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Low-Power Instrument Transformers and Energy Meters: Opportunities and Obstacles

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Low-Power Instrument Transformers (LPITs) are becoming the preferred measurement device in the medium voltage (MV) distribution network (DN). They have several benefits compared to legacy solutions. However, the adoption of LPITs results in the need for adapting the grid and its assets to accept them. One practical example is using LPITs as the current and voltage source for energy meters (EMs), which are also used for billing purposes. The resulting measurement chain introduces several metrological challenges that must be studied and investigated. Therefore, in this work, the scenarios of LPITs and energy meters are introduced along with the latest relevant international standards. Afterwards, the opportunities and obstacles due to the implementation of the LPIT plus energy meter measurement chain are discussed. The discussion focuses on metrological requirements, accuracy evaluation, target uncertainty, and influence quantities affecting the performance of the devices.

Low-Power Instrument Transformers

The in-field measurements scenario, at any voltage level, has been evolving since the introduction of the new generation of Low-Power Instrument Transformers (LPIT). They are also referred to as non-conventional instrument transformers (NCITs). There are several reasons for the massive adoption of LPITs, either the current or voltage version (LPCT and LPVT, respectively). Among such reasons, the main are (i) they are cheaper than a legacy inductive instrument transformer (IT); hence, their spread in the distribution network (DN) is facilitated. The DN is characterized by a huge number of nodes to be monitored, compared to the transmission network (TN). (ii) They are compacter than other solutions; hence, a system operator (SO) may easily install LPITs in small electrical cabinets full of other equipment. (iii) LPITs, as their name recalls, feature a low-power output. Hence, a few milliampere currents and voltages below 1 V are perfectly suitable for being connected to intelligent electronic devices (IEDs), which introduce several new applications and functionalities. (iv) Furthermore, a low-power output guarantees higher levels of safety for the measurement environment and the SOs.

All the benefits from the introduction of LPITs triggered the research and innovative findings. The literature, for example, provides works dealing with LPITs accuracy evaluation [1], [2]. Other stressed topics are their modelling [3], [4] and their characterization [5], [6].

An important result from the studies on LPITs is their main drawback. Each type of LPIT, hence each technology, suffers from the presence of one or more influence quantities. Consequently, the accuracy of the devices is altered, and typically lowered, by such quantities. Some examples of influence quantities are temperature, humidity, electromagnetic fields [7], pressure, frequency, positioning [8], etc. For instance, a current LPIT, like the Rogowski coils, suffers from its positioning with respect to the conductor and from temperature variations. Shunt resistors, instead, may suffer from temperature and frequency, which also affect capacitive dividers. Figure 1 collects some typical LPITs.

These weaknesses of the LPITs are crucial to be considered and assessed whenever (i) accurate measurements must be performed – of utmost importance in case of billing purposes – and (ii) LPITs are used together with other instruments and the overall accuracy of the measurement chain needs to be computed.

To summarize, the main LPVTs and LPCTs technologies plus the typical influence quantities are collected in Figure 2.

Fig. 1. Pictures of LPITs.

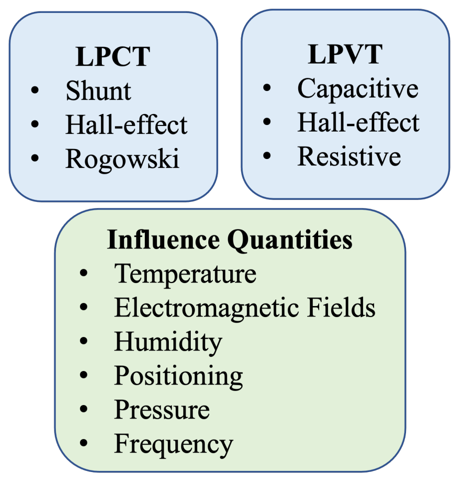

Fig. 2. Main LPITs technologies and the relevant influence quantities.

IT Standards

LPITs exploit technologies available since the 19th century. However, the development of efficient devices is two-decades old. In addition, LPITs are well covered by international standards thanks to the technical committee (TC) on ITs. The TC harmonized all the documents to help final users and manufacturers with the use of both ITs and LPITs.

The standard series dedicated to ITs is the IEC 61869. It consists of fifteen documents, each of which covers a specific kind of IT or interface. The two most important documents of the series are the IEC 61869-1 [9] and IEC 61869-6, which provide the general requirements that apply for all kinds of ITs and LPITs, respectively. Such requirements span from testing guidelines to rated values and accuracy requirements. The additional documents of the series go into much more detail for each kind of device. For example, IEC 61869-10 and IEC 61869-11 are dedicated to LPCTs and LPVTs, respectively. Inside those documents, tests developed for a specific device are described (like the immunity test for LPVTs, or the positioning test for Rogowski coils).

Of course, standards are always evolving to be aligned with the current research findings. However, one may find several lacks if specific aspects are considered. An example of a topic that is not treated in the standard yet is the use of LPITs with other devices. There is no mention of the possibility that the LPIT might be part of a more complex measurement chain and how this affects the results. The only reference to devices different from the LPITs is the so-called merging unit (MU) or stand-alone merging unit (SAMU), described inside IEC 61869-13. They are two versions of a device that aims to collect and synchronize the output of several LPITs, before sending them to a data concentrator or a generic receiver. Such a device is typically implemented within distributed measurement systems consisting of a significant number of LPITs.

Energy Meters

An energy meter (EM) is a key device for SOs and final users. They allow for measurement and registration of the consumption or generation of electricity inside residential or business buildings. In addition, EMs may be equipped with anti-fraud or anti-tampering functionalities to avoid illegal operations.

Hand in hand with the development of smart grids, EMs have changed from being electromechanical devices to smart energy meters (SEMs). SEMs have acquired several fundamental features over previous models such as: (i) their operation does not include moving parts – unlike electromechanical EMs – therefore they are not slightly affected by wear. (ii) bidirectional communication; hence, the SEMs can either send the measurement results or receive instruction from other devices. (iii) SEMs allow consumers to supervise their energy consumption in real-time and even to have a remote control on their appliances [10].

Thanks to these new characteristics and functions, SEMs will play a crucial role in the electrical power systems, resulting in (i) more virtuous behaviors by the consumers, and (ii) more efficient energy dispatching because the real-time measurements enable SOs to improve both load and generation control.

However, there is a relevant obstacle: the installation of SEMs, for all domestic and industrial users, requires a huge investment by the SOs. Therefore, electromechanical and electronic meters are still widely used in many developing countries.

Due to the increasing penetration of renewable energy sources, non-linear power converters, and loads into electrical power systems, the distortion of currents and voltages is no more negligible. Consequently, lower levels of power quality are being experienced, challenging the measurement performance of the instrumentation, including the EMs. Therefore, in literature several studies on EMs accuracy can be found. For example, [11] and [12] suggest some test waveforms to assess the EM behavior, while in [13] one of the starting points is the THD level of the input signal. These studies, and others, have been conducted to find the best test signal that may represent actual operating conditions of an electrical power system. Another reason is that the testing waveforms defined in the relevant standard are far from being representative of a typical signal.

In addition to the test signals, the literature is focusing also on the influence quantities affecting the EM performance. For example, amplitude, frequency, harmonic content, power factor, harmonic power factor, crest factor, and the symmetry and balance for three-phase systems are some of such quantities.

In conclusion, EM literature provides a lot of material to be used by TCs for preparing new standards. Such a process is significant and highly needed if one considers the EM usage for billing purposes.

EM Standards

The regulatory context dedicated to EMs is quite wide and complex. Three main standards apply to EMs, namely the European Directive 2014/32/EU [14], the EN 50470 series, and the IEC 62053 series. Briefly, the first difference among them is the range of validity. From the name, it is clear that the IEC 62053 series is an international set of documents, while the other two have a European validity. In detail, the EN 50470 has been written to be compliant with the European Directive, also known as the Measuring Instrument Directive (MID). The MID is a key standard that does not cover only energy meters, but all kinds of meters "*responding to reasons of 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*" [14].

Another difference among the documents is the accuracy classes (ACs) that have been specified. The European documents use accuracy classes A, B, and C, while the IEC ones adopt 0.2S, 0.5S, 1, 2. The two sets of ACs are similar but not identical, resulting in some difficulties depending on which marking an EM adopts. However, both sets of ACs are based on the same index to evaluate an EM. Such index is the percentage error:

$$e\%=\frac{E_m-E_t}{E_t}\cdot 100, \tag{1}$$

where E_m and E_t are the energy measured by the device under test and by a reference device, respectively.

Overall, several other minor or major differences exist; however, the reader is directed to the normative (see also Figure 3) because out of the scope of this paper.

ENERGY METERS

1. IEC 62052-11:2021, Electricity metering equipment (a.c.) – General requirements, tests and test conditions – Part 11: Metering equipment.
2. IEC 62052-21:2019, Electricity metering (a.c.) – General requirements, tests and test conditions – Part 21: Tariff and load control equipment.
3. IEC 62052-31:2019, Electricity metering (a.c.) – General requirements, tests and test conditions – Part 31: Safety.
4. IEC 62053-11:2003, Electricity metering equipment (a.c.) – Particular requirements – Part 11: Electromechanical meters for active energy (classes 0,5, 1 and 2).
5. IEC 62053-21:2003, Electricity metering equipment (a.c.) – Particular requirements – Part 21: Static meters for active energy (classes 1 and 2).
6. IEC 62053-22:2003, Electricity metering equipment (a.c.) – Particular requirements – Part 22: Static meters for active energy (classes 0,2 S and 0,5 S).
7. IEC 62053-23:2003, Electricity metering equipment (a.c.) – Particular requirements – Part 23: Static meters for reactive energy (classes 2 and 3).
8. IEC 62053-24:2014, Electricity metering equipment (a.c.) – Particular requirements – Part 24: Static meters for reactive energy at fundamental frequency (classes 0,5 S, 0,5, 1S and 1).
9. EU Directive on Measuring Instruments (MID), European Parliament and of the Council, 2014/32/EU, 2014.

Fig. 3. Main standards dedicated to EMs.

LPIT plus EM

This section opens the discussion about the core of this work. Each subsection treats a specific aspect relevant to the adoption of LPITs as source for EMs.

Motivation

The motivation for this work becomes clear if two main reasons are considered. First, the availability of new technology like LPITs opens unexplored scenarios. Their future adoption in consolidated measurement chains or procedures is natural and foreseen. Second, EMs are mainly used for billing purposes. Hence, the accuracy evaluation of the overall measurement chain, and the LPITs' contribution, is crucial to avoid that neither the customer nor the SO pay for unused energy (or vice versa).

Standard Overview

The study of the latest standards is always a good starting point for an investigation. In this case, few inputs are available inside EM standards. First, MID states that the document does not prescribe any detail in the case of an EM used with a transformer [14]. Second, the IEC 62052-11 clarifies that, in the case of operation with LPITs, the EM is treated as a "directly connected meter". An EM, according to the standard, can be considered as directly connected or connected via transformer (to the main source). A reason for such a peculiar choice might be the planned standard that will cover the use of LPITs with EMs (announced in the 2021 version of the standard). Consequently, the TC aim could have been to not discard the potential use of LPITs, until the standard will be ready (unknown date). Third, the EN 50470 series does not include the use of LPITs. Overall, only the IEC family of standards foresees the future possibility of using LPITs with energy meters. Consequently, the final user may find difficulties in understanding the actual and current levels of accuracy, from the operation of the LPIT plus EM measurement chain.

Opportunities and Obstacles

Uncertainty evaluation: is performed in the current standards considering only repeated measurements (Type A evaluation according to the guide to the expression of uncertainty in measurements) or a Type B evaluation using, for example, the known uncertainty on the pulses/kWh of the EM. The obtained accuracy is then associated with the percentage error resulting from the EM testing.

However, the main question is how is it possible to easily include the LPITs uncertainty contribution inside the energy measurement? The reference EM is also connected to the circuit at the transformers' output, reading the same quantities as the EM under test. Consequently, such a procedure can test the EM alone but does not allow to quantify how well the energy is being measured, leading to potential incorrect billing.

On the contrary, testing an EM with a portable transformer in addition to the portable EM is quite complicated and impracticable. The reasons are mainly two. First, it would increase the duration of the testing activity. Second, it would increase the costs (extra equipment and test duration). Note also that keeping additional devices under metrological confirmation is quite expensive.

Target uncertainty: is the starting point of every measurement installation. It answers the question "with which accuracy am I expecting to perform my measurement?" or "what is the maximum allowed accuracy/uncertainty for that specific measurement?".

It is consequently fundamental to run the aforementioned uncertainty evaluation to obtain precious information: the minimum accuracy value for each component of the measurement chain. In fact, from the implementation of uncertainty evaluation techniques, it is possible to obtain overall measurement accuracy, starting from the single contributions.

For example, an LPCT and an LPVT sharing the same accuracy class – e.g., 0.5 – provide the voltage and current measures with an accuracy within the interval ±0.5 %. The worst case is that both LPITs have the maximum allowed uncertainty, resulting in the minimum accuracy associated with the energy measurement.

This approach may lead to the conclusion that the adopted devices feature an accuracy class that is inadequate for the target uncertainty. Consequently, if the evaluation is performed with already installed equipment, this may result in significant replacement costs. Note, that the same consideration can be extended to the actual scenario that involves legacy ITs and not LPITs.

Influence quantities: as anticipated, are a significant issue for any kind of device. Even assuming that the LPIT is characterized before the installation, the in-field conditions may change its behavior. In detail, the characterization before the installation should (i) test all the influence quantities affecting the device (temperature, positioning, etc.); (ii) replicate the in-field conditions to ensure that it has been performed realistically; (iii) provide reliable coefficients for a real-time adjustment of the EM measurements. If even one of the three conditions is not met, it would be difficult to fully trust the measurements performed by an EM.

Of course, dealing with all the potential influences on EM accuracy is a complicated task. However, when billing purposes must be fulfilled, a huge effort is expected from operators and authorities to avoid unfair treatment of the involved parties.

Periodical calibration: has always been a topic of discussion among experts. In fact, since the first introduction of legacy ITs, defining how long the accuracy of the device will be kept has been difficult. The same can be extended to LPITs and treated like a sort of ageing that the device is experiencing. It is not expected that an LPIT or an EM will maintain its performance, considering the harsh environment in which they operate. Therefore, a simple, cheap, and efficient testing procedure should be designed to ensure the measurement chain accuracy over time.

Alternative: solutions should be discussed and potentially implemented. One option consists of the manufacturer providing the complete transformers plus EM measurement chain. In this way, it would be the responsibility of the manufacturer to test its devices in all possible conditions. Afterwards, he would provide ready-to-use coefficients for the final user. However, this solution has also drawbacks, for example, it's limiting the free market and the retro compatibility of the devices. Millions of LPITs are being and have been installed worldwide, and they will not be compatible with the new solution.

Another option would be to exclude LPITs from being the source of billing EMs. A simple choice with a huge impact on innovation enhancement should not be considered at all.

A third option is a well-structured and organized standard. This could be the preferred solution which has only one drawback: time. Preparing such a complicated document requires time and effort from experts and manufacturers. Furthermore, they shall agree on all kinds of issues (which include all the aforementioned) finding a tradeoff between industry and scientific requirements. To the authors' knowledge, there is no ongoing standard writing, which means that for many years this aspect will be uncovered. In addition to those years, many more are needed to wait for the manufacturers' alignment with the standard specifications. Consequently, one open question remains, until a choice will be taken, what will happen with the uncertainty related to EMs? And who is going to pay for that uncertainty?

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