Revenue Metering based on Low-power Passive Instrument Transformers complying with IEC 61869-10 and IEC 61869-11 Standards including Legislative View on Legal Metrology

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Abstract

The paper is focused on solution suitable for revenue (tariff or billing) metering applications in Medium voltage systems which is represented by Revenue energy meter and Low-power Passive Instrument Transformers (LPITs) based on Rogowski coil and Voltage divider principles according to IEC 61869-10 and IEC 61869-11 standards. The paper is dealing with development of Revenue energy meter for LPITs, standardization requirements for Revenue energy meter and LPITs in tariff metering applications, legislative view on legal metrology by the Czech Metrology Institute including an introduction of the national type approval process in the Czech Republic and the European Union conformity assessment process according to Measuring Instruments Directive (MID) for Energy meters with LPITs, and test results from Metrological testing of Revenue energy meter with LPITs performed by the Czech Metrology Institute.

1 Introduction

The evolution of smart grids and the broad application of renewables have created a need for the extensive use of current and voltage measurements for the effective management of power networks. These trends therefore require the use of advanced, low-power sensing technologies instead of traditional solutions using iron-core Instrument transformers, due to their physical limitations.

LPITs have been widely accepted due to their advantages and nowadays are used for protection, measurement and control applications in Medium voltage (MV) networks together with Intelligent Electronic Devices (IEDs) like Fault Passage Indicators, Protection relays and Remote Terminal Units.

Since the beginning of the LPITs evolution there is clearly visible a missing solution for use in revenue (tariff) metering applications. There were several challenges why this gap has not been closed for a long time:

- LPITs were not able to achieve accuracy performance needed in these applications, but the recent evolution in LPITs technology enables reaching the accuracy classes 0,2/0,2S comparable with conventional Instrument transformers with a much wider operating range.
- Availability of compatible Energy meter for revenue metering applications was also an obstacle for a long time but even this technical gap is closed nowadays.
- The last challenge is represented by legal metrology, where all devices (Instrument transformers and Energy meters) shall be a subject for a type approval process done by the National metrology institute(s) in order to be certified for revenue metering purposes. The approval process based on existing national and European legislations and regulations represents currently the biggest and the final challenge for a wide use of LPITs with Revenue energy meters in these applications nowadays.

2 Low-power Passive Instrument Transformers

The conventional Instrument Transformers (ITs) based on inductive principle are widely used in revenue metering applications nowadays where they are connected to conventional energy meters. The typical accuracy classes of ITs used in such application are 0,2S for current measurement and 0,2 for voltage measurement. The standardization requirements are covered by the standards IEC 61869-2:2012 for current transformers and IEC 61869-3:2011 for voltage transformers.

The requirements on LPITs are defined in the standard IEC 61869-6:2016 [1], in addition, Low-power Passive current transformers (LPCTs) are covered by the standard IEC 61869-10:2017 [2] and the requirements on Low-power passive voltage transformers (LPVTs) are defined in the standard IEC 61869-11:2017 [3]. Despite those standards ([1], [2] and [3]) define the same accuracy classes 0,2S and 0,2 for LPITs there are several noticeable differences in the requirements and the way how the performance of LPITs shall be extensively verified by relevant type tests compared to conventional ITs.

The following additional requirements and type tests are defined for LPCTs complying with [1] and [2] and for LPVTs complying with [1] and [3]:

- Temperature cycle accuracy test
- Test for accuracy versus frequency
- Test for impact of magnetic field from other phases (for LPCTs only)
- Test for accuracy with respect to the positioning of the primary conductor (for LPCTs only)
- Test for impact of electric field from other phases (for LPVTs only)

From the list above it is evident that the performance of LPITs is verified in a much more comprehensive way compared to conventional ITs as defined by existing IEC standards. Thus, high requirements are placed on the design of LPITs and the quality of used materials. For LPCTs based on Rogowski coil, the homogeneity of winding, effective shielding of internal parts and high quality of material used for the core play a key role to meet the high accuracy performance. In case of LPVTs based on resistive voltage divider the use of stable resistors and insulation material together with a proper shielding of both the primary and the secondary parts are crucial.

With the evolution of technologies and used materials it is now possible to achieve accuracy classes 0,2S for LPCTs and 0,2 for LPVTs which are needed for revenue metering applications, where the type testing according to [1], [2] and [3] fully proves the performance of LPITs over the full range of various operating conditions.

3 Revenue Energy Meter for LPITs

3.1 Basic Technical Description

For the development it was decided to use an already existing high-precision industrial grade revenue meter, equipped with additional functionality. The original meter is in the form of a standard industrial revenue meter case. The input screw terminal has been replaced by a block of RJ45 sockets, prepared for standardized connection of LPIT secondary cables (Fig. 1).

In addition, an auxiliary power must be provided, as the LPITs do not provide a source to power the meter. The device offers Class 0,5 S Active and Reactive energy meter, power quality recorder, digital fault and waveform recorder, harmonic analyser etc.

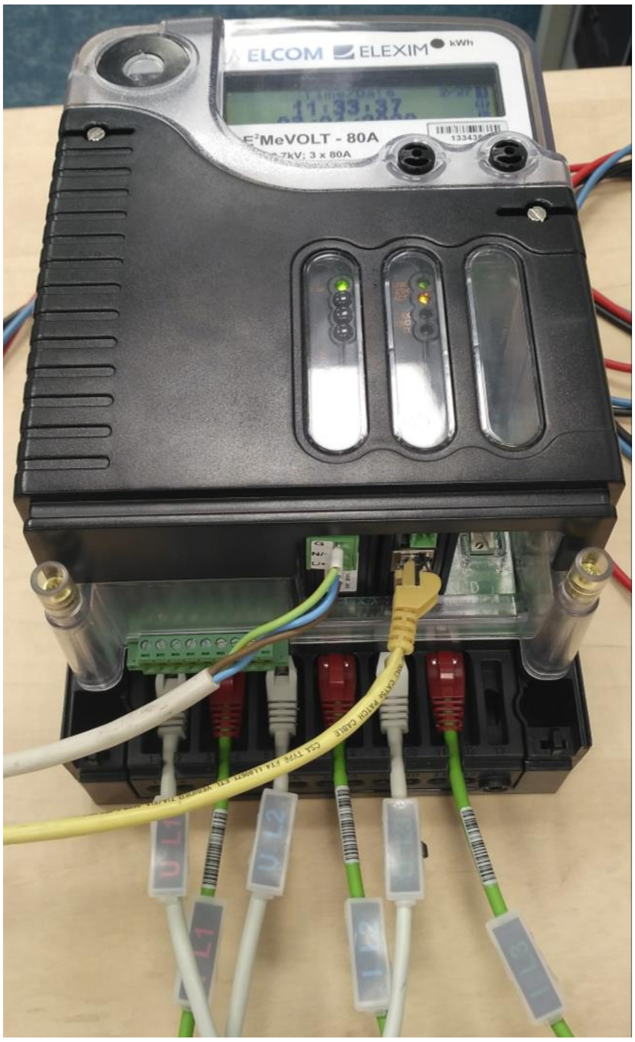

Fig. 1 Modified Revenue energy meter with block of RJ45 sockets for connection of LPIT secondary cables

3.2 Standards, precision classes

The revenue meter follows multiple international standards, covering measurement precision, EMC, safety, additional features like power quality etc.

The following measurement and precision standards define more detailed requirements in revenue metering functionality:

- EN 62052-11 – Metering equipment [4]
- EN 62053-22 – Static meters for active energy (classes 0,2 S and 0,5 S) [5]
- EN 62053-24 – Static meters for reactive energy at fundamental frequency (classes 0,5 S, 1 S and 1) [6]

Both, for active and reactive energy, multiple precision classes are defined. As a selection for industrial grade usage, we can name classes 0,2 S, 0,5 S, 1 S. The class defines the precision requirements in different combinations of active/reactive power and also in different external conditions.

Based on our development, the meter fully fulfils the 0,5 S class precision.

3.3 Modifications for LPITs

As mentioned before, the existing revenue meter with 230V/5A inputs was used for the development.

The LPITs provide a completely different level and behaviour of the voltage and current signals. LPVT provides signal of approximately 1V RMS if connected to the nominal voltage. LPCT provides a signal of tens to hundreds of millivolts RMS and by its physical nature, the signal is a derivation of the measured current.

It is obvious that such signals cannot be connected to standard inputs of the revenue meter. The main task of the development was to fully remove the original voltage and current signal input part and to replace it by signal conditioning, which adapts signals from LPITs in a way to be as close as possible to the original signals brought to meter A/D converters from original inputs.

Original meter input circuits were converting standard 230V/5A signals to approx. 1-2V signals for A/D converters. This approach of fitting LPIT measured signals into regular signals brings the possibility to leave the original revenue meter firmware unchanged.

Voltage signal modification was the easy part of the work. Current signal modification led to implementation of analogue integrator circuits, which converts derivation of the current provided by the LPCT back to the correct waveform shape/phase/level. The integrator must be very precise, stable and immune to injected noise and interferences, as the LPCT signal begins at millivolts level. The integrator design was the most difficult part and took most of the development time, iterations and testing. At the end, the meter is precise and immune enough to fulfill all requirements described in international standards [4], [5], [6], [7] and [8].

4 Legislative view on Legal Metrology by Czech Metrology Institute

States may prescribe the use of measuring instruments for measuring tasks, where they consider it justified for reasons of public interest, public health, public safety, public order, protection of the environment, levying of taxes and duties and fair trading. The possibility of using these meters for the above-mentioned purposes in the Czech Republic is declared by conformity assessment according to Directive MID 2014/32/EU or approval of corresponding meter type according to the Metrology Law No. 505/1990. The advantage of the MID is the fact that the conformity assessment is valid in all Member States, the disadvantage is limiting of corresponding harmonized standards EN 50470-1 [7] and EN 50470-3 [8] to electricity meters for measurement of active energy, which are intended for residential, commercial and light industrial use with frequency of 50 Hz. Therefore, it is not clear whether the revenue electricity meters based on LPITs are under the scope of the directive or not. Due to the state of the art of measurement technology is subject to constant evolution which may lead to changes in the need for conformity assessment, the discussion about this topic was opened in WELMEC – the association of legal metrology authorities of the EU Member States. The next meeting of relevant working group is planned in March or in April 2021, till this time no progress of the legislative view with regards to this topic is expected.

Further, it is now considered that requirements defined by [7] and [8] do not reflect the state of the art technology represented by revenue energy meters based on LPITs what do not allow to fully perform conformity assessment according to Directive MID 2014/32/EU. Therefore, the revision of the harmonized standards [7] and [8] is needed. This issue shall be addressed to CENELEC – European Committee for Electrotechnical Standardization – either via National Institutes for Standardization or initiated by European Commission.

Approval of the meter type as legally controlled measuring instrument according to the Metrology Law is limited only to the Czech Republic, but it is possible to approve the meter type for reactive energy as well. From technical view the approval of legally controlled measuring instrument is possible according to the corresponding harmonized standards [4], [5] and [6]. The electricity meters measure active electrical energy in class C according to standards [7], [8], and class 0,5 S according to standards [4], [5] and [6].

Table 1 Overview of approval requirements for Revenue energy meters based on LPITs

Approval type	Directive MID 2014/32/EU	National approval acc. to Metrology Law No. 505/1990
Validity	EU	CZ
Energy measurement	Active energy	Active and reactive energy
Accuracy class	Class C	Class 0,5 S
Applicable standards	EN 50470-1 EN 50470-3	EN 62052-11 EN 62053-22 EN 62053-24
Applications	Residential, commercial light industrial	All
Approval process	Outdated	Possible and ongoing

Both approval types verify the performance of revenue energy meters under various conditions with focus on the tests of insulation properties, tests of accuracy requirements (including temperature, voltage and frequency variations), tests of effect of disturbances of long duration, tests of electrical requirements, tests of electromagnetic compatibility, tests of the effect of the climatic environments, mechanical tests and tests of other requirements (e.g. terminal block and terminal cover).

5 Metrological testing of Revenue Energy Meter with LPITs

Already realized tests were performed using the testbench for the testing of electricity meters at laboratory of electrical quantities in the Czech Metrology Institute in Brno. The tested electricity meter and the standard meter which is a part of the testbench were loaded by requested voltage and current. So characterized power was measured by both devices and the measured values were compared by pulse method. The result is a relative measurement error of the tested meter related to the value of the standard meter. The voltage circuit was connected by voltage divider, the current circuit through the LPCTs. As initial set of measurement demonstrated, the current value is dependent on the position of primary conductor towards the ring type LPCT. The arrangement on the bottom side of the Fig. 2 fixes the position of primary conductor in the centre of LPCTs in the same way as LPCTs are assembled in actual application, thus the current value is stable. LPCT correction factors were set to the energy meter in the way as defined by the IEC standard [2].

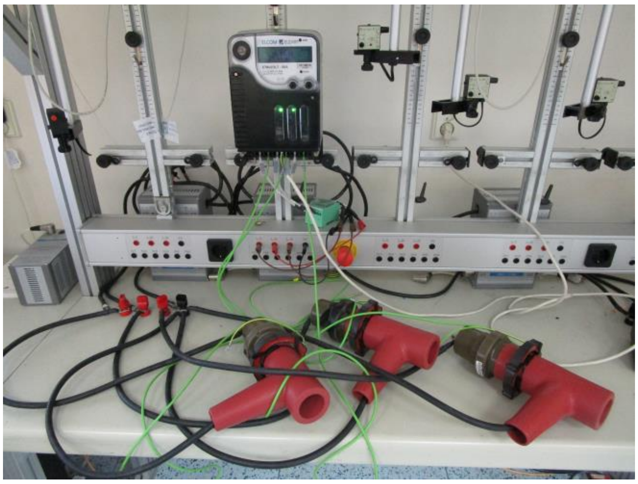

Fig. 2 Revenue energy meter connected to LPCTs during the accuracy test

The metrological requirements of the electricity meters were tested on basic accuracy at reference voltage 130 V and current from 4 A up to 96 A and power factor cos φ from 0,25 cap. to 0,25 ind. for active energy and sin φ from 0,25 cap. to 0,25 ind. for reactive energy. The current range and the shift between voltage and current were set according to the requirements of corresponding harmonized standards [4], [5] and [6]. The mentioned values of current characterize minimum and maximum current in accordance with the definitions in harmonized standard [7]. The accuracy of the electricity meter was tested in voltage range 90 % up to 110 % of reference voltage and similarly in frequency range 98 % up to 102 % of the reference frequency.

Table 2 Accuracy test at reference conditions according to EN 62053-22 (Clause 8.1 and Table 8), balance load

Current I_b=80A	Intrinsic error (%)				
	cosφ=1	cosφ=0,5i	cosφ=0,5c	cosφ=0,25i	cosφ=0,25c
1% I_b	0,12	-	-	-	-
5% I_b	0,07	0,18	0,07	0,20	-0,05
50% I_b	0,04	0,00	0,00	0,16	-0,06
I_b	0,04	0,08	0,00	0,12	-0,05
120% I_b	0,02	0,05	-0,01	0,09	-0,06

Table 3 Accuracy test at reference conditions according to EN 62053-22 (Clause 8.1 and Table 8), single-phase load

Current I_b=80A	Intrinsic error (%)					
	cosφ=1			cosφ=0,5i		
	L1	L2	L3	L1	L2	L3
5% I_b	0,06	-0,04	0,06	0,01	-0,42	0,21
50% I_b	0,03	-0,09	0,03	-0,03	-0,55	0,12
I_b	0,03	-0,09	0,03	-0,06	-0,56	0,12
120% I_b	0,03	-0,10	0,03	-0,05	-0,57	0,11

Table 4 Accuracy test at reference conditions according to EN 62053-24 (Clause 8.2 and Table 11), balance load

Current I_b=80A	Intrinsic error (%)				
	sinφ=1	sinφ=0,5i	sinφ=0,5c	sinφ=0,25i	sinφ=0,25c
1% I_b	-0,24	-	-	-	-
5% I_b	-0,01	-0,11	-0,02	-0,15	0,04
50% I_b	0,05	0,01	0,09	-0,05	0,12
I_b	0,05	0,02	0,07	-0,02	0,08
120% I_b	0,03	0,01	0,04	-0,03	0,06

The Tables 2-5 represent the relevant parts related to the accuracy measurement, the rest of the results is not included in the paper due to the limited space. The stated results of the intrinsic errors are the average values of the five measurement results for each measurement point and include the accuracy performance of the overall chain – Energy meter with LPCTs.
Based on the measured results from the accuracy test at reference conditions it is concluded that the accuracy performance is within the limits of the accuracy class 0,5 S as defined by the relevant standards [5] and [6].
Nowadays the tests of mechanical requirements, environmental tests, climatic tests and tests of electromagnetic compatibility are running.

Table 5 Accuracy test at reference conditions according to EN 62053-24 (Clause 8.2 and Table 11), single-phase load

Current I_b=80A	Intrinsic error (%)					
	sinφ=1			sinφ=0,5i		
	L1	L2	L3	L1	L2	L3
5% I_b	0,09	0,00	0,09	0,23	-0,12	-0,40
50% I_b	-0,03	-0,13	-0,03	-0,03	-0,14	-0,06
I_b	-0,03	-0,14	-0,03	-0,05	-0,16	-0,03
120% I_b	-0,03	-0,15	-0,03	-0,04	-0,17	-0,03
	sinφ=0,5c			sinφ=0,25i		
	L1	L2	L3	L1	L2	L3
5% I_b	0,31	0,21	-0,17	-0,21	-0,52	0,22
50% I_b	-0,03	-0,07	0,14	-0,23	-1,05	0,99
I_b	-0,00	-0,10	0,14	-0,15	-0,99	1,04
120% I_b	0,00	0,16	0,15	-0,13	-1,01	1,05
	sinφ=0,25c					
	L1	L2	L3			
5% I_b	-0,01	0,56	-0,79			
50% I_b	0,23	1,28	-1,32			
I_b	0,24	1,32	-1,31			
120% I_b	0,26	1,30	1,04			

6 Conclusion

It is still a common assumption in the industry that LPITs are not suitable for tariff metering applications due to their insufficient accuracy performance and thus conventional ITs are still dominantly used nowadays. However, evolution of sensor technologies enables now reaching the same accuracy performance compared to conventional ITs, outperforming them vastly in size, safety, energy savings and operating range. Moreover, the new IEC 61869 standard family introduces much stricter requirements on the LPITs than on ITs (e.g. LPIT type tests include temperature cycle accuracy test, etc.), and thus the performance of LPITs in applications is verified in all aspects and therefore does not prevent using them in revenue metering applications.

Another obstacle to use LPITs in revenue metering applications was non-availability of compatible energy meter. As was described in the chapter 3, it was possible to modify existing conventional energy meter to successfully adapt it on LPIT characteristic.

Based on the test results from accuracy tests at reference conditions it is concluded that revenue energy meter with LPCTs is capable to fulfil the requirements of the accuracy class 0,5 S even on the whole chain energy meter with LPCTs. The remaining tests on the energy meter as mechanical requirements, environmental tests, climatic tests and tests of electromagnetic compatibility are ongoing and are expected to be completed in Q2/2021.

Yet the final gap remains – a comprehensive framework of international standards and approval procedures.

Although, it is possible to perform a national approval process of the energy meter based on LPITs in the Czech Republic according to the national Metrology Law, such approval process is limited to tariff metering applications in the Czech Republic only.

The current approval process of a revenue energy meter based on existing European legislations and regulations (conformity assessment according to Directive MID 2014/32/EU) remains an uncertainty and needs to be reviewed.

In praxis, the requirements as defined by the harmonized standards and regulations may not reflect the state-of-the-art technology, in this particular case, the technology of revenue energy meters based on LPITs. Therefore, a new revision of the harmonized standards [7] and [8] is needed. This issue will have to be addressed by CENELEC – the European Committee for Electrotechnical Standardization – either via its National Institutes for Standardization or initiated by the European Commission.

The speed of processing of the new revision of the harmonized standards reflecting the technical evolution will play an increasing role in utilizing of all the benefits and advantages of LPITs in this case in MV revenue metering applications.

7 References

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