Measurement of standby power and energy efficiency

While it is usually no problem to measure power higher than about >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 realized 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 real benefit beside this. Even though the power consumption is just a few Watts for each device, the amount of billions of such devices world wide results in a huge waste of power.

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, directive 2005/32/EC in conjunction with regulation 1275/2008) and others as well as standards like EN 62301 define the marginal value of this power consumption and the measuring methods and circumstances under which compliance of these limits has to be verified. In Germany this directive was implemented by the EBPG (Energiebetriebene Produkte Gesetz).

Choosing the correct wiring

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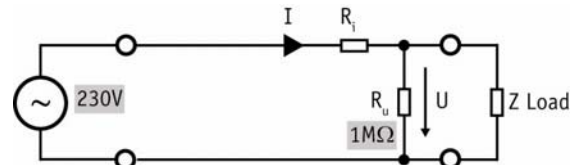

Fig. 1: Voltage correct measurement
Preferred, when current through R_u is very small compared to current through Z. Power loss in R_u: **53mW**

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% o more fundamental power measuring fault! It may NOT meet the requirements of the standard.**

For high currents, usually a circuit according to fig. 1 is applied. 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 a line voltage of 230V it is independent of the load. Typical power measuring instruments have R_u in the order of magnitude of $1M\Omega$, so the power loss in the voltage channel is in the range of 0.053W. The dissipation loss of the current channel can become several Watt with usual line applications (e.g. $R_i=10m\Omega$, result at 10A in 1W loss power). So the circuit according to fig. 1 will result a measuring fault of 0.053W while the circuit according to fig. 2 will adulterate the measurement by 1W.
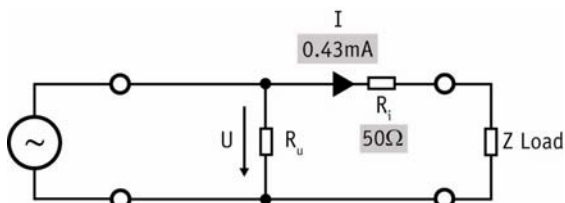

Fig. 2: Current correct measurement
Preferred, when voltage drop over R_i is very small compared to voltage drop over Z. Power loss in R_i: **9.2µW**

For a standby power of e.g. 100mW the 0.053W power consumption of the voltage channel will result in >50% error! In the case of an ohmic load with a power consumption of 100mW, 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 the failure is reduced by a factor of more than 5000.

This kind of error is systematic, which means that one could theoretically compensate it by calculating dependently of the chosen circuit. In practice the exact 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 example shown above the 9.2µW of the current channel accord only 92ppm compared to the real power of 100mW. This failure can usually be neglected compared to the measuring errors of the instrument.

Range

In order to measure such small currents as in the example above, it is usually not sufficient to use the built in range of an instrument. A measurement device with a range of 5mA would be using only 10% or less of its scale, causing a large measuring uncertainty.

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. Needless to say that this could destroy the complete valuable instrument. ZES ZIMMER® has developed special external shunts to solve this problem. The shunt series SHxxx-P consists of several shunts which realise current ranges from 500mA down to 150µA.

The main advantage is the internal protection which allows the device to be loaded with a continuous current up to 20A. In this way damage on the equipment due to overload can be prevented.

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 the following paragraph explains how automatic range selection works in principle:

During a measuring cycle, the in– stantaneous value of the current might exceed the maximum value of the ADC (Analogue to Digital Converter). The

instrument detects this situation and stops the currently running measuring cycle. All measured values up to this event are invalid because the cycle didn't stop at the end of a period but at a random point. Therefore these values are discarded. Now the instrument switches to the next upper range of the channel. As an implication of this procedure the gain of the channel changes which causing a transient oscillation on the signal. Values recorded within this period of about 50ms are invalid, thus they are also 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 valid values. If the instrument has to switch up several ranges, this algorithm is performed several times consecutively.

In summary it can be said that changing a range up will cause a measuring gap so that during particular period of time the signal is not recorded.

This is critical, if you have a pulsed current: For example you might like to measure a low basic current with a peak of a duration of about 20ms and a maximum 1000 times higher than your basic current, occurring every 2s.

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 to select a correct range manually, to measure also the highest occurred current without overrange.

On the other hand a signal might become too low for a range. Imagine a cycle time of 500ms is present. After 40ms of a running cycle the signal decreases so much that a lower range would appropriate. 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 following cycle the instrument can detect, that it could switch down to a lower range. From now on, the same algorithm described above follows.

Summing up can be said that changing a range down will cause a signal measurement with worse accuracy and a lack of values in up to about 2 cycles.

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 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 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:

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

This shows that a signal part with a 100 times higher amplitude will influence the result by 10000 times!

Where to measure the current
For single phase applications it is usually recommended to measure the current in the neutral wire because the current channel of the instrument is not floating and you won't get any problems with common mode rejection which is problematically especially for cheap

instruments because a rejection of only 60dB-80dB might not be enough!

Fig. 3 shows a common equivalent circuit for standby power investigation. 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, so the only chance to measure <u>all</u> current components correctly is to measure I_L in the supply line.

Therefore the usual recommendation mentioned before is not usable in this case and you have to apply an instrument with very good common mode rejection.

Of course it is not sufficient only to measure the current and employ the nominal voltage in order to calculate the power. Due to existing reactive and non linear loads it is not possible to estimate the power based on a current measurement only!
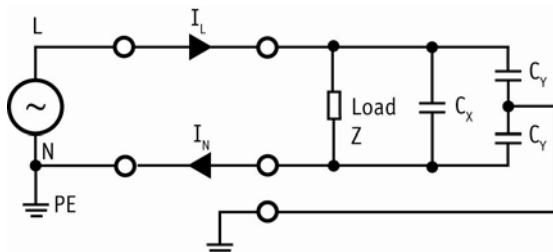

Fig. 3: Where to measure?
With one power meter the current I_L must be measured, because the load has a 3 wire connection.

Gapless

As written in section "Range selection", a gap in the measuring algorithm can end up 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.

These devices hold on for the begin of a signal period and measure for several periods in order to store the sample values. During the following period of calculation, no values are stored. Hence the measurement acquisition is fragmentary.

This kind of measuring is similar to the working principle of digital oscilloscopes and sometimes advertised as "non gapping average values": 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 produces 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 cycles, until the whole process has to be repeated. The other approach is to compensate the DC offset permanently by adjusting the instrument.

This 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 policy is only used for high end instruments.

Simple designed instruments have to generate gaps to compensate the effects of their low cost components.

The ZES ZIMMER® power meters of series LMG95, LMG450 and LMG500 never let any of these gaps occure:

- Elaborate high speed DSPs can process the sample values in real time.

- High end precision operational amplifiers require an adjustment of the DC only 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. 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 fault.

As a solution you should use pure AC coupling on the instrument, so these errors are eliminated and the accuracy increases significant.

Bandwidth

The best matching bandwidth used for the measurement depends on the setting of your DUT and your intention. Instead of answering with a single phrase, some points of interest should be considered: Active power can only be produced by voltage and current components with same frequency. So if you have an ideal 50Hz voltage source and you only want to measure the active power which your EUT consumes from this source, a bandwidth from 45...55Hz would be more than fair.

But in a real environment a power supply system 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 cover 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.

On the other hand the power source – especially if it is a switching power supply – might have a remaining ripple on 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 occur.

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 you neglect some power above 2kHz (which is physically consumed by the device!) your calculation might be completely wrong.

Anyway if your instrument has a wide range of selectable filters, it is advisable to simply 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 produced at each frequency.

Accuracy

When taking a look at EN 62301, Annex B.5 you'll find the following 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 accuracy at 50Hz for a power measurement is specified as

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

Along with the error of the SHxxx-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.

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 a relative error of 0.23%, which is 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 switching 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 a relative error of 0.48%, which is 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

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

As you can see 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 "*comfortably meet*" the requirements of the standard.

Keep in mind that EN 62301 does not limit the uncertainty of the instrument but the uncertainty of the complete measurement setup.

No instrument will fulfil the standard!

In the above examples values were used which are usual in actual state of the technology: A Power factor of 0.1 and a crest factor of 6. Modern „0W PCs"already have crest factors of 14. It is hard to decide what can be done technically or already exists, but you can be sure that an EUT with a power factor of 0.01 and a crest factor of 100 can not be measured with any existing instrument within the required uncertainty of 2%.

So it is not reputable if a manufacturer advertises his instruments by meeting the requirements or being certified concerning EN 62301. A general statement like this is untrustworthy as it is explained above.

Examples:

Manufacturer Y attained under almost ideal conditions (range fully used, crest factor < 3, ...) already a usage of 70% of the allowed uncertainty only by regarding the instrument without the environment Such an instrument can hardly be used in practice, because will not find this conditions in a real environment. It seems almost wry that this instrument is advertised as certified for measuring standby power.

Also manufacturer V achieves the requirements of the EN 62301 according to his own calculation under almost ideal conditions (power factor 1, ideal external shunt, ...). 85% of the allowed uncertainty is used by the instrument itself, again without any external components which are essential. Like the example above, his instrument can hardly be used in practice. Nevertheless the manufacturer guarantees to measure according the requirements of EN 62301 if some technical hints and the manual are regarded.

Such delusive certificates and guarantees, valid 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. To put it bluntly: Manufacturer Z will not be able to measure all possible devices! But we don't hide behind fancy guarantees and certificates. Serious certificates and guarantees have to show the limits of an instrument clearly, because common statements are not possible as shown above.

7/9

This leads to the fact, that a user can't trust to the certification of an instrument only, but has to engage with the there enclosed limits. So we use the two above examples to calculate our uncertainties to be comparable:

For the "Y" example (230V, 20mA, CF<3, 0.46W) we use a range with nominal value of 24mA and peak value of 78.12mA. Our product achieves an uncertainty of 0.84% which is the usage of only 42% of the requirements of the standard. So our instrument is roughly 2 times better than the competitor and the requirements.

And for the "V" example (230V, 4.3mA, CF<3, 1W) we apply a range with nominal value 5mA and peak value 15.63mA. An uncertainty of 0.23% is the worst case, which accords the usage of 12% of the allowed 2% uncertainty - roughly 7 times better than the competitor and the requirements. Needless to say that we do not need any certificates to achieve this.

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 test seriously:

- Use an instrument with smallest possible uncertainty. A 0.025% instrument can be used for way more critical EUT than an 0.2% instrument.

- Calculate the (instrument) un–certainty to each value you measure. This is the only way to explore the limits of an instrument and give a conclusion how reliable the received results are.

If you stick to these two rules, you will always receive a reliable statement about your measuring - this is most important for the case that you have to defend your results against any regulatory authority which will punish you in case of violating the limits.

Further influence factors

The EC directive as well as EN 62301 require an uncertainty of 2% at 95% confidence level. Not only the instrument uncertainty but all further influence factors are included in this marginal value. This requirement is extremely important to get a good reproducibility! Remember that all of your own measuring results should be reproducible by any regulatory authority to prevent trouble. In this context please keep in mind that the devices of a series will spread in production.

Beside the usual influence factors like temperature, wind, 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 lines has shown, that especially the harmonics of the 3rd, 5th and 7th order make up 2% of the total active power consumption of this EUT. The THD was 3% (EN 62301 allows only 2%) but also with much smaller THD, errors like this 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 crossed. In other words: The voltage source itself can generate 2% uncertainty of the final result, without considering the instrument.

For this reason you should use a voltage source with a very small THD to minimize this error. Further more you can determine the distribution if the power dissipation

8/9

on the harmonics by using a measuring mode which measures active power for each harmonic. Thus, you'll get knowledge instead of an estimation.

Also the voltage amplitude itself can influence the power reading, depending on the functional principle of the device: The power value at +1% deviation of the nominal voltage might be so much bigger than the value at –1% deviation, that the allowed 2% uncertainty is reached.

Conclusion

As you can see, this kind of measurement 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 using rarely needed and sometimes forgotten but nevertheless fundamental knowledge.

For some a more detailed knowledge about the working principle of the equipment is necessary. This application note should have provided the necessary information.

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

Necessary equipment for this application

In the following paragraph you will 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 LMG-SHxxx-P **or**
- LMG95 with modified current inputs **or**
- LMG500 with LMG-SHxxx-P

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