

MEASURING STANDBY POWER AND ENERGY EFFICIENCY

Measuring power above 20 W is usually accurate, but low-power measurements can be challenging. This application note explains common pitfalls and how to avoid them.

Products:

- ▶ LMG Power Analyzers ZES ZIMMER:
- ▶ LMG671
- ▶ LMG641
- ▶ LMG611
- ▶ LMG671-ATE
- ▶ Channels for your LMG600

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[LMG600 Series Power analyzer | Rohde & Schwarz](#)

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1 Overview

While fossil fuel reserves are constantly decreasing, the costs of energy are on the rise. Saving energy becomes increasingly important for consumers' buying decisions. One area with a big potential for energy savings is consumer electronics operating in standby mode, since they still drain power from the grid. Whereas every single device only consumes a few watts, the overall energy consumption is considerable.

For several years, power input gets optimized both in normal operation and standby. Standards like EnergyStar, EuP (Energy using Products, directive 2005/32/EU in conjunction with regulation 1275/2008) and others, as well as norms like IEC 62301:2011 or EN 50564:2011 define maximum power input along with the setup for measuring it.

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.

2 Choosing the measuring circuit

In principle, there are two ways to measure power consumption.

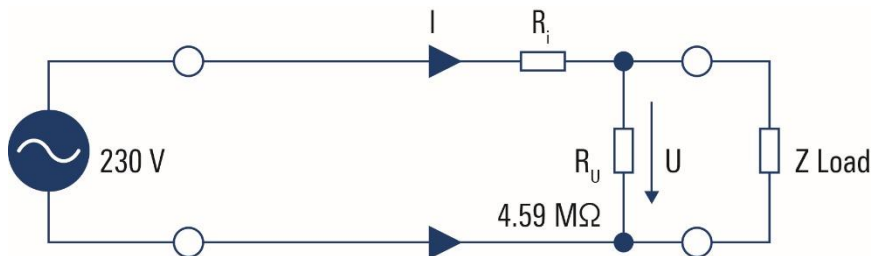


Figure 1: Preferred when current through R_u is very small compared to the current through Z . Power loss is in R_u : 12 mW

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

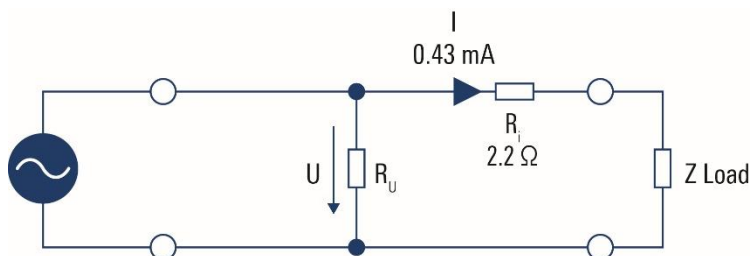


Figure 2: Current correct measurement.

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 $4.59\text{M}\Omega$ 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. $R_i = 10\text{ m}\Omega$, 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 in an error of 12 mW . For the circuit wiring according to fig. 2 the power consumption in the current channel would only be $0.4\text{ }\mu\text{W}$. 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, why not take 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 be neglected because it is then much smaller than the measuring errors of the instrument.

3 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 10 ms .

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. However, when additional shunts are used, an additional error, sensors specific error, is added to the total uncertainty.

4 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 require a signal settling time. All values recorded during this period, which takes about 50 ms , must be discarded. After that the instrument must synchronize itself to the signal before a new cycle is started. At the end of this cycle new valid values are

available. If the instrument must 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 can the instrument 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 to a square law:

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

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

5 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 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.

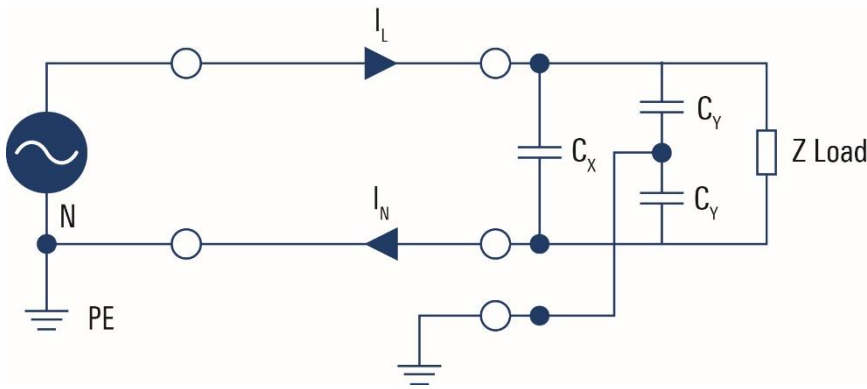


Figure 3: Where to measure? With one power meter the current I_L must be measured, because the load has a 3-wire connection

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

6 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 must 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 like 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 must 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 must 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 must generate gaps to compensate for the effects of their low-cost components.

Power analyzers of the LMG600 series never let any of these gaps occur, because it uses:

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

7 Additional settings

Also, with the methods described above 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 error.

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

8 Bandwidth

The required bandwidth of the measurement is dependent on the task. Several points should be taken into consideration: First, one must 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 must be measured, a bandwidth from 45...55 Hz or 55...65 Hz would be entirely sufficient.

But in the real world the mains have harmonics in the voltage. They will generate active power and harmonics in the current. With a 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 going 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 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.

9 Accuracy

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

To determine the maximum power measurement uncertainty, a factor, called Maximum Current Ratio (MCR) should be first calculated and depend 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 as follows:

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

- ▶ 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 system measured uncertainty shouldn't exceed 0.01 W (absolute error) at 95% confidence level.

Let us do the standby calculations for each one of LMG600 channels (S Channel, A Channel, B Channel and C Channel).

Note: *The calculations are based on the S3, A3, B3, C3 channel specifications.*

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

S Channel:

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

A Channel:

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

B Channel:

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

C Channel:

$$\Delta P = \pm (0.03\% \text{ of measured value} + 0.01\% \text{ of maximum peak value}) +$$

$$80 \frac{\mu A}{A^2} * U_{rms} * I_{rms}^2$$

9.1 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.

$$\Delta P_S = \pm 0.006 \text{ W}$$

$$\Delta P_A = \pm 0.006 \text{ W}$$

$$\Delta P_B = \pm 0.014 \text{ W}$$

$$\Delta P_C = \pm 0.008 \text{ W}$$

The relative error is 0.06% for S and A channels, 0.14% for B channel and 0.08% for C 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, B channel) of the allowed systems uncertainty of 2%.

9.2 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.

$$\Delta P_S = \pm 0.020 \text{ W}$$

$$\Delta P_A = \pm 0.020 \text{ W}$$

$$\Delta P_B = \pm 0.043 \text{ W}$$

$$\Delta P_C = \pm 0.022 \text{ W}$$

The relative error is 0.2% for S and A channels, 0.43% for B channel and 0.22% for C 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, B channel) of the directive's 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 high power. Let's therefore repeat the calculation with a typical standby power of 0.5 W:

9.3 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.

$$\Delta P_S = \pm 9,035 \text{ W}$$

$$\Delta P_A = \pm 9,035 \text{ W}$$

$$\Delta P_B = \pm 18,170 \text{ W}$$

$$\Delta P_C = \pm 9,113 \text{ W}$$

- ▶ The relative error is 1.807% for S and A channels, 3.634% for B channel and 1.822% for C channel. The MCR is equal to 60, the Upc is equal to 0.1 and the Upc*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 see that all the power channels meet the requirements
- ▶ S, A, and C channels uncertainty is below the limits of the directive, even under these conditions. B channel exceeds the limit. This is why the B 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.

9.4 No instrument will fulfil the standard under all circumstances!

In the above examples values were used, which are today the edge of 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 exist, 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.

9.4.1 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 speaking: Our products cannot measure everything under all circumstances! On the other hand, we at ZES ZIMMER – A Rohde & Schwarz company – won't hide behind fancy guarantees and certificates. Serious certificates and guarantees must 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 the S/A 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 the S/A 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.

9.5 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 sufficient accuracy at the time of calibration. But this is not 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 accuracy over time and cannot be contained in a 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 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.

9.6 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.

9.6.1 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.

10 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.

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