



Power Factor in Electrical Energy Management

An Online Continuing Education Course for Engineers

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Power Factor in Electrical Energy Management

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Every electric load that works with magnetic fields (motors, chokes, transformers, inductive heating, and arc-welding generators) produces a varying degree of electrical lag, which is called inductance. The line current drawn by an inductive load consists of two components:

1. Magnetizing current
2. Power-producing current

The magnetizing current is the current required to sustain the electro-magnetic flux or field strength in the machine. This component of current creates reactive power that does not do useful work, but circulates between the generator and the load. It places a heavier drain on the power source and on the power source's distribution system.

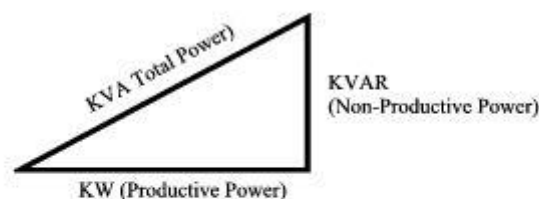
The real (working) power-producing current is the current that reacts with the magnetic flux to produce the mechanical output of the motor. Real power is measured in kilowatts (kW), which together with reactive power (KVAR) makes up apparent power. It is expressed in kilovolt-amperes (kVA.)

Power factor is the inefficiency expressed as the ratio of active or useful power to total or apparent power (KW/KVA.)

$$\text{Power factor} = \frac{\text{Active Power}}{\text{Apparent Power}} \text{ or } \frac{\text{kW}}{\text{KVA}}$$

The apparent power is always in excess of the productive power for inductive loads, and is dependent on the type of machine in use.

Graphically, it can be represented as:



$$\text{Power Factor} = \frac{\text{KW (Productive Power)}}{\text{KVA (Total Power)}}$$

The cosine of the phase angle θ between the KVA and the KW components represents the power factor of the load. KVAR represents the non-productive reactive power, and θ is lagging phase angle.

The Relationship between KVA, KW and KVAR is non-linear, and is expressed as:
$$\text{KVA}^2 = \text{KW}^2 + \text{KVAR}^2$$

A power factor of 0.72 would mean that only 72% of your power is being used to do useful work. Perfect power factor is 1.0, (unity), meaning that 100% of the power is being used for useful work.

Power factor is also referred to as leading or lagging. In the case of the magnetizing current, the power factor is lagging. That is, the current follows the voltage waveform. The amount of lag is the electrical phase angle between the voltage and the current. Power factor is equal to the cosine of the phase angle between the voltage and current waveforms.

Terminology

Apparent Power: This value is determined by multiplying the current times voltage. In a three-phase circuit, multiply the average phase-to-phase voltage by the average line current by the square root of 3 divided by 1,000. The units are kilovolt-amperes (kVA).

$$P_{\text{Apparent}} = \frac{V \times I \times \sqrt{3}}{1000}$$

Reactive Power: This term describes the magnetizing requirements of an electric circuit containing inductive loads. The value of magnetizing power is determined by multiplying the Apparent Power by the sine of the phase angle, θ , between the voltage and the current. The units are kilovolt-amperes reactive (kVAR).

$$P_{\text{Reactive}} = P_{\text{Apparent}} \times \sin \theta$$

Real Power: This term is what electricians deal with in plant loads. Real power is related to Apparent Power by the cosine of the phase angle, θ , between voltage and current. Units are kilowatts (kW).

$$P_{\text{Real}} = P_{\text{Apparent}} \times \cos \theta$$

Or

$$P_{\text{Real}} = P_{\text{Apparent}} \times \text{PF}$$

Note that:

- Real or active power is measured in KW (1000 Watts)
- Reactive power is measured in kVAR (1000 Volt-Amperes Reactive)
- Total Power is measured in KVA (1000 Volt-Amperes)

Typical Un-improved Power Factor by Industry

The typical un-corrected power factors by different sectors of industry are as follows:

Industry	Power Factor
Auto Parts	75-80
Brewery	75-80
Cement	80-85
Chemical	65-75
Coal Mine	65-80
Clothing	35-60
Electroplating	65-70
Foundry	75-80
Forging	70-80
Hospital	75-80
Machine Manufacturing	60-65
Metalworking	65-70
Office Building	80-90
Oil field Pumping	40-60
Paint Manufacturing	65-70
Plastic	75-80
Stamping	60-70
Steel Works	65-80
Tool, Dies, Jigs Industry	65-75

The typical uncorrected industrial power factor is 0.8. This means that a 1MVA transformer can only supply 800KW, or that a consumer can only draw 80 useful Amps from a 100Amp supply. To put it another way, a 3-phase 100KW load would draw 172A per phase, instead of the 139A expected.

For inherently low power factor equipment, the utility company has to generate much more current than is theoretically required. For instance, in a situation where real power demand (kW) at two plants is the same, but one plant has an 85% power factor while the other has a 70 percent power factor, the utility must provide 21% more current to the second plant to meet that same demand. This excess current flows through generators, cables, and transformers in the same manner as the useful current. If steps are not taken to improve the power factor of the load, all of the equipment, conductors, and transformers serving the second plant would need 21% more carrying capacity than those provided to the first plant.

Additionally, resistance losses (I^2R) in the distribution conductors would be 46% greater in the second plant. A utility is paid primarily on the basis of energy consumed and peak demand supplied. Without a power factor billing element, the utility would receive no more income from the second plant than from the first. To discourage these inefficiencies and to compensate for the burden of supplying extra current, the utilities typically establish a power factor penalty in their rate schedules.

These penalties appear on electricity bills as reactive power charges, KVA maximum demand, or KVA availability charges. The following is an example of known information taken from billing about an electrical system:

KVA = 1000, KW = 800, KVAR = 600, PF = .80

Typical Utility Billing Structure Examples:

1. **90% Billing Structure** - Demand billed is based on 90% of the KVA or 100% of the KW, whichever is greater. Because the facility has a power factor of 0.80, they will pay demand rates on 90% of the KVA $1000 \times .90 = 900$ KVA because it is the larger number ($900 \text{ KVA} > 800 \text{ KW}$). Thus, the facility is paying a penalty on 100 KVA of unproductive power. Correcting the facility's Power Factor to 90% + will eliminate this penalty cost.
2. **100% KVA + 100% KW Billing Structure** - One rate is applied to 100% of the KVA and another rate is applied to 100% of the KW. Both are then added together to determine the total demand charged on the bill. If we correct the power factor to unity ($\text{KVA} = \text{KW}$ or $800 \text{ KVA} = 800 \text{ KW}$), we can recover costs paid on 200 KVA at *KVA rates, assuming that an equal rate is being paid for KVA and KW.

Rather than pay demand costs on $1000 \text{ KVA} + 800 \text{ KW} = 1800$ if the Power Factor = Unity, we will pay demand costs on $800 \text{ KVA} + 800 \text{ KW} = 1600$. Savings = $1800 - 1600 = 200$.

(More examples are provided later in this course.)

*Note: Generally, the cost per KVA is greater than the cost for KW. Thus, the savings would be greater by correcting the power factor to unity.

The reactive power charges levied as penalties in the billing should always be regulated. The excess reactive currents and associated charges can be removed by a well established technology called power factor correction. Simply put, this technology offsets the inductive reactive currents by introducing equal and opposite capacitive reactive currents. Typically, this can reduce electricity bills by 5-8%, with a payback period of 12 to 18 months. In addition, the consumer will enjoy improved supply availability, improved voltage, and reduced power losses.

To improve the power factor, equipment drawing KVAR of approximately the same magnitude as the load KVAR, but in phase opposition Leading is connected in parallel with the load. The resultant KVA is now smaller, and the new power factor, $\cos\theta_2$, is increased. Thus, any value of $\cos\theta_2$ can be obtained by controlling the magnitude of the leading KVAR added.

It is never economical to attempt to improve the power factor to unity, since the nearer the approach to unity, the more KVAR that must be installed for a given improvement.

Disadvantages of low power factor

For systems with low power, factoring the transmission of electric power in accordance with existing standards results in higher expenses both for the supply distribution companies and the consumer. Many engineers are oblivious to the effects of low power factor. They view it only as a direct charge on their electrical bill, and only when stated as such. Low power factor is a direct cost to the utility company and must be paid.

Direct costs of low power factor

Power factor may be billed as one of or combination of the following:

1. A penalty charge for power factor below or above a predetermined value
2. An increase in the amount of KVA used during the month. If the power factor increases the amount of KVA.
3. A charge on the amount of KVA used during the month. If the power factor increases the amount of KVA.
4. KVA demand charge for the month. If the power factor increases the amount of KVA.

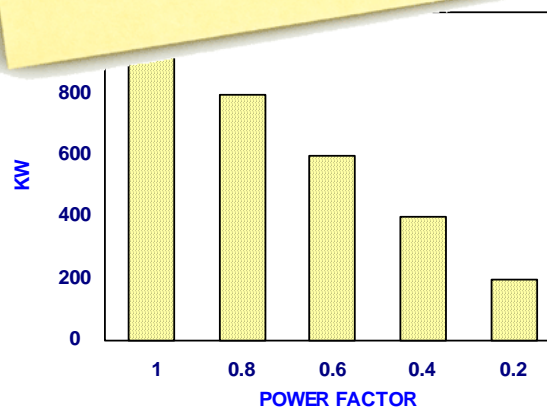
Indirect costs of low power factor

Loss in efficiency of the amount of useful power is considerably reduced carry. The figure below is designed to supply 100

at a low power factor, the amount of distribution transformers is considerably reduced. Transformers have to be replaced in equipment

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Loss in distribution capacity

In general terms, as the power factor of a three phase system decreases, the current **rises**. The heat dissipation in the system rises proportionately by a factor equivalent to the square of the current rise.