

## SURVEY

# Enhancing Microgrid Operation Through Electric Vehicle Integration: A Survey

JAMES SORA<sup>1</sup>, IOAN SERBAN<sup>1</sup>, (Member, IEEE), AND DORIN PETREUS<sup>2</sup>, (Senior Member, IEEE)

<sup>1</sup>Department of Electrical Engineering and Applied Physics, Transilvania University of Brasov, 500036 Brasov, Romania

<sup>2</sup>Department of Applied Electronics, Technical University of Cluj-Napoca, 400114 Cluj-Napoca, Romania

Corresponding author: Ioan Serban (ioan.serban@unitbv.ro)

**ABSTRACT** The integration of renewable energy sources (RES) and electric vehicles (EVs) into microgrids (MGs) has significant potential for enhancing energy resilience, addressing environmental concerns, and promoting decentralized energy systems as a global shift towards sustainable energy solutions. Therefore, this survey paper provides a comprehensive discussion on improving MG operation through EV integration. This study evaluates the status of EV integration into MGs, focusing on technological advancements, and emerging trends, while pinpointing key technical challenges and opportunities. Furthermore, this paper examines the pivotal role of EVs in participating in vehicle-to-grid (V2G) services, providing ancillary support to improve MG performance. The importance of a reliable communication infrastructure for information exchange between EVs, EV charging stations (EVCSs), and MGs has been emphasized for the effective implementation of V2G services. This discussion extends to the contributions of EVs to primary, secondary, and tertiary MG controls. The paper also analyzes the integration of EVs into AC and DC MGs and further proposes configurations for both MG cases. Finally, the paper concludes by providing recommendations for future research to unlock the full potential of EV contributions to MG performance, thereby contributing to the ongoing advancement of sustainable and resilient energy systems. The key findings of this work include solutions for MG voltage and frequency regulation implemented through EV bidirectional converter power flow control, EV charger configurations for integration into AC and DC MGs, EV contributions in improving the MG's operational resilience and adaptability, and the noteworthy challenges arising from V2G implementation in such systems.

**INDEX TERMS** Electric vehicle charging, microgrids, renewable energy sources, vehicle-to-grid.

## I. INTRODUCTION

Global energy policies and industrial intentions to advance energy security have led to a significant increase in the demand for sustainable energy. Power generation based on traditional resources such as fossil fuels will not be able to meet these requirements, as these sources are becoming increasingly scarce and are highly polluting to the environment [1]. Renewable energy sources (RES) have seen remarkable technological improvements in recent years, which have led to their widespread adoption. The evolution of the global energy landscape towards RES not only offers an alternative solution to traditional power generation resources,

but also a sustainable way to mitigate climate change [2]. Despite the optimistic expectations in the establishment of RES, the stochasticity and unreliability of power production give rise to technical obstacles such as incorporating RES into the grid system due to these intermittent attributes. To stabilize and reduce power variations from RES, energy storage systems (ESS) are utilized in these systems [3]. During low demand periods, the ESS accumulates energy from the RES and returns this energy during periods when demand is high. In addition to employing an ESS, an alternative approach to address the variability and uncertainty of RES involves the implementation of demand-side management strategies. This entails transitioning from the conventional notion, in which generation follows consumption, to a paradigm in which consumption follows generation.

The associate editor coordinating the review of this manuscript and approving it for publication was Alexander Micallef<sup>1</sup>.

The concept of a microgrid (MG) was developed to provide a reliable and stable means of effectively integrating distributed energy resources (DER), that is, RES, ESSs, and loads to operate as a single unit. In addition to the established AC topologies, DC or hybrid MGs can also be adopted. Research on DC MGs has recently gained considerable momentum. The key motives behind the transition to DC MGs are the increasing penetration of RES and ESSs into the energy mix, predominantly supplying DC power, and the growing use of DC-powered equipment [4]. The DC distribution has proven to be a more efficient interface between RES and DC loads, including electric vehicle (EV) charging. Nonetheless, the broad dissemination of DC MGs is limited by insufficient knowledge and inadequate foundations for standards [5]. An MG can operate as a stand-alone system or in grid-connected mode. The capability to supply energy in an autonomous mode, whether because there is no access to the utility grid or its temporary unavailability, represents one of the key advantages of MGs. Typically, an MG has islanding capabilities, whereby it disconnects from the utility grid in the presence of potential grid faults [6]. This critical feature enables the continuation of MG operations, thereby meeting the power needs from DER. Thereafter, the islanded MG can be reconnected and synchronized to the grid after the disturbance has been removed [7]. Grid-connected MGs are becoming increasingly popular for business and residential applications, where they are used as prosumer systems. As active consumers, these entities participate in electricity market trading and receive incentives in return for their participation [8].

The transportation division is considered the world's largest energy consumer, largely attributed to its high population and economic growth [9]. The ever-growing energy demand has resulted in an energy crisis and extreme carbon dioxide emissions. Several countries have implemented mitigation plans to minimize carbon emissions, and electrifying transportation has emerged as a promising solution. Transport electrification through EVs has begun to dominate the automotive industry in the past decade as part of efforts to minimize the carbon footprint in the transportation sector [10]. The use of EVs does not only assist in decarbonization but also helps to reduce reliance on fossil fuels. Governments across the globe subsidize consumer taxes on EVs as a way of encouraging their use and promoting a transition towards a green economy. However, there are some challenges hindering the EV market from realizing its full potential including a shortage of charging infrastructure, battery cost, load variations, and lack of charging standardization. Research on transforming EVs from passive consumers to controllable loads through their interaction with the grid by the vehicle-to-grid (V2G) concept has been ongoing since the inception of EVs. In this regard, EVs have the potential to provide grid support by providing ancillary services [11]. Some of the services provided by EVs are active and reactive power control, voltage and frequency regulation, current harmonic filtering, and distributed storage systems. The use

of bidirectional chargers in the implementation of the V2G mode of operation is helpful for attaining resilient MGs [12].

Incorporating various components, such as RES, passive and active loads, and ESSs, the necessity for optimal energy management and power flow control within the MG has become essential, leading to the development of energy management systems (EMS). An EMS performs management on both the demand and supply sides to satisfy MG restrictions to achieve a reliable, sustainable, and economical MG operation [13]. The recent deployment of artificial intelligence (AI) techniques alongside classical techniques in EMSs to participate in EV charging scheduling and power generation forecasting has significantly assisted the efficient utilization of available RES power.

The reliability in the management and control of MG systems is closely tied to the used communication networks [14]. Effective communication technologies are essential for facilitating information sharing among the MG participants. In the context of the V2G approach, efficient and successful implementation of the associated V2G services requires a connection that allows the exchange of information between the charging infrastructure and EVs. Such ancillary services have demanding communication requirements (high reliability and low latency), as packet losses and communication delays lead to poor precision and financial losses [15]. The ISO 15118/2019 standard refers to communication in V2G networks, guaranteeing integrity, anonymity, non-repudiation, and confidentiality as far as network security is concerned [16].

#### **A. OPPORTUNITIES ARISING FROM THE INTEGRATION OF EVS INTO MGS**

The integration of EVs into the MG system offers an opportunity for EVs to contribute to MG control. V2G technology provides services including frequency control, reactive power compensation, harmonic filtering, voltage regulation, balance of the local distribution system, spinning reserve, and peak power shaving [17].

##### **1) FREQUENCY CONTROL**

As the main power generators in an MG, RESs provide fluctuating power owing to the weather-dependent output, thus making the MG more susceptible to frequency deviations [18]. By leveraging the V2G functionality, EVs can compensate for the RES variability while maximizing the usage of RES for charging. It was experimentally proven that the quantity of EVs engaging in V2G influences frequency control, and it was concluded that the MG exhibits reduced frequency deviations with an increase in the number of participating EVs [11].

##### **2) VOLTAGE CONTROL AND MG ANCILLARY SERVICES**

By means of their power electronics interface, EVs can participate to a certain extent in ancillary services in the MG, such as voltage regulation, power factor correction, and

reactive power compensation. It is important to note that an EV bidirectional charger can provide such services while operating within its remaining power capacity, especially when not transferring full active power during charging, with a minimal impact on the battery lifespan [19]. An example of an EV providing MG voltage support was analyzed in [20], where voltage support was achieved by implementing a droop control characteristic within an EV charging station (EVCS).

### 3) ENERGY STORAGE AND PEAK SHAVING

EVs are now integrated into MGs as mobile ESSs. Having direct access to EV storage for charging and discharging, enables the MG system to expand its overall storage capacity [21]. EVs can remain idle in parking lots for an average of 3 to 5 hours daily; during this period, EV batteries can function as distributed energy storage, thus increasing MG reliability [22]. The energy stored in EV batteries can be utilized in valley filling and peak shaving to balance power supply and demand [23]. This involves scheduling EVs to be charged during low-power demand periods depending on the charging flexibility of the EV, that is, the ratio between the minimum charging time and parking duration. Later, when there is a higher demand, the energy stored in the EV flows back into the MG.

### 4) ECONOMIC IMPACT

V2G services offer EV owners the opportunity to generate revenue by purchasing electricity at lower prices during off-peak periods and selling excess energy at higher prices during on-peak periods [24], [25]. Existing power generation units also benefit in that V2G reduces the need for expansion or new power generation plants, thereby reducing investment costs [26]. In the case of growing power demand, this increase in demand will be catered for by EV battery storage. V2G also supports the large penetration of RES into MGs, thereby reducing the number of backup generators [27]. This is beneficial, as it reduces reliance on fossil fuels and allows the use of cost-effective RESs. As shown in [28], reduction in costs associated with power system implementation can be obtained by implementing V2G.

### 5) MITIGATING CONGESTION AND LOSSES IN DISTRIBUTION NETWORKS

The primary findings from [29] indicate that EVs do not necessarily need to begin charging as soon as they reach the EVCS. Therefore, by using information about the EV's departure and energy prices, the EV charging periods can be optimized, which helps to reduce peak congestion in the distribution network. The optimization of EV charging times also helps to minimize load variances and thus minimizing system losses [30], [31]. EVs can inject reactive power into the MG when they are not required to operate with a unity power factor. This reactive power dispatch from EVs assists in lowering the distribution energy losses in the MG without affecting the costs of charging the EV [32], [33].

### 6) GRID RESILIENCE

In the event of outages and emergencies, EV bidirectional chargers can enable backup power to ensure a continuous supply of critical loads [34]. This mechanism helps mitigate the impact of outages and enhances the overall MG resilience. To supply power to a house, bidirectional EV chargers incorporate special components to manage loads and isolate the house from the MG during blackouts (islanding). This bidirectional flow helps stabilize the MG, particularly during periods of peak demand or unexpected disruptions.

### 7) RES SUPPORT AND BALANCE

In V2G technology, EV onboard ESSs can serve as a useful and flexible resource, facilitating higher penetration of RES within the MG. EVs can be integrated with RES within an MG to buffer and store energy to better utilize intermittent energy production from wind and PV plants [35]. The everchanging weather conditions produce strong power imbalances. This is particularly challenging because it disrupts conventional methods for planning the daily operation of the MG, forcing the control mechanism to adapt its operating procedures [36]. In grid connected MGs, if the power from the RES is too high, centralized power plants must decrease production to restore power balance, or the RES must be curtailed. In this scenario, EVs can help to align consumption and generation by controlled charging and discharging. RES curtailment serves to balance MG power by resolving issues related to MG congestion, unmatched supply and demand. V2G technology assists in lowering RES curtailment, which is considered unfavorable because curtailment increases the operating costs and is an ineffective way of utilizing RES [37]. Minimizing RES curtailment also helps investors in developing future renewable energy projects.

### 8) SPINNING RESERVE

Another ancillary service of interest that can be provided by the V2G is the spinning reserve. Typically, a spinning reserve is provided by online generators that immediately adapt their output power in response to major power shortages [36]. However, the spinning reserve requires a generation capacity with a quick response time, which is well suited for utilizing EV batteries [38]. Moreover, the active power supplied must be synchronous with the MG, which suits the EVs connected to the bidirectional chargers. For the effective implementation of EVs as spinning reserves, there should be enough EVs connected to the MG with sufficient energy stored in their batteries. In such circumstances, EV owners receive incentives not only for the services they provide but also for their abilities to supply power during contingencies [39].

## **B. CHALLENGES ARISING FROM THE INTEGRATION OF EVS INTO MGS**

The migration from internal combustion vehicles to EVs, like any other new technology, has several benefits as well as possible drawbacks. The implementation of V2G techniques

poses additional MG challenges that are primarily associated with MG power quality and control, battery deterioration, high investment costs, and EV scheduling. Based on our analysis, key points associated with the integration of EVs in MGs were identified, as outlined in the followings.

### 1) POWER QUALITY ISSUES

Charging multiple EVs simultaneously leads to a change in the overall load profile of the MG. This change has a significant effect that results in the degradation of MG performance, that is, voltage deviations, poor power quality, and even total blackouts in some cases [40]. It is also projected that increasing EV penetration into MG systems will affect the voltage profile, prompting undesirable peaks in power usage within the MG, resulting in power quality issues, such as total harmonic distortion, voltage imbalance, and voltage sags [41]. Additionally, voltage imbalances may occur because of an unregulated EV connection and disconnection in the MG [42]. The cost of voltage correction devices in the MG, owing to these voltage imbalances, may also increase. EV chargers, as they are non-linear devices composed of switching semiconductor devices, can have a negative effect on grid power quality if they operate as passive consumers. However, integrating grid-supporting features into EV chargers presents a significant opportunity to enhance the power quality.

### 2) BATTERY DEGRADATION

EV batteries are subjected to multiple charge-discharge cycles when operated in V2G, which accelerates battery degradation [43]. According to the experimental findings in [44], it was concluded that V2G technology has negative effects on Li-ion cell performance, with the potential for lifespan reduction to less than five years. In [45], it is also acknowledged that using V2G twice a day reduces the battery capacity by 75% in the long run (five years). The impact of V2G on battery lifespan and performance can be a major concern for EV owners, which may potentially affect their acceptance of V2G participation.

### 3) COMMUNICATION

Reliable real-time communication is of paramount importance for an effective MG that implements V2G technology. Successful implementation of V2G services requires efficient communication among EVs, the control center, and aggregators [46]. Inadequate communication frequently results in packet losses, communication delays, diminished precision, and financial losses, which affect the overall MG performance.

### 4) HIGH INITIAL INVESTMENT COSTS

The hardware infrastructure (EV aggregators, efficient communication systems, metering, plug-in connectors, etc.), which is essential for implementing V2G, requires a high investment [47]. Moreover, costs are influenced by the

increased degradation of EV batteries when providing V2G services [48]. An extensive network of bidirectional chargers is necessary for the widespread deployment of the V2G technology, which could necessitate large infrastructural development, thereby increasing the overall MG system investment. Another form of investment involves providing incentives to EV owners for participating in V2G. Individuals should have sufficient economic motivation to allow their EVs to contribute to the MG. Without appropriate compensation, EVs will be limited to providing MG support.

### 5) STOCHASTICITY

The uncertainty associated with factors, such as EV departure, EV arrival, daily distance coverage, and battery size, undermines the reliability of the MG system [47]. Furthermore, the inherent stochasticity of RES adversely affects the reliability of MGs. This is because some MGs rely on EV batteries for storage and supply-demand balancing, and the unpredictability in EVs arrival or departure can lead to unexpected power shortages and inefficient power utilization. Uncertainties in EV usage patterns and daily distance coverage affect the MG load profile and present difficulties in performing load forecasting. Therefore, MG operators may struggle to optimize generation and storage resources, which has the potential to result in underutilization or overloading of these resources [49]. All these factors lead to fluctuations in the energy demand, resulting in MG instability.

### 6) DISTRIBUTION EQUIPMENT, OVERLOADING AND AGEING

The increase in load demand due to EV charging results in the overload of MG distribution infrastructure, such as powerlines and transformers, where applicable [50], [51]. An impact assessment was conducted in [52] to evaluate the effects of the EV penetration level (ratio between the number of EVs and the number of households supplied by the transformer) on the performance of the transformer. Their findings showed that the transformer overloading index became unsatisfactory when the EV penetration reached 75%, thereby reducing its lifetime. Furthermore, overnight charging of EVs may interfere with conventional night-time cool-down periods for transformers, likely resulting in shorter transformer lifetimes [53]. Powerlines and transformers can also overheat when overloaded by the increased number of EVs, causing outages, fires, and, more commonly, accelerated component ageing.

### 7) BIDIRECTIONAL POWER FLOW CONTROL

Implementing bidirectional power flow for V2G applications introduces complexities in the control and management of MG, especially in terms of stability and reliability. Different topologies of bidirectional power flow converters that can be used in V2G are presented in [54], and some of the challenges associated with this bidirectional flow of power include DC link voltage imbalances, increased cost, reduced reliability due to the use of electrolytic capacitors, and limited power

densities due to additional losses. The challenge of managing a bidirectional power flow becomes more complex as the number of EVs engaged in V2G services increases. This poses significant scalability challenges in designing V2G systems that can handle vast DER efficiently while maintaining the MG's performance and reliability.

### 8) CYBERSECURITY RISKS

The EV charging framework is a complex system comprising several entities that interact and share personal information, rendering it susceptible to cybersecurity threats that pose risks to the entire MG system. A number of EV charging vulnerabilities were presented in [55], and these incidents demonstrate the lack of experience in this area of cybersecurity and data protection. These threats include disruption of the supply chain and operation of embedded hardware devices in the MG system [56]. The communication equipment (ethernet and Wi-Fi) used in V2G technologies, allows hackers to access and affect the entire charging network through a single charger [57]. By infiltrating the EVCS, attackers can easily manipulate targeted critical components of the MG, which can have significant implications, including power disruptions and threats to public safety [58].

Given the high necessity of incorporating EVs into distribution grids at different scaling levels, while reducing the use of conventional energy sources, there is a crucial need to enhance research on this topic. As part of this effort, this study provides an overview of the current solutions concerning the integration of EVs in MGs. For this purpose, subsequent sections will cover the following topics: In Section II, we describe how interactive EVs assist in the control of MGs. In Section III, we discuss the communication between the MGs and EVs. In Section IV, we provide in-depth details regarding solutions for EV integration in both AC and DC MGs. Section V presents the open research challenges for EV integration in MGs. Finally, Section VI concludes the paper.

## II. CONTROL OF MGS WITH EV SUPPORT

Progress in grid-interactive EV technologies presents a significant opportunity to enhance MG control by integrating EV as an active resource. The extent of the EV contribution to MG control primarily relies on the resources accessible through the interconnection point, specifically EVCS. V2G capabilities are constrained by several factors, such as the power exchange capabilities of the interfacing converter (on-board or external charger, as outlined in a subsequent section), battery charging/discharging limits, and connection line parameters between the EVCS and MG. Fig. 1 shows the EV active and reactive power capabilities, accessible for V2G operation within the apparent power limit ( $S_{max}$ ) of the interfacing converter, and other limits discussed subsequently. In quadrants I and II, the EV charges in the inductive and capacitive modes, respectively, and the charging power is restricted by the charging-process limit. In quadrants III and IV, the EV discharges in the capacitive and inductive modes, respectively, with the discharging power restricted by the EV

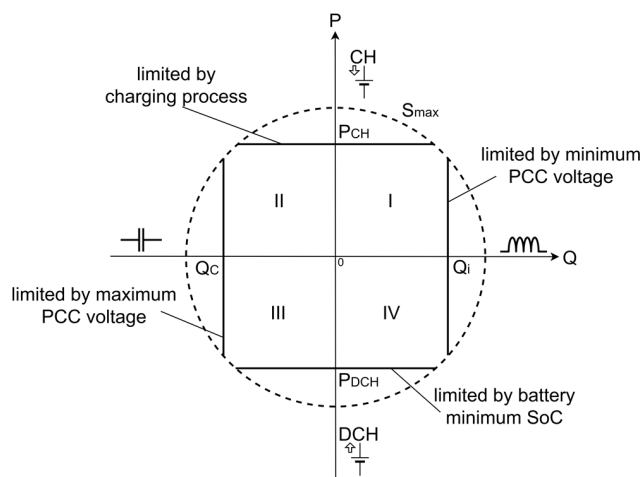


FIGURE 1. EV P/Q capabilities for V2G operation.

battery state of charge (SoC) limit. The amount of reactive power injected by the EV into the MG is restrained by the maximum voltage at the point of common coupling (PCC) whereas the reactive power absorbed by the EV from the MG is restrained by the minimum voltage at the PCC.

In the following subsection, a synthetic analysis of how EVs can participate in different control levels of an MG is provided.

### A. MG CONTROL SCHEMES

Different control schemes can be used to control a complex MG structure, depending on how the power units interact with each other and whether there is a central controller in the control system. These control schemes are classified as decentralized, centralized, and distributed.

#### 1) DECENTRALIZED CONTROL SCHEME

Each power unit independently manages its operation without exchanging information with other units; therefore, it is more versatile than other control schemes. However, the main challenge of decentralized control is the lack of coordination among the power units, which often leads to difficulties in achieving an optimal solution [59].

#### 2) CENTRALIZED CONTROL SCHEME

Each power unit sends and receives information to and from the central controller using communication channels. Centralized control is highly effective when implemented with an optimization method to enhance the reliability and stability of the MG [60]. However, a centralized control scheme is vulnerable to single-point failures (central controller), which in turn makes it difficult to manage the vast amount of data gathered from power units.

#### 3) DISTRIBUTED CONTROL SCHEME

Each power unit sends and receives information to and from other power units using communication channels. Each

**TABLE 1. Classification of hierarchical control levels.**

Control	Functions	Timeframe
Primary	Local control of DER units. Power electronics converter control. Overcurrent/overvoltage protection limits. Power sharing. Islanding detection for individual DER.	Milliseconds to seconds
Secondary	Voltage and frequency restoration. Voltage balancing and load shedding. Co-ordinated transition between grid and islanded modes. Economic operation in grid and island mode.	Seconds to minutes
Tertiary	MG energy management system. Co-ordination between multiple MGs. Powerflow management from utility to MG.	Minutes to hours

power unit performs its own control, based on this information exchange. This scheme is more reliable because it avoids the coordination challenges that arise as a result of using a single central controller [61].

### B. HIERARCHICAL CONTROL IN MGS

Owing to the complexity of MG systems, intelligent control strategies are required to address all MG abnormalities simultaneously. The use of a single MG control will not be able to achieve this, hence, a hierarchical architecture is regarded as the appropriate strategy to allow numerous variables to be controlled independently and concurrently [62]. Three separate control levels constitute the hierarchical architecture, which is primarily related to their response speed and communication requirements. The three distinct levels are primary, secondary, and tertiary control [63] and are classified in Table 1 according to their action domains and time frames in MG control.

### C. EV CONTRIBUTION TO PRIMARY CONTROL

Primary control interacts with power electronic converters directly in either grid-forming or grid-following configurations. Control signals are sent to the power electronic interface to ensure short-term MG stability by performing power sharing among the DER and dealing with some power quality concerns.

Each DG in the MG is assigned a certain active and reactive power to meet the load requirement without overloading any of the DGs, simultaneously ensuring that the voltage and frequency levels of the MG system do not deteriorate [64].

Droop control is the predominant control technique in primary control owing to its decentralized nature. Therefore, the communication requirement is minimal to non-existent. An overview of various droop control strategies, including conventional droop control, robust droop control, adaptive droop control, and virtual impedance loop-based droop control, is presented in [65].

Primary frequency control based on decentralized V2G control (DVC) is proposed in [66]. This control comprises charging with frequency regulation (CFR) and battery SoC holder (BSH) control strategies. The BSH is essential in maintaining the EV battery SoC at a predefined level by utilizing an adaptive droop to control the EV power exchange with the MG. BSH can also include a frequency control loop. The battery SoC obtained from the battery management system (BMS) together with the real-time frequency obtained from the frequency detection block provides V2G controllers with information for performing their control functions. CFR control ensures that the charging demand is met while participating in the MG frequency control. In CFR control, the EV customer provides the charging time as well as the expected SoC.

Another study on the dynamic frequency response of EVs considering their travelling behavior is presented in [67]. The EV charges at maximum power if the frequency deviation is smaller than the set frequency deviation threshold, whereas it decreases its charging power based on a droop characteristic as the frequency deviation increases above a set limit.

### D. EV CONTRIBUTION TO SECONDARY CONTROL

Secondary control acts as a mediator between primary control and tertiary control, rectifying the deviations between the measured parameters at primary control and the expected values according to tertiary control [68].

EV-assisted secondary control and power quality improvement in an MG was presented in [69]. The MG has a central controller based on two proportional and integral (PI) controllers, one for frequency restoration and the other for voltage restoration. The restoration signals are then transmitted to the voltage-source inverter and EV controllers to determine the references for the active and reactive powers. Furthermore, the EV can provide power-quality support to the MG by adjusting the reactive power references of its converter. As discussed in [70], AC/DC converters in EV chargers can operate in different states according to their active and reactive power settings. This characteristic assists the system (distribution network or MG) by increasing its capacity, lowering reactive power losses, and improving its voltage profile.

A secondary frequency control module for the EV charging control strategy was proposed in [71]. The module uses two-stage control, whereby the EV responds promptly to frequency deviations and eliminates these deviations. The first-stage control is an open-loop control that uses the MG distributed power parameters to determine the power correction coefficients to compensate for power shortages. The second-stage control eliminates some frequency deviations that result from the first-stage control.

### E. EV CONTRIBUTION TO TERTIARY CONTROL

In MGs, tertiary control provides an optimal energy distribution, typically by employing an EMS. The EMS is

responsible for performance monitoring, control, and optimization of energy generation and consumption [72]. Other roles of EMS includes forecasting of RES generation and load consumption, analysis of meteorological conditions, and market energy price. The EMS ensures optimal energy consumption while simultaneously reducing the cost of electricity, especially when the MG operates in grid-connected mode, by controlling the EV charging process to minimize power intake from the grid and to maximize the use of locally generated power [73], [74]. Advanced technologies like AI and internet of things (IoT) are being used to improve renewable energy systems to make them more robust and responsive. The EMS relies on two main control techniques: classical and AI-based techniques. The first category includes well-established techniques, such as model predictive control, stochastic and robust programming, mixed-integer linear programming, linear programming, and iterative algorithms. AI techniques for EMS include fuzzy logic techniques, neural network techniques, and evolutionary algorithms.

#### 1) MODEL PREDICTIVE CONTROL

To cope with the dynamic behavior of loads and RES output, a robust model predictive control technique for islanded MGs was suggested in [75]. The framework incorporates a mixed deterministic integer programming model for energy management to minimize costs and an online energy scheduling strategy that assists the MG in adjusting accordingly with the different unforeseen risks in energy management. This approach improves the reliability of the operational management of the MG and minimizes the operational costs of the system to some extent.

#### 2) STOCHASTIC AND ROBUST PROGRAMMING TECHNIQUE

A hybrid stochastic and robust optimization method was proposed in [76] to reduce the electricity cost and overcome some challenges of uncertainties in RES generation, load demand, and grid tariffs. The technology first selects stochastic electricity price scenarios, and then the robust optimization strategy manages uncertainties in RES generation and loads for each price scenario.

#### 3) MIXED INTEGER LINEAR PROGRAMMING

In [77], a mixed-integer linear programming-based EMS for ESSs in grid-connected MGs was proposed. The technology determines the power level for charging and discharging the ESS such that it minimizes the energy consumption costs by considering the fluctuations in grid prices, RES power generation, and power demand requirements. The simulation findings indicated that the technique could decrease the operating costs by 3.3% in comparison with other offline optimization techniques.

#### 4) LINEAR PROGRAMMING

A linear programming technique implementing a heuristic algorithm for scheduling the charging and discharging of

EVs was developed in [78]. The algorithm also addresses the uncertainties in EV departure and load demands and flattens the load profiles.

#### 5) ITERATIVE ALGORITHM

A learning-based iterative IoT algorithm was proposed in [79] for energy management. The algorithm ensures maximum usage of the generated PV energy, peak load reduction, and reduction in the cost of electricity. This is achieved through proper scheduling of loads, EV charging cycles, and battery storage systems. This optimization technology combines deep reinforcement learning with physics-based methods to learn and generate suitable commands for all loads.

#### 6) FUZZY LOGIC TECHNIQUE

A simple and low-cost EMS for an autonomous DC MG based on a PI controller and a fuzzy logic algorithm was presented in [80]. This control strategy uses supercapacitors at high charge/discharge cycles, thereby reducing the stress on the battery energy storage and resulting in a longer battery lifetime. The EMS performs DC bus voltage recovery in situations of power imbalance between the supply and demand.

#### 7) NEURAL NETWORK TECHNIQUE

To optimally schedule a hybrid MG while simultaneously maximizing power generation and minimizing the cost function, a Lagrange programming neural network was employed in [81]. To offer a cost-effective solution, the loads are separated into four categories: thermal, price-sensitive, and controlled and critical loads. This method works together with a radial basis function neural network that predicts the day-ahead load demand and uses RES power generation as the input data to the control technique. From the simulations obtained, the method proved its ability to determine the optimal solutions for the ESS and power generation resources.

#### 8) EVOLUTIONARY ALGORITHMS

Time of use (ToU) pricing scheme for a home EMS using a hybrid genetic biogeography-based optimization technique was proposed in [82]. The scheduling algorithm reduces the peak-to-average ratio and minimizes the electricity cost. A reduction in the peak-to-average ratio maximizes the operational stability and reliability of the MG.

A data-driven framework based on advanced machine learning and the point estimate method (PEM) was proposed in [83] to model the uncertainties in EV charging, RES power generation, load demand, and market price in hybrid AC-DC MGs. A support vector machine (SVM) was used as an advanced machine learning technique to determine the standard deviation of the forecast error for each parameter based on historical data. The PEM uses the data from the SVM to model the uncertainty impacts on the MG's optimal energy management. The proposed study also implemented a modified flower pollination algorithm for optimal energy management. The framework was simulated in three different

**TABLE 2.** Analysis of EMS involving EVs based on classical and AI techniques.

Technique	Contributions	Weaknesses
Model predictive control	RES power uncertainties are determined. Loadshedding implementation and battery SoC control helps in stabilizing the MG voltage. Reduced operational costs.	Decreased battery lifetime of EVs as a result of full discharge.
Stochastic and robust programming technique	Minimizes the MG overall costs. Enhances the MG reliability as a result of the realization of expected energy losses and load expectation loss.	High computational time complexity. Decreased battery lifetime as higher depth of discharge (DoD) is used.
Mixed integer linear programming	Improves MG performance by lowering the total operational costs. Capable of solving large optimization problems in reasonable time. Easily accessible from almost any programming language.	The model does not consider the cost that comes with battery degradation.
Linear programming	Easily adapts to changes in MG circumstances. Effective in attaining optimal use of available renewable energy resources.	Difficulties in performing computations.
Iterative algorithm	Capable of performing energy management with minimum information exchange, and thus effectively protecting consumer privacy.	The costs of ESS and RES generation are neglected.
Fuzzy logic	Energy exchange with the grid minimizes power peaks and fluctuations. Improved battery lifetime.	Does not consider power losses and the voltage and frequency regulation of the MG. Complex formulation hence resulting in high computational time.
Neural network	Optimized MG performance through the maximum utilization of RES and DER. Improved battery lifetime. Minimized import of power from the MG.	Complex formulation and computational time. Restricted to a specified set of input.
Evolutionary algorithms	Reduces the peak to average ratio and electricity cost. Peak demand calculation. Applicable for offline problems.	User comfort is not considered. Increased system complexity. Slower convergence.

case studies: in the first scenario, the EV was charging in an uncoordinated manner, and the system ensured that the EV was charged in a way that reduced the MG cost during peak load hours. In the second case, the EV charges in a coordinated manner which involves postponing the EV charging starting time to off-peak hours, thereby reducing the MG cost. The third scheme is dedicated to smart charging, where the charging time considers both the load demand and energy market price. In this setting, the model was able to charge the EV during periods when there was sufficient capacity in the MG, low power demand, and minimal cost of electricity. In Table 2, the EMSs based on both classical and AI techniques are summarized, along with their contributions and weaknesses in MGs with EVs [75], [76], [77], [78], [79], [80], [81], [82].

#### F. EV INTEGRATION IN AC AND DC MGs

AC and DC MGs are two distinct approaches that can be used for power distribution in a localized setup. The choice between AC and DC MGs is solely dependent on factors such as the nature of the loads, efficiency goals, and system requirements. Therefore, this subsection presents an overview of the main technical differences between AC and DC MGs, together with their implications.

#### 1) ENERGY LOSSES

In DC MGs, the reduced number of conversion stages leads to fewer power components, consequently increasing reliability and minimizing the energy losses. These power conversions in AC MGs during EV charging and discharging often lead to total one-way energy losses of between 12% and 36% [84].

#### 2) EFFICIENCY

DC MG systems have a higher efficiency than their AC counterparts. As highlighted earlier, DC MGs reduce the complexity of the power conversion stages, which also implies that there will be fewer components prone to failure. The cumulative effect is an improvement in the lifetime, reliability, and efficiency of the MG. As revealed by [85], by moving from AC infrastructure to DC infrastructure, there is a total energy-saving opportunity of up to 15%.

#### 3) EV CHARGING TIME

Currently, the three main types of EV chargers in the market are Level 1, Level 2, and fast DC chargers. Level 1 and level 2 charging involves AC/DC conversion through the onboard converter of the EV. However, the main drawback of these two charging facilities is the power constraint imposed on both the charger and AC utility. This is unappealing because

**TABLE 3. Communication technologies available in MGs.**

Type	Technology	Coverage	Rate	Advantages	Disadvantages	Application
Wireless	LoRa	5km (urban), 20km (rural)	50kbps	Low cost Easy scalability	Data loss due to packet collision Low speed	Tertiary control
	Wi-Fi	100m	11 Mbps – 10 Gbps	High transmission speeds Good adaptability	Vulnerable to interference Security threat (can be hacked easily)	Secondary control
	ZigBee	100m	250 kbps	Low cost Low power consumption	Low speed Interference due to channel noise and overcrowding	Tertiary control
	Bluetooth LE	100m	1 – 2 Mbps	Low power consumption Low cost	Security threats Low penetration	Tertiary control
Wired	Power line communication	200m	14 – 200 Mbps	Low cost High speed communication	Complicated scalability Performance highly dependent of electrical installation	Tertiary control
	Ethernet	100m	10 Mbps – 10 Gbps	Low delays Low CPU utilization	High cost Limited adaptability and mobility	Primary and secondary control

it slows the charging process, for example, filling up a 130 km battery takes 16 hours and 3.5 hours for level 1 and level 2, respectively [86]. On the other hand, the ease of integrating RES, ESS, and EV in DC MGs provides an opportunity for supplying the high power required to charge the EV within 20-30 minutes [87].

4) INTEGRATION OF COMPONENTS

Most RES produce DC power, which makes their integration into ESSs, EVs, and other DC loads easier and more efficient in DC MGs than in AC MGs. Replacing the DC to AC conversion stages with DC/DC converters is beneficial for reducing primary energy consumption, given that DC/DC converters are more compact and efficient [88].

5) CONTROLLABILITY

The control of DC MGs is easier when compared to AC MGs. The use of DC MGs removes the power quality issues such as phase imbalances and harmonic oscillations which are present in AC MGs [89]. In contrary to AC systems, DC systems do not require frequency synchronization, thereby reducing the system’s operational complexity and stability issues [90]. Adding on, in DC MGs there is absence of reactive power control [91].

6) PROTECTION

Despite the many benefits offered by DC MGs over AC MGs, designing their protection remains a significant issue [92]. Circuit breakers and fuses are currently the most common and simple overcurrent protection devices available for DC MGs. Efforts have been made to develop solutions for the protection of DC MGs, and different protection schemes have been developed [93], [94], [95]. The cost and reliability of

such devices remain major limitations in the development of DC systems.

7) STANDARDS AND REGULATIONS

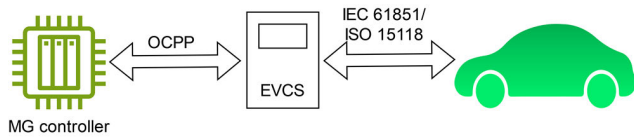
Another considerable challenge in the adoption of DC MGs is the need for voltage standards and safety regulations. The use of different voltage levels for power generation and residential, commercial, and industrial loads makes it difficult to obtain a voltage standard [96].

8) EXPERTISE

AC grids are currently the most popular grids for use. AC technology is well established and certified, whereas DC technology is still growing. This indicates a shortage of experts who have conducted in-depth studies on DC MGs [97].

III. EV-MG COMMUNICATION

The growing number of EV charging sites in both public and residential areas has given rise to the need for more efficient and secure communication between various systems of EV charging facilities [98]. EV-MG energy management is data-driven, which implies that the management and control processes are based on real-time data gathered from various sources in an MG system. Open charge point protocol (OCPP), ISO 15118 and IEC 61851 are some of the communication protocol standards used today within the EV charging infrastructure. The physical medium of a communication system can be wired or wireless. Some examples of wired communication include power lines, twisted pairs, and fiber-optic. Bluetooth, ZigBee, Wi-Fi, LoRa, and cellular technologies are some examples of wireless communication technologies. Table 3 outlines the specifics of the various wired and wireless communication technologies, as well as



**FIGURE 2.** Communication protocols available for information exchange between MGs and EVs.

their benefits and drawbacks, distance coverage, and areas of application with respect to hierarchical control levels [99], [100], [101], [102], [103], [104], [105], [106].

The OCPP is an open communication protocol between a central management system (CMS) and a charge point (CP) that accommodates any charging technique and is managed by the open charge alliance (OCA) [107], [108]. It manages EV charging processes to guarantee efficient charging and quality of service [109]. The implementation of an OCPP between a fast-charging station and an EV was described in [110]. The CP initiates two-way communication over the TCP/IP, where it sends its commands to the CMS and receives data from the CMS. Before any transaction, the CP requests authorization from the CMS. The CP also sends a boot notification (specifying the car vendor, version, etc.) and a heartbeat notification (informing the CMS that the charge point is still alive). The CP can also acquire information from the CMS, for example, meter values and firmware status notification.

IEC 61850 has emerged as a promising solution in communication standardization for MG automation, as it is established on the interoperability approach [111], [112], [113]. Information exchanges between the charging infrastructure, communication controller, and EV are governed by ISO/IEC 15118, whereas the charging specifications are detailed by the IEC 61851 standard [114].

Fig. 2 shows how OCPP can be interfaced with other communication protocols (ISO 15118 or IEC 61851) to enhance the functionality of V2G. The OCPP offers a standardized communication protocol between the MG and the EVCS. ISO 15118 or IEC 61851 protocols work alongside the OCPP to handle the communication between an EVCS and EV.

**A. INFORMATION EXCHANGE BETWEEN EVCS AND EV DURING V2G**

Upon EVs arrival at the EVCS, the EV communicates its EV identification (EVIId) to the EVCS, and the EVCS responds with an EVCSId to indicate acknowledgement. Thereafter, the EVCS performs a compatibility inspection on the EV battery, and if successful, the EV is latched onto an EVCS connector [115]. The EV can be either grid-connected or islanded. In grid-connected mode, the EVCS ensures charging of the EV only. The EV provides the EVCS with information relating to the battery SoC, maximum voltage, minimum and maximum allowable charging currents, EV departure time and the expected amount of energy to be transferred to the EV. In the islanded mode, the EVCS permits

**TABLE 4.** Main electrical parameters accessible over OCPP.

Electrical Parameter	Read(R)/Write(W)
EV charging/discharging power	RW
EV charging/discharging current	RW
EV battery SoC	R
EV maximum charging/discharging power	RW
Total energy consumed by the EV	R

the EV to discharge power to the MG. The EV communicates information on the maximum energy that can be drawn from its battery, SoC, maximum voltage, minimum and maximum permissible discharging currents, and departure time.

Table 4 shows the main electrical parameters that can be controlled (write) and monitored (read) when using OCPP for communication between the MG and the EVCS. These parameters can vary with the version of the OCPP and/or EVCS; hence, this table provides a general overview of the parameters that can be communicated during EV charging and discharging [116], [117], [118].

**IV. SOLUTIONS FOR EV INTEGRATION IN MGS**

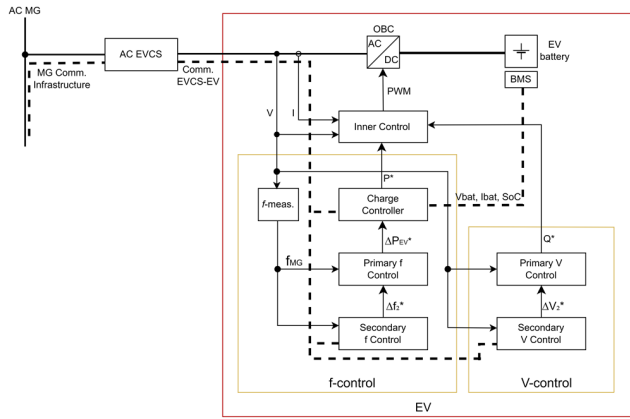
Based on the earlier discussed MG control requirements, this section offers recommendations on how EVs can play a role in enhancing the MG control processes, with a specific focus on the two main MG types, DC and AC.

**A. EV INTEGRATION IN AC MGS**

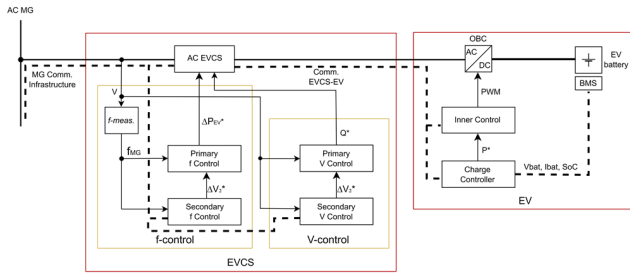
An example of EV integration into an AC MG is shown in Fig. 3, where the primary and secondary MG control levels are implemented either on the EV onboard charger (OBC) (Fig. 3a) or on the EVCS (Fig. 3b). In both cases, power flow control is performed by the bidirectional OBC. The inner loop incorporates the control of the bidirectional converter, typically implemented as a grid-following control strategy, which enables the OBC to operate in all four quadrants of the PQ plane, as evidenced in Fig. 1.

As highlighted in the proposed schematics in Fig. 3, the EV charge controller facilitates operation in either charging or discharging mode depending on the electrical parameters obtained from the BMS, information communicated by the EVCS, and power setpoints provided by the frequency and voltage controllers. The two cases have a different approach in terms of the location of MG support controllers, namely, either built in the EV control (Fig. 3a) or externally in the EVCS (Fig. 3b). In the first implementation, the EV manages all control processes, including the MG support and battery charging. In the subsequent configuration, the MG support functions are included in the EVCS, which communicates the setpoints for active and reactive powers to the inner EV control. Although both implementations have merits, we consider that the second configuration is more accessible within the current EV technology development.

Another implementation solution is shown in Fig. 4, where the EV is charged in DC by an off-board charger integrated in the EVCS. Unlike in Fig. 3, where the EVCS produces

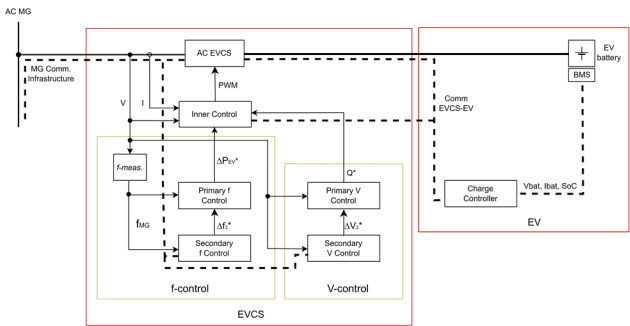


(a)



(b)

**FIGURE 3. Primary and secondary MG control implemented on: (a) EV OBC; (b) EVCS.**

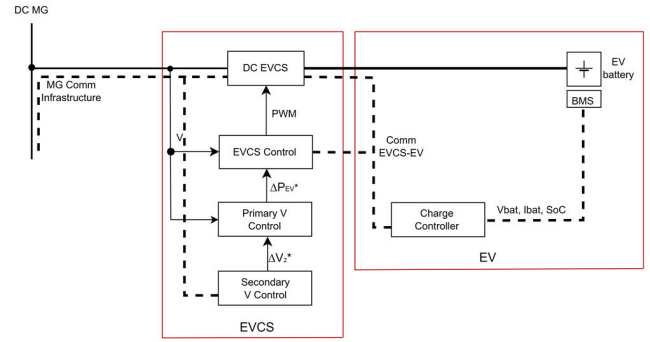


**FIGURE 4. AC MG with an off-board charger enclosed in an EVCS.**

an AC output that would then be converted to DC by the OBC, the AC/DC conversion is performed directly within the EVCS. MG support controllers are implemented in the EVCS, similar to the configuration shown in Fig. 3b. The charge controller requirements are sent from the EV to the EVCS controller through communication.

### B. EV INTEGRATION IN DC MGs

The case of EV integration in DC MGs is similar to that presented in Fig. 4, with the main difference being that the EVCS includes a DC-DC converter rather than an AC-DC converter. Fig. 5 presents this configuration, where the EVCS integrates MG voltage control. Droop control can be adopted in the primacy control of DC MGs with an EV infrastructure



**FIGURE 5. Primary and secondary DC MG control implemented on EVCS.**

**TABLE 5. Comparative analysis of EV integration configurations in AC and DC MGs.**

Performance criteria	EV-MG integration configuration			
	Fig. 3a	Fig. 3b	Fig. 4	Fig. 5
Implementation accessibility within the current EV technologies	Low	Moderate	Moderate	Moderate
EV communication burden	Low	High	Moderate	Low
Security	High	Low	Low	Low
MG control adaptability/scalability	Low	Moderate	High	High
Maintenance requirements	Moderate	Moderate	Low	Low
Energy efficiency	Moderate	Moderate	Moderate	High
Charging speed	Slow	Slow	Moderate	Fast

to maintain power balance through power sharing in the MG system. The secondary control assists in regulating the DC bus voltage of the MG to its nominal value.

### C. COMPARATIVE ANALYSIS OF EV INTEGRATION IN AC AND DC MGs

With the above discussion, Table 5 provides a comparative analysis of the EV integration configurations in AC and DC MGs. The analysis covers EV specific aspects, including communication burden, security, maintenance requirements, and energy efficiency. This information can be used to determine the EV connection configuration based on the system requirements and priorities.

### V. OPEN RESEARCH CHALLENGES

The integration of EVs into MGs as active participants, in line with the V2G concept, presents opportunities and challenges for both MGs and EV owners. Consequently, research has been ongoing over the past few years to address and mitigate these challenges, with other areas still requiring attention. It is important to note that this survey relies on the relatively limited availability of experimental evidence in the literature in this field of research on EV-MG integration. Another challenge is related to the policies and regulations governing the integration of EVs into MGs, which can vary widely

between regions. Therefore, understanding and accurately presenting these diversities, while maintaining coherence, requires extensive research and expertise in relevant policies. Furthermore, research on EV integration in MGs is complex and involves multiple disciplines, including RES, transportation (EVs), electrical engineering, standardization, communication, and economics. Given the broad nature of this research, it might be difficult to comprehensively cover and synthesize all relevant aspects of this topic, especially for researchers who specialize in one field. Based on the analysis provided in this paper, we suggest the following key recommendations for future research:

#### 1) DEVELOPMENT OF SMART CHARGERS WITH MG OPERATION FEATURES

Each EV is integrated into an MG through its interfacing converter, whether on-board or external, which adds resources for potentially providing ancillary service support. Given the diverse range of control strategies available for MGs today, additional research is needed to explore optimal solutions for the interactive operation of EVs in such systems.

#### 2) ADVANCING THE DC MGS TECHNOLOGY

As mentioned earlier, DC MGs offer notable technical advantages over AC MGs. However, the primary challenge in implementing DC MGs is the effective implementation of protection systems under diverse sources and loads. Protection in DC MGs remains a challenge because of the nature of DC fault currents and the fact that advanced DC protection technology is still in its early stages of development. Different techniques, such as efficient fault current limiters, fast fault isolating devices, and coordinated protection equipment, have been developed to handle these protection challenges [119]. Nonetheless, there is still a need to devise better protection devices, and the future of DC MG protection lies in the design of novel power electronic converters with the capability to perform current limiting and DC fault blocking.

#### 3) EV BATTERY DEGRADATION

As emphasized previously, V2G strategies have adverse effects on EV battery lifetime. Therefore, addressing this challenge is essential for prolonging battery lifespan. Advanced EV BMS strategies can be developed to reduce the number of charge/discharge cycles particularly deep cycles. AI algorithms can also be used to predict and anticipate potential issues within the battery cells.

#### 4) CYBER SECURITY AND DATA PROTECTION

A concern for EV owners engaged in V2G technologies is the disclosure of information regarding their charging locations, driving patterns, and other sensitive data to the MG system. The critical challenge lies in security, as these data are vulnerable to various threats, such as unauthorized control, eavesdropping, spoofing, data tampering, and cyber physical

attack. Therefore, further efforts should be directed towards improving the reliability and security of communication.

#### 5) DEVELOPMENT OF SMART CHARGING STANDARDS

Currently, there are few standards that support smart charging and V2G operations [120]. Despite ongoing developments in standardization activities, additional efforts are required in the interoperability domain to ensure that the smart-charging infrastructure is compatible with standardized hardware and MG equipment.

### VI. CONCLUSION

Integrating EVs into MGs offers a promising path towards sustainable energy development. This survey paper has revealed the multifaceted details of EV-MG interactions, addressing key aspects such as the challenges and opportunities that come with V2G; EV contribution to MG's primary, secondary, and tertiary control; EV-MG communication; and the integration of EVs in AC and DC MGs. EVs have demonstrated their potential to contribute significantly to enhancing the overall resilience and reliability of MGs by providing valuable services such as voltage and frequency control and peak shaving, while the inherent flexibility of EV batteries also enables them to be used as DER. However, the major drawbacks include EV battery degradation and the repercussions of large-scale EV charging on MG stability, which require careful consideration and advanced EMSs. To fully realize the potential of V2G, effective communication between EVs and MGs plays a crucial role in coordinating EV charging and discharging.

Based on the aspects highlighted in this discussion, the main contributions of this study are summarized as follows.

- Power flow control solutions implemented through the EV bidirectional converter have been analyzed, enabling the EV charger to operate in all four quadrants of the PQ plane and ensuring voltage and frequency regulation within the MG.
- Configurations have been proposed for EV integration in AC and DC MGs, with a focus on primary and secondary control implementation on the OBC of the EV and on the EV off-board charger enclosed in the EVCS.
- The specific aspects of EV integration in both AC and DC MGs represent key points of this work. While AC MGs are prevalent, DC MGs present benefits, such as lower control and hardware complexity, increased efficiency, and better compatibility with EVs and RES.

In summary, the field of EV integration in MGs is dynamic and evolving and holds significant promise for the future of sustainable energy. Collaborative efforts by interested parties across the energy sector are required to overcome these challenges and capitalize on the opportunities that come from the integration of EVs in MGs. Emphasis has also been placed on the direction for future research to further revolutionize the way for a resilient and sustainable future, given the increasing momentum of green energy.

## REFERENCES

- [1] Y. Akarne, A. Essadki, T. Nasser, and H. Laghrifat, "Modelling and control of a grid-connected AC microgrid with the integration of an electric vehicle," *Clean Energy*, vol. 7, no. 4, pp. 707–720, Aug. 2023, doi: [10.1093/ce/zkad030](https://doi.org/10.1093/ce/zkad030).
- [2] M. Tkac, M. Kajanova, and P. Bracinek, "A review of advanced control strategies of microgrids with charging stations," *Energies*, vol. 16, no. 18, p. 6692, Sep. 2023, doi: [10.3390/en16186692](https://doi.org/10.3390/en16186692).
- [3] J. Pahasa and I. Ngamroo, "Coordinated PHEV, PV, and ESS for microgrid frequency regulation using centralized model predictive control considering variation of PHEV number," *IEEE Access*, vol. 6, pp. 69151–69161, 2018, doi: [10.1109/ACCESS.2018.2879982](https://doi.org/10.1109/ACCESS.2018.2879982).
- [4] M. Fotopoulou, D. Rakopoulos, D. Trigkas, F. Stergiopoulos, O. Blanas, and S. Voutetakis, "State of the art of low and medium voltage direct current (DC) microgrids," *Energies*, vol. 14, no. 18, p. 5595, Sep. 2021, doi: [10.3390/en14185595](https://doi.org/10.3390/en14185595).
- [5] R. Cleenwerck, H. Azaioud, M. Vafaiepour, T. Coosemans, and J. Desmet, "Impact assessment of electric vehicle charging in an AC and DC microgrid: A comparative study," *Energies*, vol. 16, no. 7, p. 3205, Apr. 2023, doi: [10.3390/en16073205](https://doi.org/10.3390/en16073205).
- [6] R. Liu, Y. Peng, M. He, T. Deng, G. Wang, Q. Cao, X. Li, J. Yu, and D. Yu, "Research on smooth switching control technology between grid-connected operation and off-grid operation of micro-grid," in *Proc. Panda Forum Power Energy (PandaFPE)*, Apr. 2023, pp. 2244–2251, doi: [10.1109/PandaFPE57779.2023.10141461](https://doi.org/10.1109/PandaFPE57779.2023.10141461).
- [7] N. Gurung, A. Vukojevic, and H. Zheng, "Demonstration of islanding and grid reconnection capability of a microgrid within distribution system," in *Proc. IEEE PES Innov. Smart Grid Technol.*, Singapore, Nov. 2022, pp. 655–659, doi: [10.1109/ISGTAsia54193.2022.10003608](https://doi.org/10.1109/ISGTAsia54193.2022.10003608).
- [8] H. Ma, Y. Xiang, Y. Liu, J. Liu, Z. Sun, S. Hu, and W. Xu, "Optimal peer-to-peer energy transaction for distributed prosumers," in *Proc. Panda Forum Power Energy (PandaFPE)*, Chengdu, China, Apr. 2023, pp. 622–626, doi: [10.1109/PandaFPE57779.2023.10141013](https://doi.org/10.1109/PandaFPE57779.2023.10141013).
- [9] K. M. Tan, V. K. Ramachandaramurthy, and J. Y. Yong, "Integration of electric vehicles in smart grid: A review on vehicle to grid technologies and optimization techniques," *Renew. Sustain. Energy Rev.*, vol. 53, pp. 720–732, Jan. 2016, doi: [10.1016/j.rser.2015.09.012](https://doi.org/10.1016/j.rser.2015.09.012).
- [10] H. M. Mohan and S. K. Dash, "Renewable energy-based DC microgrid with hybrid energy management system supporting electric vehicle charging system," *Systems*, vol. 11, no. 6, p. 273, May 2023, doi: [10.3390/systems11060273](https://doi.org/10.3390/systems11060273).
- [11] M. Bayati, M. Abedi, G. B. Gharehpetian, and M. Farahmandrad, "Short-term interaction between electric vehicles and microgrid in decentralized vehicle-to-grid control methods," *Protection Control Modern Power Syst.*, vol. 4, no. 1, p. 5, Dec. 2019, doi: [10.1186/s41601-019-0118-4](https://doi.org/10.1186/s41601-019-0118-4).
- [12] M. Mousavizadeh, F. Bai, R. Garmabdari, M. Sanjari, F. Taghizadeh, A. Mahmoodian, and J. Lu, "Adaptive control of V2Gs in islanded microgrids incorporating EV owner expectations," *Appl. Energy*, vol. 341, Jul. 2023, Art. no. 121118, doi: [10.1016/j.apenergy.2023.121118](https://doi.org/10.1016/j.apenergy.2023.121118).
- [13] M. F. Zia, E. Elbouchikhi, and M. Benbouzid, "Microgrids energy management systems: A critical review on methods, solutions, and prospects," *Appl. Energy*, vol. 222, pp. 1033–1055, Jul. 2018, doi: [10.1016/j.apenergy.2018.04.103](https://doi.org/10.1016/j.apenergy.2018.04.103).
- [14] M. Ferrari, A. Sundararajan, N. Shepard, J. Smith, and B. Ollis, "Microgrid communications using the open-source open field message bus (OpenFMB) framework applied to a 480 V, 100 kW laboratory microgrid," in *Proc. IEEE 13th Int. Symp. Power Electron. Distrib. Gener. Syst. (PEDG)*, Kiel, Germany, Jun. 2022, pp. 1–5, doi: [10.1109/PEDG54999.2022.9923215](https://doi.org/10.1109/PEDG54999.2022.9923215).
- [15] I. S. Bayram, "Quantifying the effects of communication network performance in vehicle-to-grid frequency regulation services," in *Proc. Int. Conf. UK-China Emerg. Technol. (UCET)*, China, U.K., Aug. 2020, pp. 1–4, doi: [10.1109/UCET51115.2020.9205457](https://doi.org/10.1109/UCET51115.2020.9205457).
- [16] A. Belkaaloul and B. A. Bensaber, "Anonymous authentication protocol for efficient communications in vehicle to grid networks," in *Proc. IEEE Symp. Comput. Commun. (ISCC)*, Athens, Greece, Sep. 2021, pp. 1–5, doi: [10.1109/ISCC53001.2021.9631258](https://doi.org/10.1109/ISCC53001.2021.9631258).
- [17] F. Alfaverh, M. Denai, and Y. Sun, "Optimal vehicle-to-grid control for supplementary frequency regulation using deep reinforcement learning," *Electric Power Syst. Res.*, vol. 214, Jan. 2023, Art. no. 108949, doi: [10.1016/j.epsr.2022.108949](https://doi.org/10.1016/j.epsr.2022.108949).
- [18] D. Orihara, S. Kimura, and H. Saitoh, "Frequency regulation by decentralized V2G control with consensus-based SOC synchronization," *IFAC-PapersOnLine*, vol. 51, no. 28, pp. 604–609, Jan. 2018, doi: [10.1016/j.ifacol.2018.11.770](https://doi.org/10.1016/j.ifacol.2018.11.770).
- [19] V. Kuruvilla, P. V. Kumar, and A. I. Selvakumar, "Challenges and impacts of V2g integration—A review," in *Proc. 8th Int. Conf. Adv. Comput. Commun. Syst. (ICACCS)*, vol. 1, Coimbatore, India, Mar. 2022, pp. 1938–1942, doi: [10.1109/ICACCS54159.2022.9785095](https://doi.org/10.1109/ICACCS54159.2022.9785095).
- [20] S. Singh, S. Jagota, and M. Singh, "Energy management and voltage stabilization in an islanded microgrid through an electric vehicle charging station," *Sustain. Cities Soc.*, vol. 41, pp. 679–694, Aug. 2018, doi: [10.1016/j.scs.2018.05.055](https://doi.org/10.1016/j.scs.2018.05.055).
- [21] D. M. Steward, "Critical elements of vehicle-to-grid (V2G) economics," *Nat. Renew. Energy Lab.*, USA, Tech. Rep. NREL/TP-5400-69017, 1390043, Sep. 2017, doi: [10.2172/1390043](https://doi.org/10.2172/1390043).
- [22] S. Al-Rubaye, A. Al-Dulaimi, and Q. Ni, "Power interchange analysis for reliable vehicle-to-grid connectivity," *IEEE Commun. Mag.*, vol. 57, no. 8, pp. 105–111, Aug. 2019, doi: [10.1109/MCOM.2019.1800657](https://doi.org/10.1109/MCOM.2019.1800657).
- [23] S. Chowdhury, H. Keshtkar, and F. D. Mohammadi, "Microgrid peak shaving implementation using vehicle-to-grid system," in *Proc. Int. Conf. Electr. Comput. Energy Technol. (ICECET)*, Prague, Czech Republic, Jul. 2022, pp. 1–5, doi: [10.1109/ICECET55527.2022.9873000](https://doi.org/10.1109/ICECET55527.2022.9873000).
- [24] T. Kern, P. Dossow, and E. Morlock, "Revenue opportunities by integrating combined vehicle-to-home and vehicle-to-grid applications in smart homes," *Appl. Energy*, vol. 307, Feb. 2022, Art. no. 118187, doi: [10.1016/j.apenergy.2021.118187](https://doi.org/10.1016/j.apenergy.2021.118187).
- [25] C. Zhou, Y. Xiang, Y. Huang, X. Wei, Y. Liu, and J. Liu, "Economic analysis of auxiliary service by V2G: City comparison cases," *Energy Rep.*, vol. 6, pp. 509–514, Dec. 2020, doi: [10.1016/j.egy.2020.11.205](https://doi.org/10.1016/j.egy.2020.11.205).
- [26] A. Weis, P. Jaramillo, and J. Michalek, "Estimating the potential of controlled plug-in hybrid electric vehicle charging to reduce operational and capacity expansion costs for electric power systems with high wind penetration," *Appl. Energy*, vol. 115, pp. 190–204, Feb. 2014.
- [27] H. Ali, S. Hussain, H. A. Khan, N. Arshad, and I. A. Khan, "Economic and environmental impact of vehicle-to-grid (V2G) integration in an intermittent utility grid," in *Proc. 2nd Int. Conf. Smart Power Internet Energy Syst. (SPIES)*, Bangkok, Thailand, Sep. 2020, pp. 345–349, doi: [10.1109/SPIES48661.2020.9242992](https://doi.org/10.1109/SPIES48661.2020.9242992).
- [28] X. Yao, Y. Fan, F. Zhao, and S.-C. Ma, "Economic and climate benefits of vehicle-to-grid for low-carbon transitions of power systems: A case study of China's 2030 renewable energy target," *J. Cleaner Prod.*, vol. 330, Jan. 2022, Art. no. 129833, doi: [10.1016/j.jclepro.2021.129833](https://doi.org/10.1016/j.jclepro.2021.129833).
- [29] J. Soares, J. Almeida, L. Gomes, B. Canizes, Z. Vale, and E. Neto, "Electric vehicles local flexibility strategies for congestion relief on distribution networks," *Energy Rep.*, vol. 8, pp. 62–69, Jun. 2022, doi: [10.1016/j.egy.2022.01.036](https://doi.org/10.1016/j.egy.2022.01.036).
- [30] S. Hellamuri, S. H. C. Cherukuri, S. K. Sudabattula, N. Prabakaran, and E. Vossain, "Combined approach for power loss minimization in distribution networks in the presence of gridable electric vehicles and dispersed generation," *IEEE Syst. J.*, vol. 16, no. 2, pp. 3284–3295, Jun. 2022, doi: [10.1109/JSYST.2021.3123436](https://doi.org/10.1109/JSYST.2021.3123436).
- [31] S. Ray, K. Kasturi, S. Patnaik, and M. R. Nayak, "Review of electric vehicles integration impacts in distribution networks: Placement, charging/discharging strategies, objectives and optimisation models," *J. Energy Storage*, vol. 72, Nov. 2023, Art. no. 108672, doi: [10.1016/j.est.2023.108672](https://doi.org/10.1016/j.est.2023.108672).
- [32] J. Wang, G. R. Bharati, S. Paudyal, O. Ceylan, B. P. Bhattarai, and K. S. Myers, "Coordinated electric vehicle charging with reactive power support to distribution grids," *IEEE Trans. Ind. Informat.*, vol. 15, no. 1, pp. 54–63, Jan. 2019, doi: [10.1109/TII.2018.2829710](https://doi.org/10.1109/TII.2018.2829710).
- [33] K. M. Tan, V. K. Ramachandaramurthy, J. Y. Yong, S. Padmanaban, L. Mihet-Popa, and F. Blaabjerg, "Minimization of load variance in power grids—Investigation on optimal vehicle-to-grid scheduling," *Energies*, vol. 10, no. 11, p. 1880, Nov. 2017, doi: [10.3390/en10111880](https://doi.org/10.3390/en10111880).
- [34] *V2G Explained—Benefits of vehicle-to-grid Technology*. Clean Energy Reviews. Accessed: Mar. 22, 2024. [Online]. Available: <https://www.cleanenergyreviews.info/blog/v2g-explained-vehicle-to-grid-benefits>
- [35] M. S. Mastoi, S. Zhuang, H. M. Munir, M. Haris, M. Hassan, M. Alqarni, and B. Alamri, "A study of charging-dispatch strategies and vehicle-to-grid technologies for electric vehicles in distribution networks," *Energy Rep.*, vol. 9, pp. 1777–1806, Dec. 2023, doi: [10.1016/j.egy.2022.12.139](https://doi.org/10.1016/j.egy.2022.12.139).

- [36] S. S. Ravi and M. Aziz, "Utilization of electric vehicles for vehicle-to-grid services: Progress and perspectives," *Energies*, vol. 15, no. 2, p. 589, Jan. 2022, doi: [10.3390/en15020589](https://doi.org/10.3390/en15020589).
- [37] J. K. Szinai, C. J. R. Sheppard, N. Abhyankar, and A. R. Gopal, "Reduced grid operating costs and renewable energy curtailment with electric vehicle charge management," *Energy Policy*, vol. 136, Jan. 2020, Art. no. 111051, doi: [10.1016/j.enpol.2019.111051](https://doi.org/10.1016/j.enpol.2019.111051).
- [38] X. Tang, C. Sun, S. Bi, S. Wang, and A. Yingjun Zhang, "A holistic review on advanced bi-directional EV charging control algorithms," 2022, *arXiv:2202.13565*.
- [39] S. Lotfi, M. Sedighzadeh, R. Abbasi, and S. H. Hosseinian, "Vehicle-to-grid bidding for regulation and spinning reserve markets: A robust optimal coordinated charging approach," *Energy Rep.*, vol. 11, pp. 925–936, Jun. 2024, doi: [10.1016/j.egy.2023.12.044](https://doi.org/10.1016/j.egy.2023.12.044).
- [40] V. Sultan, A. Aryal, H. Chang, and J. Kral, "Integration of EVs into the smart grid: A systematic literature review," *Energy Informat.*, vol. 5, no. 1, p. 65, Dec. 2022, doi: [10.1186/s42162-022-00251-2](https://doi.org/10.1186/s42162-022-00251-2).
- [41] B. N. Harish and U. Surendra, "A review on power quality issues in electric vehicle interfaced distribution system and mitigation techniques," *Indonesian J. Electr. Eng. Comput. Sci.*, vol. 25, no. 2, p. 656, Feb. 2022, doi: [10.11591/ijeecs.v25.i2.pp656-665](https://doi.org/10.11591/ijeecs.v25.i2.pp656-665).
- [42] A. Srivastava, M. Manas, and R. K. Dubey, "Electric vehicle integration's impacts on power quality in distribution network and associated mitigation measures: A review," *J. Eng. Appl. Sci.*, vol. 70, no. 1, p. 32, Apr. 2023, doi: [10.1186/s44147-023-00193-w](https://doi.org/10.1186/s44147-023-00193-w).
- [43] J. Guo, J. Yang, Z. Lin, C. Serrano, and A. M. Cortes, "Impact analysis of V2G services on EV battery degradation—A review," in *Proc. IEEE Milan PowerTech*, Milan, Italy, Jun. 2019, pp. 1–6, doi: [10.1109/PTC.2019.8810982](https://doi.org/10.1109/PTC.2019.8810982).
- [44] M. Dubarry, A. Devie, and K. McKenzie, "Durability and reliability of electric vehicle batteries under electric utility grid operations: Bidirectional charging impact analysis," *J. Power Sour.*, vol. 358, pp. 39–49, Aug. 2017, doi: [10.1016/j.jpowsour.2017.05.015](https://doi.org/10.1016/j.jpowsour.2017.05.015).
- [45] *Will vehicle-to-grid Use Lead To Battery Degradation?* PTOLEMUS Consulting Group. Accessed: Nov. 21, 2023. [Online]. Available: <https://www.ptolemus.com/insight/will-vehicle-to-grid-use-lead-to-battery-degradation/>
- [46] G. Vishnu, D. Kaliyaperumal, R. Jayaprakash, A. Karthick, V. K. Chinnaiyan, and A. Ghosh, "Review of challenges and opportunities in the integration of electric vehicles to the grid," *World Electric Vehicle J.*, vol. 14, no. 9, p. 259, Sep. 2023, doi: [10.3390/wevj14090259](https://doi.org/10.3390/wevj14090259).
- [47] B. Bibak and H. Tekiner-Mogulkoç, "A comprehensive analysis of vehicle to grid (V2G) systems and scholarly literature on the application of such systems," *Renew. Energy Focus*, vol. 36, pp. 1–20, Mar. 2021, doi: [10.1016/j.ref.2020.10.001](https://doi.org/10.1016/j.ref.2020.10.001).
- [48] M. T. Saeed, "Vehicle-to-grid challenges and potential benefits for smart microgrids," in *Active Electrical Distribution Network: A Smart Approach*. U.K.: Wiley, 2021, pp. 311–328, doi: [10.1002/9781119599593.ch16](https://doi.org/10.1002/9781119599593.ch16).
- [49] M. N. Tasnim, S. Akter, M. Shahjalal, T. Shams, P. Davari, and A. Iqbal, "A critical review of the effect of light duty electric vehicle charging on the power grid," *Energy Rep.*, vol. 10, pp. 4126–4147, Nov. 2023, doi: [10.1016/j.egy.2023.10.075](https://doi.org/10.1016/j.egy.2023.10.075).
- [50] I. Mahmud, M. B. Medha, and M. Hasanuzzaman, "Global challenges of electric vehicle charging systems and its future prospects: A review," *Res. Transp. Bus. Manag.*, vol. 49, Aug. 2023, Art. no. 101011, doi: [10.1016/j.rtbm.2023.101011](https://doi.org/10.1016/j.rtbm.2023.101011).
- [51] Z. M. Zenhom, S. H. E. A. Aleem, A. F. Zobia, and T. A. Boghdady, "A comprehensive review of renewables and electric vehicles hosting capacity in active distribution networks," *IEEE Access*, vol. 12, pp. 3672–3699, 2024, doi: [10.1109/ACCESS.2023.3349235](https://doi.org/10.1109/ACCESS.2023.3349235).
- [52] S. Satarworn and N. Hoonchareon, "Impact of EV home charger on distribution transformer overloading in an urban area," in *Proc. 14th Int. Conf. Electr. Eng./Electron., Comput., Telecommun. Inf. Technol. (ECTI-CON)*, Jun. 2017, pp. 469–472, doi: [10.1109/ECTICON.2017.8096276](https://doi.org/10.1109/ECTICON.2017.8096276).
- [53] N. Panossian, M. Muratori, B. Palmintier, A. Meintz, T. Lipman, and K. Moffat, "Challenges and opportunities of integrating electric vehicles in electricity distribution systems," *Current Sustain./Renew. Energy Rep.*, vol. 9, no. 2, pp. 27–40, Jun. 2022, doi: [10.1007/s40518-022-00201-2](https://doi.org/10.1007/s40518-022-00201-2).
- [54] M. N. Tasnim, J. M. K. Riana, T. Shams, M. Shahjalal, N. Subhani, M. R. Ahmed, and A. Iqbal, "A critical review on contemporary power electronics interface topologies to vehicle-to-grid technology: Prospects, challenges, and directions," *IET Power Electron.*, vol. 17, no. 1, pp. 157–181, Jan. 2024, doi: [10.1049/pel2.12618](https://doi.org/10.1049/pel2.12618).
- [55] I. Skarga-Bandurova, I. Kotsiuba, and T. Biloborodova, "Cyber security of electric vehicle charging infrastructure: Open issues and recommendations," in *Proc. IEEE Int. Conf. Big Data*, Osaka, Japan, Dec. 2022, pp. 3099–3106, doi: [10.1109/BigData55660.2022.10020644](https://doi.org/10.1109/BigData55660.2022.10020644).
- [56] N. Moghadasi, Z. A. Collier, A. Koch, D. L. Slutzky, T. L. Polmateer, M. C. Manasco, and J. H. Lambert, "Trust and security of electric vehicle-to-grid systems and hardware supply chains," *Rel. Eng. Syst. Saf.*, vol. 225, Sep. 2022, Art. no. 108565, doi: [10.1016/j.res.2022.108565](https://doi.org/10.1016/j.res.2022.108565).
- [57] E. C. Summit, *5 Cybersecurity Challenges Facing the EV Industry—EV Charging Summit Blog*. Accessed: Mar. 21, 2024. [Online]. Available: <https://evchargingsummit.com/blog/cybersecurity-challenges-facing-ev-industry/>
- [58] S. Hamdare, O. Kaiwartya, M. Aljaidi, M. Jugran, Y. Cao, S. Kumar, M. Mahmud, D. Brown, and J. Lloret, "Cybersecurity risk analysis of electric vehicles charging stations," *Sensors*, vol. 23, no. 15, p. 6716, Jul. 2023, doi: [10.3390/s23156716](https://doi.org/10.3390/s23156716).
- [59] F. A. Padihilal and K.-H. Kim, "A centralized power flow control scheme of EV-connected DC microgrid to satisfy multi-objective problems under several constraints," *Sustainability*, vol. 13, no. 16, p. 8863, Aug. 2021, doi: [10.3390/su13168863](https://doi.org/10.3390/su13168863).
- [60] S. Shin, P. Hart, T. Jahns, and V. M. Zavala, "A hierarchical optimization architecture for large-scale power networks," *IEEE Trans. Control Netw. Syst.*, vol. 6, no. 3, pp. 1004–1014, Sep. 2019, doi: [10.1109/TCNS.2019.2906917](https://doi.org/10.1109/TCNS.2019.2906917).
- [61] J. Peng, B. Fan, and W. Liu, "Voltage-based distributed optimal control for generation cost minimization and bounded bus voltage regulation in DC microgrids," *IEEE Trans. Smart Grid*, vol. 12, no. 1, pp. 106–116, Jan. 2021, doi: [10.1109/TSG.2020.3013303](https://doi.org/10.1109/TSG.2020.3013303).
- [62] W. Feng, M. Jin, X. Liu, Y. Bao, C. Marnay, C. Yao, and J. Yu, "A review of microgrid development in the United States—A decade of progress on policies, demonstrations, controls, and software tools," *Appl. Energy*, vol. 228, pp. 1656–1668, Oct. 2018, doi: [10.1016/j.apenergy.2018.06.096](https://doi.org/10.1016/j.apenergy.2018.06.096).
- [63] M. H. Cintuglu, T. Youssef, and O. A. Mohammed, "Development and application of a real-time testbed for multiagent system interoperability: A case study on hierarchical microgrid control," *IEEE Trans. Smart Grid*, vol. 9, no. 3, pp. 1759–1768, May 2018, doi: [10.1109/TSG.2016.2599265](https://doi.org/10.1109/TSG.2016.2599265).
- [64] D. Y. Yamashita, I. Vechiu, and J.-P. Gaubert, "A review of hierarchical control for building microgrids," *Renew. Sustain. Energy Rev.*, vol. 118, Feb. 2020, Art. no. 109523, doi: [10.1016/j.rser.2019.109523](https://doi.org/10.1016/j.rser.2019.109523).
- [65] U. B. Tayab, M. A. B. Roslan, L. J. Hwai, and M. Kashif, "A review of droop control techniques for microgrid," *Renew. Sustain. Energy Rev.*, vol. 76, pp. 717–727, Sep. 2017, doi: [10.1016/j.rser.2017.03.028](https://doi.org/10.1016/j.rser.2017.03.028).
- [66] H. Liu, Z. Hu, Y. Song, and J. Lin, "Decentralized vehicle-to-grid control for primary frequency regulation considering charging demands," *IEEE Trans. Power Syst.*, vol. 28, no. 3, pp. 3480–3489, Aug. 2013, doi: [10.1109/TPWRS.2013.2252029](https://doi.org/10.1109/TPWRS.2013.2252029).
- [67] J. Meng, Y. Mu, H. Jia, J. Wu, X. Yu, and B. Qu, "Dynamic frequency response from electric vehicles considering travelling behavior in the great Britain power system," *Appl. Energy*, vol. 162, pp. 966–979, Jan. 2016, doi: [10.1016/j.apenergy.2015.10.159](https://doi.org/10.1016/j.apenergy.2015.10.159).
- [68] F. Gao, R. Kang, J. Cao, and T. Yang, "Primary and secondary control in DC microgrids: A review," *J. Modern Power Syst. Clean Energy*, vol. 7, no. 2, pp. 227–242, Mar. 2019, doi: [10.1007/s40565-018-0466-5](https://doi.org/10.1007/s40565-018-0466-5).
- [69] S. Gaurav and C. Kumar, "Coordinated control of EV charging stations in smart transformer based microgrid," in *Proc. 22nd Nat. Power Syst. Conf. (NPSC)*, New Delhi, India, Dec. 2022, pp. 590–595, doi: [10.1109/NPSC57038.2022.10069390](https://doi.org/10.1109/NPSC57038.2022.10069390).
- [70] A. Ahmadi, A. Tavakoli, P. Jamborsalamati, N. Rezaei, M. R. Miveh, F. H. Gandoman, A. Heidari, and A. E. Nezhad, "Power quality improvement in smart grids using electric vehicles: A review," *IET Electr. Syst. Transp.*, vol. 9, no. 2, pp. 53–64, Jun. 2019, doi: [10.1049/iet-est.2018.5023](https://doi.org/10.1049/iet-est.2018.5023).
- [71] P. Li, W. Hu, X. Xu, Q. Huang, Z. Liu, and Z. Chen, "A frequency control strategy of electric vehicles in microgrid using virtual synchronous generator control," *Energy*, vol. 189, Dec. 2019, Art. no. 116389, doi: [10.1016/j.energy.2019.116389](https://doi.org/10.1016/j.energy.2019.116389).

- [72] B. Modu, M. P. Abdullah, M. A. Sanusi, and M. F. Hamza, "DC-based microgrid: Topologies, control schemes, and implementations," *Alexandria Eng. J.*, vol. 70, pp. 61–92, May 2023, doi: [10.1016/j.aej.2023.02.021](https://doi.org/10.1016/j.aej.2023.02.021).
- [73] G. S. Georgiou, P. Christodoulides, and S. A. Kalogirou, "Real-time energy convex optimization, via electrical storage, in buildings—A review," *Renew. Energy*, vol. 139, pp. 1355–1365, Aug. 2019, doi: [10.1016/j.renene.2019.03.003](https://doi.org/10.1016/j.renene.2019.03.003).
- [74] C. Ciceu and I. Serban, "Energy management system for EV charging stations powered by renewable energy sources," in *Proc. Int. Conf. Expo. Electr. Power Eng. (EPE)*, Iasi, Romania, Oct. 2022, pp. 193–197, doi: [10.1109/EPE56121.2022.9959811](https://doi.org/10.1109/EPE56121.2022.9959811).
- [75] M. Zhai, Y. Liu, T. Zhang, and Y. Zhang, "Robust model predictive control for energy management of isolated microgrids," in *Proc. IEEE Int. Conf. Ind. Eng. Eng. Manag. (IEEM)*, Singapore, Dec. 2017, pp. 2049–2053, doi: [10.1109/IEEM.2017.8290252](https://doi.org/10.1109/IEEM.2017.8290252).
- [76] X. Chang, Y. Xu, W. Gu, H. Sun, M.-Y. Chow, and Z. Yi, "Accelerated distributed hybrid stochastic/robust energy management of smart grids," *IEEE Trans. Ind. Informat.*, vol. 17, no. 8, pp. 5335–5347, Aug. 2021, doi: [10.1109/TII.2020.3022412](https://doi.org/10.1109/TII.2020.3022412).
- [77] M. B. Sigalo, A. C. Pillai, S. Das, and M. Abusara, "An energy management system for the control of battery storage in a grid-connected microgrid using mixed integer linear programming," *Energies*, vol. 14, no. 19, p. 6212, Sep. 2021, doi: [10.3390/en14196212](https://doi.org/10.3390/en14196212).
- [78] S. Umetani, Y. Fukushima, and H. Morita, "A linear programming based heuristic algorithm for charge and discharge scheduling of electric vehicles in a building energy management system," *Omega*, vol. 67, pp. 115–122, Mar. 2017, doi: [10.1016/j.omega.2016.04.005](https://doi.org/10.1016/j.omega.2016.04.005).
- [79] Y. Gao, S. Li, Y. Xiao, W. Dong, M. Fairbank, and B. Lu, "An iterative optimization and learning-based IoT system for energy management of connected buildings," *IEEE Internet Things J.*, vol. 9, no. 21, pp. 21246–21259, Nov. 2022, doi: [10.1109/JIOT.2022.3176306](https://doi.org/10.1109/JIOT.2022.3176306).
- [80] A. S. Nasab, M. Aeini, A. Salemmia, and M. M. Kazemi, "A new method of energy management system in islanded DC microgrid using fuzzy logic controller," in *Proc. Int. Power Syst. Conf. (PSC)*, Tehran, Iran, Dec. 2019, pp. 638–642, doi: [10.1109/PSC49016.2019.9081500](https://doi.org/10.1109/PSC49016.2019.9081500).
- [81] T. Wang, X. He, and T. Deng, "Neural networks for power management optimal strategy in hybrid microgrid," *Neural Comput. Appl.*, vol. 31, no. 7, pp. 2635–2647, Jul. 2019, doi: [10.1007/s00521-017-3219-x](https://doi.org/10.1007/s00521-017-3219-x).
- [82] A. Saboor, N. Javaid, Z. Iqbal, Z. Abbas, A. J. Khan, S. Rashid, and M. Awais, "Home energy management in smart grid using evolutionary algorithms," in *Proc. IEEE 32nd Int. Conf. Adv. Inf. Neww. Appl. (AINA)*, May 2018, pp. 1070–1080, doi: [10.1109/AINA.2018.00154](https://doi.org/10.1109/AINA.2018.00154).
- [83] P. Wang, D. Wang, C. Zhu, Y. Yang, H. M. Abdullah, and M. A. Mohamed, "Stochastic management of hybrid AC/DC microgrids considering electric vehicles charging demands," *Energy Rep.*, vol. 6, pp. 1338–1352, Nov. 2020, doi: [10.1016/j.egyr.2020.05.019](https://doi.org/10.1016/j.egyr.2020.05.019).
- [84] E. Apostolaki-Iosifidou, P. Codani, and W. Kempton, "Measurement of power loss during electric vehicle charging and discharging," *Energy*, vol. 127, pp. 730–742, May 2017, doi: [10.1016/j.energy.2017.03.015](https://doi.org/10.1016/j.energy.2017.03.015).
- [85] T. Dragicevic, X. Lu, J. C. Vasquez, and J. M. Guerrero, "DC microgrids—Part II: A review of power architectures, applications, and standardization issues," *IEEE Trans. Power Electron.*, vol. 31, no. 5, pp. 3528–3549, May 2016, doi: [10.1109/TPEL.2015.2464277](https://doi.org/10.1109/TPEL.2015.2464277).
- [86] D. Kumar, F. Zare, and A. Ghosh, "DC microgrid technology: System architectures, AC grid interfaces, grounding schemes, power quality, communication networks, applications, and standardizations aspects," *IEEE Access*, vol. 5, pp. 12230–12256, 2017, doi: [10.1109/ACCESS.2017.2705914](https://doi.org/10.1109/ACCESS.2017.2705914).
- [87] B. Liu, T. P. Pantelidis, S. Tam, and J. Y. J. Chow, "An electric vehicle charging station access equilibrium model with M/D/C queueing," *Int. J. Sustain. Transp.*, vol. 17, no. 3, pp. 228–244, Mar. 2023, doi: [10.1080/15568318.2022.2029633](https://doi.org/10.1080/15568318.2022.2029633).
- [88] W. Huynh, T. T. Hoang, A. Ukil, and N. C. Nair, "Comparison of low-voltage AC and DC distribution networks for EV charging," in *Proc. 7th IEEE Workshop Electron. Grid (eGRID)*, Auckland, New Zealand, Nov. 2022, pp. 1–5, doi: [10.1109/eGRID57376.2022.9990014](https://doi.org/10.1109/eGRID57376.2022.9990014).
- [89] Y. Yu, O. S. Nduka, and B. C. Pal, "Smart control of an electric vehicle for ancillary service in DC microgrid," *IEEE Access*, vol. 8, pp. 197222–197235, 2020, doi: [10.1109/ACCESS.2020.3034496](https://doi.org/10.1109/ACCESS.2020.3034496).
- [90] B. Aluisio, M. Dicorato, I. Ferrini, G. Forte, R. Sbrizzai, and M. Trovato, "Planning and reliability of DC microgrid configurations for electric vehicle supply infrastructure," *Int. J. Electr. Power Energy Syst.*, vol. 131, Oct. 2021, Art. no. 107104, doi: [10.1016/j.ijepes.2021.107104](https://doi.org/10.1016/j.ijepes.2021.107104).
- [91] S. Ullah, A. M. A. Haidar, P. Hoole, H. Zen, and T. Ahfock, "The current state of distributed renewable generation, challenges of interconnection and opportunities for energy conversion based DC microgrids," *J. Cleaner Prod.*, vol. 273, Nov. 2020, Art. no. 122777, doi: [10.1016/j.jclepro.2020.122777](https://doi.org/10.1016/j.jclepro.2020.122777).
- [92] L. Zhang, N. Tai, W. Huang, J. Liu, and Y. Wang, "A review on protection of DC microgrids," *J. Modern Power Syst. Clean Energy*, vol. 6, no. 6, pp. 1113–1127, Nov. 2018, doi: [10.1007/s40565-018-0381-9](https://doi.org/10.1007/s40565-018-0381-9).
- [93] M. Dashtdar, Y. Belkhier, M. Bajaj, S. M. Sadegh, M. Belik, and O. Rubanenko, "Protection of DC microgrids based on frequency domain analysis using Fourier transform," in *Proc. IEEE 3rd KhPI Week Adv. Technol. (KhPIWeek)*, Kharkiv, Ukraine, Oct. 2022, pp. 1–6, doi: [10.1109/KhPIWeek57572.2022.9916455](https://doi.org/10.1109/KhPIWeek57572.2022.9916455).
- [94] N. Bayati, F. Aghae, A. Hajizadeh, M. Soltani, and Z. Lin, "A localized-protection scheme for ring DC microgrids using distribution-sensitive poverty index," in *Proc. 12th Power Electron., Drive Syst., Technol. Conf. (PEDSTC)*, Tabriz, Iran, Feb. 2021, pp. 1–5, doi: [10.1109/PEDSTC52094.2021.9405880](https://doi.org/10.1109/PEDSTC52094.2021.9405880).
- [95] M. A. Yagoub, Z. Tao, and O. M. S. O. Ibrahim, "Modelling and fault protection analysis of a DC microgrid using voltage source converter (VSC)," in *Proc. Int. Conf. Comput., Control, Electr., Electron. Eng. (ICCCEEE)*, Khartoum, Sudan, Feb. 2021, pp. 1–6, doi: [10.1109/ICCCEEE49695.2021.9429643](https://doi.org/10.1109/ICCCEEE49695.2021.9429643).
- [96] A. Chandra, G. K. Singh, and V. Pant, "Protection techniques for DC microgrid—A review," *Electric Power Syst. Res.*, vol. 187, Oct. 2020, Art. no. 106439, doi: [10.1016/j.epsr.2020.106439](https://doi.org/10.1016/j.epsr.2020.106439).
- [97] V. F. Pires, A. Pires, and A. Cordeiro, "DC microgrids: Benefits, architectures, perspectives and challenges," *Energies*, vol. 16, no. 3, p. 1217, Jan. 2023, doi: [10.3390/en16031217](https://doi.org/10.3390/en16031217).
- [98] Z. Garofalaki, D. Kosmanos, S. Moschoyiannis, D. Kallergis, and C. Douligeris, "Electric vehicle charging: A survey on the security issues and challenges of the open charge point protocol (OCPP)," *IEEE Commun. Surveys Tuts.*, vol. 24, no. 3, pp. 1504–1533, Jun. 2022.
- [99] J.-R. Terreros-Barreto, A. Bejarano, and A. G. Ruiz, "Systematic review of wired communication's technologies for active distribution networks," in *Proc. IEEE ANDESCON*, Barranquilla, Colombia, Nov. 2022, pp. 1–6, doi: [10.1109/ANDESCON56260.2022.9989622](https://doi.org/10.1109/ANDESCON56260.2022.9989622).
- [100] X. Yang, Y. Wang, Y. Zhang, and D. Xu, "Modeling and analysis of communication network in smart microgrids," in *Proc. 2nd IEEE Conf. Energy Internet Energy Syst. Integr. (EI)*, Beijing, China, Oct. 2018, pp. 1–6, doi: [10.1109/EI2.2018.8582157](https://doi.org/10.1109/EI2.2018.8582157).
- [101] R. Perez-Guzman, Y. Salgueiro-Sicilia, M. Rivera, J. Munoz, and J. Rodas, "Communication improvements for intelligent systems in microgrids—Part II," in *Proc. IEEE Int. Conf. Elect. Syst. Aircr., Railway, Ship Propuls. Road Vehicles Int. Transp. Electrific. Conf.*, Nov. 2018, pp. 1–6, doi: [10.1109/ESARS-ITEC.2018.8607558](https://doi.org/10.1109/ESARS-ITEC.2018.8607558).
- [102] I. Serban, S. Céspedes, C. Marinescu, C. A. Azurdia-Meza, J. S. Gómez, and D. S. Hueichapan, "Communication requirements in microgrids: A practical survey," *IEEE Access*, vol. 8, pp. 47694–47712, 2020, doi: [10.1109/ACCESS.2020.2977928](https://doi.org/10.1109/ACCESS.2020.2977928).
- [103] A. B. Shyam, S. R. Sahoo, S. Anand, and J. M. Guerrero, "Comparative study of various communication technologies for secondary controllers in DC microgrid," in *Proc. 9th IEEE Int. Conf. Power Syst. (ICPS)*, Kharagpur, India, Dec. 2021, pp. 1–6, doi: [10.1109/ICPS52420.2021.9670303](https://doi.org/10.1109/ICPS52420.2021.9670303).
- [104] M. Gayo-Abeleira, J. R. Sanchez, P. J. Hueros-Barrios, M. Tradacete-Agreda, C. Santos, and J. A. Jimenez, "Assessing micro-communications technologies in real-world environment," in *Proc. Int. Conf. Electr., Comput. Energy Technol. (ICECET)*, Prague, Czech Republic, Jul. 2022, pp. 1–6, doi: [10.1109/ICECET55527.2022.9873455](https://doi.org/10.1109/ICECET55527.2022.9873455).
- [105] D. Sharma, A. Dubey, S. Mishra, and R. K. Mallik, "A frequency control strategy using power line communication in a smart microgrid," *IEEE Access*, vol. 7, pp. 21712–21721, 2019, doi: [10.1109/ACCESS.2019.2897051](https://doi.org/10.1109/ACCESS.2019.2897051).
- [106] R. B. Otto, D. A. C. Costa, A. A. Braggio, F. P. Silva, and R. Ramos, "Enabling communications in microgrids: A comparison of fiber-optics, LoRa, and WI-SUN," in *Proc. IEEE PES Transmiss. Distribution Conf. Exhib.*, Montevideo, Uruguay, Sep. 2020, pp. 1–6, doi: [10.1109/TDLA47668.2020.9326189](https://doi.org/10.1109/TDLA47668.2020.9326189).

- [107] D. Priyasta, H. Hadiyanto, and R. Septiawan, "An overview of EV roaming protocols," in *Proc. ES Web Conf.*, vol. 359, Oct. 2022, p. 05006, doi: [10.1051/e3sconf/202235905006](https://doi.org/10.1051/e3sconf/202235905006).
- [108] P. Barman, L. Dutta, S. Bordoloi, A. Kalita, P. Buragohain, S. Bharali, and B. Azzopardi, "Renewable energy integration with electric vehicle technology: A review of the existing smart charging approaches," *Renew. Sustain. Energy Rev.*, vol. 183, Sep. 2023, Art. no. 113518, doi: [10.1016/j.rser.2023.113518](https://doi.org/10.1016/j.rser.2023.113518).
- [109] H. T. Mouftah and M. Erol-Kantarci, *Smart Grid: Networking, Data Management, and Business Models*. Boca Raton, FL, USA: CRC Press, Dec. 2017, doi: [10.1201/b19664](https://doi.org/10.1201/b19664).
- [110] K. Gandhi and W. G. Morsi, "Impact of the open charge point protocol between the electric vehicle and the fast charging station on the cybersecurity of the smart grid," in *Proc. IEEE Can. Conf. Electr. Comput. Eng. (CCECE)*, Halifax, NS, Canada, Sep. 2022, pp. 235–240, doi: [10.1109/CCECE49351.2022.9918406](https://doi.org/10.1109/CCECE49351.2022.9918406).
- [111] T. S. Ustun and S. M. S. Hussain, "Standardized communication model for home energy management system," *IEEE Access*, vol. 8, pp. 180067–180075, 2020, doi: [10.1109/ACCESS.2020.3028108](https://doi.org/10.1109/ACCESS.2020.3028108).
- [112] I. Ali and S. M. S. Hussain, "Communication design for energy management automation in microgrid," *IEEE Trans. Smart Grid*, vol. 9, no. 3, pp. 2055–2064, May 2018, doi: [10.1109/TSG.2016.2606131](https://doi.org/10.1109/TSG.2016.2606131).
- [113] S. M. S. Hussain, T. S. Ustun, P. Nsonga, and I. Ali, "IEEE 1609 WAVE and IEC 61850 standard communication based integrated EV charging management in smart grids," *IEEE Trans. Veh. Technol.*, vol. 67, no. 8, pp. 7690–7697, Aug. 2018, doi: [10.1109/TVT.2018.2838018](https://doi.org/10.1109/TVT.2018.2838018).
- [114] *IEC Webstore*, Standard IEC 61851-1, 2017. [Online]. Available: <https://webstore.iec.ch/publication/33644>
- [115] M. A. Aftab, S. M. S. Hussain, I. Ali, and T. S. Ustun, "IEC 61850 and XMPP communication based energy management in microgrids considering electric vehicles," *IEEE Access*, vol. 6, pp. 35657–35668, 2018, doi: [10.1109/ACCESS.2018.2848591](https://doi.org/10.1109/ACCESS.2018.2848591).
- [116] *GridX—Communication Protocol in Energy: OCPP*. Accessed: Dec. 25, 2023. [Online]. Available: <https://www.gridx.ai/blog/communication-is-key-the-importance-of-ocpp>
- [117] G. Wilkenfeld, "Evaluating international standards for electric vehicle chargers For SA," Dept. Energy Mining, George Wilkenfeld Assoc. With AusEng Pty Ltd, Sydney, NSW, Australia, Tech. Rep., Dec. 2021. [Online]. Available: [https://www.energymining.sa.gov.au/\\_data/assets/pdf\\_file/0003/813522/Evaluating-international-standards-for-electric-vehicle-chargers-George-Wilkenfeld-and-Associates-with-Auseng-Pty-Ltd-December-2021.pdf](https://www.energymining.sa.gov.au/_data/assets/pdf_file/0003/813522/Evaluating-international-standards-for-electric-vehicle-chargers-George-Wilkenfeld-and-Associates-with-Auseng-Pty-Ltd-December-2021.pdf)
- [118] *The OCPP Handbook (2023)—AMPECO*. Accessed: Dec. 25, 2023. [Online]. Available: <https://www.ampeco.com/guides/complete-ocpp-guide/>
- [119] M. S. Alam, F. S. Al-Ismail, S. M. Rahman, M. Shafiullah, and M. A. Hossain, "Planning and protection of DC microgrid: A critical review on recent developments," *Eng. Sci. Technol., Int. J.*, vol. 41, May 2023, Art. no. 101404, doi: [10.1016/j.jestch.2023.101404](https://doi.org/10.1016/j.jestch.2023.101404).
- [120] S. Tirunagari, M. Gu, and L. Meegahapola, "Reaping the benefits of smart electric vehicle charging and vehicle-to-grid technologies: Regulatory, policy and technical aspects," *IEEE Access*, vol. 10, pp. 114657–114672, 2022, doi: [10.1109/ACCESS.2022.3217525](https://doi.org/10.1109/ACCESS.2022.3217525).



integrating EV charging facilities. He was a recipient of Transilvania Academica Scholarship, in 2021.



**IOAN SERBAN** (Member, IEEE) was born in Romania, in 1981. He received the B.Sc. and Ph.D. degrees in electrical engineering from Transilvania University of Brasov, Romania, in 2004 and 2008, respectively. He is currently a Full Professor with the Department of Electrical Engineering and Applied Physics, Faculty of Electrical Engineering and Computers Science, Transilvania University of Brasov. His research interests include power converters for interfacing renewable energy sources and energy storage systems for grid and microgrid applications. He was a recipient of the 2015 IET Renewable Power Generation Premium Award.



**DORIN PETREUS** (Senior Member, IEEE) received the Ph.D. degree from the Technical University of Cluj-Napoca (UTCN), in 1998. He has been with UTCN, since 1991. He is currently a Full Professor with the Department of Applied Electronics (EA), Faculty of Electronics, Telecommunications and Information Technology (ETTI). He is also the Head of the EA Department. He is also the Founder and the Coordinator of the Renewable Energies Research Group. He is the author and coauthor of ten books and more than 200 scientific papers published in journals (WOS/BDI) and international conference proceedings. He has an international patent and five national patents. Since 2007, he has coordinated more than 16 Ph.D. theses. He was the Director or a member of research groups for seven international projects and more than 30 national grants obtained through competition. His research interests include high-efficiency power supplies, digital control, power electronics, the modeling and simulation of power electronics systems, energy conversion, and renewable energies.

• • •