The guide to reactive power

An npower briefing note

Electricity can be either direct current (DC) or alternating current (AC). Electricity supplied from a battery will be DC but that supplied from the public electricity supply is AC. AC has the advantage that it can be transformed to higher voltages where losses in its transmission are significantly lower than those that would be incurred at lower voltages.

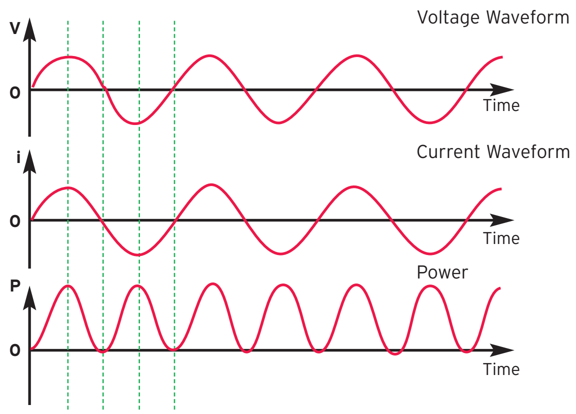
The power that is supplied to a customer is the product of the voltage at which the supply is given, and the current that is drawn by the customer's equipment. For an AC supply the voltage and the current both have an alternating or sinusoidal waveform.

The flow of current in an electrical circuit can be impeded in a number of different ways. Three different forms of impedance can be identified:

- **Resistance** - where the power is dissipated in the production of heat or light
- **Inductance** - where a magnetic field is created such as in transformers and motors
- **Capacitance** - where an electrical charge is naturally stored such as in the operation of fluorescent lighting

In a purely resistive circuit the current waveform is precisely synchronised with the voltage waveform. The power dissipated in a circuit at any point in time is the product of the current and voltage at that instant. As can be seen from figure 1 the power follows the same waveform but has twice the frequency of the voltage and current waveforms. The value of the power waveform is always positive, and the area under the waveform will be the energy recorded by the kWh meter.

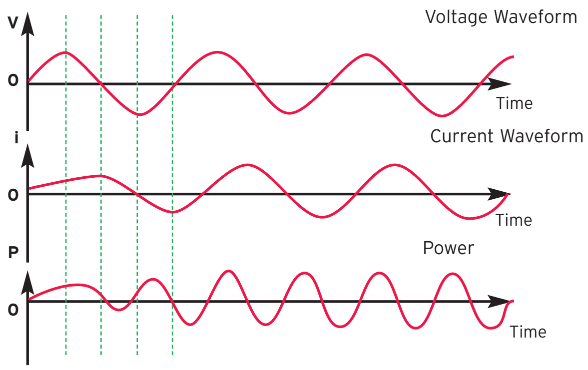
Figure 1 – Voltage, Current and Power in a resistive circuit



In a predominantly inductive circuit, which will have equipment that incorporates a magnetic circuit, the current produces an alternating flux in the magnetic part of the circuit. In order to establish the magnetic flux a magnetising current has to flow into the circuit. At the instant the circuit is completed there is an inrush of magnetising current but this flow cannot keep pace with the voltage. This might be viewed as a form of electrical inertia and causes the current to lag the voltage.

The relationship between the voltage, current and power waveforms in this type of circuit are illustrated in Figure 2. If the circuit is solely inductive then the current lags the voltage by a quarter of a cycle and the product of the current and voltage waveforms produces a waveform for the power that has a frequency of twice the voltage frequency, but whose average value is zero. This is known as wattles power, or more commonly "reactive power".

Figure 2 – Voltage, current and power in a purely inductive circuit

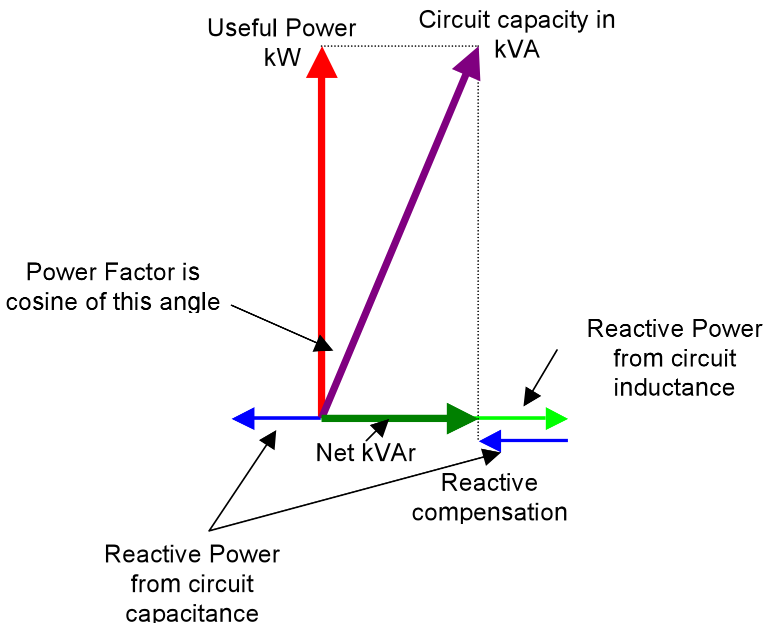


In a predominantly capacitive circuit an electrical charge is maintained in the circuit. A similar effect occurs to that in an inductive circuit but now the current waveform leads the voltage waveform as the voltage is subject to the inertia created by the electrical charge in the circuit. If the circuit is solely capacitance then the current leads the voltage by a quarter of a cycle and the product of the voltage and current again has an average value of zero, hence the associated power is again "wattles" and no energy can be extracted from it.

In a circuit where there is both inductive and capacitive impedances the combination of a lagging and leading current waveforms will tend to cancel each other out. Thus the reactive power in an inductive circuit, which is that most commonly found in industry and commerce, can be corrected through the installation of capacitors.

In practice circuits are invariably combinations of resistance, inductance and capacitance. The combined effect of these impedances to the flow of current is most easily assessed by expressing the power flows as vectors that show the angular relationship between the power waveforms associated with each type of impedance. Figure 3 shows how the vectors can be resolved to determine the net capacity of the circuit needed to transfer the power requirements of the connected equipment.

Figure 3 – Vector diagram to analyse power flows



The useful power that can be drawn from the electricity distribution system is represented by the vertical vector in the diagram and is measured in kilowatts (kW). The reactive or wattles power that is a consequence of the inductive load in the circuit is represented by the horizontal vector to the right and the reactive power attributable to the circuit capacitance by the horizontal vector to the left. These are measured in killovars (kVAr). The resolution of these vectors, which is the diagonal vector in the diagram is the capacity required to transmit the active power, and is measured in killovolt-ampere (kVA). The ratio of the kW to kVA is the cosine of the angle in the diagram shown as theta, and is referred to as the "power factor".

When the net impedance of the circuit is solely resistance, so that the inductance and capacitance exactly cancel each other out, then the angle theta becomes zero and the circuit has a power factor of unity. The circuit is now operating at its highest efficiency for transferring useful power. However, as a net reactive power emerges the angle theta starts to increase and its cosine falls.

At low power factors the magnitude of the kVA vector is significantly greater than the real power or kW vector. Since distribution assets such as cables, lines and transformers must be sized to meet the kVA requirement, but the useful power drawn by the customer is the kW component, a significant cost emerges from having to over-size the distribution system to accommodate the substantial amount of reactive power that is associated with the active power flow.

The general practice is to meter the kW and kVAr of a supply separately. The capacity of the distribution network that is required to service a customer's supply is then inferred by combining the active power component and the reactive power component. Metering for larger customers will have two registers for a load or four registers where there is generation on site. The kVA capacity is usually calculated from the maximum level of active (kW) and reactive (kVAr) demand over a month.