Low-Power Instrument Transformers: Ideal Solution for Modern Data Centers, High-Density Industrial Applications, and Digital Secondary Systems

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Abstract—**This paper discusses recent advancements in low-power instrument transformers (LPITs) and the development of LPITs as an alternative to traditional magnetic induction-based ITs. It highlights the growing LPIT use in high- and medium-voltage applications, particularly in data centers and industrial facilities, emphasizing the benefits of LPITs, such as high accuracy, small size, and suitability for integration with digital secondary systems. The paper also addresses real-life challenges in implementing LPIT technology, including issues with signal routing, system testing, and sensor shielding.**

I. INTRODUCTION

Instrument transformers (ITs) are a key component of the power system protection, control, and revenue systems. IT standardization allowed equipment manufacturers to focus their efforts and expertise in two vastly different fields, namely high-voltage (HV) apparatus design and secondary system development. While the apparatus development requires strong materials background and exceptional understanding of underlying high-energy physics, secondary system design emphasizes the design of robust electronics circuitry, digital signal processing, real-time computation, metrology, digital communications, and cybersecurity.

While originally required to provide the energy necessary to move electromechanical actuators and levers, the IT role has changed over time, reducing emphasis on the amount of power that a device is able to supply on its secondary, and now emphasizing the quality of the information it provides about the primary-side quantities being measured. It is, therefore, no surprise that the well-established and highly reliable ITs based on magnetic induction are now being challenged by an avalanche of low-power instrument transformer (LPIT) alternatives.

As much as the LPITs may be trying to displace their classical counterparts, old technology is not ready to give up without a fight. It works exceptionally well and is well understood. Most of the inherent limitations, such as the current transformer (CT) core saturation effect, limited frequency response due to voltage transformer (VT) winding resonance, ferroresonance, safety considerations with an open CT secondary, and VT fusing needs are well understood, are accounted for during the design phase, or are addressed through training and safe working practices. Simply promising to improve some of these limitations has proven insufficient for the LPITs to overturn the excellent track record and to service classical ITs provided every day. To succeed, LPITs must, therefore, deliver tangible value that can be easily recognized and applied in practice. This paper elaborates on [1] and reports on the LPIT history, state of the LPIT technology standardization, and some of the applications in which LPITs have gained a solid industry foothold.

II. LPIT STANDARDIZATION

Fostered by the early standardization in the IEC 60044-7:1999 and IEC 60044-8:2002, LPITs have steadily gained acceptance in various power system applications [2] [3]. LPIT standardization activity was initially fueled by the exciting development of optical sensing technology, which promised to deliver high accuracy and inherently safe primary equipment with significantly reduced insulation stress. Disregarding the initial challenges, optical sensors eventually delivered on those promises but failed to establish a solid foothold in the market. One of the largest challenges was the fact that while the utility engineers in charge of the primary equipment loved the new designs, the secondary system engineers faced a challenge of interfacing the new sensors to the protection and control equipment. High-power amplifiers were added to amplify the optical IT output signals, followed by the development of the 12 V low-energy analog (LEA) interface [4] [5]. The LEA interface never gained sufficient traction due to a lack of support of the corresponding secondary devices.

The final problem was the optical sensor cost that limited the optical sensor applications to 115 kV and higher voltage systems, thus lowering the potential market volume and reducing the secondary device manufacturer motivation to support the new interface. The situation was resolved only recently with the introduction of the IEC 61850-based digital secondary systems (DSSs) [6]. Complex electronics associated with optical ITs can easily support the advanced signal processing, computing, and communications resources necessary to implement the IEC 61850 logical device merging unit. This allows the optical ITs to publish measured data using interoperable data streams compliant with the IEC 61850-9-2 Sampled Values service, thus ensuring a much broader market of compatible secondary devices. An optical CT (OCT) installation example with two OCTs mounted parallel to a conventional CT is shown in Fig. 1.

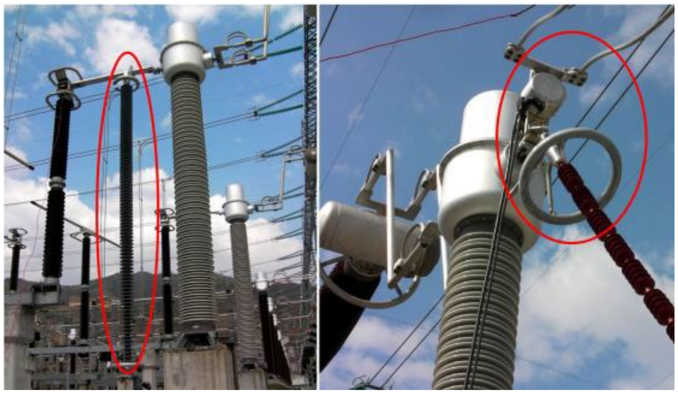

Fig. 1. OCT installation example at Chicoasén, Mexico.

The LEA interface originally designed to support the optical IT was not forgotten and is being reinvented as a low-cost LPIT interface alternative. Interest is especially high in medium-voltage (MV) metal-clad, metal-enclosed, and HV gas-insulated switchgear (GIS) applications. In these applications, LPITs provide tangible benefits, such as significant reduction in size and weight, improved accuracy, high reliability, a long life expectancy, and improved operator safety.

Recent updates of the IEC TC38 standards, including IEC 61869-1/-6/-9/-10/-11/-13, solidified the original work pioneered by the IEC 60044 series, creating interoperable analog and digital interfaces that allow LPITs to be interfaced with protective relays, merging units, and revenue meters. The new standards ensured the retention of familiar terminology and specifications, such as accuracy classes and rated voltages and current, while at the same time extending the LPIT frequency-range requirements, adding methods to describe the LPIT dynamic range, and requiring that all low-power current transformers (LPCTs) intended for protection applications be specified with dual rating, thus disclosing their performance in both protection and measuring applications. New IEC 61869 series standards, which, at the time of writing, are being updated to the second edition, can also be seen as a specification language, intended to accurately describe LPIT capabilities, regardless of the technology used in any given product. They will also include advanced corrections mechanisms for crosstalk and temperature drift and an electronic data sheet, further improving the capabilities and the interoperability of the analog interface.

Secondary injection test sets and test adapters with LEA outputs as well as test blocks are commercially available from different suppliers, making the test of merging units, relays, and other IEDs with LEA input more convenient (e.g., [7] [8]).

Most popular LPIT solutions use Rogowski coils for current measurement and capacitive/compensated resistive capacitive dividers for voltage measurement [2] [3] [4]. Typical implementation is shown in Fig. 2. Two types of sensors are often combined with the low-power voltage transformers (LPVTs) electrodes used to shield the Rogowski coil from the HV primary conductor. Both types of sensors are inherently free of saturation and ferroresonance, allowing them to operate over an exceptionally wide dynamic range.

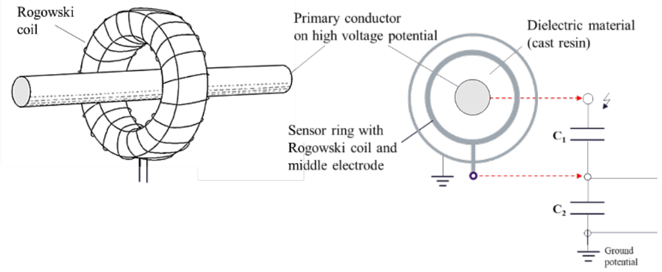

Fig. 2. Schematic description of an LPIT with a Rogowski coil and a capacitive divider.

In the attempt to address the power quality applications, IEC 61869 introduces a new frequency response mask concept and defines a new set of accuracy class extensions for harmonics named WB0 through WB4. Basic class WB0 defines the minimum requirements up to the 13th harmonic and is mandatory for all LPITs. Although not mandatory for conventional ITs, wide-bandwidth extension classes can be used to describe the capabilities of any IT. The decision to make the class WB0 mandatory for LPITs is driven by the fact that associated sensing technologies can achieve the required bandwidth without significant increase in the device cost or complexity. The highest accuracy class, WB4, is intended for traveling-wave applications with frequencies up to 500 kHz. As the applications space develops, higher bandwidth classes may be added to the standard in the future. An example of a frequency response mask is shown in Fig. 3 and Fig. 4.

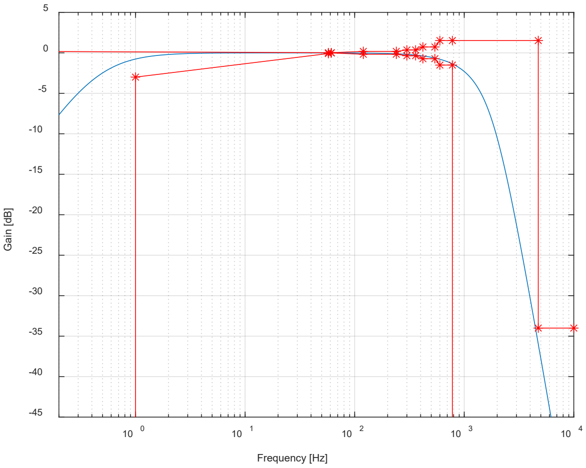

Fig. 3. Example of WB0 magnitude response mask with practical filter for a class 0,2 metering LPIT.

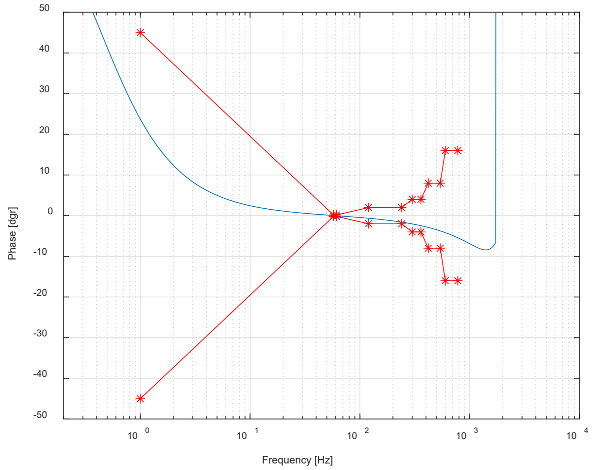

Fig. 4. Example of WB0 phase response mask with practical filter for a class 0,2 metering LPIT.

It is important to note that the frequency response mask changes (gets more stringent) for higher accuracy classes. Another important feature of the mask is the fact that it allows direct current (dc)-capable LPITs but does not require them. Instead of taking the more prescriptive approach, IEC 61869-1 establishes a –3 dB / 1 Hz as the worst-case cutoff frequency allowed for an alternating current (ac)-coupled device. Clearly defined cutoff frequency establishes an interface point between ITs and intelligent electronic devices (IEDs) using the IT output. It also establishes a clear interface point between the IEC technical committees, such as the TC38, which is responsible for ITs, and the TC95, which is responsible for protective relays. Asking the LPITs to faithfully reproduce primary signals down to at least 1 Hz and asking relays to ensure applicable protection functions are not affected by the presence of low frequencies. This is a major change from the IEC 60044 series in which the LPVTs were required to remove long, trapped charge-related decays. Although not immediately obvious, this change is instrumental in matching the relative phase of the voltage and current measurements across a wide frequency range and enabling highly accurate synchrophasor applications.

The dynamic range offered by the new LPITs can be exceptionally wide. This is best illustrated with Rogowski coil-based LPCTs, which are normally designed to match the switchgear short-circuit current capability (i.e., 100 kA-rated short-time thermal current) while simultaneously maintaining an accuracy class 0,2S performance at a rated primary current (I_{pr}) of 200 A. The same sensor may also be rated for 5 kA continuous thermal current. Specifications for such an LPCT would include a rated extend primary current factor K_{pcr} of 50 (5 kA / 200 A = 25) and an accuracy limit factor (KALF) of 1000 (100 kA / 200 A = 500). The rated symmetrical short-circuit current factor may also extend all the way to 100 kA, resulting with K_{ssc} of 500. Such an LPCT would be specified as follows:

$$0{,}2\mathrm{S}\ /\ 5\mathrm{P}500,\quad I_{pr} = 200\ \mathrm{A},\quad K_{pcr} = 25,\quad K_{ssc} = 100$$

Corresponding accuracy limits for this example are illustrated in Fig. 5.

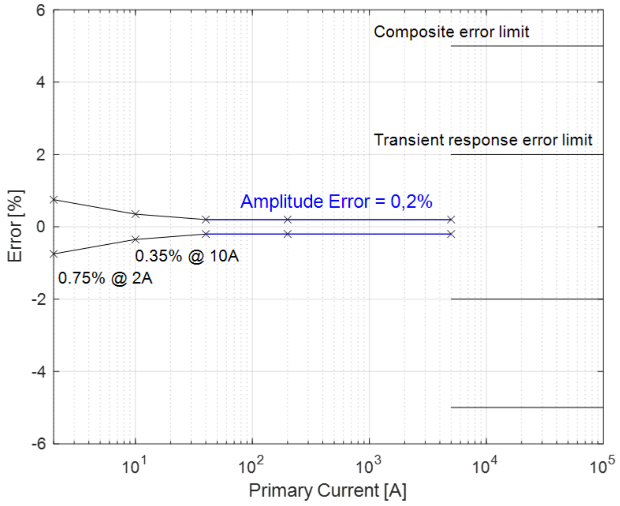

Fig. 5. Accuracy limits, as defined by IEC 61869-1, for an LPCT with an accuracy class of 0,2S/2TPM and a rated current covering 200 A to 5 kA range.

Once the Rogowski coil is combined with the merging unit or IED electronics, the digital secondary signal intended for protection applications gains yet another accuracy class describing transient performance with fully offset faults, namely the TPM accuracy class. The final accuracy class designation for the digital stream produced by a merging publishing the data from our hypothetical LPCT may have the accuracy specified as follows:

$$0{,}2\mathrm{S}\ /\ 5\mathrm{P}500\ /\ 2\mathrm{TPM},\quad I_{pr} = 200\ \mathrm{A},\quad K_{pcr} = 25,\quad K_{ssc} = 100\ kA,$$
$$T_{sec} = 0{,}5\ \mathrm{s},\quad T_i = 250\ \mathrm{ms}$$

The merging unit/IED electronics may additionally introduce input-signal clipping and may, therefore, lower the rated symmetrical short-circuit current factor, K_{ssc}, of the combined system to a lower value.

Although confusing at first, the previous specification example accurately describes an LPIT with a rated current between 100 A and 5 kA, clearly indicating the fact that a rated current specification becomes much more flexible when compared with conventional ITs. The increased range allows the users to precisely match the current used in their application. It also shifts the rated current decision from the circuit design (CT selection) phase to the measuring device configuration (setting) phase. LPITs, therefore, allow a reduction in the number of different ITs that must be warehoused and allow the circuit to be upgraded throughout the life of the installation, accommodating load growth without the need to upgrade the CTs, which is often the case with conventional technology.

It is important to note that by itself, a Rogowski coil LPIT does not have limitations related to the fully offset fault current time constant, T_i. Fault current is accurately differentiated and presented to the coil output as voltage. Problems occur once the secondary signal is integrated by the merging unit front-end electronics, which normally eliminates dc signals and introduces a high-pass filter behavior with corner frequency typically in the 0,1 to 1 Hz range. High-pass filter behavior matches conventional current transformers that are equally unable to measure dc and have cutoff frequencies in the same range. Conventional CT behavior is described with the well-known transient performance classes, TPX, TPY, and TPZ. The main difference, however, is that the Rogowski coils do not saturate and that the transient behavior is determined by the LPIT electronics. IEC 61869-13 deals with this problem by introducing a new TPM class that is somewhat similar to the TPZ class but can accommodate longer primary time constants and targets merging unit implementations with conventional input magnetics. To provide parity with the TPx/TPY classes, IEC 61869-8 (which is presently in development) plans to introduce the TPE (electronic) transient response class.

The digital output naturally requires a proper anti-aliasing filter. This introduces damping at the higher harmonics, which has a negative impact on the accuracy of the harmonic measurement of connected power quality devices. Fortunately, this damping is well known. IEC 61850-7-4 already defines a mechanism that allows the IT frequency response compensation factors to be exposed to the IED by using the frequency correction setting "CorCrv" contained within the logical nodes for current and voltage transformers (TCTR and TVTR). Correction factors are provided in the form of "curve shape setting" (CSG).

A wide dynamic range inherent with new LPITs also means that the LPIT ceases to be the main performance-limiting factor, thus shifting the burden to the electronic device used to measure the LPIT output. IEDs, such as relays or merging units, must have a well-protected front-end interface capable of accurately measuring signals with a dynamic range that may exceed 120 dB (>106). Novel solutions used to meet this challenge include the use of variable gain amplifiers, high-resolution analog-to-digital converters, and dual sets of high-resolution converters.

III. MV Applications

LPITs with LEA output have found their sweet spot in MV applications. They are especially popular in metal-clad, metal-enclosed, and pad-mounted applications in which the small size and locally mounted IEDs make it possible to also reduce the MV switchgear size. This is especially visible in purpose-built LPVTs used as busbar support insulators [9] and MV bushings. An example of LPVT-based insulator is shown in Fig. 6.

Fig. 6. MV support insulator and MV bushing insert with built-in LPVTs.

A support insulator approach eliminates the need for a separate VT-truck compartment and the associated VT fuses. Switchgear optimized for LPIT technology, therefore, offers a smaller size and higher density, providing immediate savings to the end user. LPIT wiring is also simplified by using standard shielded twisted-pair cables preterminated in the factory with standardized low-cost RJ45 connectors. Standardization allows IEDs to adopt the same connector pinout, resulting with a simple, plug-and-play system. Low voltages provided by the LEA interface make the equipment safer and easier to use. A protective relay equipped with a standardized LEA interface is shown in Fig. 7.

Fig. 7. Typical protective relay with LEA interface shown with Rogowski coil optimized for MV underground cable applications.

Due to limited dielectric withstand and the possibility of exported potential problems, the IEC 61869 series standard limits the use of RJ45 connectors to installations in which the maximum distance between the LPIT and the IED is below 10 meters. Larger distances are possible but require additional engineering effort. IEC 61869 series standards also require that such interfaces support the full 3 kV dielectric withstand test, matching the conventional IT secondary wiring requirements.

LPITs used in MV applications offer excellent performance during power system faults and are reasonably competitive in power quality type applications. Revenue metering accuracy below 0,3 percent is still easier to achieve using conventional ITs. The main factors limiting the LPVT accuracy are external magnetic field susceptibility and primary conductor position sensitivity associated with Rogowski coils, neighboring phase electric field sensitivity affecting voltage dividers as well as aging and environment temperature. Active LPVTs may also be susceptible to radio frequency fields and conducted disturbances, which may be present while supplying sensor power.

IV. GIS Applications

GIS systems are experiencing accelerated technology development with the introduction of alternatives to the traditional sulfur hexafluoride (SF6)-based systems. New designs are offered with purpose-built LPITs that clearly demonstrate the advantage of the new technology, which has now been introduced by all major HV GIS manufacturers. Fig. 8 illustrates the LPIT sensor technology potential, with the LPIT application resulting in a 30 percent reduction of the 145 kV bay length and a 25 percent reduction of its weight. Both reductions directly translate to tangible end-user benefits.

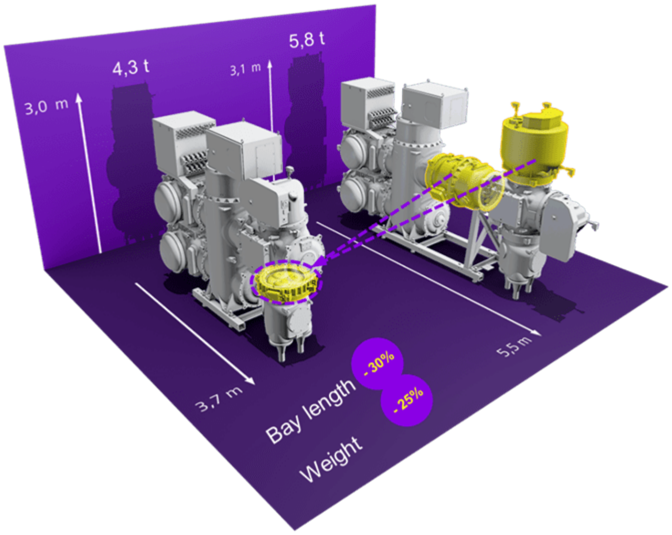

Fig. 8. Schematic overview of the 145 kV clean air GIS space and weight savings introduced by the LPIT technology application.

The LPIT unit is highly integrated, housing three LPCTs and three LPVTs that are encapsulated and built into a standard GIS partition. The unit is sealed for life using cast resin and protected from impact, mechanical shock, vibrations, and heat excursions. LPCT measurements are based on the Rogowski coil technology with direct LEA output provided using a double shielded twisted-pair cable. LPVT is implemented as a capacitive divider with the partition resin acting as the HV capacitor dielectric [10] [11]. GIS partition is shown in Fig. 9 with internal details shown in Fig. 10.

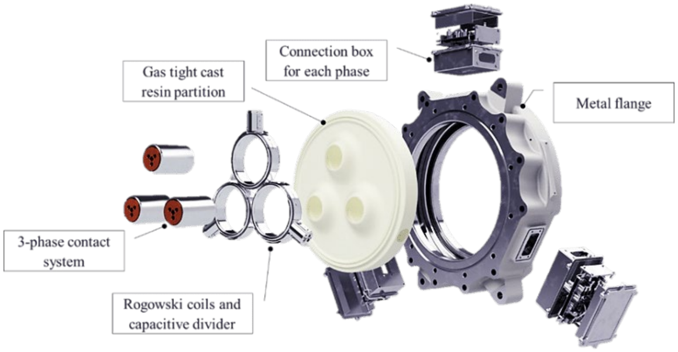

Fig. 9. Key components of the 145 kV three-phase GIS partition with integrated LPCT and LPVT sensors.

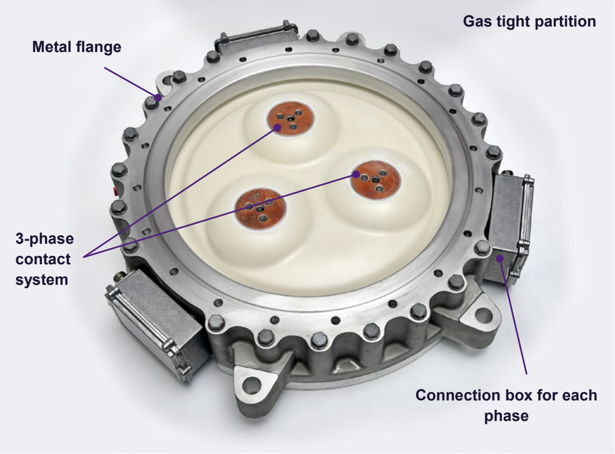

Fig. 10. Three-phase 145 kV GIS partition with integrated LPCT and LPVT sensors.

The integration of multiple LPITs into a single mechanically stable partition offers unique advantages not commonly found in other sensor applications. On the LPCT side, it ensures the Rogowski coil position is fixed during manufacturing and guarantees that the coils remain centered around the primary conductor throughout the LPIT lifetime. The fixed position means that the measurement crosstalk caused by small, winding uniformity errors introduced during the Rogowski coil manufacturing process will be constant once the partition resin is fully cured.

Due to the physics involved, crosstalk is fully linear, meaning it can be compensated by using the sensor-specific calibration constant recorded during final test at the factory. Careful construction, material choice, and coil loading further ensures LPCT output remains constant over time and temperature.

The previously described factors make it possible to mathematically derive high-quality zero-sequence current measurement in which accuracy exceeds levels achievable by adding independent coil output, as is often done in metal-clad switchgear applications. Furthermore, GIS partition provides sufficient space for two sets of Rogowski coils per phase (total of 6 LPCTs per partition), making it possible to provide two sets of fully independent current measurements (Systems A and B). The Rogowski coil dynamic range and wide frequency response make it possible to cover the full range of currents, from 100 kA fault current with protection accuracy (2TPE, 2TPM) on the high end, down to 200 A nominal with metering accuracy (0,2S) on the low end. The frequency response easily exceeds the 50th harmonic, making this LPIT suitable for most demanding power quality applications. The typical coil output during high-current faults is in the order of 20 V.

The LPVT sensor is implemented as a capacitive divider and can be operated as a displacement (capacitive) current sensor with low-resistance burden or in a capacitive divider mode with voltage output compatible with the IEC 61869-1 two megaohm burden. When operated in the voltage output mode, LPVT output can be connected to two redundant merging units, thus matching the LPCT subsystem. LPVT sensors are further enhanced with resistance temperature detector-based temperature measurements performed individually for LPVT. The temperature compensation is performed downstream inside the merging unit and is based on the factory-supplied temperature compensation constants, which enable the LPIT to achieve the 0,2S accuracy level. The resulting LPIT offers an exceptional dynamic range and dual redundant output, and it is fully integrated, saturation-free, and inherently ferroresonance-free. Furthermore, by eliminating VT magnetics capacitive sensors eliminate the need for VT disconnection during GIS and HV cable tests.

The native low-voltage (LV) analog output provided by the GIS partition-based LPVT does have its own limitation. To achieve the full dynamic range offered by the sensors, the secondary output must be well shielded and carefully routed through the switchgear. The dual shielded twisted-pair cable used for this purpose allows relatively long runs, significantly exceeding the IEC 61869-1 ten-meter limit associated with the RJ45 based connector system. For best results, it is, however, advantageous to use an IEC 61869-13-compliant merging unit to convert the LEA signals into an interoperable digital signal compliant with IEC 61850-9-2 and IEC 61869-9 standards. The CIGRE technical brochure [12] prepared by Study Committee B3 (WG B3.39) and published in 2020, gives a comprehensive overview of the technologies involved.

Two redundant merging units are typically mounted inside the GIS bay control cabinet, thus limiting the LEA signal run to several meters, and replacing it with a digital signal transmitted using optical fibers. The merging unit performs all the necessary signal corrections, including gain calibration, LPCT crosstalk correction, and the LPVT temperature compensation. Bay control and tripping commands are performed using IEC 61850 GOOSE and Manufacturing Message Specification services. A detailed description of a control and protection system using LPIT can be found in [12].

The use of LPITs provides many benefits versus conventional ITs, including the following:

- Smaller size and weight of the entire GIS due to smaller dimensions of the sensors and their integration into a GIS partition
- Easy LV connection lowering the cabling and wiring effort
- High reliability and long lifetime expectancy due to the robust design embedded in cast resin
- Less insulation gas in the switchgear
- Excellent overvoltage performance—no need for disconnection during GIS or HV cable tests
- No hazardous overvoltage at open IT terminals
- A single LPIT covering all protection and metering requirements, and thanks to its linearity, also a wide range of primary currents and voltages, simplifying stock management, engineering, and logistics
- Flexible definition and modification of the settings for rated primary current and voltage in the protective devices at any phase of the project and afterwards (in this way, the GIS remains flexible for future increases of its nominal current)

The exceptional dynamic range offered by the LPIT sensors makes it possible to perform field verification and, if necessary, field calibration at significantly reduced signal levels (<500 V and <100 A). This means that not only the common primary injection test sets can be used for commissioning tests, but also test sets designed for secondary injection [8] [13]. For a system test of an LPIT connected to an electricity meter, industry standard mobile meter test equipment [13] [14] can be used. Such primary injection allows the user to verify the end-to-end performance of the LPIT in combination with the merging unit and even the meter. Based on IEC 62052-11 (electricity meters) and IEC/IEEE 61869-21 (instrument transformer accuracy tests), a certification of an LPIT-based metering system for revenue metering according to legal requirements as a directly connected meter is feasible [13].

V. PRACTICAL CONSIDERATIONS

A. *Installation Considerations*

Although conceptually simple, LPIT technology poses some practical challenges. Low signals produced by the LPIT sensors must be well shielded and carefully routed. However, the biggest challenge occurs with personnel training and long-established wiring practices. Low-energy signals of similar magnitudes are routinely used by audio engineers at live concert venues. However, power engineers and technicians can easily miss the finer points associated with the power system environment. Although LPITs can be easily retrofitted, they work best when preinstalled and delivered integrated with an HV apparatus. The GIS apparatus shown in Fig. 8 provides one such example. Other examples include metal-clad and metal-enclosed switchgear cabinets, pad-mounted switchgear, and distribution transformers. Having the original HV equipment manufacturer perform LPIT integration ensures proper sensor polarity and makes it easy to verify correct sensor operation by performing high-current or HV injection during routine apparatus tests. The original equipment manufacturer approach also simplifies sensor cable routing and excess cable length management. It also makes it easier to add LPIT test blocks and any accessories that may be required by the customer.

B. *Connectors and Cable Length*

In retrofit installations, it is important to pay attention to several details. For example, sensor cable length is normally specified at ordering time. However, different lengths may be needed once sensors are installed because sensor runs may have different lengths. The problem of sensor cable length can be solved by looping the excess sensor cable or by reterminating the cables in the field. When reterminating the cables with commonly specified RJ45 connectors, it is important to note that connectors must be well shielded and of high quality. RJ45 plugs come in many varieties and are highly optimized for a particular shielded cable conductor cross section. Furthermore, connector pinout, described in IEC 61869-1, may require the termination of two or four cable conductors in a connector that was designed for eight conductors, possibly creating mechanical stress. The ability to perform field terminations is also very important. Therefore, it is well worth spending a few extra dollars on a well-designed field-terminable RJ45 plug with associated crimping tools and training materials. Fig. 11 shows an example of a field-terminable RJ45 plug.

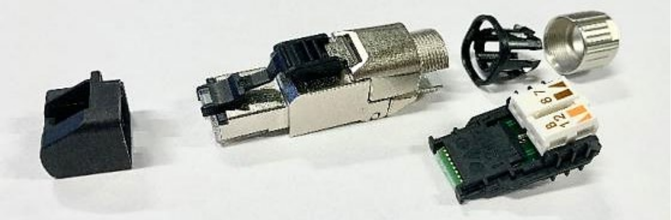

Fig. 11. Example of a field-terminable RJ45 connector.

Low-power current sensors (Rogowski coils and LPCTs) can typically be reterminated in the field. Due to their low output impedance, such LPITs are typically not affected by the output cable length.

Voltage sensors have much higher source impedance, meaning that the cable capacitance can play a much bigger role in the sensor high-frequency response and may even be purposely compensated by the sensor design. Whenever faced with the need to shorten or reterminate the sensor output cable, it is best to first consult the sensor manufacturer.

Another consideration outlined in IEC 61869-1 is the secondary cable length. It is important to note that the standard limits the maximum length of cables terminated with RJ45 and M12 connectors to 10 meters (32,8') and requires that such sensors be installed in an HV apparatus that can ensure protective equipotential bonding (PEB), thus limiting touch voltage to a safe level in case of a primary system fault. The total cable length can exceed 10 meters in the case of multiple Rogowski coils or LPCTs connected in series. Longer distances are also possible in engineered solutions where safety and system shielding have been evaluated at the apparatus level.

C. *LPIT Shielding*

Shielding is a crucial consideration for LPIT-based sensor systems. It is equally as important for the HV part of the sensor as it is for the sensor output cable. HV part shielding must consider neighboring phase proximity (crosstalk) and nearby grounded surfaces that can affect LPVT transformation ratio and high-frequency response. Problems are especially visible in MV switchgear applications where space is at a premium, neighboring circuits are in the next cubicle, and grounded surfaces abound at minimum-clearance distances.

Shielding must be continuous. For example, in the case of the Rogowski coils and LPCTs, shielding must encompass the LV output cable and the sensor winding. The winding must be galvanically isolated from the shield and normally terminated into a fully differential electronic circuit; this allows the circuit to further reject any common mode signals that may have leaked through the shield. The shield must be continuous and solidly connected to the end connector shield and, subsequently, to the IED ground system. Fig. 12 shows an example of a fully offset high-current fault measured using a Rogowski coil sensor. The green (upper) trace in the background shows the original input signal and the red (lower) trace shows the reconstructed (integrated) signal measured by the IED. The signal waveshape is faithfully reproduced, and the only difference between the two waveforms is caused by the waveform exponentially decaying the dc offset time constant, which was shortened by the integrator circuit. Fig. 13 shows what happens in the case of a compromised RJ45 connector that resulted in a floating-shield condition (i.e., no shield connection to ground).

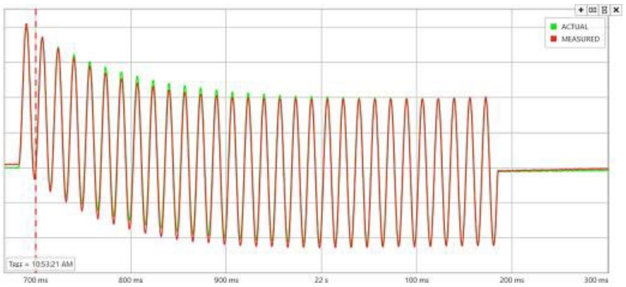

Fig. 12. Rogowski coil LPIT fully offset fault test.

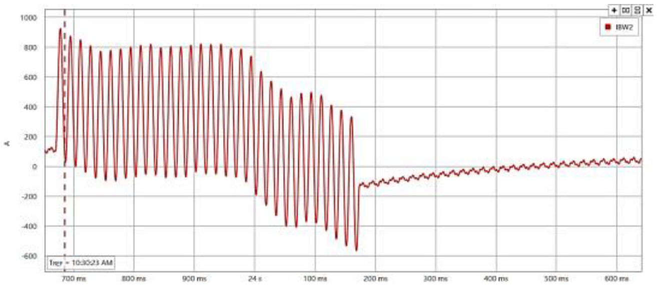

Fig. 13. Rogowski coil shielding problem example.

The waveform in Fig. 13 shows correct test signal amplitude but is severely distorted by the low- and high- frequency noise. The signal was recorded using an LV test set and would be totally unusable if the current carrying the conductor was at a higher voltage.

D. *Correction Factors*

As explained in Section IV, LPIT sensors can be exceptionally accurate. Contrary to conventional instrument transformers where strong magnetic field coupling ensures the transformer ratio is easily controlled by implementing a correct number of primary and secondary turns, which can be easily controlled during manufacturing, LPIT manufacturing tolerances are much wider. Typical manufacturing tolerances for a given design may be in the ±1 percent to ±3 percent range, with the routine test performed at the end of the manufacturing line used to measure the actual ratio. Then, the ratio correction factor is calculated and printed on the individual device rating plate. Individualized correction factors allow sensors to claim overall accuracy in the 0.5 percent to 0.2 percent range and create problems for the end user. The problem is caused by the fact that there is no standardized way to automatically read the correction factors and load them into the IEDs. The process is manual and is begging for improvement. This situation is best illustrated in the data center environment where LPITs offer a great advantage in terms of size and weight while simultaneously creating an unwanted problem of potentially managing thousands of correction factors in the same facility. A simple solution to the correction factor problem, in many cases, is not to use them and, instead, design a protection system that considers wider sensor tolerances.

IEC TC38 is presently working on an automated correction factor exchange method to develop a transducer electronic data sheet standard, but progress to date has been very slow.

The correction factor approach is also of little help in simple differential protection applications in which multiple current sensor outputs may be physically summed together by connecting them in series. In such applications, current sensor ratios must match since correction factors cannot be applied after the fact. This problem is well known and has been described for linear coupler applications for more than 50 years. A select group of sensor manufacturers is aware of the problem and offers matched sensor pairs or uses factory trimming to ensure that sensor accuracy is met without the need for individual ratio correction factors.

VI. CONCLUSION

Fostered by recent standardization, LPIT technology is making significant inroads into the traditional IT market. Advances are especially visible in the MV and GIS applications, in which the combination of LEA outputs and IEC 61850-based DSSs is providing tangible benefits to the end user. Although superior in many ways to conventional ITs, a large number of such devices already in the field means that the two technologies are likely to coexist and complement each other for a very long time. Based on the recent advances and the wealth of the LPIT products in the market, the authors of this paper are very optimistic about the future of LPIT technology.

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