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Design and Development of Hybrid Electric Vehicle

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Abstract

It is predicted that the growth of electrical vehicles (EVs) will be aided by higher pollution levels, which release greenhouse gases and cause global warming. With that in mind, HEV/EVs will connect to the power grid during this period. Grid component loads and voltage profiles will be greatly impacted using this technology. The study focused on modeling and analyzing how EVs and renewable energy sources may be integrated into a microgrid. A vehicle-to-grid (V2G) system placed close to the microgrid's load, a diesel generator serving as the main power source, and a combination of a photovoltaic (PV) and wind farm for energy generation make up the microgrid's four main components. Microgrids are significant because of their steady rise in energy output rate. The energy requirements of a district, town, or industrial site, as well as those of other institutions like hospitals, universities, and EV charging stations, can be satisfied by microgrids. To recharge an EV's battery, charging stations are necessary. The impact of EVs on the microgrid network is examined in this paper. Non-linear circuit components are incorporated into the structures of EVs. Furthermore, the incorporation of EVs and clean energy sources into the microgrid has been modeled and analyzed. Additionally, this article examines the Matlab/Simulink analysis of the microgrid with EVs.

Keywords: Sodium silicate, Rice husk ash, Activated Carbon *Grid-to-vehicle, renewable energy, sustainability, electrical vehicles, charging stations, and connected vehicles to clean energy.*

I. Introduction

This paper aims to explore the integration of RES and EVs into microgrids, assessing their impact on energy systems and sustainability. The global energy landscape is shifting towards renewable sources due to environmental concerns and technological advancements. The battery is the main problem with electric automobiles. Current research, however, suggests that battery life is no longer an urgent concern. An electric vehicle is a replacement for a gasoline or diesel engine that was designed to reduce pollution in the surroundings. The terms "grid-to-vehicle" (G2V) and "V2G" are important when discussing electric automobiles. The most common way to charge electric cars is grid-to-vehicle, or G2V. The technique by which a vehicle acts as a power source is known as vehicle-to-grid (V2G) technology 0. The widespread use of EVs and uncontrolled charging, which permits users to charge their cars whenever it is convenient for them, will have an adverse impact by increasing the daily maximum electricity consumption. Unregulated EV charging could lead to power outages, overload machinery, and interfere with power quality. However, the advantages of EV adoption would be evident if EV charging were regulated or if EVs were used as small distributed generators, especially when in V2G mode **Error! Reference source not found.**. The future of our world can be seen by EVs, which go beyond basic mobility. These vehicles are linked to a low-voltage charging station, they are emission- free. Vehicles that run on fossil fuels or Internal Combustion Engines (ICE) releases tremendous amounts of carbon dioxide into the atmosphere **Error! Reference source not found.**. EVs are categorized as eco-friendly and clean. With the help of incentives and regulations aimed at encouraging the greater use, several countries are actively promoting EVs **Error! Reference source not found.**, [4]. There are three types of electric vehicles (EVs): fuel cell electrical vehicles (FCEVs), hybrid electrical vehicles (HEVs), and pure battery electrical vehicles (BEVs) **Error! Reference source not found.**. To make sure the V2G process runs smoothly, an aggregator is used [7]. The effect of EV charging duration and EV battery efficiency on the overall load profile is examined. Optimizing V2G system performance aims to reduce environmental pollution, lower operating costs for transportation and electricity supply systems, and improve the quality, reliability, and dependability of power supply [8].

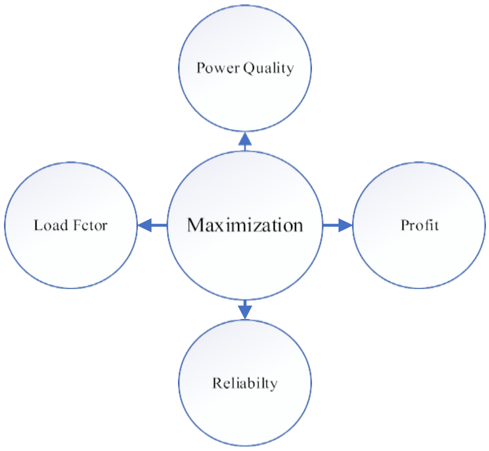

Fig. 1. Maximization objective functions of electrical vehicle integration into the distribution system.

The reduction of energy expenditure is the focus of an other line of study. Model predictive control and stochastic mixed integer linear programming approaches are used in the methods used in references [9] and [10], respectively. The method in [11] uses sequential quadratic programming and genetic algorithms to minimize load fluctuations and electrical energy costs. The assessments in [12] and [13] have revealed a crucial finding: despite the other challenges, most EV charging methods concentrated on these issues. There are several ways to charge electric cars. It is more economical to charge electric vehicles during off-peak hours. On the other hand, charging is more expensive when demand exceeds supply [14]. A power management strategy for Secondary Frequency Regulation (SFR) with an integrated fleet of EVs that takes a longer time frame into account can be found in Reference [15],[35]-[37].

EVs have the potential to be both electrical loads and sources of power. This paper presents a study of a microgrid that captures electricity loads, EVs, and renewable and non-renewable energy. Additionally, demonstrating the energy produced by each source, researching EVs as a load and an energy source, and examining how EVs affect grid performance and its function in assisting the system during peak hours. The modeling and analysis of the integration of EVs and renewable energy sources in the microgrid are the main objectives of this work. This study examines the analysis of an EV microgrid, and Matlab/Simulink has been used to validate the findings.

A brief technical overview of the effects of EV is given in Section II. The charging infrastructure is described in Section III. The harmonic components that EV produces are compiled in Section IV. The technologies and difficulties associated with EVs are covered in Section V. Section VI offers and discusses the simulation and results (analysis of the microgrid with electrical car), while Section VIII serves as the conclusion.

II. The Effect of Electrical Vehicle

A. Impact of Charging and Discharging Electrical Automobiles

EVs affect the power distribution system in both positive and negative ways [16]. EV charging and discharging processes [17] are essential for reducing battery degradation costs and minimizing peak demand on the power supply network. It might not be possible to implement a cost-minimization billing strategy that leaves out the transmission and distribution infrastructure. Several methods of optimization are used to enhance the load profile, which lowers peak demand as well as EV charging costs in general.

B. Effect on the Distribution Network

1. Impact On Power Quality

Many power quality problems, including harmonic pollution, increased power dissipation, decreased voltage, and unbalanced three-phase voltage, arise when EVs are integrated into the electrical grid [18].

2. Impact on Operation

Net loss, shorter cable and distribution transformer lifespans, and other issues are the primary signs of the distribution network's economic operation [19].

C. Environmental Impact

Temperatures will rise and the global climate will be affected if the current trend continues in the years to come [20]. It is crucial that high-energy consumers take steps to reduce their own emissions in order to support smaller nations' attempts to successfully mitigate emissions and use renewable technology [21]. Since the Tesla Roadster was first introduced, demand in the EV industry has grown substantially.

The following causes are responsible for the rise in emissions [22]:

a. A rise in the population.
b. An increase in output energy use.
c. An increase in transit.

Significant amounts of energy are used in the manufacturing of electric cars. When compared to traditional fuel-powered vehicles, the manufacturing of electrical cars releases more harmful pollutants into the surroundings.

1. Positive Effect

It has been proved that EVs emit less pollution than conventional fuel-powered automobiles. However, the energy sources utilized for charging determine how beneficial they are for the environment. Utilizing sustainable energy sources, such as wind or solar electricity, is crucial to reaching zero emissions. By installing solar panels, gasoline consumption can be eliminated and EVs can be charged for free using the electricity produced. The efficiency of the vehicle, how often it is used, and the local solar potential all affect how many solar panels are needed. Because many utility companies acquire their electricity from renewable sources, communal solar charging systems are becoming more and more common if personal solar power isn't practical [23].

2. Direct Effect

As EVs use stored battery energy for propulsion with less thermal loss, they are notable for having lower tailpipe emissions. Although there may be some negative environmental effects from the extraction and processing of battery materials, mainly from coal mining and the refining of raw materials, these effects are far less severe than those caused by running a gasoline engine [24].

3. Indirect Effect

While electric vehicles (EVs) have many advantages, concerns exist regarding their supply chain, particularly the increase in particulate matter due to coal-based electricity generation. Although there is a shift towards renewable energy and natural gas in the grid, this transition is gradual. Research indicates that while EVs generally reduce climate change impacts when powered by the current grid, they can increase particulate pollution, leading to a higher overall environmental impact compared to conventional vehicles [25].

III. CHARGING INFRASTRUCTURE

The battery of an electrical vehicle must be recharged after use. It is critical to consider the charging demand from the standpoint of the power grid as the number of EVs and individual battery ratings rise. Based on the existing standards [26], the EV/PHEV charging methodologies can be divided into three classes, as shown in Table 1.

A. STANDARD CHARGING (MODE 1, 6 h < CHARGING TIME < 8 h)

An electrical car with 3.3 kW of power can be charged conventionally by utilizing a socket outlet that has a voltage of 230 V and a current of 16 A.

Table I. Charging modes of EV/PHEV

Type	KVA	Charging time
Slow/Normal	01-May	6 h
Semi-fast/Medium	Oct-25	1-3 h
Fast	180-400	5-15 Min

This charging method, which calls for a single-phase AC charger, is mostly used in Europe. An automobile's charging process typically takes six to eight hours to complete [27].

B. SEMI-FAST CHARGING MODE (2, 1 h < Charging Time < 3 h)

Semi-fast charging uses power ratings between 7 to 22 kW, allowing a 30-kWh battery to charge with a single-phase current of 32 A or a three-phase current of 16 A. This setup provides double the available power and enables a moderate charging time of two to six hours, like Mode 2 charging. In this mode, the vehicle connects directly to an AC power source, with a control pilot conductor ensuring safety for both devices and users [28].

C. FAST CHARGING MODE (3, CHARGING TIME < 1 h)

Mode 3 charging involves using an external charger with a DC power supply for rapid vehicle charging, requiring advanced technology [29].

The available fast chargers include:

a) Fast charger
b) Super-fast charger
c) High AC charger

A fast charger converts AC to regulated DC to recharge EV batteries and is primarily found at public charging stations in Europe. It is the most expensive option, taking about 25–35 minutes to fully charge a vehicle at a power peak of 50–75 kW. Super-fast chargers aim to match the refueling time of conventional cars, while high AC chargers can provide up to 250 A for high-power AC charging, utilizing an external transformer for voltage adaptation.

IV. EV-PRODUCED HARMONIC COMPONENT

Charging modern electric vehicles (EVs) introduces harmonic components to microgrids, with current waveforms exhibiting higher harmonic levels than voltage waveforms. Total Harmonic Distortion (THD) significantly impacts the power quality of the electrical system in a microgrid, as the increasing use of non-linear loads in EVs disturbs the sinusoidal characteristics of current and voltage signals.

The main producers of harmonics in EV charging systems are AC/DC and DC/AC converters, which produce integer multiples of the fundamental frequency (e.g., 150 Hz, 250 Hz, 350 Hz, and 750 Hz). Thermal overload in power transmission lines [30], excessive heat in distribution lines, resonance phenomena, shortened transformer and electronic device lifespans, reactive capacitor disruption, and communication facility disruption are just a few of the problems that might result from these harmonics.

The environmental advantages of smart microgrids are increased by renewable energy sources, but system operation and integrity depend on THD monitoring.

THDv can be defined as follows:

$$\text{THD}(\%) = 100 \times \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \cdots + V_n^2}}{V_1}$$, (Eq.1)

V. TECHNOLOGY AND CHALLENGE INVOLVED IN EV

A. PROBLEM FORMULATION

The primary goal of the proposed study is to minimize losses in the distribution system by implementing the Vehicle-to-Grid (V2G) strategy, which responds to fluctuating load demands. The power equations for the distribution system are based on two key concepts: Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G).

B. V2G TECHNOLOGY

Electric vehicles (EVs) and the electricity grid form a mutually beneficial relationship for energy management. The grid typically lacks energy storage solutions, with pumped storage plants having limited capacity. Effective control of energy generation and transmission is essential to meet fluctuating consumer demand. EVs, powered by batteries or hybrid sources, can generate or store energy even when stationary, allowing them to supply electricity to the grid through Vehicle-to-Grid (V2G) connections [31]. They can operate solely on batteries, fuel cells, or in hybrid mode. While battery-powered EVs charge during low demand and discharge during high demand, fuel cell vehicles utilize liquid or gaseous fuels. Key attributes in power markets include regulation, spinning reserves, and peak power management.

C. CHARGING CONTROL

1. Harmonic Control

Converters play a vital role in battery charging systems by contributing to harmonic accumulation. To regulate or reduce harmonics, techniques such as pulse width modulation and multilayer converter [32] operation can be employed. Increasing the number of pulses significantly decreases harmonics in the Root Mean Square (RMS) current. Additionally, reactive power mitigation techniques can help manage unwanted harmonics. Continuous monitoring is essential to address potential power quality issues arising from harmonics in the system.

2. Coordinated Charging

Widespread charging of electric vehicles (EVs) can lead to concentrated charging, potentially affecting power grid regulation. Coordinated charging is classified as a regulated load to optimize economic efficiency while minimizing grid impact. This strategy manages the charging process by considering grid conditions, battery performance, and consumer needs, helping to stabilize load demand fluctuations and prevent new peak loads. It enhances the reliability, power consistency, and economic efficiency of the distribution network. Effective coordinated charging requires scheduling and aligning EV charging with grid demands, often facilitated by a middleman due to the challenges of direct grid management. Multi-agent technology can also support this integration, reducing charging duration during peak times.

D. V2G CHARGER AND FREQUENCY CONTROL

The purpose of frequency control is to adjust active power output to maintain frequency within the defined range of $f_0 \pm \Delta f$. Frequency adjustment metrics are divided into three sub-controls [33].

a. *Primary Control:* A rapid response mechanism that activates when frequency deviations exceed thresholds, aiming to minimize transient frequency and the Rate of Change of Frequency (RoCoF).
b. *Secondary Control:* A delayed response that intervenes after primary control to stabilize frequency, even if it falls outside the allowed range..

c. *Tertiary Control:* Follows secondary control to restore frequency to acceptable levels, currently managed by high-inertia power plants like nuclear or coal-fired facilities, but expected to shift to durable storage or demand response systems in future grids.

All these sub controls are used to manage the frequency levels in a system [34]-[39].

VI. MICROGRID ANALYSIS USING EV

Electric vehicles (EVs) consist of two main components: an internal energy source that powers the batteries and an electric motor for propulsion. They require external energy sources for charging, which can be categorized by charging speed and voltage. Key challenges in EV development include enhancing range and reducing charging time, with ongoing research focused on these issues. Using DC for charging can expedite the process, leading to an increase in charging stations with power exceeding 350 kW, often equipped with multiple plugs for simultaneous charging. However, this can create significant load demand challenges within the microgrid.

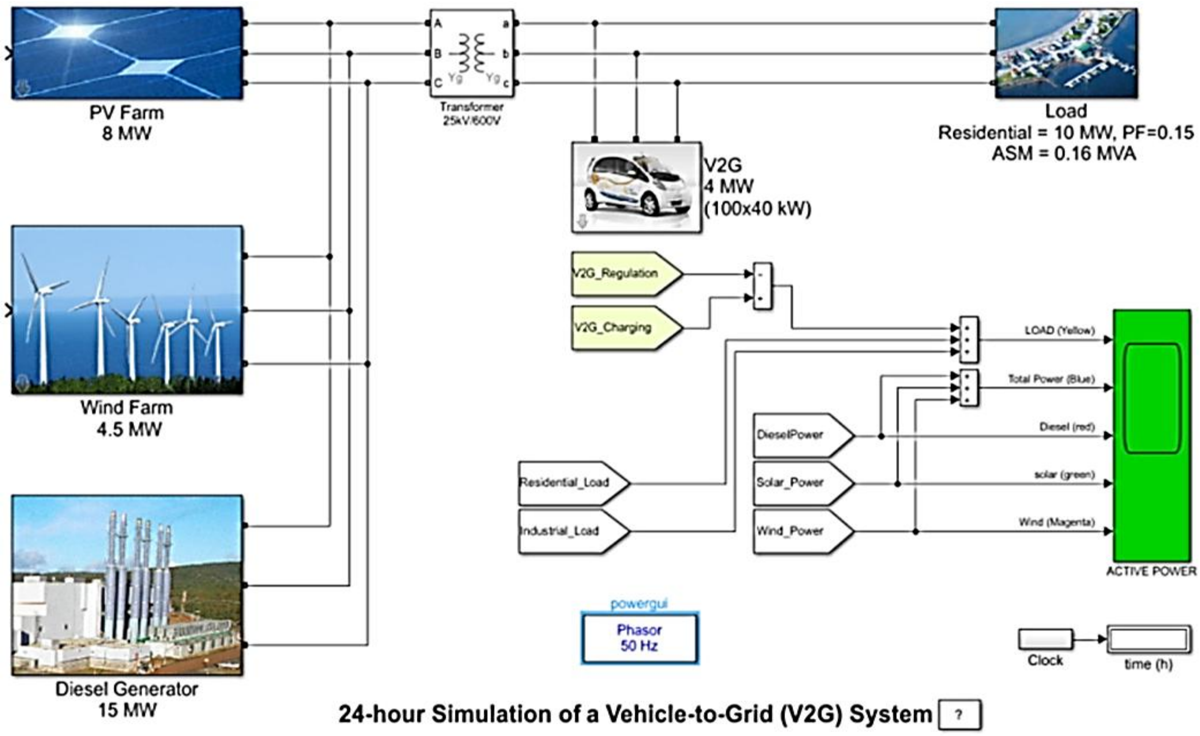

Fig. 2. V2G Model

The diagram represents a microgrid simulation setup for analyzing the performance of a Vehicle-to-Grid (V2G) system over a 24-hour period. It includes renewable and non-renewable energy sources, loads, and bidirectional V2G operations, simulating how electric vehicles interact with the grid as both consumers and suppliers of power.

This is a comprehensive simulation model for analyzing vehicle-to-grid integration in a hybrid microgrid. It models the realistic interplay between renewable energy sources, traditional power generation, dynamic loads, and electric vehicles, supporting the transition to a smart and flexible energy ecosystem.

The analyzed microgrid includes diesel generators as the main power source, alongside a PV facility and wind turbines for renewable energy. It supports a neighborhood load of 1,000 residences and 100

EVs, with a 1:10 EV-to-household ratio. While increasing renewable energy generation benefits the environment, it is dependent on environmental conditions. Effective microgrid management requires precise control of current and voltage, represented by sinusoidal waveforms at a frequency of 50 Hz.

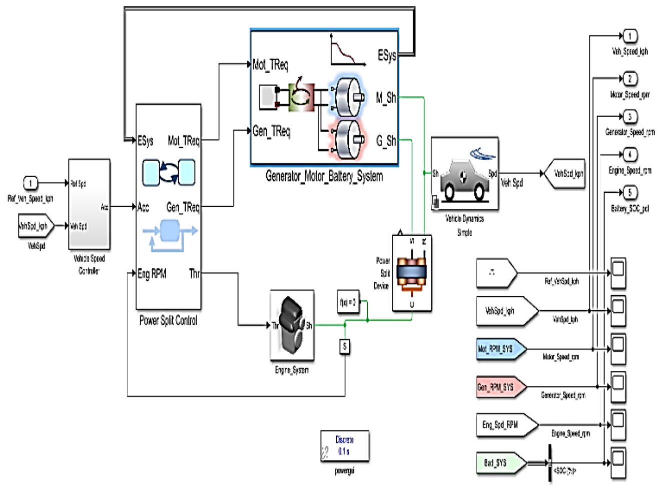

Fig. 3. HEV Model

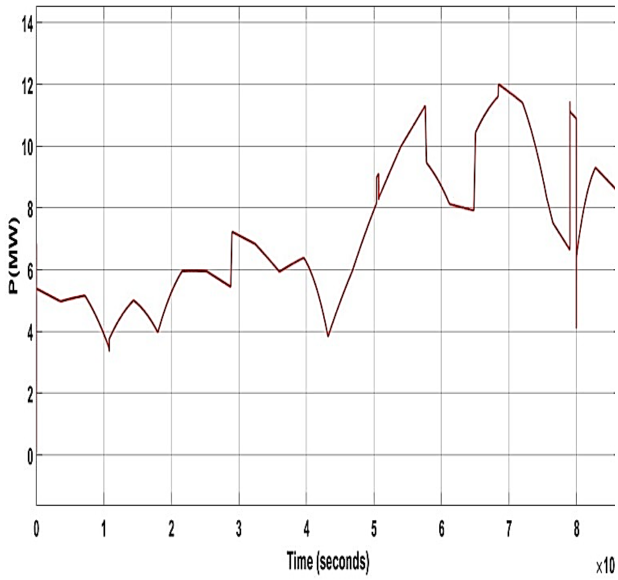

Fig. 4. Power generated by the generator throughout the day.

Fundamental variables in the microgrid can lose their sinusoidal characteristics due to various factors, leading to unwanted harmonic components. The rapid increase in electric vehicles (EVs) raises power demand, adding strain to the microgrid and increasing its variability. The diesel generator helps balance electricity consumption and generation, with frequency discrepancies determined by comparing it to the rotor speed of the synchronous machine.

While diesel generators are necessary when renewable sources fall short, they are costly and environmentally harmful. The microgrid features two renewable energy sources: a PV plant that generates energy based on solar irradiation, and a wind farm that produces power proportional to wind strength. The solar output is influenced by panel composition, irradiation levels, and weather conditions, while the wind farm operates optimally within specific wind speed thresholds.

The use of wind power plants in microgrids is increasing due to their renewable nature, simple design, and high efficiency. A key advantage of electric vehicles (EVs) is their ability to utilize Vehicle-to-Grid (V2G) applications, allowing them to supply electricity directly to the microgrid. V2G enables the transfer of energy from EV batteries to the grid, functioning as a storage system.

This plot shows a time-dependent profile of power (P in MW) over a simulation or operational duration. The shape of the curve closely resembles a smooth bell or trapezoidal wave, indicating a gradual power ramp-up and ramp-down behavior, typical in scenarios involving:

a) Controlled generator dispatch
b) Charging/discharging of energy storage systems
c) Renewable energy output (e.g., solar) mimicking diurnal variation

d) Load cycling tests in power systems

This graph depicts a controlled, single-cycle power profile over an extended time, likely representing generation or load behavior over the course of a day. The symmetric, gradual ramp-up and ramp-down coupled with a minor transient reflect a stable and well-managed system. This could be used in system design, control verification, or renewable energy profiling scenarios.

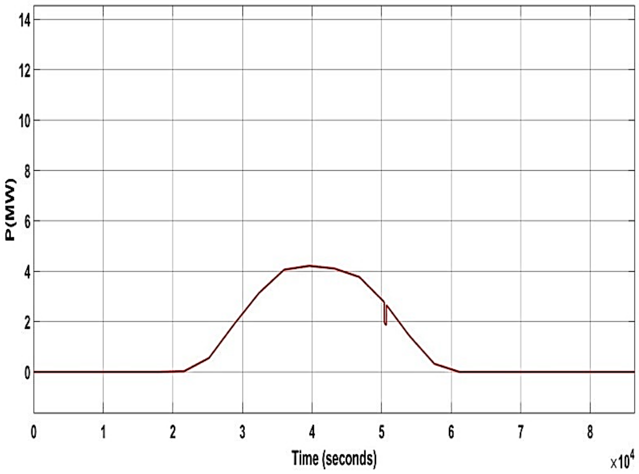

Fig. 5. Power generated by the solar throughout the day.

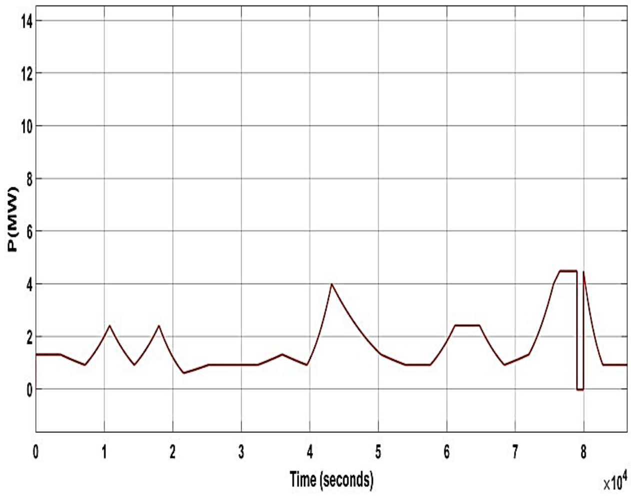

Fig. 6. Power generated by the wind throughout the day.

This graph captures the transient and bidirectional behavior of a V2G system over 24 hours. It highlights:

a. The flexibility V2G offers in managing load demand.
b. How charging/discharging cycles are timed to support the grid.
c. The non-continuous nature of V2G contribution, which depends on load status, vehicle availability, and renewable generation.

This graph presents a time-series plot of Power (P) in megawatts (MW) as a function of Time (seconds). The plot illustrates stepwise variations in power over a period, possibly representing the behavior of a discrete or controlled load/generation system.

This graph provides a clear view of controlled, stepwise power variation over a short duration. The behavior suggests a test or operation sequence involving discrete power events, likely representing load switching, generation ramp-up/down, or a controlled simulation. The system ends at a higher power level than it began, with all transitions showing reasonable control except for brief transient spikes that may warrant further examination for stability concerns.The graph you provided shows a time-series plot of Power (P) in megawatts (MW) over Time (in seconds). Here is a detailed description and analysis of the plot.

The graph illustrates the fluctuation and dynamics of power output over a prolonged period. There are notable sudden changes (spikes) and gradual trends in power, which may be indicative of operational changes, control system interventions, or faults within the system. This analysis could be helpful in further studying system stability, load forecasting, or control optimization.

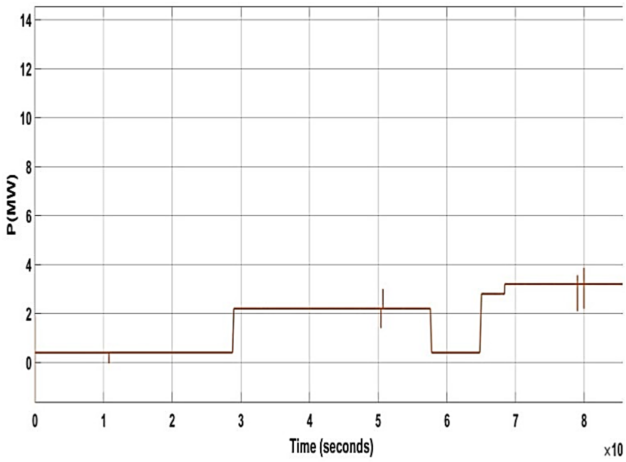

Fig. 7. Charged and regulated into the microgrid throughout the day.

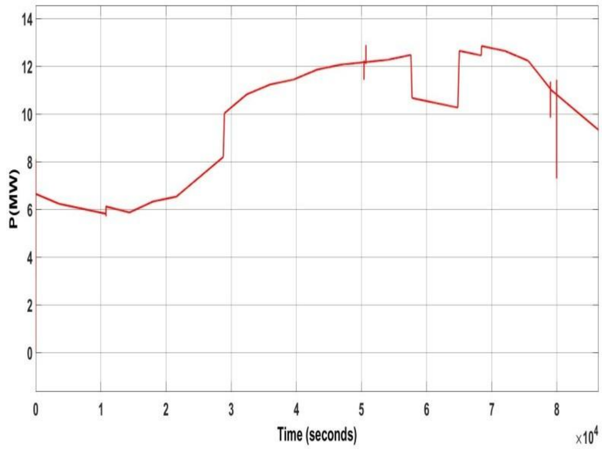

Fig. 8. Load drawn power from the microgrid during the day.

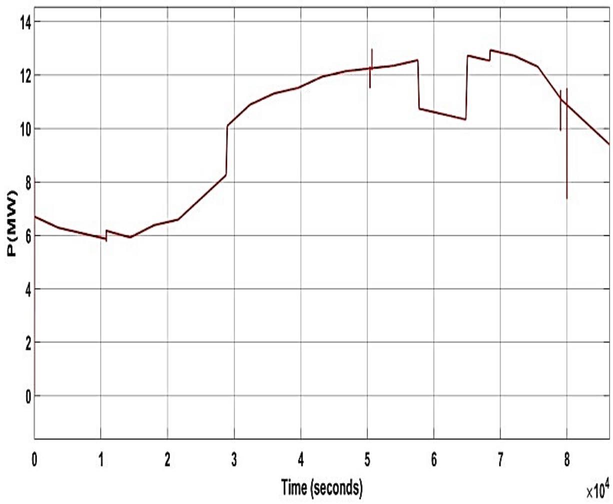

Fig. 9. Total power generation from microgrid during the day.

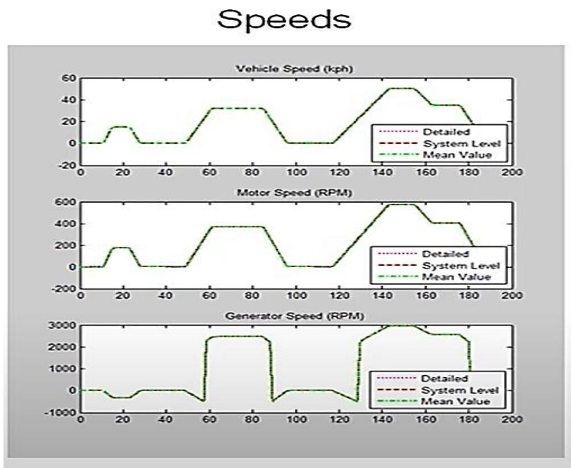

Fig. 10. Output speeds

However, simultaneous charging of multiple EVs can lead to increased electrical demand, phase imbalances, and voltage drops at charger connectors, posing challenges to energy equilibrium. V2G technology helps manage battery charge and stabilizes the grid during transient events, ensuring the availability of decentralized energy storage. The residential load is represented by the active power drawn at a specific power factor, while the total power generated by the microgrid must meet or exceed this load, maintaining equilibrium between demand and generation.Inadequate research on the complete lifecycle emissions of lithium-ion battery manufacturing was a limitation of the study. Future initiatives will focus on improving battery longevity, performance, and efficiency while lowering emissions related to EV production.

VII. CONCLUSION

The integration of Electric Vehicles (EVs) is becoming essential for the growth of distribution networks, but their increasing use may pose challenges for the distribution system. Reducing reactive power is crucial for voltage regulation in microgrids, as it improves power factor and reduces transmission losses, enhancing overall efficiency. EVs connected to the microgrid can provide reactive power support. This study analyzes the operation of a standalone microgrid, focusing on various EV charging methods and the uncertainties related to load demand, solar irradiation, and wind. Given the rising prevalence of EVs, it is vital to investigate their power quality, particularly regarding harmonic components, and implement suitable solutions. The number of charging stations is increasing in line with the growing adoption of EVs, highlighting the need for rapid development in the transportation sector, which will significantly impact both the power system and the environment.

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