Accuracy of Low Power Factor Measurements

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A combination of legislation and local and global environmental programmes are driving the need for manufacturers to perform highly accurate power analysis on their products. This accuracy can be severely affected when analysing loads with low power factors.

Eine Kombination aus Gesetzgebung und lokaler sowie globaler Umweltschutzprogrammen zwingt die Hersteller, eine hochgenaue Leistungsanalyse ihrer Produkte vorzunehmen. Diese Genauigkeit kann bei der Analyse von Lasten mit kleinen Leistungsfaktoren stark beeinflusst werden.

Les industriels ont besoin de faire une analyse de consommation précise d'énergie de leurs produits suite à la législation et aux programmes locaux sur l'environnement. Cette précision peut être sévèrement affectée quand on analyse des charges à faible facteur de puissance.

Una combinazione tra disposizioni legislative e programmi ambientali locali o globali hanno evidenziato la necessità per i costruttori di eseguire sui propri prodotti un'analisi molto accurata relativamente alla potenza. La precisione può essere fortemente degradata quando si analizzano carichi con bassi fattori di potenza.

From power generation through to the electronic equipment that is finally connected to the mains supply there is a growing demand to investigate performance by using high-accuracy power analysis. In many cases this is driven by the pressure on manufacturers to comply with legislative requirements and to address programmes that are designed to promote efficiency and environmental quality.

The need for accurate power measurement has fuelled significant growth in high-accuracy power analysis systems. Unfortunately, measurement problems can occur when using these systems to analyse equipment that operates with a very low power factor. In such cases it is not uncommon for test equipment that is rated for a basic accuracy of say, 0.1%, to return readings that are incorrect by as much as 10-20%.

The Power Transformer

A power transformer is a good example of a product on which manufacturers are expected to make highly accurate power measurements at a very low power factor. One of the most widely used elements in an electricity distribution system, power transformers typically have ratings that range from a few hundred VA (Volt-Amperes) to several hundred kVA and are used to convert electricity from the high voltage levels on utility transmission systems to voltages suitable for the business or the home.

The main pressure on power transformer manufacturers to make accurate power measurements on their products comes from the need to comply with legislation. Of particular importance are IEC76-1 in Europe and IEEE C57 in the USA. Both of these standards detail a number of different tests that should be applied to power transformers. In addition, initiatives such as the USA's Energy Star Transformer Program are also having an increasingly important influence. Designed to "promote competitiveness and environmental quality for America's electric utilities," the Energy Star program is responding to the fact that over 2% of the USA's total annual electricity generation is lost

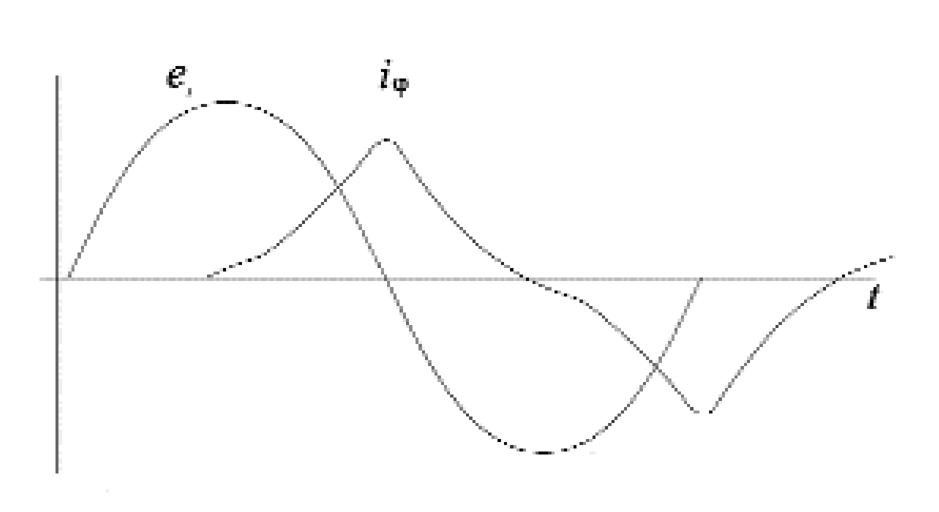

Figure 1.
Phase difference between voltage and current waveforms.

through transformer inefficiency. By making a commitment to purchasing high-efficiency distribution transformers that meet Energy Star guidelines, utilities reduce their waste energy, emissions and operating costs and can use the 'Energy Star' logo now familiar to most PC users.

Open Circuit IEC Testing

The main problem with testing a very high power transformer is that it is difficult to make measurements under full rated load conditions anywhere other than in the final application. Instead, such devices are typically tested under open circuit (off load) and short circuit conditions. The key to testing in accordance with IEC76-1, for example, is open circuit testing as this can provide a measurement of the power lost through hysteresis and eddy current losses in the core.

To perform the test, power is measured by connecting a wattmeter across one winding of the transformer. If a delta-connected winding is used then the connection is from line-to-line, while in a star connected winding the connection is from line-to-neutral. The rated voltage and frequency for the winding under test is then applied with all other windings left open circuit.

Power Analysis with Low Power Factors

The cause of the widely inaccurate power measurements recorded by many measurement systems during such tests stems from the fact that a large transformer wound with large conductors offers very low resistance and is almost a pure inductor. This means that the phase difference (Φ) between the voltage and the current waveforms is nearly 90º (*figure 1*) and the power factor ($\cos\Phi$) is almost zero (typically, between 0.1 and 0.001).

However, because the accuracy of many test instruments is often specified with a power factor of 1, problems can result even when the absolute phase accuracy of the equipment would seem to be quite good. The following describes why this is the case.

Power (P) can be defined by the expression in a system with sinusoidal voltages and currents:

$$P = VI\cos\Phi \qquad (1)$$

There can be error in each element of the measurement, (ΔV, ΔI and $\Delta\Phi$) which results in an error in power, ΔP.

Using the 'chain' rule (1):

$$\Delta P = dP/dV \times \Delta V + dP/dI \times \Delta I + dP/d\Phi \times \Delta\Phi$$

now $dP/dV = I\cos\Phi$, $dP/dI = V\cos\Phi$, $dP/d\Phi = -VI\sin\Phi$

so $$\Delta P = I\cos\Phi \times \Delta V + V\cos\Phi \times \Delta I - VI\sin\Phi \times \Delta\Phi \qquad (2)$$

Dividing by P (= $VI\cos\Phi$) gives:

$$\Delta P/P = \Delta V/V + \Delta I/I - \sin\Phi/\cos\Phi \times \Delta\Phi$$

$$\Delta P/P = \Delta V/V + \Delta I/I - \tan\Phi \times \Delta\Phi \qquad (3)$$

and multiplying this by 100 will provide the percentage error in the power measurement.

As can be seen, even though the basic accuracy of an instrument may be good, the significant contribution to the power error derives from the fact that, with a low power factor, Φ will tend to 90° and,

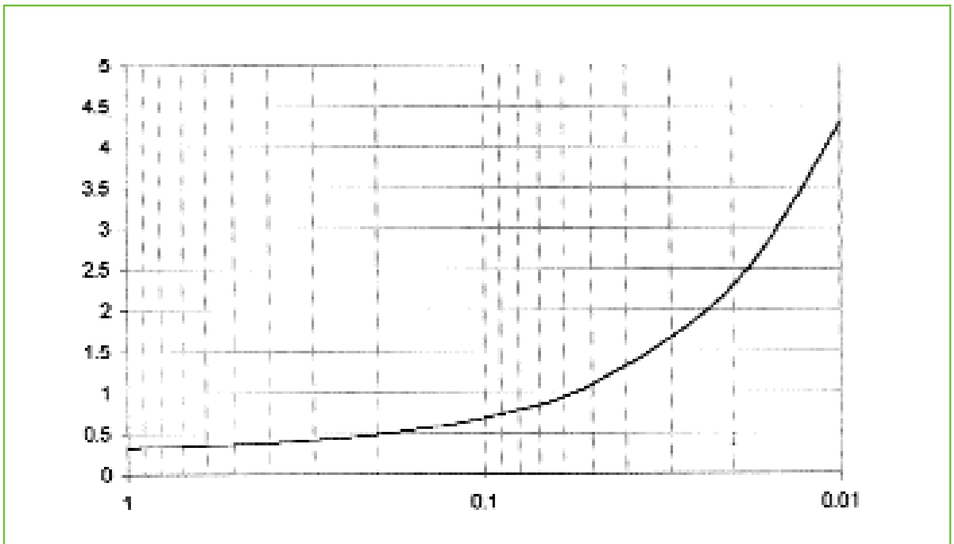

Figure 2.
Power error with varying power factor.

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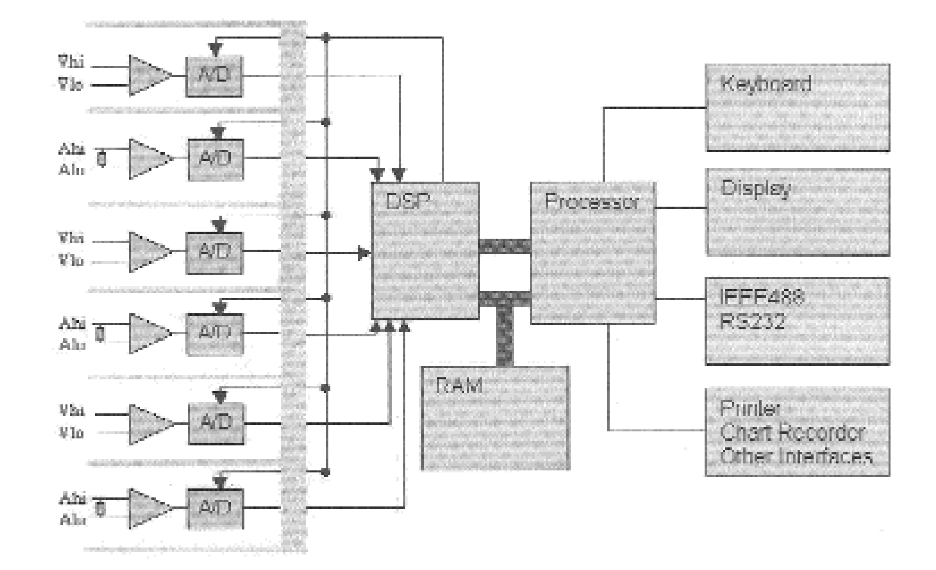

Figure 3.
Three-phase power analyser system.

therefore, tanΦ is very large. Even a seemingly highly accurate instrument can yield errors in the region of 20%. *Figure 2* shows graphically how the maximum power error can vary with power factor.

The issue here, therefore, is not the actual accuracy of the magnitude of the voltage and current measurements that are made but, instead, the absolute accuracy of the watts measurement including errors due to phase differences between the voltage and current measurement channels.

The key to ensuring high-accuracy power measurements in loads with low power factors is to minimise the phase error in the analogue measurement channels by using equipment in which the phase responses are identical for both voltage and current. For instance, in developing the three-phase power analyser described by the block diagram in *figure 3*, Voltech has designed a special current shunt that minimises phase errors by reducing, as far as possible, the parasitic inductance and capacitance.

When combined with proprietary compensation techniques this shunt design allows the current channel to provide exactly the same phase response as the analogue voltage channel.

This design is supported by sampling of the analogue channels at exactly the same moment to ensure no phase errors are introduced during the A/D conversion process. This approach has allowed the company to develop a system that offers phase measurement accuracy to around 0.005° at 50/60 Hz and, therefore, maximum one year power measurement accuracy with low power factors (0.01) of better than 4%. Traceability to International Standards is demonstrated through Voltech's ISO9001 quality system and reference measurements at the UK's National Physical Laboratory (NPL).

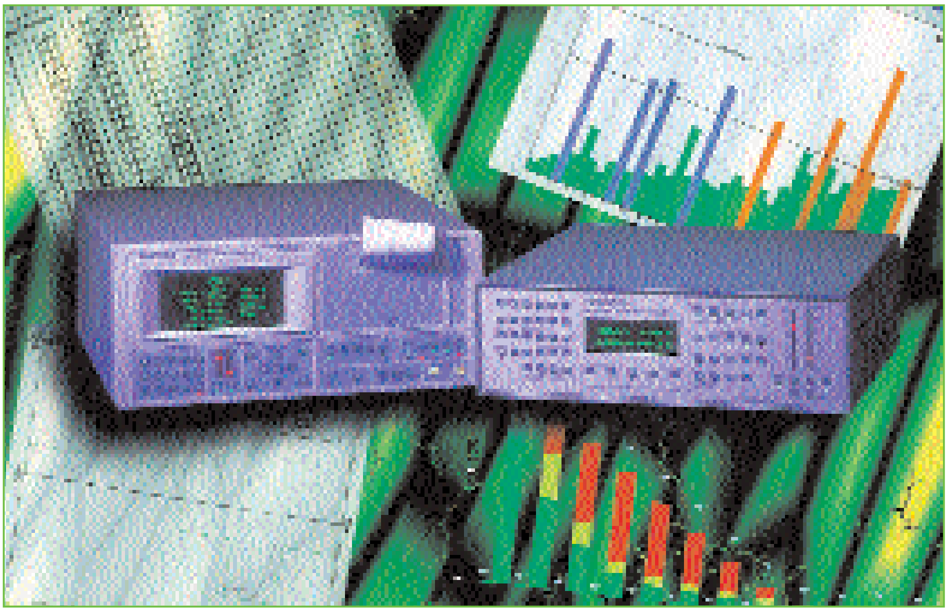

Figure 4.
Graphical software simplifies testing.

Software Simplifies Testing

The new PC-based power analysis software provides diagnostic features that reduce the time needed to test electronic equipment and sub-assemblies in accordance with EMC standards relating to AC mains distortion. Designed for use with PM3000A and PM3300 three-phase power analysers, the Windows-based software (*figure 4*) offers all of the configuration, measurement and reporting functionality needed for rapid set-up and testing of electronic systems in line with IEC1000-3 (IEC555) EMC legislation.

The software provides a graphical user interface for configuration of both the power analyser and any AC test source via an RS232 or IEEE 488 interface. Intuitive menus allow for rapid testing of steady state and fluctuating harmonics in accordance with the Class A, B, C and D categories defined in IEC1000-3-2 and voltage flicker in accordance with IEC1000-3-3.

The diagnostics functionality eliminates the need for additional, time-consuming analysis by allowing the user to rapidly identify the occurrence of non-compliant events and to cross-reference data on screen for identification of possible reasons for non-compliance.

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