Measurement of standby power and energy efficiency

While it is usually no problem to measure power higher than let's say >20W with a high grade of accuracy, lower powers can arise a lot of problems. Some are described later on together with guidelines how to prevent them.

The resources of fossil energy become smaller, the prices rise. Nowadays everybody should have understood, that it is a good idea to save energy. One area which has a big potential is the standby power consumption of devices. These standby modes are very comfortable for the user but have usually not a real benefit beside this. Even though the power consumption is just some Watt for each device, the amount of billions of such devices world wide results in a huge total power consumption.
For several years now there are efforts to reduce unnecessary power consumptions in normal operation mode as well as reducing the amount of standby power. Energy Star, EuP (Energy using Products), guideline 2005/32/EC and others as well as standards like IEC 62301 define, that this kind of power consumption has to be measured, which accuracies and other circumstances are required to do this.

Choosing the correct wiring

When measuring a power consumption there are two principle measuring circuits. One (fig. 1) measures the correct voltage and a wrong current. The other one measures a correct current, but a wrong voltage (fig. 2).

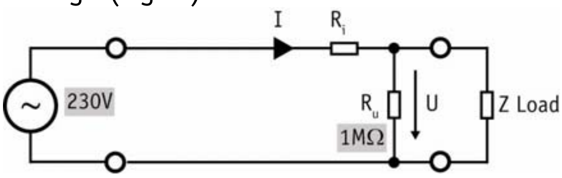

Fig. 1: Voltage correct measurement
Preferred, when current through R_u is very small compared to current through Z.
Power loss in R_u: **53mW**

For high currents it is usual to use the circuit according fig. 1. The reason is that the power consumption of the current measuring channel is defined by I^2*R_i, so it raises very fast with higher currents. The power consumption of the voltage measuring channel is U^2/R_u, so with 230V line voltage it is independent of the load. Typical power measuring instruments have R_u in the range of 1MΩ, so the power loss in the voltage channel is in the range of 0.053W. The lost power of the current channel can become several Watt with usual line applications (e.g. R_i=10mΩ, result at 10A in 1W loss power). So the circuit according to fig. 1 will give power reading of just 0.053W failure while circuit according to fig. 2 would give an 1W failure.

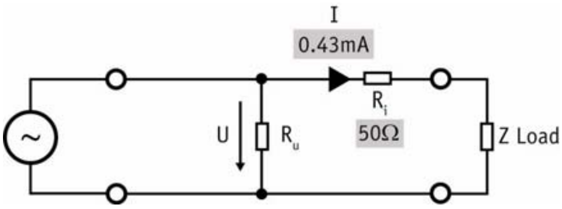

Fig. 2: Current correct measurement
Preferred, when voltage drop over R_i is very small compared to voltage drop over Z.
Power loss in R_i: **9.2µW**

For a standby power (e.g. 100mW) the 0.053W power consumption of the voltage channel will result in >50% error! In the case of a 100mW ohmic load, the current would only be 0.43mA so the power consumption in the current channel will only be 9.2µW (with Ri=50Ω). In this case it is better to use the circuit according to fig. 2 because it does reduce the failure by a factor of more than 5000!

This kind of error is systematic which means that one could theoretically compensate it by calculating independently of the chosen circuit. In practice the values of R_i and R_u are not very well defined. Further on it is much more safe and convenient to read a value which has not to be corrected any more. In the above example the 9.2µW of the current channel are only 92ppm compared to the real power of 100mW. This failure can usually be neglected compared to the measuring errors of the instrument.

Range

To measure such small currents as in the example above, it is usually not sufficient to use the built in range of an instrument. Also if you have a 5mA range, it would only be used for less than 10% which results in larger measuring errors.
Another problem can be the overload protection of such small ranges. For example if your refrigerator starts its compressor, while you are in a 5mA range, a current of 10A can flow for several seconds. This could destroy the complete instrument and result in an expensive damage.
ZES ZIMMER has developed special external shunts to solve this problem. The shunt series SH100-P consists of several shunts which realise current ranges from 500mA down to 30µA. The main advantage is the internal protection. The 30µA shunt can be overloaded continuously with 20A! So there is no risk, that the precious instrument could be damaged.

Range selection

Another point of interest is whether using automatic range selection or manual range selection. Both have advantages and disadvantages, pending on what to measure. For a better understanding some information follow, how automatic range selection works in principle:
Being in some range and the instantaneous value of the current becomes higher than the maximum measurable peak value of the ADC (Analogue to Digital Converter). The instrument detects this situation and stops the currently running measuring cycle. The up to now measured values are invalid because the cycle didn't stop at the end of a period but at a random point. Therefore the values are discarded. Now the instrument changes to the next upper range of the channel by changing some switches on the channel. Thereby the gain has been changed. This results in a transient oscillation of the signal. To discard the invalid values during this oscillation, a short cycle of 50ms is started and the result is discarded. Now the instrument has to synchronise to the signal and then it can start a new cycle. At the end of this cycle you get the first new values. If the instrument has to switch up several ranges, this algorithm is performed several times consecutively. Summarised you might say, that changing a range up will cause in a measuring gap. There is some time, during which the signal is not measured.
This is critical, if you have a pulsed current: For example you have a low basic current and each 2s you have current peaks which are 1000 times higher for about 20ms. While running automatic range selection, the current peak will always be discarded, because at the beginning of the peak, the ranges change as described above. So if you want to measure the real input current, you have

ZES ZIMMER Electronic Systems GmbH
Tabaksmühlenweg 30 • D-61440 Oberursel
Tel.: +49 (0) 6171/6287-50 • Fax: +49 (0) 6171/52086
Email: sales@zes.com • Internet: www.zes.com

to select a correct range manually, to measure also the highest occurred current without overrange.
The second situation is, when a signal becomes too low for a range. Let's say, you have cycles of 500ms. After 40ms of a running cycle the signal reduces, so that a lower range would be sufficient. But at the end of the cycle, the instrument recognizes, that the peak value of the measured signal was such high, that the actual chosen range is still the correct one. Not until the end of the now following cycle the instrument can detect, that it could switch down to a lower range. From now on, it is the same algorithm described above. Summarised you might say, that changing a range down will cause in up to about 2 cycles, where the signal is measured with worse accuracy and of course with a measuring gap at the end.
If your device has a constant input current it doesn't matter how you select a range. But in a worst case it could happen with automatic range selection, that a pulsed signal is measured completely wrong: The pulses are placed in the gap when switching up, and the signal between them is measured in a range which is too high.
So whenever possible it is strictly recommended to use manual range settings. In many cases the higher error caused by a range which is too high for some signal parts is not as fatal as missing signal parts like peaks. Please remember, that rms values are measured according a square law:

$$I_{TRMS} = \sqrt{\frac{1}{T}\int_{t=0}^{T} i(t)^2\,dt}$$

So a signal part with 100 times higher amplitude will influence the result 10000 times!

Where to measure the current
For single phase applications it is usually recommended to measure the current in the neutral wire. Thereby the current channel of the instrument is not floating and you won't get any problems with common mode rejection. Especially for cheap instruments this is problematically, because a rejection of only 60dB-80dB might not be enough!
The issue with standby power is, that a typical device could look like in fig. 3. There are some C_Y and C_X capacitors beside the load for EMC reasons and it is in fact not a 2 wire but a 3 wire system because of PE. If you measure I_N you don't capture the current which flows through PE. The only chance to measure <u>all</u> current components correctly is to measure I_L in the phase.
Therefore the usual recommendation is not usable in this case and you have to use an instrument with very good common mode rejection.
Of course it is not sufficient only to measure the current and to "know" the voltage. Due to existing reactive and non linear loads it is not possible to estimate the power on base of a current measurement only!

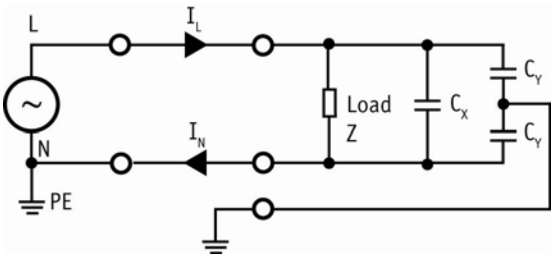

Fig. 3: Where to measure?
With one power meter the current I_L must be measured, because the load has a 3 wire connection.

Gapless
As written in section "Range selection", a gap in the measuring algorithm can result

ZES ZIMMER Electronic Systems GmbH
Tabaksmühlenweg 30 • D-61440 Oberursel
Tel.: +49 (0) 6171/6287-50 • Fax: +49 (0) 6171/52086
Email: sales@zes.com • Internet: www.zes.com

in completely unusable results, especially when the input current is not constant. This gap occurs with every instrument, because it is technically necessary.
But there are also other reasons for gaps which are not necessary: Most cheap instruments have a measuring principle like following described, because of using simple processors with low computing power.
They wait for the begin of a signal period, measure for several periods and store the sample values. Then they have a gap, while they calculate the measuring results from the stored sample values.
This is a similar working principle like a digital oscilloscope.
This kind of measuring is sometimes advertised as "non gapping average values": The measuring over several periods is non gapping (this is an average value), but that does not mean, that there are no gaps between the average values!
Another reason for measuring gaps might be the compensation of DC errors in the measuring channel: Each operational amplifier produces a DC offset which seems to be part of the measuring signal. This DC offset has to be compensated in the instrument. There are two principle ways:
You can produce artificial measuring gaps, disconnect internally the measuring signal, measure the DC produced by the channel itself and compensate this value internally.
The other method is to compensate the DC offset permanently by adjusting the instrument.
This last method requires high quality components which have a small drift, so that the offset adjustment is valid at least for the same period as the calibration. Therefore it is only used by high end instruments.
Simple designed instruments have to insert gaps to compensate the effects of their inexpensive components.
The ZES ZIMMER power meters of series LMG95, LMG450 and LMG500 do never have any of these gaps:

- They use expensive high speed DSPs which can process the sample values in real time.
- They use high end precision operational amplifiers where it is sufficient to adjust the DC once a year.


LMG95


LMG450


LMG500

Special settings

Also with the above described methods to reduce the DC errors of the channel itself, some small errors remain. The problem for this special application is, that the DC components of voltage and current will result in active power. Usually no problem but when measuring such small values also these small errors are important.

As a solution you should use pure AC coupling in the instrument. By this these errors are eliminated and the accuracy is increased significant.

Bandwidth

The question, which bandwidth is necessary for such measurements is a little bit tricky and depends on what you want to measure. And on the intention, why you want to measure.
There exists no singular answer. Instead of some points to consider: Active power can only be produced by voltage and current components with same frequency.

ZES ZIMMER Electronic Systems GmbH
Tabaksmühlenweg 30 • D-61440 Oberursel
Tel.: +49 (0) 6171/6287-50 • Fax: +49 (0) 6171/52086
Email: sales@zes.com • Internet: www.zes.com

So if you have an ideal 50Hz voltage source, and you want only to measure the active power which your EUT consumes from this, a bandwidth from 45...55Hz would be more than sufficient.
But in a real world power supply system you will have harmonics in the voltage. They could generate active power together with the harmonics in the current. In practice a bandwidth of about 2kHz should be sufficient to catch this effect.
But there are at least two more players in the game: Some devices use input circuits which are switched with frequencies from 2kHz to 50kHz and more. Their currents could cause voltage drops over the resistive and (more important) inductive part of the wires. By this you could get a voltage/current pair which might transport active power.
The second player might be the power source. Especially switched power sources might have a remaining ripple in their voltage. A value of 1V and frequencies in the range of 40kHz are not unusual. This voltage can drive appreciable currents, especially through capacitors (C_X, C_Y, see fig. 3) but also in a conventional switched power supply, when the diodes of the rectifier are conductive. Also in this case an active power might exist.
If you want to measure the active power with the intention to save energy, a bandwidth of 2kHz should be sufficient. If you want to do some calculations about the warming of your device, and miss some power above 2kHz (which is physically consumed by the device!), your calculation might be completely wrong.
Anyway, it is a good idea, if your instrument has a wide range of selectable filters, so you can simple check, in which frequency range you consume which power.

Another possibility is to use an harmonic analysis function of the power meter which can also calculate the active power which is produced at each frequency.

Accuracy

While taking a look at IEC 62301, Annex B.5 you find a nice sentence:

"Generally, a digital power analyser with a fundamental power accuracy of 0,5 % or better will comfortably meet the instrument specification and measurement uncertainty required in this standard."

This seems to be good news, because with 0.5% fundamental power accuracy you find a lot of cheap instruments.

But, this is an informative annex and the real requirements are specified in chapter 4.5:

"Measurements of power of 0,5 W or greater shall be made with an uncertainty of less than or equal to 2 % at the 95 % confidence level. Measurements of power of less than 0,5 W shall be made with an uncertainty of less than or equal to 0,01 W at the 95 % confidence level."

This is not a contradiction (yet) but another statement!

Now we use the probably most precise single phase power meter on the market, the LMG95 from ZES ZIMMER and calculate the error for some typical devices:

The standard power accuracy at 50Hz is specified as

$$\pm(0.015\%\, of\ reading + 0.01\%\, of\ range)$$

Along with the error of the SH100-P we get a maximum total uncertainty of

$$\Delta P = \pm(0.165\%\, of\ reading + 0.01\%\, of\ range)$$

which is about 1/3 of the recommendation of the standard.

ZES ZIMMER Electronic Systems GmbH
Tabaksmühlenweg 30 • D-61440 Oberursel
Tel.: +49 (0) 6171/6287-50 • Fax: +49 (0) 6171/52086
Email: sales@zes.com • Internet: www.zes.com

Example 1a

A 10W load, power factor is 1.0 so a real ohmic load. The current is 43.48mA, we use a range with 50mA nominal value and a peak value of 156.3mA

$\Delta P = \pm 0.023W$

This is an relative error of 0.23%, which is such lower than the standard's requirement of 2%

Example 1b

A 10W load, power factor is 0.3, crest factor is 3 which is typical for a switch mode power supply in this power range. The current is 144.9mA with about 435mA peak value. We have to use a range with 250mA nominal value and a peak value of 781.5mA

$\Delta P = \pm 0.048W$

This is an relative error of 0.48%, which is such lower than the standard's requirement of 2%

These two examples seem not to be the issue, at least not for such a precise instrument. For an instrument with a lower specification of 0.5% fundamental power accuracy there is also no issue. But this was a relative high power. Let's go to a power at the borderline of 0.5W:

Example 2

A 0.5W load, power factor is 0.1, crest factor is 6 which is typical for a switch mode power supply in this power range. The current is 21.74mA with about 130.43mA peak value. We use a range with 50mA nominal value and a peak value of 156,3mA

$\Delta P = \pm 7.077mW$ This is an relative error of 1.42%, which is lower than the standard's requirement of 2% and the absolute error is below 10mW

Here you can see, that the allowed tolerance of 2% resp. 10mW is utilised for about 70%. It is obvious, that a much lower specified instrument according annex B.5 will not "*comfortable meet*" the requirements of the standard!
Keep in mind that IEC 62301 does not limit the uncertainty of the instrument but the uncertainty of the complete measurement setup.

Conclusion

It is clearly shown, that this kind of measurement is not trivial, neither for the operator nor for the required equipment.

Several traps may occur in conjunction with measuring standby power and other kinds of energy efficiency. Some can be solved with rarely needed and sometimes forgotten but nevertheless fundamental knowledge.

ZES ZIMMER Electronic Systems GmbH
Tabaksmühlenweg 30 • D-61440 Oberursel
Tel.: +49 (0) 6171/6287-50 • Fax: +49 (0) 6171/52086
Email: sales@zes.com • Internet: www.zes.com

For some a more detailed knowledge about the working principle is necessary. This application note should have provided the necessary information.
With a carefully chosen and sufficiently equipped instrument, theses measuring can be run reliably.

Necessary equipment for this application

Following you find the necessary equipment in minimum configuration for this application. Further options and equipment may be necessary to meet the requirements in a concrete application.

Measuring Instruments

- LMG95 with SH100-P **or**
- LMG95 with modified current inputs **or**
- LMG500 with SH100-P

Author
Dipl.-Ing. Thomas Jäckle
Development and Application

At a glance

- **For measuring standby power use the circuit with the correct current acc. fig. 2**
- **Use external shunts for better scalability and for better protection**
- **Use manual range selection whenever possible**
- **Measure the current in the phase**
- **Please do not use an instrument with 0.5% fundamental power accuracy!**
  It may NOT meet the requirements of the standard!

ZES ZIMMER Electronic Systems GmbH
Tabaksmühlenweg 30 • D-61440 Oberursel
Tel.: +49 (0) 6171/6287-50 • Fax: +49 (0) 6171/52086
Email: sales@zes.com • Internet: www.zes.com