GRIDSTABILITY AND CONTROL IN RENEWABLE ENERGY MICROGRIDS WITH ELECTRIC VEHICLES

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ABSTRACT

The rapid increase in pollution and greenhouse gas emissions has accelerated the adoption of Electric Vehicles (EVs), which are increasingly interacting with electrical grids. This integration affects voltage stability, load demand, and overall microgrid performance. This study focuses on modeling and analyzing a microgrid that integrates renewable energy sources and EVs. The microgrid consists of a diesel generator as the primary power supply, a photovoltaic (PV) farm, a wind farm, and a Vehicle-to-Grid (V2G) system near the load. Microgrids are capable of meeting the energy needs of hospitals, universities, EV charging stations, industrial sites, and residential areas. EVs introduce non-linear loads and dynamic behavior, which can influence voltage profiles, frequency, and power quality. MATLAB/Simulink is used to simulate the microgrid, analyzing power flows, voltage variations, energy management, and the interactions between EVs and renewable energy sources. The results show that integrating EVs with renewable energy improves microgrid efficiency, reliability, and sustainability, while also enabling better utilization of renewable generation and providing grid support. This study highlights the importance of EVs and renewable energy integration for developing future smart and resilient microgrids.

Keywords:

Renewable Energy Sources (RES),Electric Vehicles (EVs),Microgrid,Vehicle-to-Grid (V2G),Grid-to-Vehicle (G2V).

I INTRODUCTION

The transport sector is a major contributor to global greenhouse gas emissions, accounting for approximately 25% of energy-related emissions. A promising solution to mitigate this impact is the adoption of electric vehicles (EVs), which are considered environmentally friendly due to their zero tailpipe emissions. Many countries are actively encouraging EV adoption through incentives and regulatory measures to accelerate the transition toward sustainable transportation.

The widespread use of EVs, however, has significant implications for the electrical grid. Unregulated charging, where consumers charge vehicles without coordination, can lead to increased peak electricity demand, power losses, equipment overload, and reduced power quality. These challenges can be mitigated through controlled charging strategies and by utilizing EVs as distributed energy resources, particularly through Vehicle-to-Grid (V2G) technology. In V2G mode, EVs can discharge stored energy back into the grid, helping to stabilize frequency and voltage, reduce peak demand, optimize costs, integrate renewable energy sources, and balance overall electrical loads.

EVs are not a single technology but a category comprising three main types: Battery Electric Vehicles (BEVs), Hybrid Electric Vehicles (HEVs), and Fuel Cell Electric Vehicles (FCEVs). While battery technology remains a critical factor in EV performance, advancements have alleviated many concerns regarding battery life and reliability. EVs provide a sustainable alternative to internal combustion engine (ICE) vehicles, which have historically contributed substantial carbon dioxide emissions. Furthermore, alternative energy storage solutions such as batteries, fuel cells, and ultra-capacitors can complement traditional sources, enhancing system efficiency.

Charging strategies are central to the effective integration of EVs into the power system. Grid-to-Vehicle (G2V) represents the conventional charging approach, while V2G enables vehicles to act as mobile power sources. The effective management of V2G systems, often coordinated through digital platforms known as aggregators, can reduce battery wear, optimize load profiles, and provide frequency regulation services. Despite challenges posed by irregular travel patterns, strategic EV charging and V2G operation offer significant potential to reduce environmental pollution and operational costs for both transportation and electricity supply systems.

In summary, EVs are a critical component of the global effort to achieve sustainable mobility. Beyond transportation, they have the potential to enhance the resilience and efficiency of the electrical grid, representing a key link between clean energy adoption and climate change mitigation.

II LITERATURE SURVEY

Less fuel consumption cuts the carbon emission which comes out to be environmental friendly. Inclusion of EVs enhances energy efficiency, minimizes the greenhouse gases and foreign oil importation, but it has also introduced a burden on power grid. However, this burden on the existing power sources can be minimized with the controlled and coordinated charging of EVs. This can be achieved by employing the efficient charging infrastructure. The charging of EVs can also be regulated with the help of different optimization approaches. The optimization approaches are also helpful in achieving the various objectives during the EVs charging methods.

These objectives can be the minimization in power losses, provision of ancillary services, integration of renewable energy sources, and regulating the voltages. Therefore, EVs charging is studied from various perspectives for minimizing the load on smart grids. It is expected that EVs will grow in a larger number in next decade. Uncontrolled or un-coordinated charging of EVs will not only degrade the power grid capability but will also affect the distribution facility of the overall power structure. If the electrification of transportation is not properly optimized, this will ultimately lead to the collapse of existing power structure (Clement et al., 2009a, Amjad et al., in press, Umer et al., 2016b).

For optimal charging of EVs, a well-coordinated and controlled infrastructure is needed. EVs charging is now well supported with the help of smart grid. Amplification of peak demand and voltage fluctuations, demand the smart charging approaches to control the electrification of EVs. It is estimated by various studies, that only 10% integration of EVs into the roads can cause a serious blow to the existing power structure. Originally power grids are designed to support the commercial and house hold utilities. Interest in smart grids for smart charging of EVs is replacing the existing grid. Smart charging is dealing with challenges like stability, infrastructure modifications, and load management. Following are the characteristics of smart grid (Habib et al., 2015, Fang et al., 2012, Mouftah et al., 2017, Rehan et al., 2017). Supportive role for integration of renewable energy sources.

For charging EVs, information regarding its charging needs is collected. This information is harnessed for optimal charging of EVs. Power from electric grids are transferred and then stored in EVs during charging state, and energy is usually consumed during discharging. EVs can enhance the load on distribution network and could also contribute as power generator to distribution network. The charging capability of EVs can be studied from various perspectives. Usually, the following factors are involved during the charging of EVs.

III EXISTINGSYSTEM

Microgrids are localized energy networks capable of operating independently or in conjunction with the main power grid. They integrate multiple distributed energy resources, such as renewable energy sources and energy storage devices, to supply electricity reliably and efficiently to consumers. In current systems, microgrids often rely on conventional generators and limited energy storage, focusing mainly on meeting demand while maintaining basic voltage and frequency stability.

Renewable energy sources, particularly solar photovoltaic systems and wind turbines, are increasingly incorporated into microgrids to reduce dependence on fossil fuels and minimize greenhouse gas emissions. However, these sources are inherently intermittent, with energy output fluctuating based on weather and time of day. Existing systems typically manage this variability using backup generators, battery storage, or load shedding, yet challenges remain in balancing supply and demand and maintaining grid stability without energy wastage.

Electric vehicles are emerging as both electricity consumers and potential energy storage units within microgrids. In the current setup, most EVs participate only in Grid-to-Vehicle (G2V) charging, drawing electricity from the microgrid as needed. This uncoordinated charging can create peak load issues, stressing local infrastructure. The Vehicle-to-Grid (V2G) potential, which allows EVs to supply electricity back to the microgrid, is rarely utilized due to a lack of control systems, aggregator platforms, and standardized strategies as shown in below fig (1).

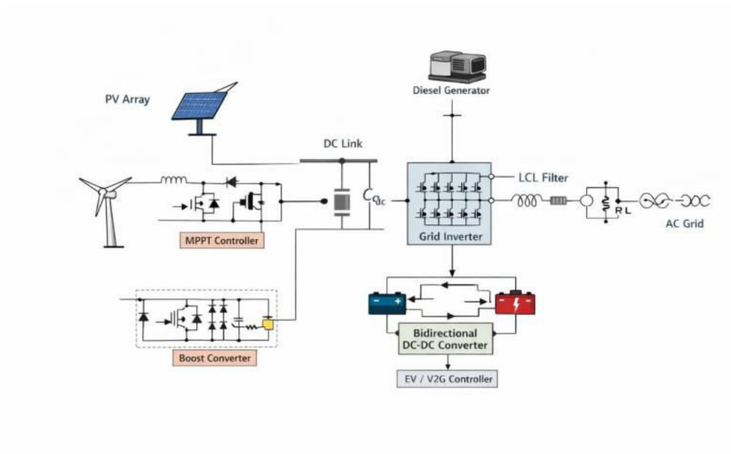

Fig (1): BLOCK DIAGRAM OF EXISTINGSYSTEM

Renewable energy from PV and wind is harvested and optimized via the MPPT controller. Voltage is boosted and stabilized through the boost converter and DC link capacitor. The stabilized DC power is converted into clean AC power by the grid inverter and sent to the AC grid or microgrid loads. The diesel generator supplements power as a backup. Electric vehicles connected to the system can either consume power (charging) or supply power back to the grid via the bidirectional DC-DC converter and EV/V2G controller, enhancing grid flexibility and stability.

IV PROPOSEDSYSTEM

Based on the provided circuit diagram, the proposed system is a renewable energy-based microgrid integrated with Electric Vehicles (EVs) using Vehicle-to-Grid (V2G) technology. The system consists of a Solar PV system, Wind Turbine, Diesel Generator, Battery Energy Storage System (BESS), EV Charging Station with a bi-directional converter, Main Load, and a centralized Microgrid Controller, all interconnected through a common AC bus.

In this system, the Solar PV array generates DC power, which is processed through a DC–DC converter for voltage regulation and then converted into AC using an inverter before being connected to the AC bus. Similarly, the Wind Turbine produces AC power, which is converted through an AC–DC converter and properly conditioned before being supplied to the AC bus. The Diesel Generator acts as a backup source and is connected to the AC bus to provide power during low renewable generation or emergency conditions.

The Battery Energy Storage System is connected to the AC bus and stores excess energy generated by solar and wind sources. It supplies power during peak demand, improves voltage stability, and enhances system reliability. The EV Charging Station is integrated through a bi-directional converter that enables both Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) operations. In G2V mode, electric vehicles draw power from the microgrid for charging, while in V2G mode, stored energy from EV batteries is fed back into the grid to support load demand during peak periods.

The Microgrid Controller plays a crucial role in managing power flow between all energy sources and loads. It performs load balancing, controls voltage and frequency, optimizes renewable energy utilization, schedules EV charging, and reduces dependence on the diesel generator. Overall, this proposed system ensures efficient energy management, improved power quality, reduced greenhouse gas emissions, enhanced reliability, and cost-effective operation of themicrogrid as shown in below fig (2).

The voltages for n modules in series are given as:

$V_{series} = \sum_{j=1}^{n} V_j = V_1 + V_2 + \ldots\ldots\ldots + V_n$ for $I > 0$

$V_{seriesoc} = \sum_{j=1}^{n} V_j = V_{oc1} + V_{oc2} + \ldots\ldots\ldots + V_{ocn}$ for $I = 0$

The current and voltage form modules in parallel is given by,

$$I_{parallel} = \sum_{j=1}^{n} I_j = I_1 + I_2 + \ldots\ldots\ldots + I_n$$

$$V_{parallel} = V_1 = V_2 = \ldots\ldots\ldots\ldots\ldots\ldots = V_n$$

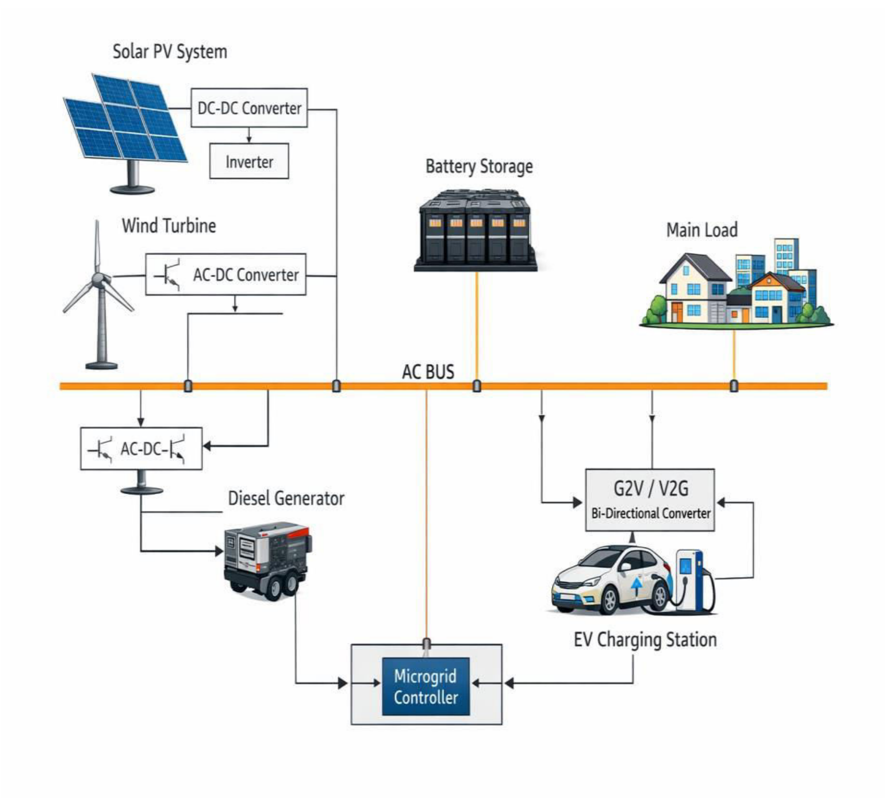

Fig (2): BLOCK DIAGRAM OF PRAPOSED SYSTEM

V MATLABSIMULINK

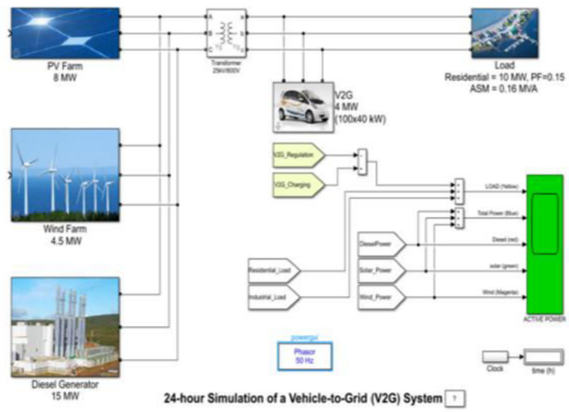

Fig (3): SIMULINK DIAGRAM

VI RESULTS

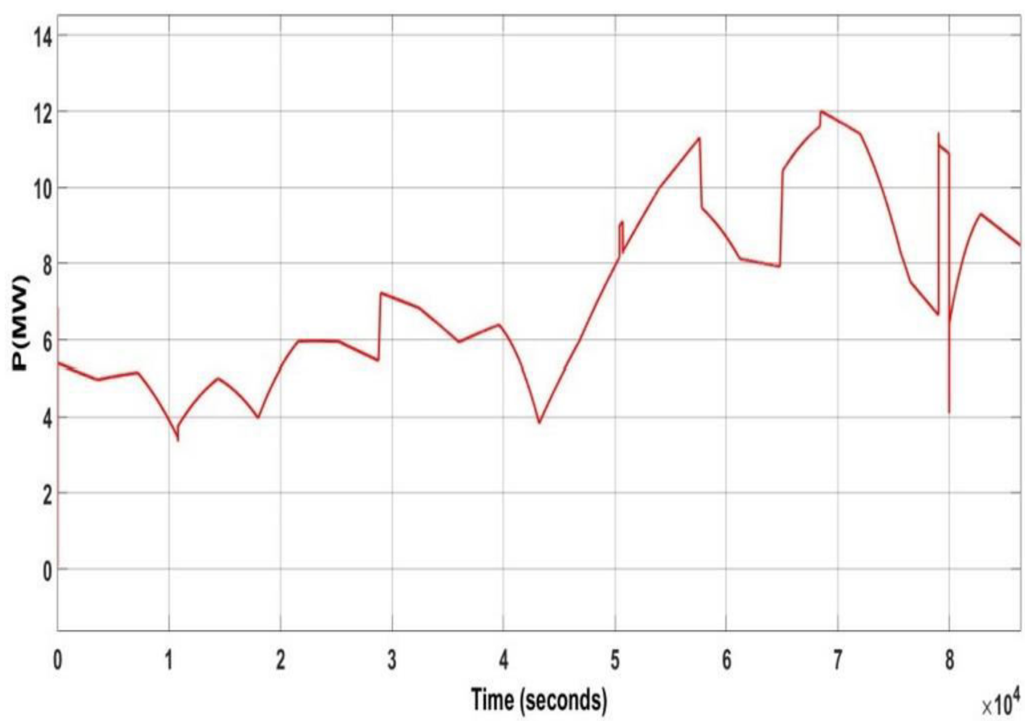

Fig (6.1): Power generated by the generator throughout the day.

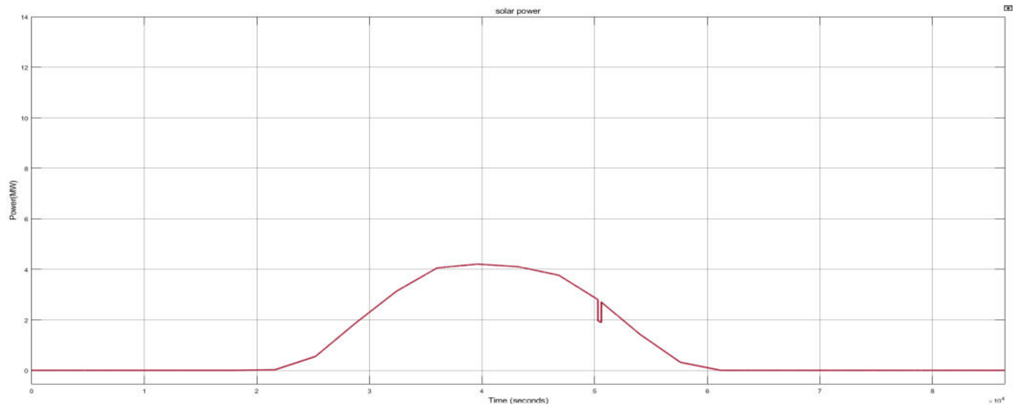

Fig (6.2):Power generated by the solar throughout the day.

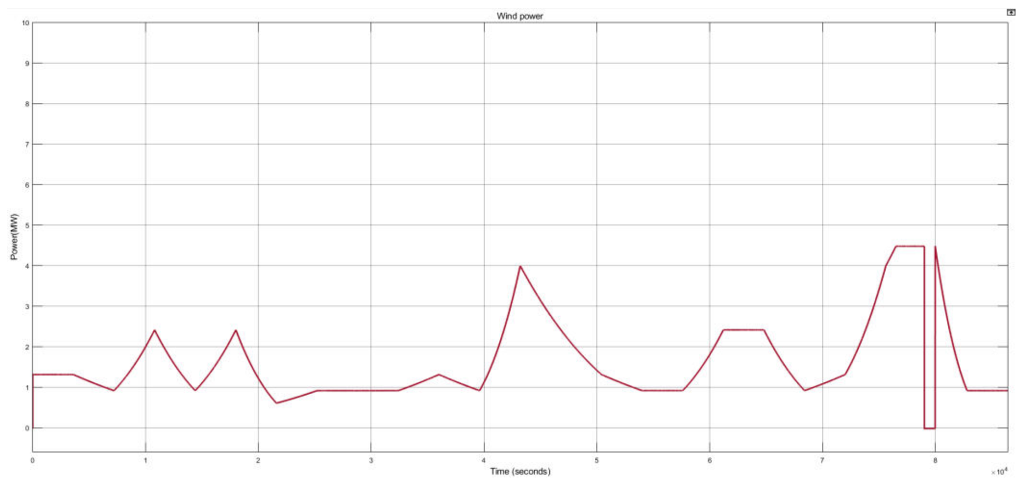

Fig (6.3): Power generated by the wind throughout the day.

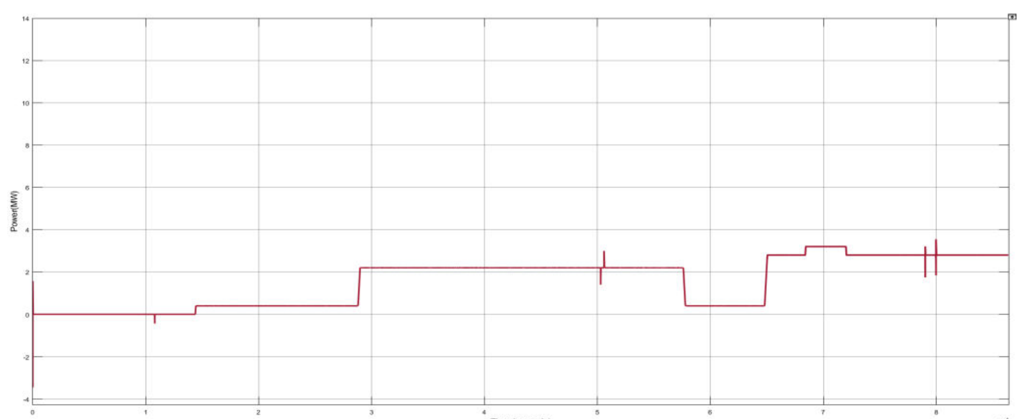

Fig (6.4): Charged and regulated into the microgrid throughout the day.

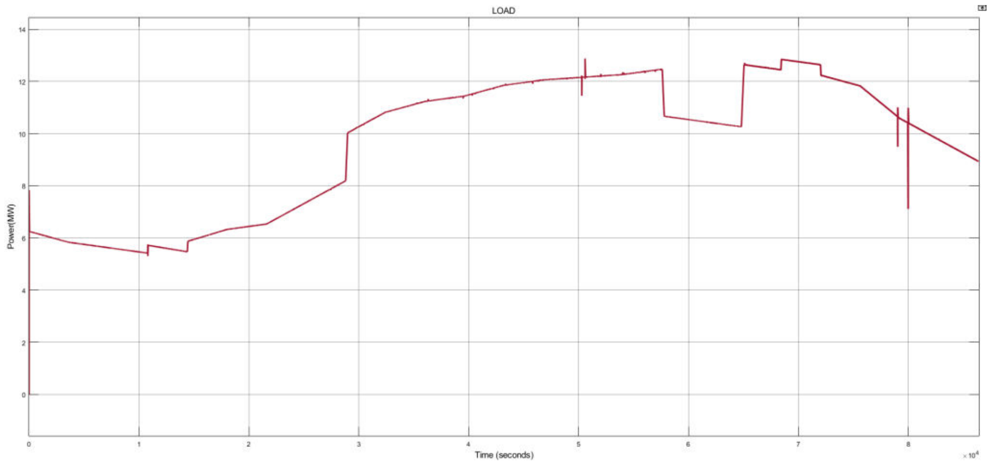

Fig (6.5): Load drawn power from the microgrid during the day.

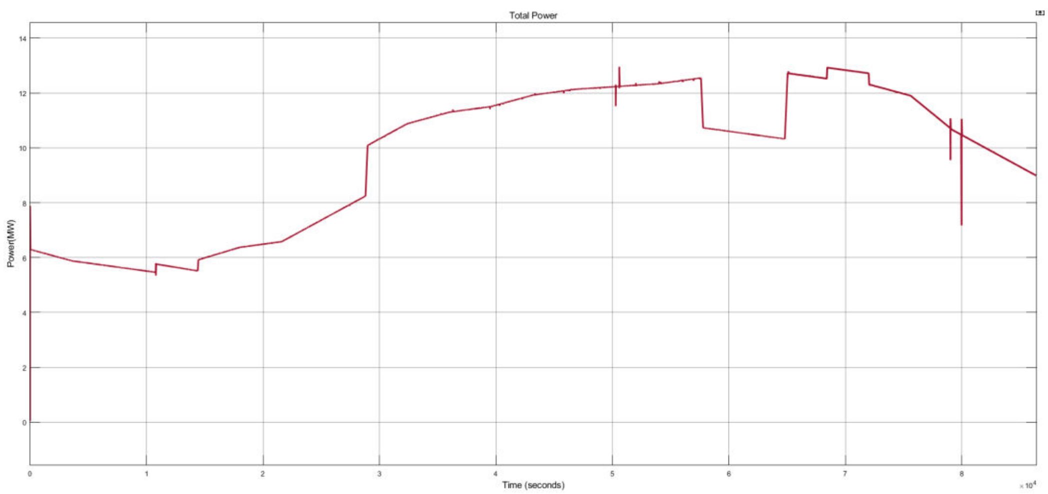

Fig (6.6):Total power generation from microgrid during the day.

The proposed microgrid system integrating solar PV, wind energy, diesel generator, and electric vehicles (EVs) was successfully modeled and analyzed. The hybrid use of solar and wind energy improves system reliability and ensures continuous power supply even during variations in weather conditions. The results indicate that renewable energy sources significantly reduce dependency on conventional fossil fuel-based generation and help in lowering greenhouse gas emissions. The diesel generator supports the system during low renewable energy availability, maintaining voltage and frequency stability. Uncontrolled EV charging increases peak load demand, voltage drop, and harmonic distortion in the distribution network. However, with coordinated charging and Vehicle-to-Grid (V2G) operation, EVs act as distributed energy storage units. During peak demand periods, EVs supply power back to the grid, helping in peak load shaving, loss reduction, and voltage profile improvement. Overall, the integration of renewable energy sources and EVs into the microgrid improves energy efficiency, enhances power quality, reduces operational costs, and supports sustainable energy development as shown in the above figures.

VII FUTURE SCOPE

The proposed integration of renewable energy sources and electric vehicles (EVs) into a microgrid has strong future potential. Advanced smart grid technologies and improved Vehicle-to-Grid (V2G) strategies can further enhance load management, voltage stability, and frequency control. Future research can focus on artificial intelligence-based forecasting, fast EV charging infrastructure, harmonic reduction techniques, and improved battery storage systems. Large-scale implementation in smart cities, industries, and rural areas can promote sustainable and reliable energy systems.

VIII CONCLUSIONS:

The incorporation of Electrical Vehicles (EVs) has become an unavoidable trend in the expansion of distribution networks. The rising utilisation of EVs will amplify possible issues for the distribution system. The reduction of reactive power is employed to ensure voltage regulation in the microgrid. Reactive power support enhances the power factor and diminishes power losses in power transmission lines. Furthermore, it results in heightened efficiency. EVs that are linked to the microgrid have the ability to offer reactive power adjustments. The study focuses on analysing the operation of a standalone microgrid, specifically examining various EV charging procedures. The effects of uncertainty relate to predicted values of load demand, solar irradiation, and wind. In considering the growing prevalence of EVs, it is imperative to conduct thorough investigations on their power quality, with a particular focus on harmonic components, and implement appropriate solutions accordingly. The number of charging stations is growing steadily in direct correlation with the rising prevalence of EVs. The rapid transformation of the transportation industry in the present day necessitates the swift development of EVs, which will significantly influence both the power system and the environment.

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