On the Remote Calibration of Electrical Energy Meters

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Abstract-The measurement of the electrical energy and its billing for tax purpose are of great relevance. In spite of its importance, in the past a scarce attention was given to issues as the calibration and the traceability of the electrical energy meters, so that, at least in Italy, more than 30 millions of energy meters operate and put a tariff without proper metrological characterization. This situation is caused by both the absence of specific laws and the high cost related to the traceability process. In this ambit, a new European Directive on measuring instruments (MID) was introduced in 2004 with the aim of providing a high level of metrological protection in order that any party affected can have confidence in the result of measurement. In Italy the MID was adopted by a legislative decree and imposed that: (i) each active electrical energy meter put into service has to be kept in test for a period for verifying its operating; (ii) after the test period, with positive result, the meter has to be calibrated at least twice in the year. The paper proposes a discussion about the issues of active electrical energy meter calibration and the analysis of requirements of the MID. Finally, the design of a device that may solve the problem of the traceability to national standards in easy and economic way is reported.

I. Introduction

The measurement of the electrical energy and its billing for tax purpose are of great importance for the definition of commercial transactions, the estimation of energy balances among countries, the performance evaluation of machines and conventional, innovative and renewable energy systems [1]-[2]. In spite of its importance, in the past a scarce attention was given to issues as calibration and traceability of electrical energy meters (EEMs) so that, at least in Italy, more than 30 millions of EEMs operate and put a tariff without a proper metrological characterization. This is mainly due to: (i) the complexity of the electrical energy measurement task, both for the impossibility to carry out direct measurements and for the difficulty of granting a proper metrological traceability of measurement instruments; (ii) the high costs of EEM calibration due to both the reference instruments to be used and the need of expert human operators; (iii) the need of electrical plant turn-off; this is an unacceptable condition for industrial plants that very often require hours for the shut down and start up procedures [3]-[4]. At the same time, deregulation and expansion of the electrical market triggered the need of greater precision, accuracy and reliability in measurements.

In this ambit, a new European Directive on measuring instruments (MID) was introduced in 2004 [5].

The MID directive deals with devices and systems applied to public interest, public health, safety and order, protection of the environment and the consumer, of levying taxes and duties and of fair trading, which directly and indirectly affect the daily life of citizens in many ways.

It starts from the consideration that a measuring instrument shall provide a high level of metrological protection in order that any party affected can have confidence in the result of measurement, and shall be designed and manufactured to a high level of quality in respect of the measurement technology and security of the measurement data. To this aim this directive establishes the requirements that the devices and systems have to satisfy with a view to their being placed on the market and/or put into use for the above mentioned tasks. For these instruments the MID directive defines requirements, maximum allowable errors, test environments, and also imposes specific constraints as for the electromagnetic immunity. Active EEMs fall into the MID directive. Requirements foresees by the MID directive as for the EMC complaints concern with the use of both measurement instrumentation able to provide non sinusoidal reference and real operating conditions during the meter calibration.

In Italy the MID has been receipt by the legislative decree referenced in [6]. The customs agency is the competent body as for the active EEM applies the requirements of this decree. This body imposes that: (i) each active EEM puts into service has to be kept in test for a period to verify its operating; (ii) after the test period, with positive result, the meter has to be calibrated at most twice per year. These calibrations have to be executed following general requirements of [4] and both test conditions and maximum allowable errors defined by [5]. This application imposes a revolution in the issues of calibration and traceability of EEMs since: (a) they have to be tested both at the beginning of their

commercial life and periodically during their use, and (b) they have to be tested in their real operating conditions. In particular, this last condition is required to take into account the influence on the measurement instruments of electromagnetic pollution [7]-[10]. Consequently, it will be necessary to change or modify the actual electrical energy meter calibration systems to comply with MID directives, trying to avoid economic troubles.
This paper is focused on the Italian case, where to satisfy the MID, more than 30 millions of energy meters should be periodically calibrated without loss of service and taking into account the real operating conditions. With the aim of giving a contribution to the above mentioned questions, the paper proposes the study of issues of active electrical energy meter calibration, analysis of requirements of the MID, and design of a device that may resolve the traceability to national standards of a great number of EEMs in easy and economic way.

II. Discussion about the suitability of the remote calibration approach

Starting from the above mentioned considerations, as far as the active EEM calibration is concerned, two contemporary requirements have to be complied with: (i) to respect the test conditions required by [4], and, (ii) to consider the measurement environments considered in the MID.
The calibration of an active EEM, put into use, is usually performed “on site” as it is very difficult to remove the meter from its placement. This is due to both practical and legal aspects. Applying the calibration methods described in [4] two main calibration schemes can be considered: (a) to use an electric power generator acting as a fictitious load and able to establish the desiderated test conditions; (b) to measure the actual energy of the electrical power plant and to increase the measurement time in order to consider as much operative conditions as possible.
Both the considered schemes might respect requirements provided by MID in terms of electromagnetic pollutions if suitable modifications are implemented.
In particular, following the (a) scheme, either the electric power generator is able to generate all the EMC disturbances considered in the MID directive or an additive calibrated power harmonics generator has to be considered. Reference instruments able to impose both sinusoidal voltages and currents required by [4] and disturbances compliant with the MID can be found on the market. Their cost is typically about of tens of k€. As for the (b) scheme both the calibrated reference meter has to be equipped with a power quality analyzer and the measurement time shall be as high to consider as much electromagnetic disturbances as possible. In the worst case (rare electromagnetic disturbances) this time may be even longer than some days.
Looking at the calibration costs they can be considered as the sum of those related to the calibrated reference instrument to be adopted and those due to the human operator. Considering the scenario that foresees the calibration of about 35 millions of active EEM twice in the year, a total of about 70 millions of calibrations have to be executed.
Taking into account the (a) calibration scheme, and also considering that each reference instruments shall be able to perform 10 calibrations per day in the best case, a total of about 19000 reference instruments and 19000 expert operators per year are required. On the other hand considering the (b) scheme and supposing a medium case of four calibrations per day a total of about 400 khours of expert operators work are required. Only considering costs related to the operator, also in this case a very high fee is obtained.
The current cost of a typical EEM calibration performed only according to [4] and don’t considering requirements of MID is about of 300 € that infers a cost of about 600 € per year for each active EEM. Even if large scale economies are possible it is very difficult to reduce this cost if also the MID has to be accomplished for. This is due to high cost of the calibrated reference instrument of the (a) scheme, and the high number of operators required by the (b) one.
To overcome these limitations it is necessary to both reduce the presence of human operators and adopt lower cost reference instruments.
The revolutionary idea could be to implement remote calibration procedures. In this case the calibration is performed without the presence of human operators that have only to be employed in the traceability of the remote device adopted as calibrated reference. It is also evident that a remote calibration approach increases the number of measurement instruments to be used. If no optimizations are possible a scenario that considers one additional reference instrument per active EEM is supposable. This solution may be adopted only if the overall cost of the additional instruments is lower than 600 € per year.
As far as the traceability of the proposed remote reference instruments is concerned, to obtain a significant cost reduction, it should have a set of auto-test procedures that may increase the time

between two consecutive "on site" calibrations even up to three or more years.
A further advantage could be attained reducing both the complexity in the remote reference meter calibration and the number of reference instruments to be adopted. A suitable solution could be a calibration procedure that consists only in the replacement of the metrological section of the remote reference instrument under test with a calibrated one.
The above reported analysis confirms the suitability of a remote calibration approach if: (i) the overall cost of the remote reference instruments is very small and lower than that provided by the (a) and (b) calibration schemes; (ii) the need of human experts is limited to their presence only in the traceability of the remote reference meter.

III. The proposal

A possible solution is to realize a low cost "add on" device able to: (i) interface with each EEM; (ii) operate the calibration procedure as required by the CEI 13.4 standard and following the guidelines provided by MID; (iii) communicate the measurement data with a main calibration centre.
Two approaches are possible: the realization of a remote reference power source or a remote reference meter, considering the (a) and (b) calibration schemes described in the previous section.
The former solution requires additional costs for the generation of reference voltages and currents, while the latter for voltage and current sensors.
With the aim of reducing costs, a mixed solution can be pursued. It consists with the realization of a reference load supplied by the AC main but able to impose the desiderated power electrical input whatever the applied voltage. In this way the calibration of the EEM can be performed without measuring the voltages and the currents across the load and without generating reference voltages. It is clear that this load cannot be realized using passive circuits or components that impose currents strongly dependent from the voltage characteristics. An active circuit operating as AC/DC converter is well suited for the purpose. It is able to give reference voltages and currents for a high number of operating conditions. This converter is used to supply a calibrated reference resistor. In this way only the output voltage has to be regulated and calibrated while the current consumption is due to the reference resistor value. This allows a drastic reduction of the sensor to be present in the remote reference device since no electric quantities have to be measured and only the time have to be estimated. In addition, in the modern AC/DC converter is very easy to regulate the Power Factor to the unity or very close to other values expected in [4].
As far as the traceability of the "add on" remote reference instrument, the quantities to be verified are the output voltage, the reference resistor, and the time. The output voltage is often regulated by a series of zener diodes, and the time accuracy is strictly related to the clock adopted. If the zener devices, the clock, and the reference resistor are implemented in a single and removable board, the calibration procedure might only consists in the replacement of this board with a calibrated one with a considerable cost saving and without loss of service.
As far as the MID requirements are concerned, the proposed solution allows the calibration to be executed in the real operative condition and in the real climatic and mechanical environments in which the EEM is immersed. As for the electromagnetic disturbances, changing the switching characteristics of the AC/DC device it is possible to generate disturbances such as the harmonic contents in the current circuits, the DC and harmonics in the current circuit, and the magnetic fields, the conducted disturbances introduced by radio-frequency fields.
This approach is certainly not exhaustive as for the MID respect but may be considered a first smart, economic and suitable solution toward the problem of active EEM calibration.

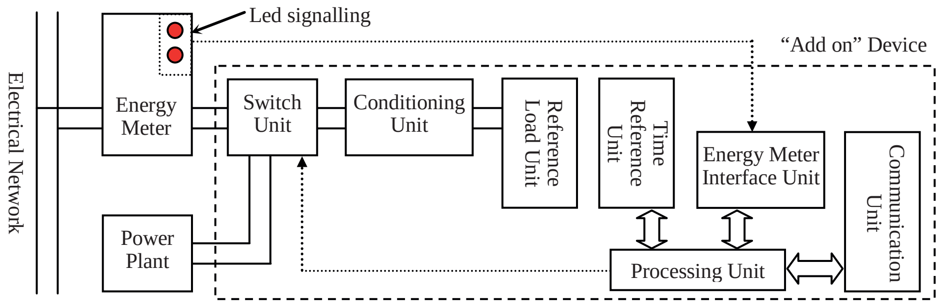

Figure 1. Architecture of the proposed "Add on" calibration device.

The schematic of the proposed add on device is reported in Figure 1. The following unit can be highlighted.
(a) The switch unit. This device, composed by a solid state relay, is able to turn off the power plant during the calibration procedure. In this way only the energy imposed by the electronic device that acts as a reference power load is measured by the active EEM under test. The relay shall be provided by a logic section driven by a processing unit.
(b) The conditioning unit. This is the core of the proposed add on device and performs three fundamental tasks: (i) it regulates the power factor versus the electrical network, (ii) it changes the current amplitude transferred to the reference load unit, and (iii) it generates the most common PQ disturbances present in the AC main. As far as the (i) point is concerned an Active Power Factor Control (APFC) section is built in the instrument, while an active power supply device performs the (ii) task. This device implements an AC/DC voltage transformation with fixed and stabilized voltage output. Being the voltage across the reference load stabilized, a known current flows in the reference circuit consuming a known power. At this stage two reference powers are considered: 150 W and 600 W equal to the 5 % and 20 % of the typical domestic power supply respectively. As for (iii), the generation of harmonics is strictly related to the operating of the AC/DC converter.
(c) The reference load unit. This load, consisting in a 0.1% accuracy power resistor, is the key-element of the proposed device. It is supplied by a stabilized reference voltage and absorbs a known current.
(d) The time reference unit. This section allows the electrical energy to be estimated starting from the measured electrical power. Since the overall calibration procedure takes not more than few minutes this system has to grant its performance in the short length of time. This allows this unit to be very precise if a high quality controlled oscillator is considered.
(e) The EEM interface unit. This device is composed by an optic interface that may be connected to the blinking led of the active EEM. In fact, each EEM gives out a led blink whenever an energy unit is booked. In this way the measured electrical energy and the reference time can be related.
(g) The processing unit. This is realized by a low cost microcontroller unit. Its tasks are the control of the switch and conditioning units, the acquisition of the reference time and the active EEM estimates, the execution of the calibration procedure, the data storage and transmission.
(h) The communication unit. At this stage the proposing add on device can guarantee two types of connection channels. The former, wireless, is performed by a GPRS modem, while the latter, wired, uses a Power Line Communication (PLC) device.

IV. Preliminary experimental results

Some preliminary results about the suitability of the proposed *add on* device are reported in the following. In particular, in this first step, the performance of the reference load unit is assessed. Tests have been executed to evaluate: (i) the stability of the absorbed power, (ii) the stability of the power factor and, (iii) the effect of the thermal drift.

A. Measurement station

The measurement station is sketched in Figure 2 and is composed as follows.
Power supply; a programmable AC power source provided by California Instruments able to grant a maximum power of 5 kVA over a bandwidth of 2.5 kHz is adopted. This unit is able both to supply the reference load and to impose harmonics, sags, swells and dips on the generated voltage waveform. Its performance allows the 0.4% as for the voltage accuracy and ± 5 ppm for the frequency stability.
Reference load; it is realized by assembling a commercial switching power supply, equipped with a PFC circuit, and a precision resistor. The Q-TEC ATX™ switching power supply and the D-84 Belotti Variatori™ variable calibrated resistor have been selected for the purpose. The former grants a

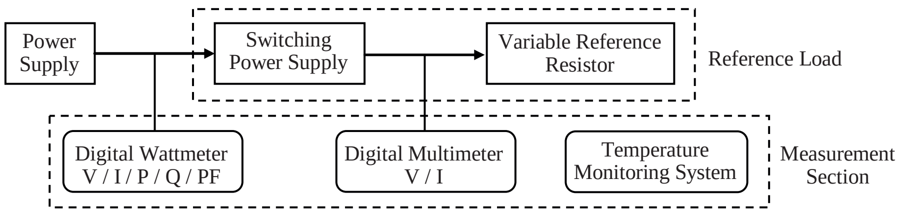

Figure 2. The measurement station.

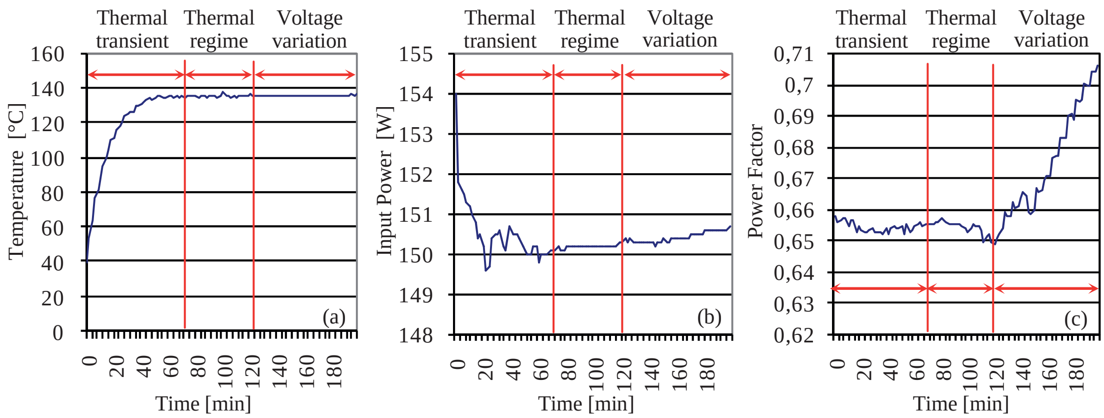

Figure 3. Behavior of the proposed reference load: (a) temperature on the reference resistor; (b) absorbed power and (c) power factor imposed to the active EEM.

maximum power of 350 W and two reference voltages respectively equal to 5 V and 12 V while the latter allows a resistor value up to 2.52 Ω and a maximum current of 13 A.

Measurement section; it is composed by: (i) a digital wattmeter able to estimate the active and reactive powers and the power factor measured by the energy meter; (ii) a digital multimeter for the voltage and current measurements on the reference resistor; (iii) a temperature monitoring system. As far as the digital wattmeter is concerned the Yokogawa WT230 TM digital power meter is adopted. The digital multimeter is the Fluke 45TM. The Fluke hydra data bucket equipped with a K type thermocouple measures the actual temperature of the reference resistor.

B. Experiments

For the sake of brevity only tests executed at a nominal power of 150 W are reported in the following. Tests have been executed selecting the 12 V output of the switching power supply and the 1.13 Ω resistance for the variable resistor respectively. Three suitable stages have been arranged.

In the first one, the system has been supplied with a stable voltage with a value of 230 V; the effect of the reference resistor thermal transient on the absorbed power has been evaluated.

The second stage has estimated the accuracy of the steady state response over a long time (1 hour) operating.

In the third stage the effects of harmonics and variations of the supplied voltage in the ±10% are assessed.

Results are reported in Figure 3. In particular, Figure 3a) reports the thermal behaviour of the reference resistor, Figure 3b) shows the absorbed power measured by the digital wattmeter and Figure 3c) sketches the cosϕ figure of merit. Looking at Figure 3a) it is possible to highlight that the thermal transient finishes after about 75 minutes and that the temperature remains very stable during the other two stages. A maximum variation of ±1.5°C is observed. Figure 3b) shows as the input power has a maximum variation of 4.5 W during the thermal transient but is very stable both in the second and the third stages. In this last stage even if a voltage variation of ±10% is present a maximum input power variation of ±0.25 W is observed. Behaviour of the cosϕ figure of merit is very stable during the first and second stages while a variation of 0.05 is observed during the application of harmonics and voltage variations. Further tests have been executed at different voltages and load conditions. They all show similar behaviours.

V. Conclusions

The discussion exposed in this paper has evidenced as in all countries of the European Union that have not yet in compliance with the MID, it is necessary a deep revision on the actual strategies and systems for the calibration of the electrical energy meter. Otherwise, there will be a great increasing of the annual electrical billing rate, particularly for the domestic users.

At the end of this discussion, a low cost add on device for the remote calibration of the active electrical energy meter has been proposed. It is able to meet the MID requirements and to drastically reduce the economic impact due to the MID application. The preliminary tests show the suitability of the proposed

solution since it grants acceptable performance even if commercial devices are adopted.
The design of an *ad hoc* reference load or the use of a commercial switching power supply equipped by an active power factor correction circuit might improve the overall performance by means of a better control of the power factor stability
Tests aimed at the experimental characterization of the whole proposed add on device are in progress.

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