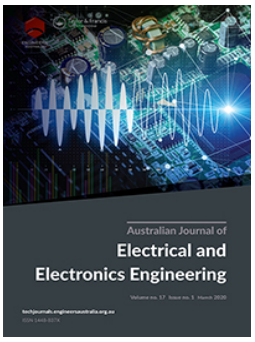

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ARTICLE

The influence of IEC 61850 standard: implementation and development of a functional substation automation simulator

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ABSTRACT
The IEC 61850 standard 'Communication Networks and Systems for Power Utility Automation' has resulted the integration and inter-operability of digital protective relays in a Substation Automation Systems (SAS). Under digital protective relays, Intelligent Electronic Devices (IEDs) are microprocessor-based devices used to perform numerous functions including protection, control and similar functions in a substation environment. The communication protocol that IEC 61850 can offer through IEDs is the Generic Object-Oriented Substation Event (GOOSE) protocol, which makes the peer to peer communication of different IEDs readily accessible. The development of portable simulators based on IEC 61850 is a benchmark for electrical engineering graduates, power engineers and protection engineers to be acquainted with a substation automation environment. This prompted Victoria University to build and develop portable IEC 61850 simulators which gained distinction among electrical utilities and developed into a real-world electrical substation called the Victoria University Zone Substation (VUZS) Simulator. This paper provides an overview of the growth and improvement of the different portable simulators that were initiated to satisfy IEC 61850 in the VUZS Simulator.

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IEC61850; Intelligent Electronic Devices (IEDs); smart grid; GOOSE protocol; Substation Automation Systems (SAS); Distributed Energy Resources (DERs); simulations

1. Introduction

Decades ago, the electrical grid was basically designed to satisfy the energy needs of consumers. The predicted load forecast was met and the power generating plants had no major difficulty in transporting electrical energy to different power utilities and industrial businesses. The revolution came subsequently due to human population growth which led to an increased in energy demand. The consumption of electrical energy surged to the extent that electric utilities have struggled to cope with the demand, and this has placed the electric grid in jeopardy. Since the planning stages of electrical market, the objective of the grid was elevated from unidirectional flow to bidirectional and multiple penetrations of Distributed Energy Resources (DERs) in the electrical system (IEEE 2013). One of the alternative solutions to the problem regarding electrical energy supply is the use of Distributed Energy Resources (DERs) (e.g. photovoltaic (PV), wind energy, fuel cells, biomass, and batteries) to be connected into the grid.

However, the rapid growth of DER technology linked to the electrical grid has brought difficulty on the part of the utility sector in terms of energy management. The most highlighted controversy was the South Australia (SA) blackout happened in September 2016. It was the first known state-wide blackout due to severe storm and proliferation of DERs with some sectors believed the result of this catastrophic blackout (Yan et al. 2018). It has prompted glitches, frequent instability and larger disturbance problems in energy delivery and distribution. The grid must have to withstand the DERs intermittent penetration, deterioration and cut-off from the grid which causes the concern of power quality and reliability in the power distribution system (Bouzguenda et al. 2011). To facilitate the connection of DERs, sophisticated control systems have been developed to improve security, efficiency and reliability of the electric grid. Furthermore, the integration of electronic control and enhanced information technology has turned the grid into an intelligent network called 'smart grid'.

Figure 1 shows the different facets of the smart grid. The smart grid is the main player that has the initiative of going further to digitalise the distribution feeders, substations, transmission and central power generation (Uluski 2010). It was a huge success for the optimal solution on energy management, power quality and reliability. The idea of smart grids started with the emergence of Smart Metering Infrastructure (SMI), where consumers are informed about their energy consumption patterns and performances. The smart grid concept, however, extends well beyond metering and evolves around the entire electric utility organisation.

Today, the significant role of the smart grid is to maintain the operation and inter-operability of electrical power systems throughout the energy supply chain. To achieve this goal, the utility sector is

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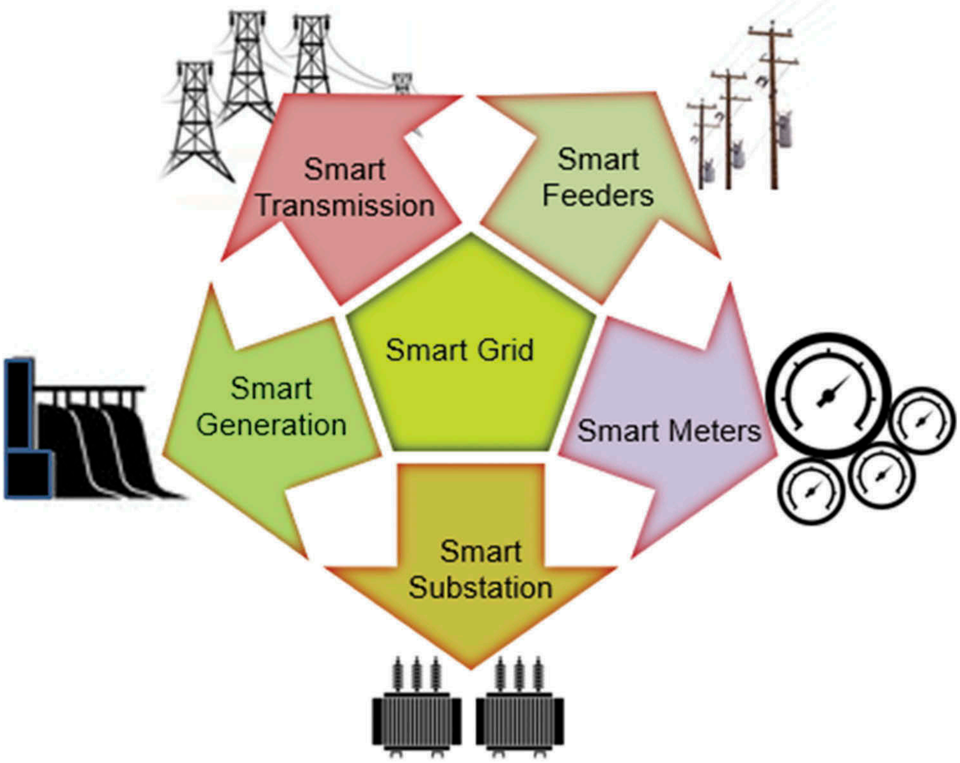

Figure 1. Smart grid initiative.

bound to implement efficient and effective methods of power delivery and utilisation through the integration of Information and Communication Technology (ICT).

2. Substation Automation Systems (SAS)

One of the most important parts of the electrical supply chain is the electrical substation which acts as a bridge for the power system, protection and control schemes of the smart grid (Tarlochan and Il-Hyung 2011). The electrical substation is an area where different organisations are confined to focus on implementing new concepts for merging operational and non-operational data. The arrival of the IEC 61850 standard enables the application of SAS in a power utility. This is necessary, especially now that DERs are widely utilised with their benefit of generating and selling energy back to power utilities.

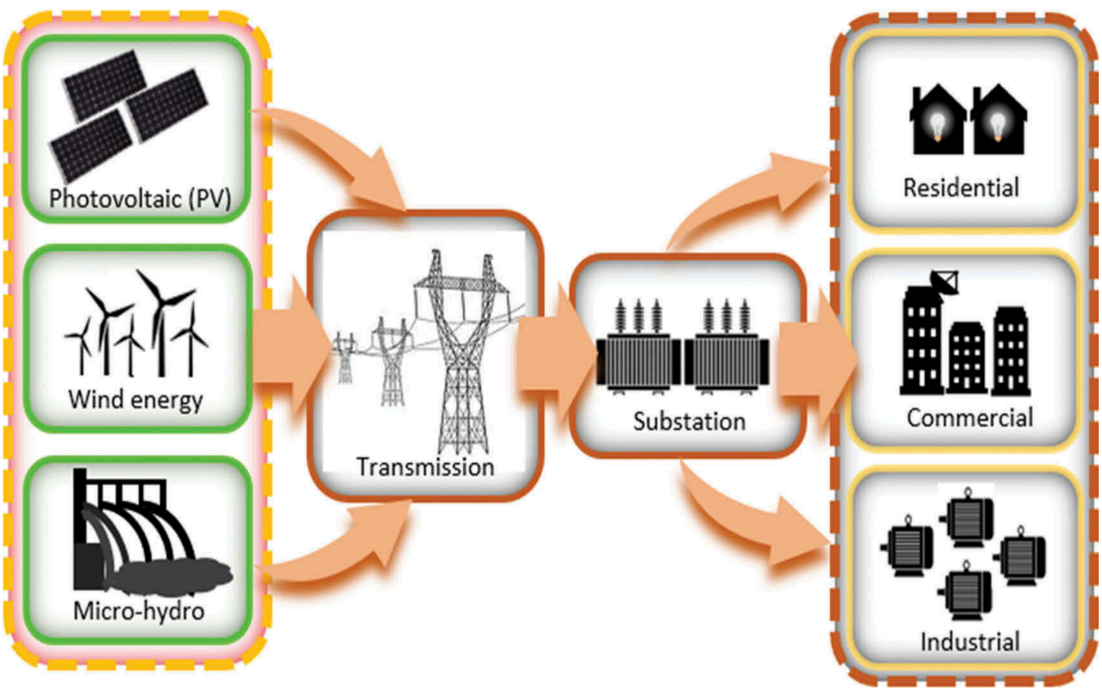

Figure 2. Grid-connected Distributed Energy Resources (DERs).

Figure 3. Multi-vendor portable IEC 61850 Testing Unit (Stojcevski, and Kalam 2011).

However, the addition of DERs within the distribution system has been alarming due to the influx of generated energy capacity being fed to line feeders which causes variations in voltage regulation and additional line losses in the system (Rizy et al. 2010). To sustain this progress, the electrical substation has been improved to become a smart substation by using digital protective relays which are unified through communication and network technologies. This equips the smart substation with various functions on control, protection and monitoring. Figure 2 illustrates the DERs connected in a grid.

2.1. Overview of Intelligent Electronic Devices (IEDs)

The rise of microcomputer technology started a revolution against analogue electromechanical devices in the power utility and electrical entities. The use of IEDs led Hydro-Quebec to improve power quality, reliability and maintenance of grid conditions and distribution systems on real-time monitoring (Zavoda 2008). IEDs have been a game-changer in terms of their distinct problem-solving capabilities in communication, protection, control, metering and monitoring of data (Sezi and Duncan 1999). However, the complexity of the application and performance asset of IEDs are concerning. These have a wide variation of functions and settings to accommodate new imprints to go well with the business requirement. To attain these appealing goals, industries must invest in personnel in order to develop highly skilled workers in IED operations (Sezi and Duncan 1999) (Kezunovic and Popovic 2005).

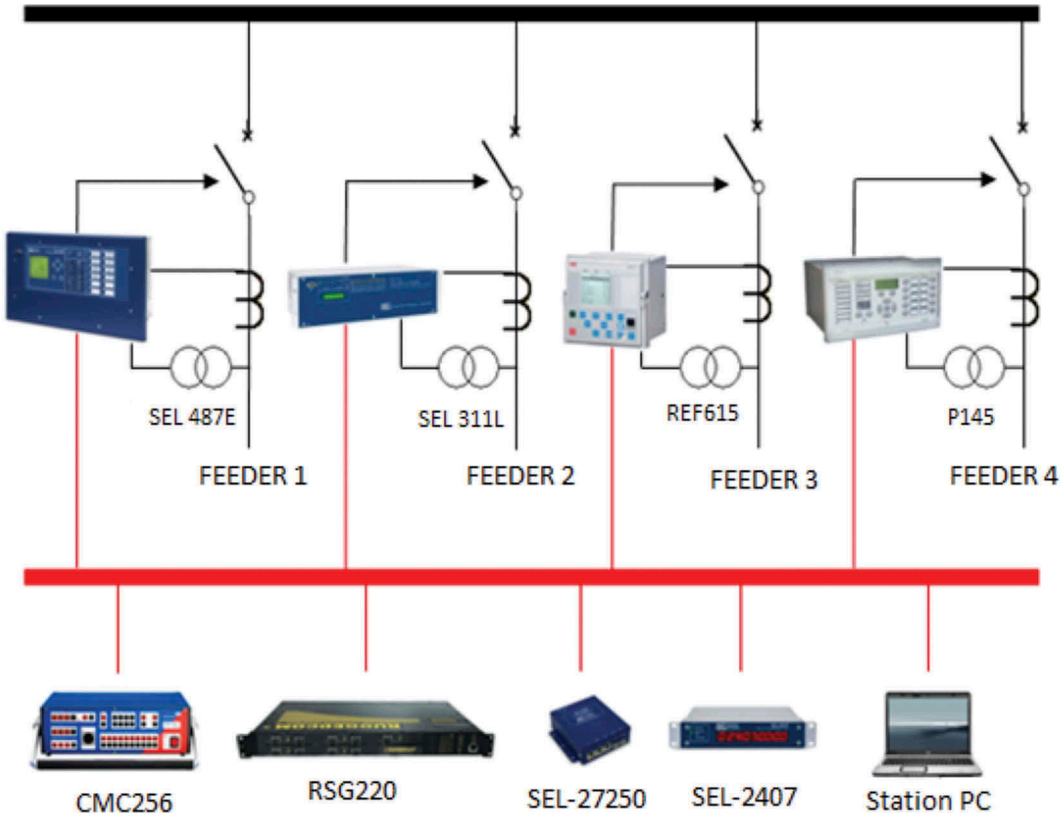

Figure 4. Portable IEC 61850 testing unit communication architecture (Stojcevski, and Kalam 2011).

2.2. *Background of IEC 61850 at Victoria University*

For many years, Victoria University (VU) in Melbourne has been the leading provider of training and workshops on the IEC 61850 standard through the Australian Power Institute (API). It started from basic knowledge of IEC 61850 related to inter-operability, configuration of IEDs using different proprietary software, and building a Multi-vendor Portable IEC 61850 Testing Unit (Stojcevski and Kalam 2011).

Furthermore, this testing unit was used to test the performance of the GOOSE messaging protocol which was verified through the standard fault test emulators, namely DOBLE and OMICRON (Amjadi and Kalam 2015).

3. Simulation testing units for IEC 61850

Portable simulators like these testing units were built to provide users with a practical response when designing real-world systems. It allows the provider to determine the efficiency and effectiveness of a design before being fully constructed. The portable IEC61850 testing unit demonstrates a powerful tool that provides a basic function of interoperability and communication interface with different IEDs.

Figure 3 shows the physical arrangement of the first portable simulator of VU. Its portability made this simulator travelled around Australia for power utilities and universities to use and learn basics of IEC 61850 standard.

Figure 4 illustrates the communication architecture of the portable IEC61850 testing unit. There are three different types of IEDs (SEL, ABB and MiCOM) used in this portable simulator. The black lines represent the hardwired copper connections of the IEDs and their circuit breakers. Each IED protects and controls an imaginary feeder using GOOSE messaging. The red lines represent the communication protocol which uses the Ethernet cables to connect the IEDs, network hubs and switches, omicron test set, and station computer. The Bus network topology was used on this simulator for peer to peer communication.

After a few years of familiarisation and adaptation of the simulator, the portable simulator testing unit was developed to become complex and more robust. The popularity of power systems and communication systems in an electrical substation prompted VU to improve the simulator by adding a Remote Terminal Unit (RTU). The RTU is an electronic-controlled device that interfaces with physical objects through centraliseda system of software and hardware called Supervisory Control and Data Acquisition (SCADA) (Amjadi, and Kalam 2015). Both SCADA and RTU play a major role in substation automation. The SCADA monitors and controls data and sends telemetry data to the RTU which is physically interfaced with different IEDs.

Figure 5 shows a larger physical built of a simulator where a Human Machine Interface (HMI) was

Figure 5. Zone substation simulator (Amjadi, and Kalam 2015).

associated. This simulator was called the Zone Substation simulator. The animated substation design was composed of a transformer, bus bar and a couple of feeders. IEDs were placed in a designated area so that the imaginary zone substation will not be left unprotected.

Figure 6 illustrates the developed portable simulator zone substation configuration architecture of IEC 61850 standard. It has three hierarchy configurations, the Station, Bay and Process level. The Station level is used for archiving documents and information from the bay level. The devices present in the station level are the station computer, HMI, Programmable Logic Controller (PLC), RTU and others, while the Bay level is composed of different IEDs that can collect sampled values from the process level. The IEDs can communicate across the bay level and the station level through GOOSE protocol. Another type of communication that applies between the station and bay level is the Manufacturing Message Specification (MMS). The MMS communication is only used between station and bay level in transporting data from SCADA to IEDs and other network devices. The process level contains the equipment like circuit breakers, intelligent switchgears, current and voltage transformers, sensors and others. The measured values coming from these devices are being sent to the bay level through a Sampled Value (SV) data transfer.

With the ongoing support of VU and its collaboration with power utilities and IED manufacturers (ABB and GE), the VUZS simulator came into fruition. The VUZS model simulator was purposely developed to provide efficient and high-quality training and to cater to the needs of future electrical engineering graduates, researchers, substation and protection engineers (Gunasekera, Peidaee, and Kalam 2017). The migration to IEC 61850 standard is a challenge for most skilled personnel who are used in working with legacy and electromechanical relay equipment. The incorporation of communication and power technology encouraged other skilled personnel to learn IEC61850 and GOOSE mapping in substation operations, testing and commissioning (Mani, Shanmugasundaram, and Buneo 2014).

The VUZS simulator provides a real-world simulation of substation automation because the design platform

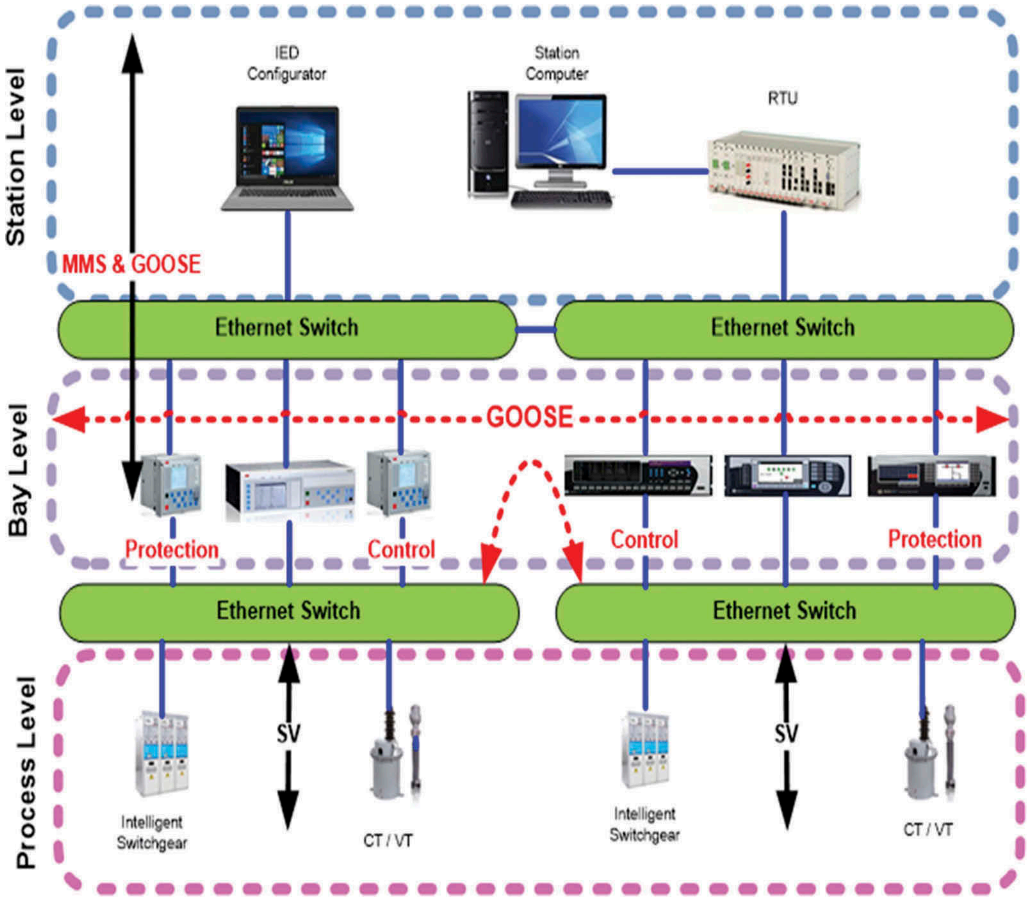

Figure 6. Zone substation simulator systems architecture.

Figure 7. Victoria University Zone Substation (VUZS) simulator.

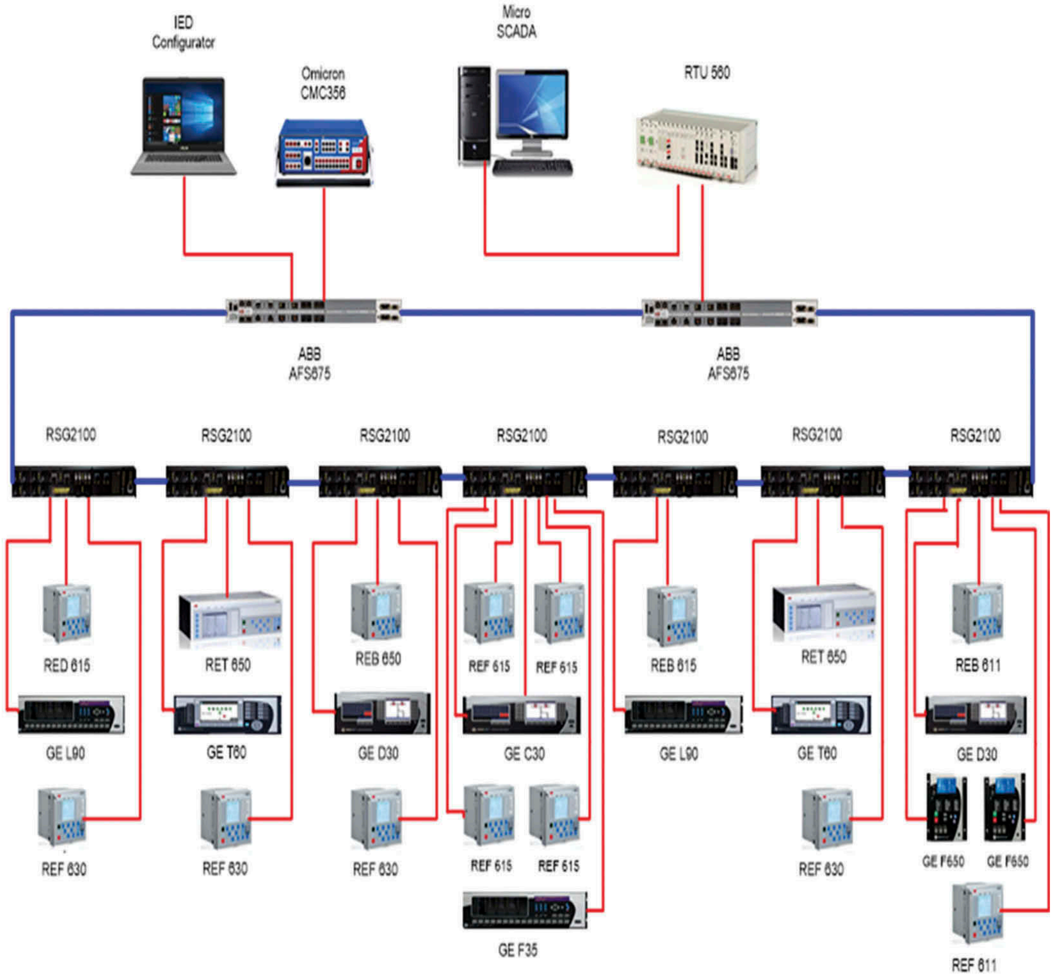

Figure 8. VUZS simulator communication architecture.

was based on an actual arrangement of an existing distribution substation in Victoria, Australia. The VUZS is so far the first zone substation simulator built in a university environment and uses different IED devices to show interoperability functions for protection and control in a substation. Figure 7 illustrates the physical property of the VUZS Simulator housed in VU power laboratory.

Figure 8 shows the basic architecture hierarchy of VUZS which is limited to the station and bay level only. The process level devices were replaced by electronic emulators such as omicron and doble test sets. There are other real-time simulators available for integration in the VUZS, such as RTDS, OPAL-RT and NovaTech.

There are different types of network topologies available for communication arrangement. These are the Star, Bus, Mesh and Ring topologies. Each topology has its strengths and weaknesses. The fundamental network communication architecture for the VUZS simulator is a combination of a ring and star network. The ring and star network connection was used in the VUZS due to multiple network devices that are involved. It was also patterned to an existing design from an actual substation in Victoria, Australia which is highly feasible for the simulator to operate in its maximum capability (Claveria, and Kalam 2018).

4. Conclusion

The influence of IEC 61850 made a huge impact on the implementation and development of substation automation simulators. The development of a simulator shows the level of learning quality VU has to offer as the leading provider of training and workshops on IEC 61850. The VUZS simulator was built in a well-structured domain and real-world-based simulator to provide high-quality trainings for students and researchers making the gap closer for the academic and industrial foundation. Different IEDs are also contained within the system for the purpose of interoperability and play a vital role in using GOOSE messaging in control, protection and monitoring of data in a system.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Joevis Claveria received his Master of Engineering from Victoria University, Melbourne, Australia in 2014. He is currently pursuing his Doctor of Philosophy (Ph.D.) in Power Systems and Substation Automation at Victoria University. His major interests include renewable energy, automation systems, distributed generation and power systems protection.

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