IEC 61850 **Standard** Based Integrated EV **Charg**ing Management in Smart Grids (Standard-Charge)

1. Project Introduction

Global warming created awareness against fossil-fuel use and a transition towards renewable energy-based power system. Citizens are more concerned about this topic and Governments, such as EU countries and Japan, have set ambitious goals towards cutting down CO2 emissions, and increasing the share of Renewables in the overall mix. This change in the power system creates unprecedented challenges such as intermittency, device control with higher resolution and demand side management for higher efficiency. All of these tasks require increased monitoring and communication for better decision-making. Connecting different equipment from hundreds of different manufacturers is impossible, unless a standard approach is taken for communication modeling and messaging. IEC 61850 is poised to fill this gap with its popularity and high-data transmission capability. It was developed for protection, automation and SCADA systems initially, but its domain has been extended with new models developed for PV panels, wind turbines, storage systems as well as Electric Vehicles.

Because it was historically used for protection only, and other models are being developed now, IEC 61850's use for full smartgrid automation and control requires a lot of investigations. For instance, mechanisms for smart energy management or electric vehicle charging control have been developed yet have not been implemented and tested. In theory, these models and mechanisms follow IEC 61850 rules, but there are no real devices to implement them for real-time demonstration and behavior investigation. When equipped with GTNET cards, RTDS can use IEC 61850 based models and send messages such as GOOSE and SV. Again, traditionally this capability has been mostly used for power system protection applications. New ideas, e.g. energy management systems, Smart meters, optimal control for Electric Vehicle charging via charging stations require more detailed models to be used and more sophisticated GOOSE/SV/MMS messages to be sent.

There is a clear lack of knowledge on how to do this kind of implementation, what are best practices in this field, what parameters impact the testing environment. The proposed research targets this research area by implementing Electric Vehicle and Charging Stations with IEC 61850 based models and data exchanges between them based on GOOSE/SV and MMS messages. MMS messages is, especially, of concern as GTNET cards have very limited support. This research also investigates the impact of this limitation on implementations and possible solutions, such as with MMS Voyageur tool of RSCAD. With these considerations in mind, the research area is very fertile and the following tasks have been realized:

With these considerations in mind, the following work items will be realized:

1. Mapping of the proposed EV charging data model to RTDS platform for real-time implementations.

2. Implementation of the EV model developed will be realized with an IEC61850 emulator.

3. A full power-communication simulation will be run on IEC61850 emulator-RTDS setup.

4. State of the charge (SOC) of EVs will be sent as SV messages, the controller in RTDS uses smart algorithm that is developed earlier. The dispatch calculation is performed and information is sent back to EV via GOOSE/MMS messages.

5. Integration of the said communication model with coordinated voltage control (CVC) scheme for voltage support in microgrids.

The main innovation of this research work is the ability to model novel devices that may not have been implemented commercially yet. IEC 61850 standardization work always leads the industry, therefore, lab testing requires models that can mimic the devices, i.e. on IEC61850 emulators. Furthermore, the coupling with RTDS enables realistic scenarios to be tested both in power and communication domains. Integration with CVC, also, exemplifies the benefits that can be reaped from this standard modeling.

The frameworks for standardized communication between EV and CS have been developed in past. The required information models of EV and CS according to IEC 61850 standards have been proposed. But there is a pressing need out validating these models for real life implementations. The outcome of this work would fill this knowledge gap and the results would serve as guidelines before the communication model is actually deployed in real life. Since, the frameworks are already developed according to a popular futuristic standard, the real time implementation and evaluation of these framework would definitely add to the scientific and technical value.

2. Literature Survey and State-of-the-Art

Coupled with Vehicle-to-Grid (V2G) technology, EVs can serve as electricity supplies to the grid during idle times to meet peak level demands and increase its reliability [1]. Further, while operating in V2G mode, EVs can supply non-anticipated loads in emergency conditions and can manage the demand response of the microgrid along with other DERs [2]-[4]. To leverage these benefits of EVs, many scheduling schemes for EV charging and discharging for integration of EV to grid has been proposed in literature [5]-[12]. In most of the studies, the scheduling of EV is done in coordination with the intermittent renewable power generation in microgrids. In these methods EV charging scheduling is carried out by optimizing the total cost and power balance in microgrids. Usually the scheduling of the EVs in microgrids is dealt in conjunction with the its energy management system [13]. It has been concluded that standardized communication-based energy management is most effective.

There has been lot of research carried out for scheduling/integration of EV in microgrids through communication [13]-[14]. In order to make this communication interaction between EV and grid standardized, standards such as IEC 61851 [15], ISO/IEC 15118 [16], SAE J2836 [17] have been proposed. These standards mainly focus of interactions of EV and the Electric Vehicle Supply Equipment (EVSE). But these standards have a limited scope for EVSE to grid interactions, which is very much essential for developing a complete integration mechanism for EV into grids (smart grid or microgrids). IEC 61850 is increasingly becoming popular standard for communication in power utility domain as it is based on with Object-Oriented and interoperability approach [18]. Different DERs and controllable loads have been modeled with logical devices and logical nodes (LN) of IEC 61850 standards in [19]-[20]. IEC 61850 communication models have been developed for multi-level management [21], energy management automation [20], Volt-VAR optimization [22] and hybrid agent architecture for automation [23] of microgrids/smart grids. IEC 61850 based PMU communication models for wide area communication have also been studied in [24]-[25]. Recently, IEC 61850 based communication models for DSTATCOM has been reported in [26]. Authors in [27] developed the information models for EV by extending IEC 61850-7-420 for V2G communications. However, later in 2016 IEC TC 57 WG published IEC 61850-90-8 [28] standard focusing on information models of E-mobility. This standard contains IEC 61850 based information models for EV and its related infrastructure. However, the earlier standards, i.e. ISO/IEC 15118, IEC 61851 and SAE J2836 as well as the recent addition IEC 61850-90-8 does not define the communication specifications and the information model for providing V2G support i.e. viz. discharging.

Said et al. [28] proposed a communication protocol for the EV charging/discharging protocol using the IEEE 1609 WAVE [29] standard. The IEEE 1609 WAVE provide guidelines for wireless communication access in Vehicle-to-Infrastructure (V2I) and Vehicle-to-Vehicle (V2V) via Dedicated Short Range Communication (DSRC) frequency. These standards provide specifications for architecture, networking services, multi-channel operations, application and management message exchanges etc. IEEE WAVE standards has been normally used for inter vehicle communications [30] and applications such as smart parking schemes [31]-[35], toll collections [30] etc. IEEE 1609 WAVE standards do not specify any interoperable information models for EV or its infrastructure components.

In [31] proposing user group presented IEC 61850 information models for EVs, RSUs and CSs detailing the different types of messages EVs will exchange with RSUs and CSs in V2I and V2G communication. Further for V2I communication harmonization of IEEE 1609 services and IEC 61850-90-8 information models have been presented.

There is a knowledge gap on performance evaluations of V2G communication in real time environment to study the feasibility for real life implementations. The performance of IEC 61850 message exchanges between EV and CS in terms of End-to-End delays, throughput and jitter under different network scenarios has not been analyzed. This is because there are no real devices implementing these models. Using RTDS seems to be a good solution, however, implementing full MMS messages and exchanging GOOSE/SV messages for purposes other than protection are not investigated. Integration with IEC 61850 emulators with power system simulation and the overall performance need to be studied.

3. Research Methodology

There are several steps that are aimed at achieving different objectives of the project:

1. Mapping IEC 61850-based models to RTDS + GTNET Cards capability

2. Achieving real time implementations of already developed communication models and frameworks.
3. Using a simplified approach which only utilizes SV and GOOSE, and observing its impact on the test results
4. Examining real time performance of IEC 61850 based communications in real-life scenarios such as EV-CS interactions

Mapping IEC 61850-based models to RTDS + GTNET Cards capability
The IEC 61850 models developed by the proposing team in their previous work shall be investigated for possible implementation with the RTDS GTNET cards. The information modeling of EV and CS with respect to their logical nodes is shown in Fig. 1. The EV and CS IEC 61850 information models will be modeled through RTDS GTNET cards and corresponding blocks from the RSCAD software. A through study on available parameters and features in the RSCAD modules and GTNET cards and their suitability for mimicking EV and CS communication modules shall be studied. And the data objects of the DEEV (logical node of EV) and DESE (logical node of CS) shall be mapped with corresponding parameters in RSCAD blocks and GTNET cards for IEC 61850. The description of DEEV and DESE logical nodes developed in previous works in listed in Table 1 and Table 2 respectively. The mapping of DOs of DEEV and DESE with RTDS GTNET card and RSCAD will be investigated under this objective.

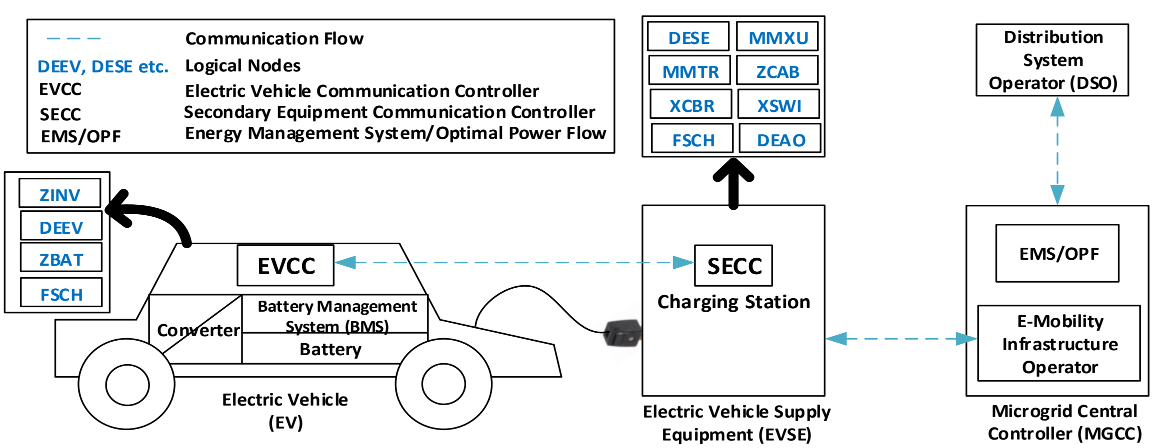

Fig. 1. IEC 61850 information model of EV and CS.

TABLE 1. DESCRIPTION OF DEEV LOGICAL NODE

DEEV				
Data Name	CDC	Explanation	T	M/O/C
Descriptions				
EVNam	DPL	EV nameplate		M
Status Information				
ConnTypSel	SPS	Selected connection type according to 61851-1		M
Measured and metered values				
Soc	MV	State of charge		M
Location	MV	GPS location coordinates of the EV		M
Settings				
EVId	VSG	In ISO 15118 compliant implementations, the EVId refers to the EVCCID Identifier as defined in ISO 15118-2		M
DptTm	TSG	Departure time is used to indicate when the vehicle intends to finish the charging process.		M
EnAmnt	ASG	Amount of energy required by the EV until the departure time has been reached or the EV battery's SoC is at 100%.		M
VMax	ASG	Maximum voltage supported by the EV.		M
AMax	ASG	Maximum current per phase supported by EV.		M
Amin	ASG	Minimum current per phase supported by EV.		M
SchdRef	ORG	Reference to the schedule logical node instance containing information on the charging profile of the EV.		M

TABLE 2. DESCRIPTION OF DESE LOGICAL NODE

DESE Class				
Data Name	CDC	Explanation	T	M/O/C
Descriptions				
EVSENam	DPL	EVSE nameplate		M
Status Information				
EmChrSlo	ING	No. of empty charging slots/outlets		M
Measured Values				
ChaPwr	MV	charging power of the EVSE		
Settings				
ChaPwrRtg	ASG	Rated maximum charging power of the EVSE		M
ChaPwrLim	ASG	The power value that the grid limits to the charger		M
ConnTypDC	SPG	True = DC charging is supported		M
ConnTypPhs	SPG	True = AC n (n = 1, 2, 3) phase charging is supported. Use ConnTypPhs1 for one phase charging, ConnTypPhs2 for two phase charging and ConnTypPhs3 for three phase charging.		M

- **Achieving real time implementations of already developed communication models and frameworks.**

The already developed EV charging management scheme involving standardized communication between EV and CS would be tested for real time performance. The infromation exchanges takes place over the developed communication models and frameworks. The information exchange sequence already developed is given in Fig. 2 and explained below.

The EV contacts the CS to request for power supply using a Manufacturing Messaging Specification (MMS) message request. The CS will send an acknowledgement, ACK through an MMS response and follow it up with an MMS request asking the EV for information about its SoC, charging mode, Alim and Vlim. The EV will respond to the CS's through an MMS message response indicating the requested information. On receipt of the information, the CS will initiate charging through a Generic Object Oriented Substation Event (GOOSE) message. The EV will then send a Sampled Value (SV) message indicating its battery level. On reaching the desired SoC level as indicated by the 'EnAmnt' parameter in the DEEV node, the CS will send a GOOSE message terminating power supply to stop charging.

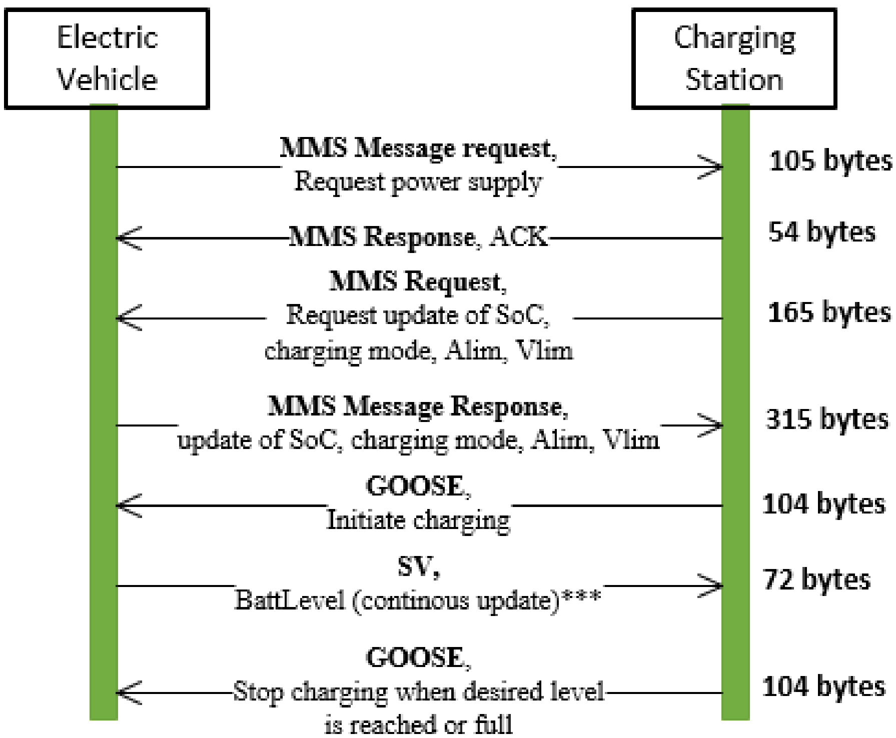

Fig. 2. Sequence of message exchanges between EVs and Charging stations.

These information exchanges will be implemented in real time using RTDS GTNET cards with the help of mapping developed in objective 1.

- **Using a simplified approach which only utilizes SV and GOOSE with RTDS-GTNET capabilities**

- **Examining real time performance of IEC 61850 based communications in real-life scenarios such as EV-CS interactions**

Among the message exchanges described in objective 2, GOOSE and SV message exchanges shall be implemented and tested for performance results. Using the GOOSE messages the battery charging process is initiated. When GOOSE message is published the connection between CS and EV (in RSCAD) is initiated. The battery level, i.e. state of charge (SoC) of the battery, is updated by EV at a rate of 10 samples per second. This information is updated though the IEC 61850 SV messages. Further investigations on feasibility of sending the SoC paramters at 10 samples per second rate through SV frame format will studied. The frame formats of typical GOOSE and SV messages are shown in Fig. 3. The real values of SoC received from RTDS simulation are monitored and when it reaches to desired level, finally a GOOSE massage is initiated to stop the process. The performance of these GOOSE and SV messages in terms of ETE delays and their impact on charging schemes shall be studied.

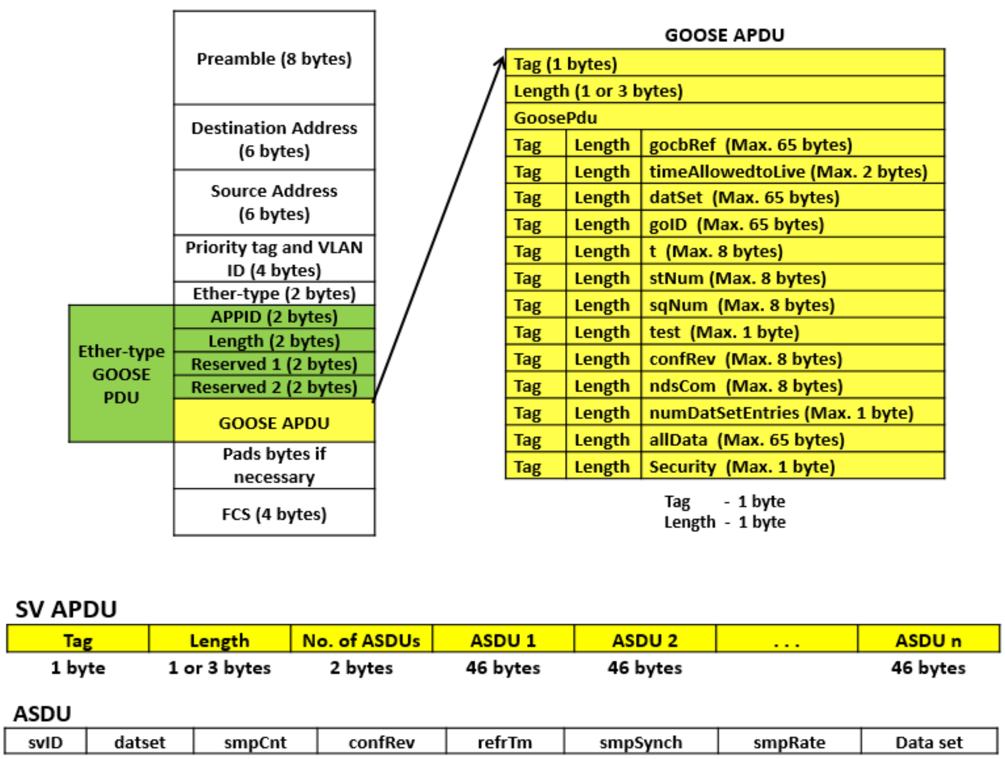

Fig. 3. Frame format of GOOSE and SV messages.

Figure 4 shows the test set-up utilized in the lab for running all the tests.

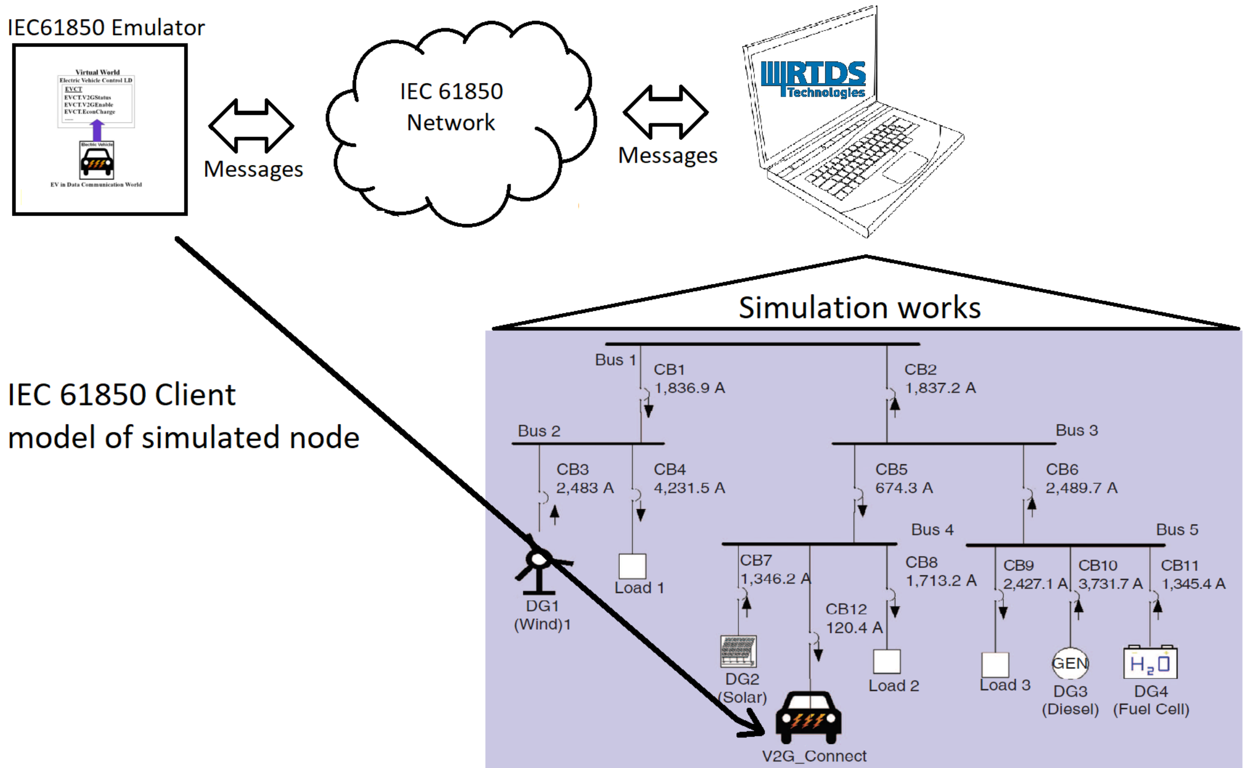

Fig. 4. Experimental Set-up

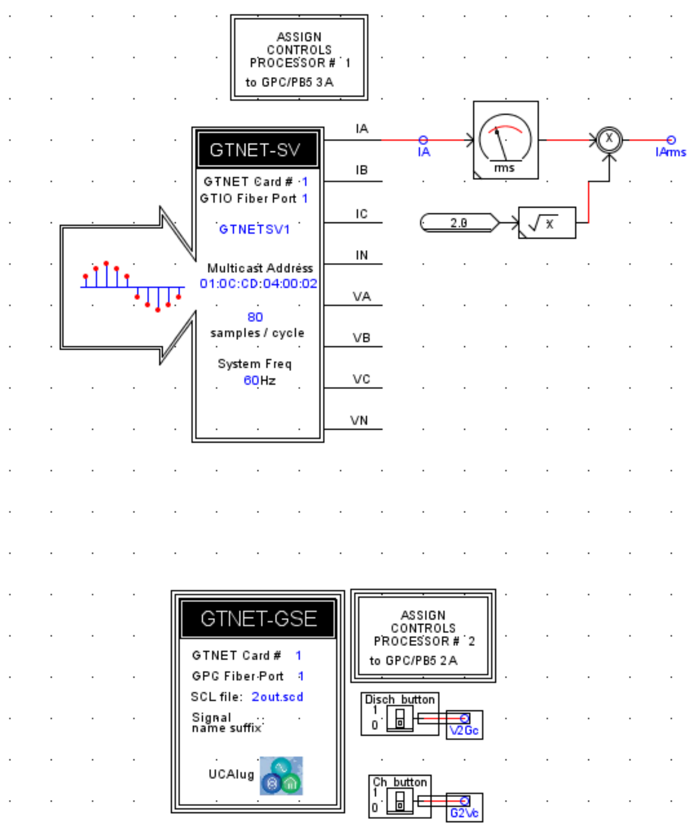

Fig. 5. Draft file in RSCAD

4. Tests and Results

The IEC 61850 models are developed and implemented in RTDS as shown in Figure 5. Here, an SV receiver receives state-of-charge value sent by the EV emulator. GOOSE control block is utilized to send charge start and stop commands based on internal decisions. It is important to note here that, a different IEC61850 has been utilized in lab tests than originally planned in the research proposal. The reason is lack of commitment and cooperation by Dr. Steven Blair who agreed to setting up rapidiec61850 as the emulator. However, during planning phases he did not follow up with emails and did not fulfill his commitments. In order to save the project from becoming dormant, FREA has acquired and utilized a commercial software (i.e. Infotech) as the IEC61850 emulator.

The runtime screen is as shown in Figure 6 where incoming SoC values are monitored for verification, as shown in Figure 7. At any instance, charge start and stop commands can be send as GOOSE messages to EV emulator.

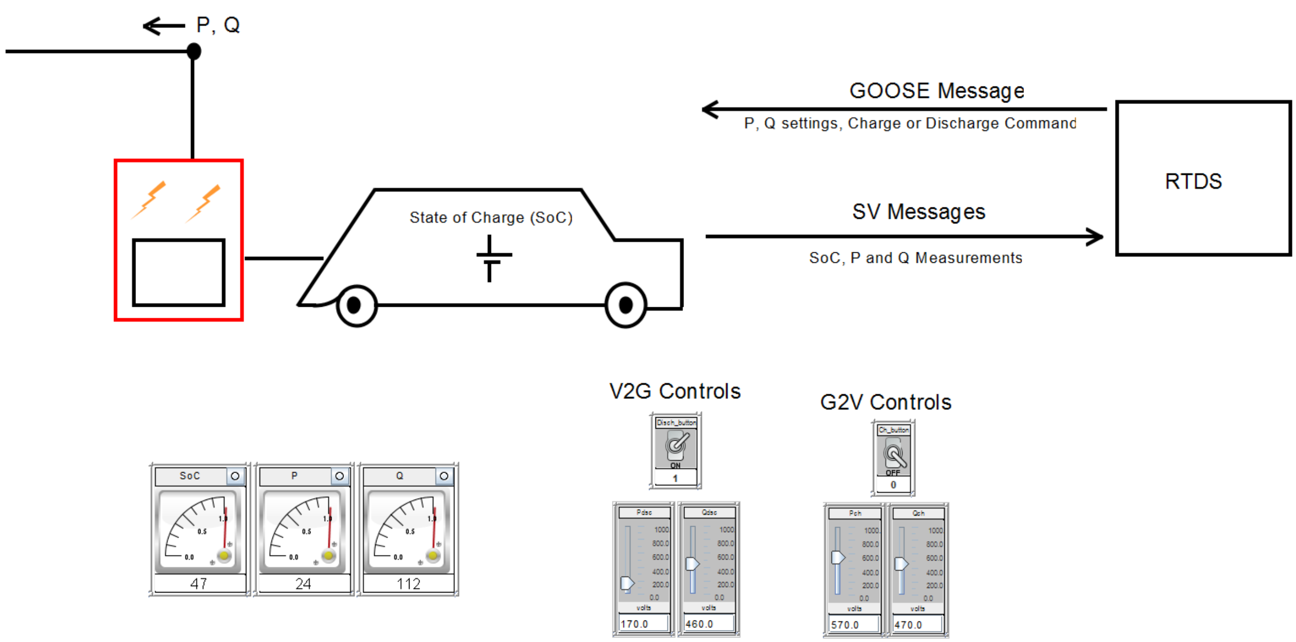

Fig. 6. Runtime Controls in RSCAD

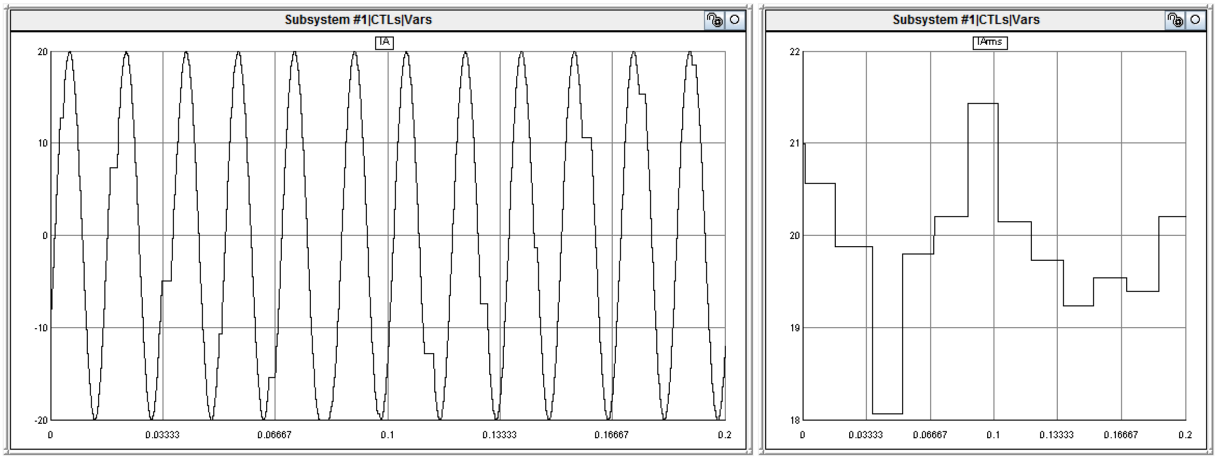

Fig. 7. Incoming SV messages in RSCAD

Once the preliminary validation is done and the integration between RSCAD and IEC61850 emulator is established, the setup is utilized to provide charge-discharge services in a coordinated voltage control (CVC) scheme in a microgrid. Figure 8 shows SoC profile for 24 hours. CVC commands EV to discharge or charge, depending on the grid's condition. With such integration, a volatile profile as in Figure 9 can be smoothened as in Figure 10. It is important to note that the impact on voltage support is highly impacted by current SoC and availability of EV (i.e. being connected to the grid)

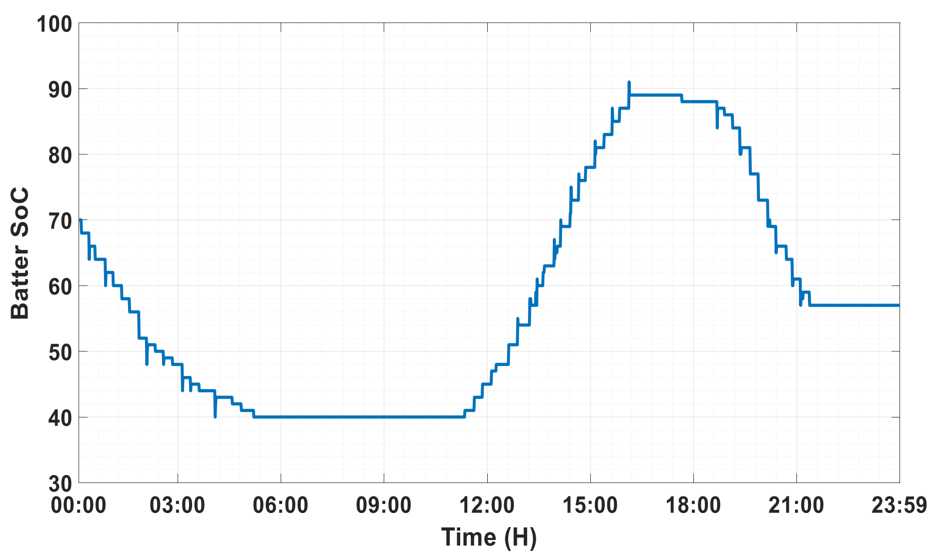

Fig. 8. 24-hour SoC profile

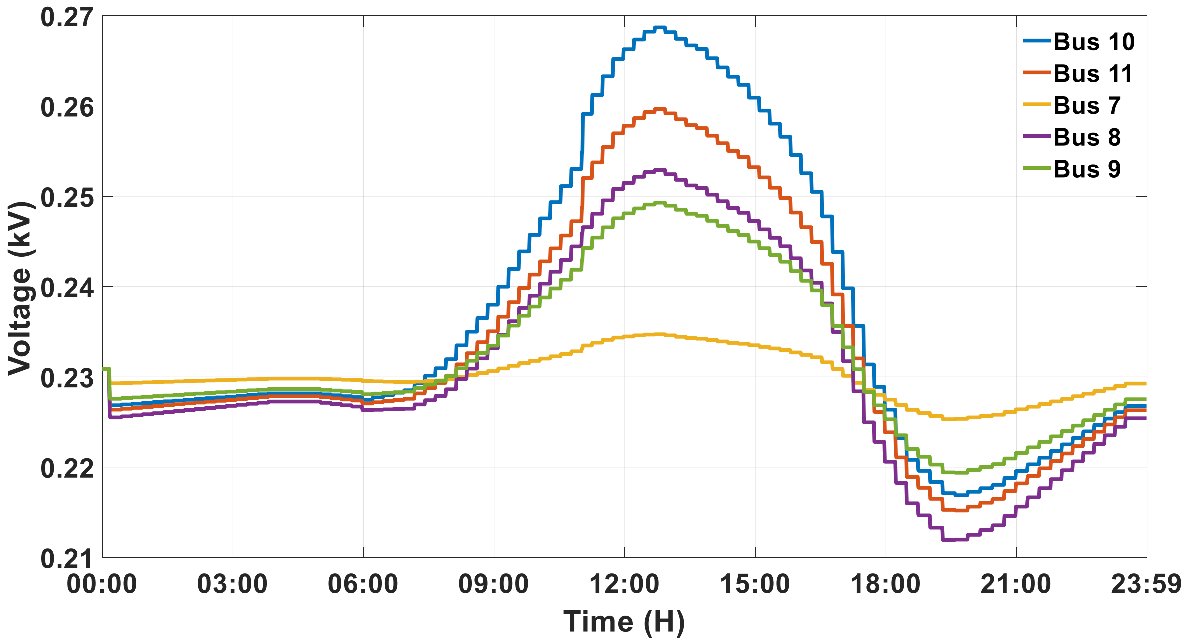

Fig. 9. Voltage profile without CVC

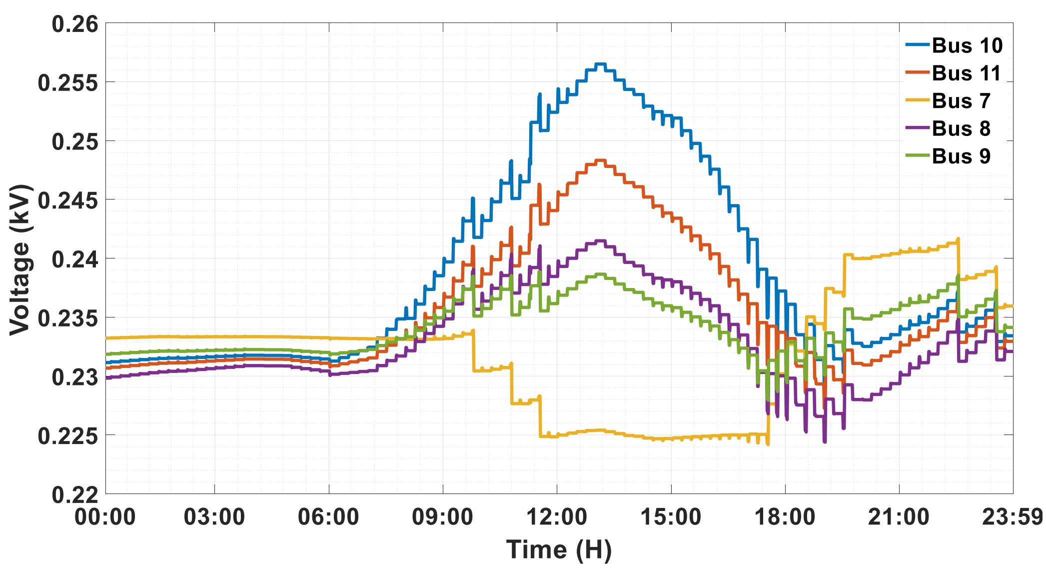

Fig. 10. Voltage profile with CVC (EV support)

5. Conclusions

This project has been very instrumental in developing, implementing and validating IEC61850-based standard models for electric vehicles (EVs) and Charging Stations (CSs). RTDS has been utilized to emulate CS and the electrical components (utility grid and the microgrid) while a commercial software is utilized to model EVs. Required message exchanges are successfully mapped unto relevant IEC61850 messages. Correct exchange of these messages enables integration of EVs with power system controls such as voltage and frequency support.

To investigate this possibility, the communication set up is integrated with power system simulation run in RSCAD. The developed models and messages are utilized to exchange EV's SoC value and send necessary charge and discharge commands to them. The simulations showed that the developed system can be used with CVC and help support voltage profile of a microgrid.

This project taught participants that commitment and fulfilling responsibilities are indispensable parts of any scientific undertaking. This research proposal was drafted together with a member of University of Strathclyde (Dr. Blair), and it was agreed that setting up IEC61850 emulator (i.e. rapidIEC61850) was to be fulfilled by them. However, once the EriGrid grant was approved, Dr. Blair became unresponsive and uncooperative. This made planning the project steps, dates of visits and responsibilities of each party impossible. To rescue the project, FREA has acquired a commercial emulator and dropped rapidiec61850 from the project. Also, Dr. Mazher Syed has taken the lead for the host institution and helped visitors with all their needs. The project has been successfully executed. However, an important lesson is learned about preparing for contingencies where partners may not fulfill their responsibilities without any notice.

6. Reference

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