Sharing Sampled Values Between Two Protection Relays According To Standard IEC 61850-9-2LE

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***Abstract*—IEC61850 Standard defines communication protocol for intelligent electronic devices at electrical substations. It describes in IEC61850-9-2 sampled values and how to digitalized measurements. Transferring data in digital format is used for the protection and monitoring application, the challenge nowadays is sharing the current and voltage measurements in substations and uses it for monitoring and protection application. Due to the fact that current and voltage transformers are able to convert the analog signals to digital format. This paper presents the measured sampled values and shares voltage level between two protection relays.**

Keywords—IEC61850-9-2LE, Sampled values, PCM600, relay, sensors

I. INTRODUCTION

The IEC 61850 protocol standard for substation authorizes the combination of all control, protection and monitoring functions by one protocol, Nowadays, all manufacturers realize the importance and the need to merge the communications of all IEDs in a substation, numerous IEDs can control commands at high speed and share data. This coordinated control can partly eliminate the need for wiring in a substation. Many utilities have already established systems of interconnected IEDs, which make IEDs measurements available to use for centralized substation and control, whilst, the majority of data in IEDs is left uncollected due to the traditional techniques were designed to support SCADA. IEC 61850 was created to be an internationally standardized method of communications and integration with goals of supporting systems built from multivendor IEDs networked together to perform protection, monitoring, automation, metering, and control [1].

A microprocessor provides the ability to process large amount of information and to make the tripping decision trip, another important application of permanent power quality monitoring is a distribution power quality recorder (DPQR) in the digital relay that can be used to define the measurements of events which occurred in the power system such as internal/external fault diagnosis, fault measurements, zero current sequences and disturbance recording.

The hierarchy structure of power system automation contains electrical protection, control, measurement, and monitoring and data communications. The power system automation is a system that is integrated into the various components connected to the power network. The numerical relay is a focal concept of the power system automation to protect the equipment and limit the damage. The system's components have better communication with each other; the information is exchanged via dozens of communication protocols; the concept can be characterized by only one sensor obtaining and collecting information from the network instead of a sensor per each component in the power system. The power system automation has several levels to integrate into the power substations and the substation supervisory system (SCADA).

This research work has been carried out in the Centre for Research and Utilization of Renewable Energy (CVVOZE). Authors gratefully acknowledge financial support from the Ministry of Education, Youth and Sports of the Czech Republic under NPU I programme (project No. LO1210).

II. IEC 61850-9-2 STANDARD

IEC 61850 defines 5 types of communication services. The first three types are time-critical and are used in protection and control schemes of the substation. They include Sampled Values (SV) and Generic Object Oriented Substation Event (GOOSE) protocols which are mapped directly to Data Link layer for reduced protocol overhead and hence increased performance; and Generic Substation State Event (GSSE) protocol which features its own custom protocol mapping [9].

IEC 61850-9-2, process bus is defined as standard:

- IEC 61850-9-2 standard for communication networks and systems in substations, part 9-2: "Specific Communication Service Mapping (SCSM) - Sampled values over ISO/IEC 8802-3" [4].
- Implementation Guideline for digital Interface to instrument transformers using IEC 61850-9-2, To facilitate implementation and enable interoperability, the UCA International Users Group created a guideline that defines an application profile of IEC 61850-9-2, which Commonly referred to as IEC 61850-9-2LE for "light edition" [2].

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TABLE I. IEC 61850-9-2 STANDARD [2]

Area	Standard IEC 61850-9-2	Implementation Guideline IEC 61850-9-2LE
Sampling rate of analog values	Free parameter	80 samples per period for protection and metering 256 samples per period for power quality
Content of dataset	Configurable	3 phases current + neutral current values and quality 3 phases voltage + neutral voltage values and quality
Time synchronization	Not defined	Optical pulse per second (1PPS)

IEC 61850-9-2 = Sampled Measured Values (SMVs)

- Enables sharing of values and measurements among IEDs.
- Transmission of sampled analog (especially U/I) and digital values from primary technology over Ethernet network.
- Data are sent in continuous data stream and packet (data link layer).
- Interface electronic device that enables digital communication over ethernet network using Sampled Measured Values.
- Providing time-coherent SMV with multiple analog values, and digitizes them according to IEC 61850-9-2.
- IED = Merging Unit in UGD.

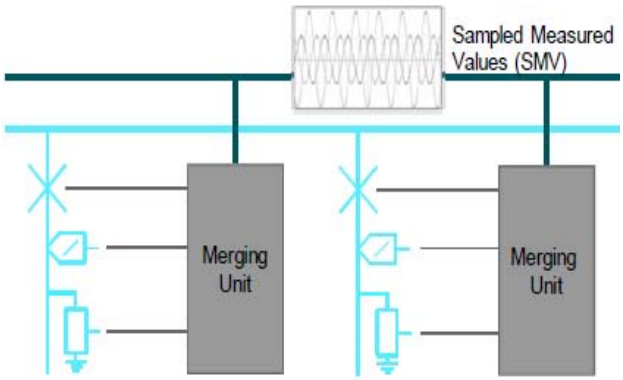

Fig. 1. Sampled Measured Values (SMVs) [3]

A. Merging Unit

Merging units are connected to the secondary sides of the current and voltage transformers and publish the voltage and current values as sampled values (SV) ethernet packets. Digitalized analog data is transferred by Fiber Optic cables to receiving protection relays (IEDs) via IEC 61850 process bus, a packet of data includes sampled values, GOOSE messages and precision time protocol. IEDs are connected into process bus by Ethernet switches.

DataSet members:

- I1 sampled value
- I1 quality attribute
- I2 sampled value
- I2 quality attribute
- I3 sampled value
- I3 quality attribute
- I0 sampled value
- I0 quality attribute
- U1 sampled value
- U1 quality attribute
- U2 sampled value
- U2 quality attribute
- U3 sampled value
- U3 quality attribute
- U0 sampled value
- U0 quality attribute

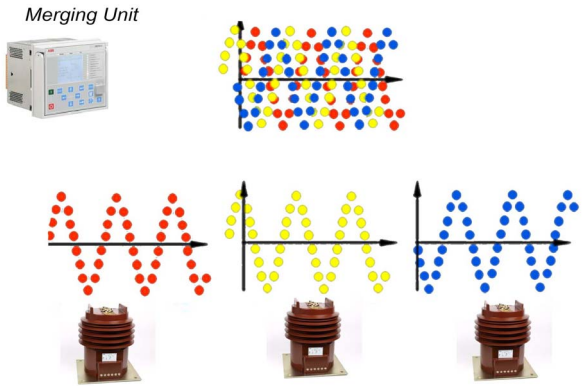

Fig. 2. Merging unit and sampled values (SVs) [3]

B. Sampled Values Profiles

IEC 61850 standard uses ethernet as physical communication layer, the sampled values are transferred via available communication bandwidth of ethernet. The transmission speed is 100 Mbit per second (100Mb/s) and light edition of this standard for MV applications determines two specific sampling rates:

- 80 samples per period for protection applications, samples can be transferred using ethernet.
- 256 samples per period for metering applications.

Sampled Measured Value message is duplicated within T depending on sample rate (SmpRate) and number of ASDUs (samples) per message (NoASDU) [5].

$$T = {}^{1}/_{SmpRate * NoASDU} \quad (1)$$

Sampling rate for 80 samples per cycle

- $f_1 = 80 \times 50\ Hz = 4\ kHz \Rightarrow T = \frac{1}{4\ kHz} = 250\ \mu s \quad (50\ Hz\ system)$
- $f_2 = 80 \times 60\ Hz = 4.8\ kHz \Rightarrow T = \frac{1}{4.8\ kHz} = 208\ \mu s \quad (60\ Hz\ system)$

Data volume broadcasted by one IED

Each IED SMV frame includes $160B = 1280b$

- $50\ Hz \times 80 \times 1280\ b = 5.12\ Mb/s\ (50\ Hz\ system)$
- $60\ \text{Hz} \times 80 \times 1280\ \text{b} = 6.16\ \text{Mb/s}\ (60\ \text{Hz system})$

According to network traffic standard is recommended to keep 50 Mb/s reserved for MMS telegram between IEDs, SCADA system, and GOOSE messages. 50 Mb/s ethernet capacity is used for SMV data sharing.

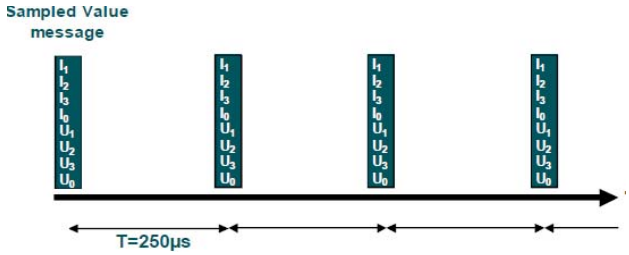

Fig. 3. IEC 61850-9-2, Process bus Data Exchange SmpRate = 4kHz

TABLE II. CALCULATION OF COMMUNICATION BANDWIDTH

Maximum amount of SMV	Single and PRP redundant network	HSR redundant network
50 Hz system	9	4
60 Hz system	8	4
Two SMV publishers	SMV=12.3 Mb/s GOOSE+MMS=87.7 Mb/s	SMV=12.3 Mb/s GOOSE+MMS=37.7 Mb/s

III. PROTECTION RELAY TESTING

This part describes the experimental measurement provided on the test setup in Laboratory of protection relays at Brno University of Technology.

A. *Engineering with PCM600*

PCM600 is a tool providing control and configure ABB IEDs, it is adapted tool with IEC61850 standard, which enables data exchange and provides efficient functionality for application configuration.PCM600 offers data transfer between IEDs. The settings in PCM600 offer a view and modify IED parameters. These parameters can be exported and imported in XRIO format or other formats [3].

Configuring Process bus to share voltage information between two IEDs (REF615 outgoing feeder and REF615 incoming feeder) is summarized in the following steps:

In this test, the process bus communication enables voltage sharing between IEDs as (SMV- Sampled Measured Values). Digital values of current and voltage transfer over ethernet network.

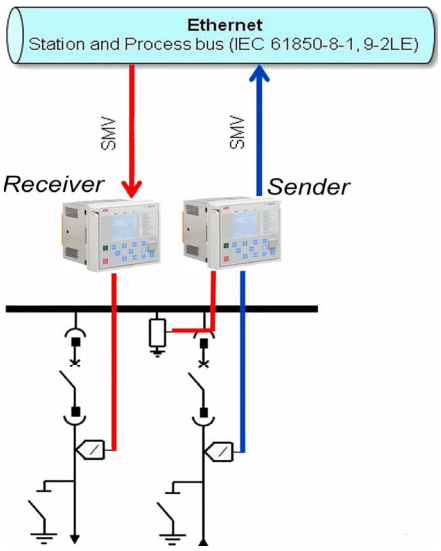

Fig. 4. REF615 Outgoing feeder – REF615 incoming feeder [7]

In the application configuration of the sampled values, the SMVSENDER function block should be added to enable and active sending sampled values according to IEC61850 standard as shown in Fig. 5. The communication channel is established and REF615 sender starts sending the voltage as sampled values (80 samples per cycle).

TABLE III. SETTINGS FOR SAMPLED VALUES COMMUNICATION

Protection Relays	IP Address	Subnet	Technical Key
REF615	172.16.2.2	255.255.0.0	ABBJ1K02A1
REF615	172.16.2.1	255.255.0.0	ABBJ1K04A1

In PCM600, a new project is created for two feeder relays REF615 (incoming and outgoing). IEC61850 Configuration Tool offers Client-Server Communication and matrix of available IEDs which are connected to the switch. One protection relay should be selected to be Sender protection relay. The SMVAENDER function block provides share the sampled values from sender protection relay as process bus sender.

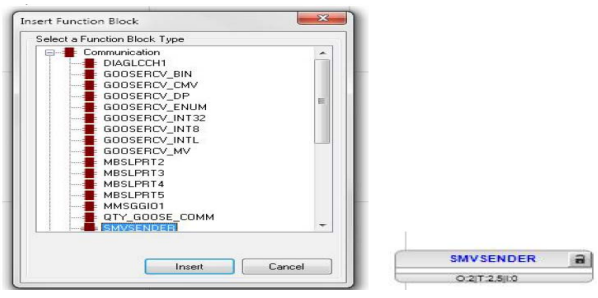

Fig. 5. SMVSENDER function block in PCM600 Application Configuration

In REF615 receiver protection relay, IEC61850 Configuration Tool is used to establish the communication between two IEDs. As shown in Fig. 6 Process Bus communication and Control Block Attributes.

Sampled Value Control Block (SvCB) attributes:

- APPID – unique SvID in network

  Reserved value range is from 0x4000 to 0x7FFF

  Default value is 0x400 based on UCA 9-2LE

- MAC address

  Unique Multicast address per SvCB is recommended.

  The multicast address range is from 01-0C-CD-04-00-00 to 01-0C-CD-04-01-FF.

- SV Control block name

  This block is created automatically, technical key.

- DataSet definition

  When SMVSENDER function block is added the DataSet generated automatically.

- VLAN ID

  Value range according to IEC 61850-90-4) is from 0xBB8 (3000) to 0xDB7 (3511)

  The default value is 0x000.

- VLAN priority

  The default value is 4 as per IEC 61850-9-2 (value range 0 …7).

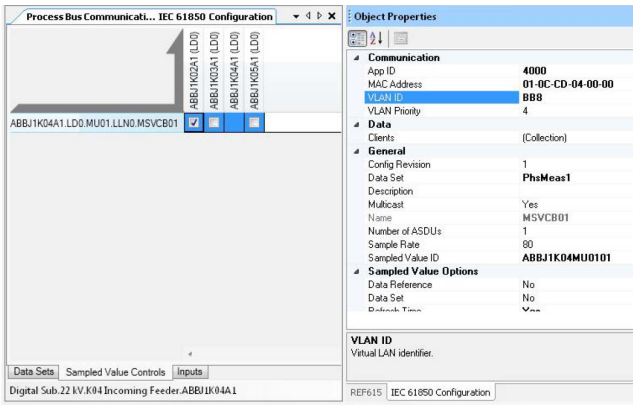

Fig. 6. Process Bus communication and Control Block Attributes

B. *Test setup with Omicron*

Omicron CMC 256 is a tester device which can test IEDs functionality and offers the IEC 61850 communications (GOOSE messages and sampled values). Three-phase voltage and current and transfer these signals to relay protection over ethernet network [10], additionally, 3x FTP cables terminated with the RJ45 connector can be used and testing adapter CMLIB REF 6xx.

Analogue signal:

- 3 x I (150mV for 50Hz system)
- 3 x U (2V/ √3 for 20kV system)

IEC61850 Testing Tools enables different test set to verify the IEC61850 protocols and communication. SVScout provides the visibility to measure and monitor the sampled values for the substation engineer, additionally, the SVScout software provides merging units testing by comparing two SV streams, more precisely, SVScout makes sampled values visible and shows detailed values of the primary voltages and currents. One important feature of SVScout is the ability to make a comparison between different SV streams, it includes the RMS values and phase angles which displayed in a phasor diagram and a measurement table.

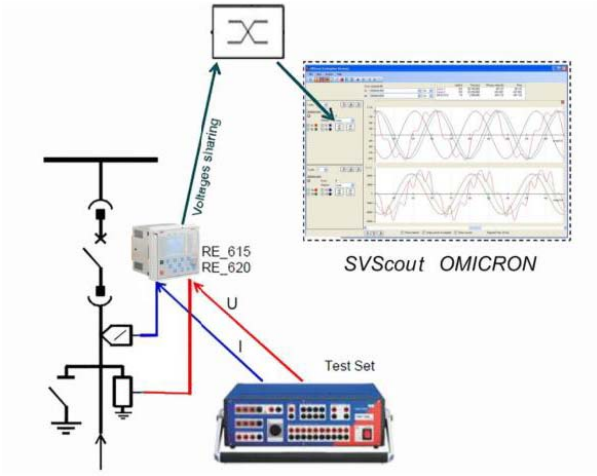

Fig. 7. Shows how to connect CMC256 to sender relay / Testing of Process bus

CMC256 provides some interfaces to test of process bus IEC61850-9-2. It simulates current and voltage sensors by using Rogowski coils for current measurements and a voltage divider for voltage measurements. the output of the sensor is connected to the ethernet ports in the IED device, the IED provides interface that showing the measurements of power, power factor, voltages and currents. Moreover, this IED shares the voltage measurements with the receiver IED that is connected to switch and ethernet. the communication between two IEDs according to the standard is based on MAC addresses (media access control address), it means the source IED have to know the MAC address of the destination IED, otherwise, the data packets could be lost in the network and the measurement cannot reach the final destination, the mac address of any device is unique and every IED has own MAC address.

Some tools and software provide the possibility to show and analyse the data packet which is sent over the network, Wireshark software offers the option to show the packet content and information about the source, destination, values of voltage and current in the Hexadecimal system [7]. SVScout sampled values is platform which can compare the output of merging units and establish recording the waves as comtrade format, however, estimated delay time of sending and receiving SMV has been measured as shown in the table.

TABLE IV. PROTECTION AND COMMUNICATION DELAYS

	SMV1	SMV2	SMV3
SMV max delay setting 50 Hz (ms)	3.75	4.25	4

There are a few parameters can define the delay time of SMV:

- Number of hops in networks
- Internal application delay of protection
- Store and forward latency
- Queue latency: queue latency calculated when the port has started to send a full-sized frame (1500 bytes) before SMV frame and the switch has been configured to prioritize SMV.
- Theoretical max delay
- Recommended max delay setting

The delay time was measured from the voltage wave to the received relay. As mentioned previously, there are several parameters to be considered in order to calculate the time of delay for the sampled values, where the protection delay is about 1.25 to 6.25 ms depending on the delay characteristics of the sampled values [8].In Fig. 8, two voltage waveforms can be noticed and those waveforms are sampled and packed according to the IEC61850 standard. The blue waveform is voltage measured sampled values which reached the receiver protection relay without any errors or distortions. The second waveform is inaccurate measured sampled values of the voltage signal and is not completed with delay time. The figure expresses a number of samples (250 samples) with voltage waveforms. As shown in Fig. 8 the lost messages are high and the sampled values quality is inaccurate.

Wireshark software tends to focus on network traffic flow rather than judging packet content. It monitors the network traffic with the available protocols in the networks as well as the sampled values contain details of source and destination, it shows each packet of measurement separately in ASCII [6]. Due to some errors which can affect packet traffic, so it is important to sure the network packet analysis.

CONCLUSION

The paper explains the sharing of the voltage level between the two protection relays and the test is performed according to IEC 61850-9-2LE standard. It determines the delay time for the measured sample values and the waveforms of the signal on the receiver side with the comparison of the inaccurate measurement due to failure of merging unite.

The test can be performed to send samples from Omicron 256 Sampled Values software; however, it was not able to simulate the merging of the sender's relay protection. The test is performed using a linear voltage sensor as input signals to the sender relay. This relay can transfer and share values that are sampled to the receiver relay when it has appropriate settings.

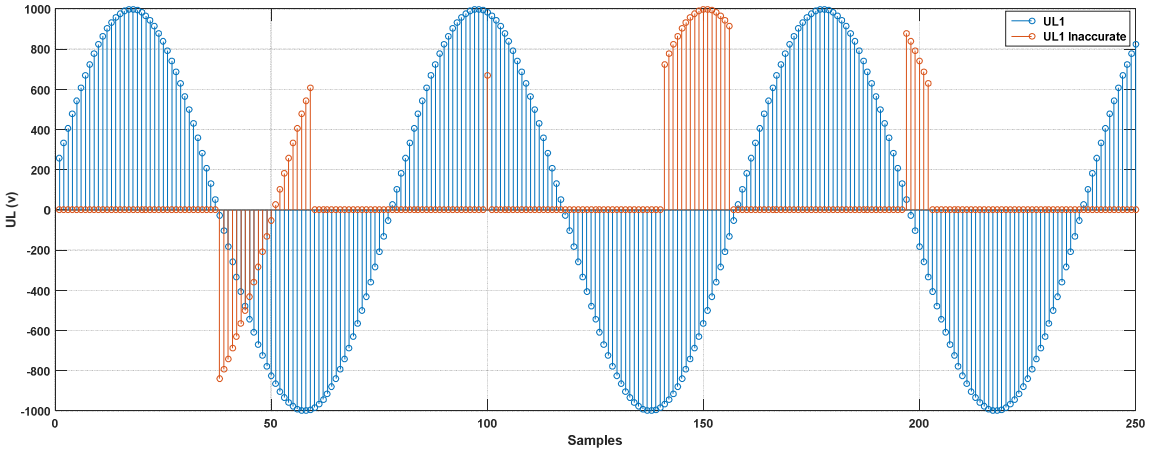

Fig. 8. Test mode of protection relays

REFERENCES

[1] V. Skendzic, I. Ender, and G. Zweigle, "IEC 61850-9-2 process bus and its impact on power system protection and control reliability," In Proceedings of the 9th Annual Western Power Delivery Automation Conference, Spokane, WA. 2007.

[2] M. Adamiak, D.Baigent, and R.Mackiewicz, "IEC 61850 Communication Networks and Systems In Substations, " 2010, pp 61-68.

[3] REG, ABB Generator Protection. "PCM600, Protection and Control IED Manager, Brochure".

[4] M.S.Almas, and L.Vanfretti. "Performance evaluation of protection functions for IEC 61850-9-2 process bus using real-time hardware-in-the-loop simulation approach. " 2013,pp 0479-0479.

[5] A. Valdes, C. Hang, P. Panumpabi, N.Vaidya, C.Drew, and D.Ischenko, "Design and simulation of fast substation protection in IEC 61850 environments, " In Modeling and Simulation of Cyber-Physical Energy Systems (MSCPES), 2015 Workshop, pp. 1-6.

[6] A. Altaher, S. Mocanu, and J.M. Thiriet, "Experimental Evaluation of an IEC 61850-Station Bus Communication Reliability. " In Journées Nationales des Communications Terrestres, 2015.

[7] L. Yang, P.A. Crossley, A.Wen, R. Chatfield, and J. Wright, " Design and performance testing of a multivendor IEC61850–9-2 process bus based protection scheme. " IEEE Transactions on Smart Grid, 5(3), 2014, pp.1159-1164.

[8] UniGear Digital , "Engineering and testing IEC 61850-9-2, Process bus".

[9] J. Jirickova, "IEC61850: Implementation in new Generation of Electrical Protection", Proceedings of The IVth International Scientific Symposium on electric Power Engineering – Elektroenergetika 2007, pp 471-473, 2007.

[10] Rafajdus, P., Bracinik, P., Hrabovcova, V., Saitz, J., Altus, J., Höger, M., Pyrhönen, J. Examination of Instrument Transformers for Their Employment in New Fault Location Method, International Review of Electrical Engineering (IREE), Vol. 7, No. 3, Italy, 2012, ADE, pp. 4585 - 4595, ISSN 1827-6660