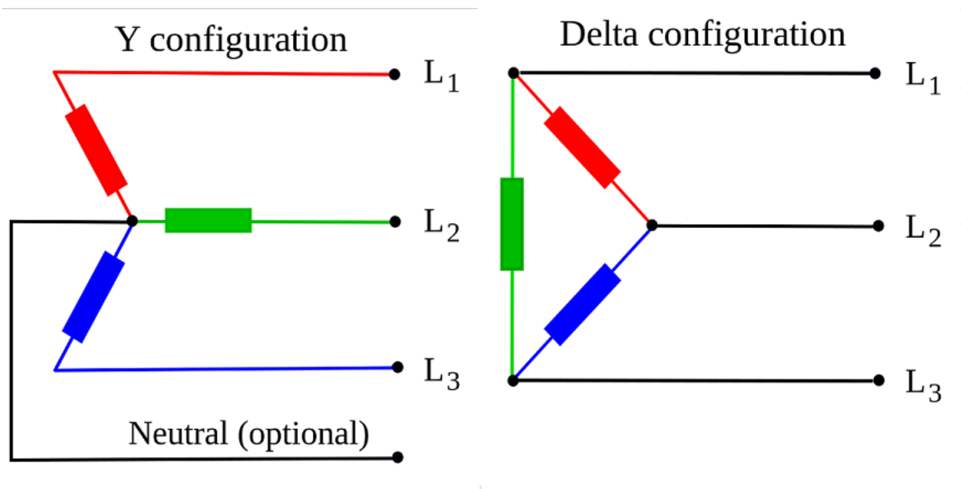
Source:
https://electricala2z.com/transformer/single-three-phase-transformer-connections/

The primary is brought in with one phase connected to primary coil and the other side of the coil to another phase or ground. For residential requirements small loads use 120 volts, and larger loads use 240 volts. The secondary coil of the distribution transformer is centered tapped and grounded. This way 240 volts are brought into the service entrance with 2 “phase” (A and B in diagram) conductors and 120 volt load can be connected between one phase and the ground.

One single phase distribution transformer typically supplies from 1 to 8 residential customers.

Below is a typical single phase, 50kVA distribution transformer. Note the primary bushing is on the top of the tank and the center tap secondary on the wide of the tank. Also, the middle connection is the center tap grounded to the tank.

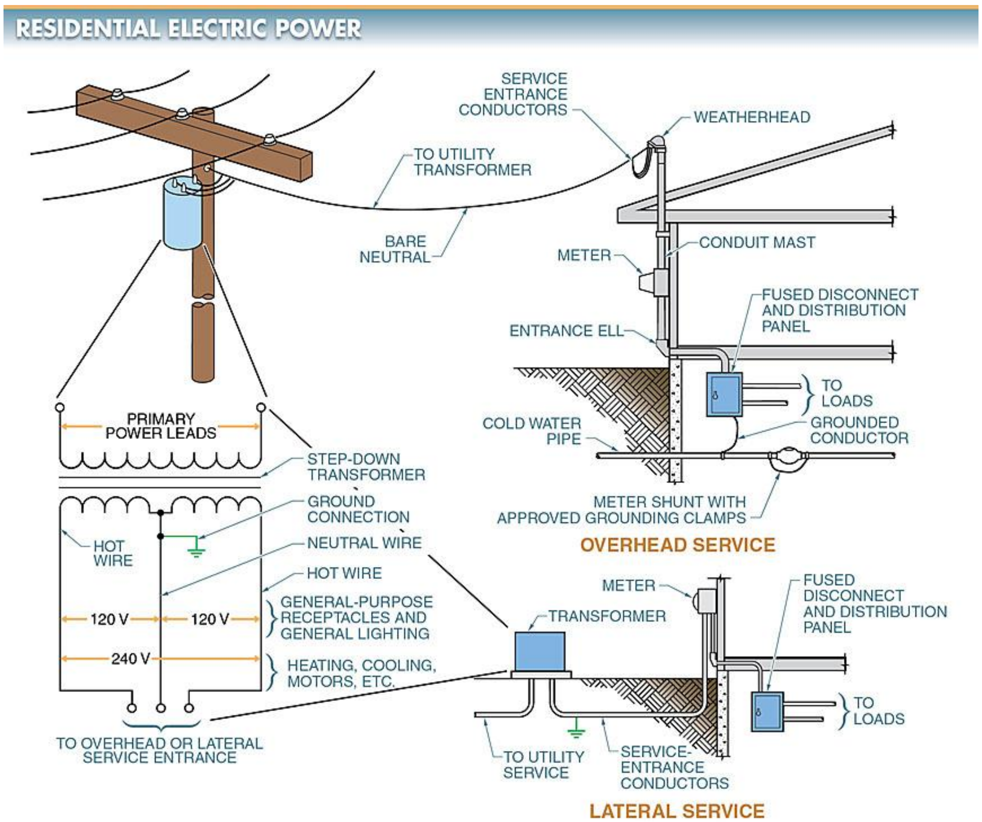
If three phase power is required 3 distribution transformers are mounted on the same pole with each of the primaries and secondaries connected in one of the two configurations (wye(Y) and delta) shown below. Other installations have a pad mounted three phase transformers. Customer voltages for three phase service are 480/277 volts.



11.Service Entrance and House Wiring

From the distribution transformer secondary two conductors and the center tap ground conductor are wired to a service entrance. Each customer usually has one service entrance.

The service entrance consists of conduit, meter, and breaker box. Refer to the diagrams below.



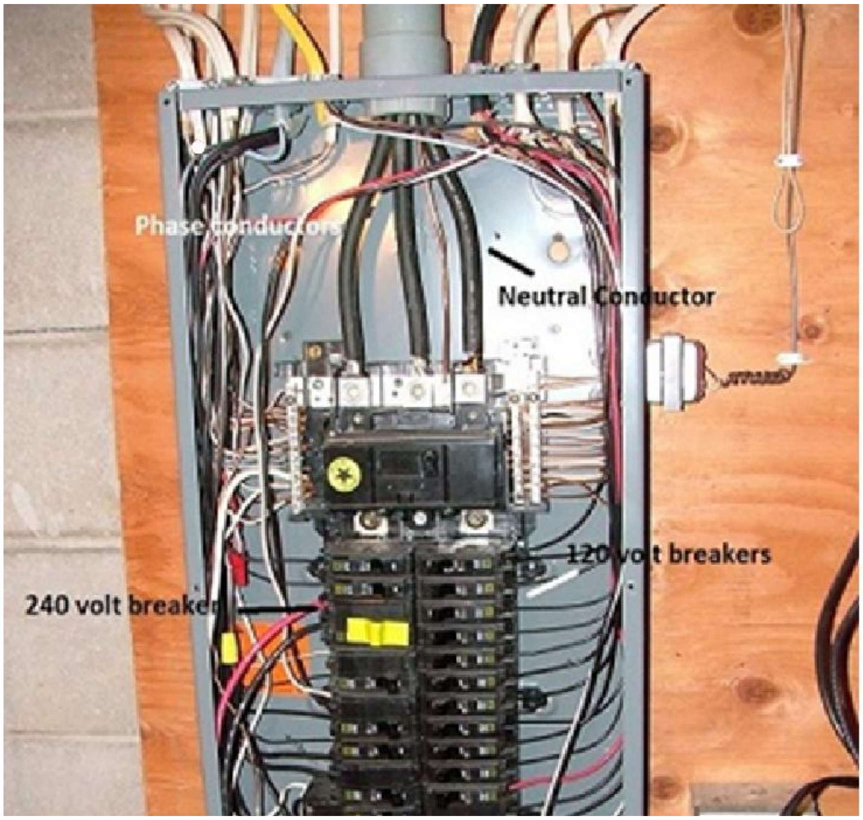
Source:
https://electricala2z.com/transformer/single-three-phase-transformer-connections/

After going through the meter the phase conductors are connected to one bus bar each and the ground/neutral is connected to a ground bus bar and to a ground source such as cold water supply pipe if copper or a copper grounding rod driven in the earth.

Single pole circuit breakers are connected to one phase bar, and the neutral bus have 120 volt house circuits connected to them to supply convenience outlets and small appliance outlets in the kitchen. The circuit breakers protect the house circuit from overloads or short circuits. They are also used for safety to open circuits for electrical wiring work.

Double pole circuit breakers connect between phase bus bars and are connected to 240 volt large appliance outlets. In the diagram below the bus bars are underneath the breakers as the breakers are snapped on to the bus bars.

There is a main disconnect just below the incoming supply conductor connections.



12.Power System Control

The unique aspect of electricity as an energy source is the generation amount must closely always match the load magnitude. This is a very complicated control problem.

Frequency is closely monitored and controlled. It is the indication of how close load and generation match. If system frequency equals 60.00 Hz load and generation are balanced. If it is greater than 60 Hz there is more generation than load. If it is less the load is greater than generation. Generating unit output is adjusted to try to bring the frequency to 60 Hz.

Power systems are interconnected for better system stability and are divided up into control areas. Interconnection also improves economics as cheaper generation is imported into an area where its units would be more expensive to operate. The interconnections are called tie lines.

Interconnection also improves stability and control as there are many generating units that ramp up or down to cover loss of generation or sudden or rapid load change. The systems schedule enough generation to cover the loss of the largest unit, typically a nuclear unit.

In the US the two major interconnected areas are the Eastern and Western interconnections generally divided by the Rocky Mountains. There is also minor interconnection, for Texas, Alaska, and Quebec. The Quebec interconnection supplies large quantities of cheap hydropower from Canada that is imported into the United States.

Control centers were built in the 1970's where computers are used for data collection and centralized control. This is called Supervisory Control and Data Acquisition (SCADA). Before this development substations were manned. The system that provides SCADA and power system computer applications is called an Energy Management System (EMS).

Substation analog and status measurements are typically scanned every 2-10 seconds on modern systems. The measurement data is stored for historical and event analysis.

A loss of a piece of equipment on the system is called a contingency. Control centers have computer applications that analyze contingency. Basically, the application uses a predetermined list of transmission and generation equipment and provides a list of overloaded equipment from a contingency. Operators may make generation adjustments or phase shifter adjustments to avoid contingency overloads or voltage issues.

There are cases where the estimated peak load cannot be met with online generation and reserves or there are localized overloads from multiple tripping of equipment. This is addressed by load shedding. Load Shed is an EMS application that will trip distribution feeder breakers to reduce system load. Load shedding can be done system wide, by areas or at a substation.

The list of loads shed feeders is predetermined and carefully planned to make sure no critical loads (ex: hospitals, police stations, etc) get shed. Load shed also rotates feeders, so no customer is out of power for more than 1-2 hours.

Voltage control is also an EMS application. Basically, each substation is monitored to see if the voltage is within a predetermine schedule plus or minus a control bandwidth. The EMS send transformer tap changer raise/lower commands or capacitor switching to ensure the voltage is within the limits. One other important function is voltage reduction.

Power companies will use voltage reduction (brownout) before shedding load. Voltage reduction is used to reduce substation voltages by 5 percent. Some loads particularly impedance type loads (ex: electrical heating) are reduced when voltage is reduced.

13.Summary

In this course the building blocks of power generation, transmission, and distribution have been discussed. Electric power needs to be produced through energy conversion. The generator output is stepped up for transmission. Transmission is stepped down at subtransmission to feed distribution stations. Distribution feeders connect to single or three phase distribution transformers. Customer loads are connected to the secondary of the distribution transformer through the house circuits protected by individual circuit breakers.

The power system must be closely monitored and controlled to avoid a blackout. Frequency must be maintained in a tight bandwidth and generator adjustments are made to keep it within these bounds. EMS applications are used to avoid equipment overloads and to control voltage.

Electrical systems were integrated to improve stability and transmit more economic generator outputs to areas with more expensive unit costs.

Diagram References: