

# Power Factor

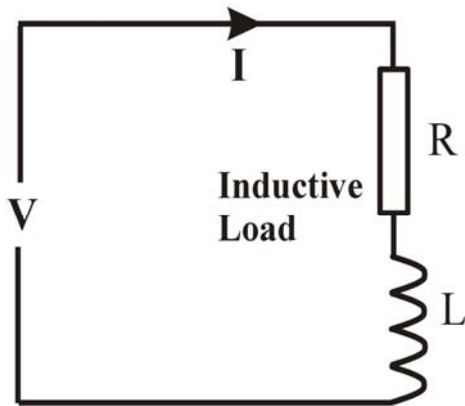
Two Myths and some Words of Comfort.

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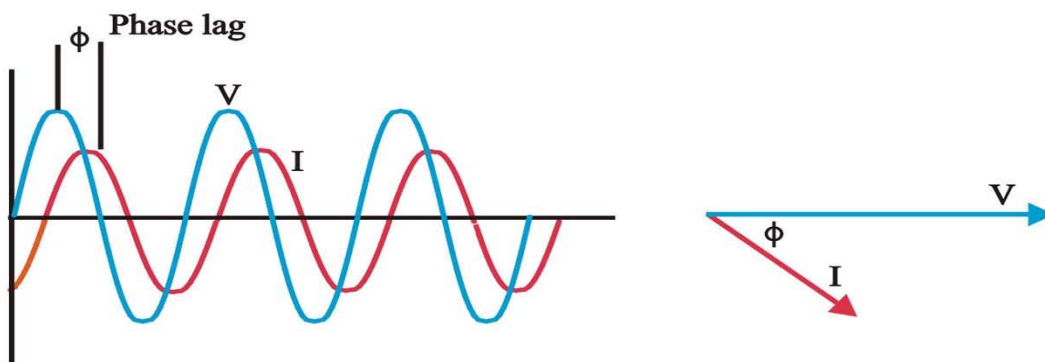
When you are buying electrical energy (kilowatt-hours) why should your supplier care about your **power factor** (PF) and why should he give you a better deal for having a high power factor?

The answer: At PFs less than 1, your supplier's generators, transmission cables and transformers hit their kVA output limit before his generators have reached their full rated kW output.

This denies him the extra revenue that delivering full rated kW output to his consumer base would give him.



**Fig 1. A generator feeding power to an inductive load, for example an induction motor.**



**Fig 2. Voltage and current waveforms of the inductive load and their vector representation. The current is shown lagging the voltage by  $\phi^\circ$**

## How we usually describe Power Factor

The motor represented by Fig 1 does not get the benefit of all the current ( $I$ ) shown here. It can only use the component that is in phase with the voltage, i.e.  $I \cos \phi$ .

$V I \cos \phi$  is the effective motor input in watts and  $\cos \phi$  is called the power factor.

The other component of current  $I \sin \phi$  lags  $V$  by  $90^\circ$  and makes no contribution to motor power. It is sometimes called quadrature or wattless current. It does however make an unwanted and costly contribution to the resistance losses and consequent capacity limitation all the way from the generator to the motor terminals.

Another way to define load PF is Watts/Volt-Amps.

### Power Factor Correction

You can eliminate that  $90^\circ$  lagging component by connecting capacitors in parallel with your load. Capacitors take a  $90^\circ$  leading current that can reduce or totally cancel out the  $90^\circ$  lagging (quadrature) component thereby minimizing your total current and increasing the PF. You do not need to connect enough capacitors to reach a PF of 1 because at some point you will spend more on adding capacitors than you save on your electric bill.

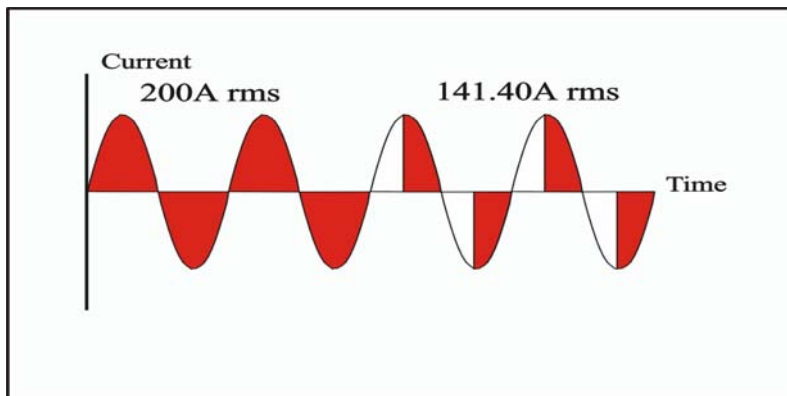
### A typical bulk tariff bill would have two parts:

1. A monthly demand charge based on the largest kVA recorded, averaged over any 15min period in the month. This penalises a consumer for excessive demands on the capacity of the system.
2. An energy charge based on total consumption. The meter is calibrated to record kVA multiplied by 0.8 instead of recording kWh. This is an incentive for a consumer to maintain a high PF.

### Loads that take non-sinusoidal currents.

Consider a resistive heater  $R$  (negligible inductance) controlled by a silicon controlled rectifier (SCR).

**Myth 1.** : “ With a resistive load (no inductance) there is no lagging current therefore PF must equal 1”. Look closer. First at phase angle control.



**Fig 3. Phase angle control showing full power at 200A and half power 141.4A**

**At full power** the rms line voltage is constant at 500V. The current is 200A rms, it is sinusoidal and in phase with the voltage so  $kW = kVA = 500V \times 200A = 100kW$ .  
Power factor =  $kW/kVA = 1$ .

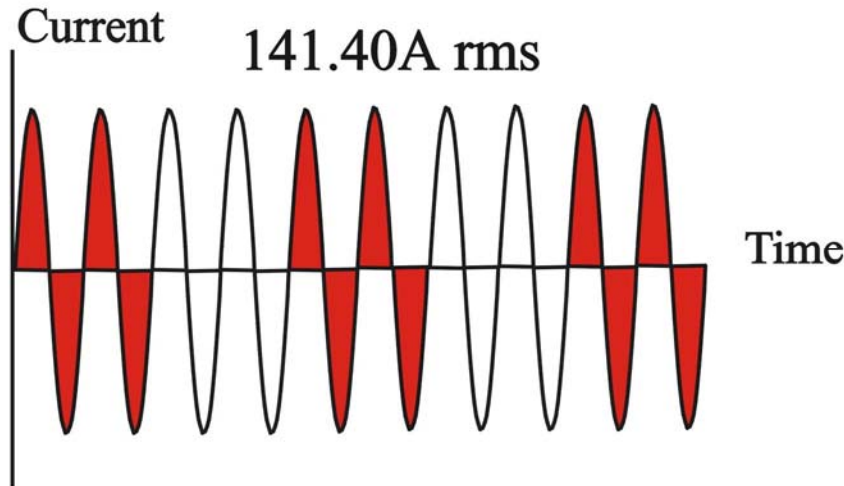
**At half power** the current does not appear until the voltage wave is at  $90^\circ$ . The current looks like it is lagging and somewhat out of shape. It cannot be represented by a vector and definitions based on  $\cos \phi$  do not apply. So let's calculate the VA and the power factor at half power (50kW).

By removing a symmetrical half of each half cycle of the current wave the **power has been halved to 50kW**.

So heater power  $I^2R$  has been halved so  $I^2$  has been halved (multiplied by 0.5). Therefore the **rms** value (not the **average** value) of current  $I$  has come down by a factor  $\sqrt{0.5} = 0.707$  and the reduced current is 141.4A rms.

The kVA comes to 500 times 141.4 = 70.7kVA and the PF (kW/kVA) = 0.707.

#### **Time proportioning control.**



**Fig 4. The waveforms representing an SCR controlled resistive load in fast cycle (time-proportioning) mode.**

The fast cycling waveform shows the current to be present for half the time, resulting in half power (50kW) into the same load as in the phase-angle case. A damped rms ammeter would show 141.4A as before. Multiply this by the line voltage (500) and you get 70.7 kVA as before and a PF of 0.707.

You can now dismiss **Myth 2**. “ With sine waves and resistive loads PF must be 1”. This myth is still circulated even by some manufacturers of SCR controls.

In both SCR firing modes above, let’s say you turn down the power by a factor “a” – call it the **per unit** power instead of percentage of full power. The PF turns out to be  $\sqrt{a}$  (the square root of a).

#### **Some words of comfort for users of SCR control.**

It is only when you turn power down that you see a decrease in PF. Your threat to the energy supplier’s capacity is thereby mitigated.

Don’t even try using capacitors for PF correction they are largely ineffective.

As little as one additional comparably sized sinusoidal resistive load such as building lighting and space heating can easily take your overall plant PF up out of the penalty zone.