A calibration-verification testbed for electrical energy meters under low power quality conditions

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ABSTRACT

A calibration/verification testbed for electrical energy meters is under development at the Istituto Nazionale di Ricerca Metrologica, the National Metrology Institute of Italy. The testbed will be employed for the calibration of commercial static power energy meters under low power conditions and for simulating the verification in the field of energy meters under real operational conditions. The activity is in collaboration with the Ministry for Economic Development and aims to the future development of regulatory documents for energy metering verification.

1. Introduction

The accurate measurement of the consumed/generated electrical energy by users/producers is crucial for the observability of the distribution network and fair energy billing. In the transition towards the smart grid concept the spread of renewable energy sources and nonlinear loads worsen the electrical power quality. These sources could have different wave shapes, for which at present, there is inadequate traceability. The old electromechanical induction meters are being replaced by static electronic meters compliant to Ref. [1], which allow smart metering, real-time pricing and in some cases the measurement of power quality parameters.

Recent surveys have shown, however, that whereas induction meters give acceptable errors even in the moderate to low power quality levels [2], the more recent static meters can have reading errors far beyond the specifications given for the sinewave regime [3]. These results suggest that the methodology of verification of the meters according to the present legislation requires further in-depth study.

In Italy legal metrology activities are under the authority of the Ministero dello Sviluppo Economico (Ministry of the Economic Development, MISE). Power and energy electrical standards and their development are commissioned to the Istituto Nazionale di Ricerca Metrologica (INRIM), a public research institution belonging to the Ministry of University and Research (MUR).

Acknowledging the need of a development in scientific metrology in order to advance the corresponding legal metrology regulation, in January 2020 MISE and INRIM signed an agreement entitled "Collaboration for the development of validation methods for electrical energy meters under realistic conditions, towards market surveillance and consumer protection".

The objectives of the agreement are:

a) To allow the verification of static electrical energy meters, both in typical operating conditions (sinusoidal steady-state regime) and under low power quality conditions, with a traceability of the measurement to the International System of units;
b) to identify proper verification conditions, and corresponding acceptance thresholds, for the validation of static electrical energy meters under low power quality conditions, typical of civilian and industrial plants;
c) to generate a final report, that includes guidelines towards a revision of the current legislation and the interaction with national and international normative bodies, focused on the verification of static electrical energy meters in the laboratory and a feasibility of such verification in the field;
d) to enable a calibration service facility for electrical energy meters, suitable to be employed as verification standards with the specifications of point (b);
e) to support a verification service of electrical energy meters as a safeguard of the correct energy pricing.
f) to establish training courses for the technical personnel which will perform validations of electrical energy meters.

In addition to these objectives, an interlaboratory comparison [4] service will be established for applicant laboratories involved in power and energy measurements directly or not directly connected to meters verifications.

The collaboration includes the development, at INRIM, of a testbed for the calibration/validation of static electricity meters under moderate-to-low power quality conditions. The status of the development is reported here.

2. The testbed

2.1. Layout

A simplified schematic diagram of the testbed is given in Fig. 1. The power phantom generator G provides three voltage channels V_1, V_2, V_3, and three current channels I_1, I_2, I_3. The waveform outputs can be independently programmed in magnitude, phase and harmonic content.

The output is measured by the reference wattmeter W_{REF}; a digital feedback control loop from W_{REF} to G adjusts G settings to match the

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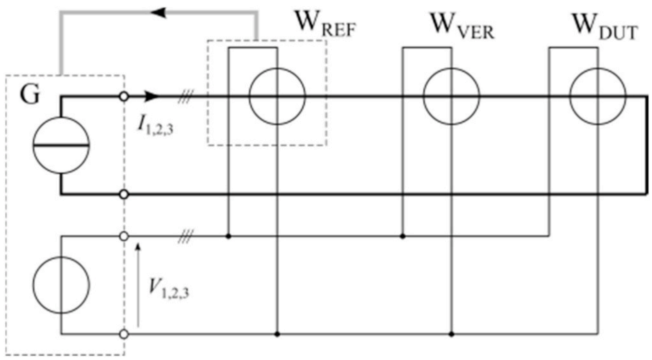

Fig. 1. Simplified schematic diagram of the testbed system for calibration/verification of static electricity meters. See Sec. 2.1 for details.

calibration point chosen.

The wattmeters/energy meters under testing are connected to the voltage and current meshes in the same way as W_{REF}. Fig. 1 shows a typical configuration, with a verification power meter W_{VER} and a static energy meter W_{DUT}, simulating a verification event in the field. W_{DUT} can be connected either directly, or with the use of voltage/current transformers (TA, TV) not shown in Fig. 1.

2.2. Instrumentation

G is a ZERA mod. MTS310 meter test system, see Fig. 2 It is composed

Fig. 2. The phantom power generator G. From top to bottom the communication module, the reading module, the voltage module for the generation of phase (or line) voltages, and the three transconductance amplifiers for the three line currents.

of a FG301-03 frequency generator, a VU221-00 voltage amplifier and three VI221-00 current amplifiers. The output spans up to 320 V and 120 A per phase, with a fundamental frequency from 40 Hz to 70 Hz and a bandwidth up to 1 kHz. A unit includes a photodetector to measure the optical output of W_{DUT}.

W_{REF}, shown in Fig. 3, is a ZERA mod. COM5003 three-phase wattmeter/energy meter, class 0.005% (50 parts per million). Voltage input range up to 500 V, current input range up to 160 A, with capability of setting up to the 40th harmonic.

W_{VER} is an optional verification wattmeter, see also Section 5. We employ a ZERA MT320 portable reference meter, accuracy class 0.05.

3. Low power quality conditions

The testbed is intended to be able to operate also by simulating low power quality conditions. The generator G can be programmed to generate, for each voltage and current channel, arbitrary waveforms, by setting the corresponding harmonic content (in amplitude and phase). An example of a distorted waveform, generated by G according to the technical standard EN 50470-3, and sampled by the reference wattmeter W_{REF}, is shown in Fig. 4.

4. Verification training setup

A verification training setup, shown in Fig. 5, has been implemented to allow operator training in conditions mimicking those in the field. An electrical cabinet, powered by G, simulates the metering section of a civilian or industrial plant; it can be equipped with two commercial static energy meters chosen from three representative models: i) a DPEE TH40C multifunction static three-phase meter, 1–10 A, class 0.5%/IEC and C/EN; ii) a CEWE PROMETER 100, 1–10 A, class 0.2% and C; iii) a Landis & Gyr 5 A, class 1%, in Aron connection with transformers. A set of voltage and current transformers are also included in the cabinet: i) S.T.E TT20 voltage transformers, 450 V3/100 V3, class 0.5% and ii) TCP10 current transformers, 80A/5A, class 0.5%.

A field verification instrument (e.g. W_{VER}) can be connected in parallel to each of the wattmeters through a dedicated terminal block.

5. Preliminary results

Preliminary active energy measurements on the DPEE TH40C (DUT) have been performed. Following the european standard EN 50470-1/-3 [5,6] we performed tests in both sinusoidal and distorted regimes. In the sinusoidal regime, the voltage $V = V_1 = V_2 = V_3$ was set to 240 V. In the distorted regime the 1st harmonic of V was set to 240 V and the 5th harmonic was set at 10% of amplitude of the fundamental harmonic component. The current waves were distorted by imposing a 40% amplitude on the 5th harmonic. Using the direct insertion scheme of Fig. 1, we measured the relative error in the energy reading of the DUT,

Fig. 3. The three-phase reference wattmeter/energy meter W_{REF}, a ZERA mod. COM5003.

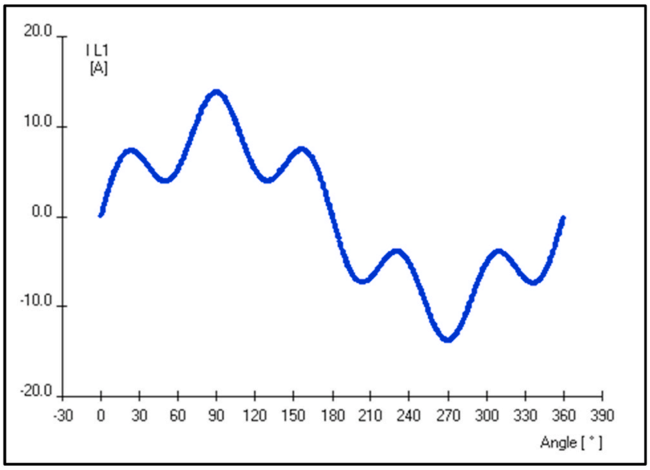

Fig. 4. An example of distorted current waveform (I_1) generated by G and sampled by W_{REF}, as specified in the technical standard EN 50470-3.

Fig. 5. The verification training setup. On the left two static energy meters, acting as V_{DUT}, provided with terminal blocks that allow the insertion of the verification wattmeter W_{VER}. On the right the set of voltage and current transformers (TV, TA) to extend the W_{DUT} voltage and current ranges.

compared to the readings of W_{REF}, in both regimes, as a function of the supplied current level within the range $0.3•I_{max} \leq I \leq 0.7•I_{max}$, where I_{max} is 10 A for the TH40C. Results are reported in Fig. 6. Each point is the average of 10 measurements at current I. A full expression of uncertainty of the measurement is under evaluation; the error bars represent the type A contribution (coverage factor $k = 1$), evaluated as the standard deviation of the mean.

The percentage error allowed by the EN 50470-3 in both sinusoidal and the tested distorted conditions, for EN-class C energy meters, is ±0.5% in the present current range. Hence, the measured error is substantially lower than the standard requirements for both sinusoidal and distorted signals here considered.

6. Measurement traceability

Traceability of measurements performed with the testbed is provided by the calibration of the reference wattmeter W_{REF}, performed by comparison with the Italian national standard of power and energy.

In the context of the Mutual Recognition Arrangement (MRA) INRIM has stated specific Calibration and Measurement Capabilities (CMC) [7], some of which are pending approval, covering active and reactive power measurements; the power range goes from 0 to 216 kW for a three-phase system, with a power factor from 1 to 0 (inductive or capacitive) and frequency from 47 Hz to 65 Hz. The expanded uncertainties range from

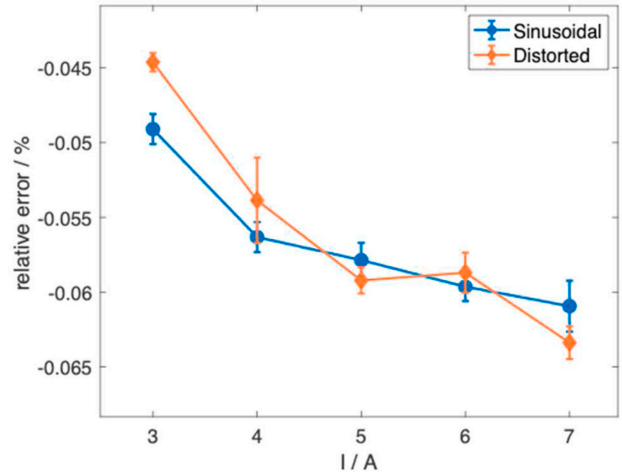

Fig. 6. Relative error of the energy measurements performed with the DPEE TH40C.

40 μW/VA to 60 μW/VA for active power and from 66 μvar/VA to 80 μvar/VA for reactive power. Details about the calibration procedure of the primary sampling power system are reported in Ref. [8].

Research towards the establishment of traceable methods for power measurements in presence of distorted signals carry out at INRIM are reported in Refs. [9,10] and further extended towards the measurement of power quality (PQ) electrical parameters in the framework of the EMPIR project 15RPT04 TracePQM. The good practice guide developed by the partners [11] covers the establishment of a reference measuring system for AC power and PQ, including high frequency and disturbances present in the electric grid. In this context, INRIM developed two macro setups for LF and for HF power measurements including PQ electrical parameters traceable directly to the national standard of DC and AC electrical quantities.

7. Outlook

The testbed is now under extensive testing. Calibrations of the verification wattmeter W_{VER} and of the energy meters included in the verification training setup are being performed, using either sinusoidal voltage and current waveforms or highly distorted waveforms. A summary of the outcome of these measurements will be presented at the Conference. Also the INRIM surveillance activity on secondary laboratories accredited for Power and Energy according to Ref. [12] by means of interlaboratory comparisons will also benefit from the results of this work. In fact, interlaboratory comparisons involving different wave shapes could be provided in future.

Acknowledgments

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Luca Callegaro*, Giulia Aprile, Alessandro Cultrera, Flavio Galliana, Gabriele Germito, Danilo Serazio, Bruno Trinchera

Istituto Nazionale di Ricerca Metrologica (INRIM), Torino, Italy

* Corresponding author.

E-mail address: l.callegaro@inrim.it (L. Callegaro).