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Design and Simulation of Multi-Function Virtual Grid Edge Intelligent Electronic Device with Standardized Semantics Based on IEC 61850 Standard

Mohd Iqbal Ridwan, Nadia Tan Mei Lin, Vassilios Agelidis

Abstract: The advancement of communication technologies has facilitated the evolution of traditional electric power system into a vast entity called smart grid. Various domains such as substation automation, distributed energy resources, advanced metering infrastructures, energy storage systems and many more serve as parts and parcels of smart grid. Fundamentally, these domains communicate and exchange information within the domain as well as other domains to execute their intended functions. One example is the grid edge domain in smart grid, where devices at customer premise interact with utility grid as well as electricity market for applications such as demand response and energy trading. Generally, devices in grid edge domain exist independently to perform its specific functions. The information model and communication standards in these devices vary depending on the implementation by its manufacturers. This pose challenges for integration works which may require these devices to exchange information with each other. Therefore, this paper aims to design and propose a multi-function virtual intelligent electronic device (IED) which capable of performing various applications at grid edge domain. The virtual IED utilizes standardized data model and semantics based on IEC 61850 standard. Information exchange based on IEC 61850 is then simulated between the virtual IED and a Client Simulator. The results indicate successful communication and information exchange based on IEC 61850 standard hence demonstrates the potential applications of the standard for grid edge domain.

Keywords: Grid Edge, IEC 61850, Intelligent Electronic Device (IED), Interoperability, Smart Grid

I. INTRODUCTION

Smart grid consists of various domains which utilize communication technologies for information exchange to execute the domains' specific functions. The National Institute of Standards (NIST), United States has outlined the concept of typical Smart Grid domains and the sub-systems within the domains. These sub-systems require seamless communication within the specific domain as well as between domains for various applications throughout the electrical power system network. Such applications typically ubiquitous communication of devices such as intelligent electronic devices (IEDs), sensors, gateways, smart meters and many more.

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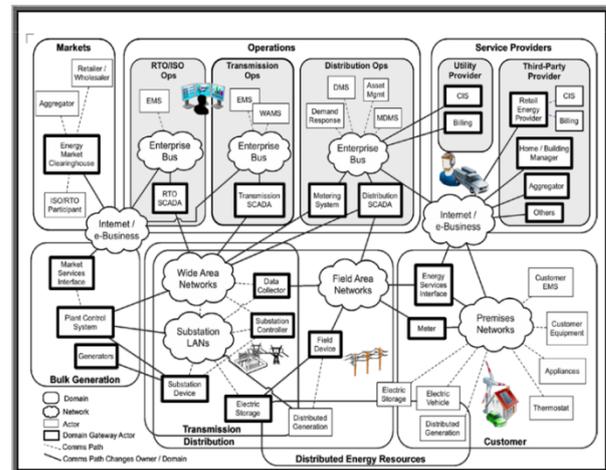


Fig. 1 Typical smart grid domains and sub-systems in electric power system network

Fig. 1 illustrates typical smart grid domains and the sub-systems within the domains[1]. Initially, the main objective of smart grid were mainly focused on enabling the acquisition of information from substations for the management of power system network [2]. This has led to the introduction of substation automation system, wide area information system and distribution automation where real-time or pseudo real-time information are utilized to protection, automation and control of power system network. However, with the advent of smart meter and advanced metering infrastructure (AMI) related technologies, the boundary of smart grid has extended beyond the domain of utility's power system network into the customer's domain [3].

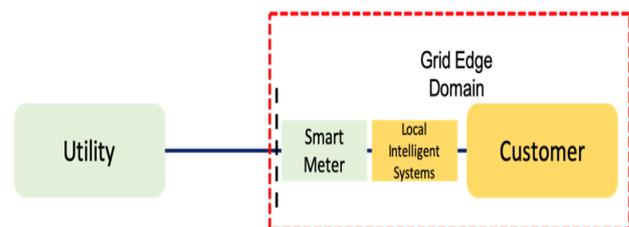


Fig. 2 Boundary between utility and customer at grid edge domain

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The customer's domain is generally defined as the Grid Edge domain, where devices and peripherals at customer domain are either directly connected to the power grid or indirectly connected by providing information related to energy consumption to power utilities [4].

At the Grid Edge domain, devices such as Smart Meter and local intelligent systems such as home energy management system (HEMS) function as data acquisition units to obtain information from customer's premise. Fig. 2 visualizes the typical boundary between utility and customer at the Grid Edge Domain. Parameters such as local load consumption, power quality measurement, generation from renewable energy resources and many others are shared with electric utility companies as raw data or analyzed information [4]. Such applications typically involve combination between Smart Meters and myriad of devices that constitute the local intelligent systems. Hence, to ensure these devices could seamlessly exchange information with each other, communication interoperability is the main issue to be addressed.

There are studies available that summarizes the international standards and open technologies for Grid Edge applications [5]–[9]. IEEE has also published the IEEE 21451.x standard series for the standardization of communication between low powered sensors at Grid Edge domain [10], [11].

However, despite of availability of international standards, it is still observed that interoperability related issues persist at the Grid Edge domain [12]. This is because most international standards and so-called open technologies do not address the full communication aspect required for interoperability [13]. One of the prominent issues in interoperability is the different data representation by the respective communication protocols which results in different interpretation by technology vendors [14]. For example, Modbus protocol (based on RFC793 and RFC791 standards) "standardizes" data by defining data areas to be divided into Data Starting Address (DSA), Data Size (DS) and Data Content (DC). However, the protocol does not define the standard values to be implemented in the data areas hence it is up to technology vendors to determine these values.

Therefore, there is a need to approach interoperability in a more holistic manner, in particular for devices at Grid Edge domain. For this purpose, IEC 61850 standard has been considered widely as the de facto standard that enables interoperability through standardized data model semantics and communication services [15]–[19].

This paper will discuss the implementation of the IEC 61850 standard through simulation of generic and multi-function Grid Edge virtual IED. Section II discusses on the overview of IEC 61850 standard and the general features defined in the standard.

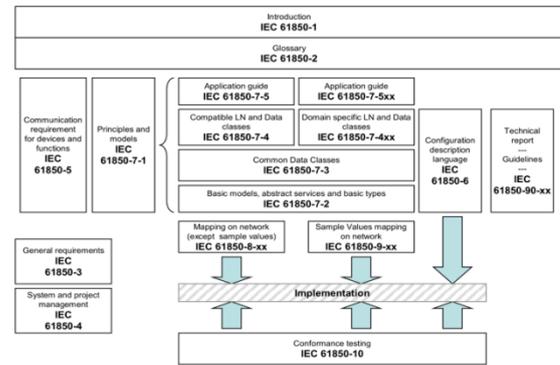


Fig. 3 Overview of parts in IEC 61850 standard

Section III elaborates on the design, simulation and experiment of the virtual IED. Section IV deliberates on outcome from the simulation and experiment of the virtual IED using IEC 61850 standard. Section V draws the conclusion for the paper and Section VI proposes the subsequent works to enhance and expand the research.

II. OVERVIEW OF IEC 61850 STANDARD

The IEC 61850 standard series was first released in 2005 under the title of "Communication Networks and Systems in Substations" and this publication is more commonly known as Edition 1.0. The standard is later revised to Edition 2.0 from 2008 and publication title is redefined into "Communication Networks and Systems for Power Utility Automation". Edition 2.0 of IEC 61850 covers the whole spectrum of Smart Grid through its 14 main parts and supporting technical report documents, including Grid Edge domain applications such as Solar Photovoltaic (Part 90-7), Electric Vehicle (Part 90-8) and Energy Storage (Part 90-9). Fig. 3 highlights the overview of the parts in IEC 61850 standard, in which the required aspects for standardized communication are defined such as definition of data models, communication requirement, configuration language and conformance testing [20].

IEC 61850 is built on the concept that real world devices could be virtually represented through data models. The data model concept in IEC 61850 is defined as LogicalNode (LN). A LN holds the specific information of a device and given a standard syntax (name) and semantics (definition). Fig. 4 illustrates the conceptual data modelling and information mapping approach utilized in IEC 61850 standard [21]. In this example, circuit breaker which is defined as a four-letter syntax XCBR. XCBR represents the actual status of the device, such as On/Off positions and many other information including operation counter and switching authority. The LNs are defined in IEC 61850 Part 7-4, and there are more than 200 LNs defined in Edition 2 of the standard representing various devices and functions that are relevant throughout Smart Grid domains. Thus, the application of LNs ensures devices support data models that carry standard naming and definition, or semantics.

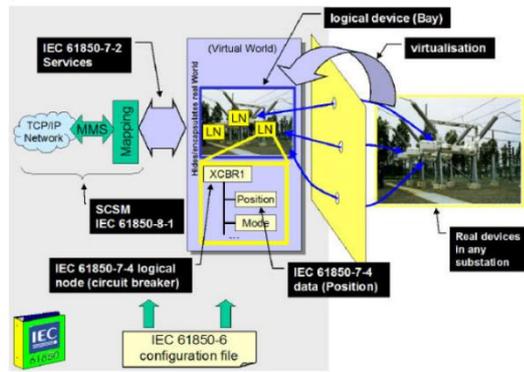


Fig. 4 Conceptual modelling approach in IEC 61850

Another important aspect of IEC 61850 standards is the implementation of hierarchical based model where devices are expected to comply to standardized hierarchy as shown in Fig. 5. The sequence of data model hierarchy in IEC 61850 starts with physical device, followed what is defined as Logical Device (LD) and then LNs. LD is the first level of large container that defines functions that a physical device may support. In other words, one physical device may contain one or more LDs in which different functions are categorized in different LDs. For example, a multi-function IED which supports protection, control and automation functions will have 3 different LDs in the device that contain

different LNs for the respective functions. This feature in IEC 61850 allows one device to perform multi-function capabilities in a standardized manner[21].

For the transmission of information from one device to the other, IEC 61850 defines 3 types of communication services and all IEC 61850 based data model are mapped to these communication services and transmitted across the communication network. The application of the communication services is dependent on the performance requirement time defined in IEC 61850 standard. Table I describes the communication services in IEC 61850 including application examples and performance requirement time.

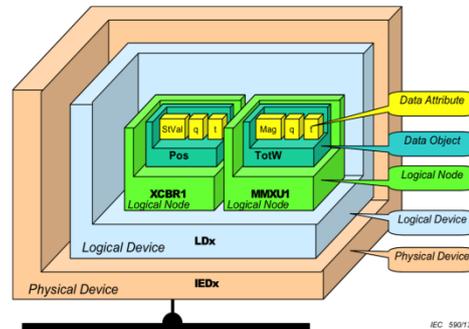


Fig. 5 Hierarchical based Data Model in IEC 61850

Table. 1 IEC61850 Communication Services

Type of communication service	Description	Application Examples	Performance Requirement Time (ms)
MMS (Manufacturer Messaging Specification)	Client-Server communication (IED to client devices such as gateways, human machine interface,)	Events, Alarms, File Transfer, Log	1000
GOOSE (Generic Object Oriented Substation Event)	Publisher-Subscriber communication (IED to IED)	Protection trip, control interlocking	3
SV (Sampled Value)	Publisher-Subscriber communication (IED to IED)	Digitized instantaneous analog quantities such as current and voltage	0.2 for 60 Hz systems and 0.25 for 50 Hz systems

In this paper, the communication service MMS is applied for the simulation of the virtual IED to send information based on IEC 61850 data model. The entity that receives the information is IEC 61850 Client Simulator software which acts as typical gateway for local intelligent systems.

III. SIMULATION OF MULTI-FUNCTION VIRTUAL IED

Definition of Functions

Utilizing the capability of IEC 61850, virtual IED is designed as a hybrid device which supports features of Smart

Meter and sensors for local intelligent systems in Grid Edge domain. The functions of the virtual IEDs includes:

1. Metering – revenue, load monitoring and power quality
2. Solar PV – tracking and ambient temperature monitoring
3. Energy Storage – battery charging information and related alarms
4. General Monitoring – general building alarms such as smoke and fire detection
5. Record – archiving capabilities for alarm events



The functions above are modeled in different LDs and each LD contains the relevant LNs that supports the standardized semantics for each function. Table II highlights some of the LNs modeled in the virtual device.

Table. 2 Samples of Logical Node Models and their Semantics in the Proposed Virtual IED

Logical Device	Logical Node	Semantics
Metering	MMXU	Measurement (current, voltage, power) for 3-phase system
	MMTR	Calculation of energy for billing purpose (3-phase system)
	MHAI	Calculation of harmonics or inter-harmonics for 3-phase systems
	MMTN	Calculation of energy for billing purpose (1-phase system)
Solar PV	DPVC	Information of PV controllers
	DTRC	Information on PV tracking system
Energy Storage	ZBAT	Information on battery status and alarms
	ZBTC	Information on battery charger
General Monitoring	ISAF	General alarm and reset
	IFIR	Information on fire alarm
Records	RDRE	Disturbance recorder function
	RDRS	Event record handling

Virtual IED Design

After defining the functions, the virtual IED is then designed using IED Builder™, an IEC 61850 data model builder software application from Grid Software Ltd., Canada. The virtual IED is modeled based on Edition 2.0 of IEC 61850 standard series because more data model semantics are defined in this edition. Fig. 6 depicts the virtual IED designed in IED Builder and highlights the LNs within Metering LD.

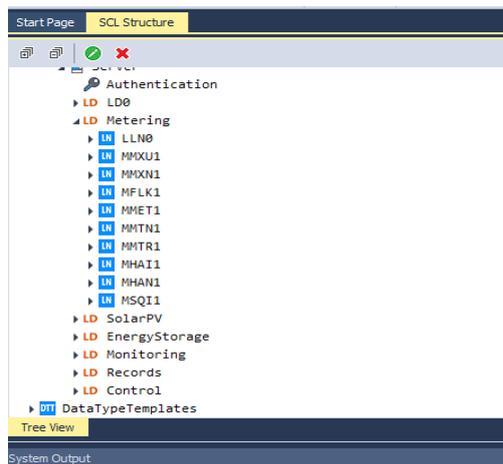


Fig.6 Virtual IED designed in IED Builder™ Simulation Setup

Finally, the virtual IED is imported to an IED Simulator software where the virtual IED is activated and signals are simulated. IEC 61850 Client Simulator software is applied to obtain signals from the virtual IED using IEC 61850 Communication Service, which is the MMS. For this simulation, both IED Simulator and IEC 61850 Client Simulator software are based on IED Scout™ software suite from Omicron GmbH, but two different IED Scout™ software suite are physically installed in two different workstations. The workstations are connected via Managed Ethernet Switch. Fig. 7 highlights the setup for the simulation.

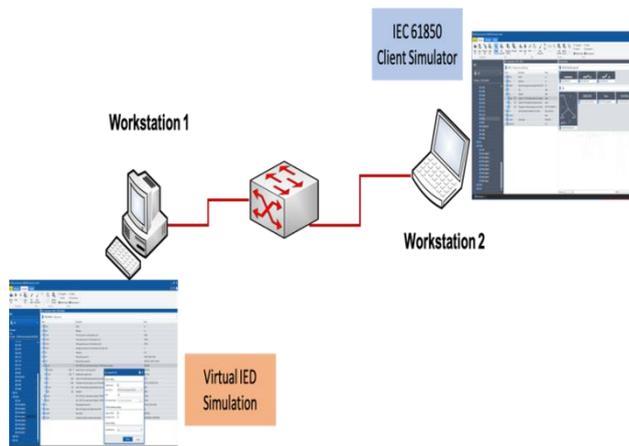


Fig. 7 Simulation setup in two workstations each with IED Scout™ software

IV. RESULTS AND DISCUSSION

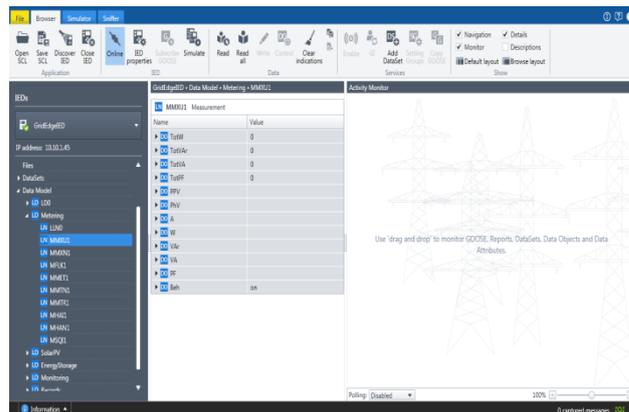


Fig. 8 Virtual IED from IEC 61850 Client Simulator perspective

Upon activation of the virtual IED, IEC 61850 Client Simulator is configured to associate and connect with the virtual IED. Fig. 8 depicts the result from the association to the virtual IED from Client Simulator perspective. It can be observed that IEC 61850 data model is successfully transmitted via communication network with the exact data models as per designed. This indicates that with IEC 61850, there is no necessity to manually configure and map



Information into complex data indexing which is required by some communication protocols and technologies.

The simulation is continued by manually changing signals at the virtual IED and observing the data change at Client Simulator. Fig. 9 and Fig. 10 depicts the results from signal change for information in Metering LD observed from IED Simulator and Client Simulator perspectives. The values simulated in Fig. 9 (virtual IED) are transmitted and accurately described by the Client Simulator in Fig. 10. One example is the value “100” which represents Energy Supply (in Watt-hour) modeled using the LN MMTN.

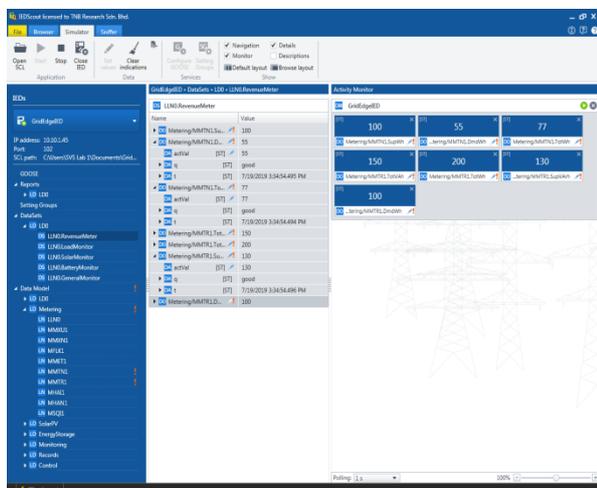


Fig. 9 Simulated values in virtual IED in IED Simulator

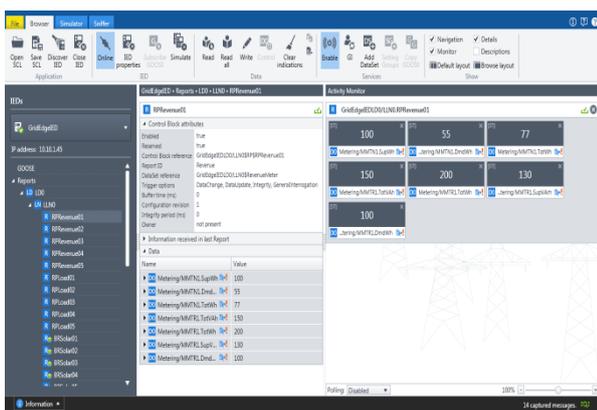


Fig. 10 Values retrieved in Client Simulator

As discussed earlier, the values from the simulated signals are sent via MMS which is one of the communication services defined in IEC 61850. Fig. 11 illustrates the actual communication via MMS captured by the Client Simulator’s network capture feature. The time (based on relative time) captured by the client for the transmission of Real Energy Supply using LN MMTN via MMS is 353.87 ms which is within the defined performance time defined by IEC 61850 standard.

The standard data model and information exchange observed from the simulation clearly indicates the capability of IEC 61850 standard for applications at the Grid Edge domain. In particular, data semantics are pre-defined and self-descriptive hence eliminates the need for any additional protocol translations. This is standardized across technology

vendors thus the interoperability related issues discussed earlier are minimized. This will significantly enhance and optimize the applications that require communication and information exchange at Grid Edge domain.

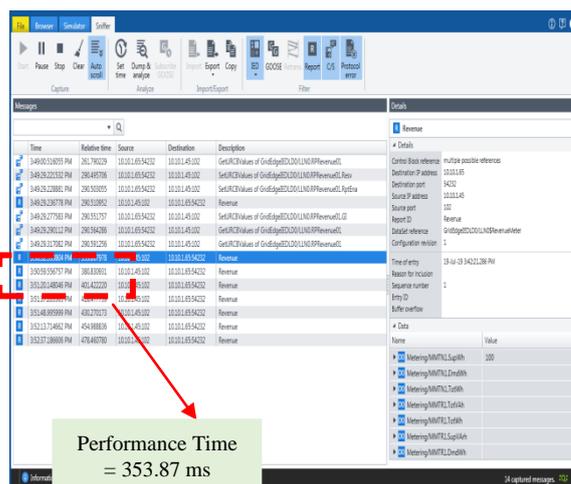


Fig. 11 MMS communication between virtual IED in IED Simulator and Client Simulator

V. CONCLUSION

The paper discussed the application of data models defined in IEC 61850 standards in which a multi-function virtual IED is designed and information exchange is simulated using specialized software suites. The simulation results have successfully demonstrated the features and capabilities of IEC 61850 data model. The semantics defined in the data model are preserved across the communication network without loss of information and transmitted within the required performance time. This is how interoperability is achieved in IEC 61850 standard where devices that comply to the standard are able to communicate using standardized data model and communication services without constraints that may be observed in other communication protocols and technologies.

VI. FURTHER WORKS

For the next endeavors, the authors aim to further explore other applications in Grid Edge domain such as Non-Intrusive Load Monitoring (NILM) and Energy Trading and design the functions based on IEC 61850 data model. Finally, the authors aspire to integrate the data model in actual IED and conduct actual experiments to validate the implementation of IEC 61850 for such features in real-world environment.

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