APPLICATION OF IEC 61850-9-2 IN MV SWITCHGEAR WITH SENSORS USE

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ABSTRACT

MV sensors (Medium Voltage Low-power stand-alone sensors) represent an alternative way of performing the current and voltage measurements needed for the protection and monitoring of medium voltage power systems. These sensors, based on alternative principles, have been introduced as successors to conventional instrument transformers and in connection with microprocessors based Intelligent Electronic Devices (IEDs) enable many benefits for both users and applications. However, to be able to fully utilize all advantages of MV sensors in MV Switchgear at primary distribution level, the way in which the voltage signal can be distributed in the switchgear has to be found. The IEC 61850-9-2 offers the solution. The combination of digitalization by use of IEC 61850-9-2 and MV Sensors brings a significant change to the way in which MV Switchgears and networks can be built.

INTRODUCTION

Development in the area of insulation materials, switching technology, power industrial electronic, and information technologies over the last 20 years has brought a number of technology changes to MV (Medium Voltage) primary AIS (Air Insulated Switchgears) and primary GIS (Gas Insulated Switchgears), and therefore MV networks.

Overall dimension of the MV Switchgears have been reduced to physical limits thanks to effective study of electric fields and the possibility to model distribution of them. Introduction of vacuum interrupting technology at the beginning of the 80s has been a revolutionary technological step in medium voltage and we do not see a signs that a new revolutionary technology in switching technology might be introduced in the near future. Microprocessor-based IEDs have been introduced at the end of the 90s with IEC 61850 standards being published in 2004.

There is one natural part of MV Switchgears which has not been significantly changed yet, which is the measurement. The majority of MV switchgears are delivered equipped with instrument transformers and this technology is absolutely dominant in MV applications. Despite all the benefits of new measuring technologies, it has not been widely accepted particularly at a primary distribution level. There are several reasons why alternative measuring technologies such as Rogowski coil and Voltage divider (called together sensors) are not yet accepted. One of the major application problems of sensors is the way in which we can efficiently distribute measuring values across the substation, particularly voltage measurement. Due to the fact that a sensor output signal is generally low power, it is impossible to do it in the same traditional way (hardwire) like with voltage transformers. IEC 61850-9-2 offers a standard way of how to transfer measurement signals between IEDs within substation layout. Implementation of process bus concept allows full utilization of sensors in medium voltage networks and it can represent essential change in measuring, protection schemes, and further optimization of medium voltage switchgear design.

CONCEPT

Taking into account measurement and protection applications in medium voltage networks, 98% of the feeders need eight basic measuring values (differential protection and synchrocheck represent max. 2% of MV feeders applications. It is not subject of this paper; however, it is possible to realize it with this concept):

- Phase currents I_{L1}, I_{L2}, I_{L3}
- Phase to earth voltages U_{L1}, U_{L2}, U_{L3}
- Residual current I_0
- Residual voltage U_0

Figure 1 of this paper shows a typical layout of the one MV single busbar section up to bus coupling when sensors and process bus are used.

- IED in incoming feeder measures phase currents, phase to earth voltages while residual current and residual voltage are calculated in IED.
- IED in Outgoing 1 measures phase currents, busbar voltage. Residual current and residual voltage are calculated. The important role of this IED is publishing of busbar phase to earth voltage sampled measured values across substation.
- IED in Outgoing 2 (or any other outgoing feeder in section) measures phase currents. Residual current is then calculated. Busbar phase to earth voltages are subscribed from process bus and used for further processing including residual voltage calculation.
- The IED in bus coupler beside measurement of phase currents and optionally calculation of residual current measures busbar phase to earth voltages the in next section. The important role

of the IED is to publish sampled measured values of busbar phase to earth voltages in section B to process the bus system.

Considering the above described measurements unfold across all sections of MV substation, it is ensured that each feeder has all the necessary measured values available for particular application-oriented processing. Measuring values always stay analogue within the feeder. When measurements reach the IED they are naturally digitalized. The IED in fact plays a role of merging unit by means of publishing busbar voltage measurements across the substation. Additionally, it is possible to use process bus communication infrastructure for GOOSE messages sharing in the entire substation.

The above described architecture is independent on primary measuring technology; however, sensors are preferred to be used since the quality of measuring signals open up new opportunities with how to realize advanced protection and control schemes. This architecture is an enabler of sensors used in medium voltage networks because it solves the elementary sensors application issue – effective transfer of sensors signals across the substation.

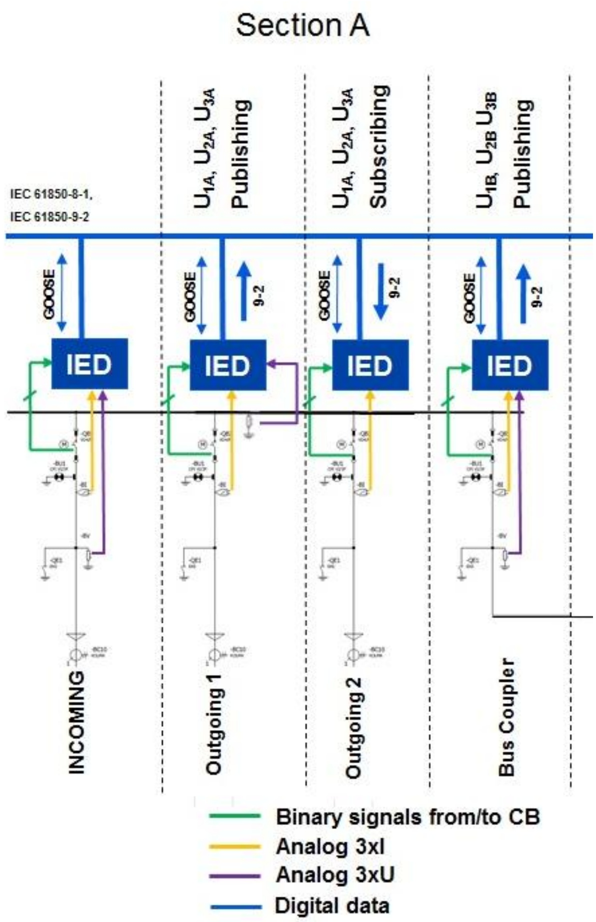

Figure 1: Medium voltage substation layout with sensors and use of IEC 61850-9-2

MV SENSORS

Many papers have been written about alternative ways of current and voltage measurements as a potential replacement of instrument transformers technology.
It is well known fact that MV sensors use non-conventional principles such as Rogowski coil or Voltage dividers which means that construction is done without the use of a ferromagnetic core. The behaviour of the sensor is therefore not influenced by the non-linearity and width of the hysteresis curve. It is however not only linearity of the characteristic which is important. Accuracy over whole required measuring dynamic range must be considered. Measurement, protection, and control applications require accurate measurements, especially currents, starting from very low values (few Amperes) up to short circuit levels (kA).

Accuracy and dynamic range

Due to the absence of a ferromagnetic core the sensor has a linear response over a very wide primary current range, far exceeding the typical current transformer range. Therefore, current sensing for both measurement and protection purposes can be realized with single secondary winding with a double rating. In addition, one standard sensor can be used for a broad range of rated currents and is also capable of precisely transferring signals containing frequencies different from rated ones [1].
The typical example of a current sensor can reach the measuring class 0.5 for continuous current measurement in the extended accuracy range from 5% of the rated primary current (e.g. 4 A) up to the rated continuous thermal current (e.g. 4000 A). For dynamic current measurement (protection purposes) current sensors can fulfill the requirements of the protection class up to an impressive value reaching the rated short-time thermal current (e.g. 50 kA). Figure 2 shows the curve of current accuracy measurement corrected by use of correction factors in the IED across typical current dynamic range in MV networks. Standalone Rogowski coil current measurement can achieve very accurate current measurement across the entire dynamic range; however, opportunity of correction factors use in the IED can even improve accuracy of current measurement both in amplitude and phase (Tab.1).

Voltage measurement by use of voltage dividers also offers excellent dynamic range with given accuracy.

Linearity of current and voltage measurements with guaranteed accuracy across an entire measurement dynamic range offers an opportunity for new and better protection scheme applications in MV networks. Protection functions and their implementations in IEDs need to be challenged. On top of the improved protection, concept of sensors with IEC 61850-9-2 also offers savings of material and energy in MV substations.

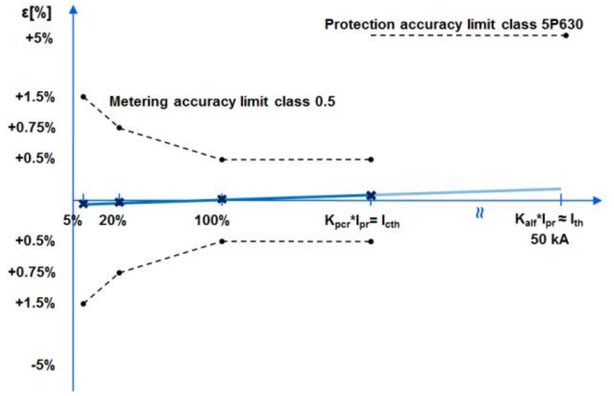

Figure 2: Example of combined current accuracy class corrected by use of correction factors in IED

Ipr (%)	5	20	100	Kpcr x 100
ε (%)	-0.02	0.00	**0.00**	0.01
φ (min)	0.6	0.2	**0.0**	-0.1
Amplitude correction factor			**0.9973**	
Phase error correction factor			**0.087°**	

Tab 1: Current Amplitude and Phase errors corrected by IEDs

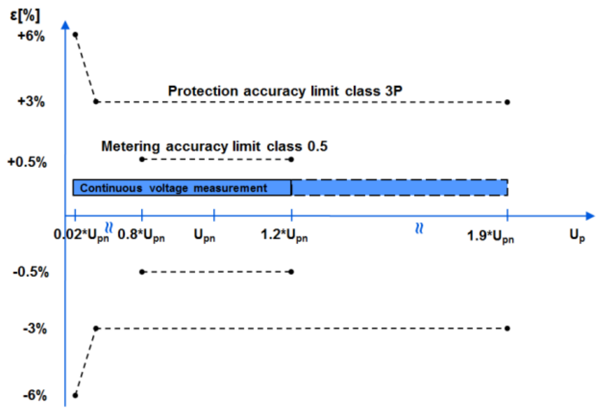

Figure 3: Example of combined voltage accuracy class

Energy savings concept

The technology means that there is no transfer of power from the primary side to the secondary side; consequently, there are negligible power losses and therefore the sensors exhibit extremely low energy consumption that is just a fraction of what is transferred to heat in a conventional instrument transformer. This fact contributes to significant energy savings during its entire operating life, supporting the world-wide effort to reduce energy consumption.

Furthermore, the temperature rise caused by internal heating up due to the current flowing through the sensor is very low and creates the further possibility of upgrading the switchgear current ratings and reduces the need for artificial ventilation.

Current transformer energy consumption

Transfer of the primary current to the secondary current in the Current Transformer (CT) is connected with power losses represented mainly by power losses in secondary winding and in burden. This fact means that CT needs to consume energy which is then transferred to heat.

Sensor energy consumption

The output signal of sensors is very low (in mV for current measurement and in V for voltage measurement) and there is no significant transfer of power from primary to secondary side. These low levels of sensors output signals, which can be designated as communication signals instead of power signals, represent negligible power losses.

Comparison of CTs and Sensors energy consumption

To be able to compare total consumed energy, the simple example is shown below. The typical switchboard was selected where there were calculations of two variants with CTs (1A and 5A secondary rated currents) and one variant with sensors only. The selected switchboard consists of 14 panels:

- 2 incoming feeders with CTs 1000/x/x A
- 8 outgoing feeders with CTs 200/x/x A
- 4 outgoing feeders with CTs 100/x/x A

All CTs have 2 cores – protection core class 5P20, 20 VA connected to the IED and metering core class 0.5Fs5, 5 VA connected to the analogue ampere-meter.

Feeder	CTs	Number of panels	Number of CTs	Power consumption	Energy consumption in 30 years
Incoming	1000/1/1A	2	6	140 VA	36 698 kWh
Outgoing 1	200/1/1A	8	24	448 VA	117 776 kWh
Outgoing 2	100/1/1A	4	12	102 VA	26 724 kWh
Total	-	14	42	690 VA	181 198 kWh

Tab 2: Consumed energy for variant with CTs rated secondary current 1 A

Feeder	CTs	Number of panels	Number of CTs	Power consumption	Energy consumption in 30 years
Incoming	1000/5/5A	2	6	172 VA	45 244 kWh
Outgoing 1	200/5/5A	8	24	629 VA	165 208 kWh
Outgoing 2	100/5/5A	4	12	179 VA	47 124 kWh
Total	-	14	42	980 VA	257 576 kWh

Tab 3: Consumed energy for variant with CTs rated secondary current 5 A

Feeder	Number of panels	Number of Sensors	Power consumption	Energy consumption in 30 years
Incoming	2	6	0,000 00 VA	0,000 01 kWh
Outgoing 1	8	24	0,000 00 VA	0,000 04 kWh
Outgoing 2	4	12	0,000 00 VA	0,000 02 kWh
Total	14	42	0,000 00 VA	0,000 07 kWh

Tab 4: Consumed energy for variant with Sensors

Material savings concept

Since the sensor elements are particularly small and the same elements are used for both measurement and protection, the current and voltage sensors can be easily integrated in the switchgear. Due to compact size of internal parts, voltage sensors can be fitted in equipment which is always used in AIS as a post insulator. On the other hand, current sensors do not necessary need to have their own primary conductor but can use the part of the switchgear primary circuit. These facts enable the design of sensors in a very optimal way which contributes to a huge material savings during sensor production compared to production of conventional instrument transformers.

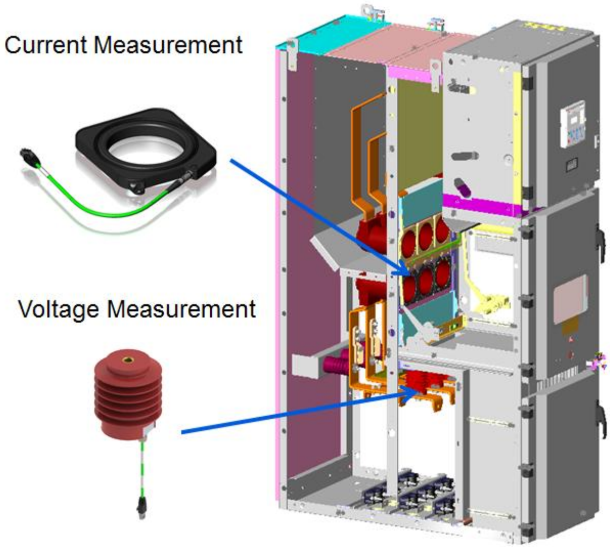

Figure 4: Example of sensors implementation in Air Insulated Switchgear

CONCLUSIONS

The introduction of IEC 61850-9-2 within MV switchgear opens up numerous advantages for users in MV applications. MV current and voltage sensors can get connected through the IEDs and signals can get distributed across the substation in a very flexible way. The paper has described the advantages of such an arrangement, which can be summarized with:

- Higher dynamic range of sensors compared to instrument transformers enable a much lower number of (sensor) variants within switchgear applications versus present instrument transformer technology.
- Linear behaviour of sensors enable measurement of higher frequency components and support cutting edge protection function implementation.
- Missing ferromagnetic core within sensors prevents ferroresonances.
- Energy consumption of sensors is negligible and therefore much lower than for instrument transformers. This has a positive contribution to the direct environmental impact and supports switchgear design to higher ratings without artificial cooling.
- Sensors require less space than instrument transformers and are therefore more flexible for positioning within the switchgear design.

REFERENCES

[1] R. Javora, V. Prokop, 2011, "Low-Power Current and Voltage Sensors for MV Applications", *Proceedings of International Protection Testing Symposium*, IPTS 2011, 2.1-2.9

[2] R. Javora, M. Stefanka, P. Mahonen, T. Niemi, O. Rintamaki, 2009, "Protection in MV Networks Using Electronic Instrument Transformers", *Proceedings of 20th International Conference on Electricity Distribution*, CIRED2009, paper no. 0168, p.4