Laboratory reproduction of on-field low power quality conditions for the calibration/verification of electrical energy meters

25th IMEKO TC4 International Symposium
23rd International Workshop on ADC and DAC Modelling and Testing
IMEKO TC-4 2022
Brescia, Italy / September 12-14, 2022

Laboratory reproduction of on-field low power quality conditions for the calibration/verification of electrical energy meters

A. Cultrera[1,*], G. Germito[1], D. Serazio[1], F. Galliana[1], B. Trinchera[1], G. Aprile[1], M. Chirulli[2], L. Callegaro[1].

[1] *INIRM - Istituto Nazionale di Ricerca Metrologica, strada delle Cacce, 91 10135 - Torino, Italy.*
[2] *VERIFICA S.p.A. Via S. Annibale M. Di Francia, 29 70010 - Locorotondo, Italy.*

**e-mail: a.cultrera@inrim.it*

Abstract **– In this work we present a method for testing static active energy meters in low power quality conditions recorded at installation sites. Voltage and current waveforms recorded on the field with a calibrated portable instrument were reproduced with an accurate phantom power generator up to the 40th harmonic. The error on the active energy measurement of an energy meter under test (W_{DUT}) in conditions reproduced from the on-field measurements was evaluated in comparison with a reference meter (W_{REF}). On-field data were recorded at a 50 kW self production photovoltaic facility. This method allows the laboratory reproduction of realistic (distorted) on-field conditions in a metrologically traceable framework.**

I. Introduction

Devices such as electric vehicles charging stations, consumer electronics, renewable energy sources and electronically driven workshop tools, to cite a few, inject disturbances in the network, producing distortion of the sinusoidal voltage and current waveforms which may affect the accuracy of static energy meters when measuring active electrical energy [1, 2, 3, 4].

Such an ubiquitous presence of nonlinear loads and electronic equipment in the electrical network, demands to pay particular attention to the effects of low power quality conditions when performing calibration and verification of household and industrial electrical power and energy meters.

Active energy meters installed within the European Union must comply with the Directive 2014/32/EU Measuring Instruments (MID) [5]. Energy meters complying with the MID are calibrated and verified on the basis of international and national documentary standards (national standards are specific to each country).

Concerning the calibration/verification of newly manufactured energy meters, the international reference documents for EU/MID active energy meters are (i) the EN 50470 [6, 7] series that is the harmonized standard in force for electricity metering equipment; (ii) the IEC 62052 and IEC 62053 series [8, 9], with amendments in order to be compliant with the MID. These standards deal with both sinusoidal and distorted (low power quality) situations and prescribe tests in both conditions, specifying simple waveform shapes intended to be generically representative of possible real-world situations.

On the other hand, the calibration/verification of already deployed energy meters is quite different from the testing of newly manufactured units. For example there could be constraints in the insertion of the verification instrumentation or impediments to burden simulation. Concerning the verification of meters already in service in Italy for example, the task is fulfilled following the guide CEI 13-71 [10]. The guide distinguishes two main cases: tests carried out with phantom power, which are performed with portable generators in sinusoidal regime; and tests made with real burden, where no particular waveforms are prescribed.

Several methods have been proposed to test static meters in non-sinusoidal conditions beyond the ones considered in the presently available standards. Some authors proposed to use waveforms with fixed or time-varying random harmonic content to test static energy meter accuracy in realistic conditions [11]; other approaches consist in looking for an ideal waveform which could be considered the the “best” one for calibrating meters [12], or using multiple non-sinusoidal waveforms, generated in random sequence [13].

In this work we show that the accurate phantom power generator implemented at INRIM [14] can be used to reproduce power quality waveforms and conditions that have been previously recorded on the field. In our setup, the amplitude phase and frequency of the generated waveforms are kept under control by means of a feedback loop with a high class three-phase comparator, so these can be accurately reproduced compared to the ones previously recorded on the field; this capability is not reported for other similar power generation systems previously presented in literature [15, 16, 17] where the generation of the waveforms was performed with stable but stand-alone calibrators. This approach represents one possibility to test energy meters in specific conditions, e.g. those found at the site where the static meter is installed, while reproducing these conditions in a metrologically traceable framework, hence representing a test in both realistic and representative conditions.

II. Power waveforms recording

The on-field measurements took place in September 2021, at the self production photovoltaic (PV) generation facility of a small factory in Italy. The facility is connected to a low voltage cabin of the national distribution network, and the installed energy meter accounts for both energy injection and absorption by the factory, depending on the moment and solar irradiation of the PV modules. The energy meter installed at the site is a GESIS 2020 OM 330, reference current 1 A, maximum current 20 A, EN class B for active energy measurement. The meter is installed in semi-direct insertion, with TA transducers of ratio 125/5 A/A of IEC class 0.5s.

During the plant operation, the waveforms were sampled with a calibrated ZERA portable reference wattmeter MT-310, having a nominal power measurement accuracy of 0.1 % in direct insertion and of 0.2 % when inserted with amperometric clamps. The instrument was inserted in 4WA mode, with amperometric clamps, and set to the voltage range of 250 V and the current range of 100 A.

The instrument recorded both the waveforms and the harmonic content of the three voltage and the three current channels. Data were stored in the instrumentàs memory in the form of an `xml` format table, which was downloaded and analyzed later.

III. Power waveforms reconstruction

A schematic of the three phase experimental setup used to calibrate a commercial energy meter with the reconstructed waveforms is shown in Fig. 1.

G is a ZERA MTS310 power and energy meters test system, described in detail in [14]. The output of G spans up to 320 V and 120 A per phase, with a frequency of the fundamental from 40 Hz to 70 Hz. The unit G includes a photodetector to measure the pulsed optical output of W_{DUT}. W_{REF}, is a ZERA COM5003 three-phase energy meter, accuracy 0.005 %. Voltage input ranges up to 480 V, current input up to 160 A, with capability of setting up to the 40th harmonic, with a bandwidth of up to 6 kHz.

W_{DUT} is the unit under test, in this case a DPEE TH40C multifunction static three-phase meter. The specifications give a reference current of 1 A, a maximum current of 10 A. The meter is in EN class C and IEC class 0.5s concerning the measurement of active energy.

To reconstruct waveforms on the voltage and current channels on the basis of their measured harmonic content measured by the MT-310, the amplitude and phase of the 40 harmonic components, relative to the fundamental, of each channel were used as input parameters for the software WinSAM™ that controls the ZERA MTS 310. W_{DUT} and W_{REF} were connected to G in 4WA configuration, similarly to the on-field verification.

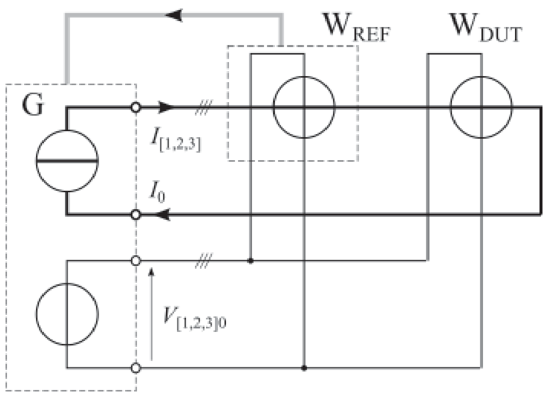

Fig. 1. Simplified schematic diagram of the testbed system for calibration / verification of static electricity meters. See Sec. III for details.

IV. Results: on-site recording

The waveforms recorded on the field, and considered in this work, had voltages of 229.97 V, 231.52 V and 231.19 V for the three phases, and currents of 10.57 A, 10.26 A and 10.41 A at the secondary TA current transducers. The influence of TA transducers, already installed at the verification site, is not discussed in the prest work.

An example of current waveform captured on the TA secondary phase 1 of the facility at the verification site is shown in Fig. 2. The plot shows the waveform in the time domain, which appears strongly distorted with total harmonic distortion (THD) of 27.25 %; double zero-crossings are clearly visible at about 0 ms and 10 ms. The corresponding voltage waveform, not shown, appears less distorted with THD = 1.16 %.

Fig. 3 shows the corresponding amplitude of the 40 recorded harmonics of the waveform given in Fig. 2; the inset shows a detail of the first 10 harmonics, the most relevant, for the three phases. The amplitudes of the harmonic components relative to each phase are normalized to the corresponding fundamental. It can be seen that mainly odd harmonics were present and that the load was non-symmetric.

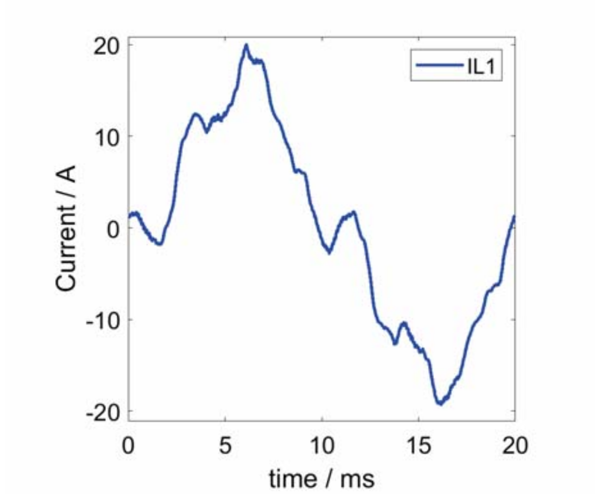

*Fig. 2. Current waveform on the phase 1 (*IL1*) recorded at the facility. Samples were stored in an* MT-310 *verification instrument.*

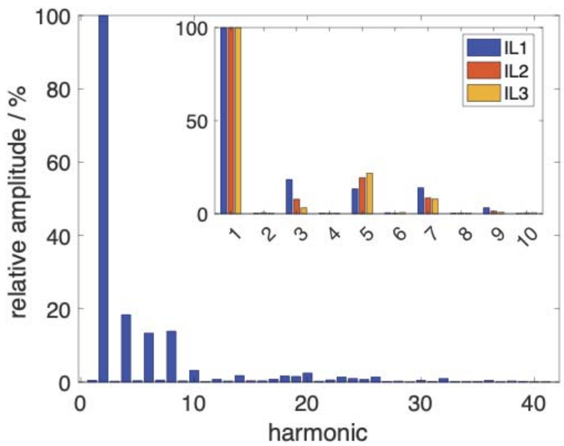

*Fig. 3. Harmonic content of the current waveform of FIg. 1 (main plot). The first 10 harmonics of all the three current channels (*IL1, IL2, IL3*) of the energy meter installed at the facility, are shown in the inset.*

V. RESULTS: REPRODUCTION IN THE LAB

The amplitude of the fundamental harmonic component of the voltage waveforms reproduced in the laboratory was set to 230 V, standard reference voltage defined in the EN 50470-1 (clause 4.1), since the on-field voltage waveforms were compatible with that, considering the EN 50470-3 (table 12). The amplitude of the fundamental harmonic of the current waveforms has been scaled down to comply with the specifications of W_{DUT} (the DPEE TH40C has a maximum current of 10 A).

According to the on-field measurements, the relative phase between the fundamental components of the voltage and current waveforms were set to -95.09 °, -68.55 ° and -64.04 ° respectively for the phases 1, 2 and 3. The burden was of capacitive type for all the 3 phases.

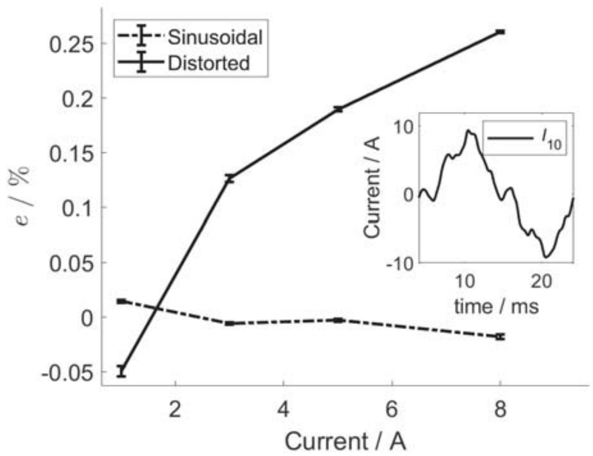

Fig. 4. Relative error, e, between W_{REF} and W_{DUT} for measurements performed with the DPEE TH40C *(main plot). The solid line represents the error on the measurement of reproduced waveforms; the dashed line corresponds to the error in sinusoidal conditions, given as a reference. The inset shows the reproduction of the on-field waveform shown in Fig. 2, generated on channel I_{10} of the presented setup.*

Following the standard EN 50470-1 we define the active energy relative error as

$$e = 100 \frac{E_{A,DUT} - E_{A,REF}}{E_{A,REF}} \%, \quad (1)$$

where $E_{A,DUT}$ is the active energy measurements of W_{DUT} and $E_{A,REF}$ is the active energy measurements of the W_{REF}. Using the direct insertion scheme of Fig. 1, we measured the relative error *e* in both sinusoidal and distorted regimes, at fixed voltage, as a function of the supplied current level I of the fundamental harmonic within the range 1 A to 8 A. For each measurement point, the fictitious power generated by G was integrated for 20 s for the sinusoidal waveforms and 40 s for the reproduced distorted waveforms to get $E_{A,DUT}$ and $E_{A,REF}$ in each of the two conditions; measurements were repeated 6 times.

Results reported in Fig. 4 show the energy measurement error *e* for sinusoidal conditions (dashed line, as a reference), and the distorted conditions (solid line). The inset shows the reproduction of the real waveform of Fig. 2. The error bars represent the type A uncertainty (coverage factor $k = 1$) evaluated as the standard deviation of the mean. A full expression of uncertainty of the measurement is under evaluation.

VI. Discussion and conclusions

Fig. 4 shows that the error *e* of the W_{DUT} spans between $e = -0.0178$ % and $e = 0.0145$ % for the sinusoidal conditions, falling within the range prescribed by the corresponding standards EN 50470 and IEC 62053 for the class of W_{DUT}. On the other hand, the error *e* corresponding to the distorted conditions is substantially larger, spanning a much larger range from $e = -0.0497$ % to $e = 0.2601$ %. Hence, under the power quality conditions recorded on the field, the measurement error *e* of W_{DUT} is larger than in sinusoidal conditions, yet the DUT is still performing reasonably compared to W_{REF}.

Note that since there are no prescriptions concerning the limits for the error *e* in generic low power quality situations in the present standards [7, 9], the results obtained in the reproduced distorted conditions can not be formally compared with any of the defined forms of permissible error found in the normative EN/IEC. Anyway, the error in the present distorted conditions is even within the permissible error prescribed for sinusoidal conditions in the standards EN 50470 and IEC 62053 for the class of W_{DUT}.

In conclusion, this work shows that the presented setup allows to generate arbitrary distorted waveforms based on the harmonic content of real waveforms sampled on the field. Moreover, results suggest that the measurement of arbitrary distorted waveforms can be roughly compared with reference conditions, provided the generation of the reproduced waveforms is under control. This approach can be considered complementary to the others presented above based on statistical methods. Future work will consider other types of on-field installations, both in terms of insertion schemes, nominal power and generation systems.

References

[1] M. R. Khalid, M. S. Alam, A. Sarwar, M.S. J. Asghar, “A comprehensive review on electric vehicles charging infrastructures and their impacts on power-quality of the utility grid”, eTransportation, vol. 1, pp. 100006, 2019.

[2] J. Silva Ortega, V. Sousa Santos, P. Sarmiento Crespo, J. Gómez Sarduy, P. Viego Felipe, E. Quispe, “Effects of power electronics devices on the energy quality of an administrative building”, International Journal of Power Electronics and Drive System, vol. 10, no. 4, pp. 1951-1960, 2019.

[3] W.A.A. Salem, W. G. Ibrahim, A. M. Abdelsadek, A. A. Nafeh “Grid connected photovoltaic system impression on power quality of low voltage distribution system” Cogent Engineering, vol. 9, n. 1, pp. 2044576, 2022.

[4] D. Lumbreras, E. Gálvez, A. Collado, J. Zaragoza, “Trends in Power Quality, Harmonic Mitigation and Standards for Light and Heavy Industries: A Review” Energies , vol. 13, no. 21, pp. 5792, 2020.

[5] Directive 2014/32/EU of the European Parliament and of the Council of 26 February 2014 on the harmonization of the laws of the Member States relating to the making available on the market of measuring instruments.

[6] EN 50470-1:2006+A1:2018, “Electricity Metering Equipment (A.C.) — Part 1: General Requirements, Tests and Test Conditions — Metering Equipment (Class Indexes A, B and C)”, CENELEC: Brussels, Belgium, 2018.

[7] EN 50470-3:2006+A1:2018, “Electricity Metering Equipment (A.C.) — Part 3: Particular Requirements — Static Meters for Active Energy (Class Indexes A, B and C)”, CENELEC: Brussels, Belgium, 2018.

[8] IEC 62052-11:2020, “Electricity metering equipment - General requirements, tests and test conditions — Part 11: Metering equipment”, IEC: Geneve, Switzerland, 2020.

[9] IEC 62053-21:2020, “Electricity metering equipment - Particular requirements — Part 21: Static meters for AC active energy (classes 0,5, 1 and 2)”, IEC: Geneve, Switzerland, 2020

[10] CEI 13-71 “Sistemi di misura dell'energia elettrica (c.a.) — Guida alla composizione, installazione e verifica”, CEI: Milano, Italia, 2015.

[11] L. Bartolomei, D. Cavaliere, A. Mingotti, L. Peretto, R. Tinarelli, “Testing of Electrical Energy Meters Subject to Realistic Distorted Voltages and Currents”, Energies, vol. 13, no. 8, pp. 2023, 2020.

[12] A. Ferrero, C. Muscas, "On the selection of the "best" test waveform for calibrating electrical instruments under nonsinusoidal conditions," in IEEE Transactions on Instrumentation and Measurement, vol. 49, no. 2, pp. 382, 2000.

[13] A. Ferrero, M. Faifer, S. Salicone, "On Testing the Electronic Revenue Energy Meters”. IEEE Trans. Instrum. Meas., vol. 58, no. 9, pp. 3042 , 2009.

[14] L. Callegaro, G. Aprile, A. Cultrera, F. Galliana, G. Germito, D. Serazio, B, Trinchera, “A calibration-verification testbed for electrical energy meters under low power quality conditions”, Measurement: Sensors, vol. 18, pp. 100118, 2021.

[15] D. Gallo et al., “A new methodological approach to quality assurance of energy meters under nonsinusoidal conditions”, IEEE Trans. Instrum. Meas., vol. 56, no. 5, pp. 1694-1702, 2007

[16] A. Olencki and P. Mróz, “Testing of energy meters under three-phase determined and random nonsinusoidal conditions”, Metrology and Measurement Systems vol. 21, no. 2, pp. 217-232, 2014.

[17] L. Bartolomei et al, “Testing of electrical energy meters subject to realistic distorted voltages and currents”, Energies vol. 13, n. 8, pp. 2023, 2020.