Remote Monitoring of Electric Vehicle Charging Stations in Smart Campus Parking Lot

Mohamed A. Ahmed, Mohamed R. El-Sharkawy, and Young-Chon Kim

Abstract—Smart parking lots are smart places capable of supporting both parking and charging services for electric vehicles (EVs). In order to manage EV charging, the parking lot local controller (PLLC) requires data exchange with EV charging stations (EVCSs) through communication infrastructures. However, data losses and communication delays are unavoidable and may significantly degrade the system performance. This work aims to investigate the underlying communication networks for remote monitoring of EVCSs in a smart campus parking lot. The communication network consists of two subnetworks: parking area network (PAN) and campus area network (CAN). PAN covers communication among EVs, charging stations and PLLC, while CAN enables dedicated communication between PLLCs and a global controller of the university. As one of the major obstacles in EV system is the lack of unified communication architecture to integrate EVCS in the power grid, we develop communication models for the in-vehicle system and EVCSs based on logical node concept of IEC 61850 standard. Furthermore, we implement network models for EVCSs using OPNET modeler. Different communication technologies and configurations are considered in modeling and simulations, and end-to-end delay is evaluated and discussed.

Index Terms—Communication network, electric vehicle (EV), electric vehicle charging station (EVCS), IEC 61850, OPNET, smart parking lot.

I. INTRODUCTION

ELECTRIC vehicles (EVs) have been given a growing interest as an enabling technology to decrease carbon dioxide emissions and reduce oil dependence. To significantly achieve these targets, many countries have set ambitious plans for the deployment of EVs, supported by policies and regulations. In Korea, there are three ministries involved in implementing the EV policies, which are Ministry of Land, Infrastructure, and Transport (MOLIT), Ministry of Environment (MOE) and Ministry of Trade, Industry and Energy (MOTIE) [1]. By 2020, the estimated number of EVs in Korea would be around 200000. Among major provinces, Jeju Self-Governing Province announces a targeted plan of replacing all conventional vehicles to 100% electric models by 2030 [2].

Currently, the service of EV charging is provided in many parking lots and places, in some cases for free. However, the process of charging and discharging cannot be achieved without reliable communication among EVs, charging stations and power grid [3]. As the number of EVs is continuously increasing, the charging might not be visible without real-time monitoring. The EV system consists of EVs, EV charging stations (EVCSs), electric power connections, intelligent electronic devices (IEDs) and meters. In order to manage, optimize, and coordinate the integration of EVs in the power grid, sensor nodes, metering devices and reliable communication infrastructures are needed as fundamental elements in EV systems [4].

Many research work and studies have been conducted to investigate the influence of EV charging on the distribution system from the perspectives of power and communication. With respect to the power grid, the impact of EV charging is expected to be significant in view of power losses, power quality, voltage deviations, harmonics and frequency shift [5]-[7]. While most of the research has focused on optimizing the behavior of vehicle charging, communication network and the underlying communication infrastructures have been less defined and discussed [8]-[10]. Some studies have assumed that the communication channels between EVs and control operators are available [9], confidential and authenticated [10]. Table I shows various communication technologies considered for the EV system [11]-[18]. In Table 1, SM stands for smart meter; CAG stands for central aggregator; LAG stands for local aggregator; EVSE stands for EV supply equipment; EMU stands for energy management unit; V2H stands for Vehicle-to-home; V2V stands for vehicle-to-vehicle; WMN stands for wireless mesh network; PLC stands for power line communication; WiMax stands for worldwide interoperability for microwave access; WAN stands for wide area network; and LAN stands for local area network.
Many authors have presented different solutions in order to provide real-time monitoring for the EV system, including EVs and charging stations. Reference [11] proposes a secure communication architecture for achieving privacy for monitoring EVs as well as rewarding processes in vehicle-to-grid (V2G) networks. Reference [12] presents a communication architecture in private parking lots. Different communication technologies are considered at different levels. Reference [13] evaluates the performance of the communication network in a charging station using an optimized network emerging tool simulator. Reference [14] analyzes the network infrastructure and communication networking for EVs in a centralized charging station, while [15] proposes a two-tier software defined networking (SDN) framework for EVs in the smart grid. In the existing literature, the realizations of scheduling and control techniques that are used for EV charging coordination require appropriate communication infrastructures and two-way communications among EV subsystems. However, most of the literature above does not consider the underlying communication infrastructure as part of the EV system, while others assume perfect communication networks. These assumptions are not accurate as data losses and communication delays are unavoidable and may degrade the system performance.

The key to realize future smart grid applications such as EVs is to select appropriate communication technologies that support reliable end-to-end communication network. This work aims to address the knowledge gap of communication network modeling and simulation of the EV system by developing communication models for the in-vehicle system and EVCS based on logical node concept of IEC 61850 standard, in order to facilitate a seamless grid integration of EVs. A case study is considered for a parking lot in a university campus. There are several parameters that need to be considered in order to design the communication model for the EV system such as types of monitoring data, traffic volume, communication requirements and candidate technologies. The main contributions of this work are as follows.

1) Propose a framework to design, simulate and evaluate the performance of communication network architecture for campus parking lots, which consist of EVs, charging stations, local controllers of parking lot and a university control center.

2) Develop a communication model for the EV system and the EV charging station based on the logical node concept of IEC 61850 standard to facilitate the integration with the power grid.

3) Implement communication models using OPNET modeller for different scenarios applied to parking lots in Chonbuk National University, Jeonju, South Korea, as a case study.

4) Evaluate the performance of the proposed communication models for different communication technologies (Ethernet and WiFi) with respect to end-to-end delay and data loss.

This paper is structured as follows. The campus EV system is described in Section II. In Section III, we propose a two-layer architecture for communication network of campus EV system and develop a communication model for EV and charging station based on IEC 61850 standard. Section IV provides the performance evaluation of a case study of a university campus. Finally, Section V concludes the paper and gives directions for future work.

II. CAMPUS EV SYSTEM

The electric distribution network is the final part of the electric power system which interfaces with consumers and supports both consumers and charging stations [17]. Distribu-
tion feeders support the electric power transfer from the electric substation to end-consumers (residential, industrial and commercial) where different protection devices are used to improve power quality, safety and reliability. These protection devices include automatic switches, circuit breakers (CBs), reclosers, capacitors, lightning arresters and fuses [19]. Based on end-user voltage requirements, transformers are used to step down the voltage to an appropriate level for residential, industrial and commercial applications.

Figure 1 shows a schematic diagram for a campus EV system, where SCADA stands for supervisory control and data acquisition. The major components are EVs, charging stations, electric power connections and communication networks. The communication network layer plays a major role in real-time monitoring of both the EVs and charging stations. At the distribution system level, communication networks are responsible for gathering local measurements such as voltage, current and power from all feeders, transformers and charging stations. At the lower level, communication networks enable local control centers of parking lots to manage the charging operation of EVs.

There are two types of strategies that could be considered for remote monitoring of EVCSs: centralized and decentralized. The centralized architecture requires direct communication between the university control center and individual charging stations in order to manage the charging operation, and control voltage deviations in the campus power network. Data collected from charging stations are processed and stored at the university control center. In the decentralized architecture, the charging operation and decision are taken individually at the level of parking lot.

Previous research works have attempted to schedule EV charging in order to overcome the peak load demand [20]-[29]. Different schemes and techniques have been considered for managing charging/discharging of EVs. However, most of these studies are lacking the underlying communication infrastructure. Communication infrastructures are crucial technologies which play an important role in the operation, monitoring and protection of EV systems. Various types of equipment (sensors, meters, protection devices, etc.) transmit measured information to the control center which will enable important decisions. Any failure in the communication infrastructure may affect system observability and result in a negative impact on the reliability and safety of the EV system.

III. COMMUNICATION NETWORK FOR SMART CAMPUS PARKING LOTS

Figure 2 shows the communication network for the campus EV system. It consists of two hierarchical levels: parking lot local controller (PLLC) centers and a campus central control center (CCC). The function of PLLC is to monitor and control the EV charging based on local measurements from sensor nodes and measurement devices. Monitoring data from EVs could be collected using short-range communication while vehicles are plugged into the charging station. PLLCs are able to communicate with EVs, charging stations as well as the CCC. CCC gathers local measurements from the electrical power system such as voltage, current and power from all feeders and transformers.

Monitoring data from EVCSs at different PLLCs are aggregated at CCC. The main role of the CCC is overall management and control of charging stations as well as the electrical power system. The CCC is the highest level in the system and all data received from different parking lots are stored and processed for appropriate decisions, as shown in Table II. The network connection between charging stations and the control center could be implemented using both wired and wireless communication technologies. WiFi and ZigBee are suitable wireless solutions that cover a small network size in parking area network (PAN) and building area network (BAN). The campus area network (CAN) is a middle range between PAN and WAN. The wireless communica-
tion between CCC and EVCSs could be realized through long-range communication technologies such as WiMAX, 2G/3G, LTE, etc.

### TABLE II
MONITORING SCOPE OF EVCS

| Level          | Monitoring scope | Network coverage |
|----------------|------------------|------------------|
| Monitoring     | EVs, EVCS, IEDs  | LAN, PAN         |
| Central        | Feeder, substation | CAN, WAN       |

A. Monitoring of In-vehicle System

The major components of the in-vehicle system are a vehicle body, a frame, a battery, an electric motor, a motor controller, a battery management system (BMS), a plug-in charger, a wiring system and a braking system. The in-vehicle system includes many sensor nodes that provide information about internal battery status and enable communication with charging stations.

BMS is a critical part of the in-vehicle system which is responsible for monitoring and controlling the charging/discharging of the battery. Different sensor nodes such as temperature, voltage, and current are used to monitor the battery status [30]. During EV charging, BMS maintains monitoring the internal data of the battery to prevent abnormal conditions (e.g. overheating, overvoltage, etc.) [31]. If any monitoring parameter exceeds their values, BMS stops the charging and generates alarms that indicate the fault.

B. Monitoring of EVCSs

EVCS is the interface between the power grid and EV. The main function of an EVCS is to support EV charging/discharging during the connection. Charging stations are installed at different places including homes, parking lots and fast charging stations, based on the charging location of EV. We classify charging stations into two types: blind EVCSs and networked EVCSs. The blind EVCS system has the basic charging function. EVCS supports EV charging at low voltage. However, no external monitoring or control information is exchanged with the grid side. The networked EVCS system offers additional functions compared with blind EVCSs. It periodically transmits monitoring measurements (status information and analogue measurement) to a local controller in a smart house, a smart building, a parking lot or a charging station. During the service of charging, EVCS exchanges information with EVs such as charging mode, metering, and payment. Also, the maintenance system operator keeps receiving, storing and analyzing the monitoring data from all EVCSs. In the case of any fault or malfunction, the charging service is disabled till the unit is fixed.

IEC 61850 standard is an international standard used for the communication in substations. The standard is being extended to cover other domains in the electric power system. In this work, we define the measuring requirements of EV system based on the IEC 61850 standard, as shown in Table III. We consider the logical node data models in [32]-[35], which are an extension of IEC 61850 standard for EV charging.

In campus EV system, charging stations are considered as devices that generate monitoring data related to their status and communicate and exchange information with other domains such as EVs, electric power system and operation and maintenance (O&M) service. PLLC is able to manage and control the EV charging based on the charging request from the EVCS. Figure 3 shows the architecture model of the EV system and all associated logical nodes. The system consists of an EV, a DC switch, a charging station, a CB and measuring devices.

Equations (1) and (2) show the logical nodes of EV $EV_{LN}$ and EVCS $EVCS_{LN}$ which include the basic parameters and information required to manage the operation and interaction with end-user as well as the power grid.

$$EV_{LN} = \{Z_{BAT}, Z_{RTC}\}$$

(1)

$$EVCS_{LN} = \{Z_{INV}, Z_{RECT}, M_{SOC}\}$$

(2)

Both the DC switch $SW_{LN}$ and the CB $CB_{LN}$ are modeled by $C_{SWI}$ and $X_{CBR}$, as shown in (3).

$$CB_{LN} = SW_{LN} = \{C_{SWI}, X_{CBR}\}$$

(3)

We define the architecture model of EVCSs based on IEC 61850 standard. It consists of $M_{MIT}$, $X_{CBR}$, and supply equipment communication controller (SECC). The attribute of EVCS includes status information (SI), analogue measurements AM and control information CI. The status information of EVCS indicates the status of the meter and the breaker, whether it is switched on or off. The charging parameters of AM include measurements such as charging voltage EVC-SPhV, charging current EVCSA, grid frequency EVCSHz, and charging active power EVCSW, as given in Table IV.
Charging stations are also equipped with different protection and control devices such as CB-IED and protection and control IED (P&C IED). These devices are responsible for exchanging protection and control information with PLLC.

**TABLE IV**

| Attribute of EVCS | Name of attribute | Explanation |
|-------------------|-------------------|-------------|
| SI                | MeterStatus       | Meter status on/off |
|                   | BreakerStatus     | Breaker status on/off |
| AM                | EVCSPhV           | Charging voltage |
|                   | EVCSA             | Charging current |
|                   | EVCSW             | Charging active power |
| CI                | V2Genable         | Switch on/off V2G |
|                   | EconCharge        | Immediate/economy charging |

### IV. NETWORK MODELING AND SIMULATION

This section presents network modeling and simulation using OPNET modeler. The OPNET modeler is one of the most widely used network simulators that include a comprehensive library of all network elements, models and protocols that allow network planners to implement and validate their future designs. We consider EVCSs that are deployed in a smart parking lot of a university campus. Table V provides a detail description of the network configuration.

**TABLE V**

| Parking lot | Network content | Configuration |
|-------------|-----------------|---------------|
| PAN         | Charging station | 1 workstation |
|             | Ethernet switch  | 1 switch |
|             | Wired media      | Ethernet (IEEE 802.3) |
|             | Wireless media   | WiFi (IEEE 802.11) |
| Control center | Server         | 1 server |
|               | PLLC             | 1 workstation |

We develop a communication network model for a smart parking lot in OPNET. Each EVCS transmits their monitoring data continuously toward the PLLC server. In order to calculate the data size generated from sensor nodes and measurement devices, we define the sampling rate and the number of channels. We assume that the sample size is 2 bytes (16 bits) based on [36]. The data rate \( R \) is calculated according to (4).

\[
R = 2N_c f_s
\]

where \( N_c \) is the number of channels; and \( f_s \) is the sampling frequency.

Table VI shows the measuring requirements for different sensors and measuring devices.

Based on the battery state of charge (SoC), the EV charging is monitored in real-time using PLLC. The dimensions of the network are set as 100 m × 60 m. We consider two operation modes for EVCS: idle mode and charging mode. The average data transmission rate of EVCS \( R_{EVCS} \) is given in (5).

\[
R_{EVCS} = R_{idle} P_{idle} + R_{charging} P_{charging}
\]

where \( R_{idle} \) is the data transmission rate of EVCS in the idle operation mode; \( P_{idle} \) is the probability of the idle operation mode; \( R_{charging} \) is the data transmission rate of EVCS in the charging operation mode; and \( P_{charging} \) is the probability of the charging operation mode.

Table VII shows the classification of data types and the operation modes of EVCS. Note that the monitoring data related to vehicle ID, charging type, voltage, current, and power are transmitted only during EV charging mode. We simulate different scenarios for monitoring EVCSs. Two different technologies are considered: Ethernet and WiFi. Each wired/wireless workstation represents an EVCS. For example, with 20 EVCSs, the Ethernet-based scenario consists of 20 workstations and one server, while 20 wireless workstations and one wireless server are considered for the WiFi scenario.

The following metrics have been considered in the performance evaluation.

1) Server FTP traffic represents the average bytes per second forwarded to the FTP application by the transport layer in the server node.

2) End-to-end delay of Ethernet is the amount of time in seconds for data to be delivered from source to destination along the communication path.

3) Wireless end-to-end delay represents the end-to-end delay of all packets received by the wireless LAN MACs of all WLAN nodes in the network and forwarded to the higher layer.

Figure 5 shows the total received traffic at PLLC server with 10 EVCSs. The total monitoring data received are 7200
byte/s, 7200 byte/s, 20 byte/s, 20 byte/s and 20 byte/s for current, voltage, CB status, EV-ID, and meter status, respectively. Note that no traffic receives from voltage and current sensors while the EVCS is in an idle mode. All transmission and reception of sensing data are received successfully.

### Table VII

**Classification of EVCS Data Types Based on Operation Modes**

| Data type     | Idle mode | Charging mode |
|---------------|-----------|---------------|
| Station ID    | √         | √             |
| Charger ID    | √         | √             |
| Meter status  | √         | √             |
| CB status     | ×         | √             |
| Vehicle ID    | √         | ×             |
| Charging type | ×         | √             |
| Voltage       | ×         | √             |
| Current       | ×         | √             |
| Frequency     | ×         | √             |
| Power         | ×         | √             |

Figure 6 shows the end-to-end delay for Ethernet-based architectures in a smart parking lot with 1, 5 and 10 EVCSs. With 10 EVCSs, the end-to-end delay is about 4.96 ms during idle mode and 12.73 ms during the charging mode, considering a link capacity of 10 Mbit/s, while the end-to-end delay is about 0.49 ms during idle mode and 1.218 ms during the charging mode, considering a link capacity of 100 Mbit/s.

![End-to-end delay for Ethernet-based architectures in a smart parking lot with 1, 5 and 10 EVCSs.](image)

Figure 7 shows the end-to-end delay for Ethernet-based architectures with 20, 40 and 80 EVCSs. Considering link capacity of 10 Mbit/s, the end-to-end delay increases from 8.80 ms (20 EVCSs) to 27.76 ms (80 EVCSs) during the idle mode and from 21.86 ms (20 EVCSs) to 71.66 ms (80 EVCSs) during the charging mode. In the case of 80 EVCSs with link capacity of 100 Mbit/s, the end-to-end delay increases from 2.85 ms during the idle mode to 7.37 ms during the charging mode. Table VIII shows the simulation results of end-to-end delay for monitoring data in the case of Ethernet-based architectures.

![End-to-end delay for Ethernet-based architecture in a smart parking lot with 20, 40 and 80 EVCSs.](image)

### Table VIII

**End-to-end Delay for Ethernet-based Architectures of EVCS**

| EVCS | 10 Mbit/s | 100 Mbit/s |
|------|-----------|------------|
|      | Idle mode | Charging mode | Idle mode | Charging mode |
| 1    | 0.000679  | 0.001335   | 0.000069 | 0.000114 |
| 5    | 0.002550  | 0.006370   | 0.000250 | 0.000586 |
| 10   | 0.004960  | 0.012730   | 0.000490 | 0.001218 |
| 20   | 0.008801  | 0.021867   | 0.000915 | 0.002250 |
| 40   | 0.018136  | 0.046216   | 0.001877 | 0.004802 |
| 80   | 0.027766  | 0.071662   | 0.002853 | 0.007374 |

Figure 8 shows the wireless end-to-end delay using a data rate of 54 Mbit/s. The maximum end-to-end delays during the idle mode are 36.64 ms, 23.34 ms, 13.46 ms, 6.77 ms and 1.48 ms for 40 EVCSs, 20 EVCSs, 10 EVCSs, 5 EVCSs, and 1 EVCS, respectively. However, the maximum end-to-

![End-to-end delay for remote monitoring of electric vehicle charging stations in smart campus parking lot.](image)
end delays during the charging mode are 109.57 ms, 43.99 ms, 26.18 ms, 17.48 ms and 3.73 ms for 40 EVCSs, 20 EVCSs, 10 EVCSs, 5 EVCSs and 1 EVCS, respectively. Table IX shows the simulation results of end-to-end delay for monitoring data in the case of WiFi-based architectures using a data rate of 54 Mbit/s.

Figure 8 shows the wireless end-to-end delay using a data rate of 11 Mbit/s. The maximum end-to-end delays during the idle mode are 54.43 ms, 27.70 ms, and 5.93 ms for 10 EVCSs, 5 EVCSs and 1 EVCS, respectively. However, the maximum end-to-end delays during the charging mode are 119.71 ms, 71.03 ms and 15.65 ms for 10 EVCSs, 5 EVCSs and 1 EVCS, respectively. However, the maximum end-to-end delays during the charging mode are 109.57 ms, 43.99 ms, 26.18 ms, 17.48 ms and 3.73 ms for 40 EVCSs, 20 EVCSs, 10 EVCSs, 5 EVCSs and 1 EVCS, respectively. Table IX shows the simulation results of end-to-end delay for monitoring data in the case of WiFi-based architectures using a data rate of 54 Mbit/s.

Figure 9 shows the wireless end-to-end delay using a data rate of 11 Mbit/s. The maximum end-to-end delays during the idle mode are 54.43 ms, 27.70 ms, and 5.93 ms for 10 EVCSs, 5 EVCSs and 1 EVCS, respectively. However, the maximum end-to-end delays during the charging mode are 119.71 ms, 71.03 ms and 15.65 ms for 10 EVCSs, 5 EVCSs and 1 EVCS, respectively.

Figure 8. End-to-end delay for WiFi-based architecture in a smart parking lot with 1, 5, 10, 20 and 40 EVCSs.

Table IX shows the simulation results of end-to-end delay for monitoring data in the case of WiFi-based architectures using a data rate of 11 Mbit/s. It is observed that using WiFi with a data rate of 11 Mbit/s is not sufficient for data transmission with 20 EVCSs. Figure 10 shows data loss in the received traffic at the parking lot control center with 20 EVCSs for CB status, charger ID and EV-ID.

Table X shows the simulation results of end-to-end delay for monitoring data in the case of WiFi-based architectures using a data rate of 11 Mbit/s. It is observed that using WiFi with a data rate of 11 Mbit/s is not sufficient for data transmission with 20 EVCSs. The data received from EVCSs could be used for other applications such as energy management system and distribution automation. Based on communication requirements for V2G and

| EVCS | Idle mode | Charging mode |
|------|-----------|---------------|
| Min  | Max       | Min           | Max           |
| 1    | 0.003060  | 0.001480      | 0.003333      | 0.003737      |
| 5    | 0.006304  | 0.0067739     | 0.016424      | 0.017486      |
| 10   | 0.012860  | 0.0134655     | 0.025168      | 0.026184      |
| 20   | 0.0224360 | 0.0233471     | 0.041104      | 0.043993      |
| 40   | 0.0355109 | 0.0366470     | 0.080671      | 0.109576      |

Fig. 9. End-to-end delay for WiFi-based architecture in a smart parking lot with 1, 5, 10 and 20 EVCSs.

Fig. 10. Received traffic from EVCSs at the parking lot control center with 20 EVCSs using WiFi-based architecture with a data rate of 11 Mbit/s.

V. CONCLUSION

In this work, we investigate the design, simulation and evaluation of remote monitoring of EVCSs in a smart parking lot. A real parking lot in Chonbuk National University, Jeonju, South Korea is considered as a case study. We develop the communication network model for the EV system in OPNET modeler based on logical node concept of IEC 61850 standard. Types of monitoring data and traffic volume are defined, calculated and discussed. Ethernet-based and WiFi-based are two promising technologies considered and evaluated. Different scenarios are configured and simulated with respect to link capacity and end-to-end delay. Based on the simulation results, Ethernet-based architectures show better performance with a lower end-to-end delay compared with WiFi-based architectures.

The maximum end-to-end delay for monitoring 80 EVCSs is about 2.85 ms during the idle mode and about 7.37 ms during the charging mode, considering Ethernet-based architecture with a link capacity of 100 Mbit/s. In the case of WiFi-based architecture, the end-to-end delay is about 27.76 ms during the idle mode and about 71.66 ms during the charging mode, for a data rate of 54 Mbit/s. WiFi-based architecture using a data rate of 11 Mbit/s is able to support data transmission of up to 10 EVCSs. However, it is not sufficient to support data transmission with 20 EVCSs. The data received from EVCSs could be used for other applications such as energy management system and distribution automation. Based on communication requirements for V2G and
grid to vehicle (G2V), the results of end-to-end delay for Ethernet-based architectures satisfy the power system requirements. This work will be extended to support the peer-to-peer energy trading among EVs in a university campus.

REFERENCES

[1] S. K. Hwang, “Comparative study on electric vehicle policies between korea and EU countries,” World Electric Vehicle Journal, vol. 7, no. 4, pp. 692-702, Dec. 2015.

[2] Jeju Research Institute. (2018, Feb.). Jeju EV Monthly Report on the Trends and Statistics of Jeju EV. [Online]. Available inline: http://jeju.re.kr/contents/index.php?mid=6413

[3] C. Tsiolindis, P. Chatzinikos, B. Flynn et al., “Distribution systems, substations, and integration of distributed generation,” in Electrical Transmission Systems and Smart Grids. New York, USA: Springer, 2013, pp. 7-68.

[4] M. A. Ahmed and Y.-C. Kim, “Performance analysis of communication networks for EV charging stations in residential grid,” in Proceedings of the 6th ACM Symposium on Development and Analysis of Intelligent Vehicular Networks and Applications, Miami, USA, Nov. 2017, pp. 63-70.

[5] A. Dube and S. Santoso, “Electric vehicle charging on residential distribution systems: impacts and mitigations,” IEEE Access, vol. 3, pp. 1871-1893, Jan. 2015.

[6] W.-J. Park, K.-B. Song, and J.-W. Park, “Impact of electric vehicle penetration-based charging demand on load profile,” Journal of Electrical Engineering Technologies, vol. 8, no. 2, pp. 244-251, Mar. 2013.

[7] P.-Y. Kong and G. K. Karagiannidis, “Charging schemes for plug-in hybrid electric vehicles in smart grid: a survey,” IEEE Access, vol. 4, pp. 6846-6875, Nov. 2016.

[8] O. I. Aloqaily, I. Al-Anbagi, D. Said et al., “Flexible charging and discharging algorithm for electric vehicles in smart grid environment,” in Proceedings of 2016 IEEE Wireless Communications and Networking Conference, Doha, Qatar, Apr. 2016, pp. 1-6.

[9] C. Rotondi, S. Fontana, and G. Verticale, “Enabling privacy in vehicle-to-grid interactions for battery recharging,” Energies, vol. 7, no. 5, pp. 2780-2798, Apr. 2014.

[10] E. Akhavan-Rezai, M. F. Shaaban, E. F. El-Saadany et al., “Optimal energy management scheme for electric vehicle charging parks involving sustainable energy,” IEEE Transactions on Sustainable Energy, vol. 5, no. 2, pp. 577-586, Apr. 2014.

[11] L. Yao, Z. Damiran, and W. H. Lim, “Optimal charging and discharging scheduling for electric vehicles in a parking station with photovoltaic system and energy storage system,” Energies, vol. 10, no. 4, p. 550, Apr. 2017.

[12] V. Lakshminarayanan, S. Pramanick, K. Rajashekar et al., “Optimal energy management scheme for electric vehicle integration in microgrid,” in Proceedings of 2017 IEEE 16th International Conference on Smart Energy Grid Engineering (SEGE), Osaka, Canada, Aug. 2015, pp. 1-6.

[13] G. Lopez, V. Custodio, F. J. Herrera et al., “Machine-to-machine communications infrastructure for smart electric vehicle charging in private parking lots,” International Journal of Communication Systems, vol. 27, no. 4, pp. 643-660, Apr. 2014.

[14] X. Ye, F. Wen, S. P. Ang et al., “OPNET-based performance analysis of the communication network in a charging station of electric vehicles,” in Proceedings of 2014 IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC), Hongkong, China, Dec. 2014, pp. 1-6.

[15] D. Gao, J. Cao, Y. Zhang et al., “Communication networking schemes for wide area electric vehicle energy service network,” Energy Power Engineering, vol. 5, no. 4, pp. 1415-1420, Jan. 2013.

[16] N. Chen, M. Wang, N. Zhang et al., “SDN-based framework for the PEV integrated smart grid,” IEEE Network, vol. 31, no. 2, pp. 14-21, Mar. 2017.

[17] G. Kiokes, E. Zountouridou, C. Papadimitriou et al., “Development of an integrated wireless communication system for connecting electric vehicles to the power grid,” in Proceedings of 2015 International Symposium on Smart Electric Distribution Systems and Technologies (EDST), Vienna, Austria, Sept. 2015, pp. 296-301.

[18] J. S. Bayram and I. Papapanagiotou, “A survey on communication technologies and requirements for internet of electric vehicles,” EURASIP Journal of Wireless Communication Networks, vol. 2014, no. 1, p. 223, Dec. 2014.

[19] C. Liu, K. T. Chau, D. Wu et al., “Opportunities and challenges of vehicle-to-home, vehicle-to-vehicle, and vehicle-to-grid technologies,” Proceedings of IEEE, vol. 101, no. 11, pp. 2409-2427, Nov. 2013.

[20] R. M. Shukla, S. Sengupta, and A. N. Patra, “Smart plug-in electric vehicle charging to reduce electric load variation at a parking place,” in Proceedings of 2018 IEEE 8th Annual Computing and Communications Workshop and Conference (CCWC), Las Vegas, USA, Jan. 2018, pp. 632-638.

[21] C. S. Ioakimidis, D. Thomas, P. Rycerzki et al., “Peak shaving and valley filling of power consumption profile in non-residential buildings using an electric vehicle parking lot,” Energy, vol. 148, pp. 148-158, Apr. 2018.

[22] D. Said and H. T. Moutfah, “A novel electric vehicles charging/discharging scheme with AD management protocol,” in Proceedings of 2017 IEEE International Conference on Communications (ICC), Paris, France, May. 2017, pp. 1-6.

[23] R. M. Shukla and S. Sengupta, “A novel software-defined network based approach for charging station allocation to plugged-in electric vehicles,” in Proceedings of 2017 IEEE 16th International Symposium on Network Computing and Applications (NCA), Cambridge, USA, Nov. 2017, pp. 1-5.

[24] E. Akhavan-Rezai, M. F. Shaaban, E. F. El-Saadany et al., “Online intelligent demand management of plug-in electric vehicles in future smart parking lots,” IEEE Systems Journal, vol. 10, no. 2, pp. 483-494, Jun. 2016.

[25] L. Yao, Z. Damiran, and W. H. Lim, “A fuzzy logic based charging scheme for electric vehicles parking station,” in Proceedings of 2016 IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC), Florence, Italy, Jun. 2016, pp. 1-6.

[26] A. A. Eajal, M. F. Shaaban, E. F. El-Saadany et al., “Fuzzy logic-based charging strategy for electric vehicles plugged into a smart grid,” in Proceedings of 2015 IEEE International Conference on Smart Energy Grid Engineering (SEGE), Ottawa, Canada, Aug. 2015, pp. 1-6.

[27] A. Mohamed, V. Salehi, T. Ma et al., “Real-time energy management algorithm for plug-in hybrid electric vehicle charging parks involving sustainable energy,” IEEE Transactions on Sustainable Energy, vol. 5, no. 2, pp. 577-586, Apr. 2014.

[28] L. Yao, Z. Damiran, and W. H. Lim, “Optimal charging and discharging scheduling for electric vehicles in a parking station with photovoltaic system and energy storage system,” Energies, vol. 10, no. 4, p. 550, Apr. 2017.

[29] V. Lakshminarayanan, S. Pramanick, K. Rajashekar et al., “Optimal energy management scheme for electric vehicle integration in microgrid,” in Proceedings of 2017 North American Power Symposium (NAPS), Morgantown, USA, Sept. 2017, pp. 1-6.

[30] F. Marra, D. Sacchetti, C. Traeholt et al., “Electric vehicle requirements for operation in smart grids,” in Proceedings of 2011 2nd IEEE PES International Conference and Exhibition on Innovative Smart Grid Technologies, Manchester, UK, Dec. 2011, pp. 1-7.

[31] X. Xing, E. W. M. Ma, K. L. Tsui et al., “Battery management systems in electric and hybrid vehicles,” Energies, vol. 4, no. 12, pp. 1840-1857, Oct. 2011.

[32] D. K. Kim, A. Alaerjan, L. Lu et al., “Toward interoperability of smart grids,” IEEE Communications Magazine, vol. 55, no. 8, pp. 204-210, Aug. 2017.

[33] W. Deng, W. Pei, Z. Shen et al., “Electric vehicle information exchange based on IEC 61850,” in Proceedings of 2014 IEEE Conference and Expo Transportation Electrification Asia-Pacific (ITEC Asia-Pacific), Beijing, China, Aug.-Sept. 2014, pp. 1-6.

[34] P. Nsonga, S. M. S. Hussain, I. Ali et al., “Using IEC 61850 and IEEE WAVE standards in AD-hoc networks for electric vehicle charging management,” in Proceedings of 2016 IEEE Online Conference on Green Communications (OnlineGreenComm), Piscatway, USA, Nov.-Dec. 2016, pp. 39-44.

[35] T. S. Ustun, C. R. Ozansoy, and A. Zayegh, “Implementing vehicle-to-grid (V2G) technology with IEC 61850-7-420,” IEEE Transactions on Smart Grids, vol. 4, no. 2, pp. 1180-1187, Jun. 2013.

[36] S. Wijetunge, U. Gunawardana, and R. Liyanapathirana, “Wireless sensor networks for structural health monitoring: considerations for communication protocol design,” in Proceedings of 2010 17th International Conference on Telecommunications, Doha, Qatar, Apr. 2010, pp. 694-699.

Mohamed A. Ahmed received the B.Sc. and M.Sc. degrees in Electrical Engineering from Minia University, Minia, Egypt, in 2003 and 2007, respectively. He received his Ph.D. degree in Electronics and Information Engineering from Chonbuk National University, Jeonju, South Korea in 2014.
He is currently working as an Assistant Professor in Department of Electronic Engineering, Universidad Técnica Federico Santa María (UTFSM), Chile. He is also an Assistant Professor in the Department of Communications and Electronics, Higher Institute of Engineering and Technology-King Marriott, Alexandria, Egypt. Prior to joining UTFSM, he worked as a post-doctoral research fellow at advanced communication and network Laboratory (AD-CAN), Chonbuk National University, South Korea, from 2014 to 2018. His research interests include wireless sensor networks, wind energy, EVs, smart grid, and cyber-physical systems.

Mohamed R. El-Sharkawy received the B.Sc., M.Sc., and Ph.D. degrees in Mechanical Engineering, Automotive & Tractors Engineering, from Minia University, Egypt, in 2003, 2007, and 2013, respectively. He is currently an Assistant Professor in Automotive & Tractors Engineering Department, Faculty of Engineering, Minia University, Egypt. His research interests include alternative fuel vehicles, EVs and vehicle emission.

Young-Chon Kim received the B.S., M.S., and Ph.D. degrees from Korea University, Seoul, South Korea, in 1980, 1982, and 1987, respectively. He joined the Department of Computer Engineering at Chonbuk National University, Jeonju, South Korea, in 1986, and is now a Professor in the School of Information Technology at Chonbuk National University. From 1989 to 1990, he was a post-doctorate fellow at the University of California, Irvine, USA. Also, from 1998 to 2000, he worked as a visiting researcher at the Network Research laboratory at the University of California, Davis, USA. He was awarded Best Professor from the College of Engineering, Chonbuk National University, in 2002. He was also awarded the Motorola Academic Excellence award in 2003. His research interests include high-speed optical communication networks, next generation IP networks, and broadband wireless communication networks.