IEC 61850 and XMPP Communication Based Energy Management in Microgrids Considering Electric Vehicles

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**ABSTRACT** Electric vehicles (EVs) can act as flexible resources in grid due to their bidirectional power transfer capabilities. In microgrids, the bidirectional power transfer capability of EVs through proper scheduling can be utilized to improve reliability, security, and quality of supply. Optimal scheduling of EVs is generally managed and controlled through the energy management system of microgrid. Since microgrid energy management (EM)-based scheduling of EVs is data driven, an effective communication between different actors of EM is required. This paper presents a IEC 61850 communication-based EM in microgrids with integrated EVs. Furthermore, augmentation of existing IEC 61850-90-8 logical nodes of EV and its related equipment with new data objects to include information exchanges for discharging operation of EVs have been proposed. Finally, in this paper, XMPP-based communication approach and its mapping to the service models for EM problem has been demonstrated.

**INDEX TERMS** Electric vehicle (EV), microgrid, IEC 61850, energy management (EM), eXtensible messaging presence protocol (XMPP).

**NOMENCLATURE**

- \(E_{\text{stored}}\) \(_{\text{final}}\): Energy stored in EV at final state (kWh)
- \(E_{\text{stored}}\) \(_{\text{initial}}\): Energy stored in EV at initial state (kWh)
- \(\eta_{\text{charge}}, \eta_{\text{discharge}}\): Charging and discharging efficiency of EV
- \(\eta_{\text{bat}}\): Efficiency of battery
- \(P_{\text{charge}}\) \(_{\text{i}}\): Estimated charging power of a \(i\)th EV (kW)
- \(P_{\text{discharge}}\) \(_{\text{i}}\): Estimated discharging power of a \(i\)th EV (kW)
- \(E_{\text{cap}}\): Battery energy capacity of EV (kWh)
- \(E_{\text{stored}}\): Energy stored in battery of vehicle (kWh)
- \(E_{\text{charge}}\): Energy required for charging the vehicle (kWh)
- \(E_{\text{discharge}}\): Energy supplied by the EV while discharging in V2G mode (kWh)
- \(P_{\text{EVSE}}\) \(_{\text{dis}}\)(\(t\)) : Aggregate power supplied by the EVSE to the grid through discharging multiple EV (kW)
- \(R_{\text{EVSE}}\) \(_{\text{ch}}\)(\(t\)) : Revenue generated at EVSE after charging the vehicles
- \(P_{\text{EVSE}}\) \(_{\text{ch}}\)(\(t\)) : Aggregate power required at EVSE for charging multiple EV (kW)
- \(P_{\text{V2G}}\) \(_{\text{i}}\), \(P_{\text{V2G}}\) \(_{\text{G}}\)(\(t\)) : Power transferred from grid to vehicle and vehicle to grid respectively (kW, kW)
- \(P_{\text{DER}}\) \(_{\text{i}}\), \(Q_{\text{DER}}\) \(_{\text{i}}\): Active and reactive power of DER respectively
- \(p_{\text{max}}\) \(_{\text{DER}}\) : Maximum power of DER
- \(r_{\text{g}}\): Ramping parameter
- \(S_{\text{DER}}\): Capacity of inverter
- \(\text{Cost}_{\text{batt}}\): Cost of EV battery
- \(C_{\text{DER}}\) \(_{\text{DER}}\) \(_{\text{i}}\) (\(P_{\text{DER}}\) \(_{\text{i}}\)) : Cost function of DER
In the effort of standardizing the communication for microgrid, IEC 61850 is emerging as one of the most promising solutions since it is based on the interoperability approach [12], [13]. Communication based EM in microgrids, without considering EVs, through the IEC 61850 based information models is reported in [14]. However, communication framework for EM incorporating EVs in microgrids to provide V2G as well as G2V support is yet to be developed. The message exchanges between the EV and charging supply equipment communication controller are governed by ISO/IEC 15118 [15] standard and charging specifications are described by IEC 61851 standard [16]. Recently, a new part IEC 61850-90-8 of the IEC 61850 series which deals with object models for E-mobility has been published [17].

However, the pre-existing standards 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. Thus, this paper proposes augmentation of existing IEC 61850-90-8 logical nodes (in the form of new Data Objects (DOs)) for EV to include information exchanges for discharging of EVs. Further, the proposed information model is utilized for carrying out communication based EM problem to enable V2G and G2V support in microgrid is developed in this paper.

To provide network scalability and information security to microgrid communication networks, which are wide area networks (WANs), IEC 61850-80-3 [18] proposes mapping of IEC 61850 services to XMPP web protocol [19]. This paper presents XMPP based communication approach and its mapping to the service models for EM problem in the microgrid. XMPP based communication for microgrid communication is utilized for reactive power management in [20]. This has been further extended to utilize XMPP for EM problem with EV penetration.

The rest of the paper is organized as follows. Section II presents EMS problem for Microgrid considering EVs. Section III describes IEC 61850 based information modeling of EV for both charging and discharging scenarios. Information exchanges for EM in microgrid is detailed in Section IV. Section V demonstrates the EM service mappings to XMPP in microgrid communication networks. Finally, Section VI presents conclusion.

I. INTRODUCTION

Electric Vehicles (EVs) are becoming more popular over vehicles using conventional internal combustion engines. This is due to their several benefits such as less greenhouse gas emissions, low cost of energy and less dependence on depleting oil reserves. Due to bidirectional power transfer capabilities of EVs which act both as Grid to Vehicle (G2V) and Vehicle to Grid (V2G) support, they can act as flexible resources in microgrid. However, EVs charging load demand characteristics are highly uncertain, dispersed and non-linear in nature [1]. 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]. EVs can play a central role in ensuring overall reliability, security and quality of supply in a microgrid.

On the other hand, dynamic nature of EVs can hamper the coordination and transient stability of microgrids. Therefore, a thorough control of EV charging and discharging conditions need to be achieved before their practical deployment [3], [4]. In literature, researchers have proposed many scheduling schemes for EV charging/discharging [5]–[7]. In [8], a global optimization for scheduling of EV has been presented to minimize the overall cost. In other work [9], an optimal EV scheduling and dispatch coordination problem has been developed by using adaptive droop based approach for EV management. In microgrids, the scheduling of EVs is generally managed and controlled through the Energy Management System (EMS) [2], [10], [11]. Microgrid Energy Management (EM) based scheduling of EV implementations are usually data-driven, which means the energy consumption decisions made by algorithms are based on the real-time power data retrieved from multiple sources. This requires an effective communication between various actors of energy management system. Although there are numerous studies in literature related to EM strategies for microgrid with integrated EVs, but there has been limited work on detailed communication design for EMS with EVs in microgrids.

The rest of the paper is organized as follows. Section II presents EMS problem for Microgrid considering EVs. Section III describes IEC 61850 based information modeling of EV for both charging and discharging scenarios. Information exchanges for EM in microgrid is detailed in Section IV. Section V demonstrates the EM service mappings to XMPP in microgrid communication networks. Finally, Section VI presents conclusion.

\[ C_{bat}(P_{bat}(t)) \]
\[ C_{grid}(P_{grid}(t)) \]
\[ E_{bat}(t) \]
\[ P_{bat}(t), Q_{bat}(t) \]
\[ p_{bat}, p_{maxc} \]
\[ E_{bat}, E_{max}, E_{min} \]
\[ a_{bat}, b_{bat}, c_{bat} \]
\[ a_{DER}, b_{DER}, c_{DER} \]
\[ \alpha_{A}, \beta_{dis} \]
\[ \gamma_{cyc} \]
\[ r_{ij}(t) \]
\[ V_{EVSE}, V_{EVSE}^{max}, V_{EVSE}^{min} \]
\[ P_{EVSE}, I_{EVSE}^{max}, I_{EVSE}^{min} \]
\[ V_{PEV}, V_{PEV}^{max}, V_{PEV}^{min} \]
\[ P_{PEV}, I_{PEV}^{max}, I_{PEV}^{min} \]
\[ N, N_{c}, N_{d} \]
II. ENERGY MANAGEMENT IN MICROGRID CONSIDERING ELECTRIC VEHICLE

EM problem for a microgrid penetrated with various DERs such as PV, Wind, CHP and EV is formulated with an objective to maximize the revenue and minimize the total losses occurring over a scheduled period, \( \tau \in \mathbb{R} \). The presence of EV in the microgrid makes the generator scheduling more complicated due to larger constraints imposed on the optimal power flow problem by EV.

The overall objective in grid connected mode is to maximize the revenue generated and minimize the losses for time interval \( \tau \in \mathbb{R} \). This is formulated as follows,

\[
F = \max \left\{ \sum_{i \in N} R_{\text{load}}(t) + \sum_{i \in \xi} C_{\text{DER}}(P_{\text{DER}}(t)) - \sum_{i \in \xi} C_{\text{grid}}(P_{\text{grid}}(t)) \right\}
\]

(1)

The power balance equation for generator scheduling in grid connected mode is given by

\[
\sum_{i \in \xi} P_{\text{DER}}(t) + \sum_{i \in \beta} P_{\text{bat}}(t) + \sum_{i \in N} P_{\text{EVSE}}^{\text{dis}}(t)\leq P_{\text{grid}}(t)
\]

(2)

In grid connected mode, the loads are served via the power from the grid and during the peak loads V2G support from the EV will be utilized.

Whereas in islanded mode the objective is to ensure reliable power supply to the customers and minimize the cost of generation and the OPF problem is formulated as (3) and (4) subjected to the constraints (5) and (6). In islanded mode MGCC may allow for discharging of EVs over a time-period to ensure balance between the generation and load.

\[
F = \min \left\{ \sum_{i \in \xi} C_{\text{DER}}(P_{\text{DER}}(t)) + \sum_{i \in \beta} C_{\text{bat}}(P_{\text{bat}}(t)) \right\}
\]

(3)

\[
R_{\text{load}}(t) = \sum_{i \in \xi} \left[ R_{\text{load}}(t) + \sum_{i \in N} C_{\text{DER}}(P_{\text{DER}}(t)) - \sum_{i \in \xi} C_{\text{grid}}(P_{\text{grid}}(t)) \right]
\]

(4)

\[
V_{\min}^{\text{min}} \leq |V(t)| \leq V_{\max}^{\text{max}} \quad \forall t \in \tau
\]

(5)

\[
i_{\min}^{\text{max}} \leq l_{ij}(t) \leq l_{ij}^{\text{max}} \quad \forall t \in \tau
\]

(6)

The only change that is required for islanded mode is to set \( P_{\text{grid}}(t) = 0 \). Otherwise, the equations remain the same.

During operation of microgrid in grid connected as well as islanded mode, the MGCC calculates the cost of generation for dispatchable DERs, battery, EVs as well as grid and total load demand of the microgrid and develops dispatch schedule.

The cost of generation of a dispatchable DER \( C_{\text{DER}}(P_{\text{DER}}(t)) \) is included in the formulation as [14]

\[
C_{\text{DER}}(P_{\text{DER}}(t)) = a_{\text{DER}} + b_{\text{DER}}P_{\text{DER}}(t) + c_{\text{DER}}P_{\text{DER}}(t)^2
\]

(7)

\[
0 \leq P_{\text{DER}}(t) \leq P_{\text{max}}^{\text{DER}} \quad \forall t \in \tau
\]

(8)

\[
|P_{\text{DER}}(t) - P_{\text{DER}}(t-1)| \leq r_{\text{max}}P_{\text{DER}} \quad \forall t \in \tau
\]

(9)

\[
P_{\text{DER}}^2(t) + Q_{\text{DER}}^2(t) \leq S_{\text{DER}}^2(t) \quad \forall t \in \tau
\]

(10)

For a battery system, the cost function \( C_{\text{bat}}(P_{\text{bat}}(t)) \) is given by (11). It is similar to the one used in [21].

\[
C_{\text{bat}}(P_{\text{bat}}(t)) = a_{\text{bat}} \left( \sum_{t=0}^{T-2} P_{\text{bat}}(t+1) - P_{\text{bat}}(t) \right) - b_{\text{bat}} \sum_{t=0}^{T-2} P_{\text{bat}}(t+1) - P_{\text{bat}}(t) + c_{\text{bat}} \left( \min(E_{\text{bat}}(t) - \delta_{\text{bat}}E_{\text{bat}}^{\text{max}}, 0)^2 \right)
\]

(11)

\[
p_{\text{bat}}^{\text{max}} \leq P_{\text{bat}}(t) \leq P_{\text{bat}}^{\text{max}} \quad \forall t \in \tau
\]

(12)

\[
P_{\text{bat}}^2(t) + Q_{\text{bat}}^2(t) \leq S_{\text{bat}}^2(t) \quad \forall t \in \tau
\]

(13)

\[
E_{\text{bat}}(t + 1) = \eta_{\text{bat}}E_{\text{bat}}(t) + P_{\text{bat}}(t)\Delta(t) \quad \forall t \in \tau
\]

(14)

\[
E_{\text{bat}} \geq E_{\text{bat}}^{\text{min}} \quad \forall t \in \tau
\]

(15)

\[
E_{\text{bat}}^e \geq E_{\text{bat}} \quad \forall t \in \tau
\]

(16)

The cost of the power purchased from the grid \( C_{\text{grid}}(P_{\text{grid}}(t)) \), a product of market energy price \( \theta(t) \) and amount of power purchased \( P_{\text{grid}}(t) \), is given in (17).

\[
C_{\text{grid}}(P_{\text{grid}}(t)) = \theta(t)P_{\text{grid}}(t) \quad \forall t \in \tau
\]

(17)

The revenue generated by serving the loads is given in (18).

\[
R_{\text{load}}(t) = \sum_{i \in \xi} \left( \theta(t)P_{\text{load}}(t) \right) \quad \forall t \in \tau
\]

(18)

\[
C_{\text{cl}}(P_{\text{cl}}(t)) = \sum_{i \in \xi} a_{\text{cl}} \left( \min(P_{\text{cl}}(t) - P_{\text{actual}}(t), 0)^2 \right)
\]

(19)

\[
p_{\text{cl}}^{\text{min}} \leq P_{\text{cl}}(t) \leq P_{\text{cl}}^{\text{max}} \quad \forall t \in \tau
\]

(20)

\[
Q_{\text{cl}}^{\min} \leq Q_{\text{cl}}(t) \leq Q_{\text{cl}}^{\text{max}} \quad \forall t \in \tau
\]

(21)

The cost of charging the EVs at the EVSE can be obtained as the net revenue generated in charging all the vehicles at EVSE during scheduled charging operation as given in (22) subject to (27)-(28). Similarly, the total cost of generation of power at EVSE’s due to discharging of EVs can be given as (24). When there is scarcity of generation and microgrid is unable to meet total load demand, only discharging is allowed. If the generation in microgrid is adequate, then
charging of EVs is also allowed. Due to frequent charging and discharging the EV battery experiences degradation, V2G schemes have a toll on the car batteries. To encourage participation in these schemes, an incentive is paid to EV owner for the degradation as it reduces battery lifetime [22]. The net cost of power at EVSE’s can be given as the cost of power transferred to grid at EVSE and the incentives minus the cost of charging, if any, as given in (29).

\[ P_{EVSE}^{ch}(P_{EVSE}^{ch}(t)) = \sum_{i=1}^{N} g_{ch}^{i} P_{EVSE}^{ch}(t) \] (22)

\[ P_{EVSE}^{ch}(t) = \sum_{j=1, \tau \epsilon t}^{N_j} P_{G2V}^{ch}(t) \] (23)

\[ Cost_{EV}^{dis}(P_{EVSE}^{dis}(t)) = \sum_{i=1}^{N} (\beta_{dis}^{i} + \gamma_{cyc}^{i}) * P_{EVSE}^{dis}(t) \] (24)

\[ P_{EVSE}^{dis}(t) = \sum_{j=1, \tau \epsilon t}^{N_d} P_{V2G}(t) \] (25)

Equations above are subject to various constraints:
1. The net charging for the battery must not exceed the charging capacity of the battery, which can be expressed as,

\[ E_{charge} = \eta_{charge} * P_{charge} * t \leq E_{Cap} - E_{stored}^{ini} \] (34)

2. To maintain the minimum SoC for the battery, the battery must not be discharged below the minimum charge level,

\[ E_{discharge} = \frac{1}{\eta_{discharge}} * P_{discharge} * t \leq E_{stored}^{ini} - E_{min} \] (35)

The next section discusses the IEC 61850 based design and modeling of different components of microgrids to achieve the above discussed EM methodology.

III. IEC 61850 COMMUNICATION DESIGN OF DIFFERENT COMPONENTS OF MICROGRIDS

The IEC 61850 information models of different microgrid components such as PV plants, wind plants, diesel plants, battery systems, controllable loads, smart meters and PMU are described in detail in [14] and [23]–[25]. The information models for different DERs developed in [14] are considered in this paper. Similarly, prior to publication of IEC 61850-90-8 standard, there have been attempts in literature to develop IEC 61850 information models of EV and its related equipment by extending IEC 61850-7-420 LNs [26], [27]. However, the IEC 61850-90-8 standard does not define the information models and data exchanges required for discharging of the EVs. Hence, in this section the authors have developed the IEC 61850 information models for EV and its related equipment which support the discharging of EVs i.e. V2G support.

The information model of EV with IEC 61850-90-8 logical nodes (LNs) is as shown in Fig. 1. The LN DEEV corresponds to EVCC, while LNs ZBAT and FSCH corresponds to battery and battery management systems respectively. LN ZINV contains the information corresponding to converter. Every Electric Vehicle Supply Equipment (EVSE) at a charging station consists of a Secondary Equipment Communication Controller (SECC). When the EV arrives at a charging station, the SECC of an EVSE communicates with the EVCC of EV. The IEC 61850 information model of SECC consists of LNs DESE, DEAO, FSCH, ZCAB, MUXU, MMTR, XSWI and XCBR. The DESE LN contains the information on monitoring and controlling the features of an EVSE. While LN DEAO contains information pertaining to the control features of an AC charging outlet (similarly LN DEDO corresponds to DC charging outlets), LN ZCAB contains information related to the power cable. MMXU and MMTR LNs correspond to measurement and metering of different parameters at EVSE. LN FSCH contains settings and information of energy services schedules at the EVSE.

Since, EV acts as a flexible load on the microgrid and can act as load (during charging in G2V mode), or battery storage system (BS) / generation (during discharging
in V2G mode) there is a need to develop discharging scenarios for the EV to act in V2G mode. The existing LNs (i.e. DEEV and DESE) have been augmented with new data objects to support V2G mode. To include discharging function for EV three new DOs are added in LN DESE namely, ‘DisPwrRtg’ for rated maximum discharging power of the EVSE, ‘DisPwrAv’ for the available discharging power at the EVSE and ‘DisPwrTgt’ for target power value required by the grid from the EVSE as shown in Table 1. The DO ‘EVSEOpMode’ contains the operating mode i.e. charging or discharging supported by the EVSE in a particular period. Similarly, the DEEV LN for EV is augmented with new data objects ‘DisEnAmt’, ‘V2GStart’, ‘V2GEnd’ and ‘EVStat’ as shown in Table 2. The DO ‘DisEnAmt’ corresponds to amount of energy to be discharged into the grid by the EV before its departure from the EVSE. ‘V2GStart’ and ‘V2GEnd’ specify the starting and ending time periods for vehicle participation in the grid. ‘EVStat’ contains the status of the EV connected to EVSE in DEEV LN. The data object ‘EVStat’ can take values such as ‘0’ for vehicle not connected, ‘1’ for EV charging i.e. G2V mode, ‘2’ for EV discharging i.e. V2G mode, ‘9’ for not available/unknown. It is to be noted that vehicle participation for providing power to the microgrid depends upon bidding and negotiation process based upon vehicle availability in the parking lot (EVSE). Thus, the modified LNs are capable of exchanging data with other LNs for supporting G2V as well as V2G mode.

IV. INFORMATION EXCHANGES FOR ENERGY MANAGEMENT

The data flow in microgrid for implementing EM function is demonstrated in this section. The load profile curve of Australia is considered as a case study [28]. The typical load profile curve has two peaks a shorter near the morning hours and a steeper in the evening hours, whereas in goes into valley mode during the daytime as shown in Fig. 2. Figure 2 also shows the daily regime of vehicle traffic in Australia (vehicle kilometer traveled (VKT)). To emphasize the role of EV on EM in microgrid, following three different case scenarios has been considered based upon the load curve and the daily
TABLE 2. Description of DEEV logical node.

<table>
<thead>
<tr>
<th>DO Name</th>
<th>CDC</th>
<th>Explanation</th>
<th>M/O</th>
</tr>
</thead>
<tbody>
<tr>
<td>EVNam</td>
<td>DPL</td>
<td>EV nameplate value</td>
<td>M</td>
</tr>
<tr>
<td>CommTypSel</td>
<td>ENS</td>
<td>Selected connection type according to 61851-1</td>
<td>O</td>
</tr>
<tr>
<td>Beh</td>
<td>ENS</td>
<td>Inherited from: Domain LN</td>
<td>M</td>
</tr>
<tr>
<td>EStat</td>
<td>ENS</td>
<td>Operating Modes of EV</td>
<td>M</td>
</tr>
<tr>
<td>Value</td>
<td>Explanation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>Not Connected</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Grid to vehicle support</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Vehicle to grid support</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Not Available</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Measured and Rated Value

<table>
<thead>
<tr>
<th>SOC</th>
<th>MV</th>
<th>State of charge</th>
<th>M</th>
</tr>
</thead>
</table>

Settings

<table>
<thead>
<tr>
<th>EId</th>
<th>VSG</th>
<th>EVId refers to EVCCID Identifier as per [ISO 15118-2:2014]</th>
<th>M</th>
</tr>
</thead>
<tbody>
<tr>
<td>DptTm</td>
<td>TSG</td>
<td>Departure time is used to indicate when the vehicle intends to finish the charging process.</td>
<td>M</td>
</tr>
<tr>
<td>EnAmt</td>
<td>ASG</td>
<td>Amount of energy required by the EV until the departure time has been reached or the EV battery’s SOC is at 100%</td>
<td>M</td>
</tr>
<tr>
<td>DisEnAmt</td>
<td>ASG</td>
<td>Amount of energy to be discharged into the grid by the EV before its departure from the EVSE</td>
<td>M</td>
</tr>
<tr>
<td>VMax</td>
<td>ASG</td>
<td>Max. voltage/phase supported by the EV.</td>
<td>M</td>
</tr>
<tr>
<td>AMax</td>
<td>ASG</td>
<td>Max. current/phase supported by the EV.</td>
<td>M</td>
</tr>
<tr>
<td>AMin</td>
<td>ASG</td>
<td>Min. current/phase supported by the EV.</td>
<td>M</td>
</tr>
<tr>
<td>SchdRef</td>
<td>ORG</td>
<td>Reference to the schedule LN instance containing information on the charging profile of the EV.</td>
<td>M</td>
</tr>
<tr>
<td>V2OStart</td>
<td>TSG</td>
<td>Vehicle to grid participation time initiation</td>
<td>M</td>
</tr>
<tr>
<td>V2End</td>
<td>TSG</td>
<td>Vehicle to grid participation time ceases</td>
<td>M</td>
</tr>
</tbody>
</table>

vehicle traffic regime viz. daytime (valley mode), evening time (steep hump mode) and early morning time (flat and low hump mode).

A. CASE I: VALLEY MODE

The valley mode occurs during the daytime when load demand is minimum. The solar energy is readily available during this period and EVs are also parked at the EVSE in schools and offices. Based upon surplus power availability and low load demand, MGCC disconnects the microgrid from the grid and operates in islanded mode. In this scenario, EVs can act in G2V as well as V2G mode, depending upon EV owner’s requirement and flexibility.

For EM, the MGCC predicts the power generation of non-dispatchable DERs based on the meteorological data and the weather forecast log. LN DRCT of each dispatchable DER IED contains DOs ‘MaxWLim’ and ‘MaxVarLim’ which communicate the active reactive power limits $P_{\text{max}}^{\text{DER}}$ and $Q_{\text{max}}^{\text{DER}}$ to MGCC used for computing DER cost function as per (7). Similarly, the battery parameters $S_{\text{bat}}$, $E_{\text{bat}}$, $P_{\text{maxdc}}$, $P_{\text{bat}}$ are communicated by data objects ‘AhrRtg’, ‘MinAhrRtg’, ‘MaxBatA’, and ‘MaxChaV’ in LN ZBTC in battery system IED to MGCC for computing cost function as per (11). All the EVSE’s communicate their rated charging power for G2V operation and rated discharging power for V2G operation through DOs ‘ChaPwrTgt’ and ‘DisPwrTgt’ of LN DESE respectively. In islanded mode, the MGCC sets the operating mode of all EVSE’s to 3 in DO ‘EVSEOpMode’ LN DESE i.e. both charging and discharging mode. Now the EVSE calculates the required charging power ($P_{\text{dis}}^{\text{EVSE}}$) and available discharging power ($P_{\text{grid}}$) at EVSE based on the number of vehicles registered for charging ($N_c$) and discharging ($N_d$) as per (23) and (25). EVSE then communicates this value to the MGCC through the DOs ‘ChaPwrTgt’ and ‘DisPwrTgt’ of LN DESE for required charging and available discharging power at EVSE respectively. Based on these communicated values the MGCC calculates the cost of discharging power at the EVSE as per (29). MGCC takes $P_l$ and $Q_l$ from the data objects ‘WRtg’ and ‘VArRtg’ of the LN CNLO of controllable load IEDs to calculate loss of revenue. The DO ‘ECPConn’ of LN DPST of different DER IEDs communicate the connection status to the MGCC. The data objects ‘TotW’, ‘TotVar’, ‘TotVA’, and ‘TotWh’ in MMXU node at different loads and EVSE communicates the total powers to the MGCC required in (2). Based on the power generation data, cost functions and the total load demand MGCC calculates the OPF dispatch, as per (1). This OPF specifies the dispatch schedule or generation range for respective DERs.

After developing the generation schedule as described above, the MGCC sends the operating mode settings to all DERs, such as constant power, constant voltage, constant VARS, constant pf mode etc. The data objects ‘SchdTyp’ and ‘SchdVal’ of LN DSCH in DER IEDs receive the dispatch schedule from MGCC. While the DO ‘SchdIntv’ receives the time period for which current schedule is valid or time for next schedule to arrive. Different data objects of LN DOPM sets the corresponding operating mode for DERs. MGCC also communicates the power required from each EVSE to the DO ‘DisPwrTgt’ of LN DESE.

B. CASE II: STEEP HUMP MODE

The Steep Hump Mode occurs during the evening time when there is a high load demand. In this peak load hours, the EVs available at the parking lots can be utilized for V2G support. It is assumed that in this case the microgrid operates in grid connected mode, due to the unavailability of PV and low wind power.

For EM, initially the MGCC sets the operating mode of all EVSE’s to 2 in DO ‘EVSEOpMode’ LN DESE i.e. V2G-discharging mode. The EVSE updates the power required for charging ($P_{\text{dis}}^{\text{EVSE}}$) to the MGCC. The MGCC calculates the revenue generated by serving the loads and cost of generation at EVSE’s ($C_{\text{grid}}$) as per (18) and (24) respectively. The LN MMXU at PCC IED sends the total amount of power exchanged from utility grid to the microgrid, which is then utilized by MGCC to calculate $C_{\text{grid}}$ ($P_{\text{grid}}$)
as in (17). As discussed above in case I, the MGCC calculates the cost of dispatchable DERs as per (7). Based upon these cost functions MGCC calculates the optimal dispatch schedules to the DERs and EVSE’s as per (1) and (2).

C. CASE III: FLAT AND LOW HUMP MODE

The flat mode occurs during night time when load demand is low and EVs are parked for charging. During flat and low hump mode, the EVs only participate in charging operation. Also, ample wind energy is available during night time and early morning hours, hence wind DERs participate effectively in microgrid. For EM, similar information exchanges as described in scenario II occurs. Apart from previous information exchanges, MGCC predicts the generation of Wind DER based upon the meteorological data and weather forecast log. All other information exchanges detailed in case scenario II occurs in case scenario III.

D. INFORMATION EXCHANGES BETWEEN EV AND EVSE FOR CHARGING AND DISCHARGING

Upon arrival of the EV at the EVSE, the EVId (identification number of the EV) is communicated to the EVSE. The EVSE acknowledges by responding with EVSEId and runs compatibility checks of EV battery if passed EV is locked on to one of the EVSE connectors.

The DO ‘EVStat’ of DEEV LN reflects the status of EV. When the EV is connected to a charging slot at EVSE, EV provides information regarding State of Charge (SoC), minimum and maximum permissible charging currents, maximum voltage, expected departure time of the vehicle and amount of energy to be transferred before departure to EV. These parameters are communicated to EVSE by following DOs ‘SoC’, ‘AMin’, ‘AMax’, ‘VMax’, ‘DptTm’ and ‘EnAmt’ of DEEV LN in EV. This information serves as the constraints for EV operation, \( V_{PEV}^{max} \), \( I_{PEV}^{max} \), and \( I_{PEV}^{min} \) in (32) and (33).

While in islanded mode the EVSE may allow EVs to discharge the power to microgrid. In such cases, after EV is plugged in to the discharging slot of EVSE, EV communicates information on the maximum amount of energy that can be discharged from the EV besides SoC, minimum and maximum permissible discharging currents, maximum voltage and expected departure time of the EV. During discharging, when the battery level reaches to minimum SoC level, the value in DO ‘MinAhrRtg’ in ZBAT LN of EV battery, the EV disconnects from EVSE by changing the status value of DO ‘EVStat’ in DEEV LN to 0 i.e. disconnect. The EVSE must acknowledge this request and responses agreement between the actors. This response is expected to be received within 2 seconds of the request for power delivery.

V. XMPP BASED MICROGRID COMMUNICATION CONFIGURATION

The information modeling of EVs and messages to be exchanged for EM in microgrids has been discussed in detail in previous sections. The service modeling and communication protocols for messages exchanged between various DERs, EVs and MGCC are detailed in this section.

Different services (for example, get, set, report, define, delete) provided by the IEC 61850 information models are defined as abstract communication service interface (ACSI) services. For realizing EM scheme in microgrid, different ACSI services invoked for communicating related information between different microgrid components is shown in Table 3. The process of mapping ACSI services to MMS protocol is known as Specific Communication Service Mapping (SCSM). The related SCSM for EM scheme in microgrids is also detailed in Table 3. The SCSM based on MMS is highly efficient and successful for substation communication networks which are local area networks having fixed communication system topology, lesser security needs and low scalability. On the contrary, when this approach is adopted for a microgrid smart grid communication network which is a wide area network it could lead to compromise in cyber security and information confidentiality. Even more, a microgrid network especially having a high penetration of EVs is a rapidly changing network in terms of rapid plugging and unplugging of EVs and due to presence of many intermittent power resource. Thus, this MMS based SCSM scheme does not suffice for such a dynamic WAN. Also, the present MMS based SCSM scheme does not provide robust security mechanisms for a wide area microgrid communication which at times is a public shared network. Thus, a middleware technology which supports dynamicity and robust data security is needed for smartgrid/microgrid communication network. Several middleware technologies such as YAMI4, ICE, OPC-UA, WAMP (JSON), ZeroMQ, MQTT and XMPP can be adopted for smartgrid/microgrid communication [29], [30]. A brief comparison among the existing middleware technologies is presented in Table 4.

Among several middleware solutions, XMPP provides robust security mechanism, very high scalability and recommendation by the standard. Thus, it is chosen as the middleware technology for smartgrid/microgrid communication. XMPP is currently employed in chat applications where clients and servers reside beside a firewall. All XMPP connections are initiated through a central server, thus avoiding any inbound connections on client side. In XMPP technique, XMPP clients connects to the XMPP servers of their domain in a WAN. These XMPP client interacts with the XMPP server in its domain through pieces of XML data known as stanzas. The domain of XMPP clients-server is identified through a unique system identifier called as JabberID (JID). The XMPP clients have a JID format as ‘client_name@domain.org’ and XMPP server has a JID format as ‘domain.org’. When the XMPP clients need to exchange information among themselves they do so via the XMPP sever over the WAN. Here XMPP server acts as a router. All messages exchanges between XMPP clients and servers are over TLS secure connections which provides privacy and data integrity.
The mapping of ACSI services as SCSM to the new XMPP protocol with XML mapping is under development in IEC 61850-8-2 [31]. Instead of defining a new mapping for ACSI services to a pure XML messaging, IEC 61850-8-2 elected a serialization based on MMS following ASN.1 XER [32]. This is done in order to easily adopt the new XMPP protocol for smartgrid communication and to benefit from already existing MMS as well as to utilize the advantages of XML technology.

The XMPP communication follows a client server type interaction. The process occurs as follows. All IEC 61850 devices are hosted by XMPP clients. Then the XMPP client initiates a TCP/IP connection with the XMPP server. Once a TCP/IP connection is established,
a TLS connection is negotiated between the client and server. After completion of this process, the XMPP client and server are able to exchange XML data called as stanzas among each other. If an IEC 61850 client needs to send a message to another IEC 61850 server, it sends it through wrapping and unwrapping via XMPP client and server. Firstly, the IEC 61850 client sends an IEC 61850 request through the XMPP client it is hosted to. This request is received at the IEC 61850 server which is hosted by another XMPP client. The request is first received by the XMPP client-1, where the MMS request is wrapped in XER message format according to its encoding rules. It is then routed to the XMPP server and then to the XMPP client receiving the request message. Finally, it is unwrapped at the XMPP client receiving the request message and translates it to original IEC 61850 request and forwards it to IEC 61850 server. In a similar fashion, response message is also processed.

A. SECURITY CONSIDERATIONS IN SCSM 8-2 MAPPING

The security requirement for a smartgrid communication network is defined in terms of availability, data integrity, authentication, and confidentiality [33]. Availability defines that the smartgrid communication network is readily present and can support data exchanges whenever required. Integrity ensures that the data that has been sent from the sender is received at the receiver in identical form and has not been tampered in transit. Authentication ensures that the sender and receiver or the communication peers are properly identified, and no false peer is involved in the communication process which can leak or hack any information. Confidentiality ensures that the data has not been accessed before it reaches the destination by any unauthorized peer or person.

Since the XMPP communication works in two layers, i.e. an IEC 61850 client/server is hosted first as XMPP client and secondly all XMPP messages are transferred through XMPP server, the XMPP communication connections are broadly classified as End-to-Middle (E2M) transport layer connections and End-to-End (E2E) application layer connections. E2M transport layer connections exist between the XMPP client-server or server-server whereas E2E application layer connections are between IEC 61850 client-server. The SCSM 8-2 mapping security mechanisms are provided at both the layers. The E2E and E2M security is depicted in Fig. 3.

In E2M transport layer communication authentication, data integrity and confidentiality are provided by implementation of two security protocols Transport Layer Security (TLS) and Simple Authentication and Security Layer (SASL). In TLS protocol an SSL/TLS profile is defined which is used to encrypt the data so as to protect it from tampering and eavesdropping. In XMPP client server communication, after establishment of TCP connection, a TLS connection is negotiated by exchanging ‘STARTTLS’ commands and X.509 certificates. After TLS negotiation, all the data transmissions are encrypted and thus become secure. In this way integrity and confidentiality is ensured in E2M communication. After TLS negotiation phase is over, SASL authentication occurs. The SASL authentication validates the end peers, for carrying out XMPP client- server communication.

The E2E application layer security is achieved by implementing MMS secure session through End to End Security Protocol (E2E SecProtocol) as specified by IEC 62351-4 [33]. In the E2E SecProtocol, an initial handshake operation occurs in configuration phase. The IEC 61850 client-server exchange the E2ESecProtocol mapped ‘Handshake_request’ and ‘Handshake_accept’ messages respectively. The confidentiality parameters in relation to the encryption type is contained in these handshake messages. The digital signature is present in authenticator field. After proper exchange of these handshake messages, IEC 61850 client server end points are validated. This step ensures authentication in E2E security. The data exchanges are encrypted by using symmetric cryptographic algorithms. This ensures the integrity and confidentiality of the exchanged messages in application layer for SCSM 8-2 mappings.

B. DATA MAPPING TO XMPP BASED MICROGRID NETWORK

In order to demonstrate the above-mentioned ASN.1 XER message exchanges for EM, a microgrid test system as shown in Fig.4 is considered. It consists of several DERs such as Wind Power Plant, PV Power Plant, CHP and EV charging stations along with their control IEDs located at different buses. These DER control IEDs and MGCC behave as XMPP clients and can connect to the XMPP server, in the same domain, through a WAN. The XMPP clients exchange pieces of XML stanzas via the XMPP server. The IEC 61850 based XMPP communication network for the microgrid test system is shown in Fig.5.

XMPP clients and server possess unique JID address such as ‘pv1@microgrid.com’ for PV plant, ‘evse1@microgrid.com’ for charging station 1 of EV, ‘mgcc@microgrid.com’ for MGCC and similarly for other IEDs. Initially all the XMPP clients establish a TCP connection with the XMPP server. Once the TCP connection is established a TLS connection is negotiated between the XMPP client and XMPP server. TLS is a cryptographic protocol which is used here to provide privacy and data integrity between XMPP client and XMPP server. Over the established TCP connection with TLS
For the sake of clarity and omitting redundant information, communication flows for EVSE is only demonstrated. The EVSE updates its charging and discharging rating along with available discharging capacity to MGCC as per (37).

\[
\text{EVChargingStationControlIED}\_\text{ESE}\_\text{DESE} \rightarrow \text{MGCC}
\]

The MGCC then updates respective DER control IEDs with the settings of operation. The communication flow for updating target power of a CS to provide power is updated as (38).

\[
\text{MGCC} \rightarrow \text{mgcc}@\text{microgrid.com} \rightarrow \text{microgrid.com} \\
\rightarrow \text{evse1}@\text{microgrid.com} \\
\rightarrow \text{EVChargingStationControlIED}\_\text{DESE} \\
\rightarrow \text{MGCC}
\]

The target settings are also communicated to other CS of EVSE2 in the same manner as given by (38). The MGCC updates the setting values to respective DERs for the EM after a fixed interval of time or whenever status of DER or load changes. On similar lines, communication flows for other cases also occurs.

Over established XMPP-based message flows between MGCC and DER control IEDs (i.e. PV, Wind, CS etc.), it is demonstrated that the EM in microgrids works effectively for both G2V and V2G support.

**VI. CONCLUSION**

This paper, is the first attempt to, propose a standardized communication based Energy Management for microgrids with a high penetration of electric vehicles. For an interoperable and standardized communication infrastructure, IEC 61850 based modeling for various components of microgrids has been adopted in this paper. The typical IEC 61850 based information modeling for EV components (such as charging unit i.e. EVSE and electric vehicle i.e. EV) has been extended to include V2G support i.e. discharging operation of EV in microgrid. Thus, the EV can provide G2V as well as V2G participation in microgrid. Based upon three distinct cases for EV participation, it is found that all these cases require different dispatch arrangements for EM, hence effective coordination/communication is essential. This communication is proposed through an XMPP protocol in a wide area microgrid network. The use of XMPP protocol for communication provides network security and scalability.

This work aims to provide future insight in to develop IEC 61850 communication model i.e. EV and design an XMPP based service mappings for microgrid communication network. This new XMPP based service mapping will ensure scalability and robust security for microgrid communication network.
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