# Power Factor and Grid-Connected Photovoltaics

As the level of Grid-Connected PV penetration continues to rise, the importance of power factor and power factor correction is going to become increasingly relevant both from the perspective of the grid and the customer.

This article explains what power factor is, what it is caused by, its impact on the grid, and how Grid-Connected PV can both degrade and improve power factor in a system.

What is Power Factor?

Power factor is a measure of the phase difference between the voltage and current in an AC power system. In purely resistive loads (such as an incandescent lightbulb or electric kettle) the current is in phase with the voltage and there is 'unity' power factor. Capacitive and inductive loads (such as a capacitor banks or inductive motor respectively) will cause the current to 'lead' or 'lag' the voltage, resulting in a 'non-unity' power factor. An example of a lagging and unity power factor is shown in Figure 1.
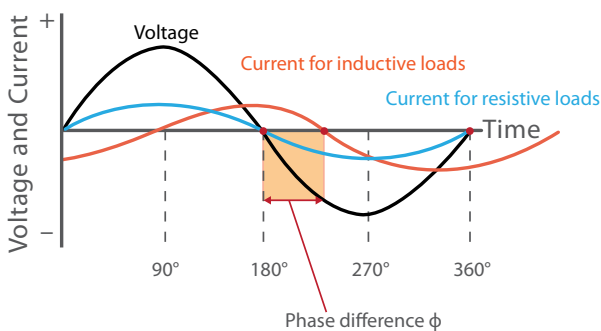

Figure 1: *AC power system with a lagging power factor (current is 'lagging' the voltage) and unity power factor*

A non-unity power factor means a load is consuming both active and reactive power. Active power (also known as real or true power) is the 'useful' component of the AC power and is what contributes to the work done in a system (e.g. rotation of a motor shaft or the glowing of a light bulb). Reactive power oscillates between the generation source and the load, and does no work in the system. Reactive power however is needed to maintain the voltage in the system, provide magnetizing power to motors and facilitate the transmission of the active power through the AC circuit.

The relationship between active and reactive power is shown in Figure 2. The vectors for active power (measured in Watts) and reactive power (measures in Volt Amps reactive – VAr) are added at right angles to give apparent power (measured in VA). Apparent power is what a generator must produce. The phase angle is given by the angle between the active power vector, and apparent power vector. Power factor can then be calculated by taking the cosine of this angle. As reactive power is increased, the phase angle also increases, resulting in a lower power factor. If the reactive power is reduced to zero, the phase angle also becomes zero, giving a power factor of = 1 (unity power factor).
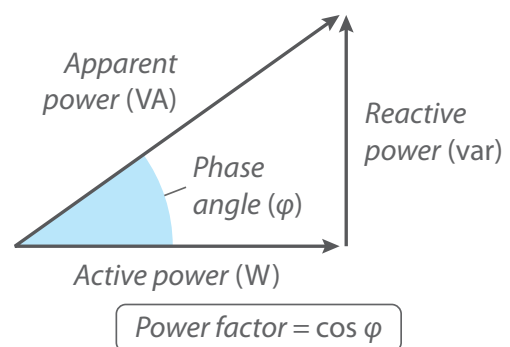
Figure 2: *Phase diagram of AC power showing active power, reactive power, and apparent power*

Creating sustainable change through education, communication and leadership

A common analogy of AC power is to a glass of beer (Figure 3). Reactive power is analogous with the head of the beer, while the liquid beer is active power (that does the work), giving apparent power as everything contained in the glass.
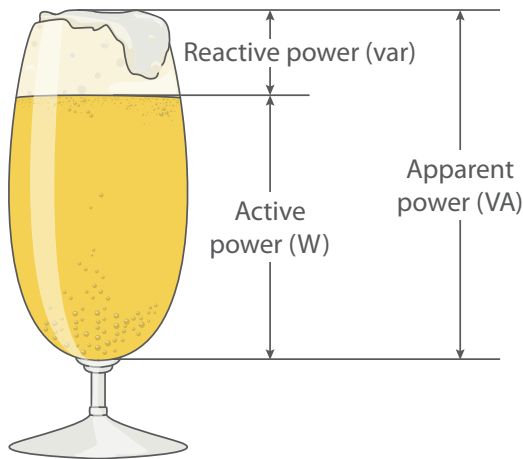

Figure 3: *The beer analogy of apparent power*

Power factor is the cosine of the phase angle in a power triangle. It is defined as the ratio between the active power (W) and the apparent power (VA). Power factor will vary between 0 and 1, and be either leading or lagging.

$$Power\ factor = \cos \phi = \frac{Active\ power\ (W)}{Apparent\ power\ (VA)}$$

For purely resistive loads (such as heaters and incandescent lamps) the voltage and current are in synchronization, therefore they have a power factor of 1, or unity power factor. With inductive loads (such as induction motors) the current lags the voltage, therefore they have a lagging power factor. With capacitive loads, (such as capacitor banks), the current leads the voltage, therefore they have a leading power factor.

Four Quadrant representation of Power Factor

Figure 4 below shows the 4 quadrant representation of power flow and power factor. The sign of active power P and power factor (cos ø) provides details

about the direction of energy flow. A positive sign indicates import mode and a negative sign indicates export mode.

In quadrants 1 and 4, a positive reactive power indicates an inductive load and a negative reactive power indicates a capacitive load in the import mode. On the other hand in export mode quadrants 2 and 3, an inductive generator is indicated by a positive reactive power and a capacitive generator is indicated by a negative reactive power.
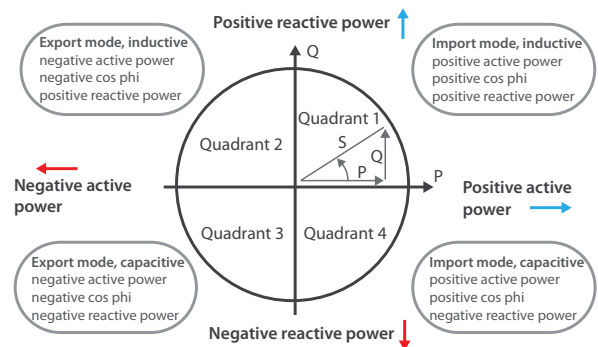

Figure 4 : *4 quadrant representation of power factor and power flow*

Power Factor and the Grid

The supply of reactive power is very important in an AC power grid. The amount of reactive power produced by generators must closely match that which is being consumed. A leading power factor in the system (due to capacitive loads) causes the voltage to rise and a lagging power factor (due to inductive loads) will cause the voltage to fall. If reactive power is either under or over supplied, the voltage on the network may rise or fall to a point where generators must switch off to protect themselves thereby decreasing the generation and cause further problems.

As can be seen from the phase diagram, increasing the reactive power increases the apparent power but has no effect on the active power. This means that the generators in the system must supply more apparent power even though there is no additional work being done by the system (as there is no increase in active power). Therefore power factor is best corrected locally. The most common way for

Creating sustainable change through education, communication and leadership

this to be performed is by using banks of capacitors that can be shunted in and out of the system depending on the operation of the load.

Residential customers do not consume enough energy to warrant the additional costs of metering equipment to measure power factor. Large industrial and commercial customers however are billed for consuming power at a poor power factor. There is therefore an incentive for these customers to improve the power factor of their loads and reduce the amount of reactive power they draw from the grid.

Power Factor and Grid Connected PV Systems

Most grid connected PV inverters are only set up to inject power at unity power factor, meaning they only produce active power. In effect this reduces the power factor, as the grid is then supplying less active power, but the same amount of reactive power.

Consider the situation in Figure 5. The factory is consuming 100kW of active power, and 32.9kVAr of reactive power, resulting in a power factor of 0.95 lagging.
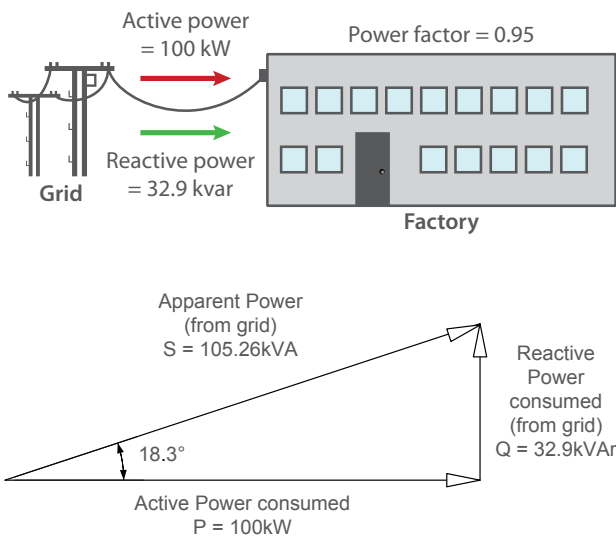

Figure 5: *Factory consuming active and reactive power*

If this factory was to install a 60kW PV system (Figure 6) that exported at a unity power factor, only the active power that is imported from the grid would be affected. The imported active power

from the grid has been reduced to 40kW, while the reactive power imported from the grid remains constant at 32.9kVAr. As can be seen from the phase diagram, this has the effect of reducing the power factor to 0.77 - lagging.
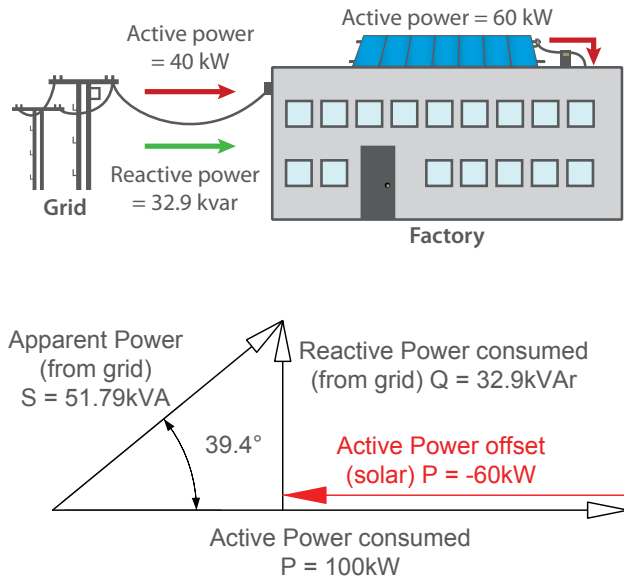

Figure 6: *Factory with 60kW PV system producing power at a unity power factor*

This problem of poor power factor however can be addressed through the selection of appropriate inverter products. Inverters with reactive power control can be configured to produce both active and reactive power, i.e. an output that is at a non-unity power factor. This means that the power factor for the load can be kept within reasonable limits.

Figure 7 (following page) shows the factory with the inverter set to a power factor of 0.95 - leading. The PV system is now producing 57kW of active power and 18.7kVAr of reactive power, reducing the amount of both active and reactive power from the grid. The resultant power factor is therefore maintained at what it was originally at 0.95 – lagging.

Creating sustainable change through education, communication and leadership
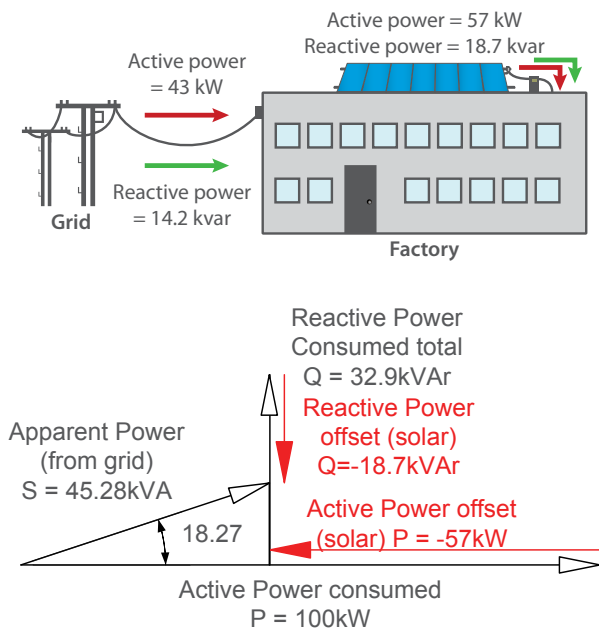
Figure 7: *System installed with reactive power control to produce both active and reactive power*

It would be possible to configure this inverter to produce more reactive power and bring the factory to a unity power factor. The optimal power factor that the inverter is programmed to export at will depend on the energy contract of the consumer. Utilities can bill industrial and commercial customers for the energy they consume, their peak demand, and their power factor. Any solar system should therefore be designed to produce the maximum amount of savings across all of these areas. For example, it may be financially beneficial to reduce the amount of active power drawn from the grid at the expense of increased charges due to a poor power factor.

GSES welcomes feedback on technical papers and other resources available on www.gses.com.au, please contact GSES by email at info@gses.com.au or by telephone on 1300 265 525.

Creating sustainable change through education, communication and leadership