Chapter 10

3-phase power monitoring

TEC/NOT/013

This paper examines the nomenclature and techniques used for AC power monitoring. In particular, the root-mean-square (RMS) values for voltages and currents, active power, apparent power, and power factor are outlined.

The following topics are discussed:

10.1 Overview

Electrical generators consist of a rotor that induces a voltage on stator windings as it rotates (ignoring solar power and batteries). For aircraft applications, the generator may be part of a main engine assembly or a dedicated motor. Often there is a backup mechanism in the event of failure.

This rotation causes an alternating voltage, or current, to be induced on the stator (hence AC). These AC signals can be thought of as sine waves:

$$V = A_v \cdot Sin(2 \cdot \pi \cdot f \cdot t)$$

$$I = A_I \cdot Sin(2 \cdot \pi \cdot f \cdot t + \phi)$$

where *A* is the amplitude, *f* is the frequency of rotation and ϕ is the phase angle between the current and voltage.

A 3-phase generator has three sets of windings, equally spaced (at 120°) about the stator. Each has a voltage induced on it. Each voltage lags or leads the next one by 120°.

If the generator is connected to a purely resistive load (no inductance or capacitance), the phase angle (between voltage and current) is 0°. If the generator is connected to an ideal inductor or capacitor, the phase angle is ±90°.

In all three cases, the devices have voltages across them and current through them but only the resistor is dissipating power. In the following figure, the phase angle is 45° (not 0 or ±90°) so it is not purely resistive, capacitive or inductive.

This paper outlines the measurement of voltages and currents and the actual power being dissipated.

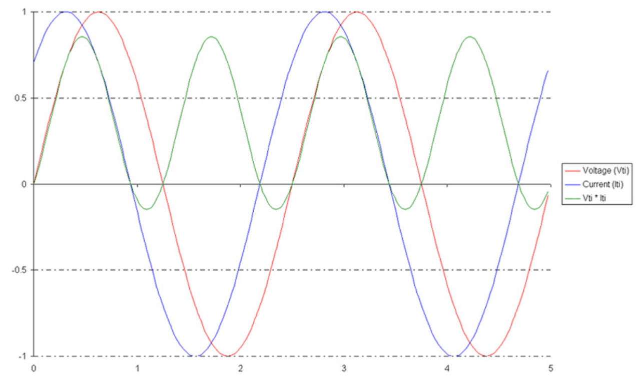

Figure 10-1: Normalized voltage and current for a phase angle of +45° and their product

10.2 Amplitude, average and root-mean-square

The following figure shows a sine wave with an offset. The equation for this is:

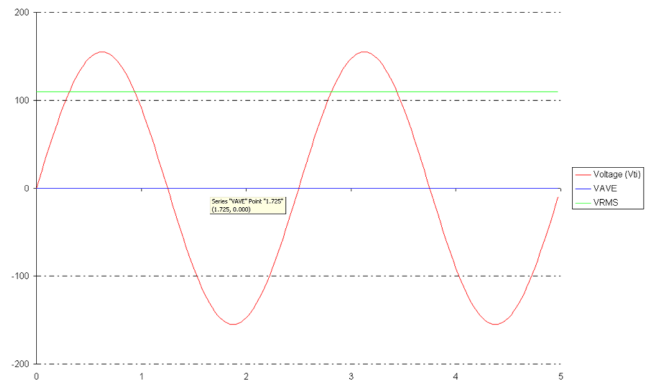

Figure 10-2: Graph of 110V_{rms} at 400 Hz

The **frequency** is -	**400 Hz**
The **period** (1/frequency) is -	**2.5 ms**
The **maximum** value (V_{max}) is -	**157V**
The **minimum** value (V_{min}) is -	**-155V**
The **peak-to-peak** difference ($V_{p\text{-}p}= V_{max}\text{-}V_{min}$) is -	**312V**
The **amplitude** ($V_{p\text{-}p/2}$) is -	**156V**

If a large number of values (for example, N = 2,048) samples (V_i) are taken over an integral number of periods, the average or mean value can be calculated as follows:

$$V_{avg} = \frac{1}{N}\sum_{i=1}^{N} V_i = 1V$$

Similarly, the RMS (root-mean-square) value is:

$$V_{rms} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} V_i^2} \cong 110V$$

If a DC voltage of V_{rms} is connected across a resistor (R), the power dissipated is:

$$Power_{Dissipated} = \frac{V_{rms}^{\ 2}}{R}$$

This is the same as the average power dissipated if $V(t)$ is connected across the same resistor. In other words, V_{rms} squared equals the average of $V(t)$ squared.

For a sine wave (with no offset):

$$Amplitude = V_{max} = -V_{min} = V_{p-p/2} = V_{rms} \times \sqrt{2}$$

$$V_{rms} = (Amplitude)/(\sqrt{2})$$

10.3 Active power, apparent power and power factor

The active power is a measure of the power dissipated in the load. If a large number of values (for example *N* = 2,048) samples for the voltage (V_i) and the current (I_i) are taken over an integral number of periods, the average or mean value for the power can be calculated as follows:

$$P_{active} = \frac{1}{N}\sum_{i=1}^{N} V_i \cdot I_i$$

The average power is called active and the RMS power is called apparent:

$$P_{apparent} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} (V_i \cdot I_i)^2}$$

The power factor is defined as the ratio between active and apparent:

$$Power\_factor = \frac{Active}{Apparent}$$

For a sine wave (with no offset):

$$Active\_power = V_{rms} \times I_{rms} \times Cos(\phi)$$

$$Apparent\_power = V_{rms} \times I_{rms}$$

$$Power\ factor = Cos(\phi)$$

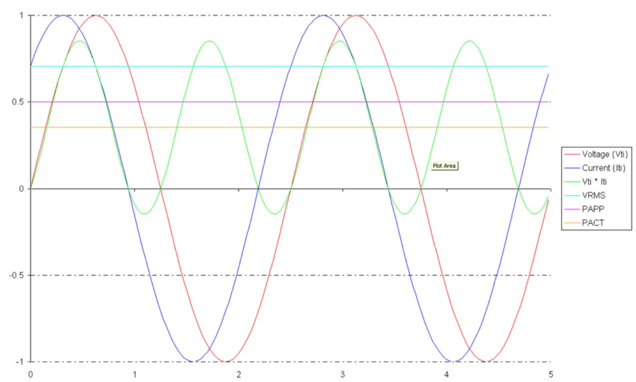

Figure 10-3: Normalized voltage and current for a phase angle of +45° and their product

10.4 Three-phase power monitoring

The following figure displays star and delta connection schemes for three-phase power distribution.

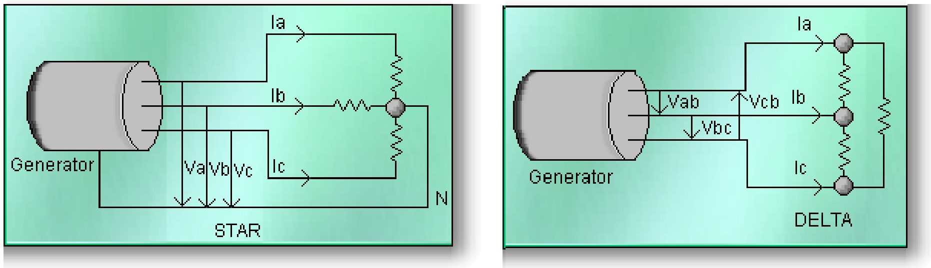

Figure 10-4: Star and delta connections for three-phase power

For balanced loads, the:

- voltage across each of the loads for a delta connection is √3 times that of a star connection
- current through each of the loads for a star connection is √3 times that of a delta connection

There are six connections to be made when monitoring three-phase power. There is one signal for each of the voltages and one for each of the currents. Usually a transformer is used to isolate the instrumentation equipment from the power and to produce a much (1/20) attenuated voltage.

Various sensors (Hall effect, resistor in series) can be used to produce a voltage representing the current.

10.5 Power monitoring and the KAD/ADC/008

Curtiss-Wright's KAD/ADC/008 accepts six single-ended voltage signals (three voltage plus three current). Each signal is connected to a separate A/D and all channels are sampled at the same time. The KAD/ADC/008 measures the period of the signal connected to channel 0 and uses a positive-going-zero-crossing to start (and later to stop) computation of the various parameters.

The maximum, minimum, amplitude, average, RMS, active power, apparent power, and power factor are calculated using the formulae in sections "10.2 Amplitude, average and root-mean-square" on page 2 and "10.3 Active power, apparent power and power factor" on page 3. There is no assumption made that the wave is sinusoidal.

At least 2,048 A/D readings are taken for each channel. If a DC signal is attached to a channel, the algorithm updates every 65,536 samples.

The ACC/TRF/001 is an external transformer that can be used to isolate and attenuate three voltages.

When programming the KAD/ADC/008, the relationship between the input voltage levels and the voltage and current being measured (scaling) should be specified.

10.6 Conclusion

In this paper, some of the nomenclature associated with power monitoring was introduced along with some formulae for deriving parameters such as maximum, minimum, amplitude, average, rms, active power, apparent power and power factor.