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Three-phase electric power

Three-phase electric power is a common method of alternating current electric power generation, transmission, and distribution.[1] It is a type of polyphase system and is the most common method used by electrical grids worldwide to transfer power. It is also used to power large motors and other heavy loads.

A three-wire three-phase circuit is usually more economical than an equivalent two-wire single-phase circuit at the same line to ground voltage because it uses less conductor material to transmit a given amount of electrical power.[2] Polyphase power systems were independently invented by Galileo Ferraris, Mikhail Dolivo-Dobrovolsky, Jonas Wenström, John Hopkinson and Nikola Tesla in the late 1880s.

Three-phase transformer with four wire output for 208Y/120 volt service: one wire for neutral, others for A, B and C phases

Contents
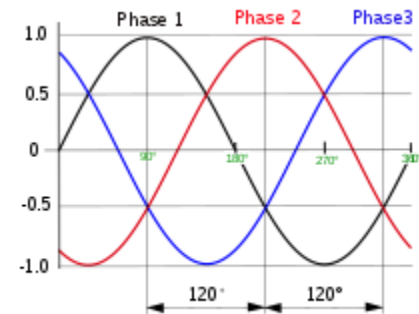
Principle

In a symmetric three-phase power supply system, three conductors each carry an alternating current of the same frequency and voltage amplitude relative to a common reference but with a phase difference of one third of a cycle between each. The common reference is usually connected to ground and often to a current-carrying conductor called the neutral. Due to the phase difference, the voltage on any conductor reaches its peak at one third of a cycle after one of the other conductors and one third of a cycle before the remaining conductor. This phase delay gives constant power transfer to a balanced linear load. It also makes it possible to produce a rotating magnetic field in an electric motor and generate other phase arrangements using transformers (for instance, a two phase system using a Scott-T transformer). The amplitude of the voltage difference between two phases is $\sqrt{3}$ times the amplitude of the voltage of the individual phases.

Normalized waveforms of the instantaneous voltages in a three-phase system in one cycle with time increasing to the right. The phase order is 1-2-3. This cycle repeats with the frequency of the power system. Ideally, each phase's voltage, current, and power is offset from the others' by 120°.

The symmetric three-phase systems described here are simply referred to as *three-phase systems* because, although it is possible to design and implement asymmetric three-phase power systems (i.e., with unequal voltages or phase shifts), they are not used in practice because they lack the most important advantages of symmetric systems.

In a three-phase system feeding a balanced and linear load, the sum of the instantaneous currents of the three conductors is zero. In other words, the current in each conductor is equal in magnitude to the sum of the currents in the other two, but with the opposite sign. The return path for the current in any phase conductor is the other two phase conductors.

Three-phase electric power transmission lines

Advantages

As compared to a single-phase AC power supply that uses two conductors (phase and neutral), a three-phase supply with no neutral and the same phase-to-ground voltage and current capacity per phase can transmit three times as much power using just 1.5 times as many wires (i.e., three instead of two). Thus, the ratio of capacity to conductor material is doubled.[3] The ratio of capacity to conductor material increases to 3:1 with an ungrounded three-phase and center-grounded single-phase system (or 2.25:1 if both employ grounds of the same gauge as the conductors).

Three-phase transformer (Békéscsaba, Hungary): on the left are the primary wires and on the right are the secondary wires

Constant power transfer and cancelling phase currents would in theory be possible with any number (greater than one) of phases, maintaining the capacity-to-conductor material ratio that is twice that of single-phase power. However, two-phase power results in a less smooth (pulsating) torque in a generator or motor (making smooth power transfer a challenge), and more than three phases complicates infrastructure unnecessarily.[4]

Three-phase systems may also have a fourth wire, particularly in low-voltage distribution. This is the neutral wire. The neutral allows three separate single-phase supplies to be provided at a constant voltage and is commonly used for supplying groups of domestic properties which are each single-phase loads. The connections are arranged so that, as far as possible in each group, equal power is drawn from each phase. Further up the distribution system, the currents are usually well balanced. Transformers may be wired in a way that they have a four-wire secondary but a three-wire primary while allowing unbalanced loads and the associated secondary-side neutral currents.

Three-phase supplies have properties that make them very desirable in electric power distribution systems:

- The phase currents tend to cancel out one another, summing to zero in the case of a linear balanced load. This makes it possible to reduce the size of the neutral conductor because it carries little or no current. With a balanced load, all the phase conductors carry the same current and so can be the same size.
- Power transfer into a linear balanced load is constant, which helps to reduce generator and motor vibrations.
- Three-phase systems can produce a rotating magnetic field with a specified direction and constant magnitude, which simplifies the design of electric motors, as no starting circuit is required.

Most household loads are single-phase. In North American residences, three-phase power might feed a multiple-unit apartment block, but the household loads are connected only as

single phase. In lower-density areas, only a single phase might be used for distribution. Some high-power domestic appliances such as electric stoves and clothes dryers are powered by a split phase system at 240 volts or from two phases of a three phase system at 208 volts.

Phase sequence

Wiring for the three phases is typically identified by color codes which vary by country. Connection of the phases in the right order is required to ensure the intended direction of rotation of three-phase motors. For example, pumps and fans may not work in reverse. Maintaining the identity of phases is required if there is any possibility two sources can be connected at the same time; a direct interconnection between two different phases is a short-circuit.

Generation and distribution

At the power station, an electrical generator converts mechanical power into a set of three AC electric currents, one from each coil (or winding) of the generator. The windings are arranged such that the currents vary sinusoidally at the same frequency but with the peaks and troughs of their wave forms offset to provide three complementary currents with a phase separation of one-third cycle (120° or $^{2\pi}\!/_3$ radians). The generator frequency is typically 50 or 60 Hz, depending on the country.
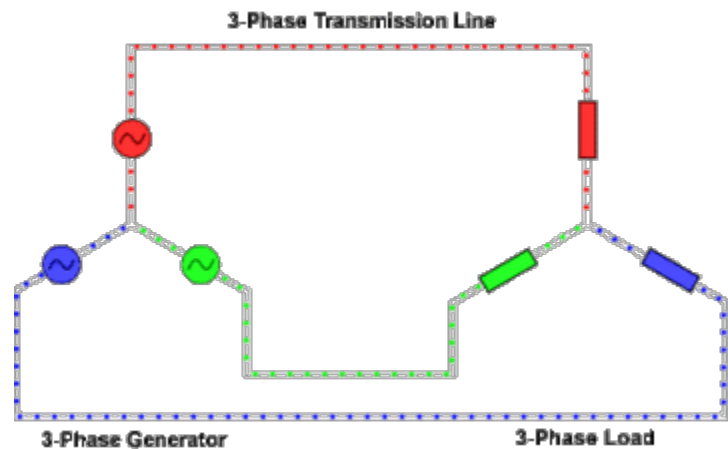
Animation of three-phase current

At the power station, transformers change the voltage from generators to a level suitable for transmission in order to minimize losses.

After further voltage conversions in the transmission network, the voltage is finally transformed to the standard utilization before power is supplied to customers.

Most automotive alternators generate three-phase AC and rectify it to DC with a diode bridge.[7]
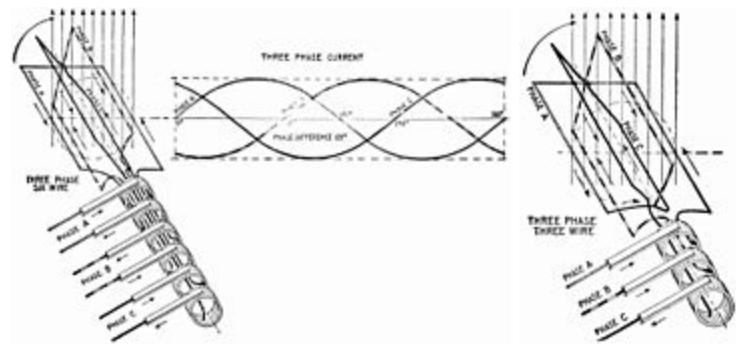
Transformer connections

A "delta" connected transformer winding is connected between phases of a three-phase system.

A "wye" transformer connects each winding from a phase wire to a common neutral point.

A single three-phase transformer can be used, or three single-phase transformers.

In an "open delta" or "V" system, only two transformers are used. A closed delta made of three single-phase transformers can operate as an open delta if one of the transformers has failed or needs to be removed.[8] In open delta, each transformer must carry current for its respective phases as well as

Left image: elementary six-wire three-phase alternator with each phase using a separate pair of transmission wires.[5] Right image: elementary three-wire three-phase alternator showing how the phases

can share only three wires.[6]

current for the third phase, therefore capacity is reduced to 87%. With one of three transformers missing and the remaining two at 87% efficiency, the capacity is 58% (⅔ of 87%).[9][10]

Where a delta-fed system must be grounded for detection of stray current to ground or protection from surge voltages, a grounding transformer (usually a zigzag transformer) may be connected to allow ground fault currents to return from any phase to ground. Another variation is a "corner grounded" delta system, which is a closed delta that is grounded at one of the junctions of transformers.[11]

Three-wire and four-wire circuits

There are two basic three-phase configurations: wye (Y) and delta (Δ). As shown in the diagram, a delta configuration requires only three wires for transmission but a wye (star) configuration may have a fourth wire. The fourth wire, if present, is provided as a neutral and is normally grounded. The "3-wire" and "4-wire" designations do not count the ground wire present above many transmission lines, which is solely for fault protection and does not carry current under normal use.

A four-wire system with symmetrical voltages between phase and neutral is obtained when the neutral is connected to the "common star point" of all supply windings. In such a system, all three phases will have the same magnitude of voltage relative to the neutral. Other non-symmetrical systems have been used.

The four-wire wye system is used when a mixture of single-phase and three-phase loads are to be served, such as mixed lighting and motor loads. An example of application is local

distribution in Europe (and elsewhere), where each customer may be only fed from one phase and the neutral (which is common to the three phases). When a group of customers sharing the neutral draw unequal phase currents, the common neutral wire carries the currents resulting from these imbalances. Electrical engineers try to design the three-phase power system for any one location so that the power drawn from each of three phases is the same, as far as possible at that site.[12] Electrical engineers also try to arrange the distribution network so the loads are balanced as much as possible, since the same principles that apply to individual premises also apply to the wide-scale distribution system power. Hence, every effort is made by supply authorities to distribute the power drawn on each of the three phases over a large number of premises so that, on average, as nearly as possible a balanced load is seen at the point of supply.

For domestic use, some countries such as the UK may supply one phase and neutral at a high current (up to 100 A) to one property, while others such as Germany may supply 3 phases and neutral to each customer, but at a lower fuse rating, typically 40–63 A per phase, and "rotated" to avoid the effect that more load tends to be put on the first phase.

In North America, a high-leg delta supply is sometimes used where one winding of a delta-connected transformer feeding the load is center-tapped and that center tap is grounded and connected as a neutral as shown in the second diagram. This setup produces three different voltages: If the voltage between the center tap (neutral) and each of the top and bottom taps (phase and anti-phase) is 120 V (100%), the voltage across the phase and anti-phase lines is 240 V (200%), and the neutral to "high leg" voltage is ≈ 208 V (173%).[8]

The reason for providing the delta connected supply is usually to power large motors requiring a rotating field. However, the premises concerned will also require the "normal" North American 120 V supplies, two of which
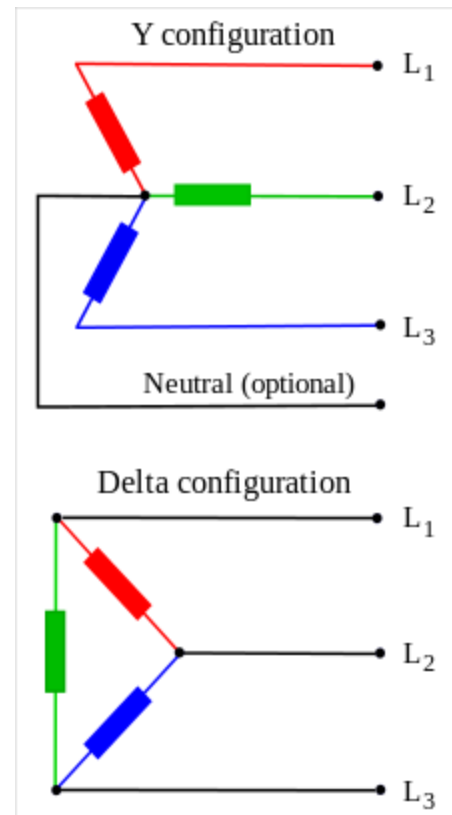
Wye (Y) and delta (Δ) circuits
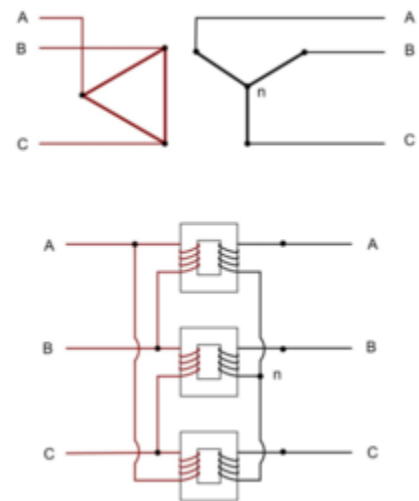
A delta-wye configuration across a transformer core (note that a practical transformer would have a different number of coils on each side).

are derived (180 degrees "out of phase") between the "neutral" and either of the center tapped phase points.

Balanced circuits

In the perfectly balanced case all three lines share equivalent loads. Examining the circuits we can derive relationships between line voltage and current, and load voltage and current for wye and delta connected loads.

In a balanced system each line will produce equal voltage magnitudes at phase angles equally spaced from each other. With V_1 as our reference and V_3 lagging V_2 lagging V_1, using angle notation, and V_{LN} the voltage between the line and the neutral we have:[13]

$$V_1 = V_{LN}\angle 0°,$$

$$V_2 = V_{LN}\angle -120°,$$

$$V_3 = V_{LN}\angle +120°.$$

These voltages feed into either a wye or delta connected load.
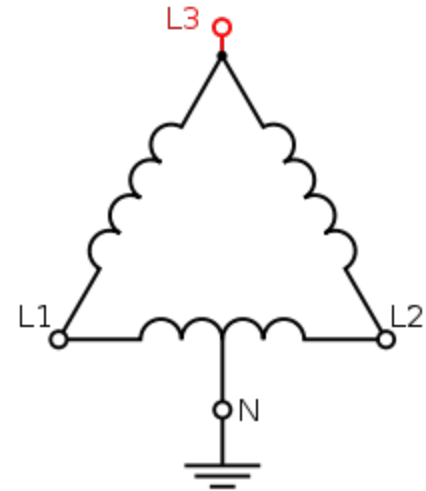
Wye (Y) also called Star

The voltage seen by the load will depend on the load connection; for the wye case, connecting each load to a phase (line-to-neutral) voltages gives:[13]

$$I_1 = \frac{V_1}{|Z_{total}|}\angle (-\theta),$$

$$I_2 = \frac{V_2}{|Z_{total}|}\angle (-120° - \theta),$$

$$I_3 = \frac{V_3}{|Z_{total}|}\angle (120° - \theta),$$

where Z_{total} is the sum of line and load impedances ($Z_{total} = Z_{LN} + Z_Y$), and θ is the phase of the total impedance (Z_{total}).

A transformer for a "high-leg delta" system used for mixed single-phase and three-phase loads on the same distribution system. Three-phase loads such as motors connect to L1, L2, and L3. Single-phase loads would be connected between L1 or L2 and neutral, or between L1 and L2. The L3 phase is 1.73 times the L1 or L2 voltage to neutral so this leg is not used for single-phase loads.
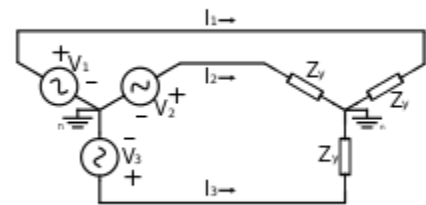
Three-phase AC generator connected as a wye or star source to a wye or star connected load

The phase angle difference between voltage and current of each phase is not necessarily 0 and is dependent on the type of load impedance, Z_y. Inductive and capacitive loads will cause current to either lag or lead the voltage. However, the relative phase angle between each pair of lines (1 to 2, 2 to 3, and 3 to 1) will still be −120°.

By applying Kirchhoff's current law (KCL) to the neutral node, the three phase currents sum to the total current in the neutral line. In the balanced case:

$$I_1 + I_2 + I_3 = I_N = 0.$$

Delta (Δ)

In the delta circuit, loads are connected across the lines, and so loads see line-to-line voltages:

$$
\begin{aligned}
V_{12} = V_1 - V_2 &= (V_{LN}\angle 0°) - (V_{LN}\angle{-}120°) \\
&= \sqrt{3}V_{LN}\angle 30° = \sqrt{3}V_1\angle(\phi_{V_1} + 30°), \\
V_{23} = V_2 - V_3 &= (V_{LN}\angle{-}120°) - (V_{LN}\angle 120°) \\
&= \sqrt{3}V_{LN}\angle{-}90° = \sqrt{3}V_2\angle(\phi_{V_2} + 30°), \\
V_{31} = V_3 - V_1 &= (V_{LN}\angle 120°) - (V_{LN}\angle 0°) \\
&= \sqrt{3}V_{LN}\angle 150° = \sqrt{3}V_3\angle(\phi_{V_3} + 30°).
\end{aligned}
$$

[13]

(Φ_{v1} is the phase shift for the first voltage, commonly taken to be 0° -- in this case Φ_{v2} = -120° and Φ_{v3} = -240° or 120°)
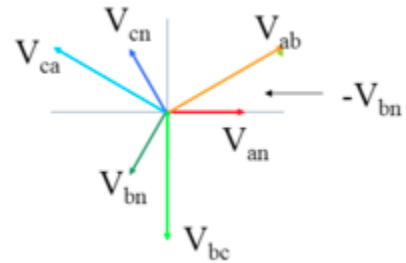
Further:

$$I_{12} = \frac{V_{12}}{|Z_\Delta|}\angle(30° - \theta),$$

$$I_{23} = \frac{V_{23}}{|Z_\Delta|}\angle(-90° - \theta),$$

$$I_{31} = \frac{V_{31}}{|Z_\Delta|}\angle(150° - \theta),$$

where θ is the phase of delta impedance (Z_Δ).

Relative angles are preserved, so I_{31} lags I_{23} lags I_{12} by 120°. Calculating line currents by using KCL at each delta node gives:
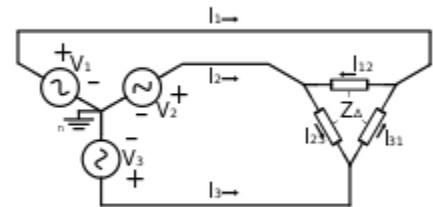
A phasor diagram for a wye configuration, in which V_{ab} represents a line voltage and V_{an} represents a phase voltage. Voltages are balanced as:

V_{ab} = (1∠α - 1∠α + 120°) $\sqrt{3}$*|V|∠α + 30°

$V_{bc} = \sqrt{3}$*|V|∠α - 90°

$V_{ca} = \sqrt{3}$*|V|∠α + 150°

(α = 0 in this case)

Three-phase AC generator connected as a wye source to a delta-connected load

$$I_1 = I_{12} - I_{31} = I_{12} - I_{12}\angle 120°$$
$$= \sqrt{3}I_{12}\angle(\phi_{I_{12}} - 30°) = \sqrt{3}I_{12}\angle(-\theta)$$
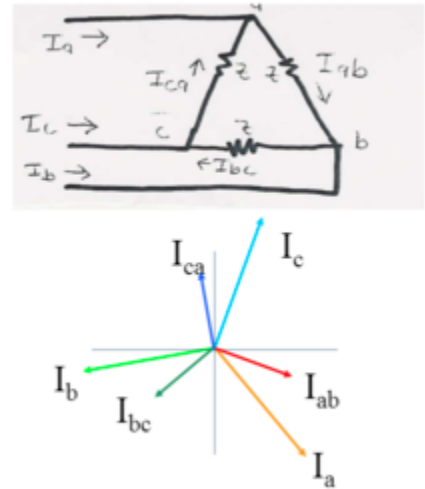
and similarly for each other line:

$$I_2 = \sqrt{3}I_{23}\angle(\phi_{I_{23}} - 30°) = \sqrt{3}I_{23}\angle(-120° - \theta),$$

$$I_3 = \sqrt{3}I_{31}\angle(\phi_{I_{31}} - 30°) = \sqrt{3}I_{31}\angle(120° - \theta),$$

where, again, θ is the phase of delta impedance (Z_Δ).

Inspection of a phasor diagram, or conversion from phasor notation to complex notation, illuminates how the difference between two line-to-neutral voltages yields a line-to-line voltage that is greater by a factor of $\sqrt{3}$. As a delta configuration connects a load across phases of a transformer, it delivers the line-to-line voltage difference, which is $\sqrt{3}$ times greater than the line-to-neutral voltage delivered to a load in the wye configuration. As the power transferred is V^2/Z, the impedance in the delta configuration must be 3 times what it would be in a wye configuration for the same power to be transferred.

A delta configuration and a corresponding phasor diagram of its currents. Phase voltages are equal to line voltages, and currents are calculated as:

$I_a = I_{ab} - I_{ca} = \sqrt{3}I_{ab}\angle$-30°

$I_b = I_{bc} - I_{ab}$

$I_c = I_{ca} - I_{bc}$

The overall power transferred is

$S_{3\Phi} = 3V_{phase}I*_{phase}$

Single-phase loads

Except in a high-leg delta system, single-phase loads may be connected across any two phases, or a load can be connected from phase to neutral.[14] Distributing single-phase loads among the phases of a three-phase system balances the load and makes most economical use of conductors and transformers.

In a symmetrical three-phase four-wire, wye system, the three phase conductors have the same voltage to the system neutral. The voltage between line conductors is $\sqrt{3}$ times the phase conductor to neutral voltage:[15]

$$V_{LL} = \sqrt{3}V_{LN}.$$

The currents returning from the customers' premises to the supply transformer all share the neutral wire. If the loads are evenly distributed on all three phases, the sum of the returning currents in the neutral wire is approximately zero. Any

unbalanced phase loading on the secondary side of the transformer will use the transformer capacity inefficiently.

If the supply neutral is broken, phase-to-neutral voltage is no longer maintained. Phases with higher relative loading will experience reduced voltage, and phases with lower relative loading will experience elevated voltage, up to the phase-to-phase voltage.

A high-leg delta provides phase-to-neutral relationship of $V_{LL} = 2\,V_{LN}$, however, LN load is imposed on one phase.[8] A transformer manufacturer's page suggests that LN loading not exceed 5% of transformer capacity.[16]

Since $\sqrt{3} \approx 1.73$, defining V_{LN} as 100% gives $V_{LL} \approx 100\% \times 1.73 = 173\%$. If V_{LL} was set as 100%, then $V_{LN} \approx 57.7\%$.

Unbalanced loads

When the currents on the three live wires of a three-phase system are not equal or are not at an exact 120° phase angle, the power loss is greater than for a perfectly balanced system. The method of symmetrical components is used to analyze unbalanced systems.

Non-linear loads

With linear loads, the neutral only carries the current due to imbalance between the phases. Gas-discharge lamps and devices that utilize rectifier-capacitor front-end such as switch-mode power supplies, computers, office equipment and such produce third-order harmonics that are in-phase on all the supply phases. Consequently, such harmonic currents add in the neutral in a wye system (or in the grounded (zigzag) transformer in a delta system), which can cause the neutral current to exceed the phase current.[14][17]

Three-phase loads

An important class of three-phase load is the electric motor. A three-phase induction motor has a simple design, inherently high starting torque and high efficiency. Such motors are applied in industry for many applications. A three-phase motor is more compact and less costly than a single-phase motor of the same voltage class and rating, and single-phase AC motors above 10 HP (7.5 kW) are uncommon. Three-phase motors also vibrate less and hence last longer than single-phase motors of the same power used under the same conditions.[18]

Resistance heating loads such as electric boilers or space heating may be connected to three-phase systems. Electric lighting may also be similarly connected.

Line frequency flicker in light is detrimental to high speed cameras used in sports event broadcasting for slow motion replays. It can be reduced by evenly spreading line frequency

operated light sources across the three phases so that the illuminated area is lit from all three phases. This technique was applied successfully at the 2008 Beijing Olympics.[19]

Rectifiers may use a three-phase source to produce a six-pulse DC output.[20] The output of such rectifiers is much smoother than rectified single phase and, unlike single-phase, does not drop to zero between pulses. Such rectifiers may be used for battery charging, electrolysis processes such as aluminium production or for operation of DC motors. "Zig-zag" transformers may make the equivalent of six-phase full-wave rectification, twelve pulses per cycle, and this method is occasionally employed to reduce the cost of the filtering components, while improving the quality of the resulting DC.

One example of a three-phase load is the electric arc furnace used in steelmaking and in refining of ores.

In many European countries electric stoves are usually designed for a three-phase feed. Individual heating units are often connected between phase and neutral to allow for connection to a single-phase circuit if three-phase is not available.[21] Other usual three-phase loads in the domestic field are tankless water heating systems and storage heaters. Homes in Europe and the UK have standardized on a nominal 230 V between any phase and ground. (Existing supplies remain near 240 V in the UK, and 220 V on much of the continent.) Most groups of

Three phase plug commonly used on electric stoves in Europe

houses are fed from a three-phase street transformer so that individual premises with above-average demand can be fed with a second or third phase connection.

Phase converters

Phase converters are used when three-phase equipment needs to be operated on a single-phase power source. They are used when three-phase power is not available or cost is not justifiable. Such converters may also allow the frequency to be varied, allowing speed control. Some railway locomotives use a single-phase source to drive three-phase motors fed through an electronic drive.[22]

A rotary phase converter is a three-phase motor with special starting arrangements and power factor correction that produces balanced three-phase voltages. When properly designed, these rotary converters can allow satisfactory operation of a three-phase motor on a single-phase source. In such a device, the energy storage is performed by the inertia (flywheel effect) of the rotating components. An external flywheel is sometimes found on one or both ends of the shaft.

A three-phase generator can be driven by a single-phase motor. This motor-generator combination can provide a frequency changer function as well as phase conversion, but

requires two machines with all their expenses and losses. The motor-generator method can also form an uninterruptible power supply when used in conjunction with a large flywheel and a battery-powered DC motor; such a combination will deliver nearly constant power compared to the temporary frequency drop experienced with a standby generator set gives until the standby generator kicks in.

Capacitors and autotransformers can be used to approximate a three-phase system in a static phase converter, but the voltage and phase angle of the additional phase may only be useful for certain loads.

Variable-frequency drives and digital phase converters use power electronic devices to synthesize a balanced three-phase supply from single-phase input power.

Alternatives to three-phase

- Split-phase electric power is used when three-phase power is not available and allows double the normal utilization voltage to be supplied for high-power loads.
- Two-phase electric power uses two AC voltages, with a 90-electrical-degree phase shift between them. Two-phase circuits may be wired with two pairs of conductors, or two wires may be combined, requiring only three wires for the circuit. Currents in the common conductor add to 1.4 times the current in the individual phases, so the common conductor must be larger. Two-phase and three-phase systems can be interconnected by a Scott-T transformer, invented by Charles F. Scott.[23] Very early AC machines, notably the first generators at Niagara Falls, used a two-phase system, and some remnant two-phase distribution systems still exist, but three-phase systems have displaced the two-phase system for modern installations.
- *Monocyclic power* was a name for an asymmetrical modified two-phase power system used by General Electric around 1897, championed by Charles Proteus Steinmetz and Elihu Thomson. This system was devised to avoid patent infringement. In this system, a generator was wound with a full-voltage single-phase winding intended for lighting loads and with a small fraction (usually 1/4 of the line voltage) winding that produced a voltage in quadrature with the main windings. The intention was to use this "power wire" additional winding to provide starting torque for induction motors, with the main winding providing power for lighting loads. After the expiration of the Westinghouse patents on symmetrical two-phase and three-phase power distribution systems, the monocyclic system fell out of use; it was difficult to analyze and did not last long enough for satisfactory energy metering to be developed.
- High-phase-order systems for power transmission have been built and tested. Such transmission lines typically would use six or twelve phases. High-phase-order transmission lines allow transfer of slightly less than proportionately higher power through a given volume without the expense of a high-voltage direct current (HVDC) converter at each end of the line. However, they require correspondingly more pieces of equipment.

Color codes

Conductors of a three-phase system are usually identified by a color code, to allow for balanced

loading and to assure the correct phase rotation for motors. Colors used may adhere to International Standard IEC 60446 (now merged into IEC 60445), older standards or to no standard at all and may vary even within a single installation. For example, in the U.S. and Canada, different color codes are used for grounded (earthed) and ungrounded systems.

Country	L1 (R)	L2 (S)	L3 (T)	Neutral (N)	Ground / protective earth (PE)
Australia and New Zealand as per AS/NZS 3000:2007 Figure 3.2 (or as per IEC 60446 as approved by AS:3000)	Red (or brown)[note 1]	White[note 1] (prev. yellow)	Dark blue (or grey)[note 1]	Black (or blue)[note 1]	Green/yellow striped (green on very old installations)
Canada (mandatory)[24]	Red[note 2]	Black	Blue	White or Grey	Green, green/yellow striped or bare copper
Canada (isolated systems)[25]	Orange	Brown	Yellow	White or Grey	Green or green/yellow striped
European Union and all countries who use European CENELEC standards since April 2004 (IEC 60446 - now replaced by IEC 60445-2017): United Kingdom since 31 March 2004, Hong Kong from July 2007, Singapore from March 2009, Russia since 2009 (GOST R 50462), Argentina, Ukraine, Belarus, Kazakhstan	Brown	Black	Grey	Blue	Green/yellow striped[note 3]
Older European (prior to IEC 60446, varied by country)[note 4]	Red	Yellow	Blue	Black	Green/yellow striped (green on installations before c. 1970)

UK before April 2006, Hong Kong before April 2009, South Africa, Malaysia, Singapore before February 2011	Red	Yellow	Blue	Black	Green/yellow striped (green on installations before c. 1970)
India	Red	Yellow	Blue	Black	Green/yellow striped, or green
Former USSR (Russia, Ukraine, Kazakhstan) before 2009, People's Republic of China (per GB 50303-2002 Section 15.2.2)	Yellow	Green	Red	Sky blue	Green/yellow striped
Norway (older systems - newer systems since the late 1990s use EU color standards)	Black	White/Grey	Brown	Blue	Yellow/green striped, older may be only yellow or bare copper
United States (common practice)[note 5]	Black	Red	Blue	White, or grey	Green, green/yellow striped,[note 6] or a bare copper wire
United States (alternative practice)[note 7]	Brown	Orange (delta systems) / Violet (wye systems)	Yellow	Grey, or white	Green

See also

- Industrial and multiphase power plugs and sockets
- International Electrotechnical Exhibition
- Three-phase
- Three-phase AC railway electrification
- Y-Δ transform

Notes

1. In Australia and New Zealand, active conductors can be any color except green/yellow, green, yellow, black or light blue. Yellow is no longer permitted in the 2007 revision of wiring code ASNZS 3000. European color codes are used for all IEC or flex cables such as extension leads, appliance leads etc. and are equally permitted for use in building wiring per AS/NZS 3000:2007.

2. In Canada the high leg conductor in a high-leg delta system is always marked red.

3. The international standard green-yellow marking of protective-earth conductors was introduced to reduce the risk of confusion by color blind installers. About 7% to 10% of men cannot clearly distinguish between red and green, which is a particular concern in older schemes where red marks a live conductor and green marks protective earth or safety ground.

4. In Europe, there still exist many installations with older colors but, since the early 1970s, all new installations use green/yellow earth according to IEC 60446. (E.g. Phase/Neutral+Earth German: black/grey + red France green/red + White Russia: Red/ Grey + Black; Switzerland: Red/ Grey +Yellow or yellow & red Denmark: White/Black + Red

5. See Paul Cook: Harmonised colours and alphanumeric marking (http://electrical.theiet.org /wiring-regulations/cable-colours/harmonised.cfm?type=pdf). IEE Wiring Matters, Spring 2006.

6. In the U.S., a green/yellow striped wire may indicate an isolated ground. In most countries today, green/yellow striped wire may only be used for protective earth (safety ground) and may never be unconnected or used for any other purpose.

7. Since 1975, the U.S. National Electric Code has not specified coloring of phase conductors. It is common practice in many regions to identify 120/208 (wye) conductors as black, red, and blue, and 277/480 (wye or delta) conductors as brown, orange, yellow. In a 120/240 delta system with a 208 V high leg, the high leg (typically B phase) is always marked orange, commonly A phase is black and C phase is either red or blue. Local regulations may amend the N.E.C. The U.S. National Electric Code has color requirements for grounded conductors, ground, and grounded-delta three-phase systems which result in one ungrounded leg having a higher voltage potential to ground than the other two ungrounded legs.

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