Electric Vehicles and V2G Optimisation: A Comprehensive Review

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ABSTRACT

Electric vehicles represent a significant alternative for mitigating greenhouse gas emissions. Electric vehicles not only decrease reliance on fossil fuels but also mitigate the effects of ozone-depleting compounds and facilitate extensive renewable energy deployment. Despite extensive study on the qualities and characteristics of electric cars and their charging infrastructure, the manufacturing of electric vehicles and network models continues to grow and face limitations. The study presents an overview of the research on the market penetration rates of Electric Vehicles, Hybrid Electric Vehicles, Plug-in Hybrid Electric Vehicles, and Battery Electric Vehicles, and examines their various modeling approaches and optimization strategies. This study uniquely addresses the critical hurdles and inadequate charging infrastructure in a developing country such as India. The emergence of the Vehicle-to-Grid idea has established an additional power source during the unavailability of renewable energy sources. We conclude that the unique qualities of electric vehicles are crucial to their mobility.

Keyword: - *Electric vehicles, Optimization Technique, Hybrid Electric Vehicles, and Battery Electric Vehicles, Vehicle mobility and plug-in hybrid electric vehicles (PHEV)*

1. INTRODUCTION

Electric cars represent a significant alternative for mitigating greenhouse gas emissions. Electric cars not only decrease reliance on fossil fuels but also mitigate the effects of ozone-depleting compounds and facilitate extensive renewable energy deployment. Despite extensive study on the qualities and characteristics of electric cars and their charging infrastructure, the manufacturing of electric vehicles and network models continues to grow and face limitations. The study presents an overview of the research on the market penetration rates of Electric Vehicles, Hybrid Electric Vehicles, Plug-in Hybrid Electric Vehicles, and Battery Electric Vehicles, and examines their various modeling approaches and optimization strategies. This study uniquely addresses the critical hurdles and inadequate charging infrastructure in a developing country such as India. The emergence of the Vehicle-to-Grid idea has established an additional power source during the unavailability of renewable energy sources. We conclude that the unique qualities of electric vehicles are crucial to their mobility.

An electric car can serve as a flexible load to stabilize the grid amid a significant proportion of variable renewable energy production. The proprietors of the electric car lack participation in the electrical market owing to the minimal impact of each individual transaction [6]. Certain scholars [7–12] examined a prevailing methodology for estimating contemporary smart policies, which were predetermined for varying situations and are exogenous. To maximize the potential of an electric vehicle, flexible load management and intelligent charging procedures must be used. A further research by [13] indicated that EV users coordinated to communicate their time and energy requirements to the aggregator. The timing requirement specifies the deadline for completing a charging operation, while the battery level addresses the energy demand. A comparable research done by [14] suggested that a decentralized framework and a central organization should deliver pricing signals to electric car users, anticipating an overlap between the centralized and decentralized frameworks. An electric car can serve as a flexible load to stabilize the grid with a significant proportion of variable renewable energy production. The proprietors of the electric car lack participation in the electrical market owing to the minimal impact of each individual transaction [6]. Certain scholars [7–12] examined a prevailing methodology for estimating contemporary smart policies that were predetermined for varying situations and are exogenous. To maximize the potential of an electric vehicle, flexible load management and intelligent charging procedures must be used. A further research by [13] indicated that EV customers coordinated with the aggregator on scheduling and energy requirements. The timing requirement specifies the deadline for completing a charging operation, while the battery level addresses the energy demand. A comparable research by [14] suggested that a decentralized framework, together with a central body, should deliver pricing signals to electric car owners, anticipating an overlap between the centralized and decentralized frameworks.

Brady and Mahoney (2016) examined the stochastic modeling methods for electric vehicles to create a dynamic trip itinerary and charging profile for their propulsion in real-world scenarios. They determined that an improvement in the conditions of parking time distribution would enhance both the accuracy of the parking time distribution and the overall accuracy of the model. Morrissey et al., 2016 [16] examined electric car users and found that they favour charging their vehicles at home during peak electricity consumption in the evening. Foley et al. (2013) examined the effects of electric vehicle charging during peak and off-peak periods within a comprehensive energy market in Ireland, concluding that peak charging is disadvantageous relative to off-peak charging. Doucette and McCulloch (2011) conducted a research on battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV) to ascertain their carbon dioxide emission levels and compared the findings with CO2 emissions from the Ford Focus. Steinhilber et al. (2013) examined the fundamental tools and methods for implementing new technology and innovation by investigating significant impediments to electric vehicles in two nations. Yu et al. (2012) proposed a driving pattern recognition method for assessing the driving range of electric vehicles utilising a trip segment partitioning algorithm. Hayes et al. (2011) examined various driving situations and terrains by developing a vehicle model. Salah et al. (2015) examined the effect of electric vehicle charging on Swiss distribution substations and discovered that elevated penetration levels and dynamic tariffs heighten the danger of overloads in some areas. The parameters are thereafter compared with one another based on their range type. The influence of different classifications of electric vehicle charging methodologies on the national grid and storage utilisation has been examined by [22–26], who investigated model-based non-linear observers for estimating the torque of permanent magnet synchronous motors in hybrid electric vehicles.

2. OVERVIEW OF ELECTRIC VEHICLES

The objective of the electric vehicle is to substitute an internal combustion engine with an electric motor, which is energised by the energy stored in batteries via a power electronic traction inverter. The electric motor utilises 90–95% of input energy to propel the vehicle, rendering it very efficient. The essential components of an electric vehicle are the battery, charging port, charger, DC/DC converter, power electronics controller, regenerative braking system, and driving system.The electric motor serves to convert electrical energy stored in batteries into power for the electric vehicle[2]. Electric vehicles become environmentally benign as they are powered by low-emission energy sources. The cells are powered by the electrical grid. The primary role of the battery is to supply electricity to the electric vehicle rendering it operational.

Electric vehicles predominantly utilise lithium-ion batteries due to their superior efficiency, lightweight nature, and little maintenance requirements compared to other cells. The production of these Li-ion batteries is somewhat more costly than that of nickel-metal hydride and lead-acid batteries. Li-ion batteries have a lifespan of 8 to 12 years, contingent upon environmental conditions and maintenance schedules. The charging port is the interface that enables the vehicle to connect to an external power supply system via a charger to replenish the battery[3].The charger functions by converting AC supply from the power source via a charge port into DC power for battery charging. It further monitors the voltage, current, temperature, and state of charge of the battery during the charging process.

The DC/DC converter transforms high-voltage direct current from the batteries into low-voltage direct current to power the vehicle's accessories. The power electronics controller regulates the speed of the traction motor and torque by overseeing the flow of electrical energy from the traction battery. Regenerative braking is crucial for sustaining vehicle power and enhancing energy efficiency. This braking technique utilises the motor's mechanical energy to transform kinetic energy into electrical energy, which is then returned to the battery. Regenerative braking improves the range of electric vehicles, leading to its widespread use in all hybrid and battery electric vehicle types. The electric motor produces forward propulsion as the vehicle advances, and when the brakes are engaged, it may recharge the batteries, a process referred to as regenerative braking[4]. It may recuperate 15% of expended energy during acceleration. As an effective component, it cannot fully recharge the electric car. The function of the drive system is to produce motion by converting mechanical energy into the traction wheel. The electric car features several internal configurations based on component utilisation and does not need a traditional gearbox. For instance, certain designs utilises many smaller motors designed to power each wheel independently. Conversely, a substantial electric motor is likely connected to the back wheels via a differential housing. The electric vehicle employs far simpler components than those found in a gasoline-powered engine. However, electric vehicles do not achieve significantly higher speeds than gasoline-powered cars.

3. ELECTRIC VEHICLE LANDSCAPE IN INDIA

The electric vehicle market in India is now minimal. The sale of electric automobiles has stagnated at 2000 units annually for the past two years [5]. There exists a vision for the sale of 100% electric vehicles by 2030, and given that we are currently in 2020, the compound annual growth rate is 28.12%. India's inaugural electric vehicle, the Reva (Mahindra), was launched in 2001, and since its introduction, it has managed to sell a limited number of vehicles. In 2010, Toyota introduced the Prius hybrid vehicle, succeeded by the Camry hybrid in 2013. Electric buses and hybrid cars have been initiated as a trial program in many cities.The Bangalore Municipal transit Corporation has just launched electric transit along a congested route in the city. A poll conducted in Ludhiana city revealed that 36% of current automobile and two-wheeler owners expressed a willingness to transition to electric vehicles [6].

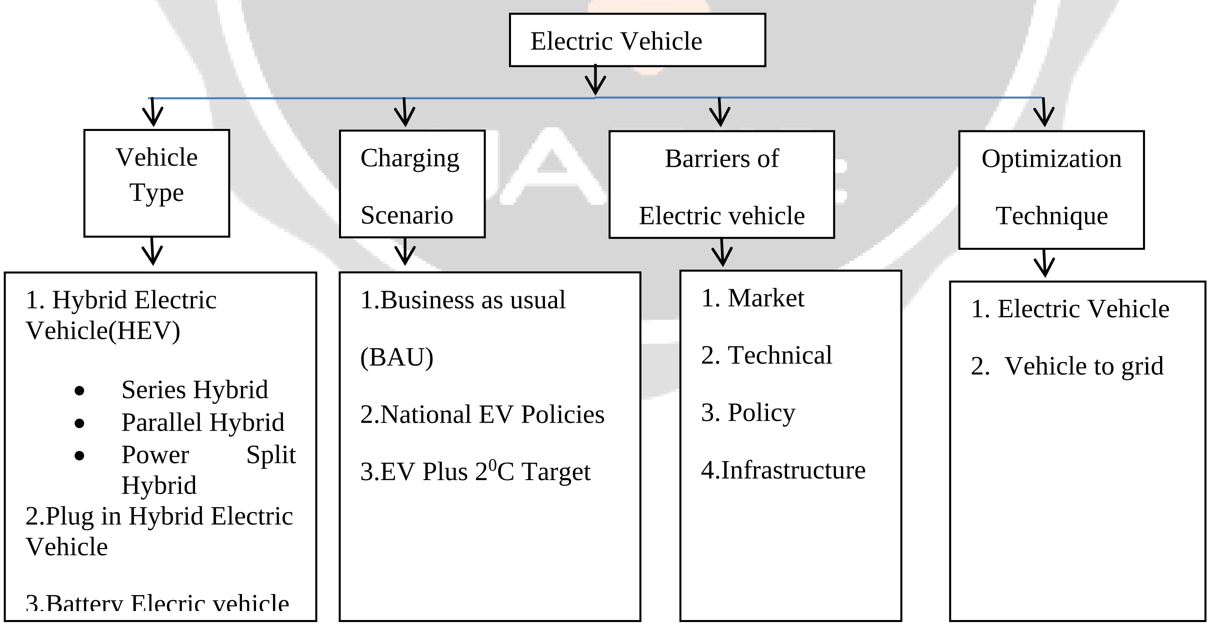

Figure 1: Overview of Electric Vehicle

The Telangana state government is promoting the use of electric vehicles (EVs) and has declared that EV owners would be exempt from road tax. In 2018, the Telangana State Electricity Regulatory Commission (TSERC) sanctioned a charging fee of INR 6 for electric vehicles (EVs). The TSERC established the service fee for the whole state at INR 6.04 per kWh[7]. The Hyderabad Metro Rail has established a cooperation with Power Grid Corporation of India Ltd to implement electric vehicle charging facilities at metro stations. The Hyderabad metro rail will be the first metro system in the nation to have electric vehicle charging stations that will be supervised and managed by the power grid. The Hyderabad Government is considering substituting diesel-powered public transport vehicles with electric ones. This year, the New Delhi government received authority to establish 131 public charging stations in the capital. In November 2018, the Delhi Government published a draft strategy aimed at converting 25% of its vehicles to electric vehicles by providing different incentives and establishing charging infrastructure in both residential and non-residential sectors[8]. This strategy aims to provide a charging outlet every 3 km by providing a 100% subsidy (up to INR 30,000) and exempting electric vehicles from road tax, parking fees, and registration taxes by 2023. A private firm, Magenta Power, is establishing EV charging infrastructure on the Mumbai-Pune route.

3.1. Framework for Acquiring Electric Vehicles in India

The Central Government and state governments have initiated numerous plans and incentives to advance electric mobility in India.The following schemes are enumerated below. The National Electric Mobility Mission Plan (NEMMP) 2020 was announced by the Government of India to improve national energy security, reduce the detrimental impact of fossil fuel-powered cars on the environment, and foster local manufacturing capabilities (GoI, 2012). The NEMMP 2020 has the potential to facilitate the sale of 6–7 million electric cars, hence enabling a reduction of 2.2–2.5 million tonnes of fossil fuel use. Vehicular and CO2 emissions could be reduced to 1.3–1.5% in 2020 due to this new approach. This strategy anticipates the deployment of 5–7 million electric vehicles by the conclusion of 2020. It underscores the significance of governmental incentives and collaboration between business and academics[9]. The Government of India is arranging for 100 GW of solar power generation by 2022, which might enhance the dependability and utilisation of renewable energy beneficial for electric vehicle charging stations.

The Government of India has initiated the Faster Adoption and Manufacturing of Electric Vehicles (FAME II) scheme to facilitate the accelerated adoption of electric and hybrid vehicles. This initiative promotes the acquisition of electric vehicles by offering several incentives and establishing charging infrastructure. In February 2019, the cabinet approved 10,000 crore for the implementation of FAME II, effective from April 1, 2019, for a duration of three years[10]. The electric vehicle manufacturers are keenly anticipating the implementation of this singular policy plan to provide a comprehensive roadmap for the electric vehicle ecosystem, including charging infrastructure and manufacturing incentives. NITI Aayog's 2017 transformational mobility study delineates a path for the adoption of pure electric cars, prompted by advancements in EV technology and the imperative to mitigate energy consumption in the automotive sector. If India implements a transformational solution for shared connected electric mobility, achieving 100% electric public transport vehicles and 40% electric private automobiles, it might become entirely electric by 2030.This idea must be disseminated to ensure the proliferation of electric cars in the near future. The Society of Indian Automobile Manufacturers (SIAM), in conjunction with other automobile manufacturers, aims to achieve the sale of one hundred percent pure electric cars (battery electric and fuel cell vehicles) for intra-city public transport fleets by 2030.According to this plan, i) 40% of new electric vehicle sales are anticipated to be available by 2030, and ii) 60% of new electric vehicle sales are projected to utilise environmentally friendly technologies such as hybrids and other alternative fuels by 2030[11]. To guarantee the seamless operation of the initiative, the government, industry, and various stakeholders must unite and invest in a long-term strategy to achieve a fully electric car system.

4. OBSTACLES FOR ELECTRIC VEHICLES IN THE INDIAN MARKET

Obstacles for electric vehicles in the Indian market may be examined from several perspectives, including technical limitations, legislative constraints, and insufficient infrastructure. These are seen in Fig. 2.

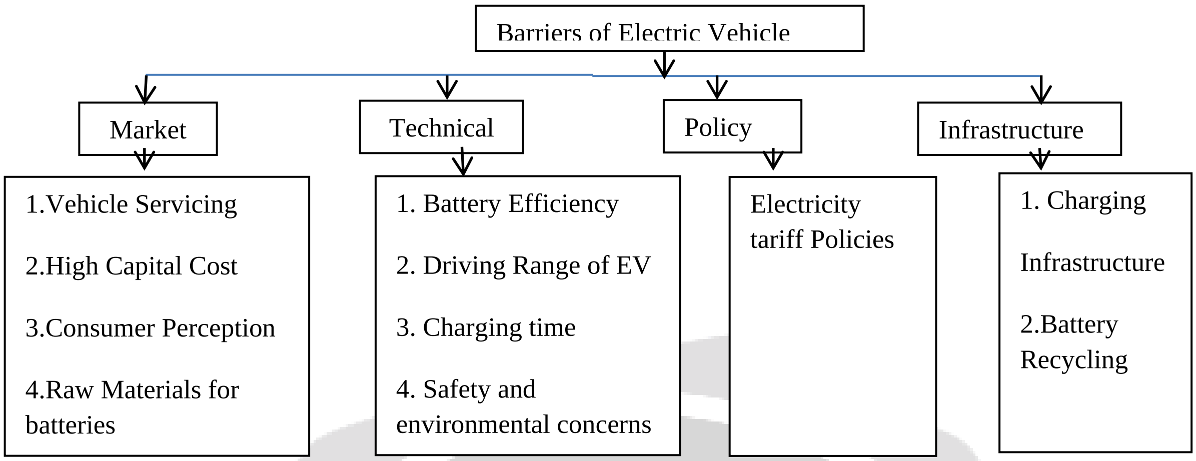

Figure 2: Various Types of barriers in Electric Vehicle

4.1. Market

4.1.1. Maintenance of Vehicles

To adequately care for the electric vehicle, a qualified technician should be accessible for repairs, maintenance, and troubleshooting [12]. They must be capable of utilising their expertise to resolve the issue expeditiously.

4.1.2. Elevated capital expenditure

The battery packs of an electric car are costly and require replacement many times over their lifespan. Gas-powered automobiles are less expensive in comparison to electric ones[13].

4.1.3. Consumer Perception

Consumer impression is crucial for gaining new customers and retaining existing ones. Despite the expanding diversity in the automotive industry including an increased selection of electric vehicles, the options for purchasing an electric car remain constrained and are anticipated to persist in this manner throughout time[14]. Thus, the firm should ensure that customers are informed of its services through advertising, social media, or alternative channels. Research indicates that insufficient understanding regarding government initiatives, economic advantages, and awareness of vehicular technology might directly affect the adoption of electric vehicles.

4.1.4. Materials for Battery Production

The basic ingredients for EV batteries comprise lithium, nickel, phosphate, manganese, graphite, and cobalt, which are classified as rare earth elements. Aluminium, copper, and steel are necessary for an internal combustion engine. Catalysts for combustion vehicles require platinum, rhodium, and palladium to filter toxic gases[15]. All of them are scarce materials, and their availability may be insufficient for battery manufacture. Lithium-ion batteries alone utilise 5 million tonnes per year of nickel, potentially resulting in a 10 to 20-fold increase in the consumption of lithium and cobalt in the future.

4.2. Technical

4.2.1. Battery Longevity/Efficiency

Electric automobiles are typically constructed utilising electric motors, batteries, chargers, and controls, substituting the fuel tank and gasoline engine of a traditional vehicle. Although EV batteries are engineered for longevity, they inevitably degrade over time[16]. At present, the majority of manufacturers provide an eight-year or 100,000-mile guarantee for their batteries.

4.2.2. Range of Electric Vehicle

The driving range is acknowledged as the primary limitation of electric vehicles, since EVs possess a shorter range compared to their internal combustion engine counterparts. The range of an electric car on a full charge or tank is regarded as a substantial impediment to its adoption. Electric vehicles in the worldwide marketplace. Most battery electric vehicles (BEVs) provide a driving range of under 250 km per charge. Nonetheless, certain recent versions can provide up to 400 km [17]. Currently, PHEVs provide a range of 500 km or greater owing to the use of liquid fuel internal combustion engines. The motorist must meticulously organise their journey and may lack the opportunity for a long-distance excursion. This establishes the extent of driving range as an obstacle.

4.2.3. Duration of Charging

The duration of charging is intricately linked to the concern of driving range. Utilising a slow charger, the electric vehicle may require up to 8 hours to get a complete charge from an empty condition when employing a 7 kW charging port. The charging duration primarily relies on the battery's capacity. The larger the automobile battery, the longer the duration required to recharge it from a depleted to a fully charged condition. The battery's charging duration is directly influenced by the charging rate of the charge station. The higher the charging price of the charge point, the shorter the time required for the battery to get a full charge. In the present context, quick chargers are employed to expedite the car charging process, hence minimising the needed duration[18]. Commercially available electric vehicles are compatible with charging stations that possess a greater maximum charge rate than their capacity allows. This signifies that the battery can be charged at a maximum pace it can accommodate without any malfunction. Nonetheless, the charging rate of the battery using a quick charger diminishes with a decrease in temperature or in cold conditions. The EV chargers are classified based on the pace at which they recharge their batteries. There are three primary types of EV charging: Level 1, Level 2, and DC rapid charging. Level 1 charging employs a conventional 120 V outlet, converting AC to DC using an onboard converter. The electric vehicle requires 8 hours to charge using 120 V outlets, providing a range of around 120 to 130 km. Level 1 pricing primarily occurs at residential or occupational locations[19]. Level 2 chargers are generally installed in public locations or workplaces and require a 240 V outlet for charging. The battery requires 4 hours to charge, providing a range of 120 to 130 km. In DC fast charging, the conversion from AC to DC takes place at the charging station equipped with the most rapid charging configurations. This enables stations to provide increased power, facilitating faster car charging. The battery may be charged in 30 minutes for a range of 145 km.

4.2.4. Safety Specifications for Electric Vehicles

The electric vehicle must comply with the safety standards established by state or municipal regulations. The batteries must comply with testing standards that account for situations such as overcharging, temperature variations, short circuits, fire impact, vibration, humidity, and water immersion[20]. The design of these vehicles must have safety measures for collision detection, short circuit prevention, and insulation from high voltage lines.

4.2.5. Environmental Impact

Electric cars typically do not contribute to environmental pollution; nevertheless, the materials for their batteries are sourced from mining operations or desert brine. This extraction exhibits little environmental impact on mining.

4.3. Policy

The Government of India intends to subsidise electric car charging infrastructure to accelerate the nation's electric vehicle revolution[21]. The Ministry of Power has recently clarified that operating an EV charging station in India does not require a licence, which may enhance the nationwide EV charging station infrastructure. The government should not only reduce the relevant rate of Goods and Services Tax (GST) on lithium-ion batteries and offer incentives and discounts to electric car purchasers, but also give incentives for transitioning the public transport sector to electric vehicles.

4.4. Infrastructure

4.4.1. Charging Infrastructure

Increased charging infrastructure is necessary to accommodate a greater number of electric vehicles, resulting in elevated needs for electrical energy. The absence of adequate charging infrastructure in India results in poor electric car sales. Electric vehicle manufacturers should value charging batteries from a design perspective to ensure that discharged batteries may be substituted with fully charged ones. During off-peak hours, at a lower power tariff, the charging station may schedule battery recharge. An option for establishing a home charging station for this car should be available, as individuals will need to start their day by charging their electric vehicle at their dwelling. In the absence of residential charging infrastructure, individuals would prefer to charge their vehicles at their office or at an appropriate charging station where they must pause for two to three hours or longer[22]. Locations like as residences and workplaces are optimal for slow charging, whereas highways and business complexes, where vehicles stop for brief periods, are more suited for fast charging. It should be emphasised that for quick charging of 30 minutes or less, the electric vehicle must be capable of accepting high current, high voltage, or both. This will not only elevate the expense of the electric vehicle but also adversely affect the battery's lifespan.A mix of slow and rapid chargers may be the optimal solution for electric vehicles.

4.4.2. Battery Reclamation

The batteries utilised in electric cars are typically designed for a finite lifespan, ultimately succumbing to wear over time. The manufacturers inadequately communicate the pricing for battery replacement; yet, if a replacement is necessary beyond the warranty term, the costs increase due to the disposal of the old battery alongside the acquisition of a new one[23]. The chemical constituents in batteries, such as Lithium, Nickel, Cobalt, Manganese, and Titanium, enhance the cost-effectiveness of the supply chain, but also raise environmental concerns during the disposal of battery components.

5. OPTIMISATION TECHNIQUE

5.1. Implementation of Optimisation Techniques for Electric Vehicles

This article characterises the charging needs of electric vehicles across multiple frameworks in distinct geographical areas. The framework comprises the Random Utility Model, Activity-Based Equilibrium Scheduling, Driving Pattern Recognition, Stochastic Model, Trip Prediction Model, Probabilistic Model, Fuzzy-Based Model, Data Mining Model, Forecasting Model, Distributed Optimisation, Hybrid Particle Swarm Optimisation, Ant Colony Optimisation, Household Activity Pattern, Particle Swarm Optimisation, Linear Programming, and Multi-

Objective Adaptive Model, which are summarised below. The objective of this study was to examine the possible advantages of the charging characteristics of all electric vehicles (EVs)[24]. Numerous research done globally by various authors to identify the optimisation techniques for Electric Vehicles.

5.2. Vehicle-to-Grid Technology

The V2G idea was initially allows the parked electric vehicle to transmit electrical power to the grid via a bi-directional charger, enabling it to either give electricity to the grid or recharge its battery. The influence of bidirectional charging of Li-ion cells on cell performance has been hypothesised in V2G and Grid to Vehicle contexts [25].An overview of the utilisation of energy storage technology in the planning and operation of a distribution system is provided by [26-30]. They examined the battery technology and policy associated with V2G technology. They presented a system for managing battery degradation, applicable for prolonging the lifespan of batteries utilised in electric vehicles. Kester et al. (2018) conducted a comparative analysis across Nordic nations examining how several specialists in electric mobility duplicate policy recommendations for vehicle-to-grid (V2G) and electric vehicles (EVs). Dubarry et al. (2017) conducted an experimental investigation on the degradation of Li-ion batteries resulting from V2G operation.

They also discovered the effect of bi-directional charging on optimising the profitability of electric vehicle users through the utilisation of commercial lithium-ion batteries. A further research conducted by [27] employed an empirical model to assess the practicality of V2G, factoring in energy costs and battery longevity concerning deterioration. Habib et al. (2015) conducted a comparative study of electric vehicle charging strategies and vehicle-to-grid technologies to assess their effects on the power distribution network. They also asserted that the charging strategy and vehicle aggressiveness might render V2G technology commercially viable.The V2G system has various advantages; nevertheless, a growth in the number of PEVs may directly affect the dynamics of the power distribution system and its performance due to the overloading of transformers, cables, and feeders. This diminishes effectiveness, necessitates more generator starts, and induces voltage deviation and harmonics [26-30]. The Vehicle-to-Grid charging method is illustrated in **Fig. 3.**

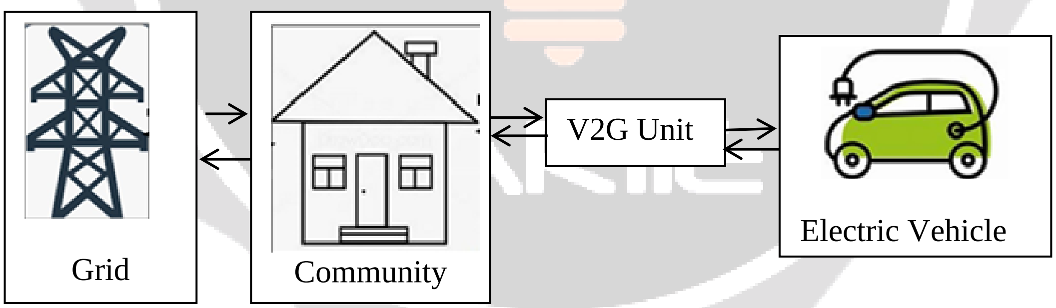

Figure 3. Vehicle to Grid Charging

5.3Implementation of Optimisation Technique for Vehicle-to-Grid (V2G)

Diverse control techniques are suggested for the best performance of V2G. A multitude of academics worldwide have examined the issues associated with V2G and various optimisation strategies.Tulpule et al., 2013 [30] conducted a feasibility study in a workplace parking lot in Columbus, Ohio, and Los Angeles, California, comparing it to residential charging systems for carbon dioxide emissions and associated costs. A comparable research conducted by [31] also evaluated the parking lot in the USA, NJ, and New Jersey, utilising a straightforward methodology to ascertain the driving requirements that solar power might fulfil in summer but not in winter. Numerous academics have examined EV fleets at various city or regional levels. A research conducted in the Kansai Area, Japan, integrated 1 million electric vehicles with 1 million heat pumps to mitigate an excess of solar electricity by 3 TWh using a smart charging approach.

6. CONCLUSIONS

Hybrid, Plug-in Hybrid, and Electric automobiles enhance fuel efficiency; nonetheless, they incur a higher purchase cost compared to conventional automobiles. Their reduced gasoline use and enhanced productivity provide economic advantages to consumers, society, automakers, and politicians over time. This article presents a comprehensive review of the research, as well as guidelines for studying the penetration rates of HEV, PHEV, and BEV in the Indian market. The latest measures and diverse incentives from the Indian Government would facilitate the advancement of e-mobility in India. The advancement of a novel Vehicle-to-Grid idea can either supply electricity to the grid or facilitate battery charging when renewable energy sources are unavailable. This technology is a crucial element of energy security, renewable energy, and addressing global warming challenges. This study summarises the limitations and challenges faced by electric vehicles in the Indian environment, which is its primary originality.

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