A State of the Art Review of Electric Vehicle to Grid (V2G) technology

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Abstract- Greenhouse gas emission, fast depletion of fossil fuels, the oil crisis and the increased cost of petroleum products are the major factors that need a shift from internal combustion engines to Electric Vehicles. The commercial deployment of EVs requires a large charging infrastructure to charge and discharge the EVs. Vehicle to Grid is a new emerging technology which came into existence because a large number of EVs can be used as load as well as an energy storage system to support the grid. However, the uncoordinated EV charging shows the crucial impact on the power system. Thus, optimum coordination of the V2G system needed. Thus, this paper presents a comprehensive state of art research of V2G system. The presented paper describes the methodology adopted for power flow under V2G scheme. Further, it explains the key barriers for adoption of V2G at a commercial level. Moreover, the state of art comparison is given for V2G, vehicle to home (V2H) and vehicle to vehicle (V2V). Later, the various optimization techniques have explained how they support the optimal energy management system under a coordinated V2G system.

Keyword: Electric Vehicle, Vehicle to Grid, Unidirectional, Bidirectional, Genetic Algorithm

Nomenclature Used

| Symbol | Full form |
|--------|-----------|
| V2G    | Vehicle to Grid |
| EVs    | Electric Vehicles |
| EU     | European Union |
| RES    | Renewable Energy Source |
| V2H    | Vehicle to Home |
| V2V    | Vehicle to Vehicle |
| PSO    | Particle Swarm Optimization |
| GA     | Genetic Algorithm |
| MW     | Mega-Watt |

1. Introduction

The existence of EVs came into the mid of 19th Century. With the technological advancements in EVs, a great demand for EVs came into the 21st Century. Internal Combustion Engines resulting air pollution in which there is an emission of a large amount of Greenhouse gases mainly Carbon dioxide [1]. Global warming is one of the major issues faced by the world at this time [2]. Government including the United States and EU have taken many incentives to adopt EVs. The rapid trend towards EVs brings a new system known as a V2G system. V2G system refers in which different types of EVs like battery EVs, plug-in hybrid EVs, and fuel-cell EVs supplies power back to the grid.

A significant effect is seen in the environment by preferring EVs in the place of Internal Combustion Engines [3]. With the use of EVs, we have improved quality of air, reduction in noise pollution and tackled the challenge of reducing greenhouse gas emissions. With the sale of 1 million electric cars in 2017, the total electric cars crossed more than 3 million. According to the international energy forecasts, there is an estimate of an increase in the number of EVs from 3 million to 125 million till
2030. Figure 1 shows the data of EVs sale by different regions during 2017. EVs have an emerging market in developing and developed markets [4].

![Figure 1 Sales of EVs During 2017](image)

In India, the top ten cities from the top twenty most polluted cities in the world are located in India. 1/3rd of pollution like particulate matter (PM) is from the transportation sources. Therefore, EVs should have an ideal platform in India. According to a source, there is an estimate of 4.7 GW EV storage in 2022. 200 charging stations will be installed in Delhi, Jaipur & Chandigarh. Smart Charging Company announced 1000 Crore rupees in India on charging infrastructure and development.

Figure 2 shows the energy transfer between the vehicle and the grid termed as V2G and G2V. Figure 3 shows the survey done on an Odhpura 132 kV substation located at Hathras district, Uttar Pradesh, India. The variations of demand of a substation during 24 hours are clearly seen in the table. At 5 a.m. the substation has a minimum demand of 18.86 MW whereas the peak demand of 48.99 MW occurs at 1 PM. There is a great difference in demand between peak and off-peak time. Therefore it is proposed that the EVs are fully charged during off-peak time and it supplies back to the grid during peak time. The planning of the V2G system is planned to solve the above-mentioned problem where EV acts as energy storage units. At the time of peak–off demand, the EVs user can purchase electrical energy at a lower price from the grid and at the time of peak-on demand, the EVs user can sell electrical energy at a higher price to the grid. Thus EVs acts as movable storage of electrical energy.

![Figure 2 V2g And G2v](image)

Figure 4 shows the summaries of the papers published in reputed journals. Series 1 indicates the number of research papers published in IEEE Conferences whereas series 2 and series 3 indicated numbers of research papers published in Elsevier and IEEE journals respectively.
Sectionalisation of the papers is as follows. Section 1 is for an introduction. Section 2 describes the methodology adopted for power flow. Section 3 explains the management of the V2G system. Section 4 describes the advantages of the V2G system. Section 5 shows the comparison between V2G, V2H, and V2V. Section 6 consists of the various challenges coming in the way of the V2G system. Section 7 explains the optimization methods used for V2G system. Section 8 is for the optimization objectives. Section 9 is for the conclusion and the future work. Section 10 is for the references.

2. Methods of Power flow for V2G
Three different types of EVs is suitable for V2G [5]. Proper communication is an essential part of the V2G system. The proper communication between the power grid and the EV battery is necessary for controlling the power flow.

The power operator wants the desired benefits from the communication facility. The main points of the consideration include profit maximization, greenhouse gases emission reduction and improvement in the power quality of the grid.

2.1 Unidirectional V2G
Unidirectional V2G refers to a technology in which there is a single direction power flow between the EVs and grid. It is attractive because of its infrastructure. These methods become more uneconomical with the addition of the controller. The unidirectional method improves the performance of the power...
grid like spinning reserve and power grid regulation. The smart trading policy is adopted to encourage V2G technology.

The optimization technique of V2G has following policies to maximize the profit by minimizing the emission [7]. Table 1 provides the value of voltage, current, and power for different methods of charging.

### Table 1 Charging Configurations and Ratings [6]

| Methods of Charging | Supply Voltage (V) | Maximum Current (A) | Maximum Power (kW) |
|---------------------|-------------------|---------------------|-------------------|
| AC Level 1          | 120               | 12/16               | 1.4/1.9           |
| DC level 1          | 200-450           | 80                  | 36                |
| AC Level 2          | 208-450           | 80                  | 19.2              |
| DC Level 2          | 200-450           | 200                 | 90                |
| AC Level 3          | 208-240           | TBD                 | >20               |
| DC Level 3          | 200-600           | 400                 | 240               |

2.2 **Bidirectional V2G**

Bidirectional power flow refers to a technology, in which there is a power flow in both directions between the EVs and the power grid. It has a number of advantages over unidirectional V2G. For the bidirectional power flow, it has an AC/DC converter and a DC/DC converter. Different Energy Management Strategies is adopted for EVs through the bidirectional [8]. Table 2 shows the comparison between unidirectional V2G and bidirectional V2G.

### Table 2 Comparison between V2G, V2H, and V2V

| V2G methods | Unidirectional | Bidirectional |
|-------------|---------------|---------------|
| Hardware required | Communication System | Communication System and Bidirectional Battery Charger |
| Power Level | 1, 2 and 3 | 1 and 2 |
| Economical | Less | More |
| Advantages | Prevent power grid from Overloading | Reduction in Power Grid Losses |
| Drawbacks | Limited Service | Complex hardware |

3. **Management of V2G system**

In the V2G system, different researchers have suggested model and management such as Optimal Energy Management, Intelligent Energy Resource Management and Battery Management System[8][10][11]. A number of charging strategies are planned for the adoption of EVs[12][13]. Talking about V2G system, and taking grid point of view, it is essential that there should be the proper arrangement of EVs charging for preventing conventional peak-load periods reducing the impact on the power grid. V2G is a new technology and therefore, the research on V2G is in the initial phase. The research on V2G emphasizes the structure, feasibility analysis and the working of each component. EVs may take part in power grid shaving. The various charging schemes of EVs are the mobile mode and parking mode. Paper [14] shows the strategies of control energy management and the algorithms for supervisory control that were used in EVs.

3.1 **Centralized V2G management**

Centralized V2G is a system in which there is a schedule for gathering the energy of EVs in specific areas considering the grid demand for controlling the charging/discharging strategies [15]. The adjustment of peak-load for EV charging is taken by the coordination of grids and charging stations. Paper [16] provides control strategies used for different type of EVs.

3.2 **Independent V2G management**

The EVs are often scattered everywhere which cannot be managed by centralized management. V2G adopted intelligent charger depending upon the cost, the reactive power demand and the electrical characteristics including voltage fluctuations. Paper [17] presents the smart charging strategies with
G2V and V2G charging structure proposed for plug-in EVs. Each region has different power load characteristics and the number of EVs also varies. Therefore, for the dispersed EVs should not have united scheduling. Based on the hierarchy control, the controlling structure of the EVs and the grid is divided into three levels: EV control center and scheduling of distribution system and scheduling of the transmission system. Paper [18] proposed an idea for modeling and control of a V2G charging station of EVs by using synchro converter technology. Paper [19] proposed a technique of the manufacturing for a controllable EV charger. This EV charger has the capability to do communication with an autonomous smart energy management system. It is designed for domestic locations.

Battery pack replacement management
Paper [19] proposed a solution of the battery which features a high ability of energy storage in braking conditions, overvoltage and under voltage protection. V2G analysis depends upon battery pack replacement. This method has similarities with the centralized V2G. The management strategy is different from V2G method. This method gives the advantages of sat charging and conventional charging reducing the problem of insufficient mileage. The charging station stores a large number of batteries in this method. In the V2G method, the grid scheduling demand plan can be easily achieved with the replacement of batteries. In these days we have adopted centralized charging and battery replacement methods. Paper [20] has six schemes which have been framed and verified: three smart unidirectional and three smart bidirectional algorithms including the V2G and V2H.

| Types of Car   | % of PEs | Battery Size (kWh) | Fuel Efficiency (Wh/km) |
|---------------|---------|--------------------|------------------------|
| Nissan Leaf   | 50      | 24                 | 173                    |
| Mitsubishi i-Miev | 25    | 16                 | 135                    |
| Chavy Volt    | 20      | 16                 | 224                    |
| Tesla Roadster| 5       | 53                 | 110                    |

4. V2G services and advantages
Paper [21] presents the advantages of the V2G technology for Plug-in Hybrid EVs. A number of advantages are seen using V2G technology in various countries in the world. EV owners, charging station, grid and utilities have various advantages. Some of them are the following.

4.1 Ancillary Services
In the paper [22], ancillary services are given. Ancillary services have mainly two categories known as the spinning reserve and the power grid regulation. Unidirectional V2G controls the EVs charging rate and thus provides the load only “ancillary services”. For achieving the ancillary services the aggregator communicates with a large fleet of EVs. The function of maintaining the frequency in order to satisfy the generation and load demand is done by the power grid regulation. The spinning reserve has a fast response that responds in 10 minutes for compensating the outage of generation.

4.2 Active Power Support
In the V2G service, power grid uses the excessive energy of EVs. This goal is achieved only by bidirectional V2G. The main objective of this service includes the flattening of the grid load profile by “peak load shaving” and “load leveling”. Generally, the demand is for a small duration of time in a day. At the time of peak load, it is economical to take supply from EVs. By applying this method, we can easily minimize the burden on power system components. One another big advantage is that EV owners will be rewarded at the superior energy rate. Paper [23] made a Housing Peak Shaving Algorithm (HPSA) used in houses that have a Plug-in Hybrid EVs.

Backup energy for home
Paper [24][25] gives the solution to the issue of RES by storing energy in the form of a fleet of EVs. The V2G system acts as a backup for RES such as solar and wind by providing alternative production. In the case of high production by RES the centralized power plants should reduce their production. An
attempt is to match the generation and consumption by charging and discharging of batteries of EVs. Excess energy is stored in EVs from RES and used when the demand is higher.

**Reactive power compensation**

Paper [26] discusses the reactive power compensation as a key feature in-built to the V2G technology. Voltage regulation is very essential for the proper functioning of the V2G system. Reactive power compensation provides voltage regulation in the grid. With the help of reactive power, there is an improvement in the power factor. Usually, reactive power compensator draws reactive power to the system. But, in most of the cases, a capacitive reactive power is preferred.

5. **Comparison between V2G, V2H, and V2V**

Figure 5 shows the various technologies used. Table 4 shows the comparison between V2G, V2H, and V2V on different parameters including key points, main factors, and functions. In some context, V2G is superior on V2H and V2V whereas in some other context V2H is better than V2G and V2V. V2V is also preferred in some places.

| **Table 4** Comparison between V2V, V2H, and V2V |
|-----------------------------------------------|
| **KEY POINTS** | **FACTORS** | **FUNCTIONS** |
| V2G | • A number of GEVs | • Control and Coordination from the grid operator | • Reactive power support |
| | • Less simplicity and more flexibility | • Number of aggregators | • Operating with Renewable Sources |
| | • Complex Control | • Battery capacity | • Release stored energy back to the grid at peak demands |
| | • Operation at a large scale | • Arrival and Departure time | • Grid Ancillary Services |
| | • Significant transmission losses | • Cost of Electricity | |
| | | • Driving habits of the user | |
| V2H | • Simple Infrastructure | • Type of Battery used | • Acts as a home back-up generator with a controllable load |
| | • with negligible transmission losses | • Characteristics of Battery Capacity | • Sell stored energy back to the grid at peak demand |
| | | | • Cost of Electricity is less at an off-peak time |
| | | | • Used for load shift by cooperating domestic electrical appliances |
| | • Easy installment | • Charging State | |
| | • More simplicity | • Driving habits of the user | |
| | • A single GEV to a single home | • Cost of Electricity | |

6. **Challenges behind V2G Technologies**

Paper [27] presents the current scenario, the latest development, and barriers in the implementation of EVs infrastructural and charging systems considering the charging codes and international standards. Despite, V2G implementation has a number of advantages and services to the power grid, it has also many challenges. V2G is not totally developed. For the adoption of V2G technology, we are also facing many barriers including economical social and technical challenges. V2G system has a huge impact on the distribution grid [28].

6.1 **Degradation of the battery**

In the adoption of the EVs, battery degradation is a great barrier. The 1/3rd whole cost of the EVs is used by the battery system. This paper [19] presents a prototype electric scooter based on the design of a battery. This battery is made from Li-on technology. The electric scooter is very efficient. Every battery has a certain number of charging and discharging cycles. After that, the efficiency of the battery decreases with the passage of time. The irreversible chemical reaction reduces the capacity of the battery. The battery aging effect depends on the charging and discharging rates. It also depends upon DOD, temperature, and voltage. The V2G technology has a requirement of such type of battery which has a maximum number of charging and discharging cycles. The paper [29] has modeling of the Lithium Ion used in EVs. Table 5 gives the data related to the charging of Nissan Leaf and Tesla Models [31].
Table 5. Battery Charging Times for Nissan Leaf and Tesla Models [30]

| Specification          | Nissan Leaf | Tesla Model |
|------------------------|-------------|-------------|
| Battery Capacity (kWh) | 24          | 85          |
| Range (km)             | 121         | 426         |
| Slow Charger (kW)      | 1.8         | 10          |
| Charge Time (hours)    | 21          | 9           |
| Normal Charger (kW)    | 3.3         | 20          |
| Charge Time (hours)    | 7           | 4.5         |
| Quick Charger (kW)     | 50          | 120         |
| Charge Time (1 hours)  | 0.5         | 1.25        |

6.2 Investment Cost
The high investment cost is also one of the major challenges coming in the way of V2G implementation. V2G needs an upgraded power system. For the V2G implementation, hardware and software infrastructure should be improved. Each EV which is participating in the V2G system will have a need of a bidirectional battery charger. The bidirectional battery charger has a complex controller and high tension cable. In the case of high tension cable, there is a need for safety. In the charging and discharging cycles, energy conversion takes place that results in energy losses in the power system. Paper [31] presents the Investment in the U.S. EV Market.

Social Barriers
Another serious challenge for V2G system is the public acceptance. EV users will store an amount of energy for the emergency purpose and unpredictable journey. Sharing energy by the grid system creates the problem of the range anxiety. The situation becomes worse due to the lack of a charging facility.

7. Optimization methods
The working of EVs with the power grid can create a complex V2G technology involving many nonlinear variables. There are different methods of solving optimization problems used in the field of engineering. These are the metaheuristic approach, an analytical approach and a hybrid of these approaches. Various methods such as Particle Swarm Optimization, Monarch Butterfly Optimization, and Genetic Algorithm are used for solving problems in the area of maths and engineering. Taking the microgrids point of view, Paper [33] presents an optimization method for EVs considering the time, space and energy transmission. Paper [32] provides the optimization constraints by PSO method. PSO is a computational method that solves a problem with the iterative method in order to improve the solution of the given problem. PSO is accredited to Kennedy Eberhart and Shi and it was based on the social behavior representation of the moment of organisms in bird flock or fish school.

Paper [33] shows the GA method used for the control of hybrid EVs. GA method is also commonly used. GA is a method that depends upon the evolutionary process of the living organism. It is a strong tool for solving various optimization problems. GA needs the genetic algorithm means a presentation of the potential solution. A string of real numbers is called chromosomes. For the new generation of the chromosome, the GA principle will repeat again after the evaluation process.

8. Objectives of the Optimization
8.1 Commercial aspects
The price of this technology consists of the fuel price, start-up price, and the V2G price. From the economical point of view, minimizing the power system price is the objective. Fuel price can be expressed in the forms of power unit generation. A huge amount of money is invested to restart a plant. The temperature of the boiler is a deciding factor in the start-up process for the gas turbine generation plant. If a unit shuts down for a short duration it will require less fuel otherwise the generation plant shuts down for a long duration of time needs a larger amount of fuel to warm up the boiler. Researchers are trying to find a way in which the overall V2G cost should be minimum.
8.2 Emission of the Carbon dioxide
For implementing the V2G system, minimization of the Carbon dioxide Gas is also playing an important role. The EU has introduced a trading mechanism, known as ETS. Each industry has a fixed amount of emission decided by ETS. If a plant exceeds the limit he has to purchase more allowance from the market otherwise it has to pay penalty for that.

Renewable Energy Generation
When renewable energy generates an insufficient amount of energy, the EV fleets will act as a backup battery for the energy demand. In case of the excessive power generation by the renewable source of energy, the EV will store the excessive power. The target of the clean power network and a reduction in the generation cost are achieved.

Power Losses and Load Curve
The excessive power stored in the EV battery is used as the active power grid. In many research papers, authors are trying to flatten the load curve by load leveling and the peak load shaving.

9. Conclusion and Future Work
The electrification of vehicles i.e. EV & PHEV offers a noise-free, clean, and efficient means of the transportation system as compared to the gasoline ICEV. Therefore the work presented in the manuscript is an exhaustive study for V2G, V2H, and V2V. Various segments, for instance, recharging infrastructure, approach and methodology adopted, and communication, signaling, and control aspects applicable to EV charging/discharging coordination applicable to optimization techniques.

Furthermore, aspects concerning the issues related to battery degradation are contemporary topics that also can be considered on account of EV charging/discharging coordination applicable to optimization techniques.

Also, from the automotive market viewpoint, there is a lot of potential for EV market research and design. Hence, novel market approaches for enabling the active or reactive EV integrated power system design, i.e. peak shaving, load shifting, valley filling, control of reactive power, and voltage regulation on the distribution level has been investigated.

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