Power Quadrant

This article will talk about the Power Quadrant and the information it can quickly convey graphically about the behavior of a power system before any further detailed analysis.

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AC POWER

Power in the context of an AC system is affected by the phase angle between the voltage and current which determines the type of power and whether it is being consumed or generated. The types of power that are seen in an AC system are as follows:

1) **Active power** or **Real power (P)** is the power that performs work and is absorbed by the resistive components of a system. Measured in Watts (W), average active power is defined by (1).

$$P = V_{RMS} I_{RMS} \cos(\theta_v - \theta_i) \quad \ldots (1)$$

$(\theta_v - \theta_i)$ is the phase difference between the voltage and current at the fundamental frequency. Active power is said to be consumed when positive and generated when negative.

2) **Reactive power (Q)** is the power that does not preform useful work and is used by the reactive components of a system i.e., inductors and capacitors that continuously stores and releases this power [1]. Measured in Volt-Amperes Reactive (VAR), reactive power is defined by (2).

$$Q = V_{RMS} I_{RMS} \sin(\theta_v - \theta_i) \quad \ldots (2)$$

Reactive power is stored when positive and released when negative.

3) **Complex Power (S)** is total power combining both the reactive and active power into one quantity. Measured in Volt-Amperes (VA). It is expressed in the complex form by (3).

$$S = P + jQ \quad \ldots (3)$$

Where its magnitude is known as the 'Apparent Power' and the phase is equal to $(\theta_v - \theta_i)$. The cosine of the phase is referred to as the 'displacement power factor' (DPF) or simply power factor (PF).

DPF is considered lagging when the current lags the voltage or leading when current leads the voltage.

POWER QUADRANT

From equation (3), complex power can be graphed on the complex plane where the real axis is active power and the imaginary axis is reactive power as seen in Figure 1. This graph is known as the Power Quadrant graph.

Figure 2 shows complex power plotted for the four (4) sign combinations of P and Q; as referenced from the IEEE1459-2010 standard [2]. [2] defines the reference direction is from the source to the load.

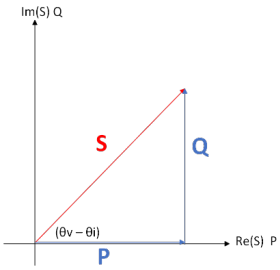

Figure 1 *Complex Power drawn on the complex plane/power quadrant*

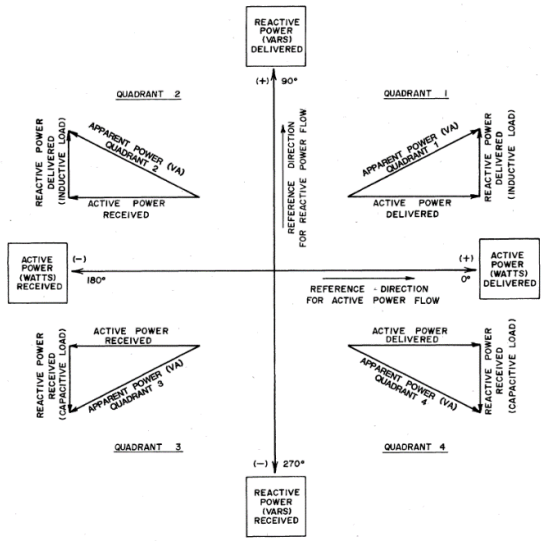

Figure 2 *Power quadrant from the IEEE1459-2010 standard*

Table 1 characterises the impedance properties of each quadrant in Figure 2. Column 4 in Table 1 shows that power factor is only positive in the first and fourth quadrants meaning power flow is to the load. Alternatively power factor is negative in quadrants 2 and 3 meaning power flow is to the source.

Quadrant	Active Power	Reactive Power	Power factor
1st	+ (consume)	+ (inductive)	Lagging (+)
2nd	- (generate)	+ (inductive)	Lagging (-)
3rd	- (generate)	- (capacitive)	Leading (-)
4th	+ (consume)	- (capacitive)	Leading (+)

Table 1

IEC standard IEC 60253-23-2003 [3], however, defines the second and third quadrants as capacitive and inductive respectively as seen in Figure 3.

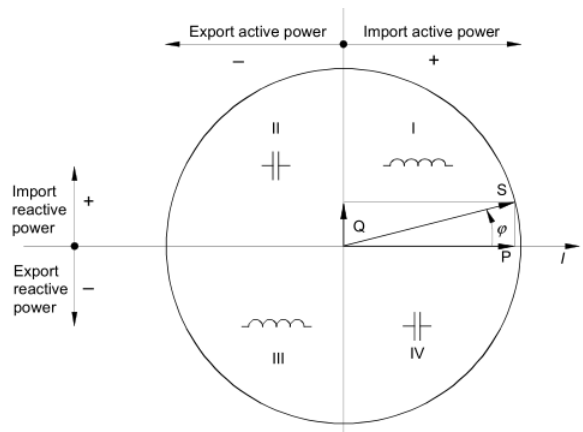

Figure 3 *Power quadrant from IEC 62053-23-2003*

With IEC, the defined source and load is not fixed and changes based on the direction (sign) of power factor.

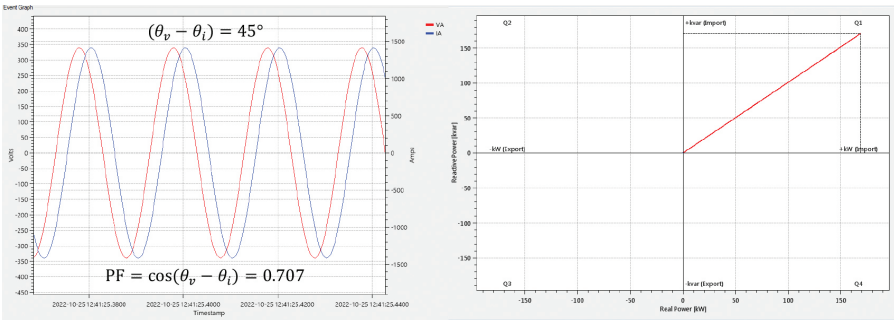

Figure 4 *Load in quadrant 1 along with the corresponding waveform where blue waveform = current, red waveform = voltage*

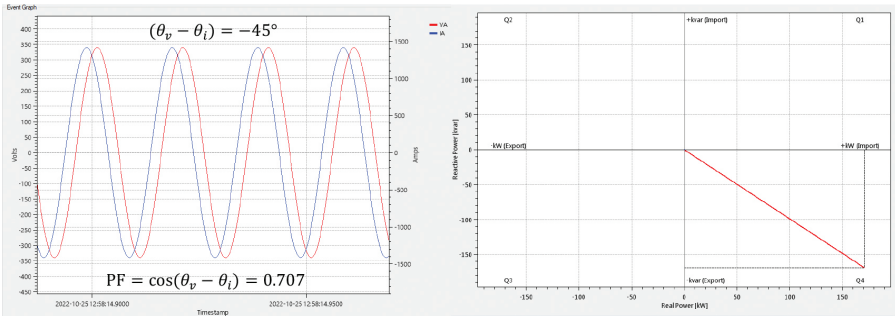

Figure 5 *Load in quadrant 4 along with the corresponding waveform where blue waveform = current, red waveform = voltage*

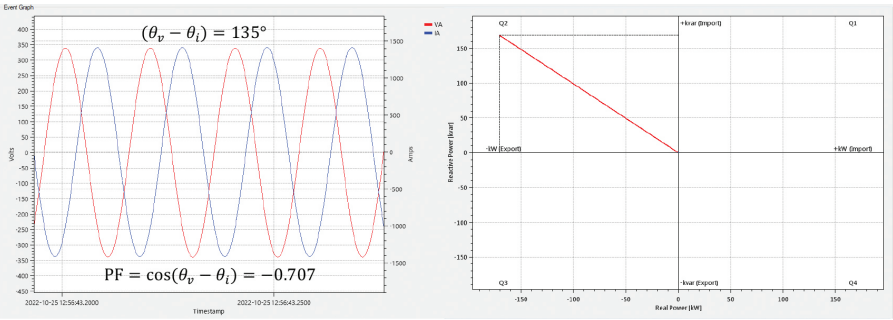

Figure 6 *Load in quadrant 2 along with the corresponding waveform where blue waveform = current, red waveform = voltage*

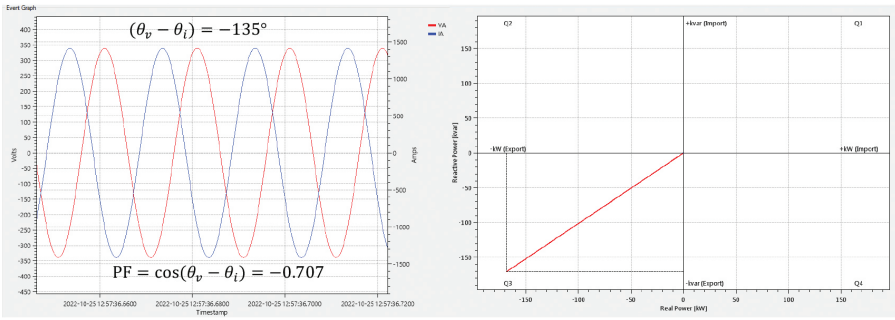

Figure 7 *Load in quadrant 3 along with the corresponding waveform where blue waveform = current, red waveform = voltage*

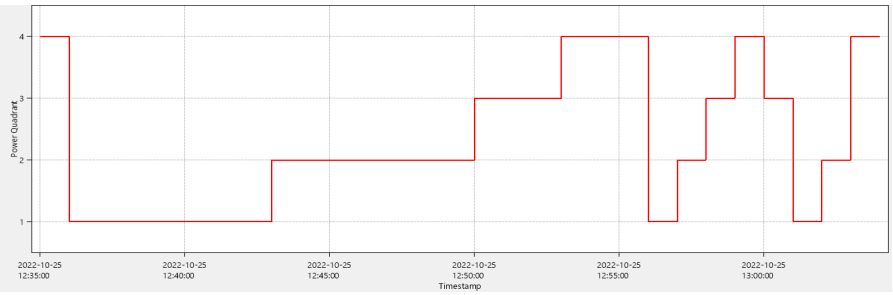

Figure 8 *Logging of the Power Quadrant with respect to time for the simulated load*

EXAMPLE (WITH MIRO PQ45)

Figure 4 and Figure 5 show current lagging and leading the voltage respectively. As expected, complex power appears on the first and fourth quadrants respectively.

Figure 6 and Figure 7, show current lagging and leading the voltage respectively with a negative power factor. As expected, complex power appears on the second and third quadrants respectively.

CHK Power Quality's portable power quality analyser model Miro PQ45 also logs and displays step changes in quadrant power over time as seen in Figure 8. This makes it for users to quickly determine which quadrant the power was in.

CHK PQ is an Australian engineering company that specialises in the design and manufacture of Power Quality Analysers, Load Loggers and Asset Condition Monitoring instruments. Our core focus is providing engineering solutions, products, and services for improving Power Quality and Asset Condition Monitoring, thereby allowing customers to optimise the maintenance, operations reliability and efficiency of their assets and networks.

References

[1] *R. N. J. David Irwin, Basic Engineering Circuit Analysis 9th edition, 2008.*

[2] *IEEE 1459-2010 Standard Definitions for the Measurement of Electric Power Quantities Under Sinusoidal, Nonsinusoidal, Balanced, or Unbalanced Conditions, IEEE, 19 March 2010.*

[3] *International Electrotechnical Comission, IEC 62053-23:2003 Electricity metering equipment (a.c.) - Particular requirements - Part 23: Static meters for reactive energy (classes 2 and 3), 2003-01-29.*