How is the Energy Measured in AC Circuits?

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Part I

What is Electrical Energy?

Electrical energy is electrical power consumed by a load for a period of time.

Electrical energy is defined by following equation:

Electrical Energy (kWhr) = Power (kW) x Time (hr)

Electricity used in Homes/offices is measured in terms of 'unit' by utilities

1 unit = 1 kWhr.
This means if 1kW load is ON for 1 hour then energy consumed is
E = P xt = 1kW x 1hour = 1kWhr = 1 unit

Consider the following example to clarify the concept

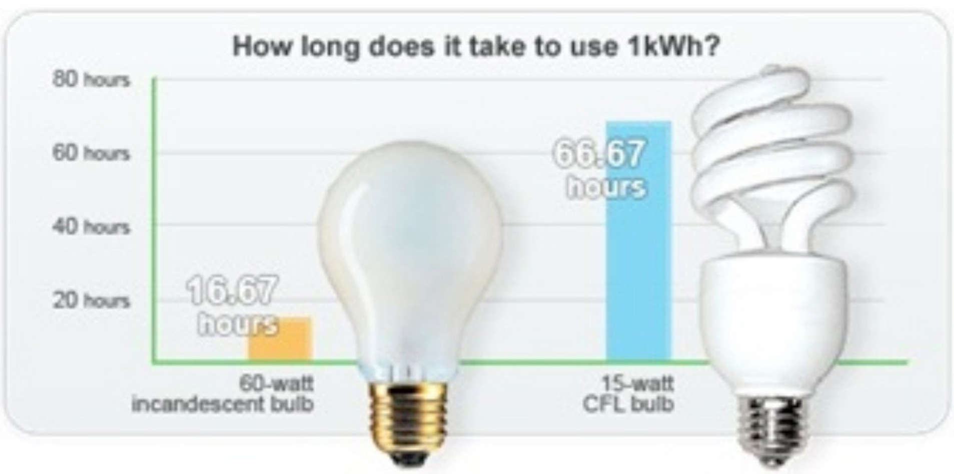

Fig : 1

In the Fig 1, there are two lamps, one of 60W and another of 15W

The lamp of 6OW (0.06kW) load will take 16.67 hours to complete one unit (1 kWhr)

E = 0.06 kW x 16.67 hr = 1 kWhr

The lamp of 15 W (0.015kW) load will take 66.67 hours to complete one unit (1 kWhr)

E = 0.015 kW x 66.67 hr = 1 kWhr

From the above equations, it can be seen that 60W bulb requires 16.6 hours to consume 1 unit of electricity whereas 15 W bulb takes 66.67 hours for the same.

Therefore, the time required for consuming 1 unit of Electricity is lower when Power of the load is higher and vice-versa.

Conclusion: Why measuring the energy matters

Energy measurement is a key requirement in calculating the cost of electricity consumed by homes, offices and industrial plants. Effecient energy measurement provides data that can aid in developing strategies to reduce energy consumption and cut losses.

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Types of Electrical Energy

Electrical energy is classified into three types: Active Energy, Reactive Energy and Apparent Energy. The classification is based on the type of power: Active Power, Reactive Power and Apparent Power

1. Active Energy is defined by following equation:

Active Energy (kWhr) =Active Power(kW) x Time (hr)

2. ReActive Energy is defined by following equation:

Reactive Energy (kVArhr) =Reactive Power(kVAr) x Time (hr)

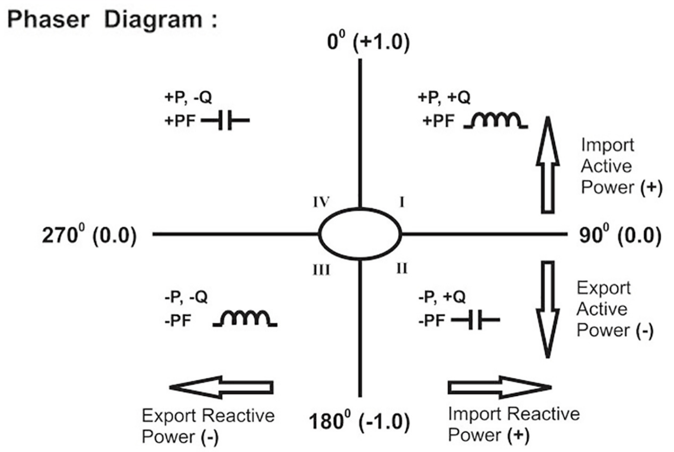
3. Apparent Energy is defined by following equation:

Apparent Energy (kVAhr) =Apparent Power(kVA) x Time (hr)

Active Energy is further classified depending on direction of the power(Positive or Negative).

Active Energy	Reactive Energy
Active Energy Import	Reactive Energy Import
Active Energy Export	Reactive Energy Export

Direction of power depends on the quadrant (I,II,III or IV) in which the load is used.



Connections with respect to active Power	Quadrant	Sign of Active Power (P)	Sign of Reactive Power (Q)	Sign of Power Factor (PF)	Inductive / Capacitive
Import	I	+ P	+ Q	+ ve	L
Import	IV	+ P	- Q	+ ve	C
Export	II	- P	+ Q	- ve	C
Export	III	- P	- Q	- ve	L

The above diagram illustrates the direction of Active Power (P) and Reactive Power (Q) in all the four quadrants of measurement

When the sign of Active Power (P) is positive, it is called Import Active power and hence Import Active Energy. This is possible in Quadrant I and IV

When the sign of Active Power (P) is negative, it is called Export Active Power and hence Export Active Energy. This is possible in Quadrant II and III.
Similarly, when reactive Power (Q) is positive, it is referredto as import and when negative it is export.

Conclusion

To sum up, when the load consumes Active Power, Active Power is Positive and therefore called Import Active Energy. When the generator supplies active power, the sign of active power is negative and therefore called Export Active Energy

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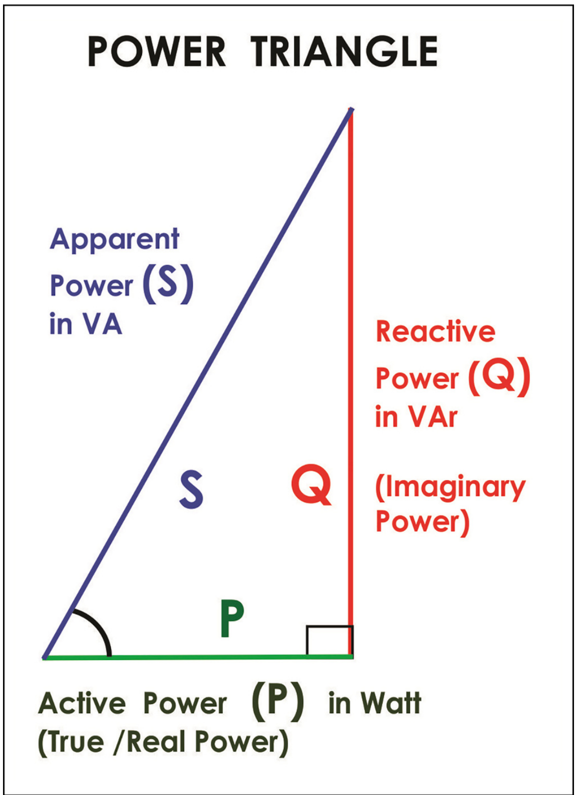
Power measurement: Multifunction meter measures power parameters like Active Power, Reactive Power and Apparent Power of the network in which it is installed. The network could be 3 phase 4 Wire or 3 phase 3 wire or single phase. Read ahead to explore the details of each parameter.



By Pythagoras theorem
$S = (P^2 + Q^2)^{1/2}$

Active Power (P) is defined as the power that is actually consumed or dissipated by the load. It is measured in Watt. This is the real power as it does does work and is utilized. Hence it is useful bower and is called true or real power. For example, when the load Is resistive, the power consumed is dissipated into the resistor in the form of heat. When a motor runs, the power that is used to rotate the motor is active power. When we switch the lights ON, the power that converts electricity into light is active power.

For 1 phase,
Active Power (P) = Voltage (VLN) x Current (I) x Cos (Phi)
where Phi is the angle between V LN and I.
VLL = Line to Line Voltage
For 3 phase 4 wire,
Active Power (P) = 1.732* Voltage (VLL) x Current (I) x Cos (Phi)

Reactive Power is defined as the power that is neither consumed nor dissipated but is taken from the grid and given back to the grid repeatedly. This power keeps moving back and forth between grid and load and not used for any useful work. Reactive power is measured in VAr (Volt-Amp-reactive).

It is stored in and discharged by capacitive or inductive load. Due to its lack of usefullness, it is also called Imaginary Power. It exists due to presence of reactive load (capacitive or inductive load). More the reactive load, more the reactive power.

For 1 phase,
Reactive Power (Q) = Voltage (VLN) x Current (I) x Sin (Phi) For 3 phase 4 wire,
Reactive Power (Q) = 1.732 * Voltage (VLL) x Current (I) x Sin (Phi)

Apparent Power is measured in volt-amperes (VA) and is the voltage of an AC system multiplied by all the current that flows in it. Apparent Power is the total power of the system. It is the vector sum of the active and the reactive power.

For 1 phase, Apparent power (S) = Voltage (VLN) x Current (I)

For 3 phase 4 wire,
Apparent power (S) = 1.732 x Voltage (VLL) x Current (I)

Power Triangle: The relation between Apparent Power (S), Active Power (P) and Reactive Power (Q) can be best explained using "Power Triangle" shown in adjoining figure. As these parameters form a right angle triangle, there exists Pythagorean relationship between them. Apparent Power is the hypotenuse, hence S = square root of (P2+Q2).

Conclusion

As the above equation illustrates, apparent power has to supply not only the active power component but the reactive power component as well which is actually not contributing to useful work. Higher the reactive component, more is the apparent power wasted. Thus, it is clear that reactive power reduces the efficiency of the system and hence is undesirable.

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Metering Type CT'S
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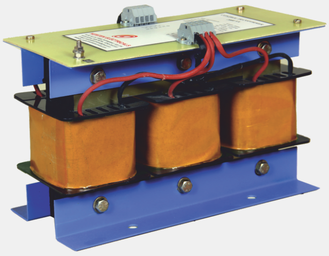

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