Measurement of standby power and energy efficiency

While it is usually no problem to measure power higher than about 20 W with high accuracy, measuring low power may be difficult. This application note lists some of the possible pitfalls and outlines recommendations on how to avoid them.

Today it is common sense that it is a good idea to save energy. Reducing the standby power consumption of electrical devices is one potential candidate for doing so. Even though the power consumption is usually just a few watts for each device, the world wide number of billions of such devices results in a huge waste of power.

Therefore for good reasons, efforts need to be undertaken to reduce the unnecessary power consumption not only in normal operational modes but as well for the standby mode.

EnergyStar, EuP (Energy using Products, directive 2005/32/EU in conjunction with regulation 1275/2008) and others, as well as standards like IEC 62301:2011 or EN 50564:2011 define the marginal value of power consumption along with the measuring methods and circumstances under which compliance to those limits has to be verified. In this document, the requirements of the EN 50564:2011 standard and of the directive 2005/32/EU will be used, as examples.

Wiring the measuring circuit

When measuring power consumption there are two possible measuring circuits. The first one (fig. 1) measures the correct voltage and an inaccurate current supplying the device under test plus the instrument.

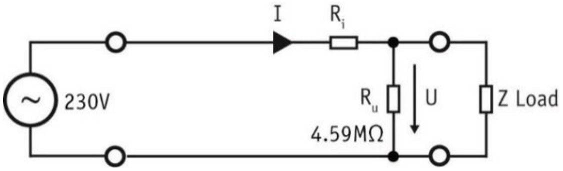

Figure 1: Voltage correct measurement
Preferred when current through Ru is very small compared to the current through Z. Power loss is in Ru: 12 mW

The other one measures a correct current, but a distorted voltage (fig. 2). For high currents, a circuit according to fig. 1 is used. Here the current through the load is usually by magnitudes higher than the current through the measuring device.

At a glance

- Use the manual range selection option whenever possible.
- Measure the current in the phase and use a wiring as shown in figure 3.
- Do not use an instrument with 0.5% or more fundamental power measuring error!
- Instruments with less accuracy are possibly NOT sufficient for the requirements of the standard and the directive

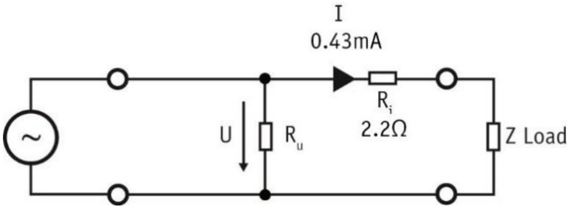

Figure 2: Current correct measurement
Preferred when voltage drop over R$_i$ is very small compared to the voltage drop over Z. Power loss is in R$_i$: 0.4 µW

Likewise if the voltage drop over the measuring device is small compared to the supplying voltage than a wiring as shown in fig. 2 is preferred.

Typical power measuring instruments have a R$_u$ in the voltage channel of 4.59MΩ and more, so the power loss is in the range of 0.01W. The dissipation loss of the current channel, however, can rise to several watts with normal appliances operating with the mains voltage (e.g R$_i$ = 10 mΩ, with 10 A yields 1 W loss power).

For standby power consumption measurements, the reader is strongly advised to use the wiring in fig. 2.

If a standby power consumption of 100 mW is assumed, a wiring according to fig. 1 will result an error of 12 mW. For the circuit wiring according to fig. 2 the power consumption in the current channel would only be 0.4 µW. The result is a relative error of 12% in the case of fig. 1, but only 0.0004% in the case of fig.2!

Since this kind of error is systematic, so why not taking it into account? The exact values of R_i and R_u are unfortunately in reality not very well known since they are e.g. frequency dependent. The error caused by the wiring is thus usually ignored. Fortunately, with a correct chosen wiring as shown above this error can in the majority of cases rightfully be neglected because it is then much smaller than the measuring errors of the instrument.

Range

Some common problems when measuring such small currents are:

- the measuring device uses only 10% or less of its total range, which causes higher measuring uncertainty.
- the potential overload of such small ranges. For example, when a refrigerator starts its compressor, while the instrument is in the 5 mA range, a current higher than 10 A can flow for several seconds. This could possibly destroy the instrument.

The lowest current on LMG600 is 5 mA, while the overload protection is for the low current ranges: 10 A continuously and 150 A for 10ms.

When there is the need to measure currents lower than 5 mA and the built in range of the device is not sufficient, external shunts can be used.

ZES ZIMMER has developed special external shunts for these applications, the SHxxx-P series. Shunts with rated current ranges from 500 mA down to 150 µA are available. The internal protection of the shunts allows an overload of 20 A continuously. However, when additional shunts are used, an additional error, sensors specific error, is added on the total uncertainty.

Range selection

Should the measurement use automatic range selection or manual range selection? Both have advantages and disadvantages, depending on what to measure.

For a better understanding the following paragraph explains how automatic range selection works in principle: During a measuring cycle, the instantaneous value of the current might exceed the maximum value of the ADC (Analogue to Digital Converter). The instrument detects this situation and stops the running measuring cycle. Already sampled values are discarded. Now the instrument switches to the next higher range of the measuring channel. Implicitly with that comes a gain change of the internal amplifiers and filters which requires a signal settling time. All values recorded during this period which takes about 50ms must be discarded. After that the instrument has to synchronise itself to the signal before a new cycle is started. At the end of this cycle new valid values are available. If the instrument has to switch up several ranges, this algorithm is performed several times consecutively.

In brief: Switching a range causes a measuring gap.

This is critical for pulsed currents. For example: Let's envisage a low nominal current having a peak 1000 times higher for about 20ms every 2s. While running automatic range selection, this peak will always be discarded, because at the beginning of the peak, the range will be shifted as described above. Automatic range switching is thus convenient but in some cases not useful at all. For highly dynamic measuring situations the manual range selection is preferred.

The situation is slightly different if the signal becomes too low for a range. Imagine a relatively long measuring cycle. Almost immediately after the start of a new running cycle the consuming device switches from normal mode down to standby. This would justify a lower range. However, at the end of this measuring cycle, the instrument has correctly registered, that the peak value of the measured signal was still within the actual range. Only after the end of the following cycle the instrument can detect, that it should switch down to a lower range using the algorithm already described above.

In brief it can be summarized here that shifting the range down will result in a signal measurement with low accuracy and a loss of samples for about 2 cycles.

If your device has a constant input current it doesn't matter how to 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 occur in the gap when switching up, and the signal between them is measured in a range which is too high.

Thus, whenever it is possible it is 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:

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

This shows that a signal part with let's say a 100 times higher amplitude will influence the result by a factor of 10000!

Where to measure the current

For single phase applications it is usually recommended to measure the current in the neutral wire. By doing so the current channel of the instrument is not floating and hence not a subject for common mode signals. This could particularly be a problem for cheap instruments because their common mode rejection of only 60dB-80dB might not be sufficient!

However such a recommendation may lead to wrong measurement results. Fig. 3 shows a simplified circuit. To fulfil the EMC requirements the circuit has a filter with capacitors (C_X and C_Y) and so the device is actually not a 2 wire but a 3 wire system because of protective earth (PE). Only by measuring I_L the entire current flowing through the device is measured.

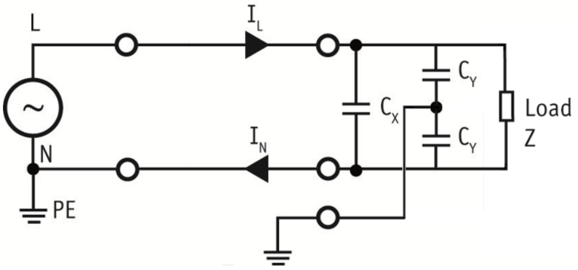

Figure 3: Where to measure?
With one power meter the current I_L must be measured, because the load has a 3 wire connection

And obviously due to the fact that loads in reality usually contain reactive and non-linear components it should be clear that only measuring the current and multiplying it with the nominal voltage in order to calculate the power consumption cannot suffice.

Gapless Measurements

As written in section "Range selection", a gap in the measuring algorithm can end up in completely useless results, especially under conditions where the input current is not constant. This gap occurs with every instrument for the reasons explained above.

But there are also other causes for gaps which can be avoided: Some cheap instruments have to work in two modes due to its limited processing capacity. At first they measure for several periods. Then the data is processed and displayed. Data acquisition is halted during the latter phase.

This kind of measuring is similar to the operational modes of digital oscilloscopes and sometimes advertised as "non gapping average values": Only the measuring over several periods is non-gapping (these are used for the average value), but there are gaps between the average values!

Another reason for measuring gaps might be the compensation of DC errors in the measuring channel: Each operational amplifier has by nature a DC offset which seems to be part of the measuring signal. This DC offset has to be compensated inside the instrument by one of the following methods:

During artificially generated measuring gaps, the channel is disconnected internally from the measuring signal, so the DC produced by the channel itself is determined and can be compensated internally for the upcoming cycles, until the whole process has to be repeated.

The other approach is to compensate the DC offset permanently by adjusting the instrument. The latter method requires high quality components with a small drift, so that the offset adjustment is valid at least for the same period as the calibration. Therefore this approach is only used for high end instruments.

The above can be summarized as: Simply designed instruments have to generate gaps to compensate the effects of their low cost components.

LMG600

ZES ZIMMER power meters of series **LMG600** never let any of these gaps occur, because it uses:

- high speed DSP which process the sampled values in real time.
- high end precision operational amplifiers which require an adjustment of the DC only once a year.

Additional settings

Also with the methods described above to reduce the DC errors of the channel itself, some small errors still remain. Mentionable is that the DC components of voltage and current will result in active power. Usually this power dissipation is negligible but when measuring small values such as standby power consumption, these small values might inflict a higher percentage measuring error.

It is therefore recommended to use an AC coupling mode, so that such errors are eliminated. This will increase the accuracy significantly.

Bandwidth

The required bandwidth of the measurement is dependent on the task. Several points should be taken into consideration: First, one has to remember that active power can only be produced by voltage and current components with same frequency. So if an ideal 50 Hz voltage source is available and only the active power which the DUT consumes from the source has to be measured, a bandwidth from 45…55 Hz or 55…65 Hz would be entirely sufficient.

But in a real world the mains has harmonics in the voltage. They will generate active power and harmonics in the current. With a measuring bandwidth of about 2 kHz this effect is sufficiently covered.

Additionally there are two more impacts: Some devices use input circuits which are switched with frequencies starting at 2 kHz and go up to more than 50 kHz. Their currents could cause voltage drops over the resistive and (more important) inductive part of the internal wires. Those are the sources for additional voltage/current tuples which consume active power for each frequency.

On the other hand the power source – especially if it is a switching power supply – might have a remaining ripple on the voltage. A value of 1V and frequencies in the range of 40 kHz are common. This voltage can drive appreciable currents, especially through filter capacitors (CX, CY, see fig. 3) but also in a conventional switched power supply, when the diodes of the rectifier are in conductive mode. In such cases further active power might be consumed.

For energy saving intentions, a bandwidth of 2 kHz should be sufficient. Estimates about the thermal effects need to take the active power above 2 kHz being generated and physically consumed into account. Otherwise the calculation might be completely wrong.

In any case a rich selection of filters is good to have for determining easily in which frequency band the power is being consumed.

Alternatively, the harmonic analysis function - if the power meter has one - can also calculate the active power produced at each frequency.

Accuracy

The EN 50564:2011 standard defines under the section 4.4.1 the accepted power measurement uncertainty. These limits are described below.

In order to determine the maximum power measurement uncertainty, a factor, called Maximum Current Ratio (MCR) should be first calculated and depends on the load’s crest factor and power factor.

$$\text{Maximum Current Ratio (MCR)} = \frac{\text{Crest Factor (CF)}}{\text{Power Factor (PF)}}$$

If the MCR is ≤ 10, then:

- if the measured power is ≥ 1.0 W, the power measurement uncertainty should be lower than or equal to 2% (relative error) at 95% confidence level.

- if the measured power is < 1.0 W, the power measurement uncertainty should be lower than or equal to 0.02 W (absolute error) at 95% confidence level.

If the MCR is > 10, then another factor, called U_{pc} should be calculated.

$$U_{pc}=0.02 * [1+(0.08*\{MCR-10\})]$$

- if the measured power is ≥ 1.0 W, the power measurement uncertainty should be lower than or equal to the calculated U_{pc} (relative error) at 95% confidence level.
- if the measured power is < 1.0 W, the power measurement uncertainty should be lower than or equal to the greater of 0.02 W or U_{pc}*measured power value (absolute error) at 95% confidence level.

Please keep in mind that EN 50564:2011 limits the uncertainty of the instrument and not the uncertainty of the complete measurement setup.

But, the directive 2005/32/EU defines the uncertainty of the complete measurement setup. More specifically, if the measured power is higher than or equal to 0.5 W, the systems measurement uncertainty shouldn't exceed 2% (relative error) at 95% confidence level. If the measured power is lower than 0.5 W, the systems measured uncertainty shouldn't exceed 0.01 W (absolute error) at 95% confidence level.

ZES ZIMMER manufactures high precision power analyzers, such as LMG600, one of the most precise instruments in the market. LMG600 is available in different accuracy classes, to allow the user to choose the right channel for every application.

Let us do the standby calculations for each one of LMG600 channels (A1 Channel, B1 Channel and C1 Channel).

The standard accuracy at 50 Hz for a power measurement is specified as:

A1 Channel:

$$\Delta P=\pm\ (0.015\%\text{ of measured value} + 0.01\%\text{ of maximum peak value})$$

B1 Channel:

$$\Delta P=\pm\ (0.05\%\text{ of measured value} + 0.02\%\text{ of maximum peak value})$$

C1 Channel:

$$\Delta P=\pm\ (0.03\%\text{ of measured value} + 0.01\%\text{ of maximum peak value}) + 30\frac{\mu A}{A^2} * U_{trms} * I_{trms}^2$$

Example 1a

Let us assume a 10 W load with power factor equal to 1.0 (i.e. a fully ohmic load) and crest factor equal to 1.414. The current is 43.48 mA with 61.49 mA peak value. Used is the range with 40 mA nominal value and a peak value of 112 mA.

$$\Delta P_{A1}=\pm 0.006\text{ W}$$

$$\Delta P_{B1}=\pm 0.014\text{ W}$$

$$\Delta P_{C1}=\pm 0.008\text{ W}$$

The relative error is 0.06% for A1 channel, 0.14% for B1 channel and 0.08% for C1 channel.

- ✓ The MCR is equal to 1.414 and the measured power is more than 1 W. Therefore, the error is in every case much less than the standard's requirement of 2%.
- ✓ The directive requirement is also met, as the device utilizes only 7% (worst case, B1 channel) of the allowed systems uncertainty of 2%.

Example 1b

Let us assume now a 10 W load, while the power factor is 0.3 and the crest factor is 3. A typical load for a switching power supply in this power range. The current is 144.9 mA with 434.7 mA peak value. The range with 150 mA nominal value and a peak value of 469 mA will be then used.

$$\Delta P_{A1}=\pm 0.020\text{ W}$$

$$\Delta P_{B1}=\pm 0.043\text{ W}$$

$$\Delta P_{C1}=\pm 0.022\text{ W}$$

The relative error is 0.2% for A1 channel, 0.43% for B1 channel and 0.22% for C1 channel.

- ✓ The MCR is equal to 10 and the measured power is more than 1 W. Therefore, the error is again lower than the standard's requirement of 2%.

- ✓ The device uses 21.5% (worst case, B1 channel) of the directives limits. There is still a large margin and the requirement for total measurement uncertainty lower than 2% is met.

These two examples do not look like a challenge, at least not for such a precise instrument. For an instrument with a lower specification of 0.5% fundamental power accuracy this would also not be a problem. But this was at a fairly high power. Let's therefore repeat the calculation with a typical standby power of 0.5 W:

Example 2

Let us assume a 0.5 W load with a power factor of 0.1 and a crest factor of 6 which is typical for a switch mode power supply in this power range. The current then is 21.74 mA with a 130.44 mA peak value. The chosen range is 80 mA nominal value and a peak value of 224 mA.

$$\Delta P_{A1} = \pm\, 9{,}035\ \text{mW}$$
$$\Delta P_{B1} = \pm\, 18{,}170\ \text{mW}$$
$$\Delta P_{C1} = \pm\, 9{,}113\ \text{mW}$$

- ✓ The relative error is 1.807% for A1 channel, 3.634% for B1 channel and 1.822% for C1 channel. The MCR is equal to 60, the U_{pc} is equal to 0.1 and the U_{pc}*0.5 W is equal to 0.05 W, which is greater than the 0.02 W. The power uncertainty should therefore be equal or lower than 0.05 W. We can notice that all the power channels meet the requirements
- ✓ A1 and C1 channels uncertainty is below the limits of the directive, even under these conditions. B1 channel exceeds the limit. This is why B1 channel is recommended for standby measurements only for non-critical conditions and applications.

It is now clear that a much lower specified instrument will not meet the requirements under these conditions.

No instrument will fulfil the standard under all circumstances!

In the above examples values were used, which are today the edge of the technology (e.g. power factor of 0.1 and crest factor of 6). However, sophisticated „0 W PCs" already have crest factors of 14. It is hard to imagine what else will be developed in the future or already exists, but it is certain that an EUT with a power factor of 0.01 and a crest factor of 100 cannot be measured with any existing instrument within the required uncertainty.

So, it is not reputable if a manufacturer advertises that the instruments meet the requirements or are certified concerning EN 50564:2011. A general statement like this is untrustworthy for the reasons explained above.

Examples:

- **Manufacturer "Y"** attained under almost ideal conditions (range fully used, crest factor < 3, etc.) a usage of 70% of the allowed uncertainty only by regarding the instrument without the environment. This instrument is advertised as certified for measuring standby power. The truth is that it can hardly be used in practice, because such ideal conditions cannot be found in reality.
- Likewise also **manufacturer "V"** achieves the requirements of the EN 50564:2011 according to his own calculation under almost ideal conditions (power factor 1, ideal external shunt, etc.). 85% of the allowed uncertainty is used by the instrument itself, again without any external components which are essential. Likewise, this instrument as well can hardly be used in practice. Nevertheless the manufacturer guarantees to measure according to the requirements of the standards, if some technical hints and the terms expressed in the manual are met.

Such delusive certificates and guarantees, valid only under ideal conditions, will last until the first uncertainty calculation with a real world EUT takes place. If the daily grind shows that these instruments will not be able to keep their certificates or guarantees promises, the bill will be paid by the customer, not by the manufacturer. Frankly spoken: Our products cannot measure everything under all circumstances!

On the other hand we at **ZES ZIMMER** won't hide behind fancy guarantees and certificates. Serious certificates and guarantees have to show the limits of an instrument clearly, because global statements are not possible as shown above.

This leads to the fact that users can't trust to the certification of an instrument only but has to make themselves familiar with the contained limits. So we will use the two foregoing examples to calculate our uncertainties to be comparable:

- ✓ For **the "Y" example** (230 V, 20 mA, CF<3, PF=1, 0.46 W) we use a range with nominal value of 20 mA and peak value of 56 mA. By using A1 channel the uncertainty of the instrument is 0.0023 W or 0.502%. The standard specifies for these conditions that the measured power should be lower than or equal to 0.02 W, which means that only the 11.5% of the standard requirements is used. Our instrument meets easily the requirements of the standard and the directive and it is almost 7 times better than manufacturer "Y".
- ✓ And **for the "V" example** (230 V, 4.3 mA, CF<3, 1 W) we apply a range with nominal value of 5 mA and peak value of 14 mA. The uncertainty of A1 channel is 0.071%, which is the utilization of only 3.55% of the allowed 2% uncertainty and many times better than the manufacturer "V". Certificates aren't necessary at all.

Can I test if a measuring instrument is suitable for this kind of measurement?

Yes and **no**!

Yes, you can measure if an instrument has a sufficient accuracy at the time of calibration. But this is not really relevant, because even an instrument with 10% specified uncertainty might have an error at calibration time of 0% by coincidence!

No, calibration is a singular event. Every manufacturer tries to specify its instruments as accurate as possible. Additionally, they are designed to meet the specification for a certain period at minimum, typically 12 months. During that time a lot happens. For instance drift, ageing, chemical reactions influence the accuracy over time and cannot be contained in an one-time calibration. But the manufacturer's specification takes care for it. So if the above 10% instrument has 0% error according to the calibration protocol, it is quite likely that this instrument will have much more than the standards limits after one year. Had it been designed for a better specification, the documentation would tell it!

So it is as much important to look for a good specification as to have a valid calibration protocol. A calibration with a good result is never a replacement for a bad specification.

How to build up a reasonable testing system?

The provocative message of last chapter that no instrument will completely fulfil the standard is unfortunately true. Nevertheless there are some strategies to perform these kinds of tests seriously:

- Use an instrument with smallest possible uncertainty. A 0.025% instrument can be used for way more critical EUTs than a 0.2% instrument.
- Calculate the instrument uncertainty for each measure point. This is the only way to get an impression about the reliability of the results and to exploit the limits of the instrument.

If one complies with these two rules, one will always receive a reliable testimony about the measurement. This might be important in cases where regulatory authorities question the results.

Additional influencing factors

We have already seen that apart from the instrument uncertainty, there is also the uncertainty of the complete system. Uncertainty of the complete system means that not only the device, but also environmental conditions and other influencing factors should be taken into account. It is then important to determine and define these factors and conditions, so as to make sure that the uncertainty is kept within the limits.

All the measuring results should be reproducible by any regulatory authority to prevent concerns. In this context it should also be taken into consideration that the product's parameters will have a spread in production.

Besides the usual influence factors like temperature, air flow, humidity, etc. the following points should be regarded:

The voltage and current harmonics, as described under "bandwidth" can have significant influence. A simple measuring at the mains has shown that especially the harmonics of the 3rd, 5th and 7th order make up 2% of the total active power consumption of the EUT. The total harmonic distortion (THD) was 3% (EN 50564:2011 allows only 2%) but also with much smaller THD, errors in this range are possible. The error depends very much on the value of each voltage harmonics and on the phase shift to the corresponding current harmonic, so the 2% can also be exceeded. In other words: The voltage source itself can generate 2% uncertainty of the final result on its own.

For this reason you should use a voltage source with a very small THD to minimize this error. Furthermore you can determine the distribution of the power dissipation on the harmonics by measuring active power for each harmonic. Thus, you'll get knowledge instead of an estimate.

Also the voltage amplitude itself can influence the power reading, depending on the functional principle of the device. For instance, the difference between the power at +1% deviation from the nominal voltage (e.g. Power @ (230+1%) V) and the power value at - 1% deviation from the nominal voltage (e.g. Power @ (230- 1%) V) could exceed the 2%. It is then possible that the uncertainty limits are exceeded only by voltage source deviations.

Conclusion

We have briefly outlined that the measurement of standby power and energy efficiency is not trivial, neither for the operator nor for the required equipment.

Several errors may occur while measuring standby power and other kinds of energy efficiency. Some can be avoided by applying this fundamental knowledge that is rarely needed and sometimes is even forgotten.

We hope to have made a clear point that an inside knowledge on how measuring instruments work helps in getting correct and reliable results. This application note should have provided the necessary information.

With a carefully chosen and adequate instrument, these measurements can be run successfully.

For all the examples and calculations, we have used:

- the specifications of LMG600 precision power analyzer
- the requirements of the standard EN 50564:2011 and of the directive 2005/32/EU.