Power Quality Application Guide

Harmonics

True RMS – The Only True Measurement

Peak value = 2.6
Crest or Peak factor = 2.6
Form factor = 1.82
True RMS value = 1.0
Averaging RMS measurement = 0.61
Mean value = 0.55

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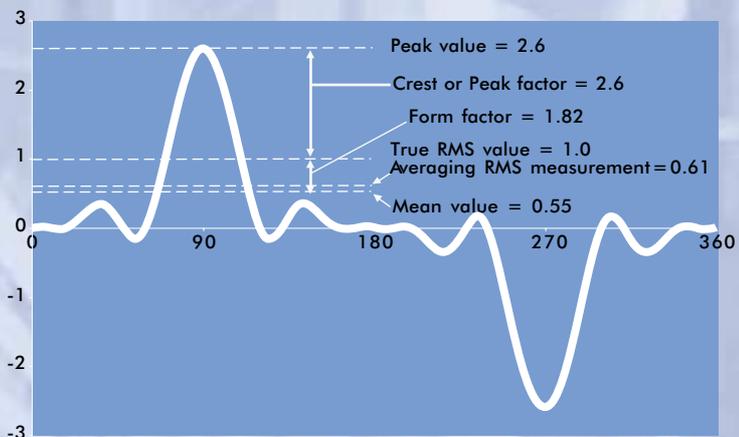
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True RMS – The Only True Measurement

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True RMS – The Only True Measurement

Many commercial and industrial installations suffer from persistent so-called nuisance tripping of circuit breakers. Often these trips seem random and inexplicable but, of course, there is always a reason and there are two common causes. The first possible cause is inrush currents that occur when some loads, particularly personal computers and other electronic devices, are switched on; this issue is discussed in a later section of the Guide. The second likely cause is that the true current flowing in the circuit has been under measured – in other words, the current really is too high.

Under measurement occurs very frequently in modern installations – but why, when digital test instruments are so accurate and reliable? The answer is that many instruments are not suitable for measuring distorted currents - and most currents these days *are* distorted.

This distortion is due to harmonic currents drawn by non-linear loads especially electronic equipment such as personal computers, electronically ballasted fluorescent lamps and variable speed drives. How harmonics are generated, and the effects that they have on the electrical system, are discussed in Section 3.1 of this Guide. Figure 3 shows the typical current waveform drawn by a personal computer. Obviously, this is not a sinewave and all the usual sinewave measurement tools and calculation techniques no longer work. This means that, when troubleshooting or analysing the performance of a power system, it is essential to use the correct tools for the job – tools that can deal with non-sinusoidal currents and voltages.
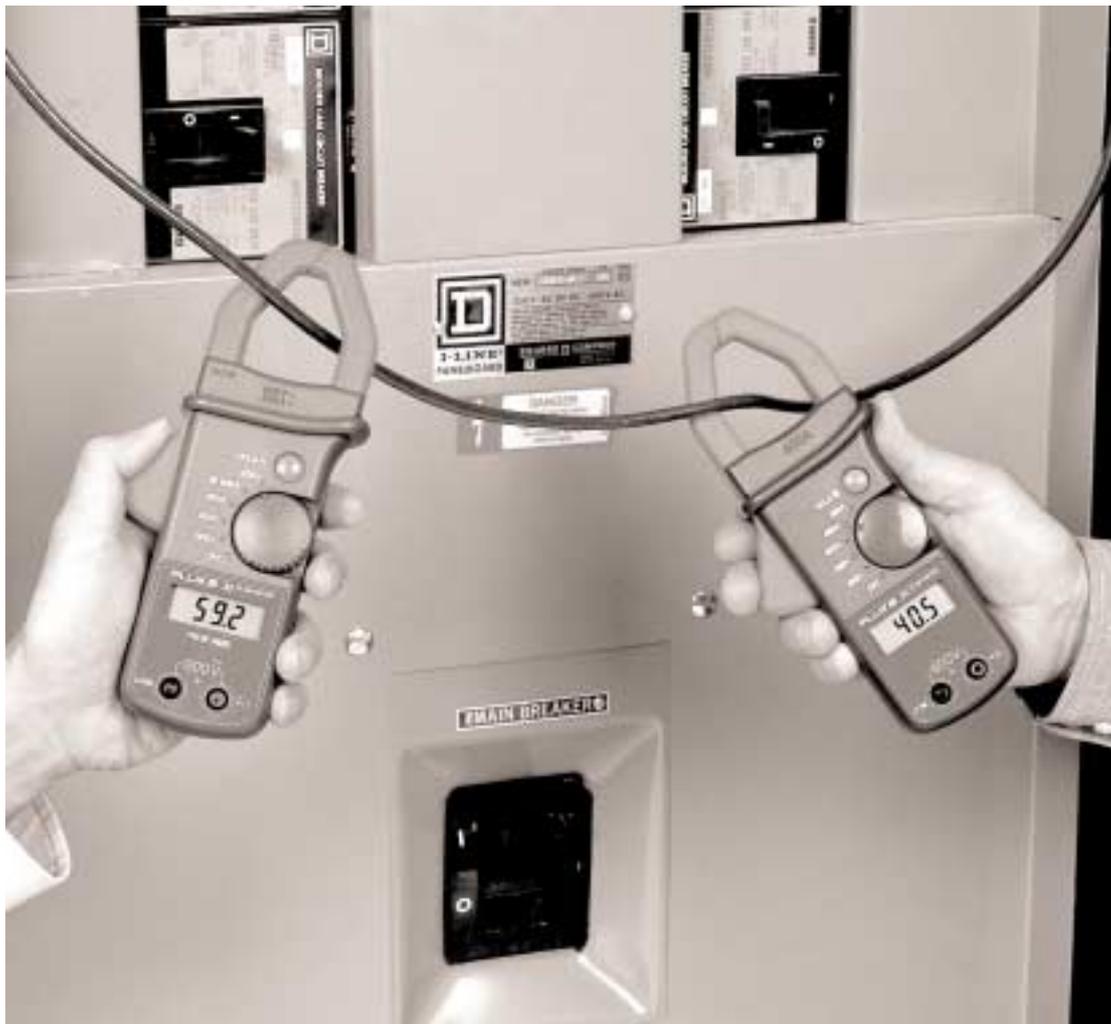

Figure 1 - One current - two readings. Which do you trust? The branch circuit above feeds a non-linear load with distorted current. The True RMS clamp (left) reads correctly but the average responding clamp (right) reads low by 32 %.

True RMS – The Only True Measurement

Figure 1 shows two clamp-meters on the same branch circuit. Both the instruments are functioning correctly and both are calibrated to the manufacturer's specification. The key difference is in the way the instruments measure.

The left-hand meter is a true RMS instrument and the right-hand one is an averaging reading RMS calibrated instrument. Appreciating the difference requires an understanding of what RMS really means.

What is RMS?

The 'Root Mean Square' magnitude of an alternating current is the value of equivalent direct current that would produce the same amount of heat in a fixed resistive load. The amount of heat produced in a resistor by an alternating current is proportional to the square of the current averaged over a full cycle of the waveform. In other words, the heat produced is proportional to the mean of the square, so the current value is proportional to the root of the mean of the square or RMS. (The polarity is irrelevant since the square is always positive.)

For a perfect sinewave, such as that seen in Figure 2, the RMS value is 0.707 times the peak value (or the peak value is √2, or 1.414, times the RMS value). In other words the peak value of 1 amp RMS pure sinewave current will be 1.414 amps. If the magnitude of the waveform is simply averaged (inverting the negative half cycle), the mean value is 0.636 times the peak, or 0.9 times the RMS value. There are two important ratios shown in Figure 2:

$$Peak\ factor\ = \frac{Peak\ value}{RMS\ value} = 1.414 \quad and \quad Form\ factor\ = \frac{RMS\ value}{Mean\ value} = 1.111$$

Peak value = 1.414

True RMS value = Averaging RMS measurement = 1.0
Form factor = 1.11
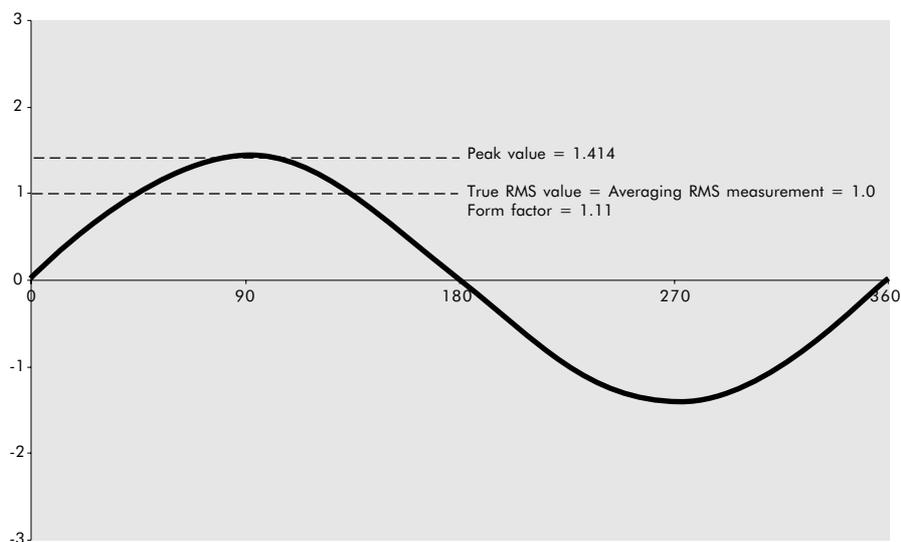
Figure 2 - A pure sinewave

When measuring a pure sinewave – but *only* for a pure sinewave - it is quite correct to make a simple measurement of the mean value (0.636 x peak) and multiply the result by the form factor, 1.111 (making 0.707 times peak) and call it the RMS value. This is the approach taken in all analogue meters (where the averaging is performed by the inertia and damping of the coil movement) and in all older and most current, digital multimeters. This technique is described as 'mean reading, RMS calibrated' measurement.

The problem is that the technique only works for *pure* sinewaves and pure sinewaves do not exist in the real world of an electrical installation. The waveform in Figure 3 is typical of the current waveform drawn by a personal computer. The true RMS value is still 1 amp, but the peak value is much higher, at 2.6 amps, and the average value is much lower, at 0.55 amps.

Figure 3 - Typical waveform of current drawn by a personal computer

If this waveform is measured with a mean reading, RMS calibrated meter it would read 0.61 amps, rather than the true value of 1 amp, nearly 40 % too low. Table 1 gives some examples of the way the two different types of meters respond to different wave shapes.

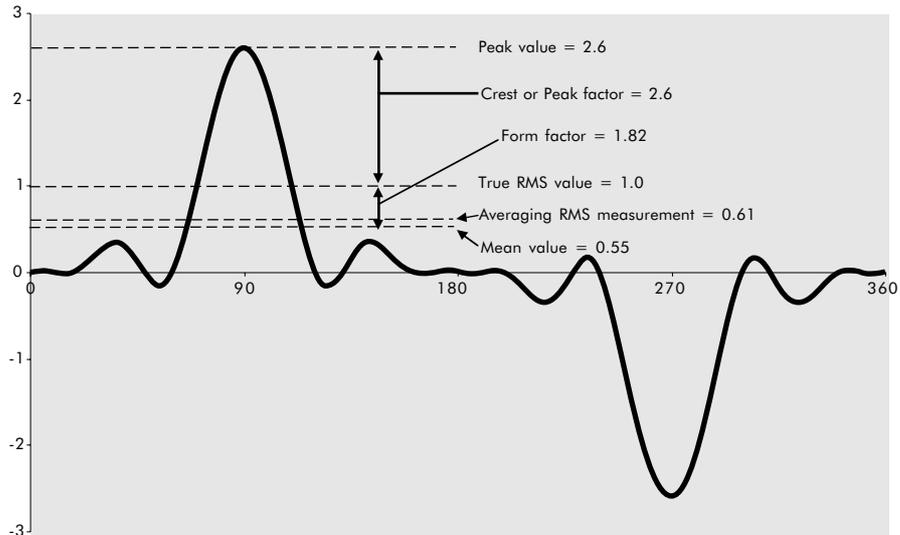A true RMS meter works by taking the square of the instantaneous value of the input current, averaging over time and then displaying the square root of this average. Perfectly implemented, this is absolutely accurate whatever the waveform. Implementation is, of course, never perfect and there are two limiting factors to be taken into account: frequency response and crest factor.

For power systems work it is usually sufficient to measure up to the 50th harmonic, i.e up to a frequency of about 2500 Hz. The crest factor, the ratio between the peak value and the RMS value, is important; a higher crest factor requires a meter with a greater dynamic range and therefore higher precision in the conversion circuitry. A crest factor capability of at least three is required.

It is worth noting that, despite giving different readings when used to measure distorted waveforms, meters of both types would agree if used to measure a perfect sinewave. This is the condition under which they are calibrated, so each meter could be certified as calibrated – but only for use on sinewaves.

True RMS meters have been available for at least the past 30 years, but they used to be specialised and expensive instruments. Advances in electronics have now resulted in true RMS measurement capability being built into many handheld multimeters. Unfortunately, this feature is generally found only towards the top end of most manufacturers' ranges, but they are still cheap enough to buy as ordinary instruments for everyone and everyday.

Multimeter type	Response to sinewave	Response to square wave	Response to single phase diode rectifier	Response to 3ø diode rectifier
Average responding	Correct	10% high	40% low	5-30% low
True RMS	Correct	Correct	Correct	Correct

Table 1 - A comparison of average responding and True RMS units

The consequences of under measurement

The limiting rating for most electrical circuit elements is determined by the amount of heat that can be dissipated so that the element or component does not overheat.

Cable ratings, for example, are given for particular installation conditions (which determine how fast heat can escape) and a maximum working temperature. Since harmonic polluted currents have a higher RMS value than that measured by an averaging meter, cables may have been under-rated and will run hotter than expected; the result is degradation of the insulation, premature failure and the risk of fire.

Busbars are sized by calculating the rate of heat loss from the bars by convection and radiation and the rate of heat gain due to resistive losses. The temperature at which these rates are equal is the working temperature of the busbar, and it is designed so that the working temperature is low enough so that premature ageing of insulation and support materials does not result. As with cables, errors measuring the true RMS value will lead to higher running temperatures. Since busbars are usually physically large, skin effect is more apparent than for smaller conductors, leading to a further increase in temperature.

Other electrical power system components such as fuses and the thermal elements of circuit breakers are rated in RMS current because their characteristics are related to heat dissipation. This is the root cause of nuisance tripping – the current is higher than expected so the circuit breaker is operating in an area where prolonged use will lead to tripping. The response of a breaker in this region is temperature sensitive and may appear to be unpredictable. As with any supply interruption, the cost of failure due to nuisance tripping can be high, causing loss of data in computer systems, disruption of process control systems, etc. These issues are discussed in Section 2 of this Guide.

Obviously, only true RMS instruments will give the correct measurements so that the ratings of cables, busbars and breakers can be determined properly. An important question is, 'Is this meter a true RMS meter?' Usually, if a meter is a true RMS meter it will say so quite prominently in the product specification but this is often not available when needed. A good idea of the answer can be obtained by comparing measurements with a known averaging meter (usually the cheapest to hand!) or a known true RMS meter while measuring the current in a non-linear load such as a PC and the current drawn by a filament lamp. Both meters should read the same current for the filament lamp load. If one instrument reads significantly (say more than 20 %) higher for the PC load than the other then it is probably a true RMS instrument, if the readings are similar, the meters are of the same type.

Conclusion

True RMS measurement is essential in any installation where there is a significant number of non-linear loads (PCs, electronic ballasts, compact fluorescent lamps, etc.). Averaging reading meters will give an under measurement of up to 40 % which can result in cables and circuit breakers being under rated with the risk of failure and nuisance tripping.

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