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Measuring power with a Fluke ScopeMeter® 190 Series

Application Note

Although many electrical test tools are available to measure voltage, few can measure current, and even fewer are equipped to measure electrical power directly. Moreover, there is always the question of how to measure power in electronic systems that are not operating at mains frequencies. The Fluke ScopeMeter 190 Series has the answer.

Power measurements

The prime parameter specified for any electrical system is operating voltage. But that voltage in itself has little meaning if, once applied, it doesn't result in power to, for example, exert a force, drive a machine or run a lighting system. Accurate measurement of electrical power is therefore crucial for understanding a system's behaviour.

Suppose we have an electrical circuit consisting of a voltage source U_1, a switch Sw and a load resistor R_L (see figure 1). By closing the switch, the supply voltage U_1 is connected to the load R_L and a current I will flow as a result. Once this current is flowing, the load will heat as a result of the power applied to it according to:

$$P = U_1 * I \qquad (1)$$

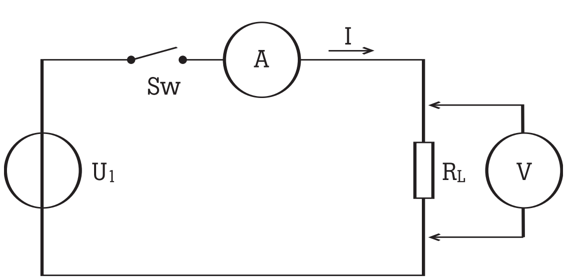

Figure 1. Basic circuit loop in which voltage and current are measured.

This elementary power measurement, using a DC-source for U_1 and a resistive load R_L requires little more than a multimeter, which will usually be a digital multimeter (DMM). The DMM is used first to measure the voltage U_1 and then to measure the current supplied to the load R_L, from which power supplied to the load is calculated from formula (1).

Once the switch is closed, all values in this DC-system are static and therefore the two measurements can be made successively using a single instrument if so desired.

If the source is a low-frequency AC source, the same rules basically apply. We can measure the RMS value of the applied voltage and that of the current, and multiply these to get the power handled by the load. As long as we're working at mains frequencies, most DMMs can do the job.

If the load isn't purely resistive but also includes inductive or capacitive elements, a phase difference between the applied voltage and the current will result that needs to be taken into account to determine the power. The relation now is:

$$P = U_1 * I * \cos \varphi \qquad (2)$$

where j is the phase-angle in degrees between voltage and current.

Multimeters are generally not equipped to make measurements on more than one input and therefore cannot measure phase angle. For these measurements, a more specialized instrument is needed, for instance a phase meter or an oscilloscope.

If power measurements are made more frequently, a power meter like the Fluke 43B Power Quality Analyzer would be the most appropriate test tool. This instrument measures both voltage and current simultaneously and automatically takes the phase angle into account. For the occasional user, however, this may be an expensive option and a more generic tool like the ScopeMeter would be preferred.

Use of the Fluke ScopeMeter

All Fluke ScopeMeters have two input channels and can measure voltage and current at the same time, whilst also measuring and displaying the phase angle between them. See also the section "practical set-up hints" near the end of this publication for further details.

If the voltage is non-sinusoidal or if the load isn't purely resistive, power measurements become too complex to be performed on a DMM. The best way to determine power under these conditions is to take a large number of current and voltage measurements over each cycle of the supply voltage. The measurements need to be made simultaneously on both signals. Each set of simultaneous measurements can then be multiplied to produce a corresponding set of data points from which a curve can be constructed of the power handling at successive moments in time.

The Fluke 190 Series ScopeMeter is capable of performing this specific function for you!

Included in the functionality of the Fluke ScopeMeter 190 Series is the ability to multiply individual curves (waveforms) to create a resultant curve. With this function, sets of samples from channels A and B are multiplied to create a resultant curve labeled M. In other words, every time a sample for channel A and a sample for channel B is taken and written on screen, these are also multiplied and displayed to create the resultant waveform M on screen. From this waveform, the (instantaneous) power can be read off, at every point in time, for instance using the cursors of the Fluke 190 Series.

Example of a light dimmer

As an example, we've applied the mains voltage to a so-called "light dimmer". This is a thyristor-based power control device in which current is allowed to flow only during a selected part of the mains cycle. The effective output voltage to the load (the lights) can be controlled by changing the phase angle. The measured voltage (see figure 2, trace A) shows that the output is active during approximately two-thirds of the time, or about 120 degrees during each half-cycle. During one-third of the time, the dimmer is 'off' and no output voltage is supplied to the lights. If we change this phase angle, the lights will brighten or dim.

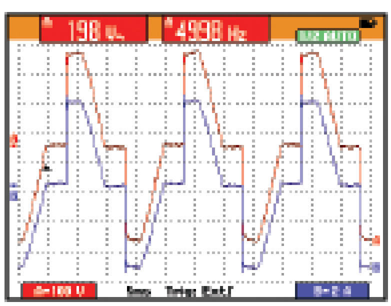

Figure 2. Output voltage and current of a dimmer driving a string of lights.

In figure 2 we can also see the resulting current through the light-bulbs (channel B, blue curve). We can now set up the ScopeMeter to calculate the power applied to the lights (see figures 3 and 4).
To do this select:
SCOPE,
then F4 (= Waveform Options),
next Mathematics, and Enter,
then A * B, and Enter.

Next we select a scaling that we expect will keep the power curve on screen; this may also be changed later. The two input waveforms and the resultant (M) will now be visible. If the resultant is too small or too large, the scaling can be modified. After pressing softkey F3 we can also change the vertical position of the resultant trace M.

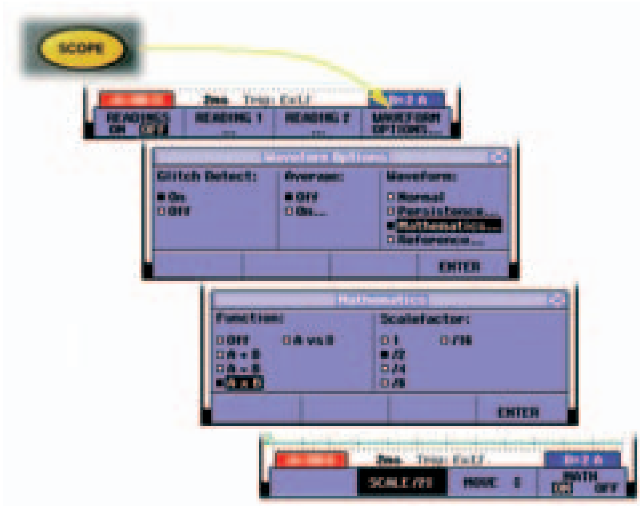

Figure 3. Menu tree for setting up the waveform multiplication.

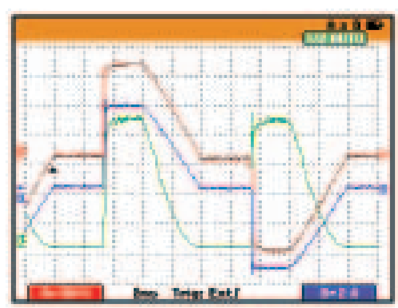

Figure 4. Voltage, Current and Power curves on the Fluke 190 Series ScopeMeter.

Figure 4 shows the voltage (waveform A, in red), the current (B, in blue) and the multiplied curve (M, in green), representing the power supplied to the lights.

On the Fluke ScopeMeter 190 Series, the cursors can be used to measure the power at any point in time, as shown in figure 5.

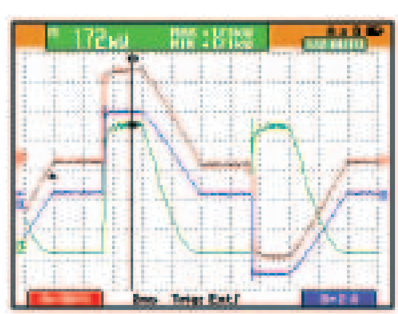

Figure 5. The ScopeMeter's cursor is used for power measurement at a specific point in time.

Here, the cursor is set at about the maximum peak of the power curve, and the reading tells us that the lights are handling a peak of approximately 1.7 kW at that instant in time.

Power measurement in a switched-mode power supply (SMPS)

In electronic systems, the frequencies of the signals are often much higher and the waveforms much more diverse than those in above example.

As an example, consider some waveforms from a switched-mode power supply (figure 6). In this system, the mains voltage is rectified and filtered, resulting in a DC voltage of about 350 V. This is then applied to a switching transistor that drives a step-down transformer.

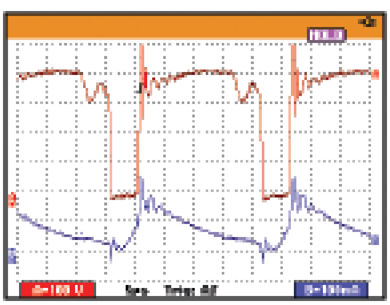

Figure 6. Voltage and current handled by the switcher component in a SMPS.

In figure 6 we can see the voltage across the switching transistor (curve A, in red) and the current through the transistor (curve B, in blue). The voltage reaches peak values of over 400 V (see the 4 divisions of amplitude at 100 V/div) and the current has a peak-value of over 200 mA. A single cycle of this converter's signal takes approximately 26 µs, which means the operating frequency is around 36 kHz. Note, however, that for a given SMPS, the frequency may vary with changes in the line voltage and loading.

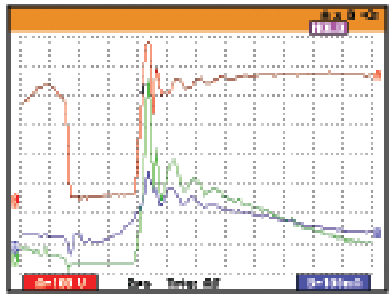

Figure 7. Voltage and current waveforms are used to create the power-curve.

From the curves in figure 6, we calculate the power that the transistor is handling by multiplying the two graphs, as in figure 7. Here also the timebase-setting has been changed to see the part of the waveform that is of particular interest in more detail.

On these curves, we can use the cursors of the Fluke 190 Series to measure the peak in power handling, as is done in figure 8.

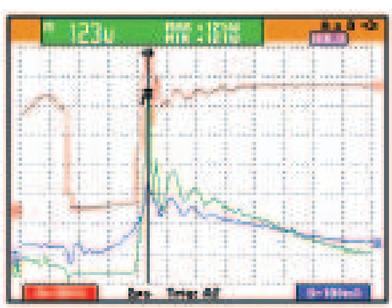

Figure 8. Cursor used to measure the peak of the power, handled by the transistor.

From this we see that the switching transistor is handling a peak power of 123 W. During design of the SMPS, one has to be aware that such power peaks may occur and the components need to be selected with this in mind.

Instrument set-up

The ScopeMeter is unique in that its inputs are fully insulated from one another, allowing direct connection to electrical wiring, even if this is at mains potential. Most standard oscilloscopes have a common 'ground' connection on the inputs which has to be used as a common reference point for all input signals (and which is connected to the mains' safety ground). In contrast, the ScopeMeter 190 Series has independently floating inputs. This allows for voltage measurements at voltage test-points as well as across current-sensing resistors, which may be at different voltage levels. See the ScopeMeter's technical specification for full details.

When used with current clamps or with current sensing resistors in the network, the ScopeMeter inputs can be set-up to read amplitudes in amps directly.

To do so, select the input channel key (e.g.: "B") and then softkey F3 ("Probe channel B"). A selection can then be made if the input signal represents a voltage or a current, or even a temperature. What's more, the sensitivity of the current clamp or the circuit's sensing resistor can be selected from a selection table, indicated in mV/mA (equivalent to V/A or simply Ω).

If we have connected a 1 Ω current sensing resistor in our network and want to measure the voltage across it, the current sensitivity would be set at 1 V/A. If we include a 0.1 Ω resistor in our network to sense the current, then the sensitivity would be set at 100 mV/A. If the voltage across that resistor is measured using the standard (10:1) voltage probe, the overall sensitivity would be 10 mV/A. By selecting this sensitivity from the menu, the current that we read on the ScopeMeter screen directly indicates the true value.

Total energy

The total energy handled over time can be calculated by multiplying the continuous power and the time the system is active:

$$W = P * t \qquad (3)$$

The result is expressed in watt-seconds (Ws), also known as joules (J). The value in joules can be rescaled into kWh, whereby
1 kWh = 1000 Wh =
1000 * 3600 Ws = 3.6 * 106 Ws

Some ScopeMeter models also contain a function for calculating the total power accumulated over a period of time, which is then selected using the cursors. Power over time equals energy, and we can read this on the ScopeMeter as watt-seconds directly.

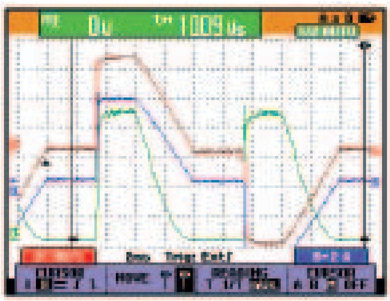

Figure 9. Power curve and energy measurement.

Looking at figure 9, we can see that between the two cursors, i.e. within a single cycle of the mains voltage, an energy of 10.09 Ws is delivered to the lights. A cycle of the mains in this case takes 20 ms.

Per second this leads to a power consumption of:

10.09 Ws / 20ms =
10.09 * 50 W*s/s = 505 W

And over a time-span of one hour, this equals a total energy consumption of:

505 W * 1 h = 505 Wh =
0.505 kWh = 1.8 MWs

Practical set-up hints

The best way to measure a current in a circuit loop is with a current clamp. These are commercially available for AC and for DC+AC measurements, and for various current ranges. The Fluke 80i-100s, for instance, measures DC and AC currents from 0.1 to 100A; the Fluke i1010 can even be used up to1000A AC and/or DC.

These clamps eliminate the need to open up the circuit loop when making measurements and provide good isolation between any 'live' wiring and the test instrument. When working on power circuits, this is definitely the safest way to measure the current.

If a current clamp is used for measuring small currents and the sensitivity of the clamp in insufficient, the effective sensitivity can be increased by feeding multiple turns of the wire through the clamp. The actual current is now the measured current divided by the number of turns.

Sometimes, however, it's not so simple to cut the wiring of an existing circuit loop in order to include a current meter, for example when all wiring is part of a printed circuit board. A possible way to bring the current meter into the loop of a low-power circuit would then be to set up the DMM for current measurement and select the highest current-range provided. Now connect the meter over the contacts of the on/off-switch. If the switch is left open, the meter will close the loop and read the current, while no wiring needs to be interrupted or modified.

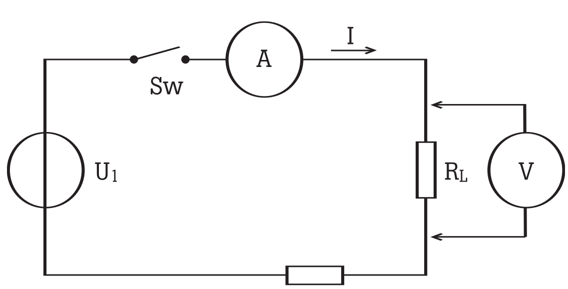

Figure 10. Adding a current sensing resistor to the circuitry to allow current measurement.

If no switch is provided, or if the DMM has no current-measuring capability, we may also add a current sensing resistor of a known value Rs to the circuit, which needs to be small in value compared with the load-resistance R_L (see figure 10). We can now measure the voltage across this sensing resistor and calculate the current from Ohms' law. Adding the resistor is a one-time modification, which is more convenient than repeatedly opening up the circuit loop.

If R_S is more than 10 times smaller in value than the load R_L, less than a percent of the energy will be handled by the series resistance, and thus the error in the power measurement that results from adding the resistor will be less than 1%.

Conclusion

Power measurements on low-frequency linear systems can be performed using a DMM. The measurement of power in electronic systems where waveforms are more complex and frequencies often much higher than the mains frequency requires more sophisticated tools. The Fluke 190 Series of ScopeMeters are well equipped to make these measurements, and can even make fast peak-power measurements to determine the power handling of fast electronic components, for instance in switched-mode power supplies.

Fluke. *Keeping your world up and running.*

Fluke Corporation
PO Box 9090, Everett, WA USA 98206

Fluke Europe B.V.
PO Box 1186, 5602 BD
Eindhoven, The Netherlands

For more information call:
In the U.S.A. (800) 443-5853 or
Fax (425) 446-5116
In Europe/M-East/Africa (31 40) 2 675 200 or
Fax (31 40) 2 675 222
In Canada (800) 36-FLUKE or
Fax (905) 890-6866
From other countries +1 (425) 446-5500 or
Fax +1 (425) 446-5116
Web access: http://www.fluke.com

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