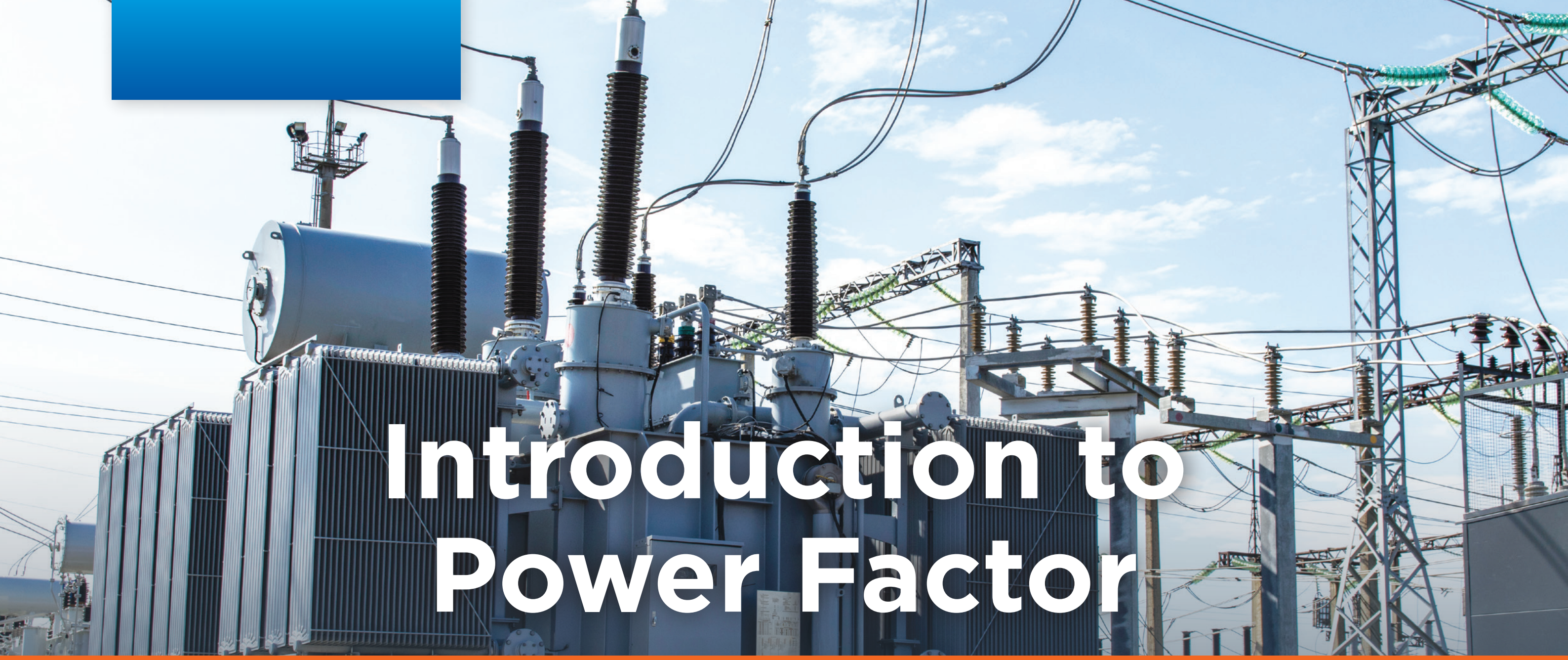

Introduction to Power Factor

This article presents Displacement Power Factor (DPF) and True Power Factor (TPF). DPF is often used in passive circuits while TPF is a generalised parameter and used when considering non-linear circuits such as rectifiers.

By Richard Lam

For AC power, the phase angle between the voltage and current determines the power present and its relative magnitude. The type of power present in an AC system are:

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

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

- **Reactive power (Q)**: Power that does not perform 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) and is defined in (2) as:

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

The total power consumed/generated for both powers can be represented as one quantity in the phasor domain. This term is known as Complex Power. It is measured in Volt-Amperes (VA) and is expressed in the complex form by (3).

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

Its magnitude |S| is known as the apparent power and is also equal to the product of the RMS voltage and current. Its phase angle ($\theta_v - \theta_i$) is the phase difference between the voltage and current. This is represented graphically on the complex plane as seen in Figure 1 and is referred to as the power triangle.

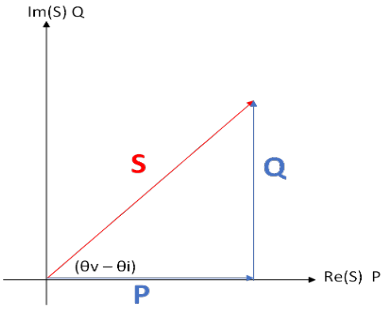

Figure 1 *Power triangle of the Complex Power on the complex plane*

The cosine of the complex power's phase angle at the fundamental frequency is the Displacement Power Factor (DPF) or commonly known as simply Power Factor (PF). Also, DPF is equal to the fundamental Active Power (P_f) divided by the fundamental Apparent Power ($|S_f|$). DPF is mathematically given by equation (4).

$$\text{DPF} = \cos(\theta_v - \theta_i) = \frac{P_f}{|S_f|} \quad \dots (4)$$

DPF indicates how much of the Apparent Power is doing useful work. In (4), P_f can be positive or negative, and therefore DPF ranges between -1 to 1 (inclusive). DPF assumes one frequency component.

Non-linear circuits give rise to harmonic frequency components and in which case, a useful parameter is True Power Factor (TPF) as given in equation (5). TPF considers Active Power at all frequency components including the DC component (P_0). TPF is equal to DPF when no harmonics or DC component are present in the system, otherwise TPF < DPF [2].

$$\text{TPF} = \frac{P_{total}}{|S_{total}|} = \frac{P_0 + P_f + \sum_{i=2}^{i=n} P_i}{V_{RMS} I_{RMS}} \quad \dots (5)$$

EXAMPLES: NON-LINEAR CIRCUITS

Figure 2 shows a practical installation of a Miro PQ45 power quality analyser connected to measure the input voltage and current of a non-linear system where the load is resistive. Figure 3 and Figure 4

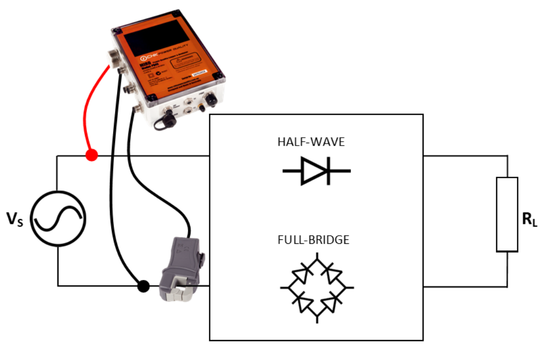

Figure 2 *Test up setup with the Miro and the half-wave/full-bridge rectifier. These tests mimic how measurements would be made in the field where only the input is accessible.*

are measurements of the input voltage and current for when the non-linear system is configured as a full-bridge and half-wave rectifier respectively.

Figure 3 shows voltage and current are in phase and the measured DPF and TPF by the Miro PQ45 is 0.999 and 0.920 respectively, close to unity as expected. Theoretically in the case of ideal diodes, the DPF and TPF will both yield unity. In Figure 4, the voltage and current are in phase, but the current waveform is a half-wave which introduces even harmonics. As a result, the DPF and TPF measured by the Miro PQ45 is 0.999 and 0.722 respectively. Theoretically, the TPF is equal to 0.707 [3]. T&D

References

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

[2] *E. F. F. Mohammad A.S. Masoum, Power Quality in Power Systems and Electrical Machines Second Edition, Academic Press, 2015.*

[3] *D. W. Hart, Power Electronics, McGraw Hill, 2011.*

CHK Power Quality Pty Ltd

Please contact us for a free and no obligation demonstration or trial:
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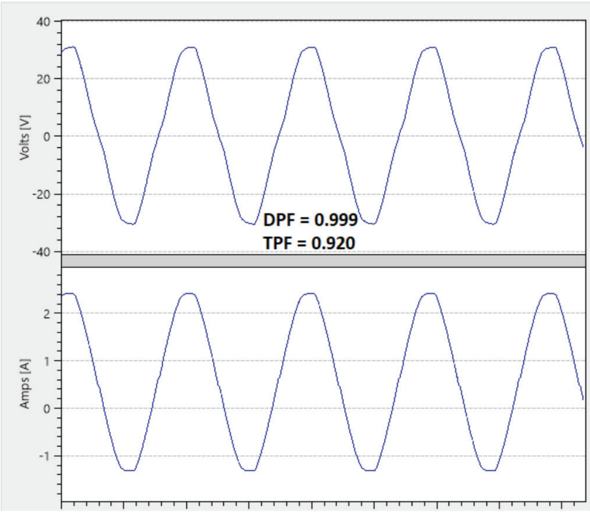

Figure 3 *Input voltage and current waveform for the full-bridge rectifier along with measured DPF and TPF values*

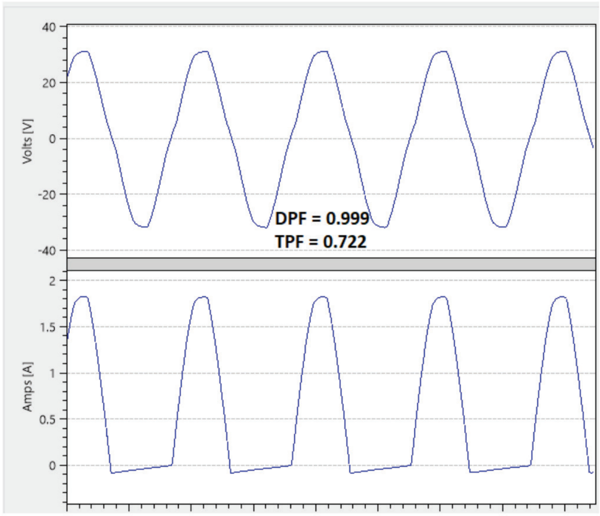

Figure 4 *Input voltage and current waveform for the half-wave rectifier along with measured DPF and TPF values*