

Useful Electrical Formulas

Common electrical units used in formulas and equations are:

- **Volt** - unit of electrical potential or motive force - potential is required to send one ampere of current through one ohm of resistance (V)
- **Ohm** - unit of resistance - one ohm is the resistance offered to the passage of one ampere when impelled by one volt (Ω)
- **Ampere** - units of current - one ampere is the current which one volt can send through a resistance of one ohm (A)
- **Watt** - unit of electrical energy or power - one watt is the product of one ampere and one volt - one ampere of current flowing under the force of one volt gives one watt of energy (W)
- **Volt Ampere** - product of volts and amperes as shown by a voltmeter and ammeter (VA)
 - In direct current systems the volt ampere is the same as watts but the energy delivered
 - In alternating current systems the volts and amperes may or may not be 100% synchronous
 - When synchronous the volt amperes is equal to the watts
 - When not synchronous volt amperes exceed watts, the difference is reactive power (VAr)
- **Kilovolt Ampere** - one kilovolt ampere - KVA - is equal to 1,000 volt amperes (kVA)
- **Power Factor** - ratio of watts to volt amperes ($\cos \phi$)

ELECTRIC FORMULAS

DC or AC with linear (resistive) load AC1

$$P = V I$$

$$P = I^2 R$$

$$P = V^2 / R$$

$$V = R I$$

$$I = P / V$$

$$I = \sqrt{P/R}$$

AC Single Phase

Total or apparent power VA = VI or $I^2 Z$

Active power W = VI $\cos \phi$ or $I^2 R$

Reactive power VAr = VI $\sin \phi$ or $I^2 X$

AC 3-Phase

Star connection

$$V_p = V_l / \sqrt{3}, V_l = \sqrt{3} V_p, I_l = I_p$$

Delta connection

$$I_p = I_l / \sqrt{3}, I_l = \sqrt{3} I_p, V_l = V_p$$

Total or apparent power VA = $\sqrt{3} V_l I_l$

Active power W = $\sqrt{3} V_l I_l \cos \phi$

Reactive power Q = $\sqrt{3} V_l I_l \sin \phi$ or kVAr = (kVA)² - (kW)²

LOADS

Inductive reactance $X_L = 2\pi f L$ (Ω)

Capacitive reactance $X_C = \frac{1}{2\pi f C}$ (Ω)

where

P = power (Watts)

V = voltage (Volts)

I = current (Amperes)

R = resistance (Ohms Ω)

V_l = Line to line voltage

V_p = Phase voltage (line to neutral)

I_l = Line current (star)

I_p = Line current (delta)

Z = impedance (Ohms Ω)

X = reactance (Ohms)

$P_{3-phase}$ = electrical power 3-phase (kW)

$\cos \phi$ = power factor

f = frequency (hz)

L = inductance (henry)

C = capacitance (farads)

Q = reactive power (VAr)

The power factor of an AC electric power system is defined as the ratio of the active (true or real) power to the apparent power where-

- **Active (Real or True) Power** is measured in watts (W) and is the power drawn by the electrical resistance of a system doing useful work.
- **Apparent Power** is measured in volt-amperes (VA) and is the voltage on an AC system multiplied by all the current that flows in it. It is the vector sum of the active and the reactive power.
- **Reactive Power** is measured in volt-amperes reactive (VAR). Reactive Power is power stored in and discharged by inductive motors, transformers and solenoids. Reactive power is required for the magnetization of motors and transformers but doesn't perform any useful work. The reactive power required by inductive loads increases the amounts of apparent power - measured in kilovolt amps (kVA) - in the distribution system. Increasing of the reactive and apparent power will cause the power factor - PF - to decrease.

POWER FACTOR

It is common to define the Power Factor - PF - as the cosine of the phase angle between voltage and current - or the " $\cos \phi$ ".

$$PF = P / S \text{ (Watts/VA)}$$

where

PF = power factor

P = active (true or real) power (Watts)

S = apparent power (VA, volts amps)

A low power factor is the result of inductive loads such as transformers and electric motors. Unlike resistive loads creating heat by consuming kilowatts, inductive loads require a current flow to create magnetic fields to produce the desired work.

An overall power factor less than 1 indicates that the electricity supplier needs to provide more generating capacity than actually required. A low power factor is expensive and inefficient and some utility companies may charge additional fees when the power factor is less than 0.95. A low power factor will reduce the electrical system's distribution capacity by increasing the current flow and potentially causing voltage drops. The use of power factor correction capacitors in system with low power factor will bring the power factor back up to near unity and provide a significant reduction in electricity consumption. In systems with a high level of waveform distortion (harmonics), harmonic filter reactors should also be used to prevent damage to the power factor correction capacitors.

The current waveform distortion that contributes to reduced power factor is caused by voltage waveform distortion and overheating in the neutral cables of three-phase systems.

International standards such as IEC 61000-3-2 have been established to control current waveform distortion by introducing limits for the amplitude of current harmonics. Variable speed drives are a common source of voltage harmonics and the use of line reactors on the supply side of the variable speed drive will reduce their effect on the system waveform.