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REVIEW

# A Study on Challenges in Adoption of Electric Vehicle and Vehicle-to-Grid Technologies in India

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**ABSTRACT**

A viable remedy for lowering hazardous greenhouse gas emissions and carbon footprint is through the adoption of electric vehicles (EVs). Electric vehicles minimize fossil fuel reliance and ozone-damaging compounds by supporting large-scale renewable deployment. However, EV modeling and manufacturing are continuing to change despite extensive study on the qualities and characteristics that are evaluated from time to time. This is due to restrictions on EV adoption and their charging infrastructure. The present study addresses the numerous modeling approaches and optimization strategies used in studies of EV, hybrid, plug-in hybrid, battery, and fuel cell EV penetration and adoption rates in the market. The study is unique for a developing country like India in that it addresses crucial challenges in adoption and the lack of charging facilities for EV consumers. In addition, when renewable energy sources are unavailable, the development and deployment of the vehicle-to-grid concept is an innovative strategy to provide auxiliary supply to the grid. It is concluded that considering the unique features of EVs is vital to their adoption and mobility.

**Index Terms—**Carbon footprint, electric vehicles, optimization strategies, renewable deployment, vehicle to the grid

## I. INTRODUCTION

The automobile sector in India is modeling and manufacturing electric vehicles (EVs) at a rapid pace. People are substantially opting for EVs. The significant adoption of EVs tends to contribute to energy security, enhance air quality, and improve economic opportunity in the country. The government of India recognized the necessity to investigate viable mobility options to minimize dependency on energy sources imported, lower greenhouse gas emissions, and reduce the effect of global warming through effective compensation. Carbon dioxide ($CO_2$) emissions can be lowered by implementing preventative actions to avoid catastrophic climate change, which poses a threat to the planet's biodiversity. The major attempts are to use fossil fuels as low as possible for the production of power and transportation and to conserve energy. Electric vehicles are an alternative source to internal combustion engines (ICE) for transportation. Electric vehicles can reduce $CO_2$ emissions significantly [1].

Despite EVs' introduction, people are yet dependent on fossil fuel-powered ICEs. Electric vehicles, on the other hand, face significant challenges compared to conventional vehicles in terms of driving range, charging, and life cycle assessment (LCA). Electric vehicle production produces 59% more $CO_2$ than production. Based on tank-to-wheel, LCA increases up to 170–180 g/km $CO_2$ emissions from the ICE. Estimation of the average $CO_2$ emissions of a vehicle is measured over its entire life cycle, rather than over a single vehicle. Depending on the power source used to manufacture and drive, the overall $CO_2$ emissions over its lifetime can vary significantly [2].

A growing number of automakers are concerned about transporta tion-related pollution and are making significant investments in EV technology. India's adoption of EVs could be boosted by several factors including technological advancement, lower vehicle costs, government policy support, incentives for vehicle purchases, parking benefits, and good public charging infrastructure. There is a negligible amount of EVs in the Indian market because of low production. Electric vehicles can be classified into the following:

1) four-wheelers (electric cars);
2) three-wheelers (E-rickshaws); and
3) two-wheelers (E-bikes).

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During the early 2000s, an Indian company launched “The Reva,” an EV that aims to produce affordable cars using innovative technology. Later, several automobile companies showed their interest in EV modeling and manufacturing. Figure 1 illustrates the evolution of EVs in India in various automobile industries [3].

Amounting to 3.2 billion metric tons of $CO_2$ equivalent, India’s greenhouse gas emissions in 2014 accounted for 6.55% of global emissions. Following the manufacturing, energy sector, land utilization, forestry, and agriculture waste account for 19.6% of India’s greenhouse gas emissions, while waste contributes only 1.9%. India’s $CO_2$ emissions in 2020 were 2411.7 million metric tons. Over the last 50 years, India’s $CO_2$ emissions have increased significantly, from 214.7 to 2411.7 million metric tons per year, reaching a peak of 11.40% in 2009 and then falling to −5.93%t in 2020 [4,5].

An EV can be employed as an adjustable load to assist grid normalization if it generates a considerable amount of stochastic renewable energy [6]. Due to single and low-power operations, the owners of EVs do not have a transaction in the power market [7]. Several authors have proposed existing practices for estimating current smart policies that are exogenous and have designed in advance for changing scenarios. Flexible load and clever charging procedures must be implemented to fully realize an EV’s potential [8-13]. In another study, it is found that EV user’s planning and operation information has been offered to the aggregator in terms of energy usage, and the timeliness requirement specifies how quickly a charging procedure must be finished, whereas the energy need is supported by the battery level [14]. According to a similar study, a decentralized structure and a central organization will deliver the pricing indication to EV owners, with the centralized and decentralized structures expected to overlap [15].

**Main Points**

- This study provides an overview of the hurdles and constraints of an electric vehicle (EV) in the Indian scenario (as the EV industry grows, the emphasis should shift from intervention to real adoption. It is also vital to analyze the gap between purpose and actual conduct).
- The present study’s key research need is consumer awareness and abilities for assessing and estimating the economic benefit and cost of EVs.
- This study aims to determine the necessary procedures, obstacles, and problems of operating a battery-powered car in a developing nation like India.
- This study figures out why EVs have not gotten much traction in India.
- One of the goals of this study is to raise awareness in India about the benefits of battery-powered automobiles over traditional fossil fuel vehicles.
- This study also intends to investigate the various government efforts aimed at encouraging electric and hybrid vehicles.
- Future directions of research on how to best educate customers might have complications for policymakers and marketers seeking to understand the financial benefits and costs of EVs.

In 2016, an investigation was conducted on EV’s stochastic simulation approach for producing a dynamic trip itinerary and charging profile for EV propulsion in a realistic scenario. Later, they determined that if the circumstances of distribution in parking time were modified, the distribution accuracy of parking time, and the model’s complete accuracy, would improve [16].

A survey has been conducted on the charging behavior of EV owners, and it is found that the owners are preferring to charge their vehicles during peak demand times at home [17]. In Ireland, an investigation has been conducted to check the effectiveness and harmful effects of charging EVs during peak and off-peak hours, and it is noticed that charging during peak hours is more harmful than during off-peak hours [18]. For introducing new and innovative technologies, investigation of critical impediments to an EV in two nations is a necessary tool and strategy [19,20]. In [21], authors developed recognition of driving pattern strategy to calculate the trip portion of EVs’ driving range using segmentation method. A vehicle model has been built to evaluate various driving circumstances and topographies in [22].

In [23], authors investigated the influence of EVs on Swiss distribution substations and observed that dynamic tariffs and greater integration levels increase the danger of overloading in specific zones. The range type of these parameters is then used to compare them to one another. Model-based non-linear observers were used to estimate the torque of a permanent magnet synchronous motor for hybrid EVs and to investigate the impact of various charging methods for EVs’ storage utilization on the national grid as presented in [24-26]. In [27,28], authors have developed the maximum transmissible torque approach to enhance the implementation of the torque control context and the permanence of EVs.

An overview of important difficulties in the management of Li-ion batteries in an EV was presented and issues such as cell voltage, state estimate, uniformity, stabilization, and battery fault analysis may give impetus for the battery management system research and design [29].

In the literature, several authors have investigated optimal modeling of energy management systems with suitable techniques for EVs. The major communication between the grid and EVs is through charging and discharging. The three diverse ways of EV interaction with the grid are grid-to-vehicle (G2V), vehicle-to-building (V2B), and vehicle-to-grid (V2G). In G2V, the grid provides a charging facility for EV, and in V2G, it is discharged to the grid. It is important to control V2G at regular intervals due to the electrical energy bidirectional flow between the vehicle and the grid. The V2G system refers to the integration of EVs into the electrical grid. The electrical energy will be stored in a portable battery, and it can be transferred from the stored source to the building in V2B [30,31].

The major contribution of this study is as follows:

1. It provides an overview of the hurdles and constraints of an EV in the Indian scenario (as the EV industry grows, the emphasis

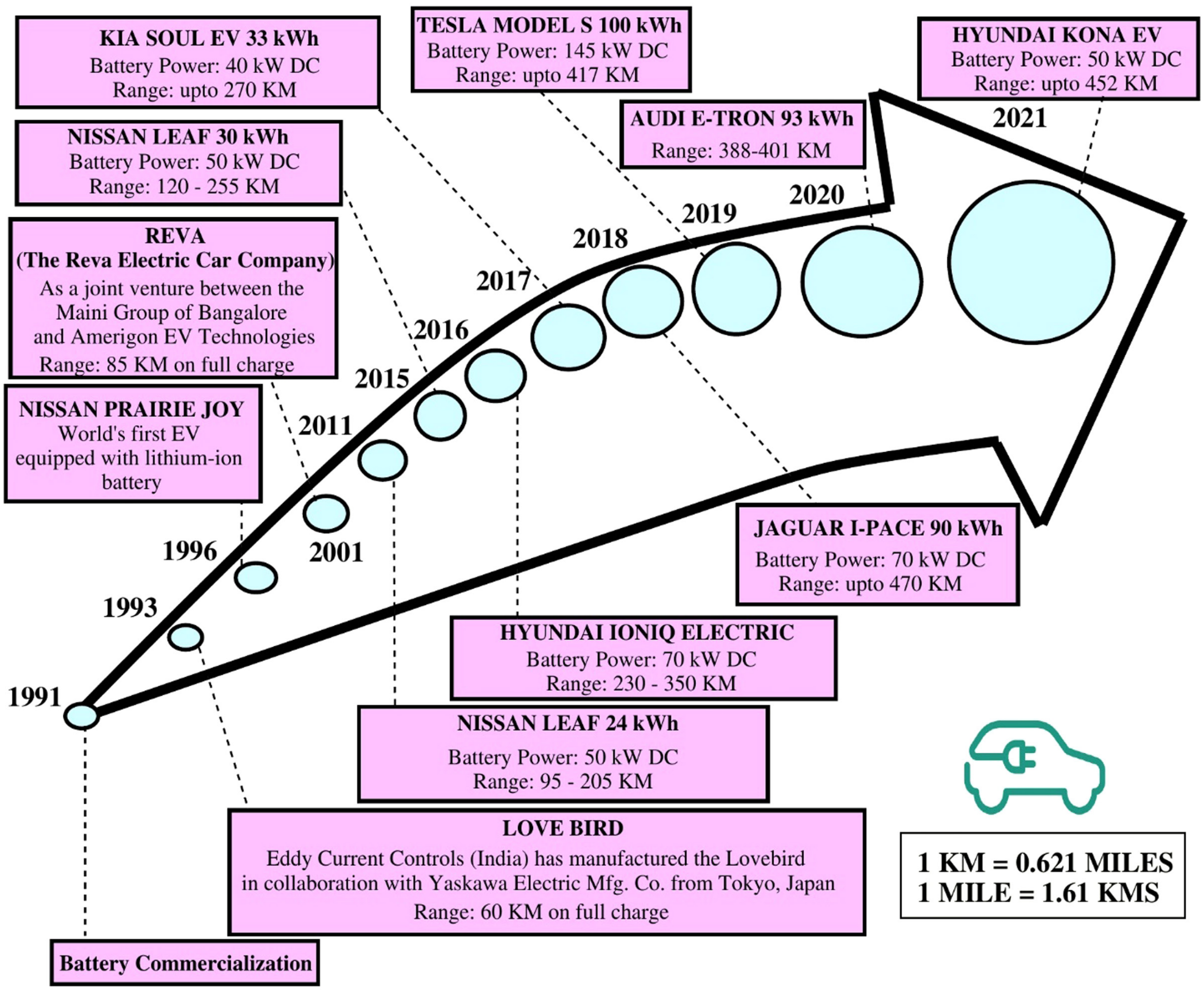


**Fig. 1.** Evolution of the electric vehicle in India.

should shift from intervention to real adoption. It is also vital to analyze the gap between purpose and actual conduct).

2. The present study's key research need is consumer awareness and abilities for assessing and estimating the economic benefit and cost of EVs.
3. This study aims to determine the necessary procedures, obstacles, and problems of operating a battery-powered car in a developing nation like India.
4. This study figures out why EVs have not gotten much traction in India.
5. One of the goals of this study is to raise awareness in India about the benefits of battery-powered automobiles over traditional fossil fuel vehicles.
6. This study also intends to investigate the various government efforts aimed at encouraging electric and hybrid vehicles.
7. Future directions of research on how to best educate customers might have complications for policymakers and marketers seeking to understand the financial benefits and costs of EVs.

Currently, there are various classes of EVs that are now on the market throughout the world. Apart from this, the major contribution of the present paper is the identification of the EV market's challenges and adoption in India. Table I summarizes the various optimization approaches that are covered. Figure 2 illustrates the complete overview of EVs.

The present study is divided into several sections, including Section II provides an overview of all forms of EV configurations, followed by Section III the scenario of EVs in India, and Section IV's The Indian market's barriers to EVs. The EV and V2G optimization approach is provided in Section V, followed by the conclusion and future directions in Section VI.

## II. OVERVIEW OF ELECTRIC VEHICLE

The main goal of the EV is to replace ICE with a motor that is powered through stored electrical energy (i.e., driven by a battery) via a power electronic traction inverter. The vehicle is powered by an

**TABLE I.**
SUMMARY OF DEVELOPMENTS AND PROCESSES IN VARIOUS ELECTRIC VEHICLE TECHNOLOGIES

| Author(s) [Reference] | Location and Country | Optimization Approach | Specific Contributions | Year |
|---|---|---|---|---|
| Qiang et al. [32] | China | Adaptive algorithm | 1. In a hybrid electric vehicle (HEV), to estimate the battery's residual energy and its state of charge, an adaptive algorithm has been employed.<br>2. This algorithm's accuracy, noise resistance, and stability make it ideal forHEV applications. | 2008 |
| Bradley and Frank [33] | United States | Structured optimization | 1. Consideration of fundamental design principles for the plug-in electric vehicle (PHEV).<br>2. The trade-off between energy storage and efficiency, battery management system, the role of drive train components, and grid connections are all described. | 2009 |
| Hajimiragh et al. [34] | Ontario, Canada | Heuristic optimization | 1. An optimization model is built based on the zonal layout of Ontario's electricity transmission network's baseload generating capacity from 2009 to 2025.<br>2. Maximum PHEV penetration levels in the transportation division are determined to determine the practicality of off-peak hours PHEVs charging. | 2010 |
| Peterson et al. [35] | USA cities | Transaction optimization | 1. The economics of employing PHEVs with vehicular batteries to store energy generated during off-peak hours for usage during peak hours are examined.<br>2. The greatest annual benefit is between $142 and $249 in three US locations with no expense for battery deterioration. | 2010 |
| Darabi and Ferdowsi [36] | United States | Heuristic method | The load profile of PHEV charging is discussed, as well as rules for three charging situations in the United States is proposed. | 2011 |
| Zoenf et al. [37] | NA | Mixed logic model | The charging procedure after PHEV travels was modeled using a random coefficient mixed logic model. | 2013 |
| Weis et al. [38] | United States | Mixed-integer linear programming (MILP) | Based on the New York independent system operator, the MILP model is developed to calculate capacity development, plant dispatch, and PHEV charging. | 2014 |
| Villalobos et al. [39] | Borup, Denmark | The weighted sum method and fuzzy control | 1. A multi-objective smart charging algorithm has been described for PHEV.<br>2. This novel technique benefits stakeholders by facilitating the integration of PHEVs into a low voltage distribution network. | 2016 |
| Reddy and Sudhakar [40] | India | A radial basis function network (RBFN) method | 1. The suggested neural network maximum power point tracking (MPPT) controller tracks the proton exchange membrane fuel cell's (PEMFC) maximum power point using the RBFN method. direct current (DC) to DC converters with a high switching frequency and a high voltage gain is required for the propulsion of fuel cell electric vehicle (FCEV).<br>2. A three-phase high voltage-gain interleaved boost converter is also created for the FCEV system to achieve high voltage gain. Interleaving minimizes the ripple in the input current and voltage stress on the power semiconductor devices. The FCEV system's performance is compared to that of the fuzzy logic controller using an RBFN-based MPPT controller. | 2017 |
| Jyotheeswara Reddy and Sudhakar [41] | India | RBFN method | 1. A high-step-up three-phase interleaved boost converter is intended to decrease the current ripples exiting the PEMFC. The interleaving approach maximizes the power capabilities of the power semiconductor devices while minimizing the voltage stress on them.<br>2. The suggested RBFN MPPT controller's performance is investigated in MATLAB/Simulink for both standalone and grid-connected PEMFC systems. | 2018 |
| Reddy and Sudhakar [42] | India | RBFN method | 1. For fuel cells, the RBFN-based MPPT controller technique is developed, while for solar photovoltaic (PV), a fuzzy logic controller is employed to extract the maximum power at various PEMFC temperatures and solar irradiation levels.<br>2. A high step-up DC–DC boost converter is used to give a high step-up voltage for the fuel cell. | 2018 |

(*Continued*)

**TABLE I.**
SUMMARY OF DEVELOPMENTS AND PROCESSES IN VARIOUS ELECTRIC VEHICLE TECHNOLOGIES (*CONTINUED*)

| Author(s) [Reference] | Location and Country | Optimization Approach | Specific Contributions | Year |
|---|---|---|---|---|
| Reddy and Sudhakar [43] | India | Adaptive neuro-fuzzy inference system (ANFIS) | 1. A maximum power point tracking controller based on an adaptive neuro-fuzzy inference system is given for a 1.26-kW PEMFC system utilized in electric car applications.<br>2. The suggested controller's performance is evaluated under normal operating settings as well as under conditions of abrupt changes in the fuel cell's cell temperature. | 2019 |
| K Kumar et al. [44] | India | ANFIS | 1. The performance of a 1.26-kW fuel cell-powered electric car system is evaluated using a modified quadratic boost converter and a neural network-based MPPT algorithm.<br>2. Acceptance of EVs in contemporary society is critical for the construction of a pollution-free environment. | 2020 |

electric motor that utilizes 90–95% of the input energy, making it extremely efficient. The charger, charging port, battery, power electronics controller, DC/DC converter, drive system, and regenerative braking are the main components of an EV. The role of an electric motor is to power the EV by utilizing the stored electrical energy in batteries. The nature of EVs is eco-friendly since low-emission power sources are utilized to recharge them. The power grid is used to charge the cells. The main purpose of the battery is to give electricity to the EV to move. Lithium-ion batteries (LIBs) are used in most EVs because they are more efficient than other cells and have less maintenance. When compared to nickel-metal hydride (NiMH) and lead-acid (Pb acid) batteries, LIBs are a bit expensive to manufacture. The lifetime of the LIBs depends on the climate and maintenance schedule.

An external power source is used to charge the battery through a charging port. The charger must absorb AC power from an electrical source and convert it to DC, which is then used to charge the battery through a charge connection. It maintains track of the battery's voltage, current, temperature, and state of charge (SoC) during charging. The DC/DC chopper is used for powering the vehicles' accessories through the conversion of the high DC voltage from the battery into low DC voltage. The controller of power electronics components is used to regulate the torque–speed characteristics.

When the car travels ahead, the electric motor provides forward momentum. The braking energy gained due to the sudden application of brakes is utilized for battery charging. This process is called regenerative braking (RB). Regenerative braking is critical for preserving vehicle power and attaining increased efficiency. This method of braking leverages the motor's mechanical energy to convert kinetic energy into electrical energy. This electrical energy is utilized to charge the battery. Because RB extends the EV range, which is used frequently in hybrid and battery electric vehicles, it can reclaim 15%

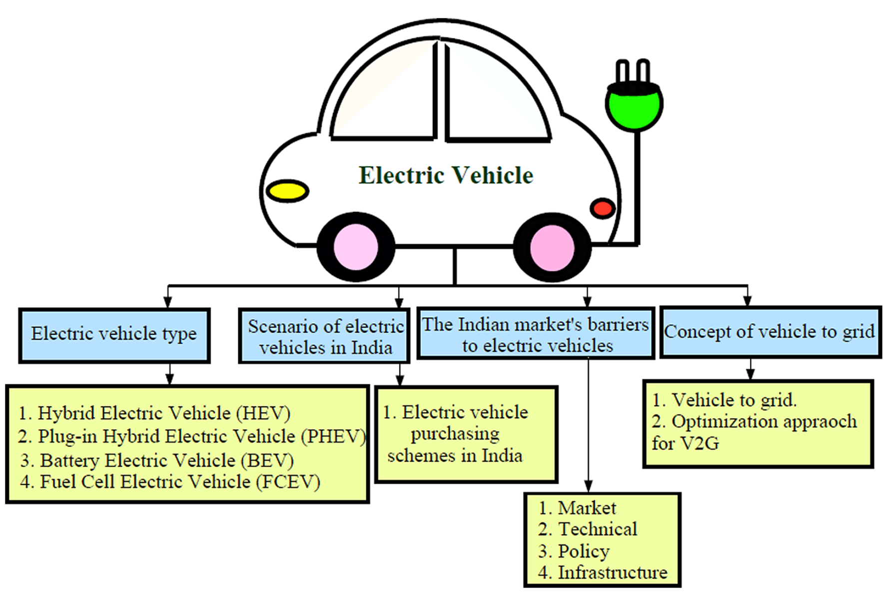


**Fig. 2.** Electric vehicle overview.

of the energy it has consumed for acceleration. However, it is unable to fully recharge the EV.

The drive system's job is to get things moving by delivering mechanical energy to the traction wheel. The electric car has many internal layouts based on the components used and does not need a traditional gearbox. Some designs, for example, employ many tiny motors to power each wheel separately. A huge electric motor, on the other hand, might be linked to the back wheels through differential housing. Compared to components of ICE, an EV's components are modest. Electric vehicles, on the other hand, would not be able to go as fast as ICE vehicles.

**A. Electric Vehicle Types**

Even though EVs are manufactured in various countries, China, the United Kingdom, the United States, and Germany account for most EV sales. Globally, the electric vehicle industry is exploding. There are four types of EVs available in the current market as illustrated in Fig. 3.

**1) Hybrid Electric Vehicle**

The hybrid electric vehicle (HEV) is a combination of an electric motor and ICE. The batteries can be charged by the energy generated by the engine when a vehicle is decelerating and brakes are applied. Due to combining an ICE with a motor as a power converter, they are now referred to as HEV. This technology is being used all over the world because of its several benefits, including the ability to provide modern performance without relying on infrastructure for charging. They reduce fuel usage by engine electrification. The HEV can be associated with numerous topologies depending on the diversity of hybrid systems. The three varieties are parallel, series, and power-split hybrid. In a series hybrid, the only power source for the wheel is the electric motor. The motor is powered by either the generator or the battery.

An ICE is used to charge the batteries. The computer has the capability of deciding and identifying power from the engine/generator or the battery. Both regenerative braking and engine/generator are used to power the battery pack. Series HEVs often have a wider battery pack and bigger motors, as well as a small ICE. They are helped by ultracapacitors to enhance the battery's efficiency, and, as a result, the loss will be reduced. They gain from a series hybrid drive train because the electric motor's perfect torque–speed characteristics reduce the need for a multi-gear gearbox, and mechanical separation among the drive wheels and the ICE enables the ICE to function in its limited optimum area.

There are some significant disadvantages to series HEVs as follows: 1) because of dual-energy conversion, the complete efficacy will be minimized, from mechanical to electrical, and vice versa; and 2) two electric machines with a large traction motor are needed to drive the wheel due to sole torque source. Since they have enough capacity for their big engine/generator combination, HEVs are commonly utilized in buses and commercial and military vehicles.

When compared to a series HEV drivetrain, the engine in a parallel HEV is linked to the wheels. Due to reduced losses and low flexibility in the mutual aligning of the mechanisms of the powertrain, the wheel is powered by the engine. Individual parallel HEVs or groups of

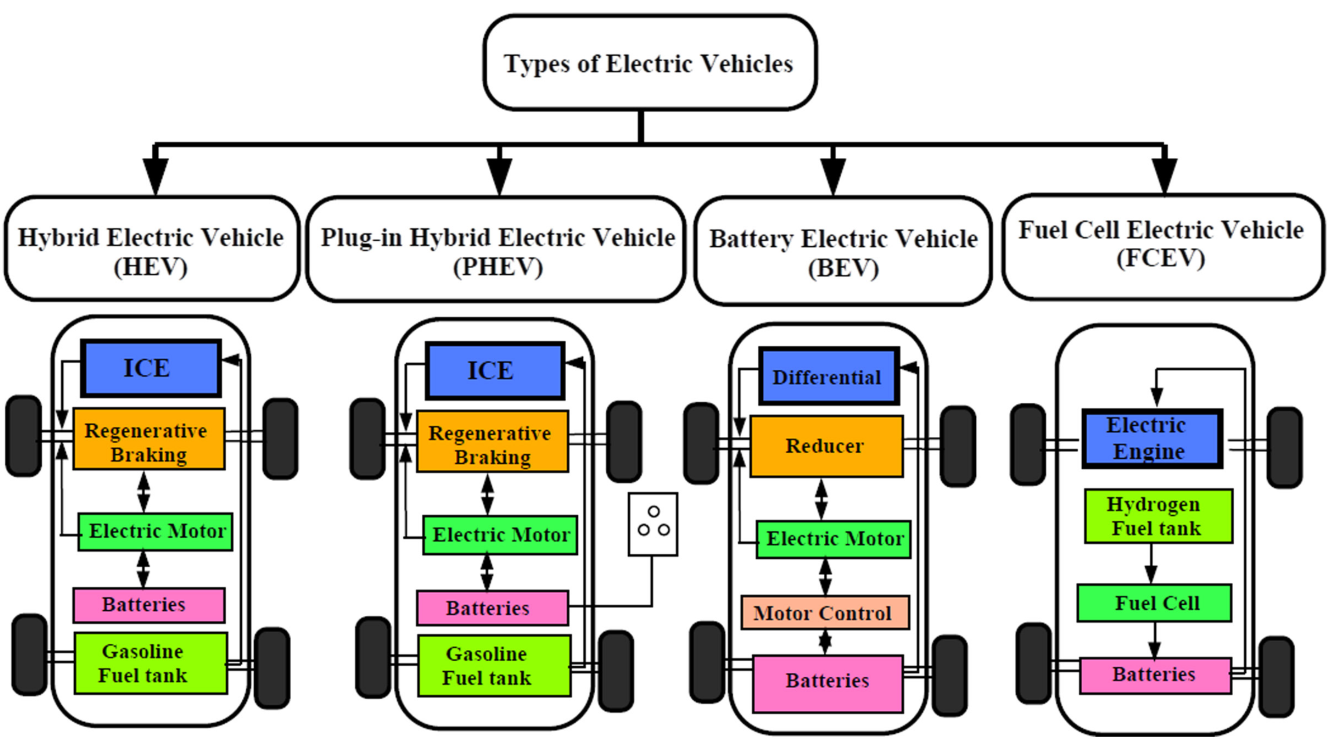


**Fig. 3.** Types of electric vehicles.

parallel HEVs can run the vehicle. It usually features a modest battery that is replenished using RB.

A planetary gearbox is used to link the engine, generator, and motor to a transmission in a power-split hybrid system. In a single frame, they can be placed in both series and parallel arrangements. The vehicle may be powered by the battery and the engine separately or jointly, and the battery can be charged at the same time by the engine. The power provided to the wheel is determined by the torque and speed of each element. To get the most out of your engine, adjust the speed and load. Figure 4 depicts the parallel HEV power flow.

**2) Plug-In Hybrid Electric Vehicle**

An ICE and an electric motor are combined in plug-in hybrid EV (PHEV). These vehicles run on gasoline and utilize electricity to charge many equipped rechargeable battery packs (RBPs). The following are some of the advantages of PHEVs:

1) The use of petroleum is reduced.
2) A PHEV consumes 30–60% less oil than a regular car.
3). Plug-in hybrids lessen oil reliance by generating power from domestic sources.
4) Emission of greenhouse gases PHEVs, on average, release fewer greenhouse gases than conventional vehicles.
5) The amount of gas emitted, on the other hand, is determined by how power is generated.

Nuclear and hydroelectric plants are more environmentally friendly compared to coal-based plants. Each will have a stipulated time duration to recharge. It is noticed that an EV can take several hours to recharge utilizing a 120-V household plug. However, it will only take 1–4 h for recharging with a 240-V charger. Also, it was observed that 30 min is enough to have a quick charge capacity of up to 80%. It is not necessary to plug in a PHEV. Gasoline can be used as fuel in PHEVs. However, they would not achieve fuel economy or maximum range if they are not charged. Calculating the fuel efficiency for combined city/highway travel, the environmental protection agency gives fuel economy estimates for gasoline only. However, a PHEV can run on gasoline, electricity, or a mix.

In 2015, China created the world's largest solar-powered EV charging station, capable of charging 80 EVs per day. It also conducted a preliminary study in Shanghai to see how well EVs can integrate renewable energy sources into the electric grid.

In 2015, solar-powered EV charging stations were started in Japan. As of December 2020, the top five countries selling EVs are China, the United States, Germany, Norway, and France [45]. Several new models have been announced by manufacturers, all of which are expected to be offered at a reasonable cost in the next years. Plug-in EVs have emerged as one of the most promising avenues for reducing $CO_2$ emissions and reducing reliance on fossil fuels. Hybrid EVs have been the subject of several investigations across the world. For instance, an agent-based method has been employed in [46].

Whereas in 2013, authors have used micro-simulation for PHEVs based on technological restrictions and individual goals [47]. China built a feed-forward model in 2013 to examine the best energy management technique for a heavy-duty parallel HEV and determined

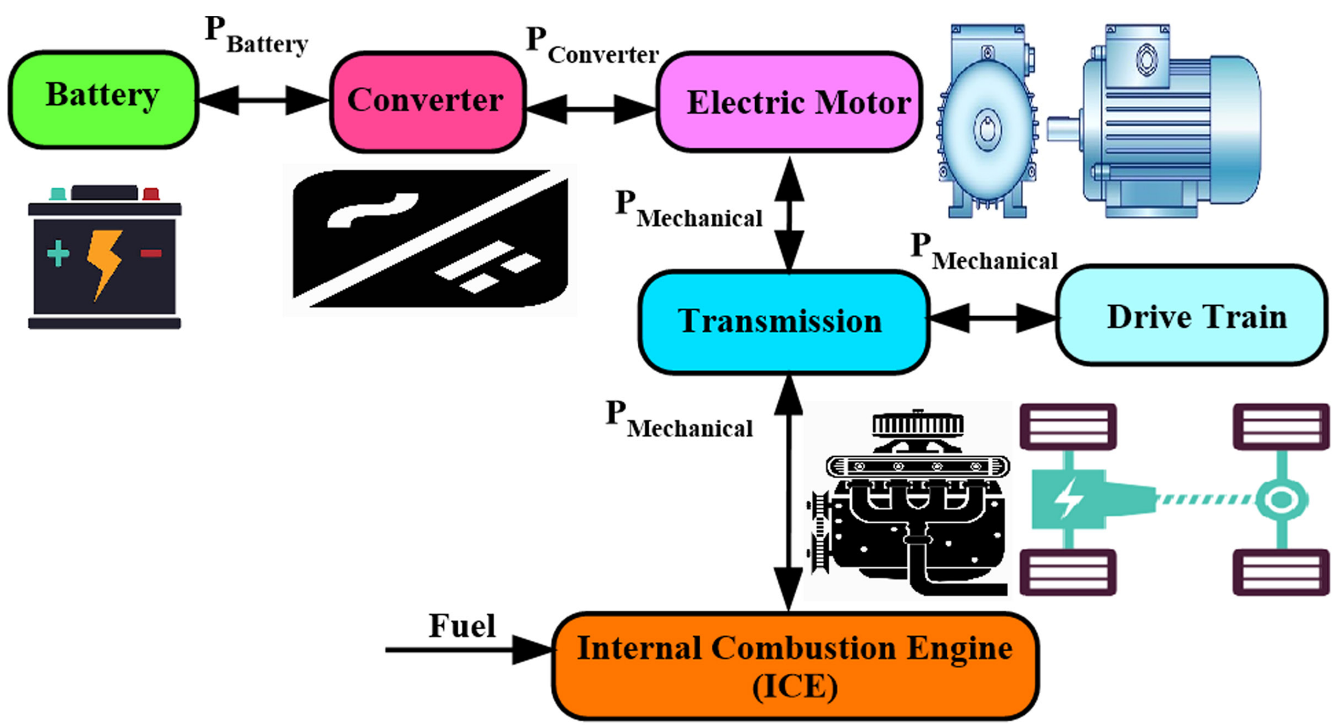


**Fig. 4.** The parallel hybrid electric vehicle power flow.

that the dynamic programming (DP) method enhances the hybrid electric truck's mileage [48]. Another study conducted in China in 2017 has found that convex programming (CP) derived from an optimum control method has an incredible closeness to DP, which is having 200 times quicker possible runs.

In [49], authors have implemented a novel CP to minimize the daily operational expense of a PHEV, in which optimal cost-control strategy has been built that flawlessly mixes the costs of the various tasks and a sensitivity evaluation optimization outcome is performed concerning price changes of battery and energy carriers. From this, it is noticed that the 0.85$ daily cost is significantly lower than the heuristics PHEV scenarios.

In 2016, authors from Chengdu, China, attempted similar work using a stochastic DP problem to optimize the distribution between the grid, household power consumption, and PHEV batteries [50]. A similar study in China was carried out in 2016, and it has been discovered that when fuel cell service life improves, the capacity option may be more convenient and the cost of the life cycle can be reduced. Their solution outperformed the current one by 1.4% recognition of the use of a 10-Ah LIB. The life cycle cost of small and big capacity LIB was greater [51]. Many researchers have reported the evolution of the trends, barriers, and economic viability of PHEVs globally and their influence on a distribution system.

**3) Battery Electric Vehicle**

A battery EV (BEV) is named a complete EV. Battery EVs have RBPs of high capacity (i.e., Ah) which are powered by an external power source. A BEV does not contain ICE.

Battery EV is the sole source of power supply to its motor and the internal electronics. This power is from the stored energy of RBPs. The BEV has the potential to reduce the emission of $CO_2$ from the ICE vehicles and the dependence on fossil fuels. Battery EVs are believed to have the greatest market share in India, accounting for more than 70% of commerce in 2017 and likely to increase in the following years. Though BEVs outsold PHEVs in several countries until 2014, PHEV sales have increased dramatically in the last 2 years, and they are now equal to BEV sales. Lead-acid batteries, NiMH batteries, and LIBs are the three types of batteries commonly used in the Indian market [52].

In India, Uttar Pradesh had the greatest amount of EV sales in 2021. In Uttar Pradesh, a total of 255 700 EVs have been registered as of December 2021. For the last few years, EV use has been expanding across India. National wise 870 141 EVs have been registered as of December 2021. It is noticed that due to the pandemic, the enhanced use of personal vehicles has led to increased demand for India's EV boom. In India, top EV selling states are Uttar Pradesh, Delhi, and Karnataka with the most EV registrations followed by Delhi with 125,347 units and Karnataka with 72,544 units. Bihar, with 58,014 EVs, and Maharashtra, with 52,506 EVs, came in fourth and fifth place, respectively, among the top five states. To accelerate the adoption and manufacturing of EVs in India, the federal government launched the Faster Adoption and Manufacturing of Electric Vehicles in India (FAME India) initiative in 2015. In April 2019, the government reintroduced FAME II for 5 years with a budgeted allocation of Rs. 10 000 crores. Additionally, the national government decreased the Goods and Service Tax (GST) on electric vehicles from 12% to 5%. Additionally, the GST on charging infrastructure was cut to encourage the construction of EV charging stations. Several state governments have also launched their EV policies to encourage the purchase of EVs. Not only have state governments increased demand but they have also provided subsidies and incentives to EV manufacturers and charging infrastructure providers to establish a comprehensive ecosystem for EVs. These reasons have contributed significantly to the increase in EV sales in India. Additionally, the skyrocketing prices of gasoline and diesel, as well as the availability of a diverse selection of electric vehicles, are boosting demand for BEVs in India [53]. Figure 5 illustrates the regional-wise EV registered between 2020 and 2021 in Indian states [54,55]. In [56], a two-step approach that first separates lane transport and their corresponding needs into an order of groups naturally and autonomously then optimizes the station assignment to the demand cluster using linear programming is suggested. This research might be valuable for city planning and constructing a BEV refueling infrastructure in a densely populated location.

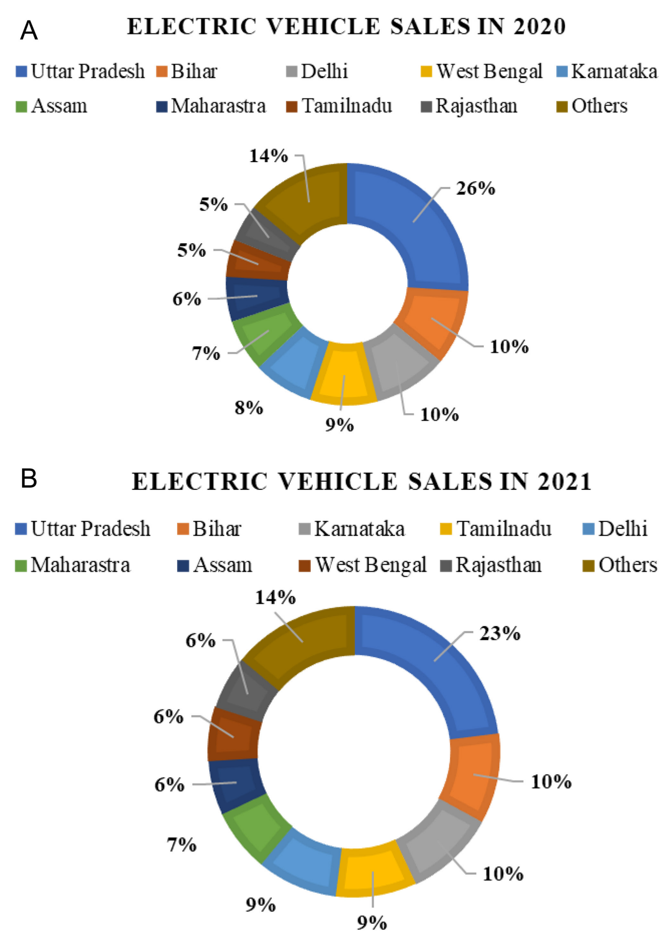


**Fig. 5.** Regional wise electric vehicles registered between (a) 2020 and (b) 2021 in Indian states [53].

In [57], authors have conducted a comparative study of hybrid and battery EV estimating strategies and techniques. Battery EVs meet two criteria: 1) an electric motor is powered by a battery that substitutes the ICE vehicle and the tank, and 2) the vehicle is hooked into a charging outlet when not in use. An overview of the various approach for determining the SoC of batteries is presented in [58]. In [59], authors have investigated standard methods such as ampere–hour (Ah) estimation and open-circuit voltage.

A review of various patents and publications associated with the SoC evaluation techniques for an EV battery has been conducted. These studies include experimental and theoretical characteristics of the evaluation techniques. These evaluation techniques are categorized into three categories: the traditional, the modern control theory, and other assorted techniques extracted from control theory algorithms on innovative ideas [60].

An EV can be classified based on its characteristics such as battery time to charge, range of driving, and the maximum weight the vehicle can hoist according to technical categorization. The charge time and driving range are two key features that customers are concerned about. The time duration of a battery to charge is defined by its capacity and the type of battery used. For each charge, the driving range might range from 20 to 400 km [61]. Similarly, some EVs' highest speeds might reach 160 km/h with a charging period of fewer than 8 h, while some vehicles' top speeds are greater. Due to considerable improvements in EVs, HEVs have sparked increased interest in developing nations such as India. Many improvements are predicted to transform the EV picture in the future as EV manufacturers strive to reduce production costs. Table II summarizes the differences between EVs, HEVsd, and BEVs.

**B. Battery Thermal Management System**

Because the usage of EVs is expected to grow shortly, producing efficient batteries is a top priority. Thermal deterioration of the batteries is a significant barrier to improving battery thermal management systems (BTMS), which has an impact on the EV's range. The BTMS's main goal is to extend battery life by controlling the temperature of the battery cell. Lithium-ion batteries are commonly utilized in EVs to store energy.

There are several obstacles to the usage of LIBs including prohibitive cost, low efficacy, decreased electrode life at extreme temperatures, low and elevated temperatures, and the strict impact on vehicle capability, dependability, and protection, as well as safety concerns about a thermal runaway. As a result, an excellent BTMS is one of the most important technologies for an EV's long-term success. Temperatures between 25°C and 40°C are the ideal working range for LIBs. The life of the battery will deteriorate when the temperature rises over 50°C.

**C. Hybridization Factor**

The hybridization factor (HF) may also be used to classify the vehicles. Hybridization of vehicles improves mileage, which is expressed in miles per gallon. Miles per gallon may be used for PHEVs, where 1 gallon of gasoline is equal to 33.7 kWh of electrical energy [62]. The HF of an EV or PHEV is expressed as follows:

$$\mathbf{HF} = P_{EM}/(P_{EM} + P_{ICM})$$

where $P_{EM}$ denotes total electric motor power and $P_{ICM}$ denotes total internal combustion engine power. For a normal automobile, HF is 0, while for all EVs, it is 1.

**TABLE II.**
COMPARISON OF HYBRID ELECTRIC, ELECTRIC, AND BATTERY ELECTRIC VEHICLES

| Parameters | HEV | EV | BEV |
|---|---|---|---|
| ***1. Technical*** | | | |
| Charging facility | Available | Available (but limited) | Available (but limited) |
| Powered by | Both internal combustion engine (ICE) and electric | Electric engine | Electric engine |
| External charging | Not required | Required | Required |
| Engine size | Medium | Small | Small |
| ***2. Economic*** | | | |
| Price range | Like ICE vehicles | High | High |
| Fuel consumption | 40–60% of ICE | None | None |
| Resale value | High | Moderate | Moderate |
| Maintenance | High | Low | Low |
| ***3. Environmental*** | | | |
| $CO_2$ emission | High | Low | Low |
| Dependence on fossil fuel | Partially dependent | Not directly dependent | Not directly dependent |

## III. THE SCENARIO OF ELECTRIC VEHICLES IN INDIA

Indian EV market is still quite modest. For the past few years, EV sales per year have been stagnant at 2000 units. However, it has been noticed since 2020, they have set a goal of selling 100% EVs by 2030, with a composite yearly growth rate of 28.12%.

Reva (Mahindra), India's first EV introduced in 2001, has only sold a few units since 2001. Later, automobile companies manufactured EVs, PHEVs, and electric buses.

Bengaluru Metropolitan Transport Corporation is the first local transportation authority to begin electric bus operation on a busy street in the city. A poll conducted in the city of Ludhiana revealed that 36% of present automobile and two-wheeler owners were excited about switching to EVs. The state government of Telangana is likewise pushing the usage of EVs by waiving road taxes for EV owners. The Telangana State Electricity Regulatory Commission established an INR 6 charging fee for EVs in 2018. The TSERC set the service rate for the whole region with the same price/kWh. In addition, to provide the charging facility for EVs power grid, Corporation of India Ltd and the Hyderabad Metro have partnered. India's first EV charging station will be incorporated in Hyderabad metro station through power grid operation and control. The city of Hyderabad is also considering replacing diesel-powered public vehicles with EVs. The New Delhi government received authority last year to build 131 public charging stations around the city. The Delhi government announced a draught strategy in November 2018 intending to transform 25% of their automobiles to EVs by giving different enticements and installing infrastructure for charging in both non-residential and residential locations.

By 2023, the same strategy aims to build an infrastructure for charging at every 3 km by providing a 100% aid (up to 30 000 USD) and waiving registration, parking fee, and road tax of EVs. A private company called Magenta Power is planning to establish infrastructure for charging EVs on the Mumbai–Pune route [61].

### A. Electric Vehicle Purchasing Schemes in India

In India, state and central governments are introducing various programs and incentives to encourage electric mobility (E-mobility). Among these schemes, few are popularized in public. The Government of India (announced the National Electric Mobility Mission Plan (NEMMP) 2020 to enhance the energy security of the nation, to reduce the detrimental effects of fossil fuel power cars on the environment, and to build local manufacturing skills. The NEMMP 2020 has saved 2.2–2.5 million tons of fossil fuel through EV sales of 6–7 million. As a result of this new strategy, vehicle emissions and $CO_2$ emissions could be reduced by 1.3–1.5%. By the end of 2021, 5.2 million EVs were on the road. The highlights are the need for industry-academia collaboration and incentives by the government. Government of India is planning to build a solar power plant of capacity 100 GW by 2022 to encourage renewable energy-powered EV charging stations and to boost the stability and utilization of renewable sources. The Indian government has established the FAME II (Faster Use and Manufacturing of Electric Vehicles) strategy, which aims to accelerate the adoption of EVs and PHEVs. This program supports EV adoption through different incentives and by creating charging infrastructure. In February 2019, for the 3-year term, the cabinet approved a budget of 10 000 crores for FAME II. This is the most awaited policy by the EV producers to develop an ecosystem for EVs, as well as production incentives and charging infrastructure made a roadmap [63]. Likewise, with the advancement of EV technology and the need to minimize automobile manufacturing sector energy demand, the E-mobility report of 2017 by the National Institution for Transforming India Aayog is transformational and established a pathway for adopting 100% EVs.

According to reports, India can become completely electric by 2030 if it adopts a transformational shared solution networked e-mobility, with 100% public transportation cars and 40% private automobiles. This concept must be shared widely for all EVs to be available shortly. By 2030, the Society of Indian Automobiles and other automakers hope to market 100% pure EVs (BEVs and fuel cell vehicles) for intracity public transportation fleets. By 2030, it is predicted that 40% of new EV sales will be on the market, and 60% of new EV sales will use cleaner technologies such as hybrid and alternative fuels. To guarantee the scheme's efficient operation, the government, industry, and different stakeholders should unite and invest in a long-term strategy to achieve a 100% electric car regime [64]. Figure 6 illustrates the various policies opted by the Indian government for EV development and faster adoption.

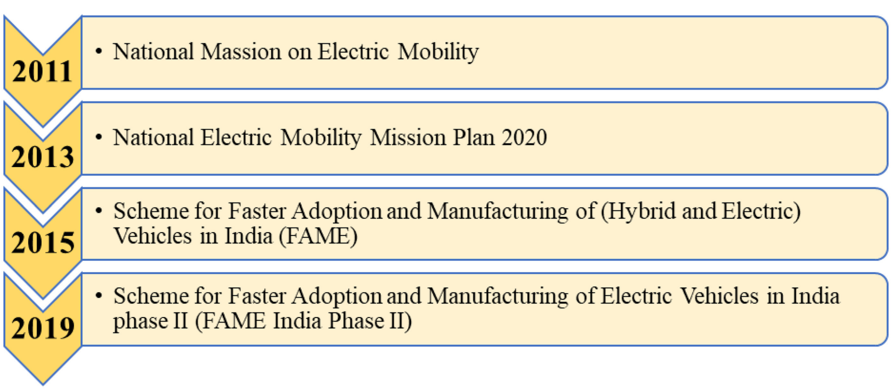


**Fig. 6.** Various policies opted by the Indian government for electric vehicle development and faster adoption.

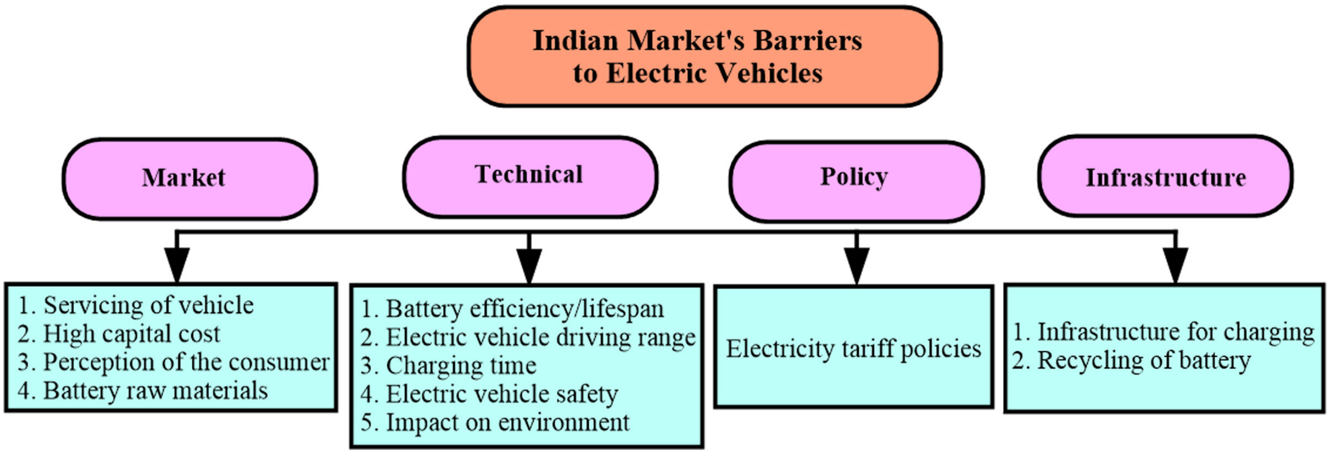


**Fig. 7.** Indian market's barriers to electric vehicle.

## IV. THE INDIAN MARKET'S BARRIERS TO ELECTRIC VEHICLES

The challenges to EV adoption in India may be approached from a variety of angles, including technical constraints, legislative impediments, and a lack of infrastructure. These are illustrated in Fig. 7.

### A. Market

#### 1) Servicing of Vehicle

It is also necessary to have proper care for an EV. The technician should be professional, and he must have hands-on experience in terms of vehicle maintenance, troubleshooting, and repair. They have to utilize their utmost skill to deal with the situation.

#### 2) High Capital Cost

Electric vehicle battery packs are expensive, and they also need to be replaced many times over the vehicle's lifetime. Gasoline-powered automobiles are less expensive than electric ones.

#### 3) Perception of the Consumer

Consumer impression is critical for acquiring new customers and retaining existing ones. Despite the expanding range of EVs on the market, the choice of purchasing an EV remains restricted and is projected to remain so soon. Thus, the client should be aware of the company's products via advertising, social media, or another channel. According to studies, a lack of understanding about the government program, economic benefits, and awareness of vehicular technology can all have a direct effect on the adoption of EVs.

#### 4) Battery Raw Materials

Lithium, nickel, phosphate, manganese, graphite, and cobalt, which are all rare earth elements, are used as basic materials in EV batteries. Aluminum, copper, and steel are necessary for an internal combustion engine. Platinum, rhodium, and palladium are required to filter hazardous gases in combustion car catalyzers. These are all rare materials, and their supply may be insufficient for battery manufacture. Lithium-ion batteries alone consume five million tons of nickel per year, which might result in a 10–20 times increase in lithium and cobalt consumption in the future.

### B. Technical

#### 1) Battery Efficiency/Lifespan

Electric vehicles are typically made by substituting chargers, controllers for batteries, and electric motors for the traditional vehicle's fuel tank and gasoline engine. Because the batteries in EVs are meant to last an extended period, they will eventually fail. Currently, most battery manufacturers give a warranty of 8 year/100 000 mile.

#### 2) Electric Vehicle Driving Range

The driving range is often seen as the primary impediment to the adoption of EVs since EVs have a shorter range than identical ICE vehicles. The range of an electric car on a single charge or full tank is viewed as a key disadvantage in terms of EV adoption in the worldwide market. The majority of BEVs have a range of fewer than 250 km per charge. However, some of the most recent versions have a range of up to 400 km. Due to the availability of liquid fuel ICEs, PHEVs currently have a range of 500 km or more. Thus, the motorist must carefully organize their travel and may be unable to make a long-distance excursion. This creates a barrier in the form of the driving range's magnitude.

#### 3) Charging Time

Charging time is inextricably linked to the issue of range. The EV can take up to 8 h to fully charge from an empty state when utilizing a 7-kW charging station with a sluggish charger. The charging time is mostly determined by the battery's capacity. The vehicle battery is directly proportional to the size of the vehicle, that is, larger automobile will consume more time to recharge from zero to full. Additionally, the battery's charging time is directly proportional to the charge point's charging rate. The higher the charging price of the charge point, the faster the battery will charge entirely. Rapid chargers are utilized in the current scenario to charge the car more quickly, hence minimizing the time necessary. Commercially available EVs are compatible with charge stations that provide a greater charge rate than the vehicles themselves can provide. This means that the battery charging at the highest rate it is capable of without experiencing any problems. It is noticed that the charging rate of the battery using a quick charger decreases during the drop in temperature or the battery is cold.

**TABLE III.**
SUMMARY OF VARIOUS OPTIMIZATION APPROACHES TO ELECTRIC VEHICLES AND THEIR SPECIFIC CONTRIBUTIONS

| Author(s) [Reference] | Optimization Approach | Specific Contributions | Year |
|---|---|---|---|
| Lam and Yin's [65] | Activity- and time-based utility theory model | 1. The activity-based model is built as a time-dependent variation inequality issue, which is solved heuristically using space–time extended networks. | 2001 |
| Perez et al. [66] | Dynamic programming (DP) | 1. The power split between the two sources is optimized to reduce fuel usage when the vehicle is operating at a certain velocity cycle.<br>2. They evaluate the constraints on the power flows from both sources.<br>3. Additionally, there is an intrinsic limitation arising from the fact that the energy in the electrical storage system must remain within safe limits to avoid physical damage. | 2006 |
| Fang and Qin [67] | Concurrent optimization using a multi-objective genetic algorithm (GA) | 1. An optimization technique based on multi-objective evolutionary algorithms is developed, which can optimize powertrain and control system parameters concurrently and effectively identify the Pareto-optimal solution set subject to user-selectable performance limitations.<br>2. This ideal parameter set enables a variety of design options that can enhance fuel efficiency and emissions without compromising vehicle performance. | 2006 |
| Wang et al. [68] | Particle swarm optimization (PSO) | 1. The fuel economy and emissions characteristics of the strategy are compared to one of the primary methods. Dividing RECTangles, the particle swarm optimization algorithm's calculation processes are explained, and a simulation study based on a series hybrid electric vehicle model is presented. | 2006 |
| Gong and Li [69] | Two scales of dynamic programing depend on trip-based power management | 1. With a micro-scale DP architecture, the actual power management may be changed during real-time vehicle operation.<br>2. The whole journey is separated into segments, and each segment's DP is solved using online traffic data provided to the car via the segment's traffic flow sensors.<br>3. The state of charge achieved in the macro-scale DP solution at the terminal site is validated as the final value. | 2007 |
| Xiaolan Wu et al. [70] | PSO | 1. The PSO method was used to optimize the control settings in a plug-in HEV.<br>2. The study is based on a charge-depleting operating strategy, and the fitness function is defined in such a way that it maximizes the fuel efficiency of the vehicle engine.<br>3. Constraints are then applied to the driving performance criteria. | 2008 |
| Kukhyun Ahn et al. [71] | A quasi-static powertrain model using DP | 1. The approach includes two types of simulations: the first is focused on minimizing equivalent fuel consumption, while the second is based on dynamic optimization.<br>2. After analyzing and comparing the data, it was shown that selecting a single optimal operating point by reducing equivalent fuel consumption resulted in high energy efficiency and maximum performance was attained from optimal control simulation. | 2008 |
| Kerem Koprubasi et al. [72] | Model-based design techniques for the control development and optimization | 1. Model-based design is a collection of approaches that place the system model at the center of the development process, from requirements generation to implementation and testing.<br>2. This technique has a variety of advantages, including decreased development time and cost, increased product quality, and a more dependable final product due to the use of computer models for system verification and testing.<br>3. Model-based design is especially advantageous in automobile control applications where calibration ease and reliability are essential features. | 2009 |

(*Continued*)

**TABLE III.**
SUMMARY OF VARIOUS OPTIMIZATION APPROACHES TO ELECTRIC VEHICLES AND THEIR SPECIFIC CONTRIBUTIONS (*CONTINUED*)

| Author(s) [Reference] | Optimization Approach | Specific Contributions | Year |
|---|---|---|---|
| Olle Sundstrom and Carl Binding [73] | Linear and non-linear approximation method | 1. It is a technique used for optimizing the charging behavior of EVs to lower charging costs, to obtain acceptable state-of-energy levels, and to achieve optimal power balance.<br>2. Two strategies for optimizing charging schedules are compared. The first formulation approximates the battery behavior linearly, whereas the second formulation approximates it quadratically.<br>3. The solutions to the two techniques are evaluated using a non-linear and state-dependent battery model. | 2010 |
| Sara Deilami et al. [74] | Maximum sensitivity selection optimization | 1. This strategy enables PHEVs to begin charging as quickly as feasible while adhering to network operating standards (such as power losses, generation restrictions, and voltage profile). | 2011 |
| Elias Wiedemann et al. [75] | Concepts based on customer-relevant characteristics | 1. During the idea stage of development, the optimization loops' objective is to obtain the best potential fulfillment of this cost function. | 2012 |
| Chenrui Jin et al. [76] | Linear programming based on the customer's perspective | 1. While the dynamic scenario is more realistic, solutions to static problems can be utilized to demonstrate the income and cost savings that can be realized through regulated pricing and thus serve as a baseline for performance evaluation.<br>2. Extensive simulation results based on real-world electricity price and load data demonstrate that optimizing charging scheduling can result in significant revenue and cost savings when compared to an unregulated baseline approach and that the proposed dynamic charging scheduling schemes also provide close-to-optimal solutions. | 2013 |
| Niangjun Chen et al. [77] | Optimality and valley filling algorithm | 1. The ideal EV charging schedule is a valley filling profile, which enables the development of a highly efficient offline method with less computing cost than centralized interior-point solvers. | 2014 |
| Mushfiqur R. Sarker et al. [78] | Optimal operation and services scheduling using inventory robust algorithm | 1. They provided an optimization approach for the battery switching station's operational model.<br>2. The suggested model considers the process of day-ahead scheduling.<br>3. Battery demand uncertainty is represented using inventory robust optimization, whereas electricity pricing uncertainty is handled using multi-band robust optimization. | 2015 |
| Shengyin Li et al. [79] | Mixed-integer linear program solved using GA | 1. The model captures network dynamics and finds the most cost-effective station rollout method in both geographical and temporal dimensions.<br>2. The multi-period location issue is expressed as a mixed-integer linear program and addressed using a genetic algorithm-based heuristic. | 2016 |
| Mostafa Rezaei Mozafar et al. [80] | Improved GA-PSO | 1. A unique strategy is given for jointly optimizing the location and size of RES and EV charging stations.<br>2. They presented an optimum technique for controlling the electric car charging process.<br>3. A multi-objective optimization problem is created using the characteristics of electric cars and a model of renewable energy sources.<br>4. The optimization problem is solved using a GA-PSO hybrid enhanced optimization technique. | 2017 |
| Abhishek Awasthi et al. [81] | Hybrid GA-PSO | 1. An innovative approach to the optimal location of electric car charging stations.<br>2. A hybrid algorithm that utilizes both GA and PSO techniques.<br>3. The voltage profile indicated an improvement in the value of the lowest voltage bus.<br>4. Higher performance in terms of solution quality with fewer iterations. | 2017 |

(*Continued*)

**TABLE III.**
SUMMARY OF VARIOUS OPTIMIZATION APPROACHES TO ELECTRIC VEHICLES AND THEIR SPECIFIC CONTRIBUTIONS (*CONTINUED*)

| Author(s) [Reference] | Optimization Approach | Specific Contributions | Year |
|---|---|---|---|
| Syuan-Yi Chen et al. [82] | Dynamic particle swarm optimization | 1. Dynamic particle swarm optimization was utilized to establish optimal solutions for hybrid electric cars' two-variable energy management and gear changing.<br>2. Six successive phases comprised the optimization process.<br>3. They have compared four distinct situations. | 2018 |
| Limmer and Rodemann [83] | Intelligent control strategy | 1. They suggested a framework for dynamically pricing and scheduling charging operations to increase the charging station operator's daily profit and lower the peak of the electrical load. | 2019 |
| Pandian Vasant et al. [84] | PSO and gravitational search algorithm | 1. They utilized PHEVs that require an adequate charge allocation strategy, which they accomplished via the use of smart charging infrastructures and smart grid systems.<br>2. To enable the everyday use of PHEVs, daytime charging stations are essential, and at this stage, only effective charging regulation and infrastructure management may result in increased PHEV adoption. | 2020 |
| Manh-Kien Tran et al. [85] | Hybrid power train technique | 1. They explored several engine designs and components to develop a hybrid powertrain that meets the EcoCAR mobility challenge performance standards.<br>2. Acceleration, driving range, braking, fuel economy, and pollutants are all included in these criteria.<br>3. They have designed in MATLAB/Simulink, a total of five distinct models. | 2021 |

The EV chargers are classified according to the recharge rate of the batteries. The EV charging has three basic types: level 1, level 2, and direct current (DC) rapid. Charging of level 1 is accomplished by converting alternating current (AC) to DC via an onboard converter utilizing a conventional 120-V outlet. Charging the EV using 120-V outlets takes 8 h and provides a range of around 120–130 km. Level 1 charging takes place mostly at home or the workplace. Level 2 chargers are frequently installed in public areas or workplaces that have a 240-V outlet. After continuous 4-h charging of the battery, the vehicle can have a driving range of 120–130km. With DC rapid charging, the transition from AC to DC is seamless and occurs at the charging station with the most advanced charging configurations. This enables stations to provide additional electricity and to charge automobiles more quickly. It charges the battery in 30 min and has a range of 145 km.

#### 4) Electric Vehicle Safety

The electric car must comply with all applicable state and municipal regulations on vehicle safety. Additionally, the batteries must pass testing under adverse situations such as the impact of fire, short

**TABLE IV.**
SUMMARY OF VARIOUS OPTIMIZATION APPROACHES FOR THE V2G MECHANISM AND THEIR SPECIFIC CONTRIBUTIONS

| Author(s) [Reference] | Optimization Approach/Concept | Specific Contributions | Year |
|---|---|---|---|
| Christophe Guille and George Gross [92] | Conceptual framework | 1. They evaluated the implementation of a battery vehicle aggregation to provide frequency control, which requires extremely rapid reaction times and energy supply for peak shaving.<br>2. Additionally, the aggregated battery car charging load was evaluated for its influence on low load generation schedules and regulatory requirements.<br>3. The assessment of these implications includes an explicit portrayal of uncertainty and the critical nature of the state of charge (SoC) as a fundamental variable in the supply and demand functions of the batteries.<br>4. The role of vehicle-to-grid (V2G) in integrating renewable energy sources has been considered. | 2008 |
| Christophe Guille and George Gross [93] | Conceptual framework | 1. A conceptual framework has been successfully implemented to integrate aggregated battery vehicles into the grid as distributed energy resources that act as controllable loads during off-peak periods to help balance the system's demand and as a generation/storage device during the day to provide capacity and energy services to the grid. | 2009 |

(*Continued*)

**TABLE IV.**
SUMMARY OF VARIOUS OPTIMIZATION APPROACHES FOR THE V2G MECHANISM AND THEIR SPECIFIC CONTRIBUTIONS (*CONTINUED*)

| Author(s) [Reference] | Optimization Approach/Concept | Specific Contributions | Year |
|---|---|---|---|
| M. Musio et al. [94] | Virtual power plant structure concept | 1. The system's instability following the addition of renewable energy sources to the grid can be mitigated by energy storage devices, demand control monitoring, and grid reinforcement.<br>2. These technologies can increase the electric grid's dependability and efficiency, while also increasing the system's flexibility.<br>3. They used an optimization problem to investigate the feasibility of using electric vehicles (EVs) linked to the grid as energy storage systems inside a virtual power plant layout. | 2010 |
| João Soares et al. [95] | Particle swarm optimization | 1. They discussed network management will be critical to incorporate automobiles into the optimum scheduling issue.<br>2. They developed the PSO algorithm and evaluated the methodology's performance using a 32-bus distribution network equipped with 66 dispersed generators, 32 loads, and 50 EVs. | 2011 |
| Sayed Saeed Hosseini et al. [96] | Virtual power plant structure concept | 1. They highlighted the V2G idea and how it simplifies the integration of renewable energy into the power grid, providing a new impetus for the inevitable transition to clean energy generation.<br>2. The economic and environmental benefits of utilizing energy storage in EVs are apparent. Research has been done to elucidate the many facets of V2G in power systems.<br>3. They examined V2G from the standpoint of power system services and energy market applications in that study.<br>4. They concentrated on the relevance of smart parking lots in the V2G concept, its advantages, and disadvantages, as well as the application of V2G to provide auxiliary services. | 2012 |
| Shi Rui et al. [97] | Bidirectional power flow control | 1. They examined the interplay of wind turbines, electric car charging stations, and the active distribution grid.<br>2. They concentrated on the idea of EV charging stations offering bidirectional power flow management to distribution network operations to increase fault-ride-through of neighboring wind turbines. | 2014 |
| Sonja Studli et al. [98] | Additive Increase multiplicative decrease | 1. They presented a novel framework for implementing both the V2G idea and non-disruptive reactive power adjustment capabilities.<br>2. The algorithms can share available/desired power optimally and fairly, with little communication needs, in a highly unpredictable, constantly changing environment. | 2015 |
| Youjie Ma et al. [99] | General approach | 1. Two technological considerations are discussed in detail: bidirectional charging and charging/discharging technique.<br>2. These two technological obstacles come from two major challenges associated with the integration of EVs into the power system: pollution caused by harmonics and load fluctuation. | 2018 |
| K. Ramakrishna Reddy and S. Meikandasivam [100] | Stochastic approach | 1. Smart grid technologies are rapidly gaining prominence in the electric power sector, both in terms of updating the legacy infrastructure with a high degree of renewable energy penetration and ensuring the dependability and quality of electric power.<br>2. The utilization of modern technology to improve energy consumption and decrease greenhouse gas emissions is unavoidably the electric utility's primary focus. Renewable energy source integration introduced a slew of complications in addition to its benefits.<br>3. Plug-in electric vehicles (PHEVs) have seen dramatic market expansion over the previous decade due to lower costs and improved energy density storage.<br>4. The integration of many PHEVs with an uncoordinated charging schedule is a significant impediment to power system functioning. | 2018 |

(*Continued*)

**TABLE IV.**
SUMMARY OF VARIOUS OPTIMIZATION APPROACHES FOR THE V2G MECHANISM AND THEIR SPECIFIC CONTRIBUTIONS (*CONTINUED*)

| Author(s) [Reference] | Optimization Approach/Concept | Specific Contributions | Year |
|---|---|---|---|
| K. Ramakrishna Reddy and S. Meikandasivam [101] | Water filling algorithm (WFA) | 1. The WFA is utilized to disperse available PHEV energy, which aids in the proper scheduling of PHEVs for the day ahead.<br>2. The adaptive neuro-fuzzy inference system (ANFIS) was used to minimize charging costs and maximize PHEV power consumption.<br>3. ANFIS is trained to prioritize cars concurrently from utility and consumer viewpoints. The effect of ANFIS priority on the aggregate power availability and load flattening of PHEVs is investigated at a particular time. | 2018 |
| K. Ramakrishna Reddy and S. Meikandasivam [102] | Multi-objective genetic algorithm (GA) | 1. Prioritization of PHEVs is performed using ANFIS and five decision factors.<br>2. It has been assumed that PHEVs are available at the planned times, and while vehicle prioritization may result in minor deviations from pre-arranged periods, the target SoC is always maintained.<br>3. When PHEVs are used for load flattening, voltage regulation is done at each bus to which PHEVs are attached by managing active power transactions between the bus and the PHEVs.<br>4. The Multi-Objective Genetic Algorithm is used to determine the ideal power transfer between the grid and PHEVs while optimizing the storage use of the PHEVs without exceeding voltage constraints. | 2019 |
| K. Ramakrishna Reddy and S. Meikandasivam [103] | Fuzzy logic controller | 1. For PHEVs, an intelligent control method is designed to alleviate power oscillations caused by load demand and solar energy combined.<br>2. Additionally, the effect of scheduling PHEVs in conjunction with energy storage units (ESU) is studied.<br>3. Slack bus power fluctuations from the prescribed value are minimized while maximizing the usage of available PHEV storage capacity.<br>4. When scheduling storage units, day-ahead energy demand and solar energy generation for the next few hours are considered (ESU and PHEV) | 2019 |
| K. Ramakrishna Reddy and S. Meikandasivam [104] | Water filling energy dispatch algorithm | 1. The effective use of a PHEV's storage capacity to mitigate solar PV and load power variations.<br>2. The client and utility benefit from a win-win approach that maximizes income for the consumer and minimizes demand swings. | 2019 |
| K. Ramakrishna Reddy et al. [105] | Multi-objective GA | 1. The present study focuses only on the distribution agent level, with the primary purpose of load flattening using PHEV storage.<br>2. The energy zones necessary for load flattening are specified, along with the charging and discharging of PHEVs required to achieve load flattening.<br>3. The entire available energy from PHEVs is allocated optimally among all intervals in each zone using WFA.<br>4. Optimal Energy Distribution with WFA took into consideration the unpredictability of PHEV availability for grid assistance while assessing the available PHEV energy capacity in each zone (charging and discharging). | 2019 |
| Mina Jafari et al. [106] | Mixed-integer linear programming | 1. The concept of regenerative breaking energy (RBE) is being used to improve the functioning of the subway system in the smart city's linked subway system.<br>2. To ensure the smart city operates well, an optimization formulation is developed to reduce the city's overall cost in the presence of subway RBE.<br>3. The traffic and route length are modeled in this article using V2G and Vehicle to Subway vehicles situated in parking lots.<br>4. Additionally, the degradation model is being developed to extend the battery life of PHEVs.<br>5. A stochastic framework based on the uncertainty technique is constructed using an unscented transformation approach to manage the unpredictable behaviors of PHEVs, distributed energy resources, and loads in the smart city. | 2020 |

(*Continued*)

**TABLE IV.**
SUMMARY OF VARIOUS OPTIMIZATION APPROACHES FOR THE V2G MECHANISM AND THEIR SPECIFIC CONTRIBUTIONS (*CONTINUED*)

| Author(s) [Reference] | Optimization Approach/Concept | Specific Contributions | Year |
|---|---|---|---|
| Benedikt Tepe et al. [107] | GA | 1. The optimization techniques given here are used to optimize pool combinations based on the power and energy capacity profiles of commercial electric vehicles.<br>2. The income of the possible pools per participating EV is determined using a genetic algorithm.<br>3. This study examines two use cases: balancing power provision on Central Europe's frequency containment reserve market and energy arbitrage trading on the European power exchange's intraday continuous and day-ahead auction spot markets. | 2021 |

circuit, temperature, overcharge, pulsation, moisture, and water immersion. The design of the vehicles should include safety features like short circuit and collision detection and HV isolation.

#### 5) Impact on Environment

Though EVs are eco-friendly, they may affect the environment. However, the battery components are mined and proper disposal is carried out, thereby having a negligible influence on the environment.

### C. Policy

To accelerate India's electric car revolution, the government plans to finance the country's EV charging infrastructure. Additionally, the ministry of electricity recently confirmed that EV charging stations in India do not require a license to operate, which will help expand the nation's EV charging station infrastructure.

It is necessary to increase and encourage incentives and concessions to EV consumers by reducing the LIBs GST, and enticements must be provided for transition from public transportation to EVs.

### D. Infrastructure

#### 1) Infrastructure for Charging

Additional charging infrastructure is necessary to accommodate an increase in the number of EVs and, consequently, the demand for electrical energy. Due to a lack of charging infrastructure in India, electric car sales are limited. Chargeable batteries should be embraced by EV manufacturers from a design standpoint, allowing discharged batteries to be replaced with fully charged ones. The charging station can arrange to charge their batteries at off-peak hours when electricity rates are lower. Additionally, there should be an option for setting up a charging station for this car at home, as residents would be required to begin their day by charging their EVs. In the lack of residential charging infrastructure, individuals would rather charge their vehicles at work or at a proper charging station where they must stop for 2–3 h or more. Slow charging is excellent for locations such as the home and business, whereas rapid charging is best for highways and commercial complexes, where vehicles must stop for a shorter period. Additionally, quick charging of 30 min or less requires the EV to be capable of handling high current and voltage, or both. This will not only raise the expense of the EV but will also have a detrimental effect on the battery's life. As a result, a hybrid of slow and rapid chargers may be the best solution for EVs.

#### 2) Recycling of Battery

The batteries used in EVs are typically designed to endure for the duration of the vehicle's life but will fail. Manufacturers do not notify consumers about battery replacement prices, but if a battery needs to be replaced outside of its warranty term, the manufacturer adds to the expense by replacing the old battery with a new one. Chemical components such as lithium, nickel, cobalt, manganese, and titanium not only improve the supply chain''s economic effectiveness but also have an environmental impact during the scrapping of the battery materials.

## V. OPTIMIZATION APPROACHES

### A. An Optimization Approach for Electric Vehicles

In the present article, the charging demand for EVs is described using various frameworks in a variety of geographical areas. The framework is comprised of the following components: random utility model, activity-based equilibrium scheduling, pattern recognition in driving, stochastic model, trip prediction model, probabilistic model, fuzzy-based model, distributed optimization, forecasting model, data mining model, ant colony optimization, household activity pattern optimization, particle swarm optimization, linear programming, multi-objective optimization, and adaptive multi-objective optimization model.

The purpose of this study was to determine the possible benefits of all EVs' charging characteristics. Several investigations have been undertaken globally by various researchers to determine the optimal strategy for EV optimization. These optimization approaches are summarized in Table III.

### B. Concept of the Vehicle-to-Grid

Kempton et al. pioneered the V2G idea in 2001. This technique is carried out by providing power to the grid with the help of a bidirectional charger. This charger is capable of G2V charging and V2G discharging [86].

The influence of bidirectional charging on LIBs has been postulated in V2G and G2V to determine their cell performance [87]. An overview of how to include various available technologies of energy storage into a distribution network for planning and operation and developments in battery technologies and policy surrounding V2G technology. Implementation of various approaches for managing battery deterioration and to improve the battery utilization for

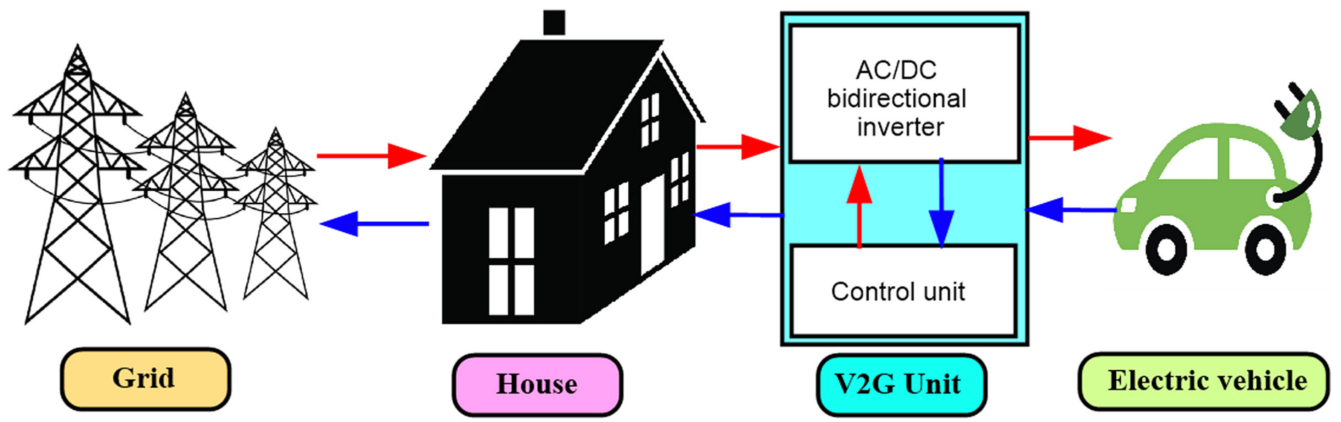


**Fig. 8.** Vehicle to-grid charging mechanism.

extending the battery life of the EV's is presented in [88-90]. Kester et al. [91] conducted a comparative analysis in the Nordic nations to determine how several EV specialists repeat strategy recommendations for V2G and EVs.

### C. An Optimization Approach for Vehicle-to-Grid

The concept of V2G eceived attention from all communities. In the present study, various investigations undertaken globally by several researchers to determine the optimal scheduling of V2G and G2V with the application of various optimization techniques are summarized in Table IV. Figure 8 illustrates the vehicle grid charging mechanism. Figure 9 illustrates the V2G with an aggregator.

Additionally, they suggested that the charging technique and aggressiveness of the vehicles might make V2G technology commercially viable. While the V2G system has various advantages, increasing the number of PHEVs may have a direct effect on the dynamics and performance of a distribution network by overloading transformers, cables, and feeders.

However, several experimental investigations have been conducted on the V2G particularly on the battery degradation concept [107-112]. Hence, the scope of the V2G technology is still under transition mode. Researchers are encouraged to conduct investigations on this technology and find an optimal solution.

## VI. CONCLUSION AND FUTURE DIRECTIONS

Hybrid EVs, PHEVs, and EVs all have the potential to improve vehicle fuel efficiency but at a higher cost than conventional vehicles. In general, their lower gasoline uses and greater productivity benefit

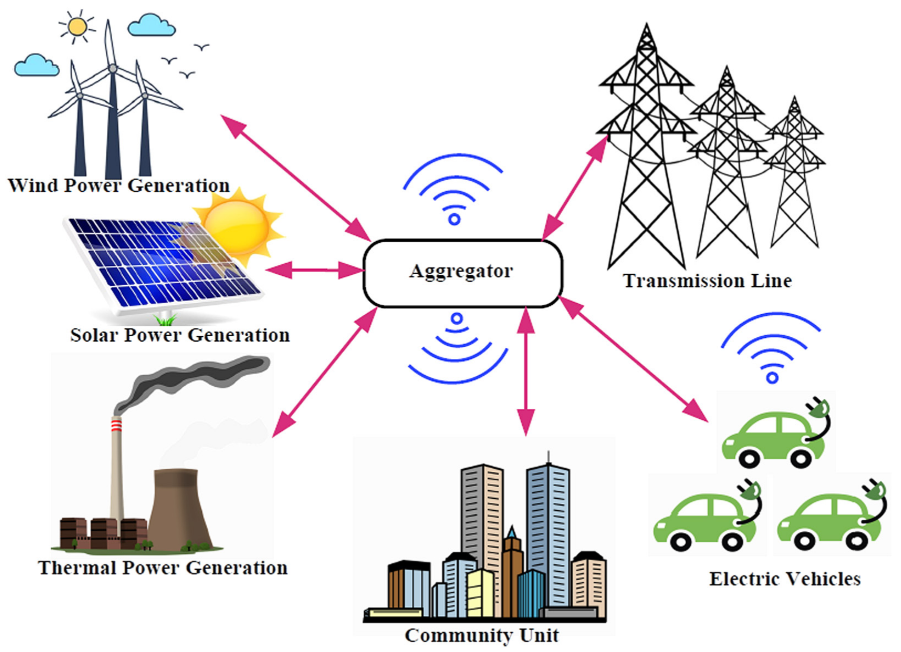


**Fig. 9.** Vehicle-to-grid system aggregator.

purchasers, society, automakers, and policymakers throughout their lives. This article includes a comprehensive review of the research, an overview, and instructions for conducting penetration rate studies of HEV, PHEV, and BEV in the Indian market. The Indian government's latest measures and different incentives will assist accelerate the country's e-mobility drive. The creation of a novel concept of V2G may be utilized to either supply electricity to the grid or to charge the battery in the absence of non-conventional energy sources. This technology is critical for energy security, renewable energy, and addressing global warming challenges. This study summarizes the challenges and issues associated with EVs in the Indian setting, which is the paper's primary innovation. However, an "intention" to adopt may not translate into a purchase. Additional research may reveal if intention will transfer to adoption. The link between intent to adopt and purchasing behavior requires extensive modeling, which is even more important when purchasing sophisticated environmentally friendly items, as the authors note. Four factors were examined in the study: Electric Converters (EC), perceived economic gain, Induction Machines (IM), and SoC. Other research might be conducted to evaluate the effects of additional confounders. These include customer perceptions of efficacy, information, skepticism, safety, risk, interest, and experience.

It would be beneficial to test this with actual EV owners in the future. With growing worldwide concern about the environment daily, this study provides enormous potential for future study.

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