Calibration: meeting the challenges of high-frequency power measurement

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What is calibration?

Calibration is the comparison of a measuring instrument (an unknown) against an equal or better standard. A standard in a measurement is therefore the reference.
Instruments are adjusted initially at the factory to indicate a value that is as close as possible to the reference value. The uncertainties of the reference standard used in the adjustment process will also dictate the confidence that the indicated value is "correct".

WT3000 Precision Power Analyser

Introduction: the need for high accuracy power measurement

As more and more innovation focuses on energy efficiency and the use of renewable energy resources, engineers are increasingly demanding accuracy and precision from their power measurements. At the same time, new standards such as IEC62301 Ed2.0 and EN50564:2011, covering standby power consumption, and the SPEC guidelines, covering power consumption in data centres, demand more precise and accurate testing to ensure compliance.

To meet these challenges, R&D teams are coming to terms with the need for new levels of precision in power measurement, but these levels of precision can only be achieved if the measuring instruments are properly calibrated with reference to national and international standards.

Regular calibration by a laboratory, which can provide very low measurement uncertainties at the specific measurement points applicable to individual users, should enable instrument makers and their customers to have confidence in their test results.

However, with power measurements in particular, the situation is not so clear cut – to the extent that the accuracy figures quoted in manufacturers' specifications – and indeed some of the parameters listed in calibration certificates issued by well-established test houses – can be meaningless when taken out of context.

The need for high frequency power measurement

One key area which is often neglected in traditional specifications is that of power measurements at high frequencies. Traditionally, AC power meters are calibrated at frequencies of 50-60Hz. Nowadays, however, there is a demand for power measurement at high frequencies on devices such as switch-mode power supplies, electronic lighting ballasts, soft starters in motor controls and frequency converters in traction applications.

Yokogawa European Calibration Laboratory

Calibration of high-frequency power has lagged behind the development of power meters to address these applications, and few national laboratories can provide traceability up to 100 kHz: the frequency at which instruments have to be calibrated to provide accurate results in these application sectors.

There are a number of other parameters involved in power measurements that determine the performance of an instrument in a particular application. It is no longer sufficient merely to list voltage and current specifications: today's power environment needs to address variables such as phase shift, power factor and the effects of distorted waveforms.

It is also important to calibrate the instrument under the right conditions. Many test houses still use pure sine waves at only 50 Hz to calibrate power meters, which renders the results virtually useless for users carrying out tests under "real world" conditions.

It is therefore important for users of power measuring instruments to look at the actual "calibrated" performance of different manufacturers' products rather than just comparing specifications. This is the key thinking behind Yokogawa's policy of having its own European Standards Laboratory with minimal uncertainties and capabilities which are almost second to none: as confirmed by the fact that it has become the world's first non-governmental facility to receive full ISO17025 accreditation for power measurements at up to 100 kHz.

What is calibration?

"Calibration" can be defined as the comparison of an instrument's performance with a standard of known accuracy.

No measurement is ever correct. There is always an unknown, finite, non-zero difference between a measured value and the corresponding "true" value. In other words, a user can never be 100% sure that an instrument is operating within its specified tolerance limits.

However, there are steps that can be taken to minimise the possibility of a measurement falling outside specified tolerance or uncertainty bands. Regular traceable calibration is a method for gaining quantifiable confidence in a measurement system by comparing the instrument's performance to a standard of known accuracy.

However, all laboratory standards and even national standards have uncertainties of measurement; hence it is difficult to be 100% confident that an instrument is operating within its stated tolerance limits.

It is important to understand the difference between "calibration" and "adjustment". Calibration is the comparison of a measuring instrument (an unknown) against an equal or better standard. A standard in a measurement is therefore the reference.

Instruments are adjusted initially at the factory to indicate a value that is as close as possible to the reference value. The uncertainties of the reference standard used in the adjustment process will also dictate the confidence that the indicated value is "correct".

As the instrument ages, the indicated value may drift due to environmental factors (temperature, humidity, oxidation, loading etc.) which will also be dependent on the quality of its design and manufacture. To ensure that the instrument continues to operate within the manufacturer's tolerances, the instrument should be compared to the reference value on a regular basis

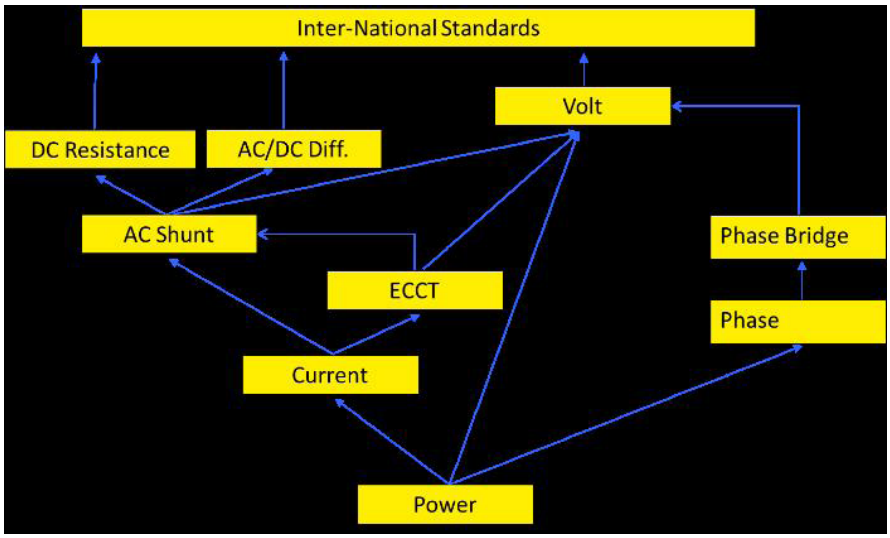

Figure 1 Traceability overview

(usually annually). If necessary, the instrument can then be re-adjusted.

If there is no appreciable change in the calibrated results, this means that the instrument's design is inherently highly stable. In this case, there is no need to adjust it, and the user can also rely on the fact that the unit will exhibit the same stability on a day-by-day basis.

It goes without saying that all instruments should be calibrated on a regular basis. Not calibrating carries a number of costs and risks:

- In production/acceptance testing, users may encounter false passes or (equally undesirable) false failures.
- In an engineering laboratory, inaccurate measurements can distort the findings.
- Contractual requirements may inadvertently fail to be met
- Quality issues may result in customer dissatisfaction or even product recalls and rework.

Regular calibration by a laboratory, which can provide very low measurement uncertainties at the specific measurement points applicable to individual users, should enable instrument makers and their customers to have confidence in their test results.

Yokogawa's calibration capabilities

As indicated above, Yokogawa's European Calibration Laboratory has become the world's first non-governmental facility to receive full ISO17025 Accreditation for power measurements at up to 100 kHz. This is in addition to its established capability for providing high-accuracy calibration at 50 Hz, especially at very low power factors (down to 0.0001) and at high currents.

At the heart of the laboratory is a special calibration system with the capability to calibrate power up to 100 kHz (Fig.1). Housed in a climate-controlled environment (23.0 ± 1.0)°C, the system is able to calibrate voltage, current, DC power, AC power, frequency and motor functions, all under fully automatic control.

The system consists of two parts, a signal generator section and a reference measuring unit. Those two parts are separated by a metal shield in order to prevent the heat generated by the signal sources from affecting the reference meters. Different sources are used to generate the calibration signal because a single source is not sufficient to generate all the signals required. Instead, multiplexers are used to select the sources needed for any particular measurement. Similarly, different reference power meters are selected via a multiplexer. This allows the selection of the best reference power meters for high-current, low-current or low-voltage calibrations. The reference power meters are from Yokogawa and are special models modified with aged components and firmware to enhance the resolution. They have an excellent stability and performance.

The power meter under calibration is connected via a multiplexer on the calibration system. Each element of the power meter under calibration is calibrated separately. A power meter with mixed inputs is easily calibrated. Extra instruments are added to the calibration system to calibrate any additional options of the power meter such as the motor function and analogue output.

The system is designed to minimise effects such as capacitive leakage and crosstalk, with special attention given to the wiring harness and multiplexers. For voltage, twisted and screened coaxial cables are used, while current uses coaxial cabling. The multiplexers use special relays to avoid leakage and crosstalk. The influence of the wiring harness is now kept to a minimum. With a worst-case measurements using 100 V at 100 kHz, the crosstalk suppression to the current channels is better than -93 dB. For mixed-input units, every element is calibrated separately to minimise the effects of loading.

The in-house developed software makes this system very flexible. A calibration is normally based on the Yokogawa Quality Inspection Standards (QIS). If the QIS is passed, it is demonstrated that the measured values are within specifications. However, on request of the customer, it is possible to calibrate additional points within our capability. The system is able to communicate with the power meter under calibration by GPIB, RS232, USB or Ethernet.

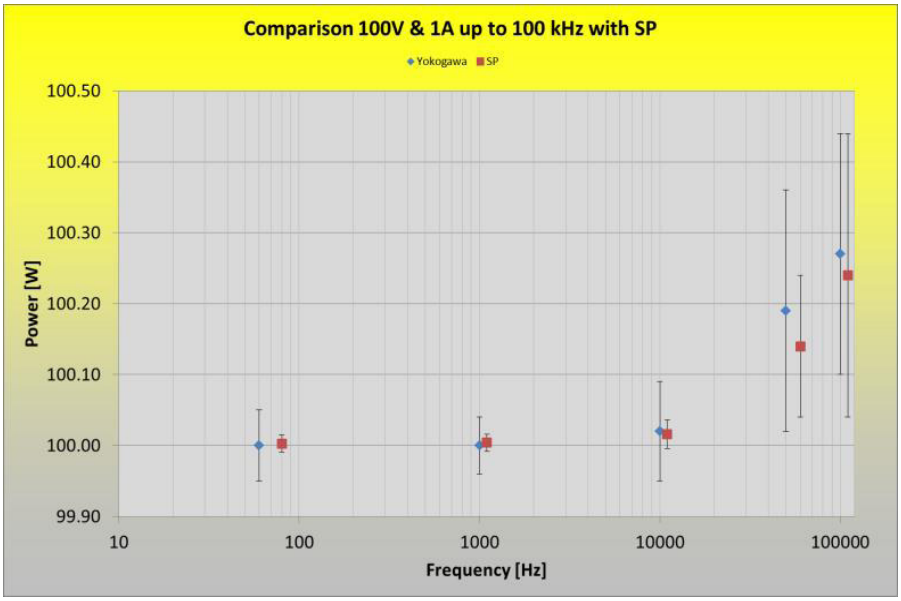

Figure 2 Power Comparison with SP

When the calibration is finished, the results are used to generate the calibration certificate.

A typical calibration of a power meter takes a few hours, depending on the number of elements. For each element, tests are made at about 45 voltage calibration points, 65 current calibration points and 78 power calibration points. Using all those points the voltage gain, voltage linearity, voltage flatness, current gain, current linearity, current flatness, power gain, power linearity, power flatness, power factor and frequency are calibrated at DC and from 10 Hz to 100 kHz. This includes also the external current sensor if applicable. A total of about 180 calibrations are done for each element. The system is also able to calibrate the motor function by using analogue or pulse shape signals. A 30-channel multiplexer measurement system is installed to measure the analogue output of the power meter.

The calibration of the system itself is also carried out in the European standards laboratory, and includes the effect of the multiplexers and wiring harness to remove the unknown uncertainty.

Traceability

Traceability for power is based on values for voltage, current and phase (Fig.2). Using these units, it is possible to calculate power by the equation:

$$P=U\cdot I\cdot \cos(\varphi)$$

which is valid only for sine waves, so that special attention has to be taken into account for the harmonic distortions of the generated signals.

The measurement of voltage is straightforward using a digital multimeter. However, using a digital multimeter to measure the current is limited due to the frequency capability and uncertainty, and therefore two different options are used. If the current frequency is 50 to 60 Hz, an electronic compensated current transformer (ECCT) is used to measure the current, but if the frequency is higher current shunts have to be used for the other frequencies. Yokogawa has built its own current shunts to measure from 1 mA up to 10 A at up to 100 kHz with a maximum AC/DC difference of 3 parts in a million at 100 kHz. Measuring the voltage over the shunt allows the current to be calculated.

To obtain the phase, a phase measurement device based on a high-speed, high-resolution digitiser is used. The digitiser is equipped with differential inputs to avoid ground loops. The biggest uncertainty here is the phase angle deviation of the current shunts, which is corrected by calibrating the shunt at different frequencies. The phase measurements device is calibrated via a phase standard, which in turn is calibrated using self-calibrating phase bridges.

This setup enables power to be made traceable at up to 100 kHz.

To confirm the calibration setup, a Yokogawa WT3000 power analyser was calibrated by Yokogawa, and then sent to the national Standards Laboratory of Sweden (SP). At SP they also calibrated the Yokogawa WT3000 at the same points which verified the results (Fig.3).

ISO17025

Power Calibration 100 kHz PF=1

Range	Applied	Measured	±Uncertainty	Unit	Deviation %
100V 50mA	5,000	5,008	0,016	W	0,165
100V 200mA	20,00	20,03	0,06	W	0,132
100V 1A	100,0	100,3	0,3	W	0,257
150V 1A	100,0	100,2	0,3	W	0,201

ISO9001

Power Calibration 100 kHz PF=1

Range	Applied	Lowlimit	Measured	Highlimit	Unit	Deviation %	Result
100V 50mA	5,0000	4,9500	5,0083	5,0500	W	0,165	Pass
100V 200mA	20,000	19,800	20,026	20,200	W	0,132	Pass
100V 1A	100,000	99,000	100,257	101,000	W	0,257	Pass
150V 1A	100,00	98,85	100,20	101,15	W	0,201	Pass

Figure 3 Differences between the ISO9001 and ISO17025 Certificates

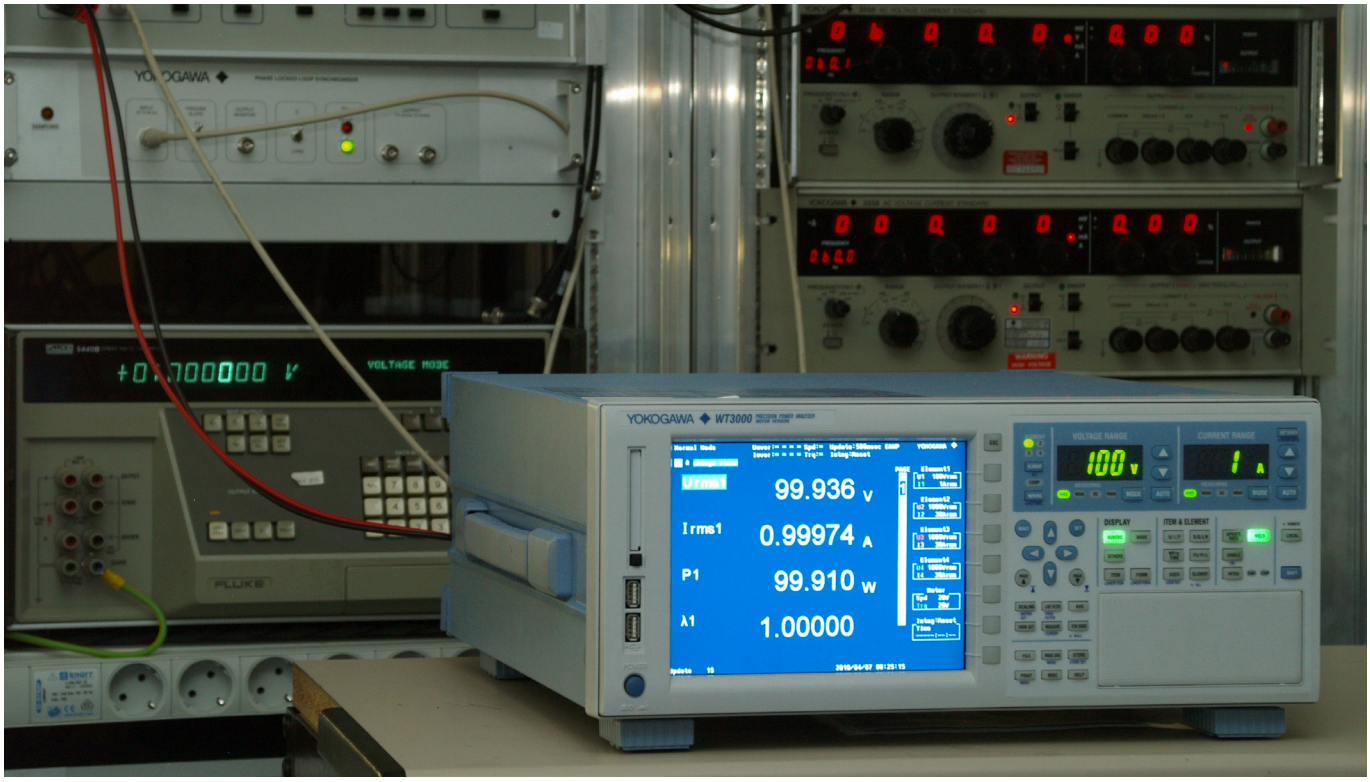

Figure 4 Yokogawa WT3000 Power Analyser

The importance of accreditation

The familiar ISO 9001 standard aims at confirming the traceability of a measurement but does not define how the measurement is carried out. Laboratories that are accredited to ISO 17025 (General requirements for the competence of testing and calibration laboratories), however, have demonstrated that they are technically competent and able to produce precise and accurate calibration measurements. Fig.3 shows an ISO 17025 certificate complete with measurement uncertainties, which confirms that the power meter is truly much more accurate than its specification. There is no guarantee that the measurements on an ISO9001 certificate are correct.

Yokogawa's European Calibration Laboratory is the only industrial (i.e. non-government or national) organisation to offer traceability up to 100 kHz, and thus is the only power meter manufacturer which can directly prove the performance of its own instruments. Only a Yokogawa Calibration Certificate gives the user trust in their instrument's measurements.

ISO17025 accreditation also reflects the attention paid to the design of the input circuits of Yokogawa's precision power analysers, with an emphasis on wideband, high-linearity characteristics that make them the world's most accurate instruments in their class (Fig.4).

Calibration results at high frequencies are available on request.

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