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Impact of IEC 61850-9-2 Standard-Based Process Bus on the Operating Performance of Protection IEDS: Comparative Study

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Abstract: IEC 61850-9-2 is an international substation automation standard that proposes a Process Bus communication network between process level equipment and bay level Intelligent Electronic Devices (IEDs) used for power systems protection and control.
This paper considers the drive towards the use of IEC 61850-9-2 Process Bus in substations. The impact of the IEC 61850-9-2 standard on the operating performance of protection IEDs in terms of dependability, security, and operating speed is considered. A lab-scale hardware-in-the-loop experiment involving the Real-Time Digital Simulator (RTDS), IEC 61850-9-2 protection IED based on Sampled Values (SV) inputs, conventional hardwired protection IED, GPS satellite clock, and industrial network switches is implemented and used for the investigations.
The experiments are directed towards the comparison of the performance of the distance protection function of the two protection IEDs when subjected to various fault types at various fault locations, fault resistances, and fault inception angles, with different Source Impedance Ratios (SIRs). Furthermore, the possible impact of random noise/delay on the protection functions of the IEC 61850-9-2 Process Bus based protection IED is investigated. The stability and security of the protection function of the protection IED based on SVs generated from the GTNET-SV card of the RTDS is investigated and compared to that of the IED based on conventional hardwired CTs and VTs.

Keywords: Distance protection, IEC 61850 process bus, power systems, sampled values, substation automation.

1. INTRODUCTION

The IEC 61850 standard is an internationally recognized non-proprietary standard for power systems substation communication networks and automation. It provides a single suite of protocols and services to address communications within and outside the substation through the integration of protection, control, and metering functions within a substation. It also provides the means for interlocking and inter-tripping, and other associated advantages of using Ethernet communication.

As utilities begin to accept the concept of this standard with the implementation of pilot schemes to test completely digital substations (Kasztenny et al., 2008; Schaub & Kenwrick, 2009; Schaub et al., 2011; Cardenas et al., 2011), there is the need to carry out performance testing of IEC 61850 9-2 Process Bus based equipment. This is because it is imperative to allay the fears of protection engineers on the performance of this technology for them to partake in the benefits it promises. Some of the benefits of the implementation of the IEC 61850-9-2 technology include a significant reduction in the overall cost of substation protection, automation, and control systems due to the reduction in the cost of numerous copper conductors compared to the use of few optic fibre cable. Also, there is a reduction in the probability of the occurrence of Current Transformer (CT) saturation and its consequences. This is because the impedance of the merging unit current input is small. Furthermore, it is much safer to use than conventional methods where an open circuit could occur. In addition, the use of IEC 61850-9-2 permits wide availability of measurements to individual protection IEDs on the digital communication bus, and system reconfiguration can be done in less time with minimum cost compared to the conventional hardwired method (Apostolov, 2006; Tholomier & Chatrefou, 2008).

Investigations on the performance of the Process Bus have been of interest to researchers. Ferrari et al., (2012) carried out an analysis on the performance of the Process Bus when non IEC 61850 devices are used together with protective IEDs. The preliminary results supported the possibility to mix different real-time data streams on the Process Bus. Similarly, Ingram et al., (2012) showed that a multi-function Process Bus can coexist on a shared Ethernet network. The results demonstrated that fully switched Ethernet network with full duplex connections did not experience collisions. However, the research evaluated the Process Bus from a data network perspective rather than examining the performance of the protection functions of the Process Bus IEDs. This is of particular interest because of the need to verify the performance of the IEC 61850-9-2 Process Bus technology in order to allay the fears of stakeholders.

Kanabar et al., (2011) investigated and proposed a Sampled Values (SV) estimation algorithm as a corrective measure for SV loss/delay.
For this, IEC 61850-9-2 based protection platform and Merging Unit (MU) simulators were implemented in a laboratory environment using industrial embedded systems. The proposed scheme made use of a COMTRADE recorder function within PSCAD/EMTDC software. The recorded COMTRADE data was converted to IEC 61850-9-2 SV messages using software codes. Similar results were reported in Kanabar and Sidhu (2011).

Sun et al., (2012) carried out a performance investigation of an IEC 61850 protection scheme using the RTDS. The implemented scheme used a permissive under-reach protection scheme with an IEC 61850 relay at the local end and a conventional relay at the remote end. Also, results were presented for the performance of the IEC 61850 9-2 IED when the data traffic exceeded the capability of the Process Bus.

This paper investigates the impact of IEC 61850-9-2 Process Bus on the reliability of power system protection. In this implementation, real protection IEDs were used in a hardware-in-the-loop set-up with the RTDS. It is necessary to make use of actual Process Bus equipment when carrying out performance analysis of this nature in order to investigate and record the performance of these equipment and their interaction with the power system network as would be obtained in real world application.

This paper extends previous works in the literature by carrying out well-structured investigations to simultaneously compare the distance protection performance of a protection IED based on IEC 61850-9-2 Sampled Values with the performance of another protection IED with hardwired analogue inputs, with both IEDs connected to the same local end. Also, performance testing and analysis of the effects of noise and delay on the protection functions of the IED based on IEC 61850-9-2 Process Bus was carried out. This is because the Sampled Values from IEC 61850-9-2 are not repeated continuously like in the case of IEC 61850-8-1 Generic Object Oriented Substation Events (GOOSE) message which is updated continuously until another event triggers a state change.

The rest of this paper is structured as follows: Section 2 describes the various instruments required for power system substation measurements. Section 3 presents the Lab-Scale Implementation of the IEC 61850-9-2 based distance protection investigation. Section 4 presents the results and discussion, while Section 5 summarizes the conclusion.

2. SUBSTATION MEASUREMENTS

2.1 Conventional Hardwired Analogue Inputs

In conventional systems, the analogue input module of the protection relay provides the interface between the onboard processor board(s), and the voltage and current quantities coming into the protection relay from the instrument transformers like Current Transformers (CTs) and Voltage Transformers (VTs) located in the substation switchyard. These analogue signals are passed through anti-alias filters before being multiplexed onto an Analogue-to-Digital Converter (ADC) chip. The ADC provides a sampled data stream output which is transmitted to the protection module via the data bus. This is as shown in Figure 1.

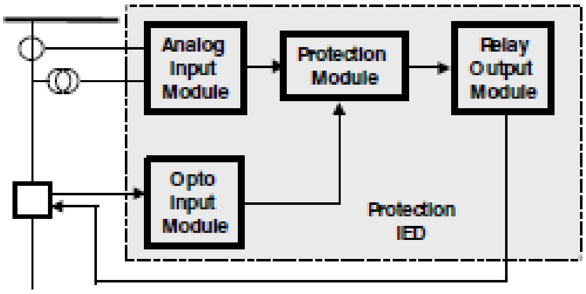


Figure 1. Conventional hardwired analogue inputs based IED (Apostolov et al., 2006).

The sampling rate is usually at a fixed number of samples per cycle. Some algorithms also make use of frequency tracking function to correct amplitude or phase error introduced by the transformers and analogue circuitry.

2.2 IEC 61850-9-2 Process Bus based Inputs

Digital substations are based on the use of automated primary equipment and networked secondary devices. These equipment are capable of sharing digital information for performing distributed protection and control functions via a common Ethernet network.

Substation automation and control systems can be divided into three distinct levels: 1. Process Level 2. Bay Level
3. Station Level

The process level takes care of the data acquisition using instrument transformers. The output of these instrument transformers are sampled, converted to digital representation, and formatted for subsequent transmission through the Process Bus Local Area Network (LAN). The Process Bus is also used to control high voltage switchgear equipment such as breakers, breaker control units, disconnect switches, etc. Process level information is then communicated over the LAN to the protection and control devices that are located in the Bay/Unit Level. The Process Bus equipment typically exchange data via the logical interfaces denoted with Numbers 4 and 5 as shown in Figure 2.

Protection, control, and metering functions are performed at the Bay Level by the bay equipment. The bay equipment receive their current and voltage input from the process level. These equipment include IEDs, fault recorders, Phasor Measurement Units (PMUs), etc.

The station level functions represent the overall substation-wide coordination, substation Human Machine Interface (HMI), and the SCADA system interfaces (IEC 61850-5, 2003).

The sub-set of the IEC 61850 standard referred to as the Process Bus allows the replacement of conventional analogue and binary signals with Ethernet messages. This enables the use of a digital communication link between devices. The Merging Units (MUs) are the interface to current/voltage transformers, switchgear, and bay devices such as protection relays, bay controllers, or metering devices.

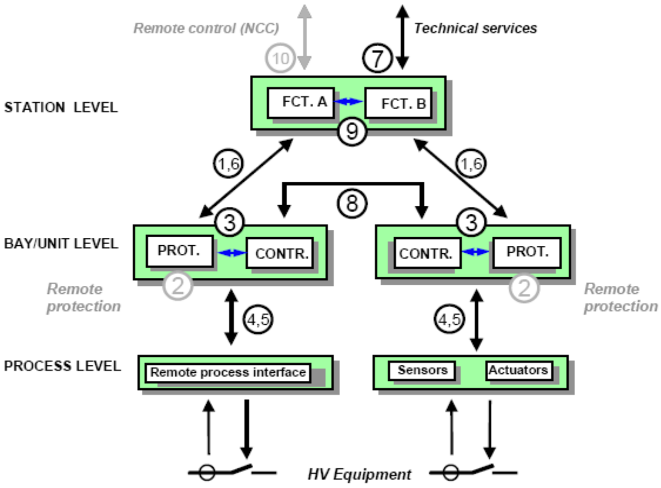


Figure 2. Model of a distributed protection system (IEC 61850-5, 2003).

In IEC 61850 Process Bus implementation, ADCs and binary I/Os modules are installed in the switchyard in close proximity to the signal sources. The analog signals from CTs/VTs are digitized in the Merging Units (MUs). The MU comprises of Logical Nodes TVTR (voltage transformer) and TCTR (current transformer), and serves as the interface unit that gathers multiple analogue information such as phase voltages and currents from instrument transformers. All these analogue signals are converted to digital Sampled Values (SV) Ethernet packets in the MUs. The digital signals/packets are communicated to the bay level protection IEDs over Ethernet based communication network known as the Process Bus. This is as illustrated in Figure 3.

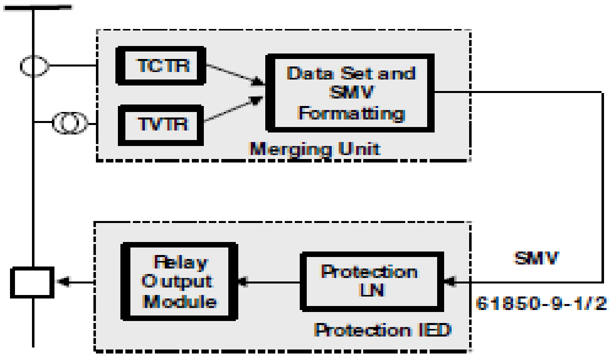


Figure 3. IEC 61850-9-2 Sampled Values based IED (Apostolov et al., 2006).

The Process Bus includes the merging units and ethernet switches. The IED receives the Sampled Values from the Process Bus and resamples these Sampled Values in order to make the data appear the same way to the IED as analogue inputs would if it were from conventional CTs and VTs.

IEC 61850 Process Bus standard defines the Specific Communication Service Mapping (SCSM) for the transmission of Sampled Values in two of its parts. These are Part 9-1 and Part 9-2 (IEC 61850 Part 9-1, 2003).
IEC 61850-9-1 defines a Unidirectional Multidrop Point-to-Point fixed link carrying a fixed dataset which is preconfigured and not user configurable in accordance with IEC 60044-8 (IEC 60044-8, 2002), while IEC 61850-9-2 defines a bidirectional user configurable dataset that can be configured using the Substation Configuration Language and multicast to multiple subscribers (IEC 61850-9-2, 2004).

In 2004, the UCA Users Group released an Implementation Guideline for a digital interface standard using IEC 61850-9-2 Process Bus for the transmission of current/voltage samples. This is referred to as IEC 61850-9-2LE (Light Edition). The IEC 61850-9-2LE defines a base sample rate of 80 samples per cycle for basic protection and control applications, and a sample rate of 256 samples per cycle for high frequency applications, such as power quality monitoring and high resolution oscillography. For 50 Hz systems, this translates to 4 kHz and 12.8 kHz sampling frequencies respectively. The IEC 61850-9-2LE is used in this paper.

3. LAB-SCALE IMPLEMENTATION

3.1 Introduction

Generally, performance testing has to do with device evaluation in order to establish the boundaries of their capabilities. While IEC 61850 Part-10 specifies the approach for conformance testing, no procedure is specified for performance and interoperability tests (Udren et al., 2007).

The laboratory-scale experiment in this paper made use of the Real-Time Digital Simulator (RTDS), IEC 61850-9-2 protection IED (IED-A), hardwired protection IED (IED-B), GPS satellite clock, and industrial network switches. A typical power system network is modelled and simulated in real-time using the RTDS in a hardware-in-the-loop configuration with the protection IEDs.

The IEC 61850-9-2 protection IED is regarded as the main Device Under Test (DUT) and is configured for distance protection of a transmission line. Similarly, a hardwired protection IED which is used for comparison is also configured for distance protection for the same line and is connected to the same local end as the DUT. Both protection IEDs and the RTDS are synchronized to the GPS. The input supply to the first protection IED is the Sampled Values of the three phase and neutral currents and voltages, while the input supply to the second protection IED is from hardwired conventional analogue inputs obtained from Current Transformer (CT) and Voltage Transformer (VT) modelled within the RSCAD draft case.
Figure 4 shows the functional implementation of the laboratory set-up. The primary quantities of the line currents and bus voltages are fed to the RTDS GTNET-SV card for onward streaming to the process bus. Similarly, the secondary quantities of the instrument transformers are used as inputs to the RTDS GTAO card. The low voltage outputs

from the GTAO card serve as inputs to the CMS-156 amplifier. Therefore, the current and voltage inputs to IED-A are the Sampled Values from the Process Bus, while the inputs to IED-B are the analogue quantities obtained from the CMS-156 amplifier.

3.2 Power System Modelling

In implementing the set-up in the laboratory, a study power system network was modelled in RSCAD software. This study network is a 5 bus network with two adjacent 230kV transmission lines of length 100km. The system parameters used is given in Table 1.

Table 1. Study network parameters

Line impedance	**Source impedance**	**Instrument Transformers**
Z1 = 1.855 +j37.66	Z1 = 2.6 + j52.724	CT ratio 600/1
Z0 = 36.18 + j122.775	Z0 = 50.66 + 171.88	VT ratio 230000/115
Line length = 100km		

The RTDS GTNET hardware with SV protocol is used with a special edition GTNET-SV component within the RSCAD draft case to generate the IEC 61850-9-2LE Sampled Values (SVs) current and voltage data stream. Thus, no external merging unit was required. This GTNET-SV component provides IEC 61850-9-2LE Sampled Values communications using the GTNET hardware. The SVs are published to the external IED through the GTNET Ethernet port. The Sampled Values are configured through the fields in the GTNET-SV component. The configuration defines the substation name, the voltage level, bay name, equipment name, logical node class (TCTR and TVTR), number of instances for the currents/voltages, VLAN ID, VLAN priority, APPID, MAC Address, etc. A XML file for the GTNET-SV component IED Configuration Description (.icd) is generated as part of the configuration. This .icd file is obtained through the configuration of the GTNET-SV component in RSCAD draft and the compiling of the RSCAD draft case.

The special edition of the GTNET-SV component (GTNET_SV_SE2) in the RSCAD component library has been designed with the capability to allow the suppression of messages, packet swapping, and the introduction of noise/delay. In this paper, control components were introduced alongside this GTNET-SV component to specify variables for generating random noise and delaying the packets. This was done in order to investigate the effects of noise and delay on the performance of the protection IED.

3.3 IED Configuration

The distance protection settings used in the configuration of both IEDs are as given in Tables 1 and 2. Zone time delay for Zones 1-3 are as shown in Table 2. Mho relay characteristics are used in both IEDs. The IED configuration is the same for both IEDs since they are from the same manufacturer with the same model type. The only difference is the configuration of the NCIT setting for the Process Bus IED. The settings at the NCIT column of the IED configuration software include the physical link type, antialias filter, MU delay, Logical Node (LN), etc. The 'physical link' type can be fibre optic or copper and it is used to define the physical connection between the IED and the Process Bus, while the 'antialias filter' setting is used to condition the Sample Values from the Process Bus. Also, the 'MU delay' must be specified for the maximum time delay expected. It is used when the IED is configured to receive Sampled Values from different MUs with the possibility that the SVs may not arrive simultaneously due to differences in MU performance or as a result of delay in the network path. Furthermore, the 'LN' is a unique name that allows the IED to receive SVs from a particular MU and must be exactly the same as the LN set in the MU that publishes the SVs.

Table 2. Protection zones and zone times

Protection Zones	**Zone Phase and Ground Reach Settings**	**Time Delay /(ms)**
Zone-1 (forward)	80% of Line-1	0
Zone-2 (forward)	(Line-1 impedance) + 20% Line- 2 impedance	200
Zone-3 (forward)	(100% of Line-1 + 100% of Line- 2) x 1.2	400
Zone-3 (reverse)	20% of Line-1	400

According to IEC 61850-9-2LE, the sampling rate for protection functions is 80 samples per cycle (4800 Hz for a 60 Hz power system). IEC 61850 recommends that destination MAC addresses in the range of 01:0C:CD:04:00:00 to 01:0C:CD:04:1F:FF be used for Sampled Values. The MAC address used for the GTNET-SV component within RSCAD draft was 01:OC:CD:04:00:22. The Sampled Values identity known as smvID of the GTNET-SV component must be specified in the Ethernet NCIT field of the IED configuration settings in order for the IED to subscribe to the Sampled Values being streamed by the GTNET-SV card of the RTDS onto the Process Bus.

Twisted pair Ethernet cables were used to connect both IEDs to the Process and Station Buses. Trip output signals were sent from the IEDs to the Circuit Breaker (CB) within RSCAD software model using IEC 61850-8-1 GOOSE messages via the Station Bus.

The IEDs were configured for disturbance recording so that the time elapsed from the inception of fault to when the IED responded can be measured.

3.4 Simulations

Extensive studies were carried out on the IEDs using the RTDS. These studies were planned to cover the investigation of the performance of the SV based IED with the conventional hardwired IED as a reference.

The experiments include forward and reverse faults covering Zones 1-3. The faults were at various locations with various fault resistances and Fault Inception Angles (FIA) with Source Impedance Ratio (SIR) of 1. Also, phase-to-ground and phase-phase faults were considered.

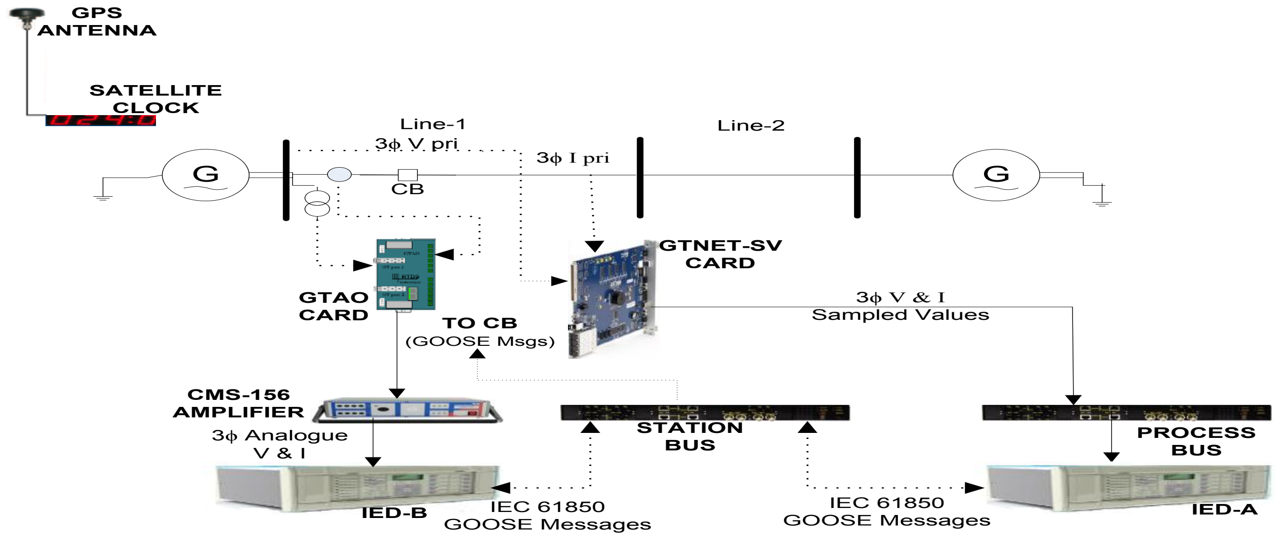


Figure 4. Functional implementation of the laboratory set-up.

Table 3. Simulation parameters

Fault Location /(%)	20, 75, 115 (forward), 20 (reverse)
Fault Resistance /(Ω)	0.5, 5, 10, 20
Fault Inception Angle /(°)	0, 30, 60, 90
Fault Type	Phase-to-Ground, Phase-Phase, and Three Phase faults
SIR	0.1, 0.5, 1, 2, 3, 5, 10, 15, 20, 25, 30

Furthermore, studies on the possible effects of SIR on distance protection were also carried out.

Table 3 is a summary of the simulation parameters used. Each of these simulations was repeated ten times and the average IED operate (response) time was calculated.

The time taken from fault inception to when the IEDs issued/published a trip signal/virtual output message is regarded as the "response time" of the operation of the distance protection element of the IEDs.

Furthermore, faults were applied at 50% of Line-1, and the operate times of the IEDs were recorded for a range of SIR values for different fault inception angles.

In addition, the effects of random noise and delay on the performance of the Process Bus based protection IED was carried out. Random noise/delay was added to the SV output in order to consider the effect of noise/delay on the SVs. When the system is running at 50Hz and the sampling rate is at 80 samples/cycle, the sample period is 250 µs, which means every 250µs there will be one SV packet being sent out when there is no delay input. When for example a 2 time-step delay is added, starting from the next sample, after the component sees the delay trigger, each packet would be delayed by 2 time-steps.

Typical MU delay is 2-3 samples, which corresponds to 500µs-750µs at 80 samples/cycle (Sun et al. 2012). Thus, a maximum delay of 3 sample–periods was adequate and the impact was investigated. The random noise/delay was truncated into an integer with a zero mean and standard deviation (σ) of 3 such that the total noise generated is less than or equals to the maximum MU delay possible. The whole idea was to generate a random integer to represent the delay which should be greater than 0 and less than a maximum delay of 12 time-steps for a 60Hz network.

4. RESULTS AND DISCUSSION

Before the simulation of faults, the magnitude and phase angles of the Process Bus based IED were checked to ensure that they represent the actual values being simulated and displayed on RSCAD runtime meters and within an accuracy of 1% as specified by the manufacturer of the IED. The maximum relative error obtained for the Process Bus based IED was 0.12% at a SIR of 15.

Afterwards, extensive simulations were carried out as detailed in the previous section in order to investigate the effect of fault resistance, fault inception angle, SIR, and noise/delay on the performance of the Process Bus IED with particular attention given to the speed of operation, dependability, and security of the protection function of the IED.

The dependability of the protection refers to the ability of the IED to operate promptly and correctly when required. While the security of the protection refers to the ability of the IED to refrain from operating incorrectly.

The results obtained have shown the response of an IEC 61850 Process Bus based IED compared with the conventional analogue inputs IED. The response and performance of the Process Bus IED for non-ideal situations like random noise and delay have also been presented.

From Figures 5 and 6 for phase-to-ground and phase-to-phase faults respectively, it can be seen that the response of the IEC 61850 Process Bus based IED (IED-A) was similar to that of the conventional analogue inputs IED (IED-B) when SIR was investigated. Results for both A-G and ABC-N faults and AB and ABC faults are presented.

Table 4. Zone-1 average operate time for A-G faults at 20% of the line

Fault Resistance/(Ω)	Fault Inception Angle/(°)	Ave. Operating Time IED-A/ms	Ave. Operating Time IED-B/ms	STD IED-A	STD IED-B
0.5	0	7.748	9.174	0.5355	0.5496
0.5	30	8.545	8.475	0.5033	0.5522
0.5	60	9.340	9.230	0.4795	0.8652
0.5	90	10.722	9.626	0.7568	0.3236
5	0	8.240	9.825	0.6103	0.4542
5	30	8.296	8.359	0.2026	0.2996
5	60	9.012	9.873	0.5019	0.5894
5	90	10.359	9.974	0.2994	0.2518
10	0	7.177	16.420	0.6672	0.4795
10	30	18.255	15.099	0.5549	0.6557
10	60	12.408	11.719	0.4767	0.8744
10	90	8.942	9.623	0.6929	0.3460

Table 5. Zone-1average operate time for ABC faults at 75% of the line

Fault Resistance /(Ω)	Fault Inception Angle/(°)	Ave. Operating Time IED-A/ms	Ave. Operating Time IED-B/ms
0.5	0	20.401	16.355
0.5	30	20.006	18.242
0.5	60	20.368	15.550
0.5	90	20.067	17.067
5	0	32.664	27.964
5	30	39.147	26.601
5	60	47.871	45.423
5	90	24.701	24.909

Table 6. Zone-2 average trip time for A-G faults at 115% of the line

Fault Resistance /(Ω)	Fault Inception Angle/(°)	Ave. Operating Time IED-A/ms	Ave. Operating Time IED-B/ms
0.5	0	217.20	215.63
0.5	30	224.55	216.05
0.5	60	230.75	231.47
0.5	90	227.96	232.07
5	0	245.45	225.33
5	30	243.47	225.02

Table 7. Reverse zone-3 average trip time for ABC fault at 20% of the line

Fault Resistance /(Ω)	Fault Inception Angle/(°)	Ave. Operating Time IED-A/ms	Ave. Operating Time IED-B/ms
0.5	0	409.76	409.34
0.5	30	409.09	409.05
0.5	60	410.63	410.56
0.5	90	409.65	409.00
5	90	422.16	427.68
10	90	428.14	428.75

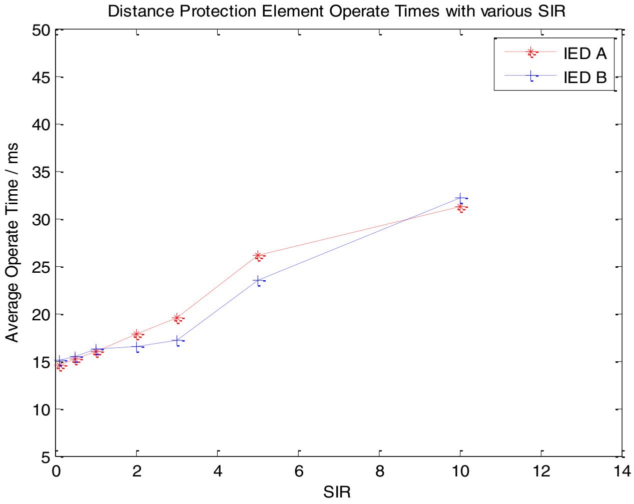
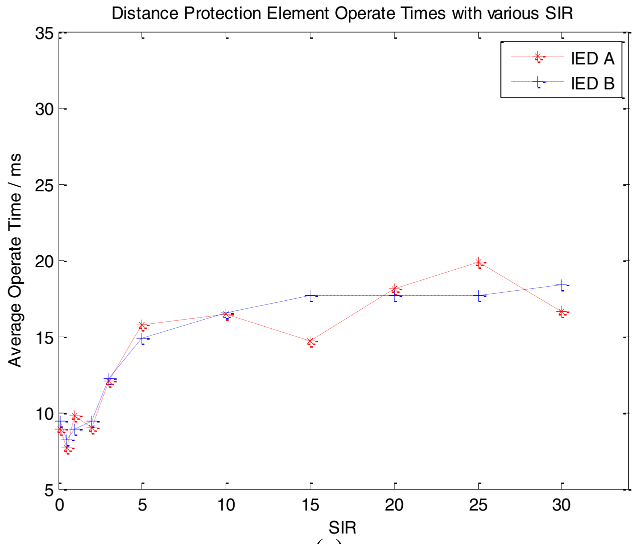
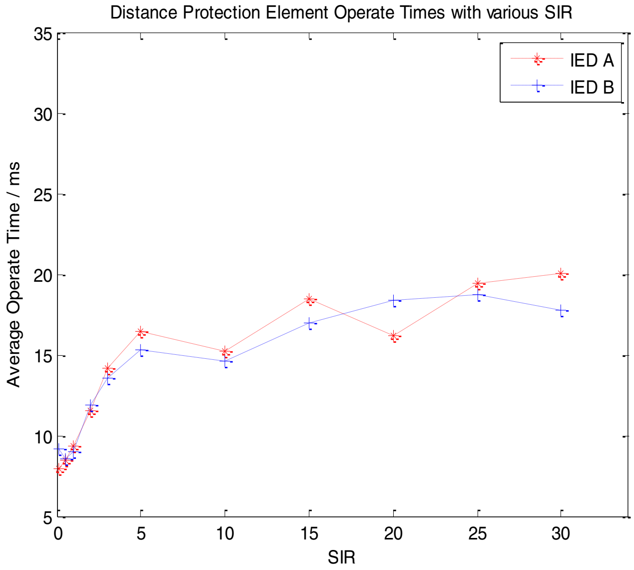


Figure 5. Effect of SIR on average operate time at 50% of the line for (a) A-G fault.



(a)



(b)

Figure 6. Effect of SIR on average operate time at 50% of the line for (a) AB fault (b) ABC fault.

Though, the operate times of the IEDs increased as the SIR increased. This could be as a result of the reduction in the voltage magnitudes of the network as the SIR increased. Thus, more time was required for the IED to perform the necessary impedance calculations.

Table 4 shows the average operate time and Standard Deviation (STD) for A-G fault at 20% of Line-1. It can be seen that the IEC 61850 Process Bus based IED (IED-A) had sub-cycle trip times and operated as fast as the IED based on conventional analogue inputs (IED-B). The IEDs all operated within 2 cycles of fault inception.
Table 5 shows the operating times of the distance protection IEDs for Zone-1 A-G faults at 75% of Line-1. The operate time of both IEDs are similar even though the operate time increased for upstream faults farther from the measurement point and for high fault resistance values. However, the highest operate time was within 2½ cycle from the inception of fault.

Table 6 presents the operating times of the distance protection IEDs for Zone-2 A-G fault at 115% of Line-1. It can be seen that the Zone-2 distance elements operated after the configured delay of 200ms. Table 7 present the results obtained for reverse Zone-3 ABC fault. The highest operate time from fault inception was well under 420ms most of the time. Figure 6 shows the average operate times for IED-A and IED-B for AB and ABC faults for various SIR values at 50% of the line for Zone-1.

Figure 7 shows the average operate times for IED-A for A-G and ABC faults in the presence of noise and delay for FIA of 0° and fault resistance of 0.5Ω. The fault location was at 20% of the line. It can be seen that the response of the IEC 61850 Process Bus based IED (IED-A) in the presence of noise/delay was similar to that without noise or delay. No delay was used for IED-B since it is based on conventional hardwired analogue inputs.

It should be noted that the results presented in Tables 4-7 are from simulations carried out at a SIR of 1. Faster response times were obtained at lower SIRs most of the time.

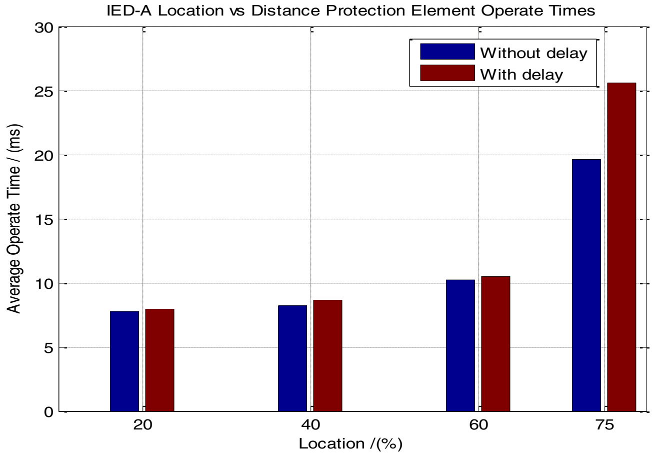


Figure 7. Effect of delay on average operate time at SIR = 1 for ABC faults.

5. CONCLUSION

The implementation of the IEC 61850 standard has indeed opened up a wide range of applications. In order to boost the confidence of engineers in these new applications, it is necessary to carry out performance testing alongside conformance testing and interoperability testing.

This study has evaluated the performance of the distance protection function of an IEC 61850-9-2 Process Bus based IED. A comparison was made with the performance results obtained from a conventional IED also configured for distance protection and connected to the same local end where the Process Bus IED was connected to.

The result of the various tests carried out demonstrated that both IEDs have similar performance with similar operating time response and tripping times for all zones of protection. The dependability and security of the IED was also verified.

Furthermore, the impact of random noise/delay was also investigated and was shown not to affect the Process Bus IED up to the point where the security and dependability is affected. The result obtained verifies that noise and delay of up to 3 sample-periods did not have any adverse effect on the operating times of the IED. Also, the Zone-1 distance protection element remained secure in all cases during faults in Zones-2 and -3 respectively.

The integration of Process Bus based IED would improve the safety in substations, utilize less copper, facilitate maintenance and easy reconfiguration, etc. while giving the same performance in terms of speed of operation, security, and dependability obtainable from conventional analogue inputs IEDs. Future work intends to consider the implementation of communication aided distance protection schemes using IEC 61850 Process Bus and GOOSE messages.

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