

# Universal Calibrator for Electrical Quantities for Power Utilities, Industry and R&D

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## 1. PREFACE

Measurement requires reliability and certainty. In other words, any information about the value of a quantity only becomes usable if we know the measurement uncertainty. In order to find out the measurement uncertainty of a device we need a comparison to a known quantity. Such a comparison is commonly known as calibration. The result of a calibration is laid down in a calibration report and includes a number of test points which should be appropriately chosen for the diagnosis of the whole measurement range.

This paper shall turn the attention of the measurement technician to various present and future challenges in the field of device calibration. It shall also strengthen awareness of the requirements that must be met by a calibrator to provide a universal solution for the calibration of electrical quantities. Typical utility equipment that requires regular calibration:

- Meters
- PQ Analyzers
- Transducers
- Phasor Measurement Units
- all kind of other measurement devices

The use of a universal calibrator suitable for many calibration jobs to be performed in manufacturing facilities where measurement equipment is produced or in a utility environment where it has to be maintained over a long time offers significant benefits such as:

- Reduction of payback period by a higher degree of economic utilization
- Facilitation and standardization of calibration procedures
- Reduction of downtimes by automated and standardized procedures
- Less error-prone procedures and thus more reliable results
- Increased satisfaction of the personnel

## 2. GENERAL CONSIDERATIONS

The requirements on a universal calibrator used as a reference device are numerous. Each application has its own specific needs; the

methods however, are the same: a highly accurate current and voltage source injects its quantities in to the equipment under test (EUT).

In order to pursue such an approach for obvious reasons, the EUT always must be disconnected from the installation (voltage and/or current transformers). It does not mean that the EUT needs to be moved to a calibration lab. In most cases it is desirable to perform the calibration on-site without even dismantling or moving the EUT, which makes the whole logistics a lot simpler. As a conclusion it can be asserted that the calibrator must be portable, such that it can be carried by a single person. There is no common definition for "portable" but 20 kg should be an upper limit for a calibration device (including carrying bag with some basic accessories).

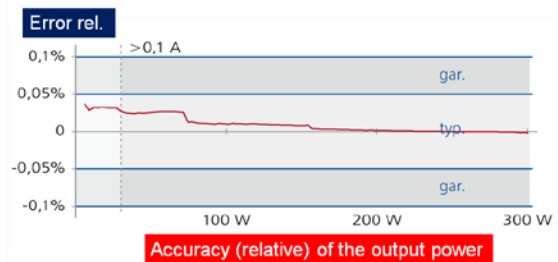


Figure 1: Definition for "typ." and "guar." and actually measured error graph (red)

In many cases, measuring devices measure three-phase system quantities. A calibrator at least has to provide six output channels, three voltages and three currents. Advanced PQ recorders often have four current and voltage inputs in order to include ground current and neutral-to-ground voltage measurements. Providing more than three voltage and current channels may be considered as a nice extra feature.

The required current and voltage magnitudes depend heavily on the equipment to be calibrated and also on the countries system voltage. Low voltage levels including secondary voltage levels range from 110 to 240 V. Considering overvoltage phenomena (voltage swells) at least for 230/240 V countries, we have to specify an output voltage range of 0 to 300 V. As far as currents are concerned we must be able to cover the secondary range of CTs (0...5 A) for CT-connected devices but directly connected devices may be specified at much higher input currents. High

output currents inevitably always results in a higher weight of the calibrator. Thus a reasonable compromise may be 20 or 25 A per phase. The device should support paralleling the output currents in order to obtain higher currents for single-phase applications. In power systems, power may flow in both directions (forward/reverse), load may be of inductive or capacitive nature. A universal calibrator needs to address this providing a setting range of the voltage and current angle of  $0^\circ$  to  $360^\circ$ .

As far as the system frequency is concerned, we face 50 and 60 Hz, in some rare cases 16.7 Hz (railway) or 400 Hz (vessel or airplane). In order to meet the requirements, however, a universal calibrator must be able to generate harmonics as well. Harmonic measurement is basically a Power Quality issue; the corresponding standards are IEC 61000-4-7 and IEEE1159. PQ meters according to these standards need to measure up to the 50th harmonic. A universal calibrator thus needs to be able to generate frequency portions up to 3 kHz.

Up to now we have spoken about sinusoidal wave forms. A modern calibrator generates synthetic voltages and currents. For such equipment the generation of transient signals is not a major challenge. It is technically feasible as for sinusoidal and periodic signals. However, sufficient transient memory and software support for the IEEE COMTRADE standard must be provided.

In order to achieve a high degree of automation the calibrator needs to be fully controlled by software. For most applications a standard software running on a notebook or desktop PC is a suitable solution. The PC or notebook is connected to the calibrator via an Ethernet-port. For sophisticated test set-ups it might be necessary to connect the calibrator as well as the EUT to the PC by means of an Ethernet switch.

For future applications the connection to an IED (Intelligent Electronic Device) might become a topic. IEDs could be meters, transducers, phasor measurement units and are not necessarily connected to analog quantities anymore. Instead they can receive their input quantities via data stream (standardized by the IEC 61850 protocol). In order to address this issue a calibrator needs to be able to generate data streams to be provided at the Ethernet-port of the device.

The previously mentioned standard software for different applications might be sufficient for most utility needs but still will not cover sophisticated use cases. This is true especially for calibrations performed at the end of the manufacturing

process. A universal calibrator thus needs to provide an open interface that permits programmers full access to the calibrator to create their own test and calibration routines.

### 3. SPECIFIC APPLICATIONS

#### 3.1 Meter Testing

Using a phantom load generated by a portable calibrator (time power method) rather than a reference meter that measures the actual energy in parallel to the EUT (comparison method), offers significant advantages. This method allows meter testing at arbitrary test points, not constrained by the given load conditions. This comparison method is still widely used, especially where the EUT cannot be disconnected for testing. Due to the inaccuracy of older current and voltage sources (phantom loads), a reference meter had to be used in parallel to the sources. This made the test set-up complex and expensive.

The requirement for a modern universal calibrator is to provide sufficient accuracy in the power (energy) to eliminate the need for an additional reference meter. The meter calibration guideline E-04 of the BMfWA (Austrian federal ministry of trade and industry) of 2007 requires for class 0.2 meters, a maximum measuring error of the test equipment of 0.04 % at a power factor of 1. For class 0.5 meters the maximum test equipment measuring error is 0.1 %. The same applies to active power sources if testing is performed without a reference measurement. The controlling software must support the testing of all kind of meters, electronic and Ferraris meters.



Figure 2: Meter Test set-up with new type of rubber-adhesive-fixed pick-up

#### 3.2 Calibrating PQ Analyzers

Testing of power quality analyzers poses a particular challenge. In contrast to meter testing there is no comparison method (passive parallel measurement). The only feasible way to test the performance and conformity of a PQ meter to the

applicable standard is to generate the corresponding PQ phenomena.

The accuracy requirements are quite demanding. For class A devices the measurement uncertainty of the voltage magnitude shall not exceed 0.1 % of  $U_{in}$  (declared input voltage). In terms of frequency measurement IEC 61000-4-30 defines a maximum uncertainty of 0.01 Hz. A calibrator should be at least 3-5 times better in accuracy, the error of the calibrator thus shall ideally be less than 0.02 % in magnitude and 0.002 Hz in frequency. Certainly the calibrator's controlling software must be capable of generating all required wave shapes such as modulations (simulation of flicker), harmonics, interharmonics or transient dips.

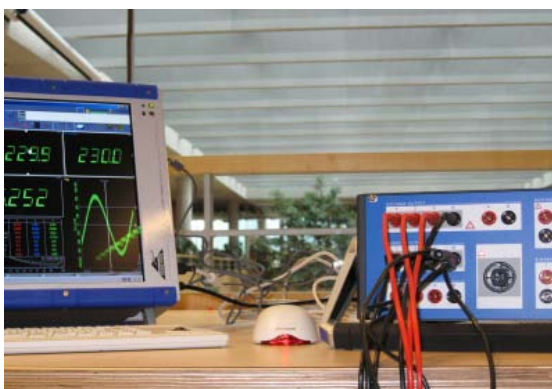


Figure 3: Test set-up with an advanced PQ-analyzer (left) and calibrator (right)

| MEASORDER | NAME      | LOWERLIMIT | UPPERLIMIT | ACTUALVA... | EVALUATION |
|-----------|-----------|------------|------------|-------------|------------|
| 10        | Frequency | 49.93315   | 50.06685   | 49.99985    | passed     |
| 11        | Frequency | 54.92795   | 55.07205   | 55.00004    | passed     |
| 15        | Frequency | 59.9277    | 60.0723    | 59.9999     | passed     |
| 16        | Frequency | 16.62987   | 16.77014   | 16.69768    | passed     |
| 20        | U_rms_L1  | 107.6555   | 112.3445   | 109.9953    | passed     |
| 21        | U_rms_L2  | 107.6555   | 112.3445   | 109.9578    | passed     |
| 22        | U_rms_L3  | 107.6555   | 112.3445   | 109.9776    | passed     |
| 30        | U_L1_H3   | 22.85615   | 23.14385   | 22.99028    | passed     |
| 31        | U_L2_H3   | 22.85615   | 23.14385   | 22.98028    | passed     |
| 32        | U_L3_H3   | 22.85615   | 23.14385   | 22.98537    | passed     |
| 33        | U_L1_H10  | 2.270615   | 2.329385   |             |            |
| 34        | U_L2_H10  | 2.270615   | 2.329385   |             |            |
| 35        | U_L3_H10  | 2.270615   | 2.329385   |             |            |
| 40        | THD_U_L1  | 1.9851     | 2.0149     |             |            |
| 41        | THD_U_L2  | 1.9851     | 2.0149     |             |            |
| 42        | THD_U_L3  | 1.9851     | 2.0149     |             |            |

Current 1s / Total 13s

Figure 4: Automatic calibration routine with customized software

For semi-automatic testing, the software needs to support the manual entry of the read results and a subsequent manual assessment. More efficiency can be obtained with an automatic approach.

Figure 4 shows a customized calibration routine that:

- Calculates the required test quantities
- Controls the calibration device via open programming interface
- Accesses the data base (SQL server) of a sophisticated PQ analyzer
- Transfers the measured data to the controlling PC
- Compares the results to a previously defined tolerance band
- Automatically makes an assessment passed/ failed
- Creates a calibration report

### 3.3 Transducer Testing and Calibration of other kind of Measurement Equipment

Transducers are widely-used all over the network to acquire data for SCADA systems. Modern transducers are multifunctional and may provide data interfaces along with the conventional analog outputs. Transducers are subject to regular calibrations. In a conventional test set-up a current and voltage source is connected to the transducer inputs, the DC output (current or voltage) is returned to the measurement input of the calibrator.

A PC controls the automated test in a closed loop. The calibrator's controlling software must support all kind of transducers (power, voltage, current, phase angle, frequency). Preferably the calibrator should support the testing of multifunctional transducers with more than 1 output without rewiring during the test.

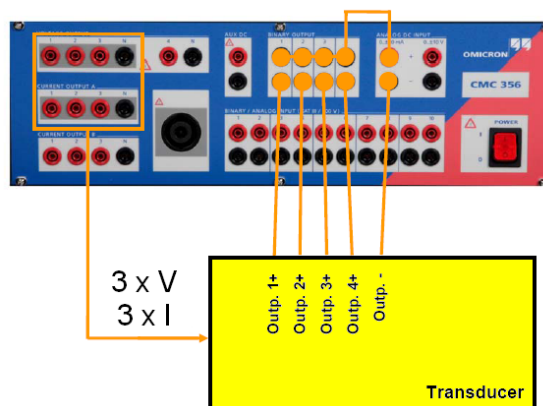


Figure 5: Testing a multifunctional transducer without rewiring (utilizing relays)

In order to include remote displays into a test routine, the test sequence must also be executable manually. Re-adjustments of inaccurate transducers must be supported as well.

For sophisticated tests (mainly in manufacturing facilities), where controlling of the calibrator and data exchange from the EUT via data interface has to be managed simultaneously it is essential to provide an open programming interface.

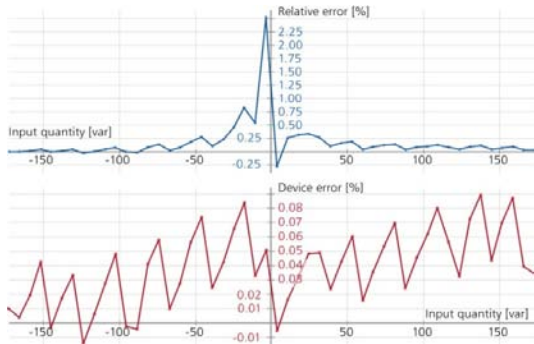


Figure 6: Plotted error curves of a reactive power transducer

### 3.4 Calibrating Phasor Measurement Units

Driven by dramatic power failures, a few years ago, first in the USA and later in other countries as well, power utilities began to install Phasor measurement units (PMU). PMUs are installed at important network nodes in order to measure accurately and synchronously magnitudes and phase angles of voltages and currents. The idea behind them is to compare and analyze the synchro-phasors in a wide area and, when necessary, react to the results of the analysis. PMUs are typically time synchronized by means of the Global Positioning System (GPS). The measured quantities are time-tagged and transferred to a monitoring center over fast communication links. The monitoring center collects, aligns, archives and provides the data to SCADA /analysis applications. The applicable standard for measuring synchro-phasors is IEEE C37.118.

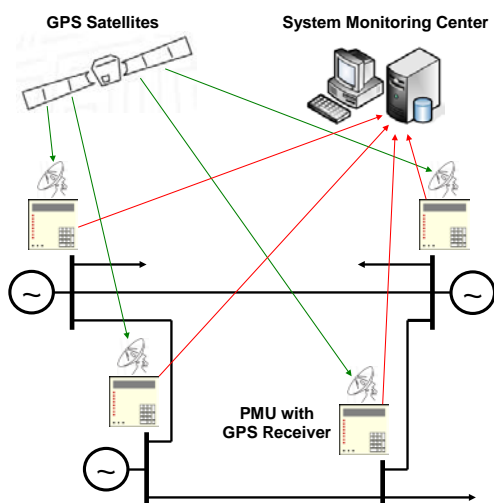


Figure 7: GPS-synchronized phasor measurements and data collection

The standard defines a total vector error (TVE) which combines errors from the magnitude and phase measurements. The maximum tolerable deviation  $\epsilon$  from the theoretical position of the top of the phasor is  $\pm 1\%$  for most applications. The standard also includes a brief statement on the requirements of a calibration device. It demands to have a test accuracy ratio of at least four ( $\epsilon = 0.25\%$ ) which is already quite challenging for a signal source. The combined worst case error of a test signal with a magnitude error of  $0.1\%$  and a phase error of  $0.1^\circ$  is already equal to a TVE of  $0.2\%$ .

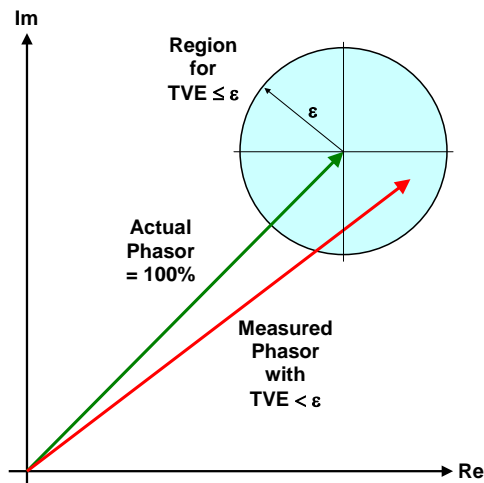


Figure 8: Phasors and Total Vector Error (TVE)

A further essential requirement of the calibrator is the provision of versatile time synchronization features. The calibrator device must be able to be synchronized with the test object by an external time source (GPS) or provide a local and stable time reference for the PMUs to be calibrated. Typically a 1 PPS (Pulse per Second) or IRIG-B signal is generated by the calibrator.

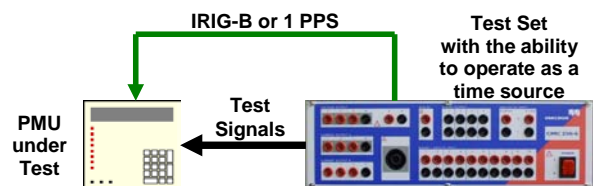


Figure 9: Locally synchronized test set-up with calibrator as time source

## 4. SUMMARY

It is a great challenge to any calibration device with active current and voltage sources to meet the various requirements of accuracy, long-term stability, versatility, portability and flexibility. However, most modern hardware and software technologies make such an advanced universal calibrator possible. Measuring devices need to be

tested and calibrated throughout the whole life cycle in order to ensure proper functioning and sufficient measurement accuracy. Functional testing and calibration thus comprises type tests, routine tests at the end of the production process and regular tests in meaningful intervals as long as a device is part of the installation. Especially for the latter, portability is a crucial requirement since on-site testing is becoming increasingly important compared to mass-testing in laboratories.

Certainly, the universal calibrator needs to be calibrated regularly against a higher standard in order to ensure a high level of process quality. Implementing such a process maintains traceability of the EUT's accuracy up to the national standard. The universal calibrator is an element of this traceability chain.

## REFERENCES

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