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LEVERAGING ELECTRIC VEHICLES AS ENERGY STORAGE FOR OPTIMIZING RENEWABLE ENERGY IN DISTRIBUTED GENERATION NETWORKS

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ABSTRACT: Electric vehicles (EVs) and renewable energy sources can work together to improve grid stability and reduce energy consumption in a groundbreaking way. By integrating smart charging and vehicle-to-grid (V2G) technologies, electric cars (EVs) can be transformed into energy storage devices that can hold onto renewable power during off-peak hours and send it back to the grid when demand is large. This lessens the impact of renewable energy's intermittent nature and our reliance on traditional power sources. This integration is made possible by state-of-the-art energy management approaches, such as AI-driven forecasts and real-time demand-response systems. There are positive environmental and economic impacts from the plan, which also promotes a decentralized and sustainable energy future. The article highlights the possibility of a more sustainable and reliable electricity grid that combines EVs with renewable power sources. Energy security and the resolution of climate change can be achieved by the adoption of a comprehensive strategy, which is proposed in this paper.
KEYWORDS: Renewable Energy, Electric Vehicles, Distributed Generation, Smart Charging, Vehicle-to-Grid (V2G), Grid Stability, Energy Optimization, Demand Response, Sustainable Energy, AI-Driven Forecasting.

1. INTRODUCTION

Electric vehicles (EVs) and renewable energy sources must be integrated by distributed generation systems in order to maximize energy use and boost grid efficiency. Solar and wind power, for example, are quite unpredictable, making it difficult to guarantee a steady supply of electricity. A flexible energy source, electric vehicles are made possible by modern charging infrastructure and integrated battery storage technologies. When needed, they can supplement the grid with the excess renewable energy they have collected. By working together, renewable energy sources and electric vehicles improve the grid, reduce reliance on fossil fuels, and optimize the energy landscape.

To maximize the benefits of energy sharing, smart charging and vehicle-to-grid (V2G) systems that efficiently control power flow are essential. Energy systems may achieve real-time equilibrium between supply and demand with the help of demand-response systems and AI-driven predictions, which reduces waste and enhances profitability. Reducing transmission losses and enhancing energy reliability, distributed production boosts generation closeness to consumption. An innovative strategy for building a reliable, decentralized, and ecologically friendly energy infrastructure is distributed generation, which combines renewable energy sources with electric vehicles (EVs).

One way to make dispersed generation networks more flexible is to turn electric vehicles (EVs) into mobile energy storage systems. To control voltage fluctuations and relieve grid congestion, bidirectional charging takes use of renewable energy sources while demand is low and resells it when demand is high. Decentralized energy markets have become a reality thanks to connectivity, which has improved the use of renewable energy sources and allowed electric car owners to trade energy. The future of renewable energy and electric vehicles' ability to work together is highly dependent on developments in smart grid infrastructure and battery technology. This can make it easier to build a long-term energy system that is reliable, efficient, and environmentally friendly.

2. REVIEW OF LITERATURE

Soni, J., & Bhattacharjee, K. (2024). To solve the Dynamic Economic Emission Dispatch (DEED) problem, this study optimizes the use of renewable energy sources including wind, solar, and plug-in electric vehicles (PEVs). Incorporating Weibull and Beta distributions, the Wind-Solar-Plug-in Electric Vehicle (WSPEV) DEED model utilizes an Oppositional-based Equilibrium Optimizer (OEO) approach. As a result, wind and solar power may be more accurately depicted. Processes for charging and discharging PEVs are also accounted for in the model. In a number of scenarios, including those including renewable energy sources and plug-in electric vehicles (PEVs), the model was able to produce a reliable and financially feasible power system. For future integration planning, this information is vital.

Pratapa, A., Tiwari, P., & Maurya, R. (2024). This study uses a hybrid optimization approach that includes network reconfiguration to find the best distribution strategy for DGs in distribution networks that provide electric vehicle charging stations. It looks at DGs with variable power factors. The suggested hybrid optimization method enhances convergence and avoids early convergence to local optima by combining genetic operators with the GTO algorithm.

Sankar, M. M., & Chatterjee, K. (2024). Optimal placement of renewable distributed generation (RDG) units within electric distribution networks with a high concentration of plug-in hybrid electric vehicles (PHEVs) is defined by this study's multi-objective framework. The study takes a close look at how PHEV adoption affects distribution systems and uses a detailed model of PHEV demand that takes into consideration several stochastic factors. To find the best solution that takes into account both scientific and financial factors, the MOAHA algorithm is used. During validation on benchmark test systems, the framework significantly reduced energy loss and increased voltage stability, proving that it successfully improves the location of RDGs in PHEVs.

Hmingthanmawia, D., Deb, S., Datta, S., Singh, K. R., Cali, U., & Ustun, T. S. (2024). In order to reduce expenses and losses, this research looks at the electric vehicle (EV) economic dispatch (ED) problem. Because the problem involves more than one objective, this research investigates different optimization methodologies, such as G2V and V2G relations. By making educated guesses about the unpredictable behavior of renewable energy sources and electric vehicles, the initiative hopes to maximize the distribution of energy resources, which will lead to economic and technological breakthroughs. The results of the simulations showed that the optimization solutions that were suggested greatly reduced operational costs and power system losses. It is possible that electric vehicles might increase the grid's efficiency.

Mukherjee, B., & Sossan, F. (2023). In order to ascertain the ideal placement of electric vehicle (EV) charging stations inside distribution networks and their particular needs, this article offers a mathematical model. Autonomous photovoltaic (PV) system efficiency gains and cost savings are the end goals. Electric vehicle charging times, line currents, nodal voltages, and transformer ratings are some of the variables that limit the model's applicability. According to the study, EV drivers have a lot of leeway in how they connect their cars to charging stations, which improves charging infrastructure use and makes photovoltaic self-consumption more efficient. To model nonlinear grid constraints, the problem is expressed as a mixed-integer linear program (MILP) using linearized grid models.
Mondal, S., & De, M. (2023). Through better scheduling and power distribution for EVs and DERs, this research hopes to improve the efficiency of imbalanced distribution networks. In order to accomplish both technical and financial goals, the study uses a multi-objective optimization framework; these goals include enhancing the voltage profile and reducing losses. Reducing operational expenses and improving system dependability are two potential outcomes of combining demand-side management tactics with vehicle-to-grid (V2G) functions. Assessing the plan in an uneven distribution system leads to substantial savings in both time and money.
Zhang, X., & Li, Y. (2022). The vast network of renewable energy sources and electric vehicle (EV) charging stations, voltage fluctuations could affect the quality of the electricity. The distribution network's voltage management becomes more difficult when basic reactive power control techniques are used. By expanding the traditional distribution network architecture to incorporate electric vehicles and other energy sources, this study creates a multi-objective optimization model. The goal is to stabilize voltage fluctuations, decrease line losses, and increase the margin of static voltage stability. Optimized results can be obtained in some cases by modifying the model parameters to account for different kinds of machinery and environmental conditions. To choose the best algorithm for a given job, it is best to use the TOPSIS decision-making approach to compare each algorithm's performance to the improved model. The suggested model outperformed competing reactive power control methods in a side-by-side comparison.
Huang, P., Lovati, M., Zhang, X., & Bales, C. (2021). In order to improve cluster efficiency, this study proposes a unified control system that incorporates energy storage, EVs, and energy sharing. Genomic algorithms can control the building cluster and coordinate the charging and discharging of electric vehicles by evaluating data from renewable energy sources and expected 24-hour electricity demand. Electric car charging and decommissioning may now be modelled. In Ludvika, Sweden, a group of real buildings were used to validate the control system. The results show that compared to traditional controls, coordinated control can lower daily power expenses by 36% and increase the cluster-level green self-consumption rate by 19%.
Engelhardt, J., Zepter, J. M., Gabderakhmanova, T., & Marinelli, M. (2021). Using a unique design that makes use of several batteries in place of a power converter, this study demonstrates a variety of energy management options. Direct connections between DC components and battery lines are made possible in these systems by means of the busbar matrix. A two-tiered control structure is employed by the energy management system. Distributed energy generation (DC) microgrid components, such as solar panels and fast

chargers for EVs, are first distributed to battery strings. The regional distribution system's power flow is regulated by the second layer. A simpler droop control is compared to a more complex control that uses predictions. By reducing grid interaction and battery cycles, improved control encourages self-sufficiency. To provide accurate representations of the unpredictable nature of electric vehicle charging, Monte Carlo models are fed real-world photovoltaic data acquired over multiple months. However, the aging process can be accelerated by placing the battery closer to its charge limitations.

Maldonato, F., & Hadachi, I. (2021). This research explores the possibility of using reinforcement learning control methods in virtual power plants (VPPs) that combine renewable energy sources with electric vehicles (EVs). Reusing EVs as home power storage or to collect renewable energy surpluses is the major goal of the project, which aims to improve energy distribution techniques. Microgrids and other virtual power plants can be made more reliable and help achieve supply-and-demand balance by connecting electric vehicles to them. This study provides evidence that machine learning approaches can be used to model power grid networks in various ways. Because of this, we can build an energy system that is both visible and integrated, and we can improve it over time.

Huang, Z., Fang, B., & Deng, J. (2020). Utilizing electric cars (EVs) equipped with vehicle-to-grid (V2G) features, this research presents a multi-objective optimization methodology for distribution networks. The goal is to create interdependent energy systems. The idea is to lessen power losses and voltage swings, making distribution networks safer and more cost-effective. To reduce the difference between peak and valley demand, we use reactive power adjustment, synchronized charging and discharging of electric vehicles, and time-of-use pricing. There would be far less power loss, voltage fluctuations, and grid strain if all electric vehicles were synchronized. This has the potential to improve distribution system safety while reducing costs, according to IEEE's 33-node test case simulation.

3. ELECTRICAL GRID

Generators can supply energy to homes and businesses through the electrical grid. Advertising, distributing, transmitting, and producing are the four parts. Most of the time, conventional power flows only one way, from producers to consumers. The advent of dispersed generation, electric vehicles, and renewable energy sources has made energy bidirectional.

Unidirectional : A unidirectional power flow occurs when all of the power in a network flows in only one direction. The energy flux is shown in Figure 1. The steps involve making something, delivering it, transporting it, and finally selling it to someone.

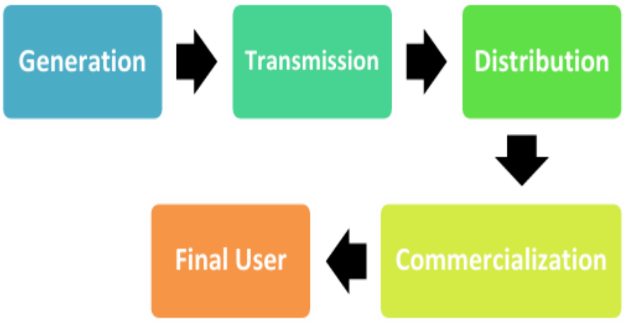

Fig: 1 Unidirectional Diagram

Bidirectional : When data can travel in both ways over a network, we say that it is bidirectional. The vehicle-to-grid (V2G) idea facilitates two-way energy transfer via smart networks and consumer-generated electricity through distributed generation (DG) and electric cars (EVs). In addition, they might think about selling the extra goods to the distribution system.

Smart grids' commercialization process and power flow are shown in Figure 2. This flow includes conventional generation, transmission, distribution, and consumer delivery.

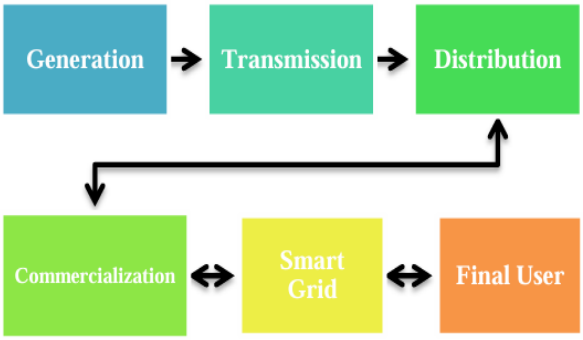

Fig: 2 Bidirectional Diagram.

Remember that PHEVs and HEVs are two completely different kinds of electric vehicles, and that they can go in either direction. Here we are talking about switching from an electric motor to a turbine that runs on gasoline. The majority of EVs' internal bidirectionality problems originate from battery short circuits.

4. SMART GRID

Electrical cables can now be more easily connected thanks to the digital grid. By analyzing data and information to automate and remotely oversee operations, the energy source can be made more reliable, efficient, and environmentally friendly.

Having clients that can affect how the network operates is a hallmark of intelligent networks. With smart meter technology, customers can track their energy usage, costs, and incentives instantly. What choices they make and how much influence they want to have are entirely up to them. Smart grids make use of distributed generation units. You may rest easy knowing that the network can quickly fix any problems that may arise. The smart grid differs in various ways from the traditional electrical system, as seen in Table 1.

Table 1. The smart grid is contrasted with the conventional grid.

Characteristics	**Conventional Grid**	**Smart Grid**
Communication	Uni-directional	Bi-directional
Monitoring control	Manual	Autonomous and intelligent
Inclusion of smart	Limited	Throughout
Sensors and meters	Passive	Active
Consumer participation	Centralized	Distributed
Power generation	Manual	Self-healing

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5. DISTRIBUTED GENERATION

Distribution networks that source their power from renewables have a significant impact on the bidirectionality of energy supply. Unlike power plants, which generate electricity from a central location, distributed generators may require the client to be physically close to the facility.

Solar and small-scale wind power are relevant to this subject due to their rapid increase, however the DG can evaluate numerous energy sources.

WIND GENERATION: Wind power is gaining popularity since it can generate sustainable energy without polluting the environment. Smart grids in distributed generation can make good use of this energy because it is both efficiently used and located near consumer demands.

Like solar power, wind power is highly dependent on the weather, which makes predicting its output challenging. Similar to other intermittent power sources, solar energy has its own set of problems.

- Fluctuation in voltage.
- Fluctuation in frequency.
- Increase in the level of failure.
- Voltage rise problem

6. ELECTRIC VEHICLE

To move people or goods, electric vehicles (EVs) transform electrical energy into mechanical energy. Propulsion can be generated by means of wheels or propellers that are driven by rotary engines. Another way to create motion is by using linear motors, inertial motors, or magnetic systems; magnetic levitation trains are an excellent example of this. Based on their power sources, electric vehicles can be classified as either plug-in or non-plug-in. Table 2 provides a brief description, abbreviation, and categorization of the vehicle.

Type	Abbreviation	Description
Electric Vehicle	BEVoVE	One term for a car that runs on batteries is a "pure electric." There is no internal combustion engine; instead, it has an electric motor or motors. Electric devices that run on batteries mostly draw power from the power grid. Personal belongings
Hybrid Electric Vehicle	HEV	It also has an electric motor or motors in addition to a combustion engine. A combination of an internal combustion engine and an electric motor drive the wheels of the vehicle. The electric motor is the only power source for some car manufacturers, while for others it is just an accessory. As cruising speed drops, the vehicle's heat engine and energy recovery system begin to automatically replenish the batteries. No connection could be made.
Plug-in Hybrid Electric Vehicle	PHEV	It combines a combustion engine with abattery and an electric motor, unlike HEVs, they have larger capacity batteries that have to be charged by connectingthem to the electrical network.(Pluggable)
Range	REEVo EREV	A gasoline engine may be there, but it is not what drives the

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Extended Electric Vehicle		vehicle. When the batteries die, it turns into a generator instead. The two things can be unrelated.
FuelCell Electric Vehicle	FCEV	They have electric motors as their only propulsion system and run on hydrogen fuel cells instead of batteries. Connection cannot be established.

Electric vehicles' inner workings shed light on the power transfer authority. There are three modes in the following list.

Vehicle To Vehicle o V2V: It makes it easier for a cluster of EVs to connect to a nearby network of bidirectional chargers, like the ones found in public spaces or parking garages. The controller of a V2H system called an aggregator is responsible for managing the energy transfer to the network. As an example, a parking garage's V2H systems can be linked together by the broker to form a V2V network. In addition to allowing all cars to communicate with one another, both kinds of controllers make it possible for energy to be transferred to the grid or other vehicles that need it. Setting priority is possible with this setup. The grid can be fed any excess power once all the linked vehicles have been charged.

Vehicle To Home o V2H: Electric vehicle (EV) batteries connected to a household power grid can be charged and discharged with the help of a bidirectional converter. Bringing an electric vehicle to a designated home outlet is the fastest and most efficient way to charge it. A bidirectional converter is a common component of vehicle-to-home (V2H) connections, which link a home's electrical grid to an electric car. The electricity could come from the local power grid or renewable sources close to the charging station. The electrical network requires an operator. This expert will be in charge of managing energy resources as the electric car interacts with the power grid.

Vehicle To Grid o V2G: Through the implementation of an integrated system, made possible by the principles of Vehicle to Home (V2H) and Vehicle to Vehicle (V2V), the Vehicle to Grid (V2G) network came to be. With the help of vehicle-to-grid (V2G) technology, electric vehicles may take power from the grid, store it, and then give it back when needed. Additionally, V2Gs must adhere to the international standard ISO 15118, which specifies the protocol for EVs to communicate with the charging and discharging network.

Fig. 3 A variety of electric vehicle (EV) layouts are shown in Figure 3 that allow for bidirectional mobility.

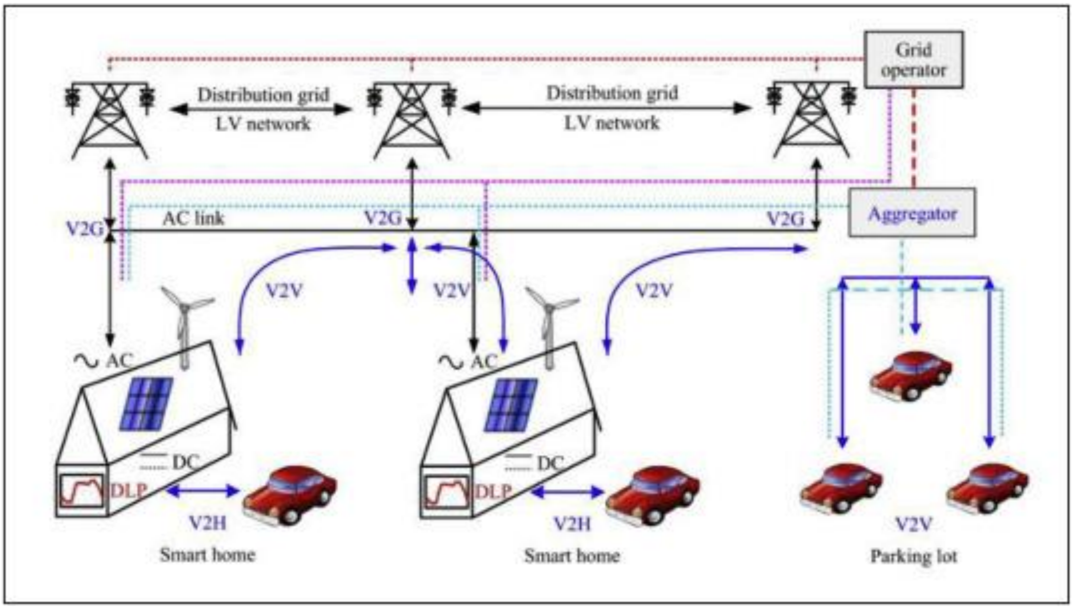

Fig: 3 Bi-directional EV settings (V2G, V2V y V2H).

7. RESULT AND DISCUSSIONS

Research on energy and battery state of charge (SOC), reactive power, efficiency, electric vehicle penetration, and frequency was examined by a smaller fraction, whereas most studies focused on voltage and active power (Figure 4).

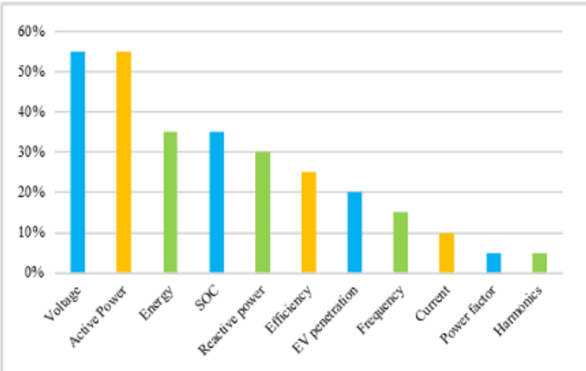

Fig: 4 Bar chart, metric evaluation

In voltage literature, the subjects of undervoltage and overvoltage are often discussed. Most research that have looked into ESSs as a possible fix for voltage problems have used these words. Energy Storage Systems (ESS) rely on State of Charge (SOC) and energy as essential components. A solution to reactive power and voltage difficulties may lie in the widespread use of electric vehicles (EVs). However, issues related to electric car technology, such as harmonics, may persist. Coordinated integration of multiple energy sources, such as distributed generation (DG), energy storage systems (ESS), bidirectionality, electric vehicles (EVs), and vehicle-to-grid (V2G) technologies, allows an intelligent grid to optimize energy, voltage, active power, reactive power, power factor, and frequency.

There are two main types of environmental implications that electric cars (EVs) have, according to the research. The main distinction between regular cars and electric ones is the amount of pollution that the former generates. There are more positive effects on the environment from driving an electric vehicle than from a gas-powered one. This position is supported by most of the articles that were reviewed. However, one may argue that the power used to charge the EV comes from the conventional grid. On occasion, coal or other possibly hazardous materials are burned in power plants to produce energy. Consequently, most papers I've read fail to appropriately address the indirect emissions caused by driving an electric vehicle.

A consensus was achieved to integrate electric vehicles (EVs) and energy storage systems (ESS) into networks that now rely on renewable energy sources like solar and wind. The goal of this action was to reduce the system's negative effect on the environment while simultaneously increasing its efficiency. In addition to controlling electrical properties like voltage and frequency, the ESS may reduce the unpredictability of renewable power sources like solar and wind.

Explore a divisive aspect of the vehicle-to-grid (V2G) paradigm, with an emphasis on the pros and cons of one-way vs two-way communication for EVs. Equipment charging levels for electric vehicles are defined by the SAE J1772 standard. Similarly, it was argued that the V2G notion is meaningless outside of public, private, and commercial settings (level 1), in contrast to homes and workplaces.

Accordingly, the development of the vehicle-to-grid (V2G) idea was prompted by the need to ease the deployment of large fleets of electric vehicles. Due to battery degradation caused by charging and discharging cycles, electric cars have a restricted operating lifespan; thus, bidirectional communication is essential to the V2G concept. In studies that don't specifically mention electric vehicles, this highlights the concept's shortcomings and calls for additional research.

8. CONCLUSION

Distributed generation that makes use of electric vehicles (EVs) to boost renewable energy sources improves grid stability, sustainability, and energy economics. Electric vehicles (EVs) can help reduce our reliance on fossil fuels by efficiently storing and using excess energy from renewable sources like wind and solar.

Electric vehicles may now store energy while in route thanks to vehicle-to-grid (V2G) technologies and novel charging ways. This way, they can take advantage of times when demand is low and feed electricity into the system when demand is high. A reduction in carbon emissions is made possible through this partnership, which improves energy reliability while lowering costs for utilities and consumers.

Infrastructure construction, grid integration, and obtaining regulatory permission are critical challenges that must be addressed to assure the project's successful completion. To keep supply and demand in balance, you need demand-response systems, energy management systems that work in real time, and advanced optimization methods. To bring about the full potential of renewable energy and electric vehicles, legislators, utilities, and electric vehicle manufacturers must work together to build intelligent networks. If we want to live in a world where everyone can easily switch to renewable energy sources, we must continue to invest in cutting-edge research and develop these technologies.

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