Studying Impacts of Electric Vehicle Functionalities in Wind Energy-Powered Utility Grids With Energy Storage Device

HOSSAM S. SALAMA1,2, SAYED M. SAID2, MOKHTAR ALY2,3, (Senior Member, IEEE), ISTVÁN VOKONY1, AND BÁLINT HARTMANN1, (Member, IEEE)

1 Department of Electric Power Engineering, Faculty of Electrical Engineering and Informatics, Budapest University of Technology and Economics, 1111 Budapest, Hungary
2 Department of Electrical Engineering, Faculty of Engineering, Aswan University, Aswan 81542, Egypt
3 Electronics Engineering Department, Universidad Tecnica Federico Santa Maria, Valparaiso 2390123, Chile

Corresponding author: Hossam S. Salama (hossam.salama@vet.bme.hu)

This work was supported by the Foundation to Support Energy Engineering Education (ETA), Vám út 5-7, H-1011, Budapest, Hungary, and also by the Chilean Government through the Project SERC Chile under Grant ANID/FONDAP15110019 and the Project AC3E under Grant ANID/Basal/FB0008.

ABSTRACT
Recently, electric vehicles (EVs) have proven remarkable impacts on reducing pollution and their suitability for utilizing renewable energy sources (RESs) instead of fossil fuels. The continuously increasing number of installed EVs has encouraged their employment for performing additional functionalities in utility grids. This paper provides study for the impacts of EV integration approaches on enhancing the operation of utility grids. The proposed study considers the targeted renewable energy powered utility grids with installed energy storage devices. Wind energy has been utilized as a case study for the RES with considering its stochastic characteristics and its continuous fluctuations with wind speed. Additionally, the superconducting magnetic energy storage system (SMES) device is chosen due to its promising long-life operation. The various aspects of point of common coupling (PCC) voltage fluctuations, reactive power support, leveling active power of the on-peak period, and power losses are considered in the proposed study. Moreover, fuzzy logic controller (FLC) systems have been proposed for controlling EVs and the SMES device. The energy management between the installed EVs, SMES, wind, and utility grid side is achieved through the coordination of the FLC systems. The results show that reduced peak and mean values of total power losses and line active power are obtained by the proposed coordination method. Moreover, improved profiles of the PCC voltage, reactive power support, active power leveling, and sustainable and reliable power supply are obtained by the proposed method for wide operating ranges and modes of operation.

INDEX TERMS
Electric vehicles (EVs), energy management, fuzzy logic controller (FLC), renewable energy, superconducting magnetic energy storage (SMES), wind energy.

I. INTRODUCTION

In the last decade, an exponential increase of renewable energy source (RES) installations has been achieved in utility grids to get over the various problems of traditional fossil fuel sources [1], [2]. Among the various existing RESs, wind energy represents one of the most promising directions, as a reduced cost and high power generation source [3]. Therefore, high penetration levels of wind energy systems have been found world-wide. Based on the annual energy reports, the capacity of installed RESs reached more than 200 GW by the year 2019 [4]. In which, the global share of wind energy generations was about 19% of the total installed RESs by 2019. There are several generation types for wind energy systems, including the doubly-fed induction generator (DFIG), permanent magnet synchronous generator (PMSG), and squirrel cage induction generator (SCIG) systems [5], [6]. The SCIG wind systems have found wide applications due to their reduced cost and high reliability. In addition, SCIG systems eliminate the need for the components that require continuous maintenance, such as the brushes, exciter, and slip rings.

From another side, electric vehicles (EVs) have found worldwide market as efficient, environmentally friendly, and...
means of transportation without fossil fuel requirements [7]. The fossil fuel-powered conventional transportation systems were the first choice previously, which have lead to increased demands of fossil fuel. Therefore, research and industry efforts have been directed towards new transportation systems that can be powered from another new, renewable, and clean sources [8]. In 2019, the sales of EVs have achieved an increase by more than 2.1 million cars with respect to the achieved sales in 2018, which account for about 2.6% of global car sales [9]. Meanwhile, the stock of EVs has increased to 7.2 million, which represents 1% of the global car stock in 2019. The continuous movement towards using the new technologies of electrification in various types of EVs has led to a significant expansion of their markets [10]. Thence, ambitious plans have been put by several countries for increasing share of EVs in the market, which rely on regulatory and other structural measures, including zero-emission vehicles mandates, and fuel economy standards.

However, wind energy systems have exhibited a fluctuating nature due to the dependency of the output power on the operating wind speeds [11]. Additionally, the connected loads in the utility grids are continuously subjected to changes in the demanded active/reactive power. The stochastic behavior of wind generation and demanded loads has imposed several challenges on the operation, control, and sizing of utility network components [3]. The utilization of various types of energy storage systems (ESSs) has proven efficient and vital solutions for various utility applications [12], [13]. Several incredible benefits can be obtained by employing ESSs in power systems through solving the intermittent power generation issues. Several types of ESSs have been widely used, including the electrical-based ESSs (superconducting magnetic energy storage systems (SMES), and supercapacitors), thermal-based ESSs (thermal fluid, ceramic thermal, and hot water), mechanical-based ESSs (flywheel, pumped hydro, compressed air), and chemical-based ESSs (battery and hydrogen fuel cell) [14]. Among the various existing ESSs, the SMES is widely preferred due to its fast response, which makes it feasible for responding to fast charging/discharging commands [15]. Additionally, the cooperative management between microgrids [16], resilient operation of microgrids [17], energy management systems of microgrids [18], optimal scheduling of microgrids [19], have gained wide concerns in recent research.

Additionally, the targeted high number of EVs in operation would result in additional stresses on the control and operation of electrical power systems due to the increased charging/discharging power [20]. They also represent additional stochastic system for utility grids. This in turn has made the integration of EV impacts the operation and control stage of electrical power systems [10]. The various control methods of EVs and the increased share of power system capacity can make considerable effects on the power system performance [21]. For instance, controlling the charging power and/or time can shape the demanded power in utility grids. Moreover, the resulting excess power from RESs can be used directly to feed the charging power for EVs [22]. The connected EVs can also be used as ESSs for balancing the supplied and demanded electricity, and hence a smooth integration of RESs can be ensured.

The various control functionalities of EVs in electrical power systems can result in several harmful consequences, especially from the supply reliability point-of-view [23]. The uncontrolled charging of EVs does not impose restrictions on the owner side, which may lead to serious impacts on the power systems. The return of employees to their homes between hours 5 and 8 pm happens simultaneously with the increase in power consumption by home appliances [24], [25]. This in turn leads to a large increase of the peak demanded load and its duration hours. Besides, additional power losses, voltage fluctuations, and electricity prices are expected to increase and hence decreased sustainability and reliability of the electrical networks result as consequences [26], [27]. Therefore, research concerns have been increased towards proposing intelligent control and better utilization of the various connected EVs, and ESSs in coordinated manner so as to enhance the performance of electrical power systems. Moreover, the impacts of controlled charging solutions on the on-peak load demand period are essential to be studied in details [28]. The different controlled charging and discharging of EVs can provide flexibility for the owners to discharge during on-peak periods while charging at reduced load periods. Thus, the various functionalities that can be made by EVs and the coordination between EVs and ESSs are highly important, and they represent the main objectives in this paper.

In the literature, the various types of uncontrolled charging and controlled charging techniques with lithium-ion battery-powered EV systems have been discussed in [29]. The fuzzy logic control (FLC) has been employed for wind systems to mitigate the under-voltage problems. The stochastic mixed-integer linear programming method solved by GAMS toolbox has been presented in [30] for achieving optimal rated power of integrating the controlled charging battery ESSs multi-level charging facility between controlled charging battery ESSs and wind energy generation systems. In [31], a three-level game theory based approach has been proposed for the energy management between the EVs and their charging stations. In which, the charging stations are considered independent decision maker for the energy scenarios and the system operator is also included as master decision maker. In [32], a robust optimization scheme for optimized and stable operation of EV aggregators with considering the uncertainties of market prices has been proposed.

In [33], the hull moving average and gravitational search algorithm has been proposed to smooth voltage fluctuations for studying the impacts of lithium-ion and NiMH based EVs with controlled charging and discharging. The wind and photovoltaic (PV) generation systems are utilized in the study. A comparison between the various approaches of integrating EVs in PV systems has been introduced. Additional study has been presented in [21] for studying the impacts of daily
load demands and PV generation profiles on the SMES systems. The reactive power dispatch has been achieved through improved efficiency sharing between the available inverters.

In [34], a control method has been proposed to minimize the charging cost of uncoordinated EV charging load model based on multi-objective optimization techniques in the presence of PV and battery systems. An optimal scheduling method using the stochastic model integrated with wind energy and fuel cells for microgrids with EVs has been proposed in [35]. The various effects of fast charging infrastructures for EVs in distribution systems have been discussed in [36] based on the controlled charging process without considering the RESs and ESSs. In [37], an electric vehicle-virtual power plant (EV-VPP) model has been proposed to overcome the problem of the transformer loading in addition to reducing the prices for congestion. A hierarchical control system (HCS) has been proposed in [38] with PV, battery, and flywheel to mitigate the low and high frequency fluctuations and to achieve DC voltage and power control functions.

Stimulated from the above-mentioned literature review, this paper provides a detailed study of the impacts of the integration approaches of EV systems on the operation of wind energy powered electrical power systems. Table 1 summarizes the contributions in this paper compared to exiting literature. The main contributions in this paper can be summarized as follows:

- The study of various impacts of control approaches and functionalities of EV systems on the performance of electrical power systems is presented in this paper. The various aspects of point of common coupling (PCC) voltage fluctuations, reactive power support, and power losses are considered in the proposed study.
- The stochastic characteristics and the continuous fluctuations of the wind, load demand, and EV loading profile are considered in the proposed study. The electricity prices are employed as inputs for the proposed energy management method.
- A coordinated control method based on FLC systems is proposed for EV systems with SMES for improving the peak load demand and its duration.
- Minimization of the dissipated power losses is investigated in this paper through the various functionalities that can be handled by EVs.

The remaining of the paper is organized as follows: Section II presents the modelling of the studied utility grid system. The various control methods of EVs in utility grids are presented in Section III. The proposed coordinated FLC systems for SMES and EV systems are detailed in Section IV. Section V provides the results of the simulated case study. Moreover, discussions and comparisons of the obtained results are provided. The paper is concluded in Section VI.

II. THE POWER SYSTEM STRUCTURE

There are several challenges facing the installations of wind energy systems and EVs in power systems. The coordination and control of the various connected sources, loads, and ESSs are crucial issues for the efficient and stable operation of power systems. Proper utilization of the available sources and ESSs can lead to more efficient operation for power systems. Moreover, it can lead to more efficient and reliable operation for the other parts of the power systems, including transmission lines, transformers, circuit breakers, etc. The benefits of improved controllers can be related to technical and economic issues of the power system. The technical benefits are related to mitigating the fluctuations from the wind energy source and fluctuated electrical loads. Therefore, continuous reliable power supply can be obtained. The economic benefits are achieved through better utilization of the connected devices to the grid to perform several additional tasks. This in turn is beneficial for reducing the number and capacities of the required devices.

The simplified single line diagram representation of the considered power system in this paper is shown in Fig. 1. The considered power system includes the connected wind energy generation system, the SMES device, residential loads, and EVs. The connection of the different devices to the PCC is achieved through step-up power transformers. The coordination control systems have to read the measured output power from the connected devices and the electricity price and the other required signals related to the devices, and then generate the control commands in accordance. In addition, the reactive power has to be controlled so as to provide local supply through the connected devices. This in turn eliminates the need for absorbing reactive power from the grid that results in reducing the losses of transmission lines. Therefore, these issues and challenges have lead researchers to develop new control techniques and they will be covered through this paper.

A. WIND ENERGY MODELLING

There are several types of the utilized generation system for wind energy. Each type of the generation has different power conversion structure and different affects on the reactive power injection/absorption with the grid. The SCIG type is selected in this study for representing the wind energy generation side. In wind systems, wind turbines have to be controlled to extract the available maximum power from the wind system. Whereas, the safety requirements require that if the wind speed is higher than safety limits, the output power
from the wind system is limited to its nominal value through pitch control mechanisms. The extracted output power from the wind $P_{WT}$ can be expressed as the following [39]:

$$P_{WT} = \frac{1}{2} \rho \pi R^2 v^3 C_p(\lambda, \beta)$$  \hspace{1cm} (1)

where, $\rho$, $R$, $v$, and $C_p$ denote to air density, blade length, wind speed, and efficiency of power extraction for the wind turbine. The estimated $C_p$ is dependent on the tip-speed ratio (TSR) $\lambda$, and pitch angle $\beta$. The TSR of wind turbines depends on blade length, wind speed, and its rotational speed. The TSR is estimated as follows:

$$\lambda = \frac{R \omega_l}{v}$$  \hspace{1cm} (2)

where, $\omega_l$ denotes to the wind turbine rotational speed. The efficiency at the maximum power point ($C_p,_{MPP}$) is obtained for any particular TSR value ($\lambda_{opt}$). To preserve the operation at the maximum power, there is a unique speed to operate the wind turbine due to the correlation among $C_p$ and $\lambda$. At the normal operation, pitch angle $\beta$ is maintained at zero. Using (1) and (2), the extracted power from the wind turbine can be expressed as follows [39]:

$$P_{WT} = \frac{1}{2} \rho \pi R^5 \omega_l^3 \frac{C_p(\lambda)}{\lambda^3}$$  \hspace{1cm} (3)

whereas, the wind turbine torque is expressed as follows [39]:

$$T_{WT} = \frac{P_{WT}}{\omega_l} = K \omega_l^2$$  \hspace{1cm} (4)

where, $K$ is expressed as follows:

$$K = \frac{1}{2} \rho \pi R^5 \frac{C_p(\lambda)}{\lambda^3}$$  \hspace{1cm} (5)

At operation with optimized value for TSR, i.e. $\lambda_{opt}$, the efficiency of power extraction becomes maximum ($C_p,_{max}$). Therefore, the wind turbine speed is controlled to maintain the optimum $\lambda_{opt}$.

B. SMES MODELLING

The SMES represents a promising ESS that has long lifetime, high efficiency, and fast response. This has resulted in applying SMES systems in several applications and functions in the power system. The SMES operates through storing electrical energy in magnetic energy forms. The SMES mainly includes large inductance from superconducting materials, which has to be operated under its critical temperature to be maintained in the superconductor state. The main components of the SMES power circuit are shown in Fig. 2. It can be seen that the SMES coil side is operated by a bidirectional dc-dc power converter. The control of the operating duty cycle of the converter can control the charging/discharging operation of the SMES. The second part is the dc-link capacitor side, which performs the power decoupling function between the dc side power and the ac side power. The third part is the bidirectional dc-ac power inverter. The two level converter is selected in the proposed system as a commonly utilized topology. Each phase leg has two power switches, which operate in complementary manner. The bidirectional dc-dc power inverter has to control the operating status of the SMES with
the utility grid system to be in charging/discharging/standby modes. Moreover, the dc-ac power inverter can participate in controlling the reactive power flow from/to the utility grid.

The stored energy in the SMES $E_{sm}$ is dependent on the value of the SMES inductance $L_{sm}$ and the current of the SMES $I_{sm}$. It can be expressed as follows [40]:

$$E_{sm} = 0.5 \times L_{sm} \times I_{sm}^2 \quad (6)$$

In addition, the active power of SMES $P_{SMES}$, the voltage across the SMES $V_{sm}$, voltage over the dc-link $V_{dc}$, and the operating duty cycle $D_m$ of the dc-dc power converter can be related as follows [40]:

$$P_{SMES} = V_{sm} \times I_{sm} \quad (7)$$

$$V_{dc} = \frac{V_{sm}}{2D_m - 1} \quad (8)$$

III. FUNCTIONALITIES OF EVs IN UTILITY GRIDS

With the increased numbers of EVs, they have become influencing elements in utility grid performance. The control of the charging/discharging time and type can change the generating and/or loading behavior of the grid. There are several control modes for EVs in the utility grid. The most featured ways for controlling EVs are (i) uncontrolled charging, (ii) controlled charging, and (iii) controlled charging and discharging integration approaches. In the uncontrolled charging integration approach (UCCIA), the existing EVs are connected without control from the utility grid operators. Therefore, they do not participate in additional functionalities in the utility grid system. The EV owners do not have any restrictions on charging time for EVs and they can charge them at any time. This control strategy adds several challenges and stresses to the power systems operation. Usually, owners start the charging process immediately after returning home between 5 p.m. to 8 p.m. [21]. In the same time slot, residential loads start and the loading behavior increases in accordance.

From another side, adding improved control strategies for EVs would provide better utilization for their inherent energy storage batteries. The first method is achieved through the controlled charging integration approach (CCIA). In this approach, the charging process of EVs is restricted during the on-peak loading time slot. Therefore, the loading profile of the system is improved compared to the UCCIA. This process utilizes the recent advancements in the communication systems and the smart grid concepts and components. Another approach has been presented through the controlled charging and discharging integration approach (CC/DIA) for EVs. In this mode, the charging time of EVs is restricted in addition to the participation of the EVs in discharging for supplying the loads during the on-peak loading and/or low wind generation scenarios. Therefore, this approach enhances the utilization of the already available EV storage components to participate in the utility grid regulation and generation/loading balance. This can also eliminate the need for new installations and/or increase capacities of the required ESS in utility grids. It has become clear that EVs can take several integration approaches with utility grids with distinguished effects on the power systems performance.

The current study in this paper is based on EV models of Nissan Leaf EVs, which have Li-ion batteries with 24 kWhr capacity in each EV. It is considered in the study that the SOC for EVs in the initial state equals to 20% with efficiency of 90% with power rating of 6.6 kW. The start time of EV connections is usually modelled using the Gaussian distribution as follows:

$$f(t, \mu, \sigma) = \frac{1}{\sqrt{2\pi} \sigma^2} \exp\left( -\frac{(t-\mu)^2}{2\sigma^2} \right) \quad (9)$$

Fig. 3 shows the daily profile for the connection of EVs in the selected study. The study considers a mean value for the distribution of 18, and standard deviation of 5. In the selected study, there are 8 buildings with 12 apartments in each building. Therefore, there are total of 96 apartments and setting the penetration level of EVs to 50%, and the total number of 48 EVs are supposed in the studied system.

IV. THE PROPOSED FLC METHODS AND THE COORDINATION ALGORITHM

In this section, three main contributions of the paper are presented, including the SMES side FLC method, the EV side FLC method, and the proposed coordination algorithm. The coordination method controls the timing and the power flow among the different connected devices in the power system based on the collected information through the communication devices. The control signals are sent to the local.
SMES controller and EV controller so as to provide the different functionality in the power system. The EV controller is responsible for controlling the charging/discharging operations of the connected EVs. Whereas, the SMES controller is responsible for controlling the charging/discharging/standby modes for the SMES. The available communication infrastructures are responsible for supplying the control system with the current electricity prices and the power flow at the PCC. Therefore, possible coordination methods can be applied to provide improved technical and economical operation of the power system. Fig. 4 shows the main components and structure of the proposed controllers.

A. FLC FOR THE CONNECTED SMES

Fig. 5 shows the structure of the proposed SMES FLC system. The proposed FLC is responsible for managing the different operating modes of the SMES. The proposed controller has two different inputs and one output to control the SMES. The first input is based on the sent information about the PCC power. The connected devices to the power system at the PCC are the wind generator, the residential loads, the EVs, the SMES, and the grid supply. The connected devices have the function of the local power supply for the loads. The power difference $P_{diff}$ is based on subtracting the load power $P_l$ from the available wind power $P_{WT}$. In addition, the difference power $P_{diff}$ with EV power are used to represent the PCC power. Therefore, the absorbed active power from the grid source is minimized through achieving better utilization of the available wind power and storage devices. The second input to the FLC method is the SOC of the SMES device, which is represented by the SMES current.

The FLC method normally has three main stages, including (i) the fuzzification stage, (ii) the interface engine and fuzzy rules stage, and (iii) the defuzzification stage. The fuzzification stage has the responsibility of converting the input variables of the controller into linguistic inputs that can be recognized by the FLC system. Each of the two inputs is implemented in this stage by five different levels using the Gaussian shape of membership functions (MFs). Each input is divided into five different levels, including big-positive (BPos), positive (Pos), zero (Zero), negative (Neg), and big-negative (BNeg). In the second stage, the manipulated inputs based on the MFs are evaluated with the fuzzy rules. The logic of the proposed fuzzy rules is extracted based on the different operation modes of the SMES. The duty cycle $D$ for the bidirectional dc-dc converter has three different operating regions, which result in three different scenarios. If the duty cycle is maintained at 0.5, the SMES operates in the standby mode. In this scenario, the SMES does not contribute to the active power flow of the system. Whereas, the SMES operates in the discharging mode if the duty cycle is lower than 0.5. In the third scenario, the duty cycle is higher than 0.5 and the SMES operates in the charging mode. The third stage in the FLC is the defuzzification stage, which generates the output command based on the estimated fuzzy rules. The output is represented by five different levels, including the fast-discharge (FDCh), the discharge (DCh), the no-action (NOA), the charge (Ch), and the fast-charge (FCh) levels. Table 2 shows the fuzzy rules in the proposed FLC design.

B. FLC FOR THE CONNECTED EVs

With the increased number of EVs in the electrical grids, proper control can maximize the benefits of their storage
devices. Based on the employed control method, EVs can participate in different functionalities in power systems using their storage devices and inverter systems. In this section, the various designs of FLC systems are presented for achieving the various operating modes and functions. Two main designs are presented based on the CCIA and the CC/DIA control methods.

There are two inputs in the designed FLC systems for EVs in this study, including the electricity price rate \( C_{\text{rate}} \), and the SOC of the connected EVs. According to the FLC rules and the required functionality, the connected EVs are controlled and their charging/discharging rates are determined. The input MF of the SOC is represented by five different sets that correspond to different levels of their SOC. The five levels are defined as very-small (VS), small (S), medium (M), high (H), and very-high (VH) levels. The triangular shape of MFs is used to represent the SOC input for the FLC system. In this approach, the owners of EVs have more flexibility in charging their EVs during the off-peak loading periods and low electricity price periods. Whereas, they can discharge and sell electricity to the utility grid during the on-peak loading and the high electricity price periods. The SOC of the connected EVs is taken into consideration in the control process. The application of this approach can lead to more regulation of the electricity demand curves, controlling the on-peak loading, and having ESS reserves in utility grids. Hence, more reliable power supply can be obtained using the controlled charging/discharging approach.

Firstly, the fuzzy rules for the CCIA are shown in Table 3. The control of EVs in this approach is achieved through representing the output of the FLC with five different control command regions. They can be classified based on the charging speed into very-low charging (VLCh), low charging (LCh), medium charging (MCh), high charging (HCh), and very-high charging (VHCh). The triangular shape of MFs is used for representing the output for the FLC method. In this approach, the connected EVs are controlled through their charging time, whereas they do not participate in supplying the electrical grid with electrical power from their storage elements. This approach motivates the EV owners to charge their EVs during off-peak loading periods and the low electricity price time slots. Hence, improved loading and control of the power system are obtained compared to the uncontrolled charging approach.

![FIGURE 6. The FLC method for the connected EVs.](image)

**TABLE 3. The various fuzzy rules in the CCIA scenario for EVs.**

| Input MFs | VS | S | M | H | VH |
|-----------|----|---|---|---|----|
| \( C_{\text{rate}} \) | LPr | VHCh | VHCh | VHCh | HCh |
|           | MPr | HCh | HCh | MCh | MCh |
|           | HPr | LCh | LCh | VLCh | VLCh | VLCh |

Secondly, the fuzzy rules for the CC/DIA are shown in Table 4. In this approach, the EVs have more participation in the regulation of electrical power grids through employing their storage devices as ESS, in addition to controlling their charging times and amounts. The output of the FLC system in this approach is represented by five different sets as high charging (HCh), low charging (LCh), zero (Zero), low discharging (LDCh), and high discharging (HDCh). By applying this approach, the owners of EVs have more flexibility in charging their EVs during the off-peak loading periods and low electricity price periods. Whereas, they can discharge and sell electricity to the utility grid during the on-peak loading and high electricity price periods. The SOC of the connected EVs is taken into consideration in the control process. The application of this approach can lead to more regulation of the electricity demand curves, controlling the on-peak loading, and having ESS reserves in utility grids. Hence, more reliable power supply can be obtained using the controlled charging/discharging approach.

**TABLE 4. The various fuzzy rules in the CC/DIA scenario for EVs.**

| Input MFs | VS | S | M | H | VH |
|-----------|----|---|---|---|----|
| \( C_{\text{rate}} \) | LPr | HCh | HCh | LCh | LCh |
|           | MPr | LCh | Zero | LDCh | LDCh |
|           | HPr | LCh | Zero | LDCh | HDCh |

**C. THE PROPOSED MANAGEMENT ALGORITHM**

In this section, a cooperative energy management strategy is presented for controlling the various devices in the utility grids at the PCC. Each of the connected devices can participate in improving the performance of the power system. Moreover, the coordination between the SMES and the EVs can be achieved, in addition to adding more functionalities to the EV systems. Each of the connected SMES and EVs has its local controller, which performs the regulation function of the measured voltages/currents so as to follow required references. Whereas, there is an additional central controller that manages the share of active/reactive power among the connected devices. The main objectives and priorities for the management algorithm can be summarized as follows:

- Minimizing the absorbed active and reactive electrical powers from the utility power grids so as to preserve local power supply for the residential loads.
- Operation of the connected devices in a cooperative way to mitigate the continuous fluctuations of the wind energy and the electrical loads.
- Controlling the voltage at PCC to be within the predefined limits and constraints by the utility grid operators.
- Studying various impacts of the different control approaches of EVs in utility grids.
- Achieving more economical operation for the owners of EVs to encourage them to cooperate interactively with the utility grid performance management.
Achieving reliable power supply operation by considering the intermittent wind generated power with different loading and EV control approaches.

Fig. 7 shows the flowchart for the proposed energy management algorithm. The proposed algorithm is divided into two parts, including the active power management, and the reactive power management. The proposed algorithm is organized as follows:

**Step 1:** The various measured signals are collected and fed into the proposed central energy management algorithm through the available metering infrastructures. The measured parameters include: load active power $P_l$, load reactive power $Q_l$, wind power $P_{WT}$, and the voltage at the PCC.

**Step 2:** The control of active power flow is achieved to provide control for the loading curves, local power supply, and economical operation of EVs. When the wind power is higher than the required residential load, the extra power is utilized to charge the EVs and the SMES according to the electricity prices. A priority is given to the EV charging operation when their SOC is lower than the minimum predetermined limit until reaching the maximum limit of SOC. Then, the SMES is controlled to charge so as to absorb the extra power from the grid.
the wind generation. Therefore, reduced stresses are achieved from the electrical grids. When the EVs and the SMES reach their full charge, the extra power is sold to the utility grids to maximize the benefits from the generated wind power.

**Step 3**: The algorithm also controls the system when the generated wind power is lower than the required load power. When the electricity price is high and exceeds the threshold economical value, the required loading power is fed from the EVs when their SOC is higher than the minimum value. If the EVs are not charged enough, the SMES is discharged to cover the required loading power. If the SMES and EVs are not charged enough, the required active power for the load is bought from the utility grid to cover the load demand.

**Step 4**: If the required loading power exceeds the wind power and the electricity price is low, the EVs and the SMES are given priority to charge during the low price rate from the utility grids. Then, the required additional loading power is bought from the utility grid to benefit from the low price rate from the utility grid.

**Step 5**: The response of the system is determined according to the employed control approach for EVs. According to the three previously discussed control approaches for EVs, the PCC power \( P_{PCC} \) can be represented without SMES as follows:

\[
P_{PCC} = \begin{cases} 
\pm P_g + P_{WT} - P_l - P_{EV} & \implies \text{UCCIA} \\
\pm P_g + P_{WT} - P_l - P_{EV} & \implies \text{CCIA} \\
\pm P_g + P_{WT} - P_l \pm P_{EV} & \implies \text{CC/DIRA}
\end{cases}
\]

where \( P_g \) represents the grid active power at the PCC, and \( P_{EV} \) the active power absorbed/injected by EVs. Whereas, the PCC power with SMES can be expressed as follows:

\[
P_{PCC} = \begin{cases} 
\pm P_g + P_{WT} - P_l - P_{EV} \pm P_{SMES} & \implies \text{UCCIA} \\
\pm P_g + P_{WT} - P_l - P_{EV} \pm P_{SMES} & \implies \text{CCIA} \\
\pm P_g + P_{WT} - P_l \pm P_{EV} \pm P_{SMES} & \implies \text{CC/DIRA}
\end{cases}
\]

**Step 6**: Additionally, the reactive power is controlled so as to achieve a local supply from the SMES inverter as a priority. The active power of SMES and the capacity of the SMES inverter \( S_{SMES} \) are used to calculate the available possible reactive power supply from the SMES inverter. The available SMES inverter reactive power \( Q_{a, SMES} \) can be estimated as follows:

\[
Q_{a, SMES} = \sqrt{S_{SMES}^2 - P_{SMES}^2}
\]

**Step 7**: The load reactive power supply is locally fed from the SMES inverter when the estimated available reactive power supply from the SMES is higher than the required load reactive power. If the required load reactive power exceeds \( Q_{a, SMES} \), then the SMES inverter supplies the load with its available reactive power supply \( Q_{a, SMES} \) and the difference is absorbed from the utility grid.

### V. RESULTS AND DISCUSSIONS

The considered case study has been simulated using the MATLAB/SIMULINK program to study the different impacts of the integration approaches of EVs on the power system performance. The modelled system includes the utility grid, the SMES, EVs, a wind generator, and residential loads. The impacts of EVs are investigated with/without SMES device in the proposed study. Moreover, the proposed FLC methods for EVs and SMES are also validated. The parameters of the tested system are shown in Table 5.

### TABLE 5. The system parameters for the studied power system.

| Parameter         | Unit | Value |
|-------------------|------|-------|
| Sampling time, \( T_s \) | \( \mu s \) | 5.0   |
| Base line-line RMS voltage | kV | 25    |
| Nominal power, \( P_{WT} \) | MVA | 0.5/0.9 |
| Line voltage at wind side \( V_{WT} \) | kV | 0.48  |
| Stator resistance and, \( R_s \) | pu  | 0.01965 |
| Stator inductance, \( L_s \) | pu  | 0.0397 |
| Rotor resistance and, \( R_r \) | pu  | 0.01909 |
| Rotor inductance, \( L_r \) | pu  | 0.0397 |
| Mutual inductance, \( L_{m} \) | pu  | 1.354 |
| pole pairs     | -   | 2     |

Fig. 8 shows the daily loading profiles of the studied system for 24 hours. The wind speed profile in the system is shown in Fig. 8a. It can be seen that the wind speed has continuous fluctuation during the whole day. Fig. 8b and Fig. 8c show the daily loading profiles of active and reactive power, respectively. The loading profiles fluctuate during the scenario due to customer loads. The loading has its peak value after the customers return home in the evening. Moreover, with the simultaneous existence of EVs during the night, it is important to study their impacts, and develop various integration approaches.

The behavior of daily profiles of the wind generation side is shown in Fig. 9. The generated active power from the wind is shown in Fig. 9a. It can be seen that the generated active power from the wind follows the behavior of the wind speed profile. The fluctuating output power from wind generation represents one of the most critical issues for high penetration levels of wind systems. Additionally, the reactive power profile of the wind generation is shown in Fig. 9b. The reactive power is also fluctuating during the 24 hours of the day. The daily profile of the voltage (in pu) at the wind generation terminal is shown in Fig. 9c. The fluctuations in the active and reactive power cause the fluctuation of the terminal voltage during the daily profile in the case study.

Fig. 10 shows the daily loading profiles for the SMES side. Fig. 10a shows the daily profiles of the active power of SMES at the different integration approaches of EVs. It can be seen that the profile of the active power is fluctuating during the 24 hrs.
Fig. 8 shows the daily profiles of the studied scenarios for one day. The daily profiles of the active power during the day-time are the same due to the working hours. However, the profiles are different during the night-time due to the return of owners. The UCCIA imposes the worst behavior of the SMES output power profile due to the charging of the EVs without any control from the utility. Whereas, the CCIA improves the active power profile of the SMES compared to the UCCIA. The peak active power discharge of SMES is reduced in this approach. Whereas, the CC/DIA represents the best approach regarding the active power profile of SMES. The charging/discharging currents of SMES are controlled in this approach in addition to the reduction of the peak discharged power from SMES.

Fig. 9 shows the daily profiles of the wind generation side. Fig. 10b shows the profile of the reactive power of the SMES inverter. It can be seen that the SMES inverter contributes to the local supply for the required load reactive power. Additionally, the various EV integration approaches possess the same profiles of the reactive power of the SMES inverter. The SMES energy and current profiles for the different integration approaches are shown in Fig. 10c, and Fig. 10d, respectively. The UCCIA approach results in the highest energy and discharging process for the SMES due to the absence of the control of the charging time/amount of EVs. It can also be seen that the CCIA improves the energy and current profiles of the SMES. This is a direct result of the control of the charging times of SMES after the owners return.
home in the evening. The CC/DIA can effectively improve the profiles of the SMES energy and current due to the share of EVs in the active power control, in addition to the control of the charging times and amounts. The profiles show the improvements in the stress reduction of the SMES due to the EV integration approach.
TABLE 6. The statistical analysis of the obtained results of total power losses and the line active power.

| Parameter | UCCIA | UCCIA with SMES | CCIA | CCIA with SMES | CC/DIA | CC/DIA with SMES |
|-----------|-------|-----------------|------|----------------|--------|------------------|
| Max       | 6628  | 331.4           | 6154 | 292.7          | 6024   | 281.2            |
| Mean      | 2193  | 134.2           | 2159 | 127.2          | 2081   | 119.6            |

| Parameter                          | UCCIA | UCCIA with SMES | CCIA | CCIA with SMES | CC/DIA | CC/DIA with SMES |
|------------------------------------|-------|-----------------|------|----------------|--------|------------------|
| The line active power (kW)         |       |                 |      |                |        |                  |
| Max                                | 628.5 | 186.8           | 599.3| 316            | 571.2  | 154.6            |
| Mean                               | 147.9 | 35.81           | 141  | 32.35          | 112.2  | 23.91            |

**Fig. 11** shows the daily profiles at the PCC side. **Fig. 11a** shows the line active power profiles for the different EV integration approaches with/without SMES. This study investigates the benefits of the cooperative coordination between SMES and EV integration approaches. It can be seen that the utilization of SMES can reduce effectively the line active power, especially during the on-peak load periods. The SMES also helps in regulating the line active power, regardless of the existence of EVs during the fluctuating wind and loads during the day time. Moreover, the utilization of various control approaches for EVs during the night period reduces the line active power at CC/DIA compared to the other methods.

**Fig. 11b** shows the daily profiles for the line reactive power for the EV integration approaches with/without SMES. The existence of SMES has a great influence on the line reactive power. The SMES side inverter contributes to the local reactive power supply for the connected residential loads. However, the various EV integration approaches do not affect the reactive power performance as they do not contribute to the reactive power support. The ability of the SMES inverter to achieve local reactive power supply for the connected loads can effectively reduce the stress on the utility grid for the reactive power supply.

**Fig. 11c** shows the profiles of the PCC voltage for the EV integration approaches with/without SMES. It can be seen that the cooperative operation of SMES and EVs achieves a near unity pu voltage profile. The various fluctuations due to wind speed fluctuations in addition to residential and EV loads are effectively mitigated with the cooperative operation between the SMES and EVs. Moreover, the CC/DIA has little improvements compared to the other approaches in the cases without SMES due to the control of EV charging/discharging operation.

**Fig. 11d** depicts the active power losses at the line side for the studied approaches with/without SMES. The efficient operation of the power system is shown here with reduced line power losses by the management algorithm between the SMES and EVs. The absence of SMES leads to increased line power losses due to the absorption/injection of the active/reactive power from/to the utility grids. The local active/reactive power supply of loads using the SMES and EV integration approaches is advantageous from this point of view. The reliability of the supply power and various components is improved in accordance.

The response of the proposed FLC system is validated at step changes in the load. **Fig. 12** shows the performance of the studied system with the proposed SMES based FLC method at sudden load changes. The response of the DC-link voltage of the SMES inverter with the load changes is shown in **Fig. 12a**. It can be seen that the proposed controller responds fast to preserve the DC-link voltage constant with the different load step changes.

**Fig. 12b** shows the PCC voltage with the different load changes with/without SMES and with/without load changes. The proposed FLC with SMES has very small fluctuations in the PCC voltage with load step changes as shown by the zoomed-in view of the obtained results. However, the absence of SMES leads to a higher drop in the PCC voltage with load step changes. The results show the ability of the proposed controller to preserve controlled DC-link voltage of the inverter in addition to the PCC voltage at various step changes in the loads.
### TABLE 7. Comparison of EV different cases with/without SMES.

| Merits/Uncontrolled charging case without SMES | Demerits/Uncontrolled charging case without SMES | Comparison in this paper |
|------------------------------------------------|-------------------------------------------------|--------------------------|
| The usage and operation are easily achieved | Increased loading at the on-peak period           | The value of the on-peak load is the highest among all the studied cases |
| No restrictions exist for grid and consumer sides | High power loss, and voltage oscillation          | The value of the power loss is the highest among all the studied cases |
| Simple algorithms are needed                   | High disturbances from the RESs exist due to weather variations | The value of the voltage oscillations is the highest among all the studied cases |
| The usage and operation is easy for EV owners | Increased loading of power system components, such as transmissions line, transformers, etc. | No local reactive power supply is achieved |
| Supply the electrical grid with good support and auxiliary services | Support is essential for the power system components | EVs is absorbing the required active power without restrictions |
| Reduce power loss and on-peak load period | Information and communication systems are needed | SMES injects reactive power to the electrical network. |
| SMES system supply reactive power | Cooperation is required from owners of EVs | P_{line,mean} is decreased from 147.9 kW in case without using SMES to 35.81 kW in the case of using SMES. |
| The impacts of wind fluctuations are reduced | Capital cost and control complexity are high | P_{loss,mean} is decreased from 2193 W without using SMES to 134.2 W with using SMES. |

### Controlled charging case with SMES

| The usage and operation is easy for EV owners | The on-peak load period and power loss have higher values | $-P_{line,max}$ is decreased by 4.65% compared with uncontrolled charging case |
| Simple algorithm implementations | Voltage oscillations and disturbances due to fluctuations of RESs are high | $P_{loss,max}$ is decreased by 7.15% compared with uncontrolled charging case |
| The charging of EVs has barriers based on electricity price | Increased loading of power system components | $V_{PCC}$ at PCC has a little improvement compared with uncontrolled charging case |
| The SMES supplies reactive power | It needs information and communication systems | No external reactive power sources are needed |
| The impacts of wind fluctuations are reduced | The capital cost and control complexity are high | |

### Controlled charging/discharging case without SMES

| It presents benefits for the owners of EVs | Voltage oscillations have higher values | $P_{line,max}$ is decreased by 9.11% compared with the uncontrolled charging case and 4.69% compared with the controlled charging case |
| The alleviation helps at reinforcing the electrical network | The disturbances from the RESs are high due to weather variations | $P_{loss,max}$ is decreased by 9.12% compared with the uncontrolled charging case and 2.11% compared with the controlled charging case |
| The on-peak load power and power loss are effectively reduced | It needs information and communication systems | $V_{PCC}$ at PCC has little improvement compared with the uncontrolled charging case and controlled charging case |
| Controlled charging/discharging case with SMES | Cooperation is required from EV owners | No external reactive power sources are required |

### Controlled charging/discharging case with SMES

| Charging of EVs has barriers based on electricity price | It needs information and communication systems | $P_{line,max}$ is decreased by 72.93% compared with the controlled charging/discharging case without using SMES. |
| Grid is supplied with good support and auxiliary services | Cooperation is required from owners of EVs | $P_{loss,max}$ is decreased by 95.33% compared with the controlled charging/discharging case without using SMES. |
| Power loss and on-peak load period are extremely reduced | The capital cost and control complexity are high | $V_{PCC}$ at PCC maintains 1.0 pu compared with the controlled charging/discharging case without SMES unit. |
| The SMES achieves local reactive power supply | Reduced impacts of wind fluctuations | $P_{line,mean}$ is decreased from 112.2 kW in the case without using SMES to 23.91 kW in the case of using SMES. |
| More robust and stable grids | | $P_{loss,mean}$ is decreased from 2081 W without using SMES to 119.6 W with using SMES. |
Additionally, statistical analysis of the various obtained results is made to evaluate the energy management and different integration methods. Table 6 shows the estimated mean and peak values for the obtained results of the total power losses and the line active power. The peak values are employed for determining the maximum loading of the system components. In addition, the mean value provides a reflection of the consumed energy losses in the studied system. The various analysis can be made for the other obtained results of the studied system. Table 7 shows the main merits, disadvantages, and performance comparison between the various EV integration approaches with/without SMES.

In which, \( P_{\text{line, max}} \) and \( P_{\text{line, mean}} \) denote to the peak and mean values for the absorbed line active power, respectively. Whereas, \( P_{\text{loss, max}} \) and \( P_{\text{loss, mean}} \) denote to the peak and mean values for the absorbed line power losses, respectively.

It has become clear that the current study provides a straightforward mean for the decision making process for planning and developing various control methods of EVs with considering practical study of renewable energy sources and energy storage devices. The proposed analysis and obtained results are crucial for the policy makers for evaluating the status and future trends of EV integration on the power systems. This in turn can be employed for more economic, secure, and efficient operation of future smart grids. In particular, the proposed study considers the following aspects:

- The nature of the renewable energy sources and their dependency on the weather conditions.
- The wide extension of the energy storage devices in power systems.
- The increased and future installations of EVs and hence their possible contribution in power system control and management.
- The nature of the installed loads and their variability with time as active and reactive power demands.
- The voltage fluctuations at the point of common coupling (PCC).
- The reactive power flow and the possibility of its local supply.
- The estimations of power losses due to the various integration methods of EVs.

Thence, the aforementioned considerations and the evaluated metrics are very important guiding factors for the decision-making process and the policy makers. Moreover, coordinated control of the FLC of energy storage and EVs is proposed in the paper. The various economic, reliable, and efficient operation strategies can be considered in the proposed design through defining the weights and priorities of different criteria. For instance, the priority of charging/discharging operation and constraint limits can be considered in the proposed power management strategy. Moreover, the various integration methods and economic encouragements can be employed within the fuzzy rules in the proposed method. The various integration approaches and operating modes are considered in the study that can be incorporated in the decision-making process.

**VI. CONCLUSION**

This paper presents a comprehensive study for the various impacts of different integration/control approaches of EVs on the enhancement of utility grid performance. The proposed study takes into consideration the stochastic properties of wind power generation and residential loads based on practical daily loading profiles. Moreover, the proposed study presents the effects of cooperative operation of energy storage systems with installed EVs in the utility grids. Two FLC methods are proposed in this paper for the SMES and EVs, respectively. The share of the different devices is achieved through the proposed management algorithm for supporting the local active/reactive power supply for the connected loads. Simulation results have been presented to investigate the power system performance criteria, such as the PCC voltage fluctuations, PCC reactive power flow, and transmission line power losses. The results show that the utilization of the CC/DIA, and the CCIA achieves reduction of the peak absorbed line power by 9.11%, and 4.65% compared to the UCCIA without SMES, respectively. Whereas, the peak value of the total line power losses is decreased using the CC/DIA, and the CCIA by 9.12%, and 7.15% compared to the UCCIA without SMES, respectively. While, using the SMES with the different charging methods leads to reduction of the total line power losses compared to without using SMES by 95.33% for the CC/DIA, 95.24% for the CCIA, and 95% for the UCCIA. Moreover, reduction of the peak absorbed line power by 72.93%, 72.8%, and 70.27% for the CC/DIA, CCIA, and UCCIA, respectively through using the SMES compared to without using the SMES. The proposed study represents a straightforward study that can be applied for larger power systems with different component types and numbers by extending the SMES capacity to overcome the requirements of the large test systems. This extension in the SMES energy would not affect the proposed method performance. Moreover, the recent optimization techniques can be employed for further optimizing the proposed control methods as future research extension of this paper.

**REFERENCES**

[1] E. M. Ahmed, M. Aly, A. Elmelegi, A. G. Alharbi, and Z. M. Ali, “Multifunctional distributed MPPT controller for 3P4W grid-connected PV systems in distribution network with unbalanced loads,” *Energies*, vol. 12, no. 24, p. 4799, Dec. 2019.

[2] K. Mahmoud and M. Abdel-Nasser, “Fast yet accurate energy-loss-assessment approach for analyzing/sizing PV in distribution systems using machine learning,” *IEEE Trans. Sustain. Energy*, vol. 10, no. 3, pp. 1025–1033, Jul. 2019.

[3] M. Aly, E. M. Ahmed, and M. Shoyama, “Thermal and reliability assessment for wind energy systems with DSTATCOM functionality in resilient microgrids,” *IEEE Trans. Sustain. Energy*, vol. 8, no. 3, pp. 953–965, Jul. 2017.

[4] 2020. *REN21-Renewables 2020 Global Status Report*. Accessed: Dec. 9, 2020. [Online]. Available: https://www.ren21.net/status-of-renewables/global-status-report/

[5] R. Teodorescu, M. Liserre, and P. Rodríguez, *Grid Converters for Photovoltaic and Wind Power Systems*. Hoboken, NJ, USA: Wiley, Jan. 2011.
[6] Z. Alnasir and M. Kazerani, “A small-scale standalone wind energy conversion system featuring SCIG, CSI, and a novel storage integration scheme,” Renew. Energy, vol. 89, pp. 360–370, Apr. 2016.

[7] H. S. Salama, S. M. Said, I. Vokony, and B. Hartmann, “Power system improvement of different coordinated electric vehicles integration approaches with superconducting magnetic energy storage,” Int. J. Electr. Eng. Syst., vol. 16, (6), p. 407, Dec. 2019.

[8] N. Mleton, J. Assen, and S. Goldberg, “Evaluating plug-in electric vehicle policies in the context of long-term greenhouse gas reduction goals: Comparing 10 Canadian provinces using the ‘PEV policy report card,’” Energy Policy, vol. 107, pp. 381–393, Aug. 2017.

[9] IEA. 2020. Global EV Outlook 2020: Entering the Decade of Electric Drive,. Accessed: Dec. 9, 2020. [Online]. Available: https://www.iea.org/reports/global-ev-outlook-2020

[10] H. Ren, A. Zhang, F. Wang, X. Yan, Y. Du, M. Shafie-khah, and J. P. S. Catalão, “Optimal scheduling of an EV aggregator for demand response considering triple level benefits of three-parties,” Int. J. Electr. Power Energy Syst., vol. 125, Feb. 2021, Art. no. 106447.

[11] J. Shi, W.-J. Lee, and X. Liu, “Generation scheduling optimization of wind-energy storage system based on wind power output fluctuation features,” IEEE Trans. Ind. Appl., vol. 54, no. 1, pp. 10–17, Jan. 2018.

[12] S. Said, M. Aly, and B. Hartmann, “A robust SMES control for enhancing stability of distribution systems fed from intermittent wind power generation,” Turk. J. Elec. Eng. Comput. Sci., vol. 27, no. 5, pp. 3863–3898, Sep. 2019.

[13] A. E. Mohamed, E. M. Ahmed, A. Elmelegi, M. Aly, O. Elbakaswi, and A.-A. A. Mohamed, “An optimized fractional order controller for frequency regulation in multi-area power systems,” IEEE Access, vol. 8, pp. 213899–213915, 2020.

[14] S. M. Said, M. Aly, B. Hartmann, A. G. Alharbi, and E. M. Ahmed, “SMES-based fuzzy logic approach for enhancing the reliability of microgrids equipped with PV generators,” IEEE Access, vol. 7, pp. 92059–92069, 2019.

[15] H. S. Salama, M. M. Aly, M. Abdel-Akher, and I. Vokony, “Frequency and voltage control of microgrid with high WECS penetration during wind gusts using superconducting magnetic energy storage,” Elect. Eng., vol. 101, no. 3, pp. 771–786, Aug. 2019.

[16] N. Bazmohammad, A. Tahsiri, A. Anvari-Moghaddam, and J. M. Guerrero, “Stochastic predictive control of multi-microgrid systems,” IEEE Trans. Ind. Appl., vol. 55, no. 5, pp. 5311–5319, Sep. 2019.

[17] M. Mohiti, H. Monsef, A. Anvari-Moghaddam, and H. Lesani, “Two-stage robust optimization for resilient operation of microgrids considering hierarchical frequency control structure,” IEEE Trans. Ind. Electron., vol. 67, no. 11, pp. 9439–9449, Nov. 2020.

[18] V. Suresh, P. Janik, J. M. Guerrero, Z. Leonowicz, and T. Sikorski, “Microgrid energy management system with embedded deep learning forecaster and combined optimizer,” IEEE Access, vol. 8, pp. 202225–202239, 2020.

[19] S. Esmaeili, A. Anvari-Moghaddam, and S. Jadid, “Optimal operation scheduling of a microgrid incorporating battery swapping stations,” IEEE Trans. Power Syst., vol. 34, no. 6, pp. 5063–5072, Nov. 2019.

[20] J. Yao, S. Xiong, and X. Ma, “Comparative analysis of national policies for electric vehicle uptake using econometric models,” Energies, vol. 13, no. 14, p. 3604, Jul. 2020.

[21] H. S. Salama and I. Vokony, “Comparison of different electric vehicle integration approaches in presence of photovoltaic and superconducting magnetic energy storage systems,” J. Cleaner Prod., vol. 260, Jul. 2020, Art. no. 121099.

[22] A. Ali, K. Mahmoud, D. Raiss, and M. Lehtonen, “Optimal allocation of inverter-based WTGS complying with their DSTATCOM functionality and PEV requirements,” IEEE Trans. Veh. Technol., vol. 69, no. 5, pp. 4763–4772, May 2020.

[23] A. Florescu, A. I. Bratu, I. Munteanu, A. Rumeu, and S. Bacha, “LQG optimal control applied to on-board energy management system of all-electric vehicles,” IEEE Trans. Control Syst. Technol., vol. 23, no. 4, pp. 1427–1439, Jul. 2015.

[24] C. Mu, W. Liu, and W. Xu, “Hierarchically adaptive frequency control for an EV-integrated smart grid with renewable energy,” IEEE Trans. Ind. Informat., vol. 14, no. 9, pp. 4254–4263, Sep. 2018.

[25] J.-H. Teng, S.-H. Liao, and C.-K. Wen, “Design of a fully decentralized controlled electric vehicle charger for mitigating charging impact on power grids,” IEEE Trans. Ind. Appl., vol. 53, no. 2, pp. 1497–1505, Mar. 2017.

[26] H. Liu, J. Qi, J. Wang, P. Li, C. Li, and H. Wei, “EV dispatch control for supplementary frequency regulation considering the expectation of EV owners,” IEEE Trans. Smart Grid, vol. 9, no. 4, pp. 3763–3772, Jul. 2018.

[27] C. Shao, X. Wang, X. Wang, C. Du, and B. Wang, “Hierarchical charge control of large populations of EVs,” IEEE Trans. Smart Grid, vol. 7, no. 2, pp. 1147–1155, Mar. 2016.

[28] S. F. Aliabadi, S. A. Taher, and M. Shahidehpour, “Smart deregulated grid frequency control in presence of renewable energy resources by EVs charging control,” IEEE Trans. Smart Grid, vol. 9, no. 2, pp. 1073–1085, Mar. 2018.

[29] S. Faddel, A. A. S. Mohamed, and O. A. Mohammed, “Fuzzy logic-based autonomous controller for electric vehicles charging under different conditions in residential distribution systems,” Electr. Power Syst. Res., vol. 148, pp. 48–58, Jul. 2017.

[30] H. Mehrjerdi and R. Hemmati, “Stochastic model for electric vehicle charging station integrated with wind energy,” Sustain. Energy Technol. Assessments, vol. 37, Feb. 2020, Art. no. 100577.

[31] B. Shakergiabadi, A. Anvari-Moghaddam, E. Ebrahimzadeh, F. Blaabjerg, and C. L. Bak, “A hierarchical game theoretical approach for energy management of electric vehicles and charging stations in smart grids,” IEEE Access, vol. 6, pp. 67223–67234, 2018.

[32] S. S. Barigha, B. Mohammadi-Ivatloo, A. Anvari-Moghaddam, and S. Asadi, “Risk-involved participation of electric vehicle aggregator in energy markets with robust decision-making approach,” J. Cleaner Prod., vol. 239, Dec. 2019, Art. no. 118076.

[33] A. Ali, D. Raisz, and K. Mahmoud, “Voltage fluctuation smoothing in distribution systems with RES considering degradation and charging plan of EV batteries,” Electric Power Syst. Res., vol. 176, Nov. 2019, Art. no. 105933.

[34] K. Chaudhari, A. Ukil, K. N. Kumar, U. Manandhar, and S. K. Kollimilla, “Hybrid optimization for economic deployment of ESS in PV-integrated EV charging stations,” IEEE Trans. Ind. Informat., vol. 14, no. 1, pp. 106–116, Jan. 2018.

[35] P. Aliasghabari, B. Mohammadi-Ivatloo, M. Alipour, M. Ahapour, and K. Zare, “Optimal scheduling of plug-in electric vehicles and renewable micro-grid in energy and reserve markets considering demand response program,” J. Cleaner Prod., vol. 186, pp. 293–303, Jun. 2018.

[36] L. G. Gonzalez, E. Siaivichay, and J. L. Espinouza, “Impact of EV fast charging stations on the power distribution network of a Latin American intermediate city,” Renew. Sustain. Energy Rev., vol. 107, pp. 309–318, Jun. 2019.

[37] J. Hu, H. Morais, T. Sousa, S. You, and R. D’halfist, “Integration of electric vehicles into the power distribution network with a modified capacity allocation mechanism,” Energies, vol. 10, no. 2, p. 200, Feb. 2017.

[38] L. Shen, Q. Cheng, Y. Cheng, L. Wei, and Y. Wang, “Hierarchical control of DC micro-grid for photovoltaic EV charging station based on flywheel and battery energy storage system,” Electric Power Syst. Res., vol. 179, Feb. 2020, Art. no. 106079.

[39] H. Ahuja and P. Kumar, “A novel approach for coordinated operation of variable speed wind energy conversion in smart grid applications,” Comput. Electr. Eng., vol. 77, pp. 72–87, Jul. 2019.

[40] S. M. Said, A. Ali, and B. Hartmann, “Tie-line power flow control method for grid-connected microgrids with SMES based on optimization and fuzzy logic,” J. Modern Power Syst. Clean Energy, vol. 8, no. 5, pp. 941–950, 2020.
SAYED M. SAID was born in Aswan, Egypt. He received the B.Sc. and M.Sc. degrees in electrical engineering from Aswan University, Egypt, in 2006 and 2014, respectively, and the Ph.D. degree from the Faculty of Electrical Engineering and Informatics, Doctoral School of Electrical Engineering, Budapest University of Technology and Economics, Budapest, Hungary, in 2021. He was a Research Assistant with the Electrical Engineering Department, Aswan University, in 2010. He is currently an Assistant Professor with the Department of Electrical Engineering, Aswan University. His research interests include power system analysis, renewable energies, power system control, wind energy systems, and superconducting magnetic energy storage (SMES). Also, his research focuses on the integration of wind/PV with SMES into the utility grid.

MOHDI A. M. (Senior Member, IEEE) received the B.Sc. and M.Sc. degrees in electrical engineering from Aswan University, Aswan, Egypt, in 2007 and 2012 respectively, and the Ph.D. degree from the Department of Electrical Engineering, Kyushu University, Japan, in 2017. In 2008, he joined the Department of Electrical Engineering, Aswan University, as an Assistant Lecturer, where he has been an Assistant Professor with the Faculty of Engineering, since 2017. He is currently a Postdoctoral Researcher with the Solar Energy Research Center (SERC-Chile), Universidad Técnica Federico Santa María, Chile. His current research interests include the reliability of power electronics systems especially in renewable energy applications, multi-level inverters, fault-tolerant control, electric vehicles, and light emitting diode (LED) lamp drivers. He is also a member of the IEEE Power Electronics Society (PELS), the IEEE Industrial Electronics Society (IES), and the IEEE Power and Energy Society (PES).

ISTVÁN VOKONY received the Master of Science degree in electrical engineering and the Ph.D. degree from the Budapest University of Technology and Economics (BUTE), in 2007 and 2012, respectively. He is currently a Senior Lecturer with the Department of Electric Power Engineering, BUTE. He is also a former Officer of the AEE Hungary student chapter. His research interests include system stability, renewable energy integration, energy efficiency, and smart grids.

BÁLINT HARTMANN (Member, IEEE) received the M.Sc. degree in electrical engineering and the Ph.D. degree from the Budapest University of Technology and Economics (BME), in 2008 and 2013, respectively. He is currently an Associate Professor with the Department of Electric Power Engineering, where he has supervised more than 40 bachelor’s and master’s theses. He is also a Supervisor of four Ph.D. students and a Research Fellow with the Centre for Energy Research. His research interests include the role of energy storage in power systems, computer modeling and simulation of distribution networks, and integration of variable renewable energy sources. He was a Board Member of the Hungarian Electrotechnical Association from 2013 to 2019 and the Chair of the IEEE PES Hungary Chapter.