TTE Training Ltd.

Phase 2

Electrical Course Notes

E2-CN-013

Power Factor

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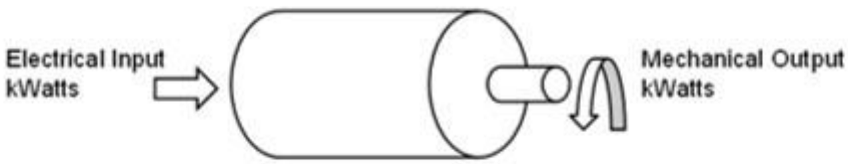
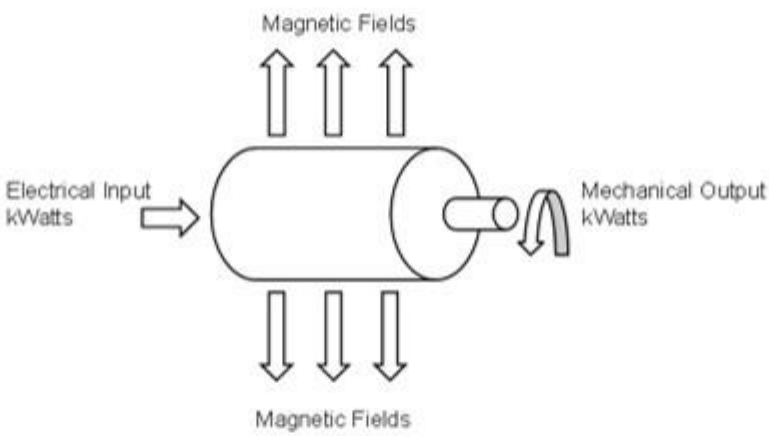
Power factor correction using capacitors.

In an ideal induction motor at 100% efficiency the electrical input in kilowatts will be equal to the mechanical output in kilowatts.

i.e. 3 kilowatts electrical input = 3 kilowatts mechanical output.

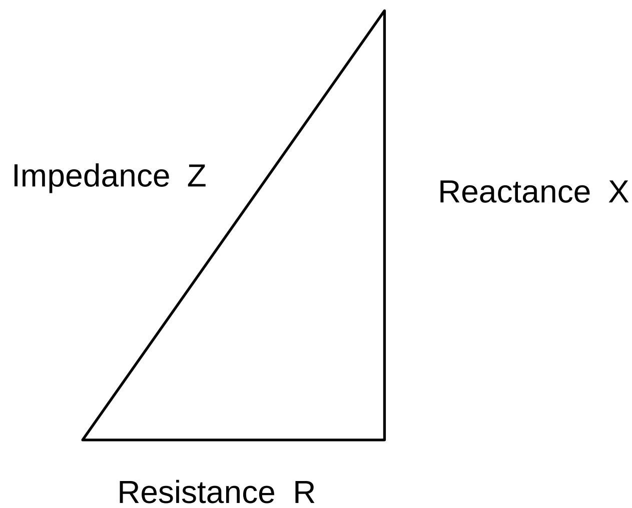


However, some of the energy from the electrical input is required to produce the magnetic fields around the coils of wire situated in the Stator.



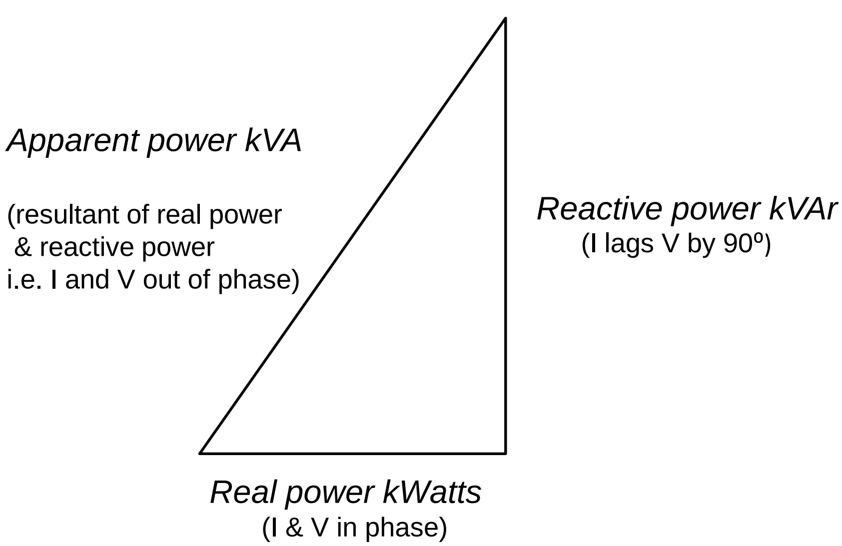
So electrical input = mechanical output plus the magnetic fields.

This situation can be compared to the impedance triangle.



In terms of power the impedance triangle can be reconfigured.

Power Triangle



Real Power

This is the electrical power that is used to drive the motor to produce the "mechanical kilowatts". Here just like the impedance triangle, voltage and current are in phase and it is rated in Watts (W).

Reactive Power

This is the electrical power used up to produce the magnetic fields around the coils in the motor Stator. This splits the voltage and current so that the current lags the voltage by 90º. Hence the reactive power is drawn on the triangle as 90º away from the real power and is rated in VAr's (r = reactive).

Apparent Power

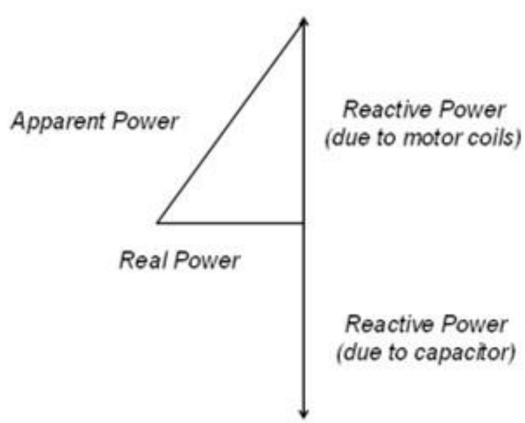
This is the power drawn from the supply by the motor to provide both the real power and reactive power. This is measured in Volt Amps i.e., the product of the supply voltage and the current drawn by the motor, it is expressed in VA's.

These three types of power make up the power triangle (like the impedance triangle).

Referring to right angle trigonometry Cos Φ = Real power / Apparent power

The idea now is to get both Real and Apparent power to be equal by reducing the Reactive power to zero.

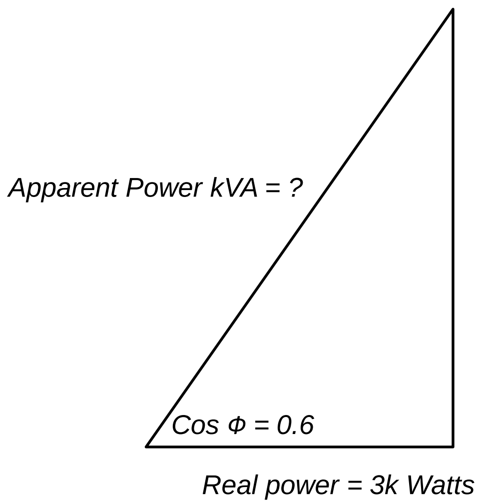
To reduce the phase angle Cos Φ to as near 0º as possible, the Reactive power can in effect be cancelled out by adding a Capacitor across the motor supply. This is because with a Capacitor the current leads the voltage by 90º, i.e., the exact opposite of an inductor or coil, where current lags voltage by 90º.



Example: A motor is rated at 3 kilowatts. The supply voltage = 415 Volts.

Current drawn by motor = Real power / √3 Supply voltage, 3000 / √3 415 = 4.17 Amps

If the Power factor is 0.6 then the referring to power triangle:



Cos Φ = Real power / Apparent power

So Apparent power = Real power / Cos Φ

So Apparent power = 3000 / 0.6 = 5000 Volt Amps or 5 kVA

Current drawn by motor due to Apparent power = Apparent power / √3 supply voltage

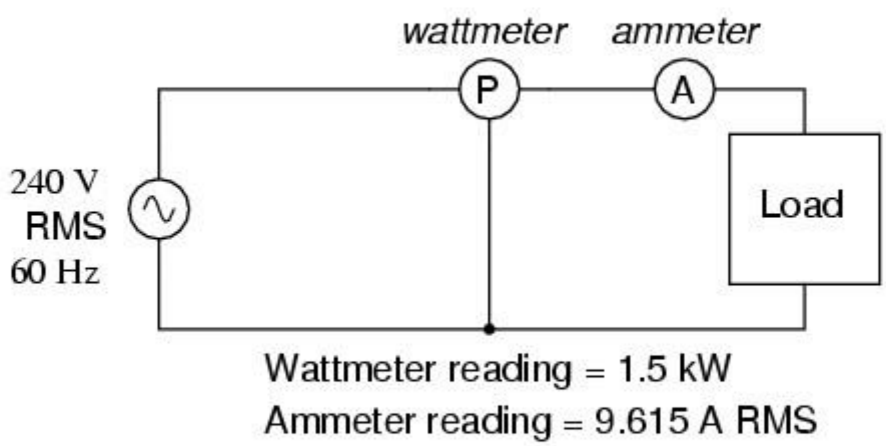
= 5000 kVA / √3 415 Volts = 6.95 Amps

Without power factor correction the 3-kilowatt motor will need 6.95 Amps to produce 3 kilowatts of mechanical power instead of 4.17 Amps if Power factor correction had not been applied.

Practical Power Factor Correction

When the need arises to correct for poor power factor in an AC power system, you probably will not have the luxury of knowing the load's exact inductance in Henrys to use for your calculations. You may be fortunate enough to have an instrument called a *power factor meter* to tell you what the power factor is (a number between 0 and 1), and the apparent power (which can be calculated by taking a voltmeter reading in volts and multiplying by an ammeter reading in amps). In less favourable circumstances you may have to use an oscilloscope to compare voltage and current waveforms, measuring phase shift in *degrees* and calculating power factor by the cosine of that phase shift.

Most likely, you will have access to a wattmeter for measuring true power, whose reading you can compare against a calculation of apparent power (from multiplying total voltage and total current measurements). From the values of true and apparent power, you can determine reactive power and power factor. Let us do an example problem to see how this works: (Figure below)



Wattmeter reads true power; product of Voltmeter and Ammeter readings yields Apparent power.

First, we need to calculate the apparent power in VA. We can do this by multiplying load voltage by load current:

$$S = IE$$

$$S = (9.615\ \text{A})(240\ \text{V})$$

$$S = 2.308\ \text{kVA}$$

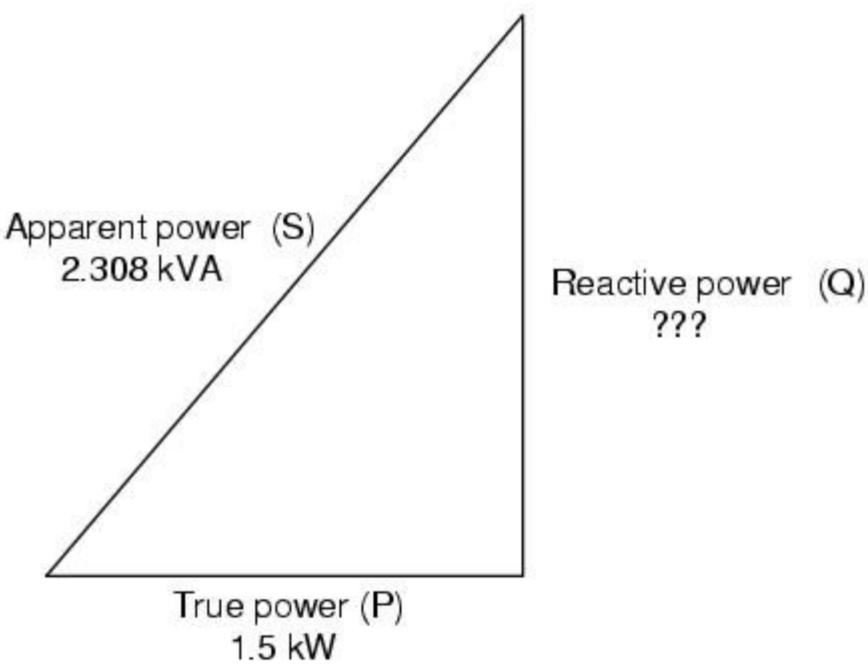
As we can see, 2.308 kVA is a much larger figure than 1.5 kW, which tells us that the power factor in this circuit is rather poor (substantially less than 1). Now, we figure the power factor of this load by dividing the true power by the apparent power:

$$\text{Power factor} = \frac{P}{S}$$

$$\text{Power factor} = \frac{1.5 \text{ kW}}{2.308 \text{ kVA}}$$

$$\text{Power factor} = 0.65$$

Using this value for power factor, we can draw a power triangle, and from that determine the reactive power of this load: (Figure below)



Reactive power may be calculated from true power and apparent power.

To determine the unknown (reactive power) triangle quantity, we use the Pythagorean Theorem "backwards," given the length of the hypotenuse (apparent power) and the length of the adjacent side (true power):

$$\text{Reactive power} = \sqrt{(\text{Apparent power})^2 - (\text{True power})^2}$$

$$Q = 1.754 \text{ kVAR}$$

If this load is an electric motor, or most any other industrial AC load, it will have a lagging (inductive) power factor, which means that we'll have to correct for it with a *capacitor* of appropriate size, wired in parallel. Now that we know the amount of reactive power (1.754 kVAr), we can calculate the size of capacitor needed to counteract its effects:

$$Q = \frac{E^2}{X}$$

. . . solving for X . . .

$$X = \frac{E^2}{Q}$$

$$X = \frac{(240)^2}{1.754 \text{ kVAR}}$$

$$X = 32.845\ \Omega$$

$$X_C = \frac{1}{2\pi f C}$$

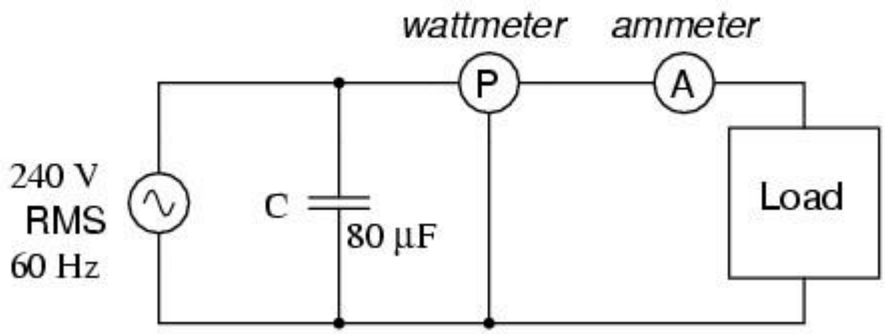
. . . solving for C . . .

$$C = \frac{1}{2\pi f X_C}$$

$$C = \frac{1}{2\pi(60\text{ Hz})(32.845\ \Omega)}$$

$$C = 80.761\ \mu\text{F}$$

Rounding this answer off to 80 µF, we can place that size of capacitor in the circuit and calculate the results: (Figure below)



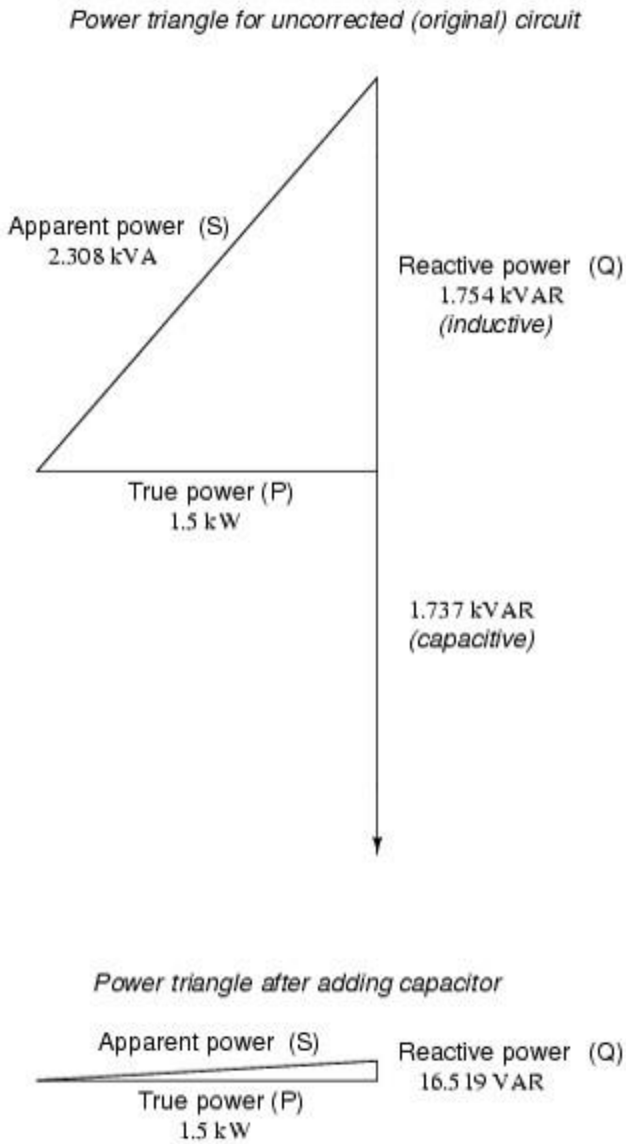
Parallel capacitor corrects lagging (inductive) load.

An 80 µF capacitor will have a capacitive reactance of 33.157 Ω, giving a current of 7.238 amps, and a corresponding reactive power of 1.737 kVAr (for the capacitor *only*). Since the capacitor's current is 180º out of phase from the load's inductive contribution to current draw, the capacitor's reactive power will directly subtract from the load's reactive power, resulting in:

$$\text{Inductive kVAR} - \text{Capacitive kVAR} = \text{Total kVAR}$$

$$1.754 \text{ kVAR} - 1.737 \text{ kVAR} = 16.519 \text{ VAR}$$

This correction, of course, will not change the amount of true power consumed by the load, but it will result in a substantial reduction of apparent power, and of the total current drawn from the 240 Volt source:



Power triangle before and after capacitor correction.

The new apparent power can be found from the true and new reactive power values, using the standard form of the Pythagorean Theorem:

$$\text{Apparent power} = \sqrt{(\text{Reactive power})^2 + (\text{True power})^2}$$

$$\text{Apparent power} = 1.50009 \text{ kVA}$$

This gives a corrected power factor of (1.5kW / 1.5009 kVA), or 0.99994, and a new total current of (1.50009 kVA / 240 Volts), or 6.25 amps, a substantial improvement over the uncorrected value of 9.615 amps! This lower total current will translate to less heat losses in the circuit wiring, meaning greater system efficiency (less power wasted).