The Need for High-Frequency 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. But these levels of precision can only be achieved if the measuring instruments are properly calibrated with reference to national and international standards. **Clive Davis, Marketing Manager T&M and Erik Kroon, Metrology Expert, Yokogawa T&M Center Europe, Amersfoort, Netherlands**

The need for new levels of higher precision in power measurement arises, 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.

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 50-60 Hz. 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 inverters in traction applications.

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 behind Yokogawa's opening of its own European Standards Laboratory. It has become recently the first non-governmental facility to receive full ISO17025 accreditation for power measurements at up to 100 kHz.

Why calibration?

Calibration can be defined as the comparison of an instrument's performance with a standard of known accuracy because no measurement is ever correct. There is always an unknown, finite, non-zero difference between a measured value and the corresponding "true" value.

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 (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.

Yokogawa's calibration capabilities

At the heart of the laboratory is a special calibration system with the capability to calibrate power up to 100 kHz (see Figure 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

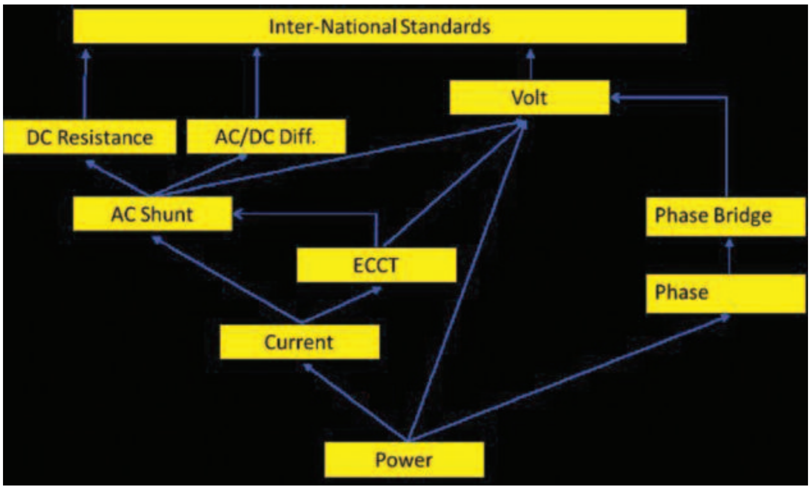


Figure 1: **Traceability overview**

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.

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 minimize 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 minimize the effects of loading.

A calibration is normally based on the internal Quality Inspection Standards (QIS). If the QIS is passed, it is demonstrated that the measured values are within specifications. However, on request it is possible to calibrate additional points. The system is able to communicate with the power meter under calibration by GPIB, RS232, USB or Ethernet.

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 (shunt) 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.

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

Traceability

Traceability for power is based on values for voltage, current and phase. Using these units, it is possible to calculate power by the equation P = U x I x cos phi 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 (ppm) 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 digitizer is used, 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

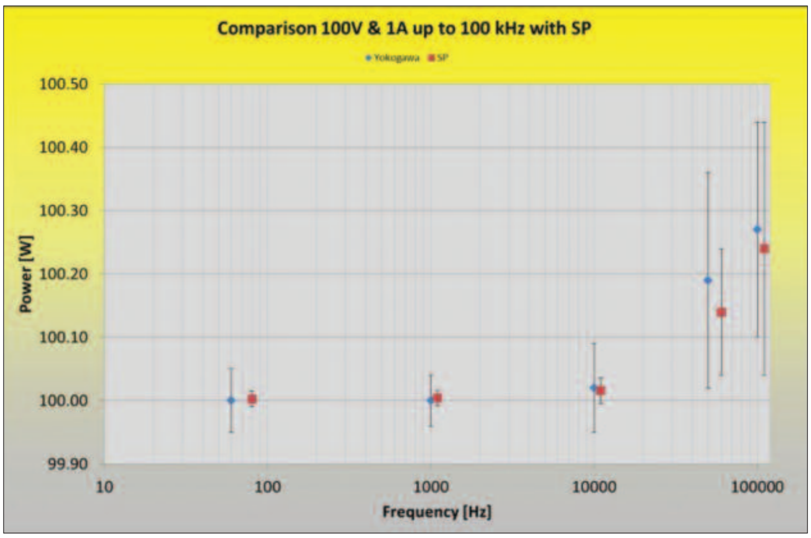
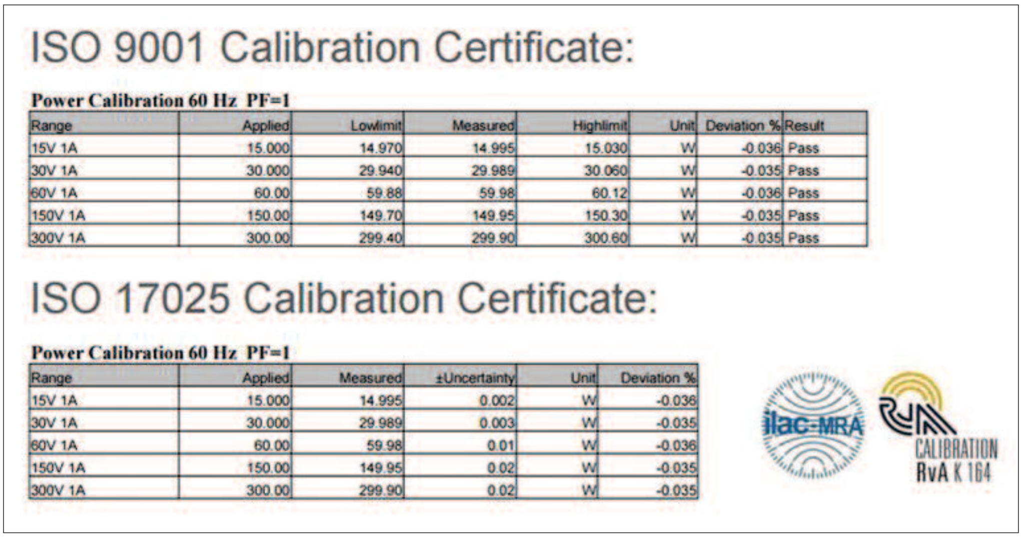


Figure 2: **Power comparison with national Standards Laboratory of Sweden (SP)**



ISO 9001 Calibration Certificate:

Power Calibration 60 Hz PF=1

Range	Applied	Lowlimit	Measured	Highlimit	Unit	Deviation %	Result
15V 1A	15.000	14.970	14.995	15.030	W	-0.036	Pass
30V 1A	30.000	29.940	29.989	30.060	W	-0.035	Pass
60V 1A	60.00	59.88	59.98	60.12	W	-0.036	Pass
150V 1A	150.00	149.70	149.95	150.30	W	-0.035	Pass
300V 1A	300.00	299.40	299.90	300.60	W	-0.035	Pass

ISO 17025 Calibration Certificate:

Power Calibration 60 Hz PF=1

Range	Applied	Measured	±Uncertainty	Unit	Deviation %
15V 1A	15.000	14.995	0.002	W	-0.036
30V 1A	30.000	29.989	0.003	W	-0.035
60V 1A	60.00	59.98	0.01	W	-0.036
150V 1A	150.00	149.95	0.02	W	-0.035
300V 1A	300.00	299.90	0.02	W	-0.035

Figure 3: Differences between the ISO9001 and ISO17025 certificates

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 analyzer 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 (Figure 2).

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. Figure 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.

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

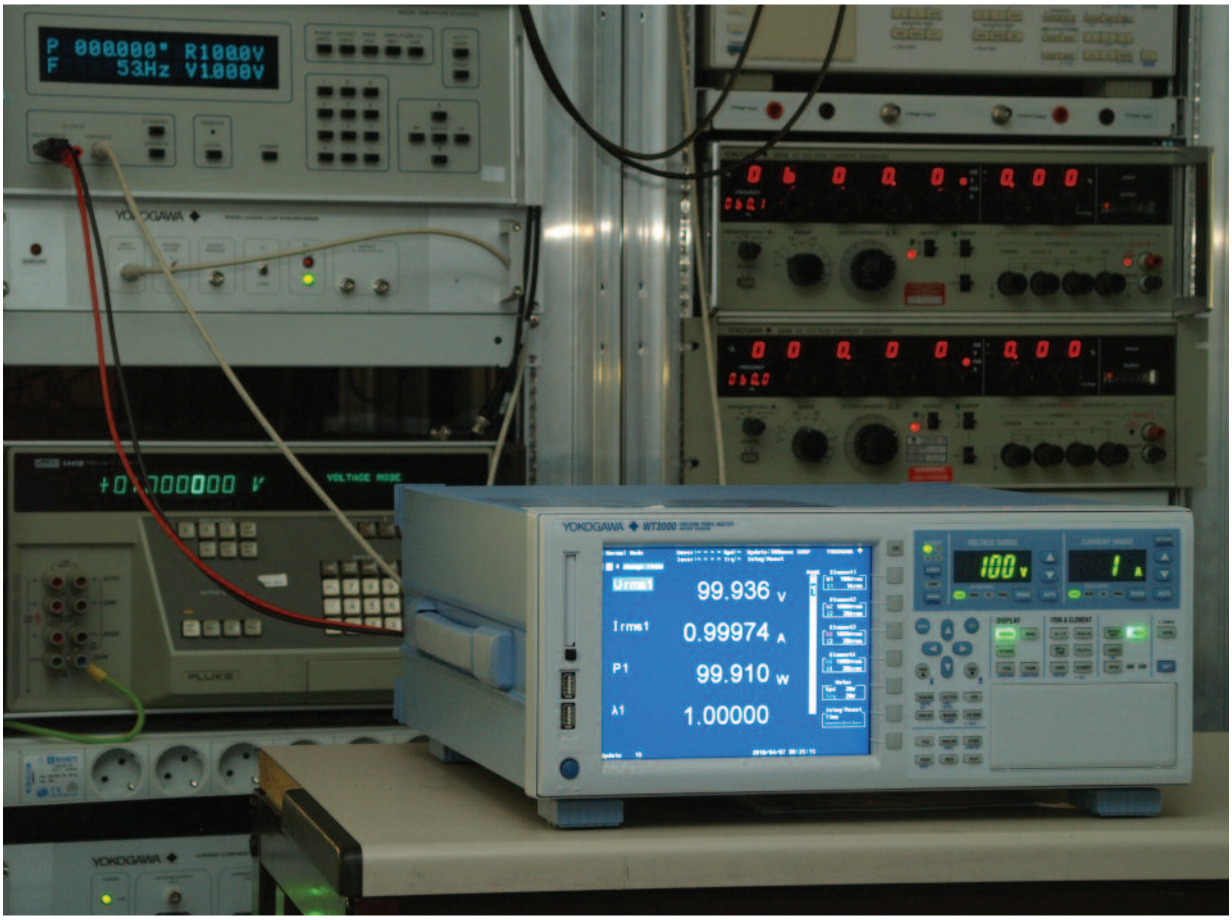


Figure 4: Yokogawa WT3000 Power Analyser