Revenue electricity metering using digital metering systems

Rapid development of the technologies based on the IEC 61850-9.2 standard has led to the extensive use of IEC-supporting equipment both for relay protection and automation and for revenue metering. Application of the standard is based on receiving digital measurements either from digital instrument transformers, or from converters.
In this article we will review the effects which occur during the construction of revenue metering systems using digital instrument transformers: optical for current measurement, and electronic for voltage measurement, combined with digital energy meters.

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Estimation of the effects is presented in the context of applying digital transformers manufactured by Profotech, however it is fair to say that the advantages mentioned in the present article are applicable to all digital systems constructed according to a similar architecture.

Optical current transformers outperform the conventional ones significantly due to a different physical measurement principle. They are characterized by high linearity of measurement characteristics in a wide current range, their measuring parameters do not depend on the value of the optical transformer's secondary burden and on the amount of connected secondary devices (telemetry systems, relay protection and automation, etc.). Due to the absence of a magnetic core, the magnetic saturation effect and the measurement accuracy degradation are entirely absent. Unlike the Rogowski coil, the output signal value does not depend on the level of harmonics.

Also, electronic instrument voltage transformers demonstrate better measurement performance compared to the conventional voltage dividers. Capacitive voltage dividers do not contain any electromagnetic devices which introduce significant distortions to the measurement signal upon changing the burden of secondary loads or changing the mains frequency.

Let us consider the specific aspects of creating an information measurement channel (IMC) based on digital instrument transformers and digital meters, operating with digital input signals by IEC 61850-9-2LE standard (Figure 1).

The digital streams from the instrument transformers are transmitted directly to the meter's input using optical cables. Secondary circuits, additional loads and other factors degrading the device's measurement accuracy are absent.

The digital measurement signal, transmitted in the data stream, contains already labelled values of currents and voltages. The digital meter for calculating the energy magnitude only carries out mathematical operations. Digital signal (RS 485 or Ethernet) is generated at the meter's outputs for transmission to the higher level of the automated measuring and information system for electric power fiscal accounting.

For comparison, let us consider a version of IMC constructed using conventional instrument transformers and electronic meters (Figure 2). Although nowadays it is generally being called «digital», that is fundamentally wrong, as every up-to-date electronic meter uses analog values of currents and voltages as an input signal, as opposed to the «true» digital one which uses IEC 61850-9-2LE.

Therefore, the traditional metering system has a range of fundamental factors which contribute to the degradation of the measurement accuracy:

1. Requirements for rated impedance of secondary circuits according to GOST 7746-2015; GOST 1983-2001; PI 3021-2006 and company standard of PJSC FGC UES

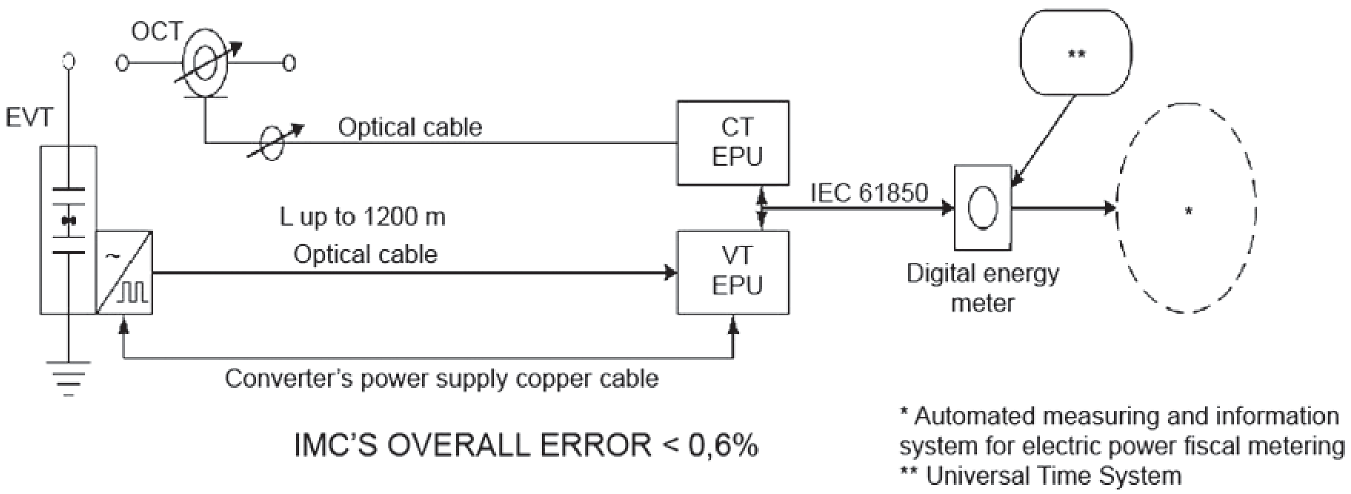

Figure 1. Diagram of the information measurement channel (IMC) which uses digital instrument transformers and a digital meter, operating with digital input signals by the IEC 61850-9-2LE standard

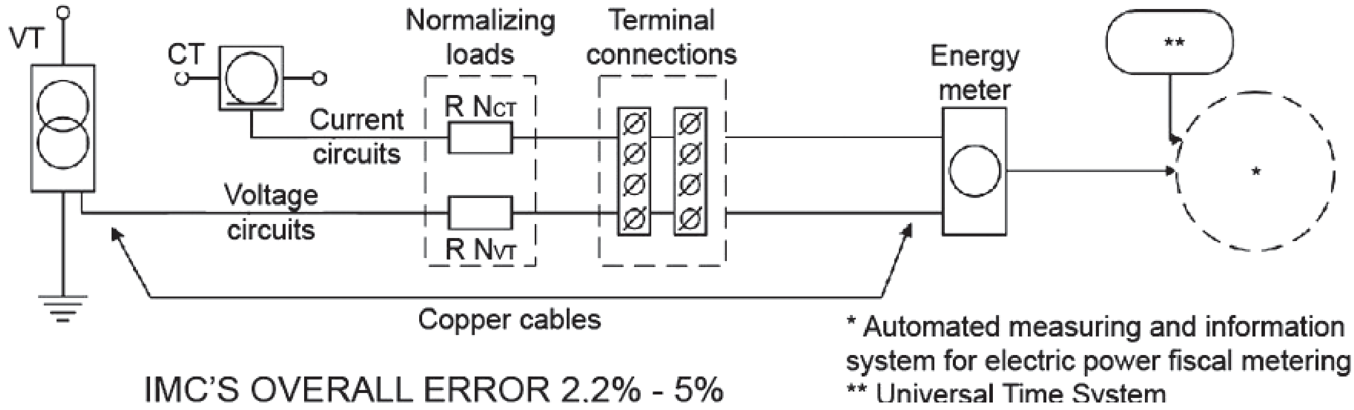

Figure 2. Diagram of the information measurement channel (IMC) based on conventional instrument transformers and an electronic meter

70238421.17.220.20.002-2011: secondary burden of the instrument transformers must be within 25–100% from the rated one.

2. Requirements for secondary metering circuits: losses in voltage circuits must not exceed 0,25%.
3. Secondary terminal circuits in the current and voltage circuit mean additional voltage dips and increased resistance (load) of the secondary circuits.
4. Long metering circuits, due to their own capacitance and inductance of the connecting cables, introduce non-linear distortions to the measurement signal.
5. Residual magnetization of the transformers' cores due to various operational moments, such as short circuits, inrushes during commutation, lightning strokes, etc. According to a number of estimations, residual magnetization can make up to 30%, and for the instrument transformers in power generators' circuits – up to 60%.
6. Error of the electric meter itself. Any state-of-the-art electric meter has analog current and voltage signals at the input (100 V and 1/5 A). The measurement process comes down to the conversion of these current and voltage parameters to internal digital format of the meter. For this purpose, the meter is equipped with current transformers, resistive voltage dividers and stable reference voltage generators, using which the meter's internal ADC carries out the conversions and then calculations of the necessary power values using special digital processors. All these processes lead to occurrence and accumulation of the meter's internal errors. These processes are also influenced by ambient temperature, input signal form, occurrence of harmonics in the input signal, etc., which is why such meters will always have an error.

Therefore, the digital IMC, upon calculating its errors according to the existing methods, would have the errors of the transformers themselves and the error assigned to the digital meter. Digital IMC has no secondary circuits, transformers have no residual magnetization, and the measurement accuracy does not depend on the load of the metering circuits. There is one more essential point: the digital meter does not perform the analog signal conversion, it operates with already labelled values and it only carries out mathematical operations with these values. The execution accuracy of such operations is by several digits higher than that of the measurement process in analog meters. According to the existing methods of instrument type approval, the error is estimated for a digital meter, but its actual value is several times lower than the one that is assigned, due to the lack of necessary qualification methods for digital meters.

To sum up everything mentioned above, when applying digital optical instrument current transformers, electronic voltage transformers and digital meters, the IMC's actual error is notably lower than the conventional IMC's error.

Up to the present day, Profotech has carried out works creating digital IMC at several plants, and according to the results of the metering methods certification, it is safe to say that the digital IMC's overall error is lower. For the IMC consisting of digital optical current transformers 220kV, electronic voltage transformers 220kV and ESM-type digital meters, the overall error is ±0,7%.

Calculation of confidence error of the measurement results is performed according to Appendix E based on CD 153-34.0-11.209 «Automated Electric Energy and Power Monitoring and Metering Systems – Standard Method for Measurements of Electric Energy and Power» and in compliance with PI 1317-2004. With the same parameters, error calculation for analog CT and VT and electronic meter shows IMC's error to be 2,8%.

In light of this, what leads to the improvement of measurement accuracy and reduction of the IMC's overall error?

Calculation of commercial efficiency from reducing the IMC's error can be performed based on the method presented in the issue by L.V. Andreeva, L.K. Osika, V.V. Tubinis «Revenue electricity metering on wholesale and retail markets» (Technical library of the non-commercial partnership «ABOK», Moscow, 2010, Appendix 9, pages 372–379). The calculation is based on the informational approach and the associated concept of the risk of measurement result uncertainty.

As a calculation example we shall use an imputed value of electricity cost for a conventional accounting period, which equals 1 000 000 rubles, and an error of analog IMC, equaling 2,8%.

1. Hazardous interval for a conventional IMC's measurement error with losses of 2,8% would be:

$$1\,000\,000 \text{ RUB} \times 0{,}028 = \\ = 28\,000 \text{ RUB.}$$

For IMC being a part of optical transformers and a digital meter, the IMC's error value is 0,7%.

2. Hazardous interval for IMC's measurement error with losses of 0,7% would be:

$$1\,000\,000 \text{ RUB} \times 0{,}007 = \\ = 7\,000 \text{ RUB.}$$

With regard for symmetric error distribution, and the fact that nearly always it has a negative value for calculations, we shall use a half of the hazardous interval's value.

Therefore, the effect from upgrading the IMC's accuracy class would be:

$$(28\,000 \text{ RUB} - 7\,000 \text{ RUB}) : 2 = \\ = 10\,500 \text{ RUB.}$$

This example shows what economic benefits can be achieved using high-accuracy digital measurement systems.

The calculation presented above is aimed at the consumers, the profits for power generation can be calculated in a similar manner. Grid companies will additionally achieve higher metering accuracy due to the fact that digital IMC is extensively better at reactive energy metering, and therefore better at measuring the total energy, received and served by the grid.

Profotech is currently finishing the installation and commissioning of a digital electric power revenue metering system for one of the electric energy consumers. The scope of the project includes combined electronic optical current and voltage transformers 220 kV. Figure 3 shows mounted columns with transformers.

Application of the combined transformers provides maximum effect due to reduced costs of the construction and installation works: just one column is mounted, equipped with significantly lighter optical transformers. Risks of fire and oil spill are eliminated entirely, since instrument transformers contain little to no oil. Risks of consumer de-energizing are reduced significantly.

Calculations of economic factors, technological advantages, reduced costs for construction, installation and current operation, presented above, demonstrate the advantages of digital technologies for implementation of

Figure 3. Columns with combined electronic optical current and voltage transformers 220 kV

revenue electricity metering systems. But the possibilities of the digital systems extend beyond that. Digital transformers perform complete and complex measurement function. Simultaneously with the generation of digital streams for revenue metering purposes (SV 256 – 256 samples for a commercial frequency period), digital electronic and optical transformers, manufactured by JSC Profotech, also generate a value stream with the sampling rate of 80 samples for a commercial frequency period (SV 80) for relay protection and automation and emergency control automatics. SV 256 stream might be used for telemetering, which allows to perform all types of measurements: for revenue metering, telemetering, relay protection and automation in relation to a single time mark.

Profotech's digital instrument transformers have a high internal sampling frequency of the measurement signal (internal sampling frequency is 64 kHz), which enables the compliance with nearly all modern requirements. Particularly, this is how the corporate standard support of PJSC Rosseti (PJSC FGC UES) is accomplished: 96 samples for a commercial frequency period for relay protection and automation and 286 samples for revenue metering.

JSC Profotech has mastered the production of the full range of optical instrument current transformers, applicable for generators, power grids, electric plants of the consumers with voltage classes from 6 kV to 500 kV. All the transformers ensure measurement accuracy class 0,2S for measurement and 5P for protection. Optical instrument transformers are able to carry out advanced performance diagnostics and to perform integration with any upper level system, providing the customer with the possibility to arrange maintenance of these systems on demand, which drastically reduces the maintenance costs.

The interest for implementation of digital relay protection and measurement systems and the transition to creating a full digital substation has increased significantly, which is proved by a growing number of implemented projects using Profotech's optical transformers. We have successfully completed projects creating digital metering systems in Russia: automated measuring and information system for electric power revenue accounting at the 500 kV substation «Tobol» (PJSC FGC UES); Krasnoyarsk aluminum smelter; digital metering system at the «Yasen» substation (PJSC Lenenergo). We have also completed multiple projects worldwide: in Switzerland (Groupe-E and Swissgrid), Netherlands (DNV-GL), France (EDF), Italy (Terna), Finland (Fingrid).