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EXPLORING CHARGING-DISPATCH APPROACHES AND VEHICLE-TO-GRID TECHNOLOGIES FOR ELECTRIC VEHICLES IN DISTRIBUTION NETWORKS

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Abstract - Various electric vehicle charging and discharging strategies (EVs) and V2G technologies are discussed in this article as their impacts on energy distribution networks. The V2G application that can be used on vehicles offers many benefits, as demonstrated. Features such as active power regulation, reactive power support, load balancing, and current harmonic filtering are incorporated into this technology.Although V2G technology has many benefits, there are also several challenges. These challenges include reduced battery life, communication overhead between EVs and grids, and changes in distribution network infrastructure. The article briefly discusses the effects of electric vehicle penetration levels,charging profiles, and various other aspects of controlled charging and discharging from a performance perspective. This includes over loading, deteriorating power quality, and power loss. A comprehensive analysis of controlled and uncontrolled charging–discharging methods, delayed charging discharging methods, indirect controlled discharging methods, bidirectional charging–discharging methods, and intelligent scheduling is presented in this study. Several challenges and issues regarding electric vehicle applications are discussed from an aggregator's perspective. Analysis shows that Li-ion batteries can be recharged 2000–4000 times, and a mass-produced Li-ion battery costs $200–$500 per kWh.Degradation costs of batteries at 80% discharge depth are estimated to be $130 per MWh at 300 kWh investment cost. 10% of peak capacity could come from PEVs in the 20% range. Around 87.5% of PEVs are properly charged.

***Key Words*:** Electric vehicles(EV),penetration,overloading, Communication,Deteriorating,Degradation.

1.INTRODUCTION

This article delves into various electric vehicle (EV) charging and discharging strategies and Vehicle-to-Grid (V2G) technologies, emphasizing their impacts on energy distribution networks. V2G applications integrated with EVs bring numerous advantages, including active power regulation, reactive power support, load balancing, and current harmonic filtering.Despite these benefits, V2G technology encounters several challenges, including diminished battery longevity, increased communication overhead between EVs and grids, and changes in the distribution network infrastructure. The article briefly explores the consequences of factors such as electric vehicle adoption rates, charging patterns, and controlled charging and discharging in terms of performance, addressing issues like overloading, deteriorating power quality, and power loss.The study provides a thorough examination of various charging and discharging methods, encompassing controlled and uncontrolled approaches, delayed strategies, indirect control methods, bidirectional charging and discharging, and intelligent scheduling. Furthermore, it discusses multiple challenges and concerns pertaining to electric vehicle applications, viewed from an aggregator's perspective.

In the realm of electric vehicles and distribution networks, a comprehensive exploration has been undertaken to investigate the intricacies of charging and dispatch strategies, along with the remarkable innovations in Vehicle-to-Grid (V2G) technologies. This study delves deep into the dynamic world of electric vehicle charging and its interplay with distribution networks, shedding light on the strategies that drive efficient power management.In this pursuit, we unravel the myriad approaches and techniques used to charge electric vehicles and harness their power for the grid. This exploration serves to uncover the potential impacts, challenges, and benefits of integrating electric vehicles into the larger energy distribution ecosystem. Our journey takes us through the fascinating realm of V2G technologies, where electric vehicles play a dual role as consumers and contributors to the grid.By delving into this realm, we aim to gain a profound understanding of how electric vehicles can be harnessed not only as a means of transportation but also as distributed energy resources.

Electric vehicles, once regarded as mere modes of transportation, have metamorphosed into dynamic, mobile energy assets, with the potential to redefine the relationship between consumers and the grid. The orchestrated orchestration of EV charging and dispatch has emerged as a critical puzzle piece in the grand mosaic of energy distribution networks.At its essence, the exploration of charging dispatch strategies represents an intricate dance between supply and demand in the context of energy, often requiring an intricate choreography of time, location, and energy sources. It involves the orchestration of when, where, and how electric vehicles draw energy from the grid, as well as when and how they can contribute surplus power back to it. This delicate ballet is driven by a synthesis of advanced software algorithms, real-time data analytics, and state-of-the-art communication protocols.

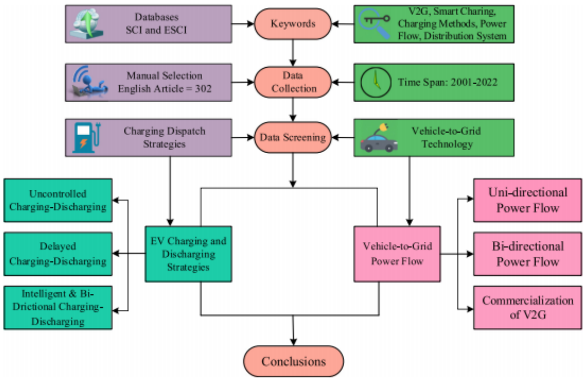

Fig1. A flow diagram showing how the bibliometric review is carried out.[1].

As we delve into the intricate world of charging dispatch strategies, we venture beyond the superficial and venture into the realm of intricate energy management paradigms, where sophisticated algorithms and innovative technologies converge to balance the equation of supply and demand in a rapidly evolving energy landscape. This study embarks on a journey to unravel the complexities of these strategies, providing insights into their applications, challenges, and transformative potential for the electrified future.

2. LITERATURE REVIEW

A Plug-in Hybrid Electric Vehicle (PHEV) draws energy from two distinct sources: fossil fuel and a battery, while a Battery Electric Vehicle (BEV) relies solely on a battery as its energy source. Both of these vehicle types have the capability to interact with the electrical grid, allowing them to recharge their batteries and, when technically feasible, discharge stored energy [9]. Throughout this paper, we will use the term 'EV' to encompass both PHEVs and BEVs.Remarkably, more than 90% of residential, workplace, and public locations are equipped with charging infrastructure for EVs, enabling them to stay connected to the grid for the majority of their operational time [10–13]. Additionally, a statistical analysis conducted by Bhattarai et al. [14] reveals that a substantial portion of vehicle owners (approximately 60%) commute from their homes to workplaces between 6:00 and 9:00 a.m., returning home from 2:00 to 5:00 p.m. Notably, the analysis also indicates that 94% of EVs

remain available for recharging (and discharging when technically supported) throughout the day. This high level of EV availability is corroborated by various studies; for instance, [15] suggests that the likelihood of an EV being parked during daylight hours exceeds 90%, with more than a 50% probability of it being parked at home for the majority of the day.Electric Vehicles, in contrast to Internal Combustion Engine (ICE) vehicles, contribute significantly to reducing CO2 emissions and other harmful pollutants [16–18]. They also diminish noise levels and promote improved urban air quality [17]. Nevertheless, studies like [12,17,19] highlight that when EVs are charged using power generated from conventional sources, particularly coal-based plants, they may produce more CO2 and harmful emissions than traditional ICE vehicles. Hence, for EV adoption to have a positive environmental impact and mitigate harmful emissions, it must be coupled with the integration of Renewable Energy Sources (RES), hydropower plants, and nuclear power facilities.

EVs are equipped with charging systems, which can be unidirectional, meaning they only absorb energy from the power grid [20], or bidirectional, allowing them to both draw and inject energy to and from the grid [21]. Research indicates that coordinated smart charging and discharging of EVs is significantly more efficient than uncoordinated charging, particularly when advanced converters are employed. These optimization techniques result in reduced power losses within the power grid and

lower operational costs for the entire system. Furthermore, various stakeholders, including Parking Lots (PLs), Charging Stations (CSs), Power System Operators (PSOs), and individual EV owners, reap substantial benefits from this coordinated approach [20,21,23–30]. Coordinated charging and discharging mitigate the adverse impact of EVs on the power grid, even at high penetration levels [33]. In contrast, uncoordinated charging may negatively affect the power grid, even with a low penetration level [34]."Vehicle-to-Grid (V2G) technologies have garnered significant attention in the realm of sustainable energy and electric mobility. Kempton and Tomić (2005) laid the foundation for V2G by conceptualizing electric vehicles as potential grid resources. Wu, Ren, Luo, and Cheng (2012) delved into power scheduling and optimization, exploring how V2G systems can effectively balance the demands of electric vehicle charging with grid requirements. Sortomme, El-Sharkawi, and Harris (2012) investigated the economic aspects of V2G, shedding light on the market participation and revenue potentials for EV owners. Kintner-Meyer, Schneider, and Pratt (2007) addressed grid reliability and stability, assessing V2G's capacity to provide essential ancillary services. Han, Sezaki, and Yoshida (2008) examined technical challenges and opportunities, emphasizing the significance of communication protocols and bidirectional power flow control. Lopes, Soares, and Almeida (2007) tackled regulatory and policy considerations, taking into account infrastructure and market frameworks. Feng, You, Hu, and Gu (2013) explored the integration of renewable energy sources with V2G systems to facilitate the grid's transition toward sustainable energy. Savaghebi, Jalilian, Vasquez, Guerrero, and Quintero (2012) focused on control strategies, highlighting the role of power

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electronics. Su, Chen, and Guerrero (2014) delved into cybersecurity aspects, evaluating vulnerabilities and potential threats in bidirectional communication systems. Gomis-Bellmunt, Junyent-Ferré, and Bergas-Jane (2015) examined V2G technologies within microgrid contexts, emphasizing their role in enhancing local energy resilience. This body of research underscores the multidimensional nature of V2G, spanning technical, economic, regulatory, and environmental dimensions, in the pursuit of a sustainable and efficient electric vehicle ecosystem.".

3. METHODOLOGY

The methodology for a study on charging-dispatch strategies and Vehicle-to-Grid (V2G) technologies for electric vehicles in distribution networks involves a structured approach to investigate and analyze various aspects of this complex and multifaceted field. Here's a generalized outline of the methodology:

4.1 Categorizing All Charging Strategies:

Following an extensive review of the existing literature on various charging and discharging strategies, it was apparent that a comprehensive classification of charging methods had not been established in the available literature, to the best of our knowledge. As a result, this paper takes the initiative to categorize all diverse charging techniques into 14 primary strategies, guided by multiple criteria outlined in subsequent sections. Additionally, we introduce novel strategies that hold the potential for future research endeavors. These strategies are grouped into two primary categories: (A) Uncoordinated Strategies and (B) Coordinated Strategies. Detailed comparisons of these strategies, considering both technical and economic facets.

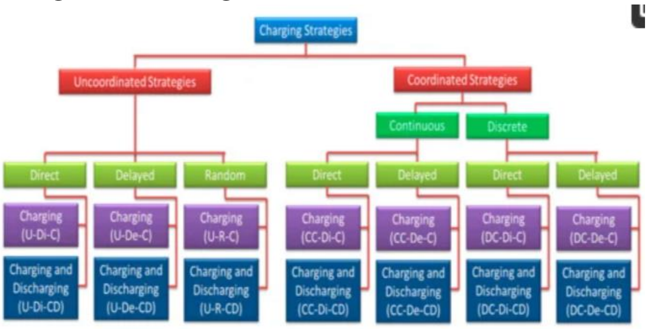

Fig2: Coordinated and Uncoordinated Strategies.[2].

4.1.1Uncoordinated Strategies:

Uncoordinated Strategies (USTs) refer to the charging and discharging processes, also known as modes, for an individual EV or a fleet of EVs. These processes occur in an uncoordinated manner, devoid of predefined schedules, optimization techniques, inter-EV coordination on shared transformers, or adherence to pricing mechanisms. This category encompasses three distinct methods of charging and discharging, along with six principal strategies. The first charging method, labeled "Direct,"involves immediate charging initiation upon plugging in the EV, and it concludes either when the desired State-of-Charge (SOC) level is achieved or when the EV is disconnected. The second method, "Delayed" charging, allows for the postponement of charging to off-peak hours, reducing the overall load congestion during peak periods. The third method, "Random" charging, closely resembles the "Direct" approach but differs in that the plug-in times of EVs on a bus are distributed randomly.

4.1.2Coordinated strategies:

Coordinated Strategies (CSTs) encompass the charging and discharging modes for individual EVs or fleets, conducted in a coordinated manner through scheduling, optimization techniques, potential inter-EV coordination on shared transformers, and adherence to pricing mechanisms. This category consists of two major branches: "Continuous" and "Discrete" Charging Strategies, each comprising two methods of charging and discharging—namely, "Direct" and "Delayed," similar to those discussed previously. In total, it comprises eight distinct strategies.Continuous Charging Strategies involve the uninterrupted charging and discharging of EVs throughout a specific time period, without dividing the charging into separate intervals. This approach is applicable in various settings, including homes, Parking Lots (PLs), and Charging Stations (CSs). In contrast, Discrete Charging Strategies involve segmented charging and discharging during a defined time frame, with the total charging duration divided into intervals (e.g., 5 minutes each). Charging may occur during specific intervals, with other intervals allocated to different EVs. This approach is primarily utilized in PLs, not for individual EVs. CSTs have been a subject of extensive study in recent years, recognized as promising strategies for EV integration. They involve controlled, coordinated, and optimized charging and discharging modes, with the aim of transforming the potential negative impacts of EV penetration into positive contributions to the power grid (PG). Many studies focus on the Grid-to Vehicle (G2V) concept, primarily concerning the charging mode, while others consider both V2G and G2V concepts, involving bidirectional power flow. The primary objectives of these strategies include reducing power losses in the PG, minimizing operational costs, and alleviating peak load conditions. Additionally, there are related concepts, such as Vehicle-to-Vehicle (V2V), Vehicle-to-Home (V2H), and Home-to-Vehicle (H2V), which share similar goals with those of Vehicle-to-Grid (V2G) and G2V modes.

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4.2Vehicle-to-grid system: Why it is needed

Electric vehicles (EVs) possess the capability for bidirectional interaction with the grid, a technology known as Vehicle-to-Grid (V2G). V2G enables vehicles to recharge power from the grid or supply it to a building or local power distribution system. This functionality proves particularly valuable during grid outages resulting from events like natural disasters or unforeseen circumstances. As EVs increasingly integrate V2G capabilities, they become versatile assets for a range of stakeholders, including emergency managers, policymakers, and individuals. In outage situations, these vehicles can serve as backup generators, supplying power to specific structures such as emergency shelters, hospitals, and critical facilities, or even entire neighborhoods. Utilities can also harness V2G technology for backupgeneration during public safety outages, collaborating with partners to address such events.The utilization of mobile energy storage systems enhances infrastructure resilience, supporting planning, preparedness, and emergency response efforts. With the rising frequency of extreme weather events, cyber-security threats, and physical risks to critical infrastructure, the demand for additional power sources to fortify resilience and reliability continues to grow. Notably, the combined capacity of the EV fleet in the United States significantly surpasses that of all-electric power plants. This is especially relevant for electric school buses and other medium- and heavy-duty electric vehicles (MHD EVs) equipped with sizable batteries, operated by fleet managers with predictable routes and usage profiles, and often inactive during adverse weather conditions.Beyond its contribution to infrastructure resilience, integrating electric vehicles with onboard energy storage diminishes the reliance on separate stationary energy storage units and additional diesel generators during emergencies. It also mitigates the need for acquiring distinct backup power sources, reducing the environmental impact of diesel generators and the associated procurement costs.

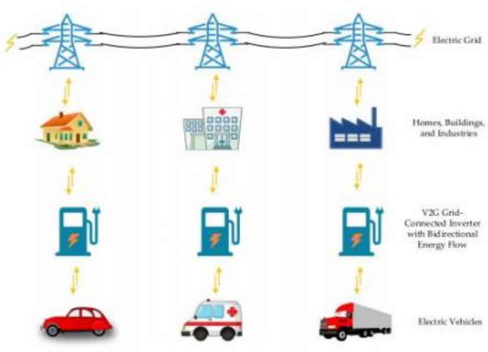

Fig.3 Applications of vehicle-to-grid technology.[1]

4.3 Conceptualization of charging and dispatch strategies for V2G networks:

"Electric vehicle-to-grid technology, also known as car-to-grid, enables electric cars to send the energy they generate back to the power grid through their batteries. This technology allows a car's battery to charge and discharge based on local energy production or consumption signals.Electric vehicles (EVs) can supply electricity to grids, even when they are parked or not in use. The generation of power through vehicle-to-grid technology occurs while the vehicles are in motion. Various types of electric vehicles exist, including fuel-cell cars, battery-electric cars, and plug-in hybrids. To reduce peak energy consumption, battery-electric vehicles can be recharged during periods of lower demand. In electric vehicles, either liquid or gaseous fuel is used to generate electricity.Electric-drive vehicles (EDV) can be operated conventionally or in electric mode with plug-in hybrid technology. Every vehicle requires three components: a network connection for power flow, a logical interface for control with the grid operator, and an onboard instrumentation system for monitoring the vehicle. A companion article provides more information about these components.Generators produce electricity that is supplied to consumers and can be returned to the grid when battery electric vehicles are used. The simplest implementation methods include over-the-air, wireless, direct internet links, and power line carriers. A wide range of vehicles receive electricity from the grid operator. Signals can be sent directly to vehicles or received by fleet operators' offices that manage individual vehicles through distributed power aggregators. An independent parking lot and scheme are available for the signal.Applying vehicle-to-grid (V2G) concepts can enhance electricity grid performance in terms of efficiency, stability, and reliability. V2G vehicles offer benefits like active power regulation, load balancing, monitoring of renewable power, reactive power management, and current harmonic filtering.These technologies provide ancillary services, including voltage and frequency control, spinning reserve, and other ancillary services. V2G's storage capability can accommodate spikes in consumption, preventing outages and compensating for disruptions when switching energy sources.

The ability of many vehicles to interface with the grid (V2G) is essential. A connection to the grid is established, communication with the grid operator is ensured, and appropriate measurements are made. There must be significant information exchange to efficiently transfer power.Unidirectional V2G requires fewer hardware requirements and can be implemented earlier than bidirectional V2G. It is also easier to set up and maintain, with longer-lasting results."

4.4 The vehicle-to-grid system faces numerous challenge:

The implementation of V2G (Vehicle-to-Grid) faces numerous challenges, resulting in several associated costs. For instance, these challenges include battery degradation, infrastructure adjustments, increased communication requirements between electric vehicles (EVs) and the power grid, effects on the distribution network and its parameters, energy losses, and other technical issues.Frequent charging and discharging of batteries can lead to a reduction in battery life and storage capacity. Overcoming these obstacles requires the development of more cost-effective and efficient battery designs, which can be mutually beneficial for both operators and manufacturers. Coordinated efforts between operators and aggregators can help minimize the impact of V2G implementation on the distribution network.

4.4.1Degradation of batteries:

Battery degradation is influenced by discharge depth and cycling frequency, impacting the withdrawal rate of battery energy. Bi-directional ancillary V2G services can have adverse effects on battery life. Predicting battery cycle life can be done using the equivalent series resistance (ESR), which tends to increase more rapidly with deeper discharges in many battery types, leading to faster cell deterioration.Maintaining a middle state of charge (SOC) range is advisable to slow down battery degradation. A novel battery SOC control model and simulation for assessing economic and reliability impacts of SOC limitations were proposed. Intelligent control and optimization can minimize additional degradation by optimizing charging schedules and energy flows. Various battery research projects are currently underway to extend battery cycle life. Reduced investment costs for stored energy are also anticipated.Batteries exhibit varying life cycles depending on their chemical composition and manufacturing processes. Presently, Li-ion batteries are the most promising technology for V2G due to their efficiency, energy density, and long cycle lives. For instance, lithium-ion batteries can be recharged 2,000-4,000 times, with mass-produced Li-ion batteries costing approximately $200-$500 per kWh. Over 3,000 cycles, batteries have an investment cost of $300 per kWh, resulting in estimated degradation costs of $130 per MWh at an 80% discharge depth. Economic losses related to battery degradation were calculated based on lithium cells found in an A123 Systems 16-kWh battery pack, indicating a maximum net annual benefit of $10-$120 when considering battery degradation.Three case studies examined the potential for extending PEV (Plug-in Electric Vehicle) batteries in stationary applications. Used battery packs can be integrated into microgrids to optimize their use. Aggregators create storage contracts for managing frequency regulation and energy sales or purchases on the ISO energy market. The use of PEV batteries in stationary applications proved highly valuable when they were later reutilized.

4.4.2 Impacts of intelligent scheduling and charging on distributed networks:

The effects of charging an electric vehicle (EV) become evident when we understand the standard energy and power requirements for these vehicles. When an EV is connected to a power source, it has the capability to store energy, and conversely, it releases energy when in discharging mode.Electric vehicles primarily serve as a mode of transportation, but they also have the potential to act as fast response loads and contribute power to the distribution network when they are parked and connected to the supply grid, enabling power generation through the grid.Several factors influence the charging behavior of electric vehicles, including:

- The type of connection, which can be unidirectional or bidirectional.

- The presence of multiple vehicles charging within a specific area.

- The geographic location.

- The charging voltage and current levels.

- Battery capacity and status.

- The duration of the charging process.

4.4.3 The load profile of electric vehicles:

Electric vehicles and distributed networks introduce various challenges, making it prudent to prepare for a potential surge in vehicle adoption to avoid undesirable effects on grid operations. A comprehensive examination of the positive and negative impacts on the supply grid is hindered when detailed usage data for each vehicle is lacking.To estimate the total electricity demand from electric vehicles, understanding the timing and energy requirements of each vehicle's charging is crucial. Electric vehicles consume more electricity than they generate, placing stress on the transmission and distribution of power within the grid. An electric vehicle's load profile, measured in Watts per hour, reflects the total electricity it consumes over a specific period. Assessing how distributed networks respond to electric vehicles relies on predicting these charging load profiles.Fast charging, which consumes more than double the energy of an average household, can strain grid and distribution networks. The location of EV charging stations and the charging habits of EV fleets influence the electricity demand on the grid, potentially leading to undesirable peak loads, harmonic issues, and a low power factor on congested distribution networks. Charging during nighttime, as shown in prior research, has minimal impact on the grid, but electrifying vehicles can significantly affect distribution networks due to increased electricity demand.Intelligent planning for electric vehicle charging is essential, as EVs influence the overall load profile of the power system during charging and discharging. Efficient power system operation and EV charging patterns can be achieved through intelligent charging and discharging strategies. The focus of intelligent planning is to optimize load distribution, which can involve charging EV batteries from the distribution networks during periods of low demand and discharging to the grid during high demand. This approach minimizes the strain on the grid's peak load and ensures that EV batteries are charged optimally.Collectively, a group of EVs can shift a substantial portion of the aggregated grid load from peak to non-peak periods by optimizing their charging and discharging patterns. This optimization enhances the grid's capacity to handle the load on distribution networks.

4.4.4 Phase unbalance and voltage instability:

High load requirements are a critical factor in grid voltage stability. The unique characteristics of these loads, such as electric vehicles (EVs), introduce uncertainty in predicting their energy consumption and power demands compared to conventional loads like residential, industrial, and commercial facilities. EVs, in particular, impose a significant power demand when charging their batteries.Single-phase electric vehicle chargers can create phase imbalances within the distribution network. Maintaining these imbalances within acceptable limits is crucial for the overall performance of the distribution system and its connected loads. Research has explored the impact of electric vehicle charging on voltage changes, deviations, and phase imbalances.One study, conducted by the Institute of Electrical and Electronics Engineers (IEEE), examined voltage stability in a 43-bus distribution system and revealed that rapid EV charging has a notable effect on distribution network voltage stability. Another study investigated the effects of uncontrolled charging on voltage deviations over various time intervals and found that voltage deviations often exceeded acceptable limits, especially during peak EV charging periods.Strategies involving stochastic programming were proposed to minimize voltage deviations caused by uncontrolled EV charging. The effects of uncontrolled EV charging were evaluated in urban, suburban, and rural distribution networks, with voltage regulation devices proving necessary in rural networks with long feeders due to observed voltage drops.Further research indicated that uncontrolled EV charging led to voltage deviations in both primary and secondary distribution networks. The extent of these deviations was influenced by factors like the type of EV (Battery Electric Vehicle - BEV or Plug-in Hybrid Electric Vehicle - PHEV) and the charging level (level 1 or level 2). BEVs, with their higher battery capacities, caused more significant voltage fluctuations than PHEVs, and level 2 charging resulted in more pronounced voltage fluctuations compared to level 1 charging.

4.4.5 Levels of penetration and their impact:

The increasing demand for clean energy has led to the growing popularity of electric vehicles (EVs). Assessing the grid's capacity to accommodate the rising EV penetration is of utmost importance. Understanding the standard energy requirements for EVs is a prerequisite to predicting their impact on the distribution network. Therefore, it is essential to determine EV energy and power requirements to assess their effects.As EVs become more prevalent, the grid faces challenges in adapting to their increasing presence. Charging multiple EV batteries simultaneously with varying energy demands presents a demand-side management dilemma.Electric vehicles come with batteries that can be charged at home or in parking lots. When these EVs are connected to the grid, they become electric loads, affecting distribution parameters. The charging process for electric vehicles, as illustrated in Figure 5, exerts additional strain on the existing power transmission and distribution systems.Integrating electric vehicles into the grid raises concerns about penetration levels, particularly when the distribution network experiences congestion. High levels of EV penetration can reduce the reliability of reserve capacity within a system, especially in the absence of Vehicle-to-Grid (V2G) capabilities.The economic impact, CO_2 emissions, and distribution network consequences of the V2G concept are influenced by EV penetration levels and charging/discharging strategies. Unrestricted deployment of EVs can potentially destabilize the electric grid, as highlighted in Figure 6. Figure 6(b) emphasizes the dominance of peak power demand by electric vehicles in total peak requirements. Additionally, as EV penetration increases, the annual electricity energy demand for EVs, as depicted in Figure 6(a), is expected to rise. Higher penetration levels may lead to significant disruptions in distribution networks, depending on charging schemes and power distribution methods.

4.4.6 Distortion caused by harmonics :

Charging electric vehicles (EVs) can introduce power quality issues, primarily due to the use of electronic devices in EV chargers. These chargers inject harmonics into the power grid, which can negatively impact components designed to receive clean sinusoidal waveforms and increase overall system losses.While some studies have suggested that EV chargers have a minor effect on harmonic distortion in the power network, others have reported more significant impacts. For instance, commercial electric vehicle chargers were found to produce at least 0.8% total harmonic distortion (THD) compared to home chargers, as indicated by one study.Uncontrolled rapidcharging can result in an increase in the THD ratio, reaching 11.4%, exceeding established limits. To address this issue, some solutions involve using photovoltaic (PV) inverters as active filters to mitigate harmonics.Different EV models were assessed for total harmonic distortion (THD) when charged with slow or fast chargers. Fast chargers were found to produce higher THD, with estimates suggesting that up to 24% of fast-charging currents exhibit high distortion.Some studies have shown that traditional EV chargers harm voltage quality and current drawn due to high THD. Smart chargers, designed with a unity power factor and sinusoidal current, have been proposed as a solution to reduce THD significantly compared to traditional chargers.Home charging of electric vehicles has been associated with power quality degradation in distribution networks, affecting transformer life. Maintaining acceptable THD levels, generally not exceeding 25-30 percent, is essential for extending transformer life.Studies analyzing the impact of EV chargers' harmonic currents on distribution system capacity have indicated that overloading can occur at certain penetration levels. This emphasizes the importance of implementing filters in EV chargers to reduce harmonics resulting from their integration.In summary, while a few studies suggest that EV chargers have only a minor impact on the distribution network in terms of harmonics, others emphasize the importance of mitigating harmonic distortion through circuit design, charging strategy control, and filter implementation in charger systems to prevent adverse effects on distribution network components, such as transformers and cables.

4.5 . Drawbacks and solutions of vehicle-to-grid technology :

During periods of peak demand, electric grids can be bolstered by fleets of electric vehicles (EVs) equipped with batteries, serving as a means to support and provide power to the grid. The integration of charging and battery-storage solutions is on the rise, repurposing established technologies to realize this vision.The increasing adoption of renewable energy sources is driven by the goal of reducing emissions, as countries strive to transition to cleaner energy sources. To effectively cater to the energy demands of the growing population of EV owners, it becomes crucial to manage the energy requirements resulting from the electrification of vehicles.On average, an electric vehicle consumes roughly the same amount of energy daily to power a typical household as it does to cover a distance of 100 miles. When all these chargers operate simultaneously, it can potentially strain the grid's capacity.

4.5.1 GaN technology allows for faster, more energy-efficient charging :

Wide-band gap technology, exemplified by gallium nitride (GaN), serves as a foundational element for creating more efficient Vehicle-to-Grid (V2G) solutions. A power supply or power management system based on GaN can handle a significant amount of power within the same form factor as traditional silicon devices while offering three times the power density of silicon-based power supplies in electric vehicles (EVs), EV charging stations, and energy storage systems. This translates to the potential for faster charging, smaller designs, and reduced ownership costs.Engineers, utilizing GaN technology, can achieve a threefold increase in power density compared to conventional transistors while concurrently decreasing the size and cost of applications like DC wall boxes. According to David Snook, manager of GaN products at our company, GaN's appeal in these applications lies in its compact size and reduced weight.The adoption of GaN can lead to the creation of smaller and lighter charging stations, allowing grid operators to more efficiently deploy them in various locations and reduce installation costs. Electric vehicle owners can also benefit from the convenience of portable systems, such as DC wall boxes, enabling them to simultaneously recharge their EVs at home and power their residences.

4.5.2 Sensing technology reduces energy consumption:

An essential element of electric vehicle (EV) efficiency lies in the incorporation of sensing technology to facilitate the transfer of energy between EVs and the grid. For effective implementation of voltage and current control loops within power conversion systems, a microcontroller is required, one that is both isolated and capable of swift and accurate voltage and current measurements. Current shunt resistors, along with Analog-to-Digital Converters (ADCs) and isolated amplifiers, play a role in reducing power dissipation, thereby enabling high-resolution measurements and precise power distribution when returning electricity to the grid. With accurate current sensing, battery energy can be efficiently converted into alternating current.Energy efficiency is enhanced when EV owners monitor the "state of charge" of their batteries. Accurate battery monitoring can protect battery cells from permanent damage, potentially extending their lifespan by up to 20%. In cases where EVs are primarily used for commuting and not for other transportation purposes, it may not be necessary to maintain the batteries at a full charge continuously. By combining intelligent sensing technologies within the EV, along with improved accuracy, the EV can potentially notify its owner of the optimal time to return power to the grid or recharge the battery.Safety is a crucial consideration in the development of Vehicle-to-Grid (V2G) solutions, alongside efficiency. EV owners must have confidence that power transfers to and from their EVs will be reliable and consistent. A battery management system, working in conjunction with sensing technology, can monitor the "state of health" of the batteries by tracking voltage and current levels, temperature, and other vital indicators. This battery management system acts as the first line of defense, ensuring that the battery is in good health. If the battery's condition is not optimal, connecting it to the grid can lead to accelerated aging, ultimately affecting the vehicle's driving range.

4.5.3 V2G can be made possible by semiconductor technology:

While some events, like power outages, may be challenging to predict, electric vehicle (EV) drivers can still benefit from semiconductor technology when experiencing home power disruptions. Innovations that support Vehicle-to-Grid (V2G) solutions enable customers to use their car batteries as a backup power source during such incidents.Vehicle-to-Home (V2H) solutions, incorporating solar cells and battery storage systems alongside bidirectional charging between homes and the grid, have the potential to promote the adoption of renewable energy sources.For the successful electrification of vehicles, the necessary infrastructure must be in place, with allthe required technology components seemingly ready from a technical standpoint. Additionally, V2G contributes to better power load management, thereby enhancing efficiency and benefiting the environment.Smart solutions can facilitate EV users in feeding power back into the grid, effectively converting the energy they generate into electricity. Semiconductor technology plays a pivotal role in helping the grid manage the power demands arising from vehicle electrification.

4. RESULTS & DISCUSSIONS:

The study on charging-dispatch strategies and vehicle-to-grid (V2G) technologies for electric vehicles (EVs) in distribution networks provides valuable insights into the integration of EVs into the electrical grid. The results and discussions of this topic can be summarized as follows:

1) Charging-Dispatch Strategies: The study explores various strategies for charging EVs within distribution networks. It discusses the importance of optimizing charging times to manage grid congestion and peak demand periods effectively. Results demonstrate that smart charging solutions, such as time-of-use pricing and demand response programs, can significantly influence charging patterns, reducing the stress on the grid during high-demand periods.

2) Vehicle-to-Grid (V2G) Technologies: The research delves into V2G technologies, which allow EVs to not only consume energy from the grid but also provide power back to the grid when needed. This innovative approach presents opportunities for grid stabilization, demand response, and even revenue generation for EV owners. The study outlines the technical aspects of V2G systems and discusses their potential benefits for grid resilience and cost optimization.

3) Grid Integration Challenges: The study recognizes that while V2G and advanced charging strategies offer numerous advantages, they also present challenges. Grid integration of EVs and V2G systems requires robust communication networks, secure protocols, and interoperability standards. Discussions center on these challenges and the need for a coordinated approach among stakeholders, including utilities, EV manufacturers, and policymakers.

4) Impact on Distribution Networks: The study highlights the impacts of EV charging and V2G on distribution networks. It discusses potential overloads, voltage fluctuations, and the need for grid reinforcement to accommodate the growing EV fleet. Results show that careful planning and investment in grid infrastructure areessential to support the widespread adoption of EVs and V2G technologies.

5) Environmental and Economic Considerations: The research examines the environmental and economic implications of EV integration. It discusses the potential reduction in greenhouse gas emissions through the use of renewable energy sources and the economic benefits of V2G, such as grid services and reduced energy costs.

In conclusion, the results and discussions of the study emphasize the importance of developing effective charging-dispatch strategies and implementing V2G technologies to maximize the benefits of EVs in distribution networks.

5. CONCLUSION

This comprehensive paper delves into the realm of Electric Vehicles (EVs) equipped with Vehicle-to-Grid (V2G) systems and various charging strategies, aiming to dissect the advantages and limitations of V2G technology while evaluating its impacts on distribution networks. V2G technology, when integrated into grid and distribution networks, offers a multitude of benefits in terms of enhanced reliability, efficiency, loss mitigation, and stability. The paper underscores the pivotal requirements, advantages, and challenges associated with V2G implementation. It becomes evident that, with the right power electronics devices, intelligent grid connections, and charger control hardware, electric vehicles can serve as dependable backup energy reserves during power outages. The essential role of smart meters and intelligent EV connectivity and communication with grid operators in ensuring the efficient operation of V2G is emphasized.EVs, while significantly affecting the lives of their owners, hold substantial cost-effectiveness for grid operators and owners. Beyond their core V2G applications, electric vehicles can perform a myriad of other functions, including active and reactive power management, load balancing, current harmonic filtration, and utility cost reduction. These additional capabilities enable the provision of various ancillary services, such as spinning reserves and voltage and frequency regulation. However, alongside these merits, several technical challenges are acknowledged, including concerns related to battery degradation, extensive communication requirements between EVs and the grid, and potential network infrastructure modifications.

The paper also reviews an array of charging strategies, encompassing controlled, uncontrolled, delayed, off-peak, and intelligent scheduling methods. It is evident that coordinating these strategies can lead to optimal charging times and power demand, contributing to the efficient and reliable operation of distribution networks. Smart charging and discharging technologies are recognized as instrumental in reducing energy costs, voltage deviations, and transformer power surges, ultimately
enhancing technical stability and efficiency within the distribution network. Therefore, coordinated charging strategies emerge as the most effective and valuable approach for both EV owners and grid operators.Looking ahead, it is expected that both EV owners and distribution grid operators will closely examine the numerous benefits that electric vehicles bring to the table. The paper introduces novel perspectives on V2G service inspection and outlines charging and discharging planning techniques, where energy trading services on trading platforms are anticipated to play a pivotal role in serving end-user needs and are deemed crucial for future research.The paper concludes with several critical and specific recommendations for advancing and shaping the future research directions of V2G technology development. These encompass establishing V2G strategic plans, increasing fundamental research, addressing social aspects, exploring voltage dip detection and control, investigating the impact of V2G on battery life, and dealing with the operational requirements of high-voltage, high-power, and high-frequency systems. Moreover, the optimization of charging scheduling algorithms and further research into the economic justification of smart chargers are proposed.The insights and recommendations presented in this paper provide a comprehensive foundation for the development and implementation of sophisticated V2G control systems. They serve as a valuable resource for researchers and manufacturers alike, offering a deep understanding of V2G control techniques and applications that can propel the future of V2G technology production and innovation, benefiting both academia and industry.In essence, this research underscores the significance of proactive measures to harness the potential of EVs and V2G technologies in distribution networks. The findings highlight the need for a coordinated approach among stakeholders, including utilities, EV manufacturers, and policymakers, to overcome challenges and maximize the benefits of electric mobility. As we move forward, the successful integration of EVs and V2G holds the promise of enhancing grid resilience, reducing environmental impacts, and providing economic advantages, ultimately contributing to a more sustainable and efficient energy ecosystem.

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