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VEHICLE TO GRID CONCEPT AS PART OF POWER SYSTEM AND ELECTRICITY MARKET

Masters of science thesis

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ABSTRACT

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The demand of electricity is increasing day by day with the increase in world's population. Renewable energy sources (RES) are being integrated into the smart grid system. Renewable energy sources have fluctuating nature such as wind and solar power, and thus accurate forecasting of generation from these sources is nearly impossible. At the distribution end, load forecasting is also challenging as the load demand is not constant all the time. Hence to deal with the intermittent nature of RES and to fulfil the peak load demand, there is a need for a storage system that can be integrated with the smart grid environment. Electric vehicles (EVs) serve this purpose and replace the internal combustion engine vehicles in transportation. They are considered as mobile energy storage systems which do not only reduce the environmental pollution but also provide power to the grid in peak load time by storing energy in their batteries at off peak times when the demand is quite low.

The aim of this thesis is to understand the concept of V2G. It includes the short introduction of different types of EVs, their construction, advantages and issues related to them. Charging of EVs is considered as an important phenomenon as the penetration of large fleet of EVs in the grid when behaving as a load (charging), would impact the power system and may cause overloading. Thus to avoid this situation, an intelligent charging infrastructure is needed which is explained in this thesis. There are different applications for using EVs as supplying energy back to the system, such as vehicle to home (V2H), vehicle to building (V2B), vehicle to grid (V2G) etc. EVs charge their batteries in off peak time and then discharge them by connecting to the grid when the load demand is very high. This way of supplying power back to the grid is known as V2G.

The main concern of this thesis study is to analyze the different aspects of V2G. Basically, this thesis is a literature review of V2G concept and explained its mechanism, benefits, applications and challenges associated with it. Different case studies have been analyzed which explained the implementation of V2G. Moreover, this thesis demonstrates the concept of ancillary services provided by EVs in V2G mode. These ancillary services include frequency regulation and spinning reserve. Impact of V2G on power system has been studied in detail. Electricity market competition will increase with the increasing number of EVs which are supplying ancillary services to the grid.

PREFACE

This thesis is the part of Master's Degree in Electrical Engineering and written at Tampere University of Technology (2016). The Examiner and main supervisor of this thesis is Professor Pertti Järventausta.

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Maria Aslam

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LIST OF SYMBOLS AND ABBREVATIONS

SYMBOLS

A	Amperes
CO_2	Carbon dioxide
$	Dollar
€	Euro
SiO	Silicon monoxide
%	Percentage

ABBREVATIONS

AC	Alternating Current
BEV	Battery Electric Vehicles
CNG	Compressed Natural Gas
CS	Charge Sustaining
CD	Charge Depletion
DC	Direct Current
DOE	Department of Energy
DSO	Distribution System Operator
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
ESR	Equivalent Series Resistors
ESS	Energy Storage System
EU	European Union
e-mobility	electronic mobility
GEV	Grid Enable Vehicles
G2V	Grid to Vehicle
GHGs	Greenhouse Gases
GW	Giga-Watt
HEV	Hybrid Electric Vehicles
ICE	Internal Combustion Engine
IIT	Illinois Institute of Technology
ISO	Independent System Operator
kWh	kilo Watt-hour
kWp	kilo Watt peak
Li-ion	Lithium ion
LP	Linear Programming
MWh	Mega Watt-hour

MV	Medium Voltage
PEV	Plug-in Electric Vehicles
PHEV	Plug in Hybrid Electric Vehicles
PV	Photovoltaic
PQ	Power quality
PEVS/A	Plug-in Electric Vehicle Supplier/Aggregator
RES	Renewable Energy Sources
RT	Real Time
SO	System Operator
SLI	Starting Lighting Ignition
SOC	State of Charge
THD	Total Harmonic Distortion
TSO	Transmission System Operator
TWh	Tera Watt-hour
USA	United States of America
V2G	Vehicle to Grid
V2B	Vehicle to Building
V2H	Vehicle to Home
VPP	Virtual Power Plant

1. INTRODUCTION

Energy is the basic need of human beings but the way of using energy is causing serious environmental issues. There is a need to decrease the problems caused by environmental pollution especially carbon dioxide ($CO_{2)}$ emissions for a sustainable development. CO_2 emission from the internal combustion engine (ICE) vehicles is one of the main reason of pollution nowadays. Limited resources of fossil fuels as well as global warming are the main issues. Thus to reduce the consumption of oil there is a need to minimize the use of fossil fuels and oil for electricity generation. In a power system, production capacity should always be greater than the consumption to meet the peak load demand but this causes wastage of generation capacity at off peak times when the load demand is less than the production capacity. Moreover, the penetration of renewable energy sources (RES) is increasing with the smart grids but the intermittent nature of RES such as wind or solar causing certain challenges in the power system. Thus there is a need for a storage system which can store extra power produced by these sources and supply it to the power grid at peak load times [1].

Electric vehicles (EVs) are the battery driven vehicles which do not only serve the transportation purpose but also behave as an electricity storage system. They have potential to decease the fuel cost, reduce the oil consumption and minimize the dangerous emission of CO_2 [2]. EV has an electric motor and chemical batteries. Fuel cells or ultra-capacitors are used as energy sources in EV unlike conventional fuel engine in ICE vehicle [3]. EV gets energy from the pack of rechargeable batteries which store energy from the grid [4]. Thus EVs can be given another name of “Mobile storage system”.

EVs connect with the grid as load and charge their batteries. This is known as grid to vehicle (G2V) mode. They have capability to discharge their batteries and supply power back to the grid. This concept is termed as vehicle to grid (V2G). They can also supply power to the building and homes and these mechanisms are known as vehicle to building (V2B) and vehicle to home (V2H) respectively. V2G is a broader concept and an important application of EV. According to this concept, EVs can store energy in their batteries when the demand of electricity is low and can supply back-up power to the grid in peak load times. This allows the owners of EVs to take advantage by selling the energy to the power system. It also helps system operator (SO) to manage the electricity grid at peak load time. However, there must be a communication and control infrastructure for EVs to communicate with the grid [2].

In conventional power system, only unidirectional power flow is possible i.e. from generators to electricity users. In V2G mode, power flow is bidirectional, which means power can flow from grid to users (vehicles) as well as from users to the grid. It must be controlled by SO or some other aggregator. Moreover, there should be a communication infrastructure between the aggregator and electric vehicles. Figure 1.1 shows the proposed V2G system which explains the concept of bidirectional power flow [5].

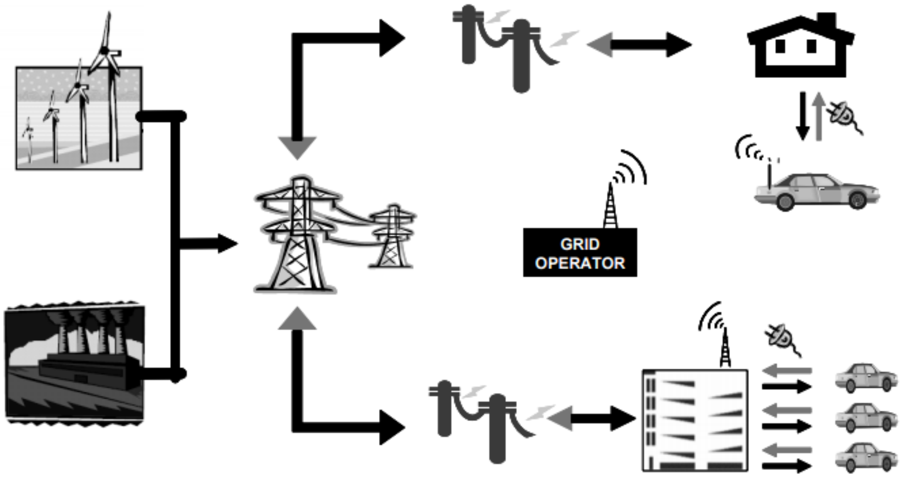


Figure 1.1. *Bi-directional power flow through V2G [5].*

It is shown in the figure 1.1 that electricity is generated from primary energy sources, transmitted and distributed to end users. Illustration of bidirectional power flow is clear from double arrows which show that user's own vehicles can provide power to the grid through bi-directional communication. Thus there is a need to provide a communication infrastructure for the bi-directional power flow between power grid and EV [5].

There are different actors or operators in a power system that are responsible for different tasks. Transmission system operator (TSO) is an operator that transmits electricity from generation plants over electrical grid to local electricity distribution operators. Distribution system operator (DSO) is the operating manager of electricity distribution networks. The DSO has responsibility of managing security of supply and quality of services. Moreover, it also involves in active network management operations in smart grid infrastructure [6].

The purpose of this thesis is to describe the V2G concept in detail which includes its benefits, applications and concept of intelligent or smart charging. Moreover, the thesis attempts to determine the issues related to the utilization of this concept from power system reliability and power quality perspective. The thesis consists of a literature survey on V2G concept. It includes the study of the impact of V2G on power system operation, including both transmission and distribution as well as electricity market. It also deals with the certain challenges related to charging and provides the appropriate solution for optimized charging infrastructure.

The thesis begins with a short introduction to EVs and V2G concept in chapter 1. Electrification of transportation is discussed in chapter 2 of the thesis. Chapter 3 provides the advantages and drawbacks of V2G mode of operation. Some examples of V2G are discussed in Chapter 4. Impact of the V2G on power system is discussed in the chapter 5 of the thesis. Finally, Chapter 6 of the thesis consists of conclusions and future prospects.

2. Electrification of transportation

An increasing concern of environmental impacts of fossil fuel and energy sustainability are causing the remarkable changes in electric power system and transportation sector. Serious environmental, social and economic issues are rising because of greenhouse gases (GHGs) related to ICE powered transportation. For instance, in United States of America (USA) by the year 2010 the total emission of CO_2 from the transportation sector was approximately 1881 million metric tons and from electric power sector this emission was 2271 million metric tons. Thus there is need to reduce these CO_2 emissions by using RES in the power system as well as by electrification of transportation system [7].

Electric transportation is defined as “a technological shift in advanced electric drive vehicles and reshaping of the automotive industry by utilizing the more efficient source of power that is electricity”. Electrification of transportation is the most advanced and promising way to improve the efficiency of both the power system and the transportation system. As an advanced control infrastructure, exchange of energy is also possible between vehicles and grid [7].

As batteries and power electronic devices are getting better day by day, so number of electric vehicles should increase on roads and it would be possible only in case when fuel price will go high. Batteries that are used in the EVs may be recycled after the expiry of their life time and thus can be utilized again. According to a survey in [8], environmental impact of pollution comes from the burning of fuel rather than manufacturing and disposal of oil. Thus by using batteries in EVs it would be possible to use fuel free transportation that will cause reduction of harmful emissions on environment [8].

Electric transportation simply is a concept that is related to the replacement of ICE vehicles by the EVs and by making the fuel combustion transportation truly depends on electric energy. So there is a need for electric transportation both for the purpose of moving people and goods and also for power system efficiency improvement. Charging of EVs is considered as a high power load and consumes a great amount of energy. Thus DSO has to manage the operation of the grid accordingly [9].

To get a sustainable transportation that causes minimum emission of hazards substances and maximum efficiency, there is need to increase the electrification level in each vehicle. The electrification level can be defined as “The percentage of vehicle’s electric power to its total power”. Thus there are vehicles available from 0% electrification level i.e. contains no electric power to 100% electrification level i.e. fully electric powered vehicles. Conventional vehicles have electrification level of 5-10%. This level should be increased in the upcoming years to get maximum reliability as well as efficiency from transportation sector and power system [10].

EVs contain batteries, energy storing devices, electrical machines, power electronics devices and embedded software as well. Electric machines that are mostly used in the EVs are permanent magnet motors, induction motors and switched reluctance motors. Each one of them has its own benefits as well as drawbacks. Power electronic converters are used in EVs such as alternating current/direct current (AC/DC) converter, alternating current/alternating current (AC/AC) converter and direct current/alternating current (DC/AC) converter. All of them are used to convert and control electric power in the vehicles [10].

Three different packs of batteries can be used in the EVs which are lead-acid batteries, nickel metal hybrid batteries and lithium ion (li-ion) batteries. Lead acid batteries are typically used for starting, lighting and ignition applications commonly known as (SLI) while nickel metal hybrid and li-ion batteries are used for traction purposes. From the past few decades, car manufacturers are mostly utilizing li-ion batteries because of their higher specific energy [10].

Together with the batteries used in EVs, ultracapacitors or supercapacitors are used as new emerging technology in the automotive industry. They are energy storing devices which can store and discharge energy rapidly. The performance and efficiency of EVs can be improved with the combination of batteries and ultracapacitors. Batteries serve the purpose of energy storing devices in EVs while ultracapacitors behave as power storage devices [10].

2.1 Types of EVs

There are different types of EVs based on certain characteristics associated with each one of them. In the following section, three different types of EVs and their features are discussed.

Battery electric vehicles

Battery electric vehicles (BEVs) or also known as pure electric vehicles completely utilize batteries instead of gasoline or other fuels and thus there is no risk for the emission of harmful oxides just like traditional gasoline powered vehicles. These vehicles rely only on electricity, having very smooth and quiet performance. However, BEVs have short driving range thus they need large battery packs to maintain long driving range which in turn requires long charging time and thus consume high amount of power from the grid to charge their batteries. Currently, li-ion batteries are becoming more popular than conventional lead acid and nickel metal hydride batteries due to their longer life time and higher energy density [11].

During charging cycle of battery, deterioration of battery occurs and its capacity decreases if only conventional carbon based materials are used in batteries. Researchers at Nissan motor company are developing the batteries which contain silicon monoxide (SiO) which can carry more li-ion charges that can increase the battery capacity and thus longer life span can be achieved. Utilization of li-ion batteries can also increase the driving range of EVs [12].

Hybrid electric vehicles

As the name shows, hybrid electric vehicles (HEVs) are the combination of battery EVs and conventional ICE vehicles. They utilize both batteries as well as conventional fuel engine. They have all the characteristics almost same as those of ICE vehicles. The only difference is that they use less fossil fuel as compared to ICE vehicles [11].

In HEVs, battery powers the electric motors. The batteries of these vehicles can be charged by two different ways. First way is to charge the battery of HEV by regenerative braking. Regenerative braking is a practical system of applying brakes frequently specially in urban areas. When a driver applies brakes the electric motors start behaving like a generator and transform the vehicle’s forward momentum into electricity. The battery of HEV can also be charged by conventional fuel engine which is used in vehicles. The engine is powered by fuel, compressed natural gas (CNG), biofuel or diesel which feed the generator. The generator then feeds the electricity into batteries to charge them [10].

Plug-in hybrid electric vehicles

Plug-in hybrid electric vehicles (PHEVs) are the HEVs which can be plugged into the grid. PHEVs can be recharged by plugging the batteries of these vehicles into the plugging outlet. They have batteries larger than HEVs but smaller than those of BEVs. Due to this larger battery pack, they have longer driving range than HEVs. There are two modes of operations in PHEVs. Charge sustaining mode (CS) and charge depletion mode (CD). In CS mode of operation, these vehicles rely both on electricity as well on gasoline to sustain the state of charge (SOC). SOC of a battery is the measurement of how much energy is remaining (in percentage). On the other hand, in CD mode PHEVs utilize electricity until the batteries get drained and then switch to fuel. PHEVs have longer driving range than that of BEVs [11].

PHEVs can be operated as a load in charging mode as G2V and as a generation in discharging mode as V2G. According to a research, almost all the private vehicles are parked 93-96 % of time in their whole life time. So it would be more advantageous to utilize these parking vehicles to be operated as V2G mode. Thus it enables the concept of using cars as mobility service as well as a storage system [6]. When the PHEVs are stationary and parked, they recharge their batteries by drawing electric power from the grid [10].

With the recent developments in power electronic devices, the market progress of PHEVs has increased. It is because of the reason that bidirectional converters enable the different mode of operations with the EVs such as V2H, V2B, and V2G. For instance, AC/DC converters allow the connection of EV with the grid so that it can draw AC power from the grid at high power factor and low total harmonic distortion (THD) and then this vehicle can supply the stored power back to the grid when the power system requires it [10].

2.2 Advantages of EVs

EVs have many advantages over conventional transportation. Some of them are discussed in the following section:

Electric cars are charged by electricity and run on it instead of diesel or fuel. Thus the owner has to pay less comparatively. Though electricity is not free but the cost of charging the EV through electricity is always less than the fuel price in conventional vehicles [13].

One remarkable benefit of using EVs is that the maintenance cost of these vehicles is very low as they don’t use fuel engine which require special maintenance. All these vehicles run on electricity thus there is very low maintenance cost on them. On the other hand, there might be a need to change the batteries over certain times of years [13]. Although the capital cost of EVs is higher than that of ICE vehicles but this high capital cost is expected to decrease in the near future. Moreover, the lower maintenance cost gives a favorable bias over ICE vehicles as far as high capital cost is concerned [14].

Electric transportation is a great contribution in making the environment eco-friendly as the EVs have no CO_2 or any other emission of harmful gases. USA department of energy (DOE) estimated that if only 10% of automobiles are zero-emission vehicles such as EVs then 60,000,000 tons of GHGs can be eliminated per year and amount of air pollutants can be reduced to 1,000,000 tons per year. By achieving 100% electrification, following environmental benefits can be obtained [14].

- Global warming is caused by emission of CO_2 in the air, thus by replacing every single ICE vehicle with the EV this CO_2 emission would be cut into half.
- The electric motors used in the EVs are able to provide a smooth and noise free drive over long distances. Thus noise pollution can be reduced by using electric transportation.
- As EVs do not use engine or fuel oil thus wastage of oil dumping pollution would be decreased.
- Nitrogen oxides which are the sources of GHGs emission would be decreased by using EVs. This GHGs emission is one of the main cause for global warming.
- EVs also eliminate the causes of depletion in ozone layer. Reduction of smog is also possible by EVs.
- Today’s transportation industry is heavily dependent on the oil reserves which will depleted out in the near future. In USA a conventional ICE vehicle uses 94 barrels of oil in its whole life time while EV utilizes only 2 barrels. Although oil is used for the generation of electricity in EV process but the percentage of this oil utilization is only 4% as shown in the figure 2.1 [14].

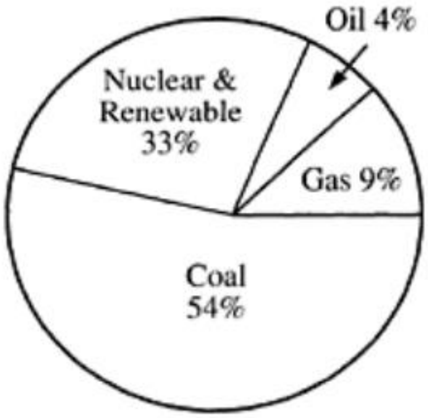


Figure 2.1. *Pie-chart for different sources of electricity generation in USA [14].*

Figure 2.1 shows utilization percentage of different sources to produce electricity in USA. It can be seen from the pie-chart in figure 2.1 that the consumption of oil used for the electricity generation is only 4%. Hence, through electric transportation system dependency on limited reserves of oil can be reduced to much extent.

2.3 Challenges of EVs

Apart from many remarkable advantages that are being offered by electric transportation, there exist some disadvantages of this modern technology which are discussed below:

- All the public places have no charging stations. The development of charging stations is under process [13].
- Due to battery degradation problem, its replacement is necessary in almost all types of EVs after few years [13].
- Some models of EVs are still very costly which means initial price is very high up till now [13].
- Certain areas which are already facing power shortage are not suitable for this transportation as over loading due to charging of these vehicles will cause extra burden on power system [13].
- Limited driving range of EVs is a big issue to deal with but with the passage of time this challenge can be overcome by enhancing battery’s capacity and using fuel cells [14].
- Time taken by the vehicles to recharge their batteries fully is quite long and usually depends on the charging stations. Hence large number of charging stations and charging management infrastructure is required. This advance infrastructure will give the information to the owner of the EV that which time is suitable for charging

according to grid capacity and low power rates. This type of infrastructure is known as “smart charging”. So intelligent or smart charging techniques are required to be build up to get fully benefited by this electric transportation of modern technology [14].

- Storage is not a piece of cake and have many associated problems. However, different countries have their own agreements with each other such as an organization called “Union for the coordination of transmission of electricity” (UCTE). The different partners of UCTE purchase and sell electricity to each other. Enormous flow of energy is possible between partners of UCTE [15].

2.4 Charging of Electric vehicles

Charging of EVs can be done in homes as well as through different public charging stations. These charging stations are also known as EV charging stations, electric recharging point or electric vehicle supply equipment (EVSE) [16].

The public charging stations are provided either by government or by private companies for charging of vehicles. Figure 2.2 shows a public charging station where different cars are being parked and getting charged at the same time [16].

***Figure 2.2** Electric vehicles charging station [16].*

The part of the needed electricity is produced by local solar panels as shown in figure 2.2. Smart grid provides the flexibility for charging of EVs as this can be done in periods of lower energy demand, decreasing or increasing the charging power, or in emergency situations the charging process can be stopped. Moreover, the integration of RES is possible such as charging can be done by solar or wind [17]. In order to ensure the demand flexibility in PEVs, the charging of these vehicles need to be coordinated. This coordination of charging can be performed within two main types of control architectures. These are centralized and decentralized control architectures. These categories can be defined by the level on which the charging decision is made by meeting the objective and constraints requirements. Centralized control mechanism relies on planned scheduling procedure that are communicated to a planned scheduling instance. Distribution system operator (DSO) and transmission system operator (TSO) are considered to be responsible to make sure that technical constraints are meeting up the requirements and thus ensure the safe and reliable operation [18]. However, this task management varies from country to country, as in some market models, DSO and TSO are not responsible for this task. This centralized charging mechanism has high degree of reliability and can be easily integrated into the existing power system but certain issues and challenges are also there to deal with. For instance, very high degree of information and communication is required in this type of infrastructure so that accurate planning can be done by central instance. Moreover, increasingly more complex constraints get involved in this scheme which need to be programmed and by the addition of every new EV in the centralized control architecture, the degree of this complexity goes high. EV owner does not have any control on the charging process of his vehicle. Figure 2.3 shows the charging coordination of centralized, decentralized and hierarchal control architecture [18].

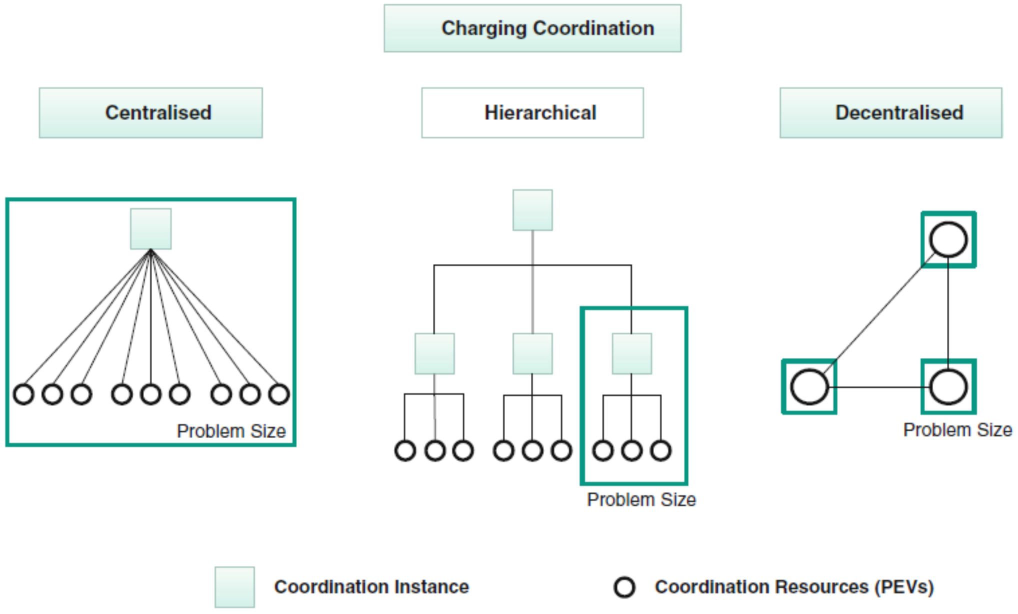


Figure 2.3 *PEV charging coordination schemes including three different types of control mechanisms [18].*

Decentralized coordination is purely based on the pricing mechanism. It enables the owner to make decision about the charging process that when and which objective charging process need to be organized. The prices can be uniformly distributed or may vary, for instance, in some countries, electricity prices depend on the location and demand response time. More exchange of information is required in decentralized coordination approach but the number of parameters that are needed to be communicated are less and hence system is not so complex unlike centralized coordination [18].

Hierarchical charging coordination is a mixture of both control architectures: centralized and decentralized. It can either follow a schedule or a price based control approach. Prices can be determined by an aggregator or by an auction. An aggregator is a mediator between the electricity wholesale and retail market. The main objective of aggregator in a power system is to create the profit from different cost structures between different bulk power markets and customers [19]. These prices set by aggregators or day-ahead spot markets can be communicated to the owner of vehicle. Prices may vary based on the location [18].

During the day time, when the EVs are mostly on the roads or in parking of working places, implies that the charging will be done in the evening when the owner of car will arrive at home. This means that the charging of EVs load will coincide with the already existing peak load in residential areas. Thus uncoordinated charging can result in excessive peaks that occur just for a few hours in a day, while the remaining part of the day is unaffected. This could have long lasting effects on distribution grids due to high peak power demand which alternatively results in voltage drop and thus increase the cost of electricity by need of network investments to strength the network. Usually cars are parked for a longer period of time at night and for some hours during the day that would make them to be used as a storage potential and balancing power. The EVs can also be charged through the buildings at the time when the production or generation of power is more than consumption, for instance at the day time when solar panels are producing excess power [17].

Traditional charging of PHEVs and BEVs includes either slow charging or fast charging options. Slow charging and fast charging both depend on power rating and hence on time of charging. Usually in slow charging process, the battery of vehicle gets full in a duration of 6-8 hours by 3kW charging power. This time is almost equivalent to charge the vehicle over the night time. As far as fast charging is concerned, it is supposed that any charging other than slow charging is considered as fast charging. However, the main issue in slow or fast charging is that both of them operate in any case without knowing the real time status of power system grid. Thus in peak load time, the addition of these EVs load will become the cause of producing the surges at peak or rush hours. Thus there would be a risk of security and unreliability of power grid [20].

2.5 Intelligent or smart charging

Many researchers have concluded that uncoordinated charging of PHEVs leads to power losses and voltage deviation issues. Thus there is a need to determine optimum charging schedules and all the researchers have agreed that if proper load management techniques would be applied, the losses and voltage deviation problems can be avoided [18].

Thus the idea of intelligent or smart charging has been proposed that will take into account the real-time status of power grid utility as well as the desire of the owner for charging the EV simultaneously to avoid network reinforcements, conventional peak loads and associated costs. Hence this scheme can balance the power demand and storage capability according to the need [20]. Smart charging provides active management system of charging. It contains two hierarchal structures from which one is leaded by plug-in electric vehicle supplier/aggregator (PEVS/A) and other one by DSO. The controlling of the charging will provide benefits for both of them. PEVS/A will have possibility to take benefits of flexible charging. PEVS/A can charge their vehicles when charging rates are very low and thus load management of these charging vehicles can be shifted from peak load hours to off peak load times. It will reduce the power losses, improve the operating conditions of power system and will reduce the need of investments by DSO to reinforce the power system [18].

In normal operating conditions, PEVS/A will monitor all the vehicles connected to the grid and their respective states. Certain set points are send to vehicle controllers related to charging rates as well as for the request of several ancillary services. This can be achieved by communicating the SOC of each vehicle to the PEVS/A after regular intervals just to make sure that at the end of the charging process, batteries are fully charged according to owner's requirements. In case when the grid is operating near its technical limits, DSO can also send set points to PEVs. This type of charging control provides most efficient usage of available resources and provides necessary voltage regulations. Thus smart charging supports the load management in a way that it fits with the purpose of PEVS/A as well as for the requirements of power system [18].

Figure 2.4 shows the power load curve of a grid within one-day period for conventional and smart charging [20].

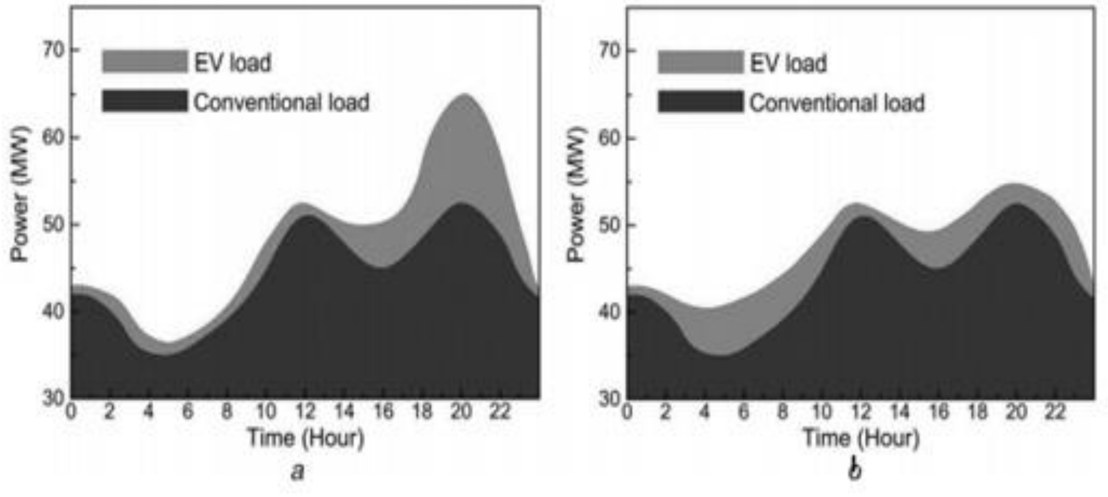


Figure 2.4 *Load curve for different charging strategies, a) for conventional charging b) for smart charging [20].*

It is clear from the figure 2.4 (a) that in case of conventional charging, EVs load will cause to add up in the already existing peak load. On the other hand, in smart charging strategy, EVs load flatten the load curve as shown in figure 2.4 (b) that will ultimately reduce the operating cost, increase the system efficiency and reliability. Another main advantage of smart charging technique is to enable the EVs to be charged from the power that is generated by renewable energy sources. For the execution of smart charging technique, communication among EV, electric vehicle supply equipment (EVSE), control center and power grid is an important factor to be considered [20].

As discussed in Chapter 1, the smart grid is the natural platform for the integration of smart charging process of vehicles. Figure 2.5 shows the interaction of smart grid with smart charging of PEVs. The grid supervisor determines the energy dispatching strategy for each vehicle and power distribution grid delivers the energy to each vehicle according to that strategy. Charge monitor is connected with the core controller. Its purpose is to control and monitor the battery SOC and network operating conditions [21].

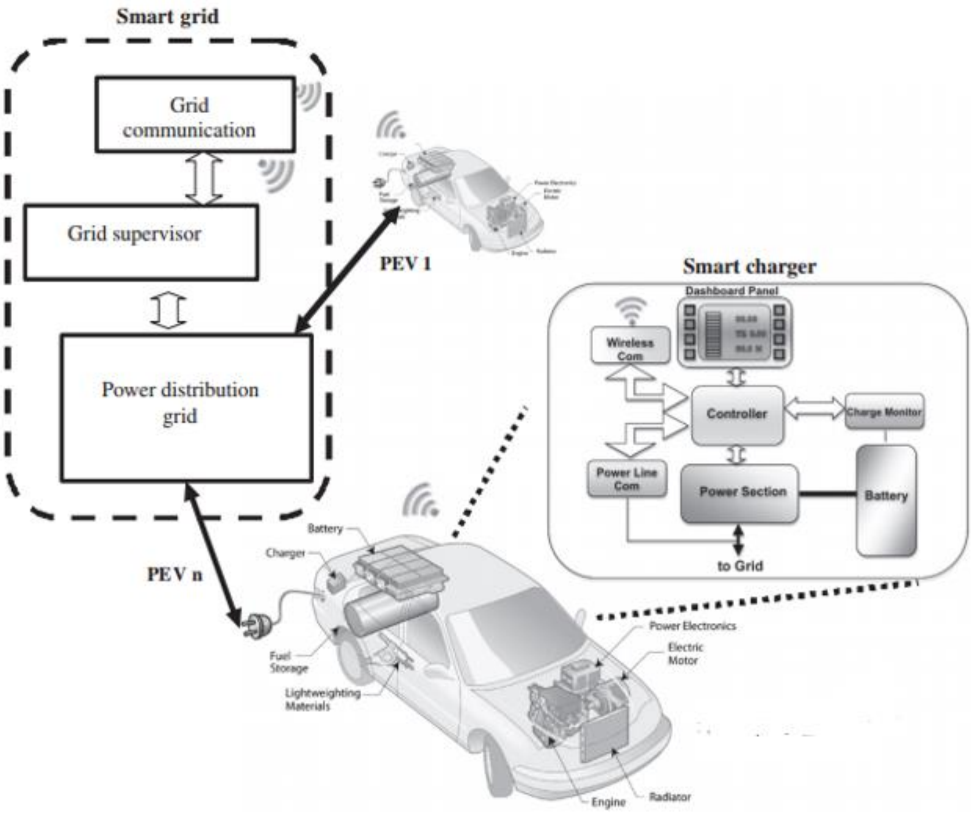


Figure 2.5 *Smart grid interacting with PEV smart chargers [21].*

As bi-directional communication is possible in smart charging method thus it causes an intelligent coordination that results in decreasing the peaks in the grid. Flexible charging process is possible in this method as it will take into account the available utility grid capacity as well as the EV user desired constraints at the same time [22].

2.5.1 Owner’s role in Smart charging

The implementation success of smart charging and electronic mobility (e-mobility) depend mostly on owner’s need and behavior. Smart charging enables the owner of EV to play an active role in the way they use energy. At the cost of their freedom to charge their vehicles whenever they want to, they can get benefited by low cost price of energy and advanced services by using electricity for charging at off-peak times. This will result in lower cost of ownership for the EVs owner. Through appropriate optimization of electricity utilization by smart charging process, they can bring remarkable social and environmental benefits by playing active role [17].

To make the owners more active and engaged in smart charging techniques, it is crucial that they are well-informed and motivated about the charging strategies. They will play an active role in charging schemes only when they are offered attractive low electricity rates. They should be provided not only the important information about charging scheme but also some necessary tools for the process. Smart charging techniques should must be encouraged by grid tariffs and prices [17].

As RES are penetrating into the power system day by day and EVs are increasing as loads into the power system. There is need for smart grid infrastructure for the manipulation of smart charging of EVs. The communication is needed between EVs and smart grid system in a more reliable, easy and efficient way [17].

For an efficient flow of information, smart charging demands intelligent bi-directional communication. In this way the information about several grid constraints such as RES sources available, maximum demand and available capacity should be considered. Moreover, detailed and clear information should be provided the to the customers so that they would be able to come to know the variable price rates for different time intervals [17].

2.5.2 Challenges in Smart charging

Apart from numerous advantages which are offered by smart charging mechanism, there are certain challenges and practical issues related to it. Some of them are discussed in the following section.

Formulation of the correlational model between information flow and energy is quite complex and is considered as a big challenge to have a coordination between both of them as illustrated in the figure 2.6 [20].

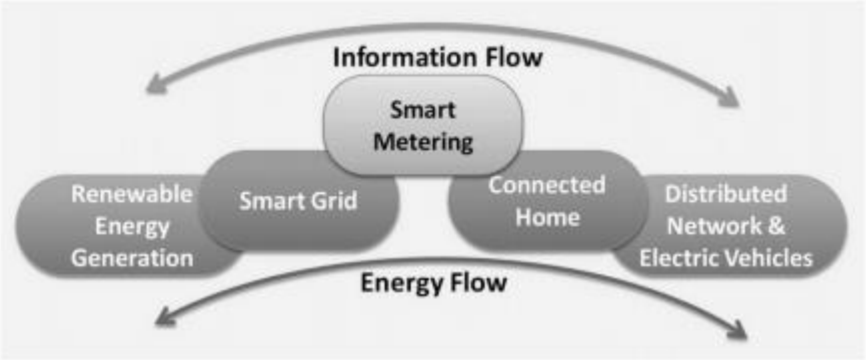


Figure 2.6 *Smart charging integration of information and energy flow [20].*

It is obvious from the figure 2.6 that some integration pattern is needed among RES, smart grid, smart metering, homes and EVs for the flow of information and energy in both directions. This bi-directional flow will then enable the connection of vehicles back to the grid as V2G concept [20].

Obtaining, transmitting and processing of the information flow is quite complex. Also affordability of energy cost and service cost is high [20]. User's experience and willingness towards smart charging technique effect a lot. For instance, the way he applied for charging i.e. conventional or friendly [20].

Hence it can be concluded that smart charging is the best solution for charging of EVs to overcome the power peak due to conventional charging. However, these above mentioned issues need to be solved to get maximum benefits of this scheme.

3. VEHICLE-TO-GRID (V2G)

Electric transportation offered a considerable change in the transportation system as well an improvement in the power system's efficiency. RES are being introduced in the existing power system to make it smart power system. There is a need also to have electric transportation system of EVs which can be integrated with the upgraded power system. With the increase in penetration of EVs, the challenges in the electricity management for smart grids are increasing due to increasing loads of EVs. However, EVs also support the power grid by serving as mobile energy storage system and providing power back to the power system through V2G mechanism. This broader concept of V2G can be implemented in the residential areas to reduce the burden of load on transformers or to increase their capability to deal with the RES penetration. A good corporation between grid operator and EV's owner is required for this concept to be implemented [23]. Figure 3.1 shows that power flow between vehicle and grid is bi-directional as V2G and G2V.

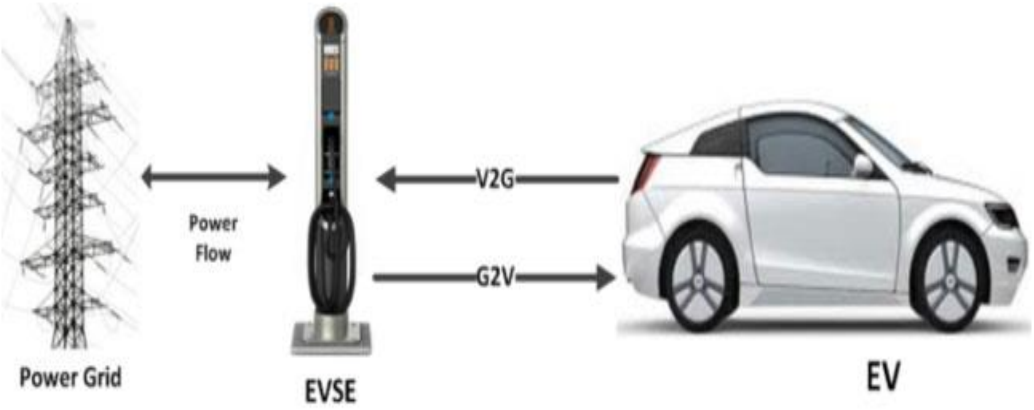


Figure 3.1 *Schematic diagram of V2G and G2V [23].*

The power flow is through EVSE which acts as a medium between EV and grid as shown in figure 3.1. G2V means that EVs are charging their batteries by taking supply from the electric power grid and then providing electricity back to the grid as V2G i.e. discharging their stored power [23].

Figure 3.2 presents certain general grid elements, RES such as solar power plants and wind farms, loads and some other smart systems such as smart buildings, smart homes etc. [24].

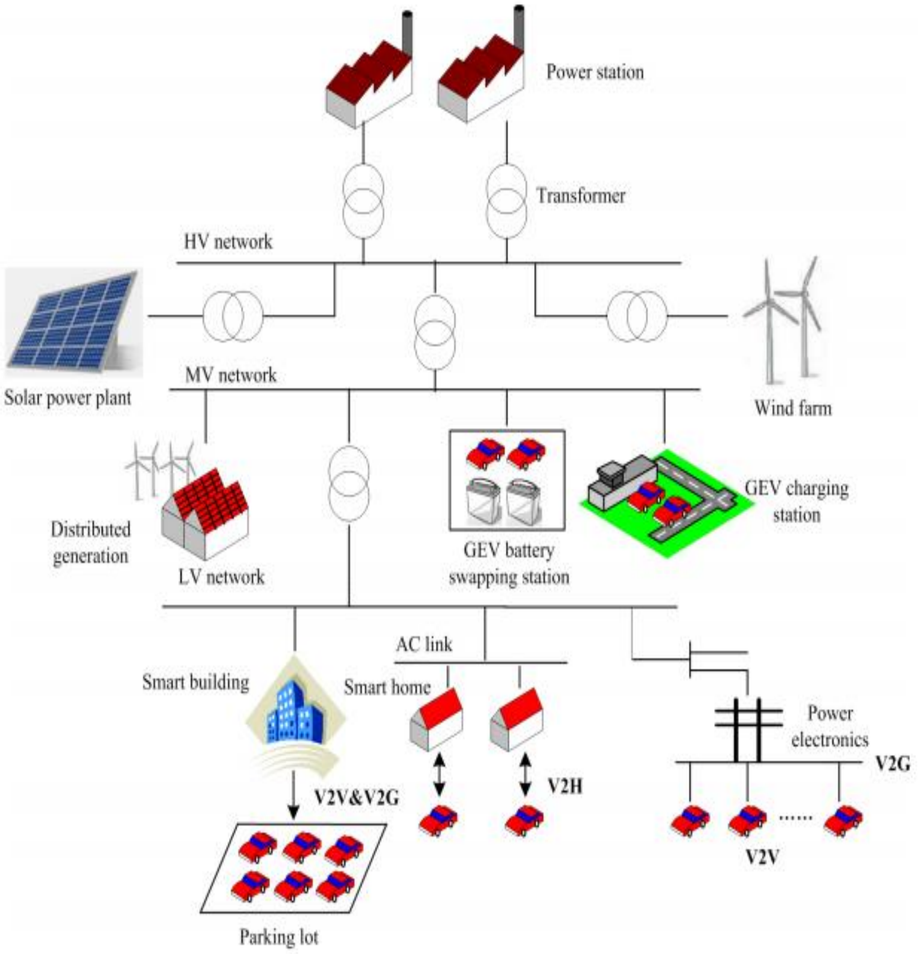


Figure 3.2 *V2G framework [24].*

It can be seen from the figure 3.2 that distribution generation, grid enabled vehicle (GEV) charging station and GEV battery swapping stations are connected with medium voltage (MV) network. Battery swapping station is a place where the depleted batteries of EVs are replaced with fully charged batteries [24].

Apart from V2G, there are two other modes of operation through EVs, such as V2B and V2H. V2H is a concept that is used to exploit PEVs possibilities to store energy from local distribution grid and provide this stored energy to home loads. It can increase system efficiency, reduce electric bills and provide backup power in emergency cases. This V2H system is composed of at least one PEV, a bi-directional charger, home loads, a local distribution grid, a smart meter, smart home and a home energy management system.

V2B is often known as an intermediate step between V2G and V2H. However, it can provide significant advantages to building owner. Hospitals, office buildings, shopping malls, restaurants, universities and many others can be benefited by V2B technology. It can also support critical loads in the buildings. V2B system consists of number of PEVs, local distribution generation, critical loads and a management system which is known as building energy management system.

3.1 Functions of V2G

Basically V2G has four main functions which are valley filling, peak shaving, frequency regulation and spinning reserve. All of them are described in detail as follows:

Valley filling

Valley filling is a term commonly used in the Power system. It can be defined as charging of EV at night when the demand is low or at off-peak load.

Peak shaving

Peak shaving can be considered as supplying power back to the grid when the demand of electricity is high i.e. in peak rush hours. V2G has a capability to help balancing the load by valley filling and peak shaving terminologies.

Frequency regulation

The power system infrastructure is a network of wires and switches controlled by high-speed computers. Its basic function is to move power from generation to utilization point. In a power system, the load and generation must be balanced all the time. The energy flow is in the form of real and reactive power. In balancing the load and generation the system frequency must be kept at, or very near to, nominal frequency which is 60 Hz for United States and 50 Hz for many other countries. The deviation from this nominal frequency requires some action by system operator to keep the power system balance. If the frequency is too high, it means that generation is more than load. Thus in this case load must be increased or generation must be reduced to keep the system balance. If the frequency is too low, it means that there is too much load in the system and the generation must be increased to meet the load demand or load should be decreased to maintain the power balance in the system. These adjustments are known as “frequency regulation” or simply “regulation” [25].

The most valuable ancillary market is the frequency regulation market. Regulation is responsible to maintain the nominal frequency (50 Hz or 60 Hz). This frequency is maintained by a real time communication signal sent by grid operator often known as “regulation-up” and “regulation-down”. When the load exceeds generation, system operator sends a signal for regulation up. If generation exceeds the load, the call for regulation down is send by system operator to decrease the generation in order to maintain the frequency. The time scale for this communication signal is very small. Thus it can be said that EVs can provide regulation as it can be used both as load and generating source. In this way frequency can be maintained balance by charging the battery of vehicle when there is too much generation in the system. When there is too much load in the system, they can behave as generating sources by discharging the battery power [25].

Besides this regulation service, EVs can provide some other services when connecting to the grid such as spinning reserve, peak management and back-up service etc. Back-up service is provided when one or more vehicles are connected together to behave as a micro grid in case of power outage in a neighborhood. Peak management concept can be realized as when there are number of EVs parked and connected to reduce the system peak. Thus by having large number of EVs in V2G mode, an emerging and optimized storage system of electricity can be established [25].

Spinning reserve

Spinning reserve is a generation capability to provide power in unplanned events immediately to the grid and can reach its maximum capacity within 10 minutes. It is called by DSO or TSO. The power must be supplied through an electrical equipment which is synchronized with grid. The cost is paid to provide power during emergency situations such as in case of generator failure etc. The typical call for spinning reserve is almost 20-25 times a year. For example, in USA, in the year 2007 the minimum duration for this reserve was 5 minutes while the maximum duration was 51 minutes [25].

In either ancillary service market (regulation or spinning reserve) the maximum value potential can be determined by its capacity to provide high power connection in bidirectional capability. Its means that vehicle can sell both regulation up and regulation down anytime as per requirement [25]. Figure 3.3 shows the comparison chart of high potential value of regulation and spinning reserve values. This shows the ten-year present values produced by V2G capable vehicle by assuming that it provides V2G service 80% of the time in a year, i.e. 7,008 hours per year.

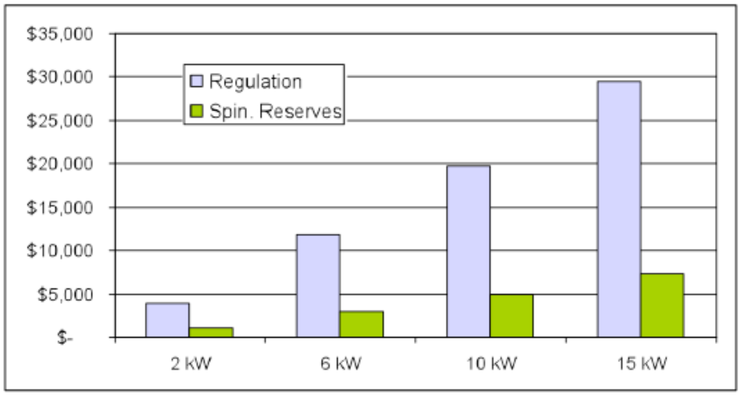


Figure 3.3 *Discounted present values of gross revenues of selling regulation and spinning reserves at different power levels [25].*

Figure 3.3 shows the much higher value of a high power connection in both energy markets, i.e. regulation and spinning reserve. The figure also illustrates the higher potential revenue in the regulation market, compared with spinning reserves. It also shows that an EV capable of providing 15 kW is more valuable than a vehicle that is providing only 2 kW based on regulation and spinning reserve values.

3.2 Advantages of V2G

V2G has several advantages which are discussed as follows:

- In V2G mode, the total capacity of EVs fleet is considered as a virtual power plant (VPP). V2G capacity along generation and transmission sectors can be evaluated through VPP. The purpose of VPP is to balance the power supply and demand and decrease the generation of power plant. This can also be utilized for replacement of costly power plant units in high demand periods. This approach can also be used for minimizing pollution, decreasing energy cost, and increasing the integration of RES into the existing power system. The total capacity of EVs batteries is available for VPP to provide necessary grid services along with other resources. Accordingly, VPP concept is used in micro grids as a backup for intermittent nature of RES [2].
- To get the more secured services of V2G approach, optimal placement of EVs is needed to be optimized. Optimal placement of EVs is necessary in micro grids and distributed grids to deal with the issues such as outage management, emergency conditions and system security related problems. This application requires the optimized parking lots for placement and dispatch of EVs power. Thus EVs should be placed in an optimized way such that their location can be identified [2].
- In micro grids V2G provides services for voltage and frequency regulations. Mostly the resources that supply electric power to the micro grids are RES and due to their intermittent nature, the storage capability of EVs reduce the unreliability and uncertainty of these RES and provide active demand side management in autonomous grids [2].
- Apart from supplying power to grid, V2G can be utilized to meet peak hour demands such as providing power supply to the residential and commercial buildings as V2B and to the houses as V2H. Public charging lots such as shopping centers, offices and gas stations which are equipped with bidirectional chargers and controllers can help to integrate this vehicle's energy with the building or residential peak load curve [2].
- "Valley filling" is term commonly used in the Power system. It can be defined as charging of EV at night when the demand is low or at off-peak load time. Another term "Peak shaving" can defined as supplying power back to the grid when the demand of electricity is high i.e. at peak rush hours. V2G has a capability to help balancing the load by valley filling and peak shaving terminologies. By this way load management becomes easy which improves the efficiency of power grid [26].
- V2G can help the power system to meet sudden demands in case of emergency such as shortfall or in type of typical fault occurring situation. This is known as spinning

reserve capability. V2G can provide supply as a backup to meet the sudden load demand [26].

- In the time period of high demand, the price of electricity goes very high to purchase. However, peak shaving helps to reduce the high cost of electricity. This can be made possible by storing excess energy from RES into this storage system of EVs and after that, V2G mode of operation allow the feasibility of peak shaving load [27].
- PHEVs provide primary necessary services which are known as ancillary services. The purpose of these ancillary services is to make the operation of power system more stable and reliable. PHEVs can work either as a load or as power supply source in order to regulate the frequency [27].
- V2G helps the transportation system by reducing petroleum use, making the economy strong enough, decreasing strain on petroleum infrastructure and increasing the national security. Thus environment can be improved by using EVs as V2G [28].
- V2G has potential to reduce almost 50% of whole oil import of USA [28].
- It could assist the electric power system by providing new electricity demand. V2G can help the power system by supplying the power at peak load time and thus reducing the need of building new power plants [28].
- V2G can increase the market share of EVs such as PHEVs [28].
- As power system is designed in such a way that it can fulfil the highest demand or peak load anytime, thus the generation capacity must be greater than the consumption but peak demand occurs only on specific time of the day and a lot of energy capacity remain unused. V2G helps the power system by utilizing this extra energy to EVs charging and for many other electric transportations while drawing power at off-peak time. It would allow the utility companies to earn some extra profit during these low demand periods [28].

3.2.1 Advantages for aggregator/service provider

The demand of electricity varies during the daily 24 hours and over the year. For example, figure 3.4 shows the variety of produced and demanded electricity on the third Wednesday of July and in December 2007 in Germany [15].

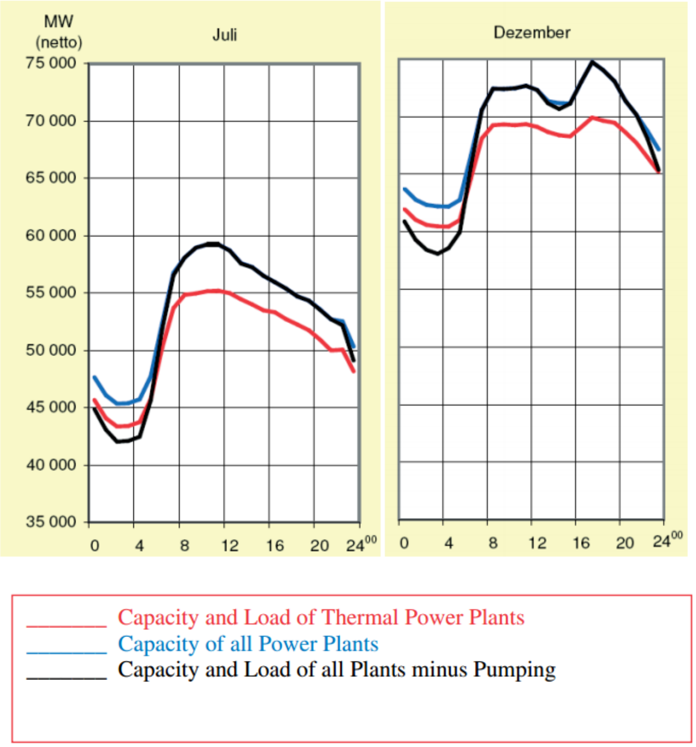


Figure 3.4 *Output and load of German power plants of energy suppliers in 2007 [15].*

It can be seen from the graphs in figure 3.4 that minimum demand is around 42 GW and maximum demand is almost 75 GW. There is almost 79% difference in maximum and minimum demand of electricity during the 24-hour day. To provide the constant and uninterruptable supply, the service providers have two possibilities: [15]

1- Producing or purchasing the electricity whenever needed at the spot.
2- Storing the electricity at the time of low demand and then bring this power back to the grid when demand is high and there is a need to fulfil the demand at any cost.

Both the above mentioned possibilities have their own challenges such as in the first case, sometimes when the demand is very high, the capacity of electricity production should be rated such that it can meet the peak load demand. Otherwise it would cause grid breakdown because of lack of the electricity. However, if RES produce enough energy then it can be utilized to meet the peak load demand but the rest of energy will be wasted when the demand will be low. This scenario will add fixed cost. In addition to this, buying energy at high peak load time when it is needed will be very expensive as selling of this electricity at off peak time at low demand will results in very low or no profit. Thus both of the solutions (producing or buying extra energy at the moment) will cause extra cost to the power providers [15].

To meet the high load demand at rush hours, storage is a better option and there are different storage options such as pumped-storage power stations, batteries, compressed air etc. but all of them have their own limitations. For instance, pumped storage system needs very large volume and maximal height which limits its feasibility to build. Moreover, all these storage options are very expensive and a lot of energy is required to make them efficient. In spite of all these issues, a stable energy system of load management is needed both for companies as well as for the whole society. Thus the batteries that are being utilized in V2G operation can be considered as a flexible storage system to avoid lack of grid supply. For instance, it is expected that by the year 2020, there would be almost one million EVs in Germany. If only 92% of these EVs connect to the grid as V2G while each of them having a battery capacity of 55 kWh then just 50% discharge of their batteries would give the electrical energy of 25,3 TWh [15]. This would be a considerable advancement in electricity sector and also beneficial for power providers or EVs owners.

3.2.2 Advantages for owners of EV

Few decades ago, EVs were not so common but today new concepts are being introduced about EVs such as design flexibility, no environmental pollution and cutting edge technology etc. Thus customers of different countries are seemed to be more interested in buying EVs. The purchase of vehicles very much depends on the incentives offered by the companies or governments. For example, according to a survey tax incentive of EVs will increase the deposition of purchasing the EVs as it will overcome the disadvantage of initial high cost of EVs [15].

Currently, EVs are more expensive than ICE vehicles due to high cost of batteries that are used in EVs but their maintenance and operating cost is quite low. If we compare the life cycle cost of ICE vehicles and EVs, it would be analyzed that life cycle cost of EVs is almost 6% more than that of ICE vehicles [15]. However, the situation would be different in 2020 where a considerable advancement in battery technology will reduce the initial cost of EV. Moreover, the life cycle cost of these vehicles will also be 20% less than an ICE car [15]. By connecting the EVs to the grid in V2G infrastructure additional income can be obtained.

The owner of the car then can get the profit in return [15].

3.3 V2G motivations

Different motivations are described for using V2G application for different entities that are involved in this scheme such as home owner, vehicle battery supplier, vehicle owner, vehicle supplier, aggregation service provider, EVSE owner and electric utility [29].

Utility motivation

Electric utility or DSO has two main obligations for its customers and owners/stakeholders. Electric utility has to provide reliable supply for electricity to its customers. It also has to maintain profitability for its owners or stakeholders [29].

The electric utility finds the use of PHEVs as V2G attractive for two main reasons:

- As storage medium and load balancing of intermittent RES
- Providing grid support obligations

Renewable sources are being integrated with the smart grid system. Moreover, the production of energy from RES is not consistence in nature and thus cannot meet the daily peak load demands. This intermittent nature of RES makes the electric power system unstable and unreliable. This issue can be resolved by utilizing EVs as storage medium and if sufficient number of EVs are being provided as V2G at right times, optimized production of electricity can be made possible. Unpredictability of some renewable sources such as wind may be problematic because there would occur some instances where the grid may be overwhelmed due to surge of wind and sometimes the grid may face shortage of electricity production capability due to lack of wind. If the PHEVs are connected to the power grid to store the surplus energy, then this stored energy can be utilized in peak demand times and thus the need for incremental peaking power plant would be reduced to a remarkable level. Thus by storing power in PHEVs in periods of low demand, and providing the power to the grid when the demand is high, load curve can be flattened. Thus V2G provides the efficient use and application of both the RES and PHEVs to support the power system. The mechanism to store energy in off peak time at low rates and supply it to the grid when the demand is high would reduce the operational and maintenance cost and thus this cost effective benefit of V2G will provide the alternative of peaking power plant and it depends on the utility, region and demand [29].

Aggregator/service provider motivation

A single EV connected with the grid has very little impact on the power system. However, when the large number of EVs are connected with the grid this impact is quite large. The aggregator or service provider manages the group of battery services in order to provide the service to utility grid. The aggregator enrolls and integrate the participant vehicles, assure their availability and validates the participation of EVs in the power system. The service provider should also have capability to manage the sufficient number of vehicles participation so that enough committed vehicles can be guaranteed. A communication infrastructure is needed for this purpose to make sure that energy transfer from and to the energy storage system (ESS) is controlled and optimized by both the vehicle owner and system operator [29].

EVSE motivation

EVSE provides the connection between vehicle’s battery and electric service that connects to electric grid. The vehicle and EVSE both should be designed in such a way to provide a communication path for bi-directional power flow in order to have an access and control for charging as well as discharging of the batteries. Owner would have to purchase the EVSE having these capabilities to get financial potential benefits of participating in aggregator services offers [29].

EV’s owner motivation

When PHEVs are parked, they connect with the grid to charge their batteries and service provider or independent system operator (ISO) have direct access to control the charging and discharging of batteries of those vehicles to ensure the reliable and economic operation of recharging. In a V2G system, a vehicle owner can be a consumer and seller of electric energy and reduce electricity rates would be the motivator for EV owner. If the owners are provided with the appropriate information about benefits, risks and technology plans, they would be able to make optimized decision about participation in V2G program infrastructure [29].

Battery manufacturer motivation

The main aim of the EV battery’s manufacturer is to provide the battery for the purpose of motive power for vehicle. Battery manufacturers are required to produce batteries having long range, better performance (increased motive power) and long life time. These properties of batteries, if fulfilled by manufacturer, will cause an increase in the adoption of EVs that will ultimately provide the need to meet the daily load demands of consumers [29].

3.4 Challenges of V2G

A lot of research has been done on EVs and their different infrastructure schemes including V2G. There are so many advantages of V2G mode of operation that have been described in the section 3.1. Apart from all these above mentioned advantages, certain challenges are still there to cope with.

PHEVs may cause overloading of cables, transformers, and electric feeders. This will increase voltage deviation as efficiency decreases and injects harmonics. One of the greatest challenge in implementing V2G scheme is the high initial cost of EVs as compared to ICE vehicles. This high initial cost is mainly due to batteries that are used in EVs and also because of the fact that these EVs are not so common nowadays practically [30].

Another main issue is that the distribution grid is designed for one-way communication traditionally rather than having two-way communication infrastructure. This would obviously limit the use of EVs as service provider for V2G [30]. For reliable and secure operation through V2G, bidirectional communication is required between the aggregator and EV. As without bidirectional communication, V2G cannot be implemented. Security issues increase at public charging station places. Thus proper and intelligent two-way communication is needed for safe, secure and optimized performance of EVs as V2G [30].
Some disadvantages caused by V2G scheme are discussed as follows:

Battery Degradation

EVs can be used both as a load or as storage devices by charging and discharging their batteries respectively. This continuous charging and discharging of batteries will result in batteries degradation. This degradation of batteries mainly depends on the amount of energy withdrawn, cyclic frequency and discharge depth. There is no proper way to calculate the cost caused by battery degradation but equivalent series resistors (ESR) is used to forecast the life cycle of battery. As deeper discharge of battery will increase the cell deterioration rate and will result in an increase in ESR. ESR value depends on temperature and SOC. It increases at low temperature and high SOC. The calculation driven by ESR have proven that using the batteries at middle SOC is a better way to slow down the degradation rate. While deeper discharging will increase the degradation rate. This degradation rate can also be minimized by smart charging techniques. Li-ion batteries have proved to be the best for V2G capable EVs because of having certain characteristics such as long life cycle, deep cycling capability, high efficiency and energy density as compared to other batteries. Normally li-ion batteries can survive for 2,000-4,000 deep cycles. Due to additional cost by battery degradation, the net profit, obtained by V2G enabled EVs, would be expected to decrease [30].

Impact on distribution equipment

Charging of EVs has a remarkable impact on distribution equipment as it can cause overloading of local distribution equipment. Charging can increase distribution transformer losses, voltage deviation, harmonic distortion, and peak demand. To avoid all these losses huge investment and high transformer capacity is needed. Degradation of transformer is obvious by overloading effects but this degradation can be reduced by using smart or intelligent control methods of charging [30].

Many researchers have studied the impact of the penetration of large number of EVs and the results show that if coordination of charging scheme is not optimized (charging time is not coordinated) and large number of EVs are connected to grid, it would have a greater impact on distribution grids and thus will reduce the reliability as well as efficiency of the power system [30].

The control of charging of EVs is necessary to have longer transformer life as because of uncontrolled charging of vehicles transformer life reduces by 200-300%. On the other hand, it increases to 100-200% by using controlled or smart charging infrastructures [30].

A demand response strategy is proposed to reduce the impact of charging on a distribution network. To minimize the issues related to the voltage drop there are certain ideas such as use of on-load tap changing transformers, utilizing capacitor banks, or by using reactive power services [30].

Investments cost and losses

In many research articles it has been analyzed that extra generation cost or investment is needed for additional PHEVs demand. It is considered that if in 2020 EVs would be preferred vehicles then an extra investment would be needed in electricity network to fulfil the additional demand of these vehicles as well [30].

Energy losses are always there when energy is generated, transmitted and distributed. Thus every time when energy is supplied back to the grid through V2G scheme, the loss of energy is certain. In off-peak time when most of the EVs are connected and batteries are getting charged, the energy losses increase as compared to the same situation (off-peak hours) when there is no EV connected to grid [31].

Environmental concern

V2G infrastructure utilize batteries in EVs and by continuous charging and discharging battery degradation occurs. Thus battery life span decreases and they need to be replaced sooner than usual. Battery manufacturing is not an efficient process generally. Thus recycling of old or completely utilized batteries causes so many environmental issues and hence V2G scheme is not so promising to environmental benefits [32].

Battery protection issues

The fault on power system can occur anytime thus this uncertainty in fault occurrence phenomenon has profound effects on the protections of batteries that are online. Utility cannot guarantee about the safe operation of charging/discharging of the batteries packs that are being utilized in the G2V/V2G schemes respectively [32].

Power grid control issues

Numerous amount of EVs act as mini generators when connecting to the grid by V2G. Control of these millions of small generators is challenging and need to be considered effectively. The integration of these EVs in the grid cannot be controlled by traditional infrastructure. The grid operator should know some basic information about these EVs charging and discharging such as status, availability and inclination of these EVs. Certain issues such as voltage drop may decrease the charging rate. This voltage drop issue can be resolved with certain infrastructures but in participation of EVs in electricity market share, these schemes for managing and controlling voltage drop don’t work properly [32].

Unreliability

It is well documented that V2G are considered as storage system to provide power back to the grid during peak load shaving but the reliability of this access to the grid truly depends on the owner behavior. Driving habits of the EVs owner have also a remarkable effect on V2G. For instance, mobility behavior of EV owner is different on weekdays with that of weekends. In addition to this, the willingness of connecting the vehicle to the grid by owner also depends on behavior of owner as he may not be intended to supply power to the grid at any time. It may then cause serious shortage when the demand is high and not enough number of EVs are connected to the power gird as V2G [32].

The connection to the specific point is also very important such as if enough vehicles are providing electricity to the power grid at certain location of the grid while the demand is high on other side of the grid where very few of them are providing supply. This would also result in shortfall of power. Transmission losses should also be considered then while transmitting the energy to the high demand side [32].

An upgradation is needed to be built in the traditional power system to make possible use of EVs both for driving purpose as well as for V2G application [32].

3.4.1 Technical limitations of V2G implementation

Integrating EVs with the electric power grid through V2G concept is considered to have potential to create an income stream that offsets a portion of vehicle ownership costs. However, apart from all the advantages there are different technical limitation and problems in the implementation of V2G. Some of them are described below:

- Power electronics along with the batteries is quite complex and needs to be integrated and control carefully [29].
- Power quality issues arises in grid due to integration of RES into the existing power system. Up till now there does not exist an advanced and smart power system for the integration of EVs into the power system [33].
- Due to the integration of RES into the power system, traditional methods of load forecasting will no longer be possible. Uncertainty in charging habits and pattern will also effect the load forecasting [33].
- One remarkable challenge in electric transportation is the control of electric variables such as current, voltage, frequency and connection to the vehicles [33].
- The size of the public charging station should be large enough to facilitate all the vehicles which serves as V2G [33].
- For reinforcement of power system as well as to provide charging facilities, large investments are needed for distribution grid [33].
- Intelligent charging infrastructure is needed for two-way communication so that charging of EVs load can be only done in off-peak hours to avoid overburden on utility grid. But the smart charging scheme needs optimized controlling structure [33].
- In addition to intelligent charging, intelligent scheduling is also needed in order to meet the energy needs along with profit for the power system [33].

- In bidirectional communication of smart charging infrastructure, management of large amount of information is also a big issue [33].
- PEV loads will not grow uniformly in utility area thus it may cause to have overloading in the service area of distribution grid [33].
- In areas of low voltage networks, grid compatibility is a big issue in charging schemes of EVs [33].
- Coupling of load control with different usages is a big challenge such as with PEVs, intermittent RES and intermittent generation [33].
- Implementation of cost effective technologies in the presence of distributed generation is necessary [33].
- Development of some sensors must be considered to observe the network constraints.
- The optimized timing for an EV for selling or buying electricity from a grid is not easy to determine in cases when scheduling issues rise because of frequency turnover [33].
- Appropriate planning of power delivery network is needed as many of the EVs are connected to remote locations with the power delivery network [33].
- A complete revision of electrical architecture is needed for the implementation of V2G scheme to avoid complexity and to get maximum benefits from EVs [33].

3.4.2 Testing and evaluation

Unfortunately, sufficient testing has not been done yet to remove current barriers to adopt V2G operation by industries and academia. This is the reason that net benefits of V2G scheme are just theoretical and causing primary barriers for many regulators to make decision. Three broader areas are there for testing the evaluation of V2G and these are discussed below:

Battery performance and impact testing

Battery performance and impact testing include the testing of charging/discharging cycles of battery life time and thermal impact from frequent charging/discharging. Battery life time under V2G operation needs to be evaluated in this category of testing to determine the actual profit [29].

Network communication efficiency testing

This communication testing will determine different communications and protocols that are needed for direct messaging/communication between aggregator and EVs for an effective V2G operation. This testing will result in optimized network schemes for the V2G, i.e.

evaluation of cost versus performance issues by considering the reliability and availability issues [29].

System response testing

This test will evaluate the understanding of adopted technologies and profiles that will work effectively in an aggregated service network. This includes all aggregated vehicles, local and remote control mechanism, data storage, capture and user interface that will alternatively help in market evolution. It also determines power quality characterization, system response time and data storage values [29].

4. EXAMPLES OF V2G

The most reliable, economic, efficient and clean performance of smart grid and its environmental friendly interaction will give a bright prospect to EVs. A lot of improvements can be done to increase the overall efficiency. Hence, integration between EVs and smart grids becomes more and more feasible and attractive for many entities. This simple interaction is defined by the concept V2G in electric power system.

The functionality and benefits of V2G are described in detail in chapter 3, which show the importance of this new technology. Due to high influence on the climate and environment, governments of different countries have decided to established some rules for sustaining development. For instance, European Union (EU) has set the ambitious to meet the “20-20-20” targets. This term is related to the target of 20% reduction in GHG emissions by 2020 as compared to by the year 1990, 20% increase in the use of RES and a 20% reduction in energy consumption by increasing energy efficiency by 2020 [34]. Hence, in certain parts of the world, this V2G mode is being implemented practically to analyze the benefits as well as issues related to this term. In the following section, some of the case studies for implementation of EVs with power system have been described briefly.

4.1 Case study for Croatia

Croatian national grid is considered as a test model with a group of 9000 EVs. The typical daily load curve of Croatian national grid for a time period of 24 hours is shown in the figure 4.1 [34].

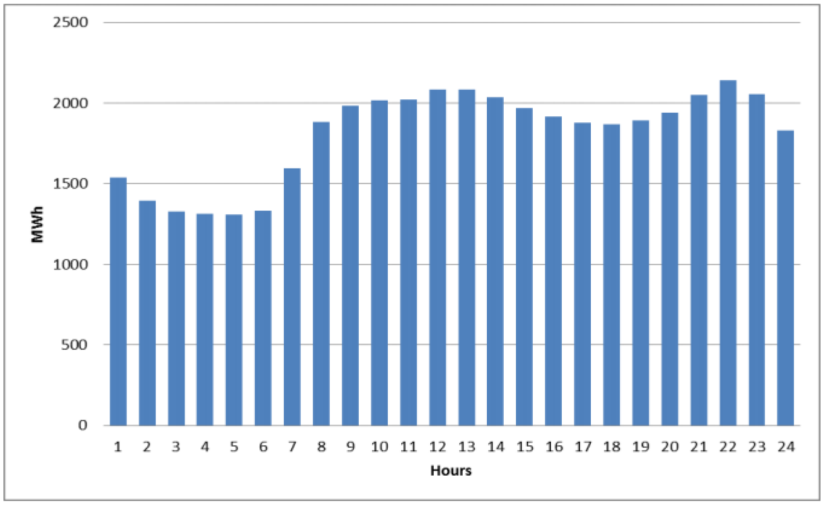


Figure 4.1 *Typical daily load curve in Croatia [34].*

Each EV is considered to have 10 kWh capacity and thus total of 90 MWh (mega-watt hour) is achieved. In this test case, it is considered that the availability of EV is higher for the time period of 00:00 to 06:00 am while the unavailability is only considered for driving period of vehicle that is from 07:00 am to 07:00 pm. Figure 4.2. shows the average EV hour availability for 24 hours a day [34].

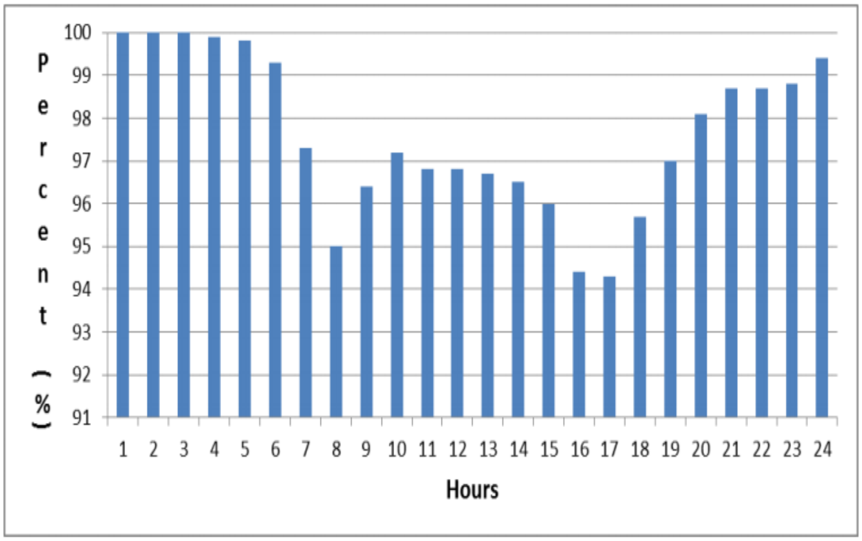


Figure 4.2 *Availability of EV during one of the weekdays [34].*

It can be seen from the figure 4.2 that availability of EV is lower from 06:00 am to 06:00 pm. This is because of the reason that during this time period, EVs are mostly on roads on parked idly outside the workplaces.

Charge-discharge cycle of EVs with the grid is analyzed and is shown in figure 4.3. The positive values in the graph show that the EVs are behaving as generation units while negative values show that EVs are behaving as load units particularly at night when the demand is low. So the EVs charge their batteries and appear as load on power grid. During the day time when the demand is high these fully charged EVs help the Croatian national grid to reduce the peak values by providing the stored electricity to the grid [34].

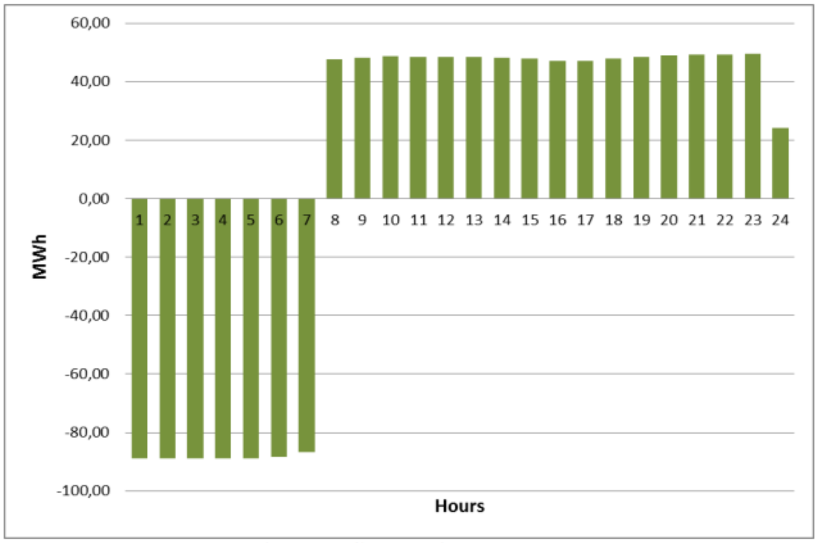


***Figure 4.3**. Charge-discharge plan [34].*

Based on the results in figure 4.3, it can be observed that batteries of EV are getting charged in seven hours from 01:00 am 07:00 am while discharging is being done onwards, i.e. from 08:00 am to 12:00 am. The constraints in this test case study for charge-discharge cycle are available time of EVs and their charge-discharge power.

$$P_{ij}min \leq P_{ij} \leq P_{ij}max \qquad (1)$$

In equation (1) $P_{ij}max$ and $P_{ij}min$ represents the maximum and minimum power of charge-discharge power of station i in period j.

To simply calculation in this case study, charge-discharge power limits are set as given in equation (2).

$$-50\ MW \leq P_{ij} \leq 90\ MW \qquad (2)$$

The lower limit of discharging than charging is set due to the driver's necessity of attaining satisfying charging level of battery for further driving needs. Analysis shows that these constraints are effected by number of available EVs, charge-discharge current, voltage of vehicle battery in V2G mode and on distribution network line or transformer capacity with V2G charge-discharge station [34].

The load curve of Croatian national grid after improvements with V2G process is shown in Figure 4.4 [34].

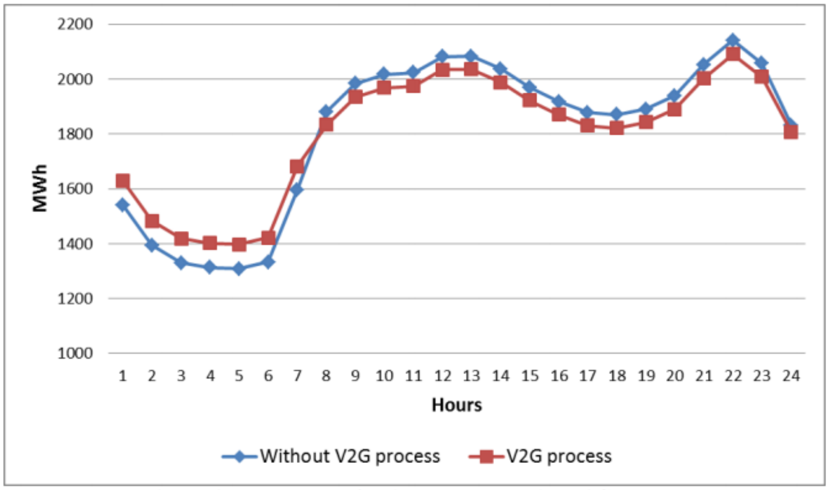


Figure 4.4 *Load curve after implementing V2G strategy [34].*

It is based in the figure 4.4 that EVs help the national grid in reducing the peak values. As an example, the peak value is reduced from 2141 MWh to 2091,65 MWh which is a reduction of 2.3% in required power at peak. This result shows that this load shifting through EV is beneficial for practical applications and can decrease the need of other energy storage capacity. As this analysis for Croatian national grids is carried out through V2G having the total capacity of 90 MWh. So higher contribution of EVs will increase the total capacity and thus can assist the national power grid in decreasing the peak values further more [34].

4.2 Case study for Lombok

Integration of large scale EVs fleets have been studied and modeled in many cases. In Lombok, the city of Netherland, a small scale test model is applied to national grid of Lombok. This test case study determines the potential of increasing the self-consumption of photovoltaic (PV) power with smart charging of EVs with LomboXnet, an internet server in Lombok. The model is applied to a micro grid in Lombok. This micro grid consists of an internet server, a 31 kWp PV installation, an office, three households and two EVs [35]. kWp is the unit of peak power or output power of a solar panel under full radiation.

Figure 4.5 shows the components of LomboXnet micro grid. It consists of five main components. PV installations, three households, controllable loads, uncontrollable loads and an energy management system [35].

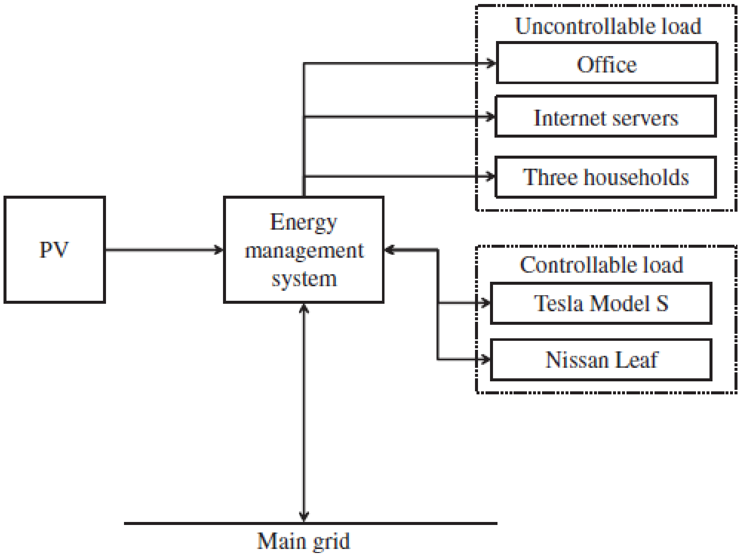


Figure 4.5 *Micro gird at LomboXnet [35].*

The arrows in the figure 4.5 indicates the power flows. Uncontrollable loads consist of an office, three households and an internet server. The demand from each one of the section has different load curve. For instance, in office the demand is high during daytime, internet server has a constant demand and three households have peak demands in morning and evening times. The yearly load demand from office and internet server was 27 MWh in 2012. As there is no measurement available for load demand from households so it is estimated by using data sets. It is clear from the figure 4.5 that PV provides power to both controllable and uncontrollable loads. If there is shortage of power from PV, the electricity is drawn from the micro grid but if the PV has excess power, electricity is provided back to the main grid. Two EVs are available in this test study, Tesla model S and Nisan leaf. Each of them is used for three trips per week on average and have a duration of 3-6 hour per trip. A minimum energy level of 20% of battery capacity is assumed while having a power conversion efficiency of these EVs is 90%. Figure 4.6 shows the 24-hour daily load profile curve [35].

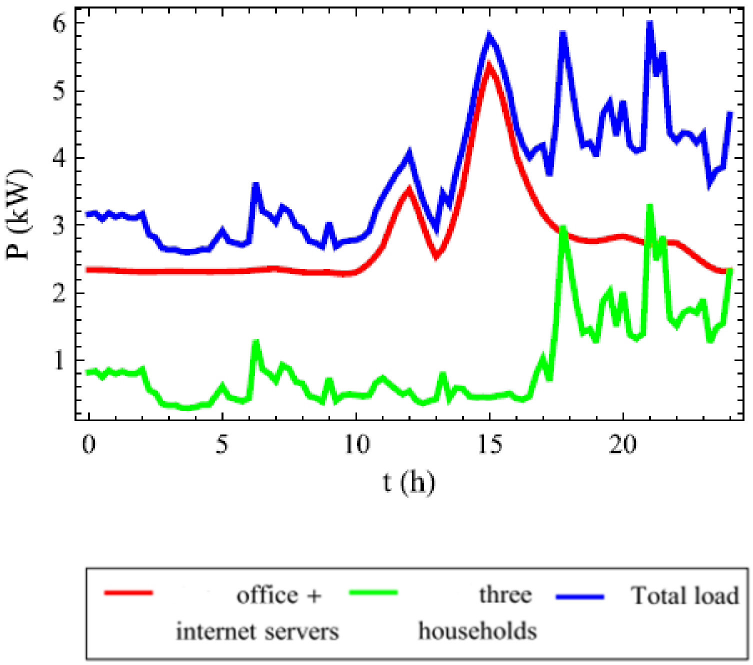


__Figure 4.6__ Load profile curves [35].

The peak from different loads at different times can be seen in the figure 4.6. The green curve is for load of three households, red is for load of office and internet server and blue curve is for total load demand. Three types of control algorithms are adopted for this case. One is real time (RT) algorithm without V2G, second is RT with V2G and the third is linear programming (LP) algorithm. These algorithms are run in the energy management system which decides the charging pattern of EVs [35].

In RT algorithm, the EVs only use PV power to charge their batteries. This is the RT control without using V2G mode. In second algorithm RT control is used along with V2G. In this case EVs charge their batteries with PV power as much as possible and then discharge this stored power to the grid to fulfil the demand of uncontrollable loads when PV power is not enough to meet them. Both of these algorithms use real time information thus optimization of charging pattern is not possible in these algorithms. Therefore, LP approach is implemented which will reduce the peak significantly. For LP algorithm, PV power consumption and demand must be known in advance [35].

Figure 4.7 shows the flow of information for RT algorithms. In this scheme, the EV charging pattern will be decided based on certain factors such as PV power, uncontrollable load, planned EV trips and SOC of EVs [35].

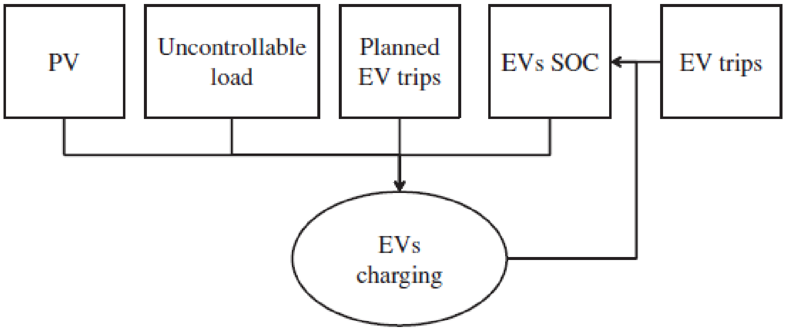


Figure 4.7 *Power flow information for RT algorithm* [35].

The RT algorithm decides the charging pattern of EVs by considering the energy content of EVs. This algorithm determines the difference between PV power supply and load demand at regular intervals of time. If PV power is more than demand, EVs charge their batteries trough excess PV power. If there is shortage of PV power available, EVs extracts energy from the grid. If there is not enough power from PV to meet the load demand, then power can be extracted from EVs.

In this case study, the main aim is to increase the self-consumption of PV power for charging of EVs, use this charged energy from EV to meet load demand and minimize the extraction of energy from grid. LP solves this purpose as maximizing the self-consumption of PV by controlling the charging pattern of EVs is described by linear optimization problem. Figure 4.8 shows the flow of information for LP algorithm [35].

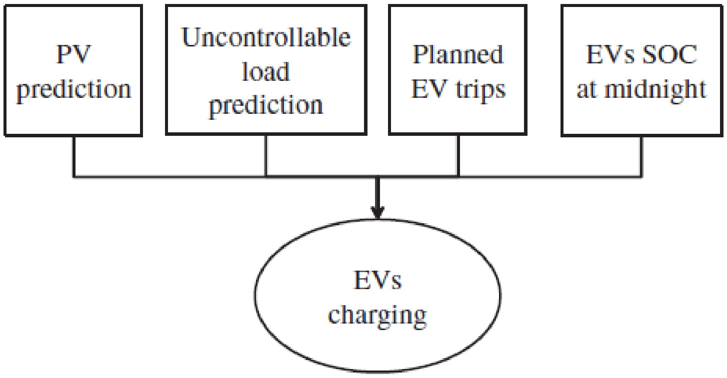
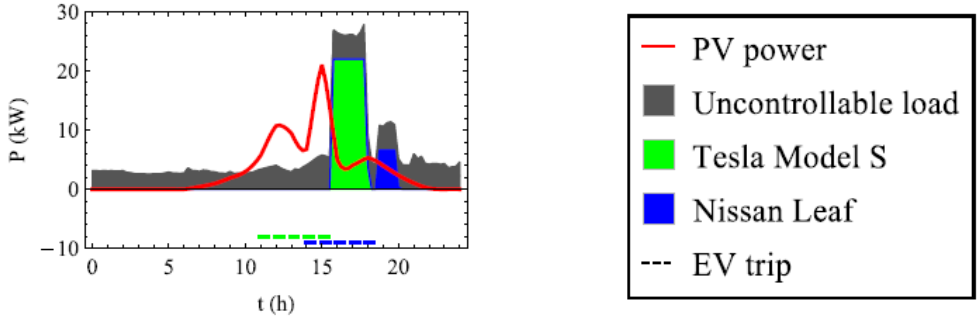


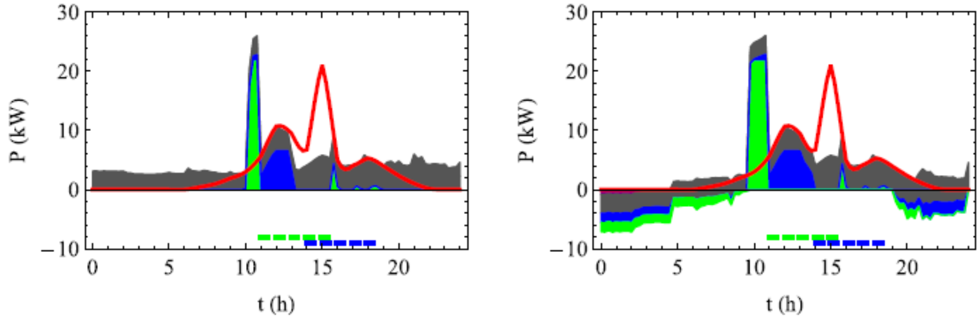
Figure 4.8 *Flow of information for LP control algorithm* [35].

This LP control algorithm can be evaluated in two ways, LP perfect information and LP with uncertainties. Load demand prediction can be determined by the pattern from the previous day [35].

Figure 4.9 represent the results of different cases for a 24-hour day in July where PV power yield is high. In the case of No Control (Fig. 4.9a), the Tesla Model S charges in the late afternoon after the trip while Nissan Leaf charge its battery in the evening.

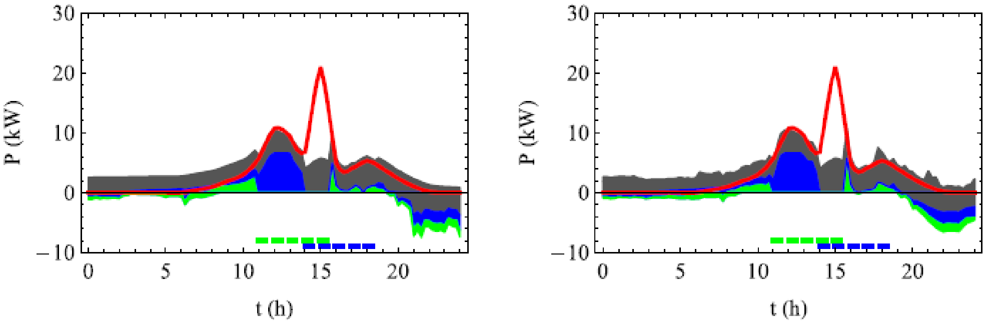


(a) No Control



(b) RT Control

(c) RT Control + V2G



(d) LP – Perfect Information

(e) LP – Uncertainties

Figure 4.9 *Results of 24-hour simulations for different algorithms [35].*

In Figure 4.9(b), for the case of RT control without V2G, the Tesla Model S starts charging at 10:00 am because it needs the energy for a trip. While the Nissan Leaf starts charging when there is excess PV power available for instance at 11:00 am. In the case of RT+V2G, both EVs start discharging in the night to provide power to the grid, because at that time there is no PV available to fulfil the load demand as shown in the Figure 4.9(c). This causes a large peak in the morning for the Tesla Model S because of insufficient energy available for trip during the day. The trip with the Nissan Leaf takes place later in the day [35].

Moreover, higher self-consumption of PV power is possible with this RT+V2G algorithm as compared to RT algorithm without V2G because vehicle discharges all the stored energy at night and thus more energy can be stored in day time through PV which results in the consumption of PV. In the evening the available energy in the EVs is discharged to cover load demand [35].

In the case of LP – perfect information as shown in the figure 4.9(d), system takes into account the planned trips so both of the EVs charge much less in the morning as compared to previous cases. In the evening the energy available in the EVs is discharged to cover the load demand. figure 4.9(e) shows that the LP – uncertainties is almost similar to LP –perfect information, just the load curve is almost as much flat as for the case of LP-perfect information. This is because of the deviation from the predictions [35].

4.3 Case study for Chicago

Despite of the many advantages that can be obtained by EVs as compared to traditional combustion engine vehicles, there are certain challenges associated with the charging battery of EVs for automotive manufacturers, utilities, customers, and other parties to work through. The government of USA has invested more than \$2 billion for advanced battery development in EV related technologies [36].

As the expansion and modernization of existing power grid is nearly impossible and expensive, so the concept of micro grid is the best approach to be implemented in different locations such as shopping centers, university campuses, and at many other urban areas. Illinois Institute of Technology (IIT) Chicago, is working on innovations for future electricity. USA DOE and other organizations are funding the IIT to convert it into the micro grid. Distributed generation, controllable loads and storage are the main energy resources in IIT. To charge the EVs at IIT, one DC and six AC charging stations along with a solar cover are installed [36].

Figure 4.10 shows that a solar panel of 20 kW power is installed at the side of these charging stations to supply some portions of IIT campus load. The power generated by solar panel is DC which is then converted to AC through grid inverter. The main purpose of solar PV generation is to draw maximum real power while injecting no reactive power to the grid [36].

Figure 4.10 *Solar panels and charging stations at IIT [36].*

In order to measure the voltage and currents from the charging stations and solar panels, eight voltage sensors and eight current sensors are applied. The data from these sensors is converted to real time voltage/current data through a data acquisition equipment [36].
Based on the collected current data, the status of the charging station can be determined that either it is in charging state or not. If the current is larger than 2A the station is in charging state but if it is less than it, it means that the power is being absorbed by the device itself. For this case study, the hourly load curve and electricity price at IIT campus is shown in figure 4.11 [36].

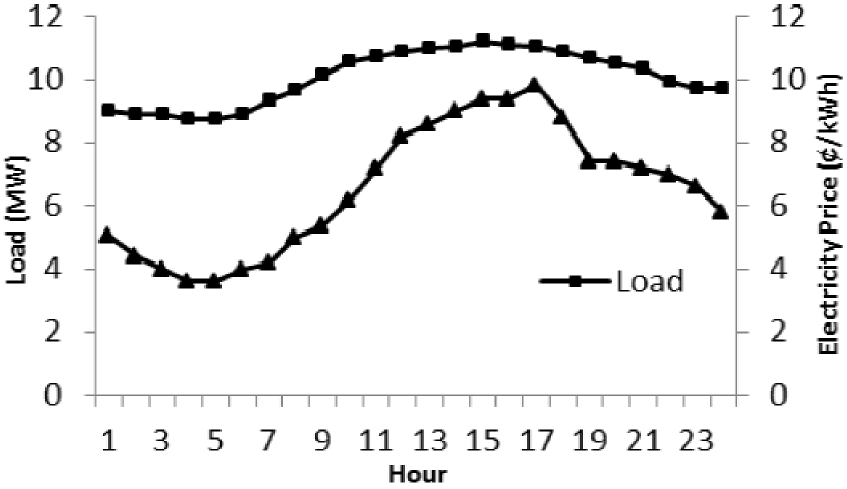


Figure 4.11 *Hourly load curve and electricity price [36].*

Total yearly peak load at IIT campus is 10MW. The main distribution energy resources at IIT micro gird are 8MW gas fired power plant, 8kW of wind power plant and 80kW of PV cells that also includes solar panels as already described in this case study. To increase the efficiency and reliability, 500kWh of battery storage capacity is installed in IIT micro grid [36].

Two cases are taken into account in this study: [36]
Case 1 is when EVs are considered as normal charging load which gets charged by the grid. Usually the charging period is during the day time at IIT and thus V2G capacity is not considered in this case.
Case 2 is the comparison of two scenarios, i.e. by considering the V2G capacity and without V2G capacity. Figure 4.12 and 4.13 show the hourly charge/discharge status of EVs in case 1 and case 2 respectively.

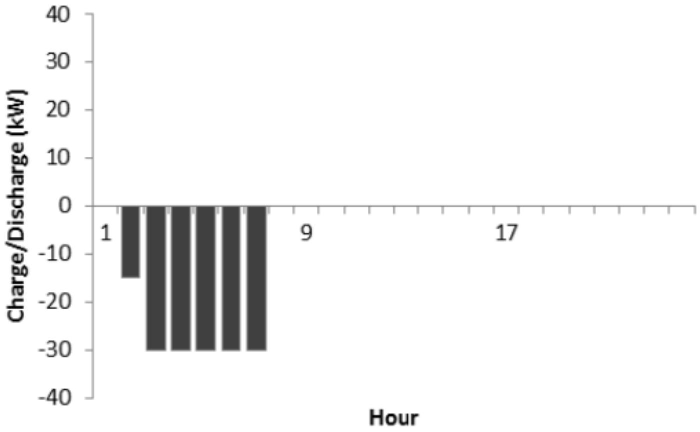


Figure 4.12 *Hourly charge/discharge status of EVs in case 1. (without V2G capacity) [36].*

EVs are getting charged when the electricity prices are low but they are not providing power back to the grid in discharging mode that can be seen in figure 4.12. This is due to the fact that case 1 is analyzed by considering EVs without V2G capacity.
Hourly charge/discharge status of EVs by considering V2G capacity is shown in figure 4.13 [36].

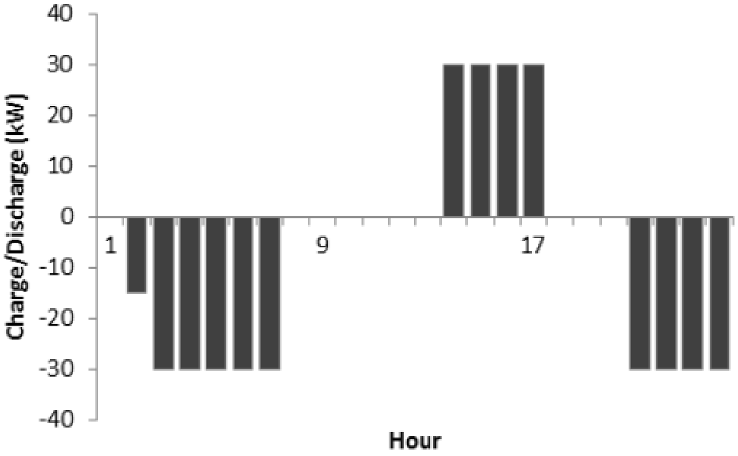


Figure 4.13 *Hourly charge/discharge status of EVs in case 2 (with V2G capacity) [36].*

In this case EVs are getting charged in different time periods when electricity prices are quite low and provide power to local power system when the prices are high as shown in figure 4.13.

Figure 4.14 shows the hourly main grid supply and local micro grid supply.

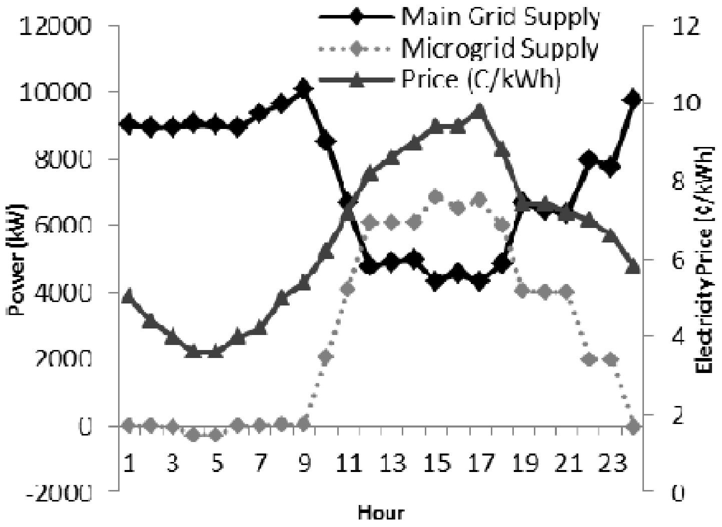


Figure 4.14 *Hourly main grid supply and local micro grid supply [36].*

In case 2 when the electricity prices are low, the storage and connected EVs behave as load and absorbs power from the grid but when the prices go high, the connected EVs with V2G help shifting the peak load to off peak time as shown in figure 4.14. It would help in increasing reliability as well as certain economic benefits can also be achieved. By considering the V2G capacity, it is observed that operational cost decreases. If the prices of electricity keep on increasing in the future, more economical benefits can be achieved by EVs with V2G mode of operation [36].

5. IMPACT OF V2G

The studies and analysis up to so far show that with the increase in penetration of EVs and distribution generation such as PV, the utilization of power electronics based devices are also increasing day by day. The integration of these devices in the power system may impose some power quality issues such as load balancing, voltage regulation and frequency regulation etc. If the quality of the current drawn by EVs or injected by PV into the power system is not good enough, it may produce voltage quality issues in the network connection point of the customers. Some of the effects produced by EVs in V2G or G2V mode of operation are discussed in detail in the following sections.

5.1 Power quality in distribution networks

Power quality (PQ) is a measure of the accuracy of electrical power transfers. Low PQ can cause variations in voltage magnitude, problems with continuity of service, and transient voltages and currents.

The deviation of current and voltage waveforms from the perfect sinusoidal waveform is known as harmonic distortion of current and voltage respectively. Harmonic distortion is one of the basic causes of reduction in PQ. As EV charge controllers are considered as non-linear load, thus in these type of load the current distortion is very common due to presence of power electronics switching devices to convert power from AC to DC. These distorted currents can distort the utility supply voltage and overload the electrical distribution equipment. EVs demand a large amount of power as well as the charge controllers used in EVs are nonlinear loads thus PQ issues due to EV charging have an adverse impact on distribution feeders [37].

Harmonic profiles of three different types of test EVs such as Opel Ampera, Nissan e-NV200 and Tesla Model S are formed by observing time-domain waveform of charging current. Figures 5.1-5.3 represent the typical current waveforms of charging these three types of EVs with the charging current [38].

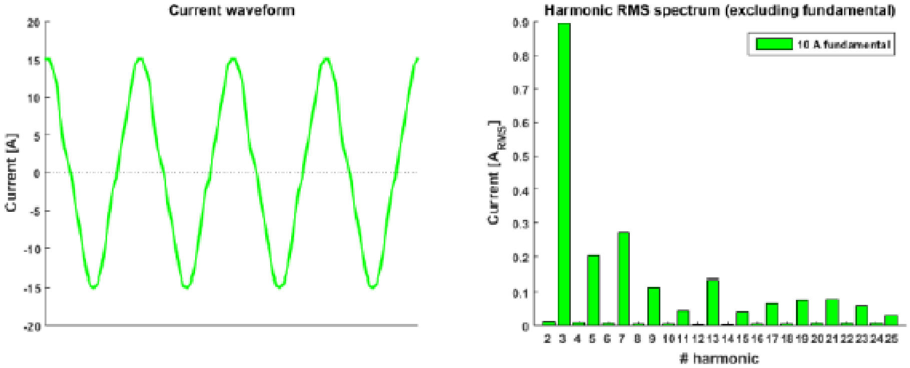


Figure 5.1 *Current waveform and harmonic amplitude spectra of Opel ampere charging [38].*

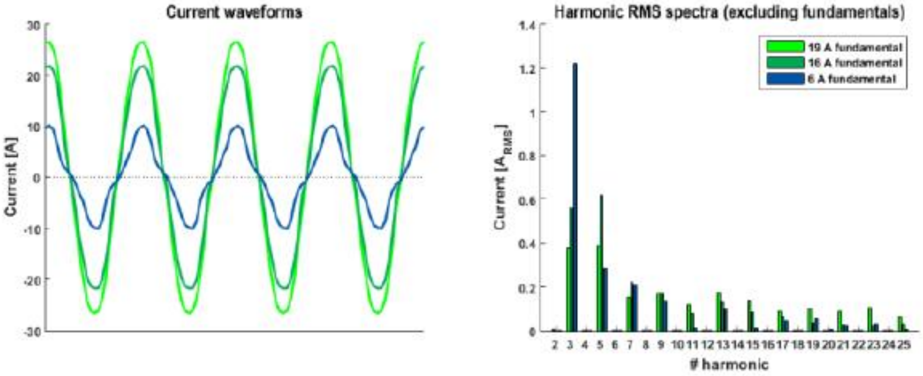


Figure 5.2 *Current waveform and harmonic amplitude spectra of Nissan e-NV200 charging [38].*

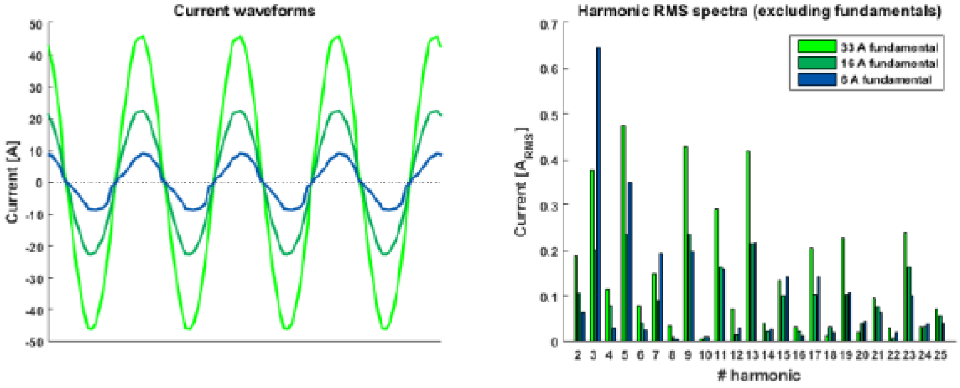


Figure 5.3 *Current waveform and harmonic amplitude spectra of Tesla model S charging [38].*

5.2 Impact of charging on distribution networks

The main functions and advantages offered by EVs are discussed in detail in Chapter 2. They can supply power to the distribution grid when it is needed most. The increasing penetration of EVs is also causing some challenges such as charging process of these vehicles. The charging process of random number of batteries with random energy demand needs a demand side management infrastructure [39].

Distributed storage capacity that can be provided by V2G mode of operation, by considering a large number of EVs, has several impacts on the operation of power system grid. Thus EVs impose new challenges to existing infrastructure of power system in terms of electrical transmission and distribution system [39].

As EVs behave both as load or generation, there are many factors which effect the charging/discharging process of EVs such as follows: [39]

- Type of connection i.e. unidirectional or bidirectional
- Total number of vehicles that are being charged in a given area
- Geographical location
- Levels of current and charging voltage
- Status of battery and its capacity
- Duration of charging

Charging in different areas by fleets of EVs has an impact on the total power drawn. Charging of EVs in congested distributed networks will cause to produce harmonics injection and undesirable consumption. Charging and discharging of EVs introduce the change in overall load profile of a power system peak loads and often cause low power factor. Charging of EVs at night have minimal impact on supply of the power grid. The electrification of transportation will have a dominant impact on the distribution network as it will increase the demand of electricity and thus can increase the peaks in electrical system. The load profile can be made more effective and smooth by intelligent charging. If charging of EVs occur more often, it may lead to overloading of transformers. Similarly, if large amount of fast charging occurs, it will cause the overloading of conductors of the main feeders [39].

The power demand for charging of EVs depends on the switch on and off time of charging, number of EVs and characteristics of batteries. In case of congested distribution networks, the risk of unreliability increases when the rising penetration of EVs connected to the grid. Moreover, it causes the unreliability as the reserve capacity of the system decreases when increasing number of EVs are connected as load with the power system [39].

Charging profile of EVs charging has major effect on distribution networks as the way of charging from the supply grid has an impact on voltage level. Uncoordinated charging causes system losses due to voltage deviations and also increase the system peak load. Thus to avoid this critical situation, coordinated charging also known as intelligent charging, is needed to be implied. This type of charging is done to optimize the time and power demand [39].

Battery degradation is one of the major factor to be taken into account in V2G mode of operation. It relies on the amount and rate of power drawn and depends on depth of charging and discharging cycle frequency. Intelligent charging scheme can minimize the effect of battery degradation also [39].

5.3 Market analysis

According to statistics Finland, there are more than 2.6 million cars on the rods and few hundreds of them are EVs among them. With the passage of time, if all of them changes to EVs fleets, it would cause serious problem regarding their charging process. On the other hand, a source of bulk storage would be obtained. There are two main reasons for slow penetration of EVs into the electricity markets [40].
1) The high initial cost of EVs
2) The less frequent availability of charging facilities for EVs

There are different factors which should be taken into account when defining the costs related to EVs if they are participating into the electricity market. For instance, the battery of EV should not be deeply discharged and over-charged as it would reduce the battery efficiency as well as life span of battery. So it must be operated between 10% to 90% SOC of the full capacity of battery. In this way, the useful battery capacity is considered to be 80% of the full battery capacity. The overall battery energy cycle efficiency is considered almost 63% [40].
The major cost factors by considering the EVs in V2G mode or as a power source is given by the following equation: [40]

$$C_{V2G} = C_L + C_D + C_{PM} + C_{BE} \qquad (3)$$

Eq. (3) shows the energy cycle cost per kWh when EV is participating as V2G. Different costs associated with this overall cost function are defined as follows:
C_L = Cost of losses
C_D = Cost associated with battery degradation
C_{PM}= Profit margin cost
C_{BE} = Base cost of energy originally purchased for charging

As EVs use resources from storage such as battery system etc. so when behaving as V2G some extra cost is associated with them. For instance, battery degradation cost per kWh which depends on the initial cost of the battery and total life time of the battery. If the life time of battery used in the EV is much longer, the battery degradation cost per kWh will reduce. Longer life span means battery could transfer more kWh energy throughout its lifetime. Another important factor about battery degradation is the charging/discharging rate. High rating chargers have high impact on battery lifetime as well as on its performance. Cost of losses, C_L, also depends on the charging/discharging efficiency of the battery. The more efficient chargers would be, the less will be the cost of losses and hence cost of energy in

V2G will be decrease also according to equation (3). Another cost function in the equation (3) is base cost of energy,C_{BE}, which is directly reflected from the energy market. Profit margin cost depends on the EVs owner's choice that how much profit they want to get in return [40].

The degradation cost of battery per kWh of energy cycle is shown in figure 5.4 [40]

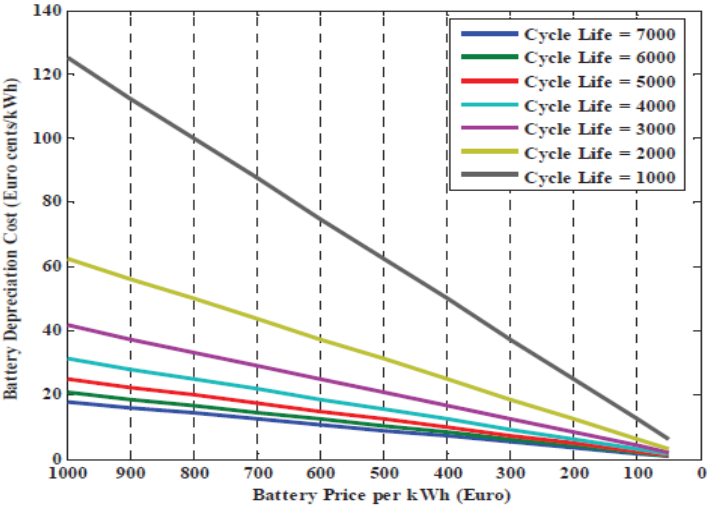


Figure 5.4 *Battery degradation cost per kWh of energy cycle [40].*

Initially, the cost of the battery was almost 1000 €/kWh but with the advancements in battery technology, nowadays it is reduced to 300 €/kWh. In EU energy market for a feasible value of V2G energy price, the cost factor of battery degradation cost, C_D should be at minimum possible value [40].

V2G revenue depends on the market scenario. For instance, for some market models that deal with the electricity energy, the base and peak load scenarios are computed by following relation: [41]

$$R = \rho.P.t \tag{4}$$

Where,

R = Revenue ($)
ρ = Market rate for electricity sale ($/kWh)
P = Exported power (kW)
t = Total time power is exported (hours)

While for spinning reserve and regulation services, market revenue is defined by the following equation: [41]

$$R = \rho.P.t + \acute{\rho}.\Upsilon.\acute{P}.t \tag{5}$$

$\hat{\rho} =$ capacity price ($\$/\mathrm{kW}-\mathrm{h}$)
$\acute{P} =$ contracted power capacity (kW)
$t =$ contracted time (hours)
$\Upsilon =$ percentage regulation time

In the above two equations, it can be seen that there is difference between two energy capacity price units. $\$/\mathrm{kW}-\mathrm{h}$ means $\$/\mathrm{kW}$ capacity is available during one hour whether used or not. While energy price unit $\$/\mathrm{kWh}$ means $ per kWh [41].

5.4 Power regulation market

Before adding EVs into the power grid system, a number of issues need to be solved. These issues are regarding electricity market such as the difference between wholesale and retail markets and their associated tariffs. Retail energy transactions are those between end users of energy and a distribution company associated with the distribution grid. Whereas, wholesale energy transactions are those among energy generators, grid operators, and bulk energy purchasers. Wholesale is associated with the transmission grid. One another difference between these two terms in electricity market in USA is that retail is regulated within the states while wholesale is regulated at federal level [42]. An EV capable of V2G operation has two reasons to be connected to the grid,

1. Charging, to draw energy from the grid to charge its battery
2. To provide V2G ancillary service

In former, the customer buys electricity to charge his vehicle's battery so logically it is retail transaction. The latter is wholesale transaction. Thus it can be said that a vehicle connected to the grid will be involved in retail as well as wholesale transaction simultaneously. Logically these two energy transactions can be differentiated as to charge net energy as a retail transaction (present practice) and regulation service contract is termed as a wholesale transaction through the aggregator. The distribution utility will get paid for all the net energy delivered to the vehicle. As retail transaction is for net energy and wholesale transaction is for the ability to control the timings of the power capability (regulation). By considering these definitions, a vehicle that is plugged in for recharging and for providing V2G service (regulation service) would be billed for retail energy for recharging the battery and regulation value would be treated as a separate transaction through the aggregator [42].

In regulation market, the increasing number of EVs will increase the supply of regulation service that will cause the down trend in market prices. This is a favorable scenario for electricity ratepayers but not for regulation service providers. The overall demand for regulation will increase due to growth in load and increase in the generation of wind power. Thus additional regulation will be needed to reduce the gap in actual generation and forecasting of intermittent nature of RES. However, currently as the regulation capacity by EVs is growing slowly, it would be expected to have a minor impact on the regulation market prices [42].

5.5 Comparison chart

The detailed analysis of the V2G mode including its different characteristics, advantages and challenges has been done. There are two other modes of operation through EVs such as V2H and V2B as discussed in chapter 3.
Table 1. shows the comparison between V2G/V2H/V2B in different perspectives.

Table 1. *Comparison between different modes of delivering from PEV batteries*

	V2G	**V2H**	**V2B**
Characteristics	• Large scale EV fleets • Complex operation • System Level communication • Need more regulation • Advanced structure • Need incentive	• Small scale single EV • Simple operation. • Home Level communication. • Can work automatically. • Easy structure	• Small scale EV fleets. • Local building level communication. • Need regulation. • Complex structure • Need incentive
Supportive infrastructure	• Aggregator. • Long transmission lines • Large scale smart parking lots	• Home energy management system • Smart meter at home level	• Building energy management system • Smart meter at building level • Small scale smart parking lots
Applications	• Ancillary Services. • Reactive Power Support • Operate at Large scale	• Operate at Home level • Single EV • Easy implementation	• Operate at building level • Provide backup power in V2G mode

It can be seen from the table that V2H is very simple approach as it does not require large infrastructure for long distance transmission lines. V2B is almost same as V2H but it requires more technological support than V2H.

On the other hand, V2G requires more complex and expensive infrastructure for bi-directional communication. Moreover, bi-directional power losses in long distance transmissions lines are also significant in V2G operation. However, V2G is the most powerful source among all as it is a grid level energy transmission and can provide significant ancillary services such as frequency regulation and spinning reserve.

6. CONCLUSION AND FUTURE PROSPECTS

Today the electricity and transportation systems are facing number of challenges related to reliability, security and environmental sustainability. Internal combustion engine vehicles cause serious environmental issues such as emission of CO_2. Moreover, due to limited resources of fossil fuels and increase in penetration of intermittent nature of renewable energy sources, there is a need for energy storage system for back-up power.

The concept of electric vehicles is considered as emerging technology that has potential to not only reduce the dangerous CO_2 emission but also to provide certain necessary support to power grid as well. EVs have capability to reduce the dependency of oil and make the environment eco-friendlier. They are considered as mobile energy storage system. EVs charge their batteries by simply connecting with the grid as a load and can also provide the stored power back to the grid by discharging their batteries and thus behave as distributed energy resource. This concept is termed as V2G technology.

In this thesis, the detailed study on EVs have been done which includes it working, advantages, challenges, charging schemes and applications. Furthermore, one of its main application called V2G is analyzed in detail. Based on the analysis of V2G technology, this thesis aims to review the functions of V2G, it’s remarkable advantages, issues related to this technology and impact of V2G on distribution system network. In addition to this, certain case studies have been studied to demonstrate the applicability of V2G in real world.

V2G enabled EVs can supply power to the gird during peak load times and can get their batteries charged when the demand is low. This can reduce the need of building new power plants. EVs have four functions that can be provided to the grid through V2G technology such as peak power, spinning reserve, regulation and storage system for RES. The combination of spinning reserve and regulation service is known as “ancillary service”.

However, there are some challenges in V2G technology which need to be solved before the integration of large fleet of EVs into the power system in the near future. Some of these include a need of intelligent charging infrastructure for charging the batteries of vehicles, high capital cost of EVs, battery degradation which causes the reduction in life span of battery and complexity in the power electronics circuitry used in battery technology which impose controllability issues.

A large fleet integration of EVs will impact the electricity market in the near future as the electricity prices will go down. Concluding from all the findings of the thesis, an energy storage system should first and foremost utilize a technology that can handle the increasing energy demand without building new power plants.

In the future, there should be an on-board mapping system for all the rest stops of EVs. Among which some locations or buildings can serve as charging points and the on-board map systems will enable the people to choose the charging point of their choice i.e. public or private charging point, by using on-board mapping system. However, security precautions need to be investigated to protect the owner of EV as well as the grid system in order to make the energy system more flexible and reliable.

To get the maximum benefits of the V2G technology, there should be a smart infrastructure for V2G mode. For instance, the owner of the EV park his car in the parking lot of the office building and plug in outlet of the meter, swipe the card and the system identifies the owner data. It identifies the owners default charging profiles such as prefer time of discharging, the time of leaving from office and driving range etc. Modification option can be there to modify the charging preferences according to owner’s requirements. At day time when the demand is high, power grid can take supply from the plugged car to meet the surging demand by making sure not to take so much. In case if the owner has to leave early in some emergency situation, he can do adjustments in charging profile through online system quickly. A small profit can be made by this way. The vehicle can be charged again at night at home when the rates are quite low.

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