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Identifying and Mitigating the Barriers for Vehicle-to-Grid Adoption in India

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ABSTRACT- This study gauges the current scenario of EVs in India as a precursor to the adoption of V2G on a large scale. It outlines the barriers to complete EV adoption under three challenge categories. It discusses the motivation for the use of vehicle-to-grid by describing the technology in detail and discussing an overview of how it works. Lastly, the study outlines how popular optimization techniques have been employed to solve individual optimization and scheduling tasks to optimize power, cost, and emissions for V2G.

General Terms: Particle Swarm Optimization, Double-Layer Optimal Charging, Cost and Emission Optimization.

Keywords: Vehicle-to-Grid Technology, Electric Vehicles, Smart Grid and Power Optimization.

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1. INTRODUCTION

Recent years have seen significant interest in two booming directions- renewable energy and electric vehicles (EVs). The two naturally reinforce each other. As larger portions of our energy start to come from renewable sources---the cost, efficiency, and environmental control with the adoption of EVs is expected to be more prominent. To this end, the advent of Vehicle-to-Grid (V2G) technology promises to further mitigate the individual foreseen challenges. V2G considers EVs as small portable power plants (S3Ps) or energy storage systems, thus having the ability to provide much-needed stability to renewable energy sources. Not only does this allow us to make best use of our resources, but also removes the reliance on conventional energy sources and the associated pitfalls.

With the rapidly expanding Indian Automobile sector, there is great momentum for Passenger Electric Vehicles (PEVs). The Automobile sector is projected to reach INR 16.16-18.18 lakh crores (US $251.4-282.8 billion) by 2026 [5], and along with it, electric vehicles are expected to have a significant share in the future. The industry data for the first half of FY2021-22 shows that a total of 6,261 PEVs were sold during the period, i.e., April to September 2021, exhibiting a 234% Year on Year growth although it has a low base of the previous year still, PEVs contribute less than even 1% of total passenger vehicles that are sold in India.

The first half of the financial year 2021-22 experienced a total sale of 13A, 87,714 Passenger vehicles where electric vehicles accounted for only 0.45 percent of the total passenger vehicles market. But there is an expected growth as the 6,251 PEVs sold during the first half of FY 2021-22 have already surpassed the total PEVs sold in FY 2020-21 of 5,905 units [16].

In the past 10-15 years, Wind and Solar energy have proved to be a trusted sources of sustainable energy production, but there is an associated problem with these energy sources, i.e., these sources are not regular and reliable, which means that they cannot provide energy to the electrical grid at the need of peak hours and we have to build reserve power plants, which demands price hikes during peak hours but these plants prove to be a pricey measure. To mitigate a significant percentage of variable renewable energy generation and fluctuations, an electric car can be employed as a flexible load to help standardize the grid, which is the main motive behind this study and the **Vehicle to Grid** (V2G) technology.

With the support of investments from various Original Equipment Manufacturers (OEMs), there is an exception for the rise of more and lower-cost EVs in the next years due to hazardous emissions coming out from the transportation sector. There are some challenges and barriers in the road ahead for the growth of PEVs in India; some of them include Battery Optimization, battery state estimation, and equalization, large-scale charging infrastructure. Technology breakthroughs, government support, incentives for purchase, parking benefits,

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lower car costs, and enough public charging infrastructure could help India in adoption of Electric Vehicles.

2. RELATED WORK

2.1 Vehicle-to-Grid

Vehicle-to-Grid technology is a technology that draws unused power from the cars back into the power grid. With this technology, a car's battery can be charged as well as discharged on the basis of the need or excess of energy nearby [13].

This technology can help the power grid during peak hours on National Level and can help to power nearby buildings or fans and lighting at the local level [11].

For example, In a region where a large percentage of power is being generated via means of renewable energy sources like Solar and Wind Power but since, they can't supply power during the night and the power output largely depends on the external environmental conditions that are hard to predict and can sometimes harm the power grid as well [13].On the other hand, the batteries in electric cars are just lying as potential energy stored in batteries that are portable and can be employed as per the need. V2G technology can act as a bridge to solve the issue of fluctuations in power production by acting as a secondary source of power when needed [17].

Our study is particularly inspired by similar assessments and analysis done for other regions of the world, considering economic and behavioral factors [7].

2.2 Electric Vehicle Adoption in India

The electric car market in India is at a nascent stage. For the previous two years, the sales of electric cars have been hovering at around 2000 units per year. However, by 2030, it is anticipated to have sales of majority electric vehicles, with a compound annual growth rate of 28.12% since 2020.The Reva (Mahindra) which was India's first electric vehicle, was debuted in 2001 but the sales have remained muted since then. In 2010, Toyota debuted the Prius hybrid, succeeded by the Camry hybrid in 2013. As part of a pilot project to test the feasibility, electric buses and hybrid cars have been tested and tried in a few locations. The government is offering a scheme that allows consumers to purchase an electric vehicle at a cheap cost. The Indian government has created the National Electric Mobility Mission 2020, which aims to lower the cost of electric vehicles and increase their sales in India. The Indian government's Niti Ayog plans the policies that will be implemented for electric mobility. Niti Ayog is also working hard to improve the conditions for the sale of electric automobiles in India. In India, low-cost financing is a serious hindrance to the growth of electric vehicles. In comparison to other countries, India is a late adopter of electric mobility technology. And Indians are having a hard time adjusting to this new technology. Even if they acquire an electric car, they will not be able to utilize it on a daily basis or for long-distance travel. Poor battery technology is to blame for this, as it delivers less range and takes longer to fully charge. In India, there is also a scarcity of charging stations where consumers may power their vehicles.

Several recent studies look at the resistive adoption from an economic perspective [8, 6] while others perform intensive analysis of other potential factors that influence this change [14, 15, 2, 1].

2.3 Optimization

Currently, Vehicles that are involved in V2G technologies are more generally referred to as gridable vehicles, and they essentially act as small portable power plants (S3P). In order to bring into effect, the true potential of V2G and have a tangible impact with respect to power generation and storage, it is essential to employ intelligent and effective optimization techniques [17].

Several parameters including cost [22], emissions [24], operations [12], and scheduling [23] are necessary to ensure an effective system without underlying inconvenience to users.

3. ELECTRIC VEHICLES

The power electronic traction inverter, which places an electric motor, in place of internal combustion engine, which is powered by energy stored in batteries, is the ultimate goal of electric vehicles. The electric motor is extremely efficient, using 90–95 percent of the input energy to successfully power the vehicle. An electric vehicle's battery, power electronics controller, charging port, charger, DC/DC converter, regenerative braking, and drive system are all required. An electric car's objective is to use the energy stored in batteries to power the vehicle. EVs allow the environment it is recharged with low emissions. Cells are charged in the electrical grid. The charging port is an area that allows the car to connect to an external charging system to charge the battery.

The charger function uses the charging connector to connect to a power source and transforms to DC power to charge the battery. It also keeps track of voltage, current, temperature, and battery charging status. The DC/DC converter transforms high DC voltage extracted from the battery into low DC power that can be used to power automotive accessories. The towing truck's speed and torque are controlled by the electronics power controller, which regulates the electrical energy flow from the towing battery. Regenerative braking is crucial for keeping the car's strength and improving its strength. This braking method recharges the battery by converting kinetic energy into electrical energy using mechanical energy from the engine. The drive system's job is to move the vehicle by distributing the traction wheels' power. An electric automobile can have a variety of interior configurations based on its components and does not require a standard transmission.

3.1 Types of Electric Vehicles

3.1.1 Battery Electric Vehicles

They are entirely electric vehicles that are equipped with rechargeable batteries and without any gasoline engine, sometimes known as BEVs and more commonly referred to as EVs. The energy that is required to operate the car is provided by the battery pack, which is recharged from the grid. Battery Electric Vehicles are considered emission less cars since they

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produce no harmful emissions coming out from exhaust or contaminate the air in the same manner as other vehicles with gasoline-powered engine do.

3.1.2 Plug-in Hybrid Electric Vehicles
PHEVs (or plug-in hybrid electric vehicles) have an engine and an electric motor to power the vehicle. They, similar to conventional hybrid cars, can recharge their batteries by the help of regenerative braking technology. But they do differ from other hybrid automobiles in a manner that they possess a much larger battery that can be recharged by connecting it to the grid. PHEVs have a range typically from 10 to 40 miles before switching to gasoline (considering the drive at moderate speeds), but regular vehicles can only sustain 1-2 miles and then we need to switch to gasoline engine.

3.1.3 Hybrid Electric Vehicles
A gasoline engine along with an electric motor power HEVs. All of the energy consumed for the battery is provided by regenerative braking, which recovers power that is supposed to be lost otherwise and helps to assist the gasoline engine during acceleration in the process of braking. Heat is dissipated as breaking energy in the heat pads and rotors in a standard IC engine car.

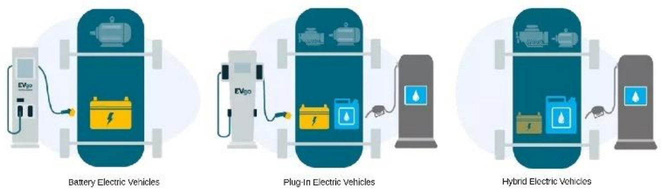

Figure 1: Types of Electric Vehicles

4. ELECTRIC VEHICLES IN INDIA
A technology like vehicle-to-grid is largely dependent on the mass population switching to electric vehicles and adopting bi-directional charging. When looked at from an individual perspective, the benefits of V2G seem insignificant--only when millions of individuals jointly adopt such a framework does this technology reap its true potential. Thus, in order to assess the feasibility and practicality of this technology, it is essential to gauge where we stand. In this section, we would take a look at the current scenario of electric vehicles in India, the most prominent barriers in the way of their mass adoption, and a perspective on the future.

4.1 Barriers
Several past studies have reviewed the barriers to complete EV adoption in India [3, 4]. In this report, we classify the challenges of EV adoption in India into three main categories: (i) Operation and Maintenance Challenges, (ii) Technical Challenges, and (iii) Infrastructural Challenges.

4.1.1 Operation and Maintenance
Switching from traditional gas-powered vehicles to electric vehicles not only involves a large change with respect to how an individual operates and maintains the vehicle but also how the entire market around transportation and repair functions.

Firstly, a significant amount of expertise and human skill is already present around gas-powered vehicles in India. Considering the structural differences between such vehicles and EVs, this manual skill-set and market would need to change immensely.

Moreover, frequent, and well-operated charging stations would need to be set up throughout the city. Governments and organizations are already giving thought in this direction. For instance, the New Delhi government announced its vision of setting more than a hundred public charging stations in the state this year. This is encapsulated in the larger goal of converting at least one-fourth of the current vehicles to EVs and developing a charging point at a radius of every 3 KM.

Further, electric vehicles involve a high capital cost in comparison with gas-powered vehicles. The battery packs of EVs are costly and need to be changed after every several years in order to ensure the proper functioning of the vehicle. This makes the position of EVs less certain among the economic divisions of India.

4.1.2 Operation and Maintenance
One of the most prominent concerns around the adoption of EVs revolves around the driving range. In comparison to similar standard gas-powered vehicles, EVs have a much smaller range of distance that can be travelled with full charging. The current state-of-the-vehicles offer up to 450 KMs per charge, however, the average across their lifetime remains a low of 250 KMs. Due to this reason, consumers must plan their journey with precision and longer trips remain difficult to perform [10, 20].

This concern of low driving range is strongly coupled with the large charging time. Gas-powered vehicles take minutes to "recharge" because they just need their fuel tanks to be filled up. EVs, on the other hand, require several hours to recharge their electric batteries.

Several types of technologies exist around charging EVs. Particularly, the most popular three types are Level 1, Level 2, and DC fast. Level 1 charging makes use of a standard 120 V outlet by performing AC-DC conversion using an onboard converter. Generally, it has been shown to take up to 8-9 hours for charging an EV for a range of 120-130 KMs, depending upon the vehicle. This kind of charging is usually designed for a home or workplace setup. On the other hand, Level 2 chargers are usually set up at public places, employing a 240 V outlet. It takes up to 4 hours to charge the battery for a similar driving range. DC fast charging usually occurs in a charging station, allowing for the fastest charging arrangements with special AC to DC conversion. Stations are modified that can charge the vehicles quickly by supplying more power. It can also easily charge the battery in as low as 30 minutes for a range of 145 KMs. Currently, this method of charging is the most efficient in terms of time and convenience, however, it is also the most expensive to set up and maintain.

4.1.3 Infrastructural
The batteries used in EVs generally last for a limited amount of time and are likely to wear out before the vehicle. Currently, the

costs of battery replacement is not being disclosed transparently by manufacturers and whenever the instance arises for battery replacement outside a given period, it adds to the expenses for the consumer. Not only that, the chemical elements like Lithium, Nickel, Manganese, Cobalt, and Titanium that are used in these batteries pose a concern to the environment. All these elements are scarce and their availability might rapidly decline in the future. Lithium-ion batteries alone consume more than five million tons of nickel per year, and this is estimated to reach 10–20 times in the future from current levels, with the advent of EVs [16].

5. VEHICLE-TO-GRID

It is a technology that draws unused power from the cars back into the power grid. With this technology, a car's battery can be charged as well as discharged on the basis of the need or excess of energy nearby.

This technology can help the power grid during peak hours on National Level and can help to power nearby buildings or fans and lighting at the local level.

For example, in a region where a large percentage of power is generated via the help of renewable energy sources like Wind and Power but since, they can't supply power during the night and the power output largely depends on the external environmental conditions that are hard to predict and can sometimes harm the power grid as well. On the other hand, the batteries in electric cars are just lying as potential energy stored in batteries that are portable and can be employed as per the need. V2G technology can act as a bridge to solve the issue of fluctuations in power production by acting as a secondary source of power when needed.

5.1 How it Works

The basic principle behind the working of Vehicle to Grid technology involves the extension of the electrical grid and considering the electric vehicles' batteries as a part of the electrical grid where we can store the power as well as draw the power from it when needed. In this way, the charging of cars evolves to a bidirectional process, where the power grid not only supplies electricity to the vehicle's battery but also utilize it as a power source that can meet various needs of energy consumption.

It is also an important component in the development of an intelligent distribution network, which is commonly known as a smart grid, where energy flows are constantly optimized by the help monitoring at every step along the way.

The most important thing to remember is that EV drivers have enough energy in their car batteries when they need it. When they go to work in the morning, the automobile battery must be properly charged to drive them to and from work at any time. A major requirement of V2G and any other charging system is that the EV driver be able to specify when they want to unplug the car and the battery percentage at the time.

In this technology, the smart system works in a way to optimize the power transfer and frequency to meet the needs of the electrical grid such that whenever there is a need for power in the Grid, the system draws the power from electric vehicles' cars and supplies to the nearest location where power is needed because the Power Grid also works in the same way of transferring the power via the shortest route possible. In the same way, whenever there is an excess supply of power in the grid, the system stores the excess power in the car batteries and uses them as energy storage devices.

This system works because the batteries are not 100% charges, rather fluctuate between the minimum power capacity required for sustained performance of the battery and the maximum power that is optimum for the battery life while keeping in mind to maintain the battery percentage at the level indicated by the user at the time when the user needs to use the vehicle.

5.2 Optimization Techniques

Vehicles that are involved in V2G technologies are more generally referred to as grid-able vehicles, and they essentially act as small portable power plants (S3P). In order to bring into effect, the true potential of V2G and have a tangible impact with respect to power generation and storage, it is essential to employ intelligent and effective optimization techniques.

5.2.1 Optimal Vehicle Scheduling

The use of Vehicle to Grid technology poses a problem of unexpected triggering events, that is, as the technology involves the user to indicate the time of departure and required battery percentage beforehand while leaving the car at charging station but in an event when the user unplugs the car before the scheduled departure time or if a new vehicle gets connected to the system, these are known as unexpected triggering events which might put a load on the power grid, destabilize the grid and thereby, negating the whole purpose of using V2G technology.

To deal with this problem, we can employ an Optimal scheduling scheme where there will be scheduling centers that communicate with the charging facilities [18] During the normal course of events, the charging facilities will send the inputs like time of departure, state of charge (SoC) of the car at the time of initiating the charging process, the required battery percentage as indicated by the user.

Whenever a car disconnects from the network unexpectedly before the scheduled departure time, the mathematical model is updated based on the changes in the inputs, and re-scheduling is done in the scheduling center using the revised model. Finally, to coordinate energy exchange between PEVs and the power grid, revised charging facility scheduling instructions will be provided. Until the next triggering event occurs, the procedures will continue.

However, if a PEV is disconnected at or after the expected time indicated by its owner, the rescheduling operation will not be triggered.

- The problem is solved by upgrading the optimization model and rescheduling the triggering events, which include the PEV when it is connected to the grid and unexpectedly when it is disconnected.

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- This method can deal with the uncertainty that arises from electric car connections that are stochastic.

Plug-in electric vehicles look forward to functioning as a revolutionary distributed energy storage system in V2G operation, assisting them in achieving the balance between supply and demand of the power grid while smoothing out power load profile fluctuations.

5.2.2 Optimizing Cost and Emissions

The most salient attributes of the V2G technology can be inculcated together in a unifying objective function, that would be minimized using the most appropriate optimization technique. Here, the objective function is composed of three such attributes, given as a function of the output power $P_i(t)$ at a time t: fuel cost $(FC_i(P_i(t)))$, emission $(EC_i(P_i(t)))$, and start-up cost $(SC_i(t))$. Each of them is given as a polynomial equation:

$$FC_i(P_i(t)) = a_i + b_i + c_i P_i^2(t) \quad \dots (1)$$
$$EC_i(P_i(t)) = \alpha_i + \beta_i P_i(t) + \gamma_i P_i^2(t) \quad \dots (2)$$
$$SC_i(t) = \begin{cases} h - cost_i & MD_i \le X_i^{off}(t) \le H_i^{off} \\ c - cost_i & X_i^{off}(t) > H_i^{off} \end{cases}$$

Hence, the net objective function that unifies cost and emissions is given by:

$$\min \prod = W_c \times (Fuel + Start - up) + W_e \times Emission$$

$$= \sum_{i=1}^{N} \sum_{t=1}^{H} [W_c(FC_i(P_i(t)) + SC_i(1 - I_i(t-1))) + W_e(\psi_i EC_i(P_i(t)))] I_i(t) \quad \dots (3)$$

where, ψ_i represents the unit i emission penalty factor. The weighing factors W_c and W_e can be used to consider ($W = 1$), not consider ($W = 0$), or consider with varying precedence ($0 < W < 1$) the cost/emissions in the fitness function, thus adding to the system flexibility.

Further, this optimization occurs under particular well-defined constraints in the V2G setup. Particularly, 12 constraints are considered for this optimization problem, as outlined in *Table 1*

The Particle Swarm Optimization (PSO) method can be effectively used to solve the problem of optimization that has been outlined above [21]. PSO is a biologically-inspired evolutionary algorithm. Each of the potential solution (termed as a particle) travels in a multi-dimensional space ans that too with a velocity that varies dynamically according to the particle's own experience and that of other particles in the neighborhood. PSO is an iterative method where the position as well as velocity of each particle is updated as follows:

$$v_{ijt} = w \times v_{ijt} + c_1 \times rand_1 \times (pbest_{ijt} - x_{ijt}) + c_2 \times rand_2 \times (gbest_{jt} - x_{ijt}) \quad \dots (4)$$

where, v_{ijt} represents the current velocity of the considered particle (inertia). The cognitive element of the particle is given by ($pbest_{ijt}$ - x_{ijt}) where the agent changes the velocity in correspondence to its own memory. While the social element of PSO is depicted in the term ($gbest_{jt}$ - x_{ijt}), where the particle is changing its velocity at every step which is based on the social-psychological knowledge adaption from the entire swarm.

An N × H binary matrix which is used here for generating units can be easily optimized using PSO, owing to the 0/1 nature of possible states. Whereas, standard PSO has less balance b/w local and global entities to search for optimization of a given H × 1 column vector with integer states (as for gridable vehicles). This is because the number of vehicles connected with each other can range from 0 to $N_{V2G}^{max}(t)$ at an hour t. Thus, binary PSO has been used for the better optimization of vehicles of V2G here. The complete algorithms is given in *Figure 2*.

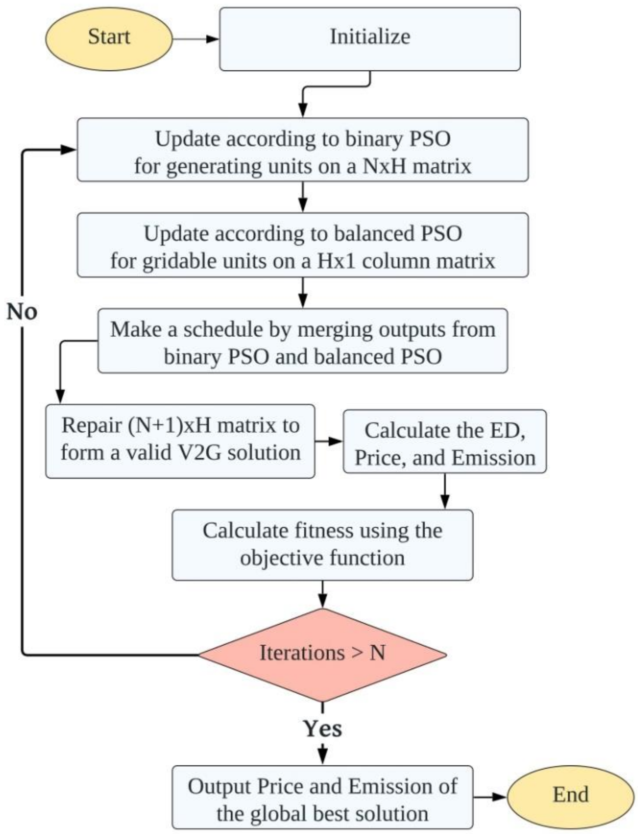

Figure 2: Particle Swarm Optimization for the given Vehicle-to-Grid cost and emission optimization problem. Joint use of balanced and binary PSO has been made to solve the problem efficiently

5.2.3 Optimizing Charging Schedule

When providing charging services for PEVs, the best charging strategy is found to be by calculating the charging power over each individual time slot as well as for separate charging port. The charging capacity of each charging point in the same time slot is however kept constant here. The goal of this technique is to reduce the regional grid's total load variation throughout the next one-day cycle.

A double-layer optimal charging (DLOC) technique can be employed to address the daunting problem of excessively high computational complexity caused by the increase large-scaled PEVs than ever and charging posts required by them [19].

Central concept used here is to group all of the regional grids' charging ports under the control of a few charging stations.

The CCC plans ideal operating power schedule for each charging station as a whole in the first layer optimization to decrease total load variation.

The station control server can then plan the required charging power for each charging post hosted under its control in optimization second layer, trying to satisfy the instructions provided by CCC in the first layer optimization. Charging centers that are located in the same streets, parking spaces, or the same residential complex might be considered the same charging station if they are in the exact location or linked to the same node transformer.

Table 1: Constraints considered for the optimization of cost and emissions in V2G

Constraint	Formulation
Vehicle Balance	$\sum_{t=1}^{H} N_{V2G}(t) = N_{V2G}^{max}$
Discharging Frequency	F=1/day
Power Balance	$\sum_{i=1}^{N} I_i(t)P_i(t) + P_v N_{V2G}(t) = D(t) + Losses$
Spinning Reserve	$\sum_{i=1}^{N} I_i(t)P_i^{max}(t) + P_v^{max} N_{V2G}(t) \geq D(t) + R(t)$
Generation Limits	$p_t^{min} \leq P_i(t) \leq p_t^{max}$
State of Charge	-
Number of Discharging Vehicles	$p_t^{min} \leq P_i(t) \leq p_t^{max}$
Efficiency	-
Minimum Up/Down Time	-
Ramp Rate	$p_t^{min} \leq P_i(t) \leq p_t^{max}$
Prohibited Operations	-
Initial Status	-

6. CONCLUSION

Compared to conventional automobiles, all variants of electric vehicles like Hybrid, Plug-in Hybrid can help in dealing with threats like Global Warming and Climate change as well as other issues like Energy Security, better deployment of renewable sources of energy. enhance fuel efficiency although increasing the cost of ownership. In certain cases where non-conventional energy sources might be unavailable to consume, we can still use a better Vehicle-to-Grid concept to either deliver surplus electricity whenever there is a need to the grid or simply charge the battery. In this paper, we've explored numerous technologies that can optimize various parts of the electric vehicle space, such as cost, rate of emission, and load on charging stations, with the goal of optimizing these parameters for the Indian electric vehicle market.

7. FUTURE WORK

There are a number of research possibilities in this area as we can better compare the most effective optimization techniques for the Vehicle to Grid technology once we have better measuring equipment and enough datasets to satisfy various variables required for different optimization methods. There is a need of fast and real-time data transfer with respect to the load variance by conventional and renewable sources of energy which will enable researchers to devise more accurate forecasting models for the optimal load sharing and scheduling of charging stations.

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