AC Power – Basics

Power in an electric circuit is the rate of flow of energy past a given point of the circuit. In AC circuits, energy storage elements such as inductance and capacitance may result in periodic reversals of the direction of energy flow. The portion of power that, averaged over a complete cycle of the AC waveform, results in net transfer of energy in one direction is known as **real power**. The portion of power due to stored energy, which returns to the source in each cycle, is known as **reactive power**.

REAL, REACTIVE, AND APPARENT POWER

In a simple alternating current (AC) circuit consisting of a source and a linear load, both the current and voltage are sinusoidal. If the load is purely resistive, the two quantities reverse their polarity at the same time. At every instant the product of voltage and current is positive, indicating that the direction of energy flow does not reverse. In this case, only real power is transferred.

If the load is purely reactive, then the voltage and current are 90 degrees out of phase. For half of each cycle, the product of voltage and current is positive, but on the other half of the cycle, the product is negative, indicating that on average, exactly as much energy flows toward the load as flows back. There is no net energy flow over one cycle. In this case, only reactive energy flows—there is no net transfer of energy to the load.

Practical loads have resistance, inductance, and capacitance, so both real and reactive power will flow to real loads. Power engineers measure apparent power as the vector sum of real and reactive power. **Apparent power** is the product of the **root-mean-square** voltage and current.

Engineers care about apparent power, because even though the current associated with reactive power does no work at the load, it heats the wires, wasting energy. Conductors, transformers and generators must be sized to carry the total current, not just the current that does useful work.

Another consequence is that adding the apparent power for two loads will not accurately give the total apparent power unless they have the same displacement between current and voltage (the same power factor).

If a capacitor and an inductor are placed in parallel, then the currents flowing through the inductor and the capacitor tend to cancel out rather than adding. Conventionally, capacitors are considered to generate reactive power and inductors to consume it. This is the fundamental mechanism for controlling the power factor in electric power transmission; capacitors (or inductors) are inserted in a circuit to partially cancel reactive power 'consumed' by the load.

Engineers use the following terms to describe energy flow in a system (and assign each of them a different unit to differentiate between them):

- **Real power** (P) or **active power**: watt [W]
- **Reactive power** (Q): volt-amperes reactive [var]
- **Complex power** (S): volt-ampere [VA]
- **Apparent Power** ($|S|$), that is, the absolute value of complex power S: volt-ampere [VA]
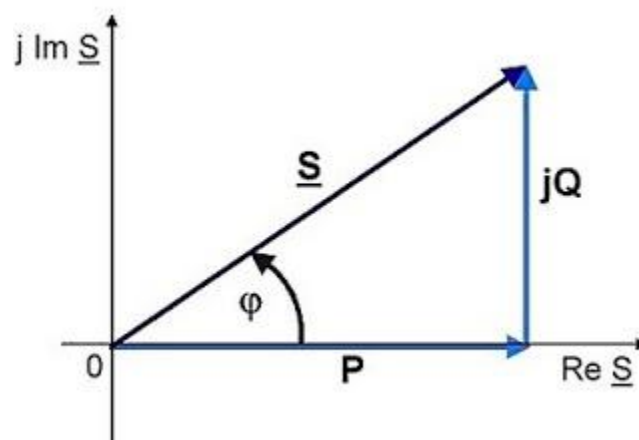
In the diagram, P is the real power, Q is the reactive power (in this case positive), S is the complex power and the length of S is the apparent power.

Reactive power does not transfer energy, so it is represented as the imaginary axis of the vector diagram. Real power moves energy, so it is the real axis.

The unit for all forms of power is the watt (symbol: W), but this unit is generally reserved for real power. Apparent power is conventionally expressed in **volt-amperes** (VA) since it is the product of rms voltage and rms current. The unit for reactive power is expressed as VA$_r$,

which stands for volt-amperes reactive. Since reactive power transfers no net energy to the load, it is sometimes called "wattless" power. It does, however, serve an important function in electrical grids and its lack has been cited as a significant factor in the Northeast Blackout of 2003.

Understanding the relationship between these three quantities lies at the heart of understanding power engineering. The mathematical relationship among them can be represented by vectors or expressed using complex numbers,

S = P + jQ (where j is the imaginary unit)

Example for simple understanding
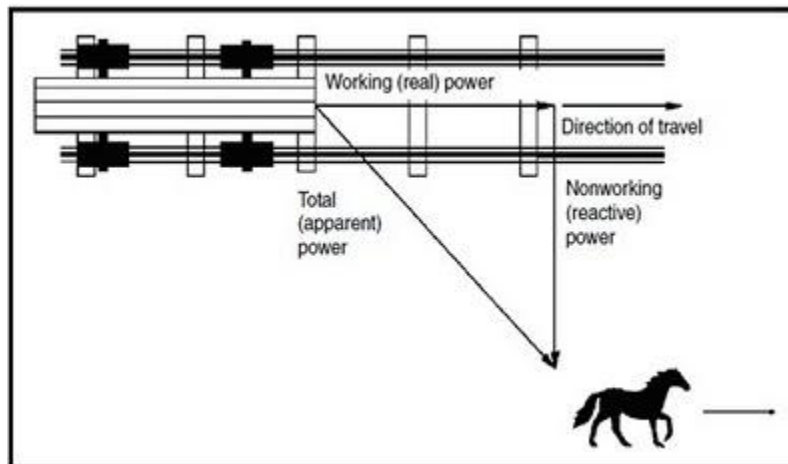
Visualize a horse pulling a railroad car down a railroad track. Because the railroad ties are uneven, the horse must pull the car from the side of the track. The horse is pulling the railroad car at an angle to the direction of the car's travel.

The power required to move the car down the track is the working **(real)** power. The effort of the horse is the total **(apparent)** power. Because of the angle of the horse's pull, not all of the horse's effort is used to move the car down the track. The car will not move sideways; therefore, the sideways pull of the horse is wasted effort or nonworking **(reactive)** power. The angle of the horse's pull is related to power factor, which is defined as the ratio of real (working) power to apparent (total) power. If the horse is led closer to the center of the track, the angle of side pull decreases and the real power

approaches the value of the apparent power. Therefore, the ratio of real power to apparent power (the power factor) approaches 1. As the power factor approaches 1, the reactive (nonworking) power approaches 0.

Power factor

The ratio between real power and apparent power in a circuit is called the power factor.

Power factor = Real power / Apparent power

It's a practical measure of the efficiency of a power distribution system. For two systems transmitting the same amount of real power, the system with the lower power factor will have higher circulating currents due to energy that returns to the source from energy storage in the load. These higher currents produce higher losses and reduce overall transmission efficiency. A lower power factor circuit will have a higher apparent power and higher losses for the same amount of real power.

The power factor is one when the voltage and current are in phase. It is zero when the current leads or lags the voltage by 90 degrees. Power factors are usually stated as "leading" or "lagging" to show the sign of the phase angle, where leading indicates a negative sign.

Purely capacitive circuits cause reactive power with the current waveform leading the voltage wave by 90 degrees, while purely inductive circuits cause reactive power with the current waveform lagging the voltage waveform by 90 degrees. The result of this is that capacitive and inductive circuit elements tend to cancel each other out.

Where the waveforms are purely sinusoidal, the power factor is the cosine of the phase angle (φ) between the current and voltage sinusoid waveforms. Equipment data sheets and nameplates often will abbreviate power factor as "$\cos\varphi$" for this reason.

Real power = 100 kW

Reactive power = 100 kVAR

Apparent power = 142 kVA
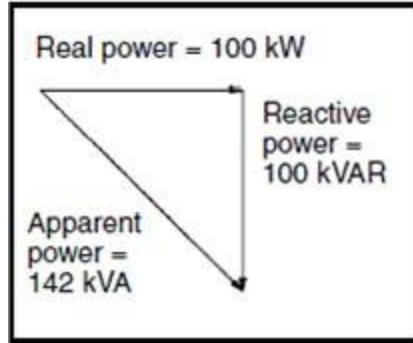
For example, using the power triangle illustrated here, if

Real power = 100 kW and

Apparent power = 142 kVA then

Power Factor = 100/142 = 0.70 or 70%.

This indicates that only 70% of the current provided by the electrical utility is being used to produce useful work.

Reactive power

In power transmission and distribution, significant effort is made to control the reactive power. This is typically done automatically by switching inductors or capacitor banks in and out, by adjusting generator excitation, and by other means. Electricity retailers may use

electricity meters which measure reactive power to financially penalize customers with low power factor loads. This is particularly relevant to customers operating highly inductive loads such as motors at water pumping stations.