

GRID FREQUENCY CONTROL USING FUZZY LOGIC WITH V2G SYSTEM

A Dissertation submitted in fulfillment of the requirements for the Degree of

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In

Electronics Instrumentation & Control Engineering

Submitted by

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DECLARATION

I hereby certify that the work which is being presented in the dissertation entitled "Grid Frequency Control Using Fuzzy logic with V2G System" by Ankit Painuli (Roll No. S01451002) in partial fulfilment of requirements for the award of degree of Masters of Engineering in Electronic Instrumentation and Control Engineering submitted in the Department of Electrical and Instrumentation Engineering at THAPAR UNIVERSITY, PATIALA is an authentic record of my own work carried out under the supervision of Mr. Nirbhawjap Singh, (Assistant Professor, EIED) and Ms. Manbir Kaur (Associate Professor, EIED). In case of any plagiarism or copyright violation, I will be solely responsible for it.

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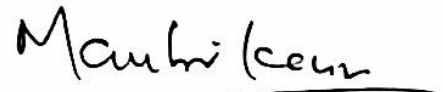
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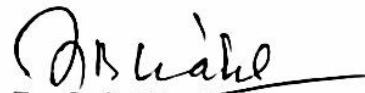
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ABSTRACT

Battery operated vehicle and hybrid vehicle are the future way to travel or commute within the city, which efficiently reduce the carbon footprint from the world. The power needed by these vehicles to charge their battery is less but as the number of electric vehicles is growing it can have effect during peak loading hours, to counter this problem a new type power management, or some sort of system to deal with the charging is required. Not only the electric vehicle helps decarbonizing the transport, they are considered as mobile power storage device as they have power stored in battery. Same as conventional vehicle the electric vehicle are not utilized as they are stay most of the day as idle on parking. This is going to change in the future as a new technology has emerged which used to link all idle vehicle to the power grid. Such technology is known as Vehicle-to-Grid system which when applied enables charging load to be shifted to off-peak periods, thereby flattening the daily load curve and significantly reducing both generation and network investment needs. not only this, the system can effectively use to transfer the power stored in the batteries of the EV's to further tone down the peak loading curve.

The motive behind this thesis is to control the frequency of the grid which droops during the peak load time, as the load on the grid start increasing the power demand the frequency start dropping. To fill in the gap between the supply and demand, the EV can help out by transferring the stored power to the grid by using the V2G system. Also this new technology is very cost effective as the vehicle will charge itself during the off peak loading time when the rate of electricity is cheaper, hence shooting two birds with one arrow. Various researches are going on throughout the world on how effectively this new technology will work and how to optimize the charging and discharging of the EV's and PHEV's.

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LIST OF ABBREVIATIONS

Abbreviations	Details
EV	Electric Vehicle
PEV	Plug-in Electric Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
V2G	Vehicle to Grid
V2H	Vehicle to Home
V2V	Vehicle to Vehicle
SOC	State of Charge
IEEE	Institute of Electrical and Electronics Engineers
APC	Achievable Power Capacity
LFC	Load Frequency Control
BESS	Battery Energy Storage System
AC	Alternating Current
DC	Direct Current
PWM	Pulse Width Modulation
IGBT	Insulated-Gate Bipolar Transistor
MF	Membership Function
PV	Photo Voltaic
MVA	Mega Volt-ampere
MWh	Mega Watt hour

CHAPTER – 1

INTRODUCTION

1.1 Background

Now day's electric vehicles are common for commutation, reason being the fast depletion of fossil fuel. The number of EV will highly increase in the future and hence there will be more power storage capability available that can be used to supply power demand. EVs are an eco-friendly substitution for the daily purpose transportation. The EV uses the battery as a power source which can also act as a mobile power source; this stored power can be used to enhance the grid capability. As a result, a new technology is developed known as vehicle to grid (V2G) system [1]. Most of the EVs are unused during the complete day as from night to morning vehicles are free at home and are parked during normal working hours. Thus, the power stored in the battery can be used for power transmission during the peak load hours [1-2]. This system is used to transfer the power stored in the battery back to the main grid during peak load hours and recharge itself in off-peak time maintaining the nominal state of charge (SOC) of the battery. Frequency is the major concern for the grid to work properly in terms of transferring the power while maintain quality of power to the respective node. V2G system transfer of power can also regulate frequency in the grid and reduced cost of power production.

One of the major hassles of the power generation is to deliver the continuous generation of power to the grid, and maintain power quality. However, in peak load hours the frequency lags behind its expected value (which is 60Hz in Europe and America while it is 50Hz in Asia as a standard). In case the frequency continuously drops for a long duration, then the grid starts shedding the load from the area to maintain the quality of power, this process is known as load shedding. Load shedding is done to avoid the monetary penalty on the power corporations. A major reason of frequency variation at the grid is dependent upon the load on the grid. The power grid frequency is inversely proportional to the load on the grid. During the peak loading hours, the demand of the power from the grid is high (generally occur in the afternoon and more in summer afternoon). In such case V2G system can be used to overcome the power demand by contributing to the deficit power from the battery or self-power generating vehicles.

1.2 Literature Survey

The literature survey related to the dissertation is presented in three parts, discussed individually in this section as follows. The first part is related to the latest trends in vehicle to grid technology, second part is related to grid frequency control using V2G and third part is dedicated to fuzzy logic controller.

The bidirectional transfer of power from electric vehicles, hybrid vehicles and fuel cell can be implemented with the use of a bidirectional charger to fulfill the power scarcity during the peak load timing to avoid load shedding [4]. The various power electronics topologies to connect the plug-in-vehicles as well as the hybrid vehicle with the grid have been discussed [5]. A conceptual framework to integrate the electric vehicles into the grid for realization of V2G concept with an aggregator for fast response time and energy supply for peak shaving has been developed [6]. An on-board V2G Integrator with the conversion efficiency of 90% as well as the response time of the inverter is far better than that of the power plant to overcome the power difference of the power grid [10]. The design and analysis of a multi-function bi-directional charger for battery charging of vehicle to grid (V2G) and vehicle to home (V2H) has been presented [7]. A scheme to distribute the power from V2G, while considering the convenience of the user and the condition of the battery as well as whole power system contribution is proposed. The proposed scheme is implemented to houses, which works as "Smart Storage" in the ubiquitous power grid [8]. A comparison of the light EV fleet with the electric power system has been presented and concludes synergistically tapping of power of an EV fleet to resolve the harmonizing needs of the grid manager and the driver [9].

In order to maintain the power quality it is essential to regulate the grid frequency at standard value as per the norms. A unidirectional V2G system has been demonstrated in which a hypothetical group of 1000 EVs is considered and the power output is optimized from those EVs by applying an algorithm to increase the profit by reducing the load impacts and gain economic profit under dynamic conditions [13]. The working of EV's is analogous to the power generator droop to minimize the frequency deviation in the grid has been verified [12]. An optimal aggregator by controlling the charging and discharging for regulating the frequency of the grid has been demonstrated. A model based on PHEV fleet for multiple time slot horizon to meet the required battery level in the PHEV after the plug has been pulled out [15].

An analysis of V2G battery provision to regulate the power system frequency in relation to EV battery SOC has been presented. In the control strategy the V2G is interconnected with the wind farm to verify the frequency control [16]. A discussion has been presented for V2G and vehicle to vehicle (V2V) services. A symbolic logic management is employed, to attenuate the impact of charging PEVs for the grid's ability to maximize the use of renewable energy and facilitate the grid's ability to manage the utility frequency resulting in profitable power utility [17]. Sekyung Han et.al. [18] have presented active discharge of the plugin electrical vehicle is enabled utilizing the regulation signal to avoid the energy constraint. The discharge is enforced through uneven distribution of the regulation signal. The regulation signal was erratically allotted between the regulations up and down for the discharge purpose. Sekyung Han et.al. have discussed the chance distribution of the achievable power capacity (APC), four doable contracts between a grid operator and a V2G regulation supplier square measure advised and, for every contract profits are developed from the APC and therefore the penalty obligatory to the V2G aggregator [19].

A sensible storage theme which is anticipated to take care of power frequency quality for low carbon power systems has been proposed. The sensible storage works as a spinning reserve with quick response, and does not interfere with typical load. As a result, reduction of battery energy storage system can be accomplished [20]. A frequency regulation strategy for decentralized V2G, which not solely guarantee the first and secondary frequency regulation, however EVs solely participate within the primary frequency regulation has been developed [21]. Task Masuta have shown that the Battery energy storage system is one in all the effective solutions to those issues. Attributable to a high value of the BESS, an application of manageable hundreds like electrical vehicle and warm pump storage tank with the ability of system management is taken into account for the reduction of the desired capability of the BESS. The effectiveness of the planned LFC methodology is shown by numerical simulations conducted on the ability system model with an oversized integration wind generation and electrical phenomenon generation [22]. Murat Yilmaz and Philip T. Krein [23] have shown and states the costs of V2G embrace battery degradation, the necessity for intensive communication between the vehicles and therefore the grid effects on power distribution, instrumentation, infrastructure changes, and social, political, cultural, and technical obstacles. Though V2G operation will scale back the time period of car batteries, it is projected to become economical for vehicle owners and grid operators. The success of the V2G is thought to depend on standardization of necessities, infrastructure

selections, battery technology, and economical and sensible planning of restricted fast-charge infrastructure.

The grid frequency control is a highly nonlinear and complex power system distribution problem. In literature fuzzy logic is a theory that mimics a human reasoning capability and has been proved capable of solving complex practical problems [1965 paper L.A Zadeh]. An introduction to basic concept of fuzzy theory and applications related to information processing, control, system identification and, more generally, decision processes involving incomplete or uncertain data has been discussed [24]. Among the various applications of fuzzy theory, Mukesh Singh et.al. have connected the EV at the charging station and coordinate it with need of the power grid as the EV are mostly in their idle time are present on the charging station for battery charging. Charging stations will coordinate with the help of fuzzy controller and decide the amount of power required by each electric vehicle [11]. Further, Manoj Dutta has reported an efficient LFC regulation approach by using PEVs combining with fuzzy logic for isolated and varying load by considering only active power [27]. A fuzzy based plug-in electric vehicles (PEV's) strategy to control the aggregator for controlling the frequency instability due to load demand variation and uncontrolled discharging and charging of PEV's has been presented [14].

1.3 Gaps of Study

It is a well-established fact that research and experimental work are underway for integration of the V2G system with conventional grid. Although there are many techniques available to implement the system, most of them use a fleet of electric vehicle with some combination of hybrid electric vehicle. The use of EV as an isolated power source to power a house during the peak demand hours is known as vehicle to home (V2H). EV is used for auxiliary services like voltage control, frequency regulation, etc. However, in the study reported in the dissertation, fuzzy logic control for frequency regulation is carried out by optimizing the V2G power output.

1.4 Organization of Dissertation

The Dissertation is organized as follows:

Chapter-1 Introduction and literature survey about the V2G technology.

Chapter-2 contains a brief history of the EV and V2G system

Chapter-3 describes the fuzzy logic and its application.

Chapter-4 includes the solution methodology and the underlying simulation model of the integrated system.

Chapter-5 includes the results and discussion.

CHAPTER – 2

Vehicle to Grid System

2.1 Introduction

This chapter presents the historical development and the present scenario of the EV and the V2G system. A further discussion on the salient features of the systems and its advantages and limitations are presented lastly an approach is presented to counter the limitations of the system.

2.2 Electric Vehicle

Electric vehicles (EVs) also known as electric drive vehicles were among the earliest automobiles. EVs are dated back to 1820's when a Slovak-Hungarian priest Anyos Jedik invented a tiny car fitted with a crude but viable electric motor. From 1832 to 1839 many early experiments on EV are carried out for example, in 1835, a Dutch professor Sibrabus Straingh, built a small scale electric car, in 1935 American inventor and blacksmith Thomas Davenport built an electric toy locomotive, Robert Davidson a Scotsman built an electric locomotive which can reach 6 miles per hour of speed.

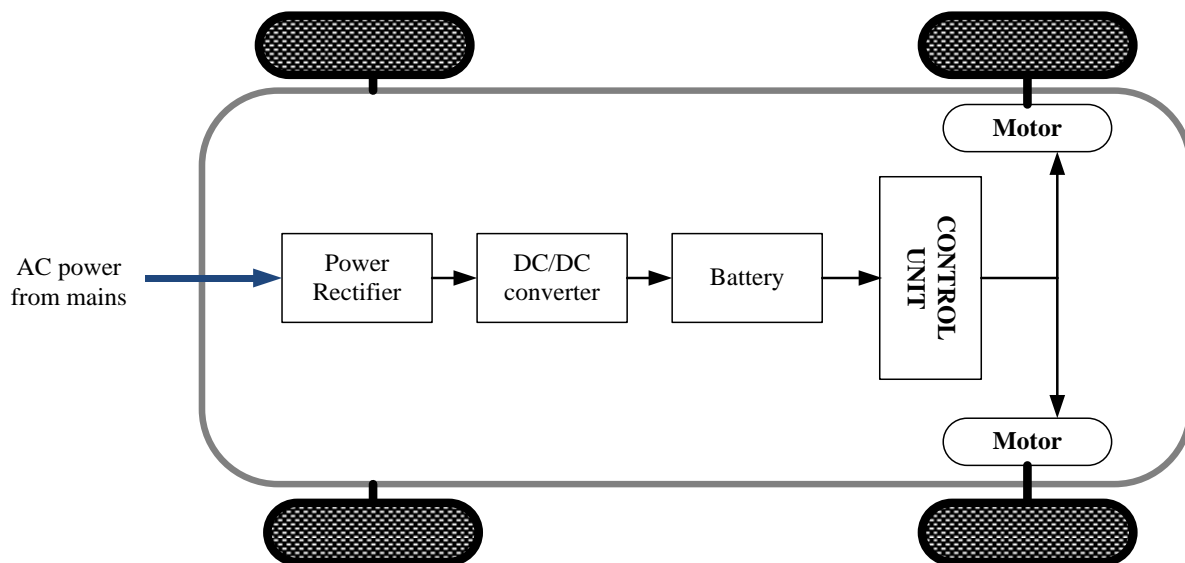


Figure 2.1: Basic internal block diagram of an EV

The Figure 2.1 shows the internal block diagram how the energy from the grid get converted and utilized by the vehicle. The electric energy from the grid, which is alternating firstly get converted to DC by using a power full wave rectifier, this rectifier can be located either on the charging station or inside the vehicle itself. The converted power is high voltage DC which needs to convert to a safe voltage level, also storing the high voltage DC is a hassle for the manufacturer due to factors like battery temperature risking fire conditions. To subdue this, a DC to DC converter or chopper is used to convert this high voltage DC to low level voltage. The power is then stored in a battery; almost every manufacturer uses Li-ion battery due to the fact that it can store more power in a much lesser area. Li-ion batteries are light, can be maintained easily, have longer life span of around three to four years.

A control unit connected between the batteries and the motor to control the power from the batteries to the motor. As the owner pushes the acceleration pedal the control unit allows only the amount of the power that is required by the user, power unit also responsible for calculating the SOC of the battery and warns the owner. Here in the figure we can see that the motors are coupled with the tyre, this arrangement is bulky and reduces the efficiency of the vehicle. EV manufacturing companies had solved this problem by fitting the motor inside of the tyre rim so to reduce the extra weight, also reducing the friction loss and in turn increasing the efficiency.

2.3 Vehicle to Grid system

Vehicle to grid system is the bidirectional power transfer between the power grid and electric vehicle (EV) and plug-in electric vehicle (PHEV) to meet the load power demand either by providing the power to the grid or charging the vehicle at a faster rate. The term V2G was devised by the California based company AC Propulsion which is a leader in research and developing V2G systems. EVs and PHEVs act as a dynamic power storage system. There are several ways to use the energy stored in PHEV such as:

- a. Peak shaving,
- b. Load smoothing,
- c. Smoothing output of intermittent generation,
- d. Backup power supply, and
- e. Auxiliary services.

An important application of V2G is to regulate a frequency of grid that result in power generation cost reduction by improving the power gap during peak loading hours [30]. The

Figure 2.2 shows the power gap rectify with the power injected by the V2G during peak loading hours and peak shaving when power is more than 100%.

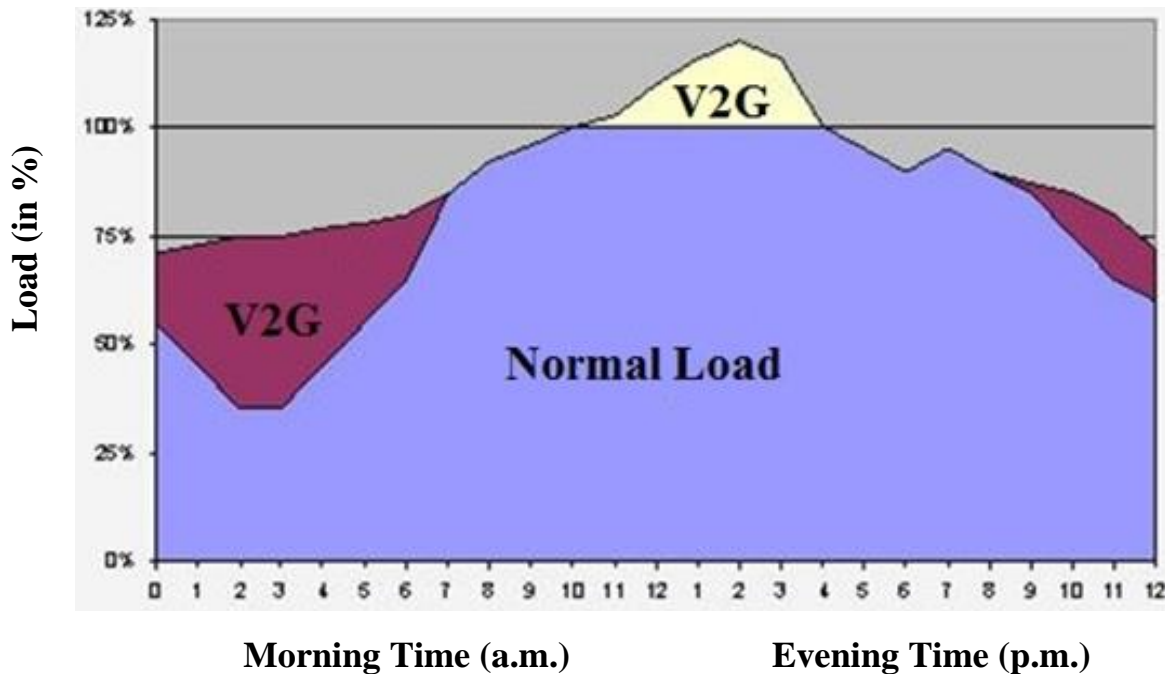


Figure 2.2: Role of V2G during peak loading and power shaving

2.3.1 Classification of V2G system

In power source is an essential for V2G system, depending upon the sources of power the V2G system has three versions. The Figure2.3 presents a pictorial view of V2G system versions

- A fuel cell vehicle that generates power by using biomass, electrolysis or H_2/O_2 cell (popularly known as a fuel cell) into power.
- Solar vehicle convert the solar radiation directly into electric power that can transfer to the grid during the peak loading time.
- Battery powered vehicle or Plug-in electric vehicle that supplies its excessive amount of power to the grid to counter the peak load demands. It can recharge itself during off-peak hours at cheaper rates absorbing excess generation. This version of the V2G system has a bidirectional flow of energy that is from the grid to the vehicle and vice versa.

The first two versions are also known as V1G *i.e.* one directional flow of power from vehicle to the grid not the other way around. The third version is the true V2G as the flow of power is bidirectional that is from the grid to vehicle and vice versa.

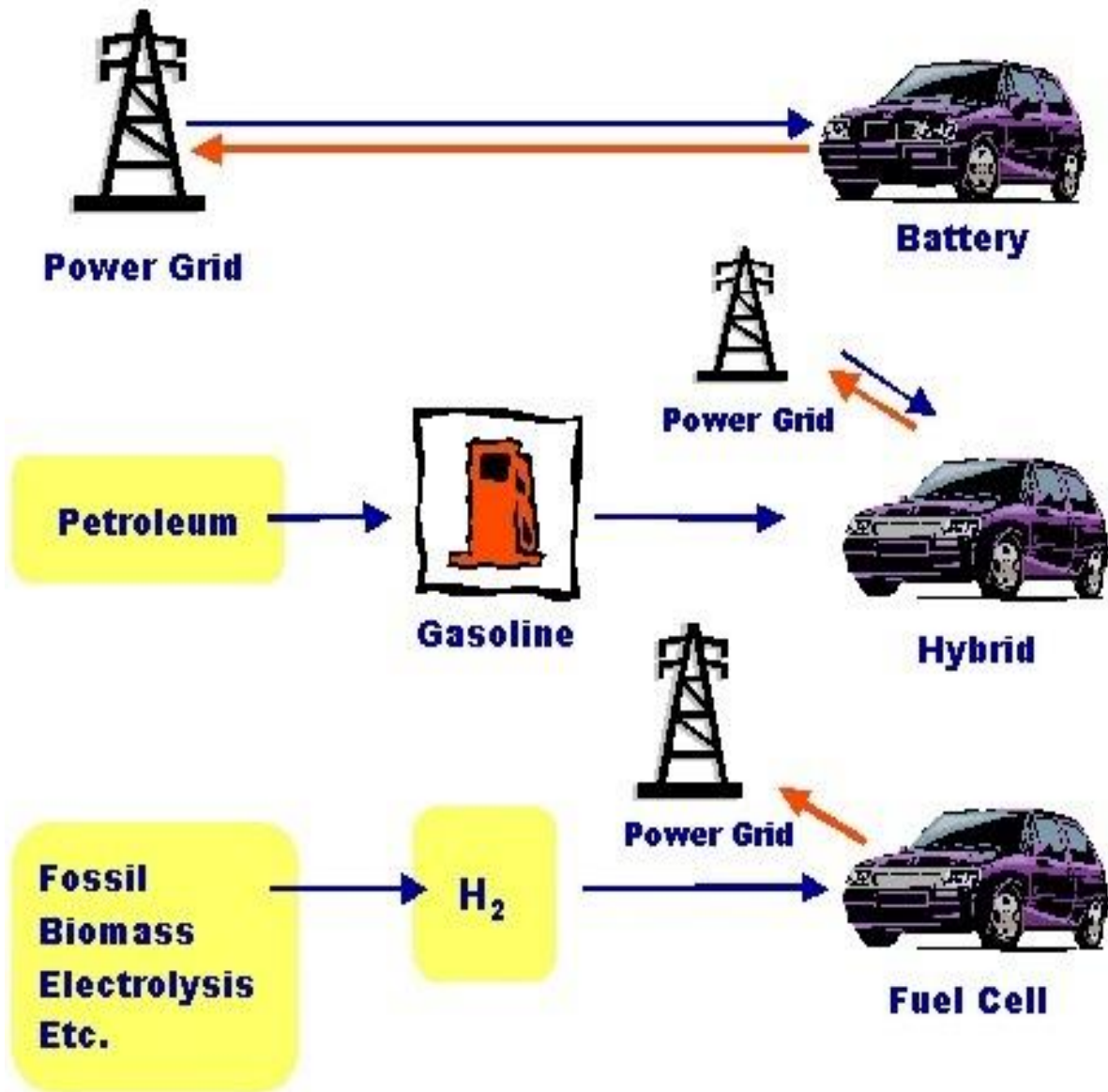
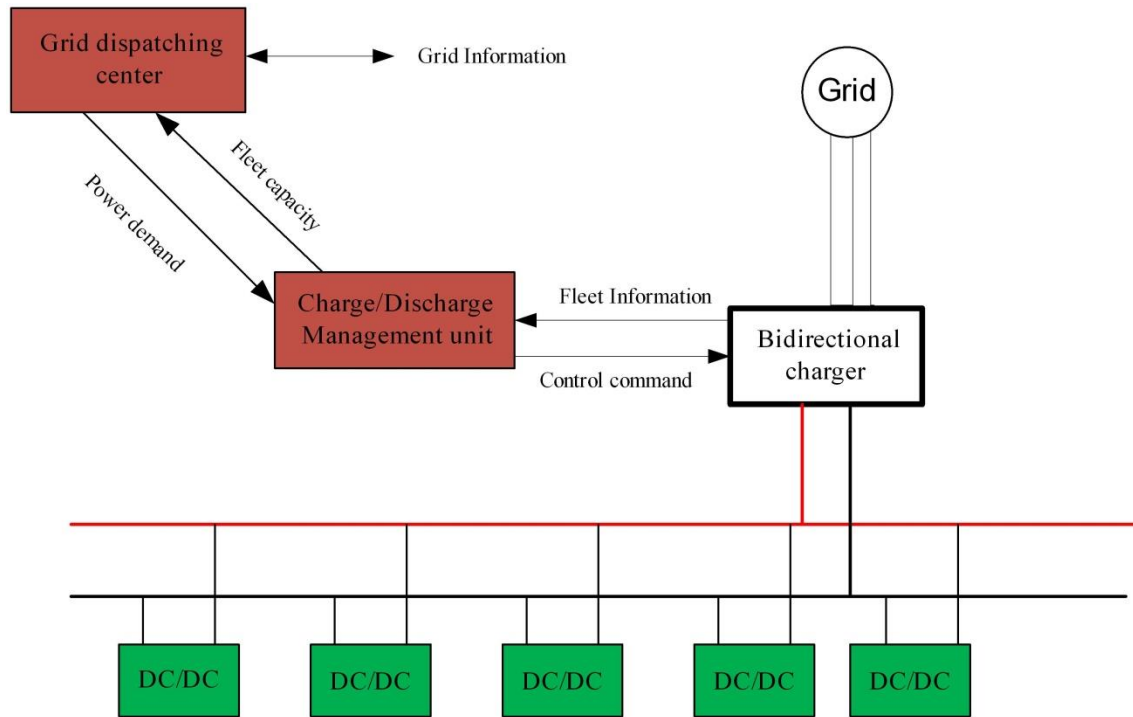


Figure 2.3: Different version of V2G system

2.3.2 Blocks of V2G

The V2G system is composed of many smaller constituents and each part is crucial to the working of the V2G system. The figure 2.3 shows the basic blocks of a V2G system. A group of parked EV is called a fleet, which is used as the power source of V2G system. It acts as a small power storage unit which has a bidirectional flow of power. The grid dispatching center receives the grid parameters and if there is any deviation on the grid the information is sent to this center. This center also gives commands to the management unit and also receives the information about the capacity of the fleet.



A fleet of parked electric cars

Figure 2.4: Block diagram of V2G system

The management unit has two way communication links with a bidirectional charger. The management unit gives command, whether to charge the vehicles or to discharge the power to the grid.

A bidirectional charger is required by the EVs to connect with the grid. The figure 2.4 shows the basic configuration of a bidirectional charger [7], the charger has two working conditions:

- a) Grid to the battery for charging (rectifier action) the battery, when the SOC level of the battery is lower than nominal value or pre-determined value.
- b) Battery to the grid (inverter action) for discharging or transferring the power to the grid.

In the present work, a three arm 6-pulse IGBT is used. A PWM generator is used to provide the gating pulses for firing of IGBT at specified angles. The SOC of the battery and grid frequency controls the switching of the inverter depends on SOC and grid frequency.

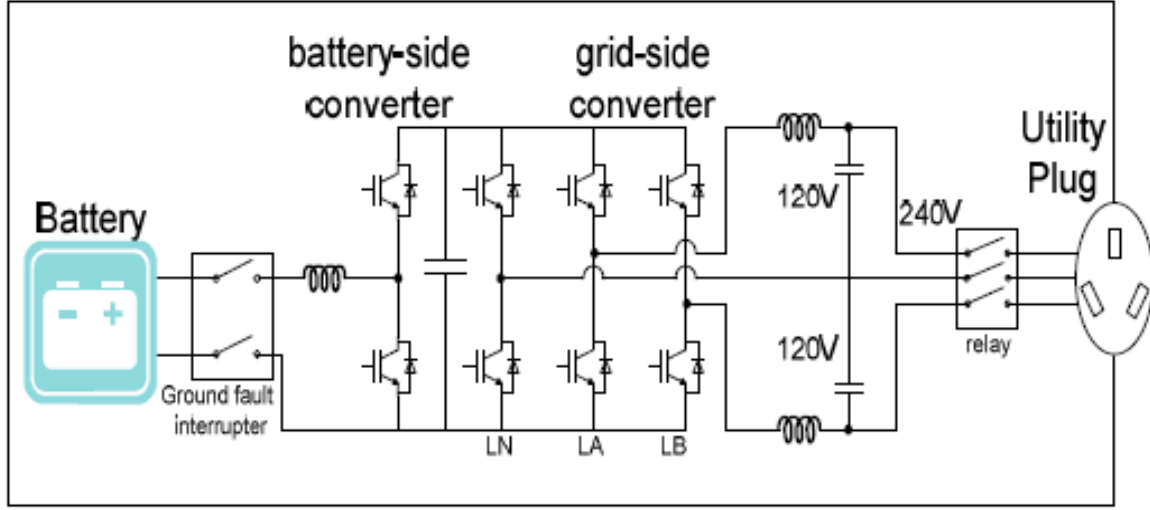


Fig.2.5: Bidirectional charger topology

The charging and discharging operation of power stored in the battery depends upon the SOC. The calculation of the SOC is required to know how much charge is left in the battery according to which the system decides whether to charge or Discharge the EV.

The load frequency control signal only responds after charging within the limit of its capacity

$$E_{control}^{\min} \leq E_{control} \leq E_{control}^{\max} \quad (2.1)$$

Where control is the total energy of the controllable EVs, $E_{control}^{\max}$ are lower and upper energy capacity limits respectively. By computing (2) and (3) get the energy capacity depending on the control strategy, i.e. the SOC.

$$E_{control}^{\min} = \frac{N_{control}.C_{kWh}}{1000} \times \frac{80}{100} \quad (2.2)$$

$$E_{control}^{\min} = \frac{N_{control}.C_{kWh}}{1000} \times \frac{90}{100} \quad (2.3)$$

$E_{control}$ is calculated using the following equation.

$$E_{control} = -E_{LFC} + E_{control-in} + E_0 - E_{plug-out} \quad (2.4)$$

Where;

E_{LFC} = energy from load frequency control signal

$E_{control-in}$ = increase in energy in EVs

E_0 = initial energy

$E_{plug-out}$ = decrease in energy due to plug-out which is calculated from (4)

$$E_{plug-out} = \frac{Z}{N} \sum_{i=1}^N E_i \quad (2.5)$$

Where;

E_i is the energy from i^{th} E

N is the total number of EVs, and

Z is the number of the plug-out EVs

2.3.3 Limitations of V2G

Electric Vehicles (EV) are not used for about 90% of the day, during that time the energy stored in EVs can be used by the power grid. However, today EVs are capable of fast charging and are usually rated between 50-100 amperes at 220-240 volts, irrespective of the charging station [30]. The EVs are free to charge during off-peak load and each EV can charge between 12kW to 24kW, this heavy charging load of several vehicles can severely influence the power grid. Since, the number of EVs is likely to increase exponentially; a mechanism to tackle this critical issue of charging EV is a need of an hour.

2.3.4 Countering EV limitations using V2G System

Although the V2G system contributes to the power demand also the EVs, too, need charge to themselves using power from the grid, and thus can contribute to the overall peak demand time and can cause the grid frequency to fluctuate. To overcome this problem, the proposed strategies are

- a. Tight control must exert over the amount and duration of EV battery charging, to avoid increasing peak demand [29].

b. Energy stored in the EV batteries should be used to reduce the peak demand [29].

Above mentioned strategy can be applied only by a bidirectional charger in EV, where SOC of the battery banks will decide when to discharge and when to charge detail.

CHAPTER – 3

FUZZY LOGIC

3.1 Background

Fuzzy logic is a diverse mathematical methodology that enables tough simulated issues with several inputs and output variables. Fuzzy logic has ability to leads the shape of advice for a particular interval of output state [31]. Fuzzy logic is an approach based on the degree of certainty rather than the classical Boolean logic (0 or 1). The idea of fuzzy logic dates back to 1920s, as “infinite-valued logic” notably by Łukasiewicz and Tarski, but it was in 1965 that Dr. Lofti A. Zadeh of University of California, USA gives the final form of it [32]. Dr. Zadeh finds that it is not possible for a computer to understand the natural language nor their logic and reasoning and cannot be always given as absolute terms of true or false (0 or 1).

The extreme cases of fuzzy logic are 0 and 1, in between; there lies the reasoning and logic of the fuzzy system. The fuzzy logic controller seems to work very close to the reasoning ability of how the human brain works Fuzzy logic mimics human logical reasoning and decision only much faster, it can be implemented in hardware, software or a combination of both [33].

The shown in Figure 3.1 shows control analysis method. Fuzzy logic receives one or more measurements existing in the system which is to be controlled. The input measurements are then processed by “if-then” rules expressed in linguistic way. All the processing is based on averaged and weighted into one single output. The resultant output signal is a precise defuzzified value.

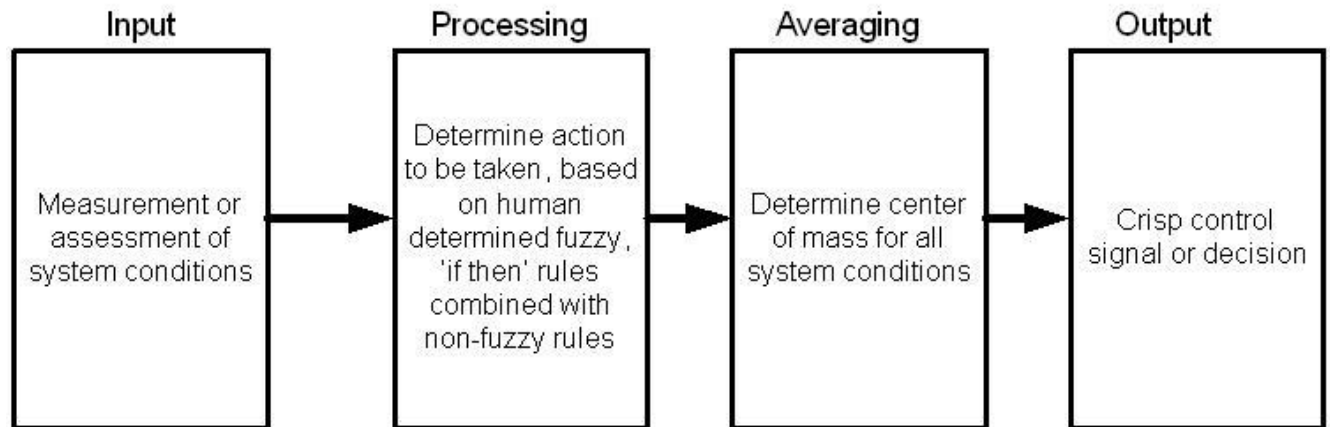


Figure 3.1: Fuzzy logic control-analysis method

The variable representation used in fuzzy logic, is non-numeric in contrast to the other control logics for better interpretation that of human thinking. It helps to facilitate the expression of the rules and facts [33]. The advantage of using non numerical or linguistic variable is that the variables can be modified via linguistic hedges applied to primary terms.

3.1.1 Fuzzification

The process of converting a crisp value to fuzzy variable is known as fuzzification. The process depends upon the uncertainty present within the crisp value. The fuzzified values are represented by membership function and then used as an input for a fuzzy inference system.

3.1.2 Membership function (MF)

The information stored in a fuzzy set is represented by the membership functions (MF's), it is a graphical magnitude presentation of each input. MF's are used by the inference engine for creating the rules, to determine the influence on the fuzzy output sets [34]. A typical trapezoidal membership function is shown in Figure 3.2. The figure shows the membership function (or MF) used in the fuzzy logic to obtain the result. Here three input membership function was created, i.e. battery state of charge, time till frequency deviate and grid frequency. The output membership function is given by the power output of the V2G system.

3.1.3 Inference engine

The inference engine is a component of fuzzy logic that uses to evaluate the membership function. Mamdani inference system is used for this study in the dissertation.

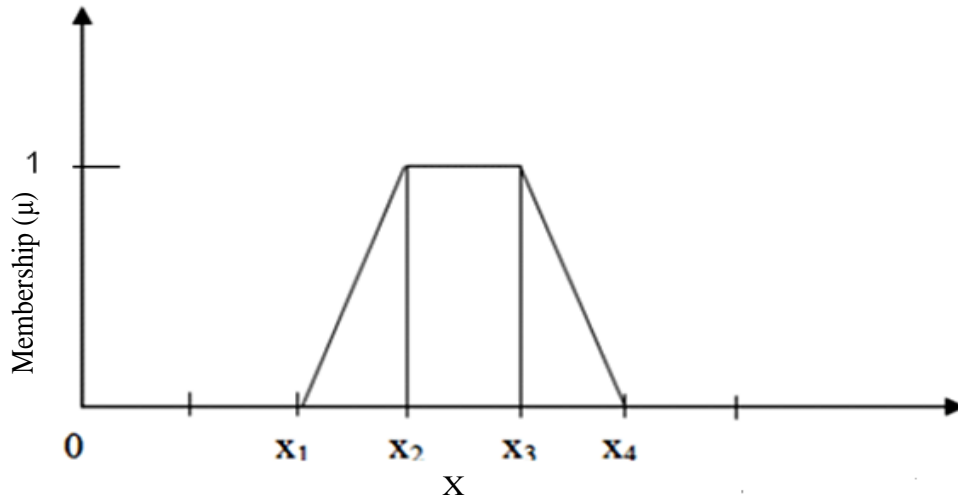


Figure 3.2: Trapezoidal membership function

3.1.4 Defuzzification

The opposite of the fuzzification where the fuzzy representation is converted back to the crisp or precise value is known as defuzzification. After combining or comparing the membership function defined in linguistic variable, the output of the fuzzy system can be achieved. The inference engine calculates the output of the fuzzy controller on basis of rules defined and the degree of membership. There are many defuzzification methods available such as a weighted average method, mean maximum membership etc. here for this study, centroid method is used. Sugeno in 1985 proposed the centroid method which is the most accurate method.

An output linguistic variable as shown in figure 3.3 where x^* is the de-fuzzified value which is given by an algebraic equation as:

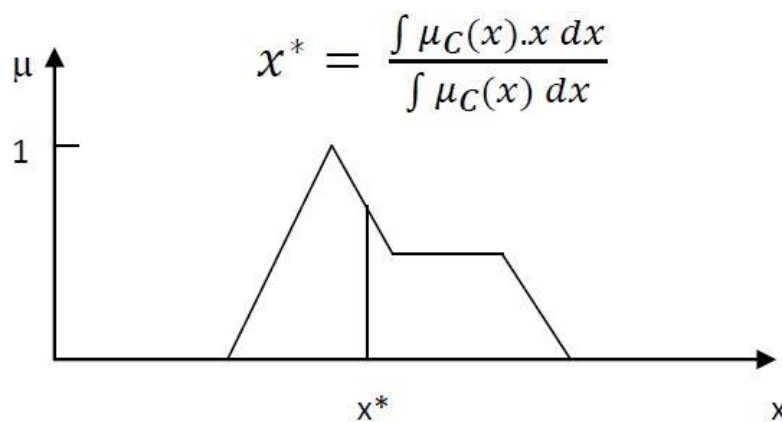


Figure 3.3: Centroid curve and formula

3.2 Fuzzy Logic controller with V2G

An electric vehicle contains battery as a storage device to power the motors for propulsion, this power stored inside can be transfer back to the grid, but the power stored in the battery is in DC, and the grid is working on AC. So an inverter is used to convert the DC power to AC power, this can be achieved by V2G technique. The efficiency of the V2G system can be calculated by the charging and discharging of the batteries. The process of charging and discharging can be properly schedule to improve the efficiency of the system, for better scheduling, a controlling method should be applied. Here in this study fuzzy logic controller is used. The Figure 3.4 shows the conceptual block diagram of the fuzzy controlled V2G system. The power from the PV solar cell and the wind farm is connected to the grid. The grid is working 50 Hz. The V2G system consists of several EV's known a fleet, the power of the single vehicle is collected and ready for the transfer to the grid.

The input variables of the fuzzy logic are battery SOC, frequency and frequency deviation time. The output of the fuzzy is in the form of power in which is directly fed to the grid for compensating the gap between power demand and supply.

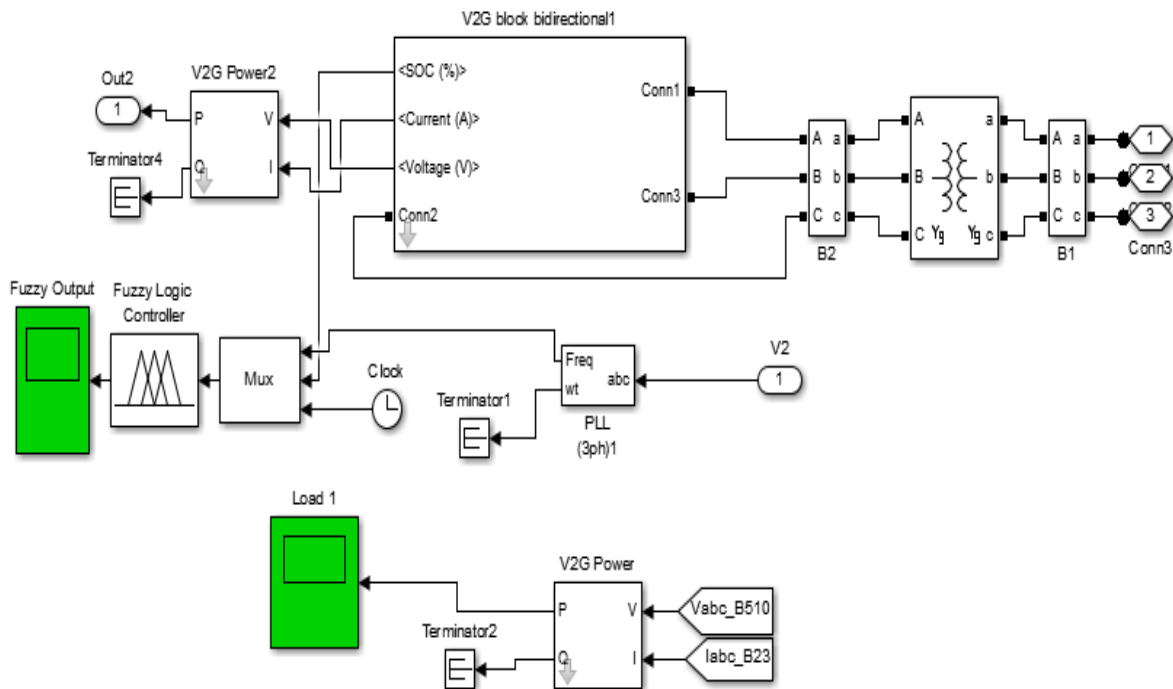


Figure 3.4: Simulation model of V2G Fuzzy logic controller

3.2.1 Fuzzy Membership Rules used in the simulation model

1. If (FREQ is LOW) and (Time is LM) and (SOC is M) then (GRID_OUT is DL)
2. If (FREQ is LOW) and (Time is L) and (SOC is M) then (GRID_OUT is DL)
3. If (FREQ is LOW) and (Time is LM) and (SOC is HM) then (GRID_OUT is DM)
4. If (FREQ is LOW) and (Time is M) and (SOC is HM) then (GRID_OUT is DM)
5. If (FREQ is LOW) and (Time is HM) and (SOC is H) then (GRID_OUT is DH)
6. If (FREQ is LOW) and (Time is H) and (SOC is H) then (GRID_OUT is DH)
7. If (FREQ is HIGH) and (Time is LL) and (SOC is HM) then (GRID_OUT is CL)
8. If (FREQ is HIGH) and (Time is L) and (SOC is M) then (GRID_OUT is CL)
9. If (FREQ is HIGH) and (Time is LM) and (SOC is LM) then (GRID_OUT is CM)
10. If (FREQ is HIGH) and (Time is LM) and (SOC is L) then (GRID_OUT is CM)
11. If (FREQ is HIGH) and (Time is HM) and (SOC is LL) then (GRID_OUT is CH)
12. If (FREQ is HIGH) and (Time is H) and (SOC is LL) then (GRID_OUT is CH)

TABLE 3.1: Fuzzy set matrix time vs. frequency

FREQ	LOW	BALANCE	HIGH
TIME			
LL	DL	NA	CL
L	DL	NA	CL
LM	DL	NA	CM
M	DM	NA	CM
HM	DH	NA	CH
H	DH	NA	CH

TABLE 3.2: Fuzzy set matrix SOC vs. frequency

FREQ	LOW	BALANCE	HIGH
SOC			
LL	NA	NA	CH
L	NA	NA	CM
LM	NA	NA	CM
M	DL	NA	CL
HM	DM	NA	CL
H	DH	NA	NA

Where;

LL = Least Low	CM = Charge Medium
L = Low	CH = Charge High
LM = Low Medium	DL = Discharge Low
M = Medium	DM = Discharge Medium
HM = Highest Medium	DH = Discharge High
H = High	NA = No Action
CL = Charge Low	

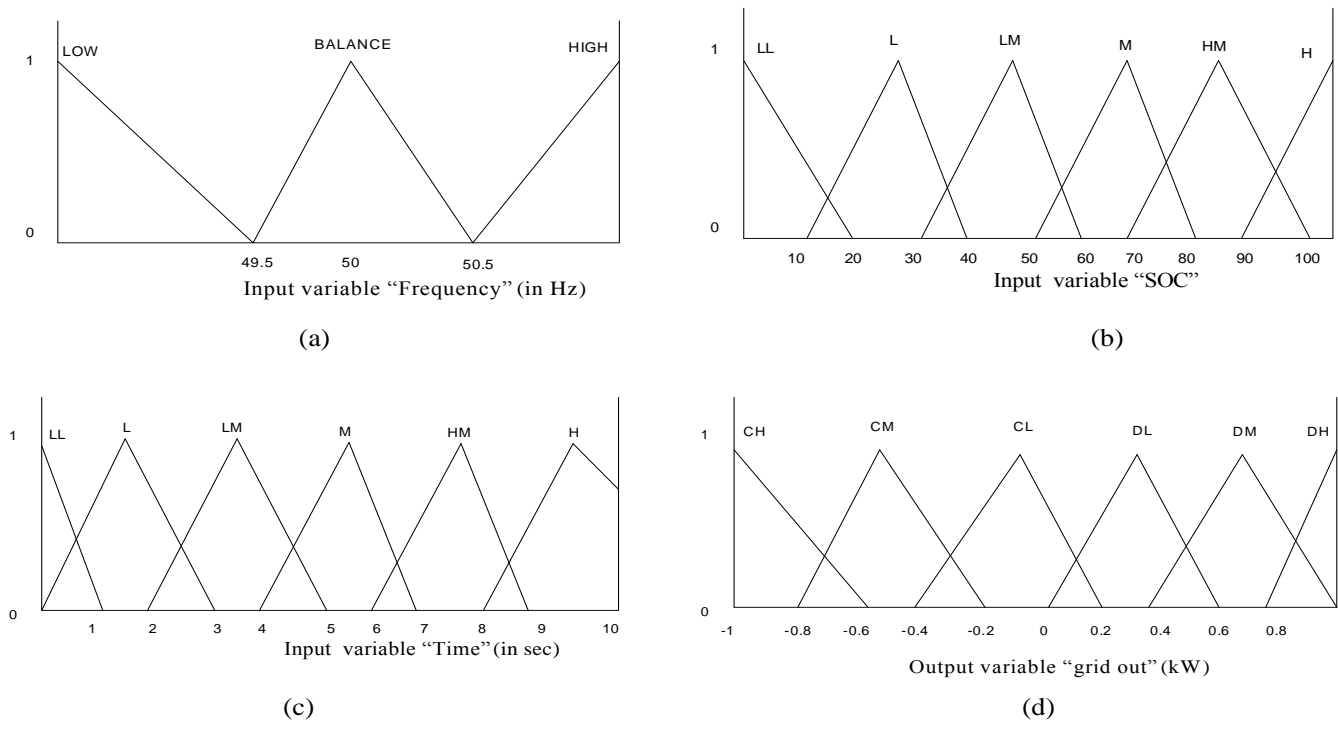


Figure 3.5: Membership functions of (a) Frequency (b) SOC (c) Time (d) Grid output

3.2.2 Surface Plot of Inference Engine

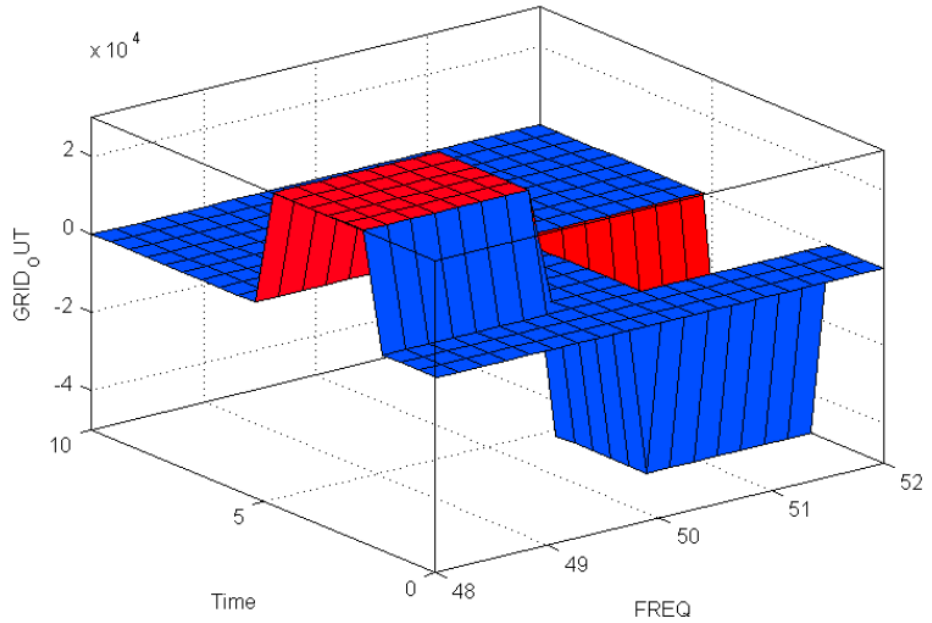


Figure 3.6: Surface plot of SOC and frequency with grid output

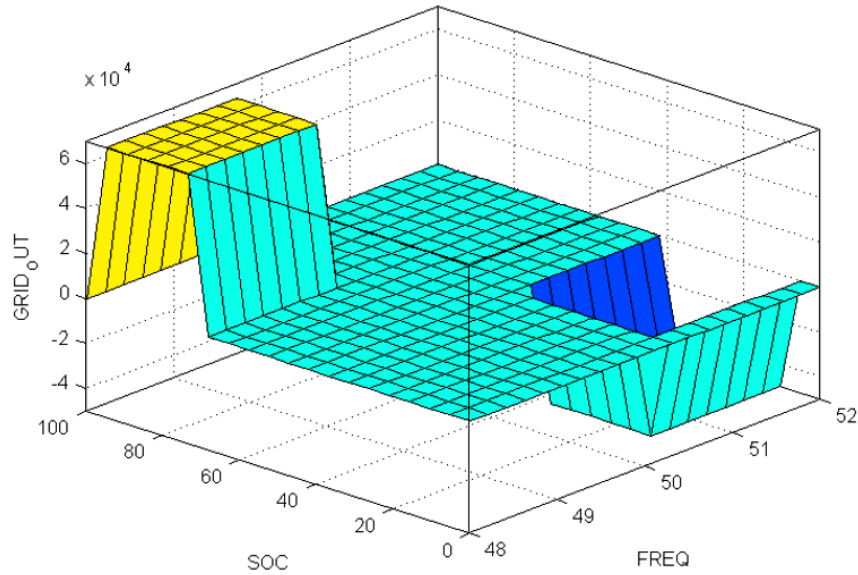


Figure 3.7: Surface plot of frequency and time with grid output

The Figure 3.6 shows the surface plot between grid frequency and frequency deviation time. The Figure 3.7 shows the surface plot between SOC of the battery V2G system and the frequency of the grid versus the fuzzy output. When the frequency is low and the SOC is optimal the power is transferred to the grid from V2G system. The red plateau shows the power output from the fuzzy controller. The deep blue trough shows the power transferred from the grid to the V2G system when the frequency is greater than required and SOC is lower than the acceptable value

CHAPTER - 4

INTEGRATED V2G AND GRID CONNECTED SYSTEM

4.1 Micro-grid

Microgrid is a local grid consisting of low voltage electricity sources which may or may not be synchronized with the traditional macrogrid. Mostly microgrid uses renewable energy resources for producing electric power. Microgrids are used for emergency in power outage and have the ability to work as islanded mode and grid-connected mode. The major challenges for the microgrids are control and protection.

a. Remote Microgrids

These grids are often installed where transmission and distribution of power from macrogrid is not possible due to remote location or an island. These types of grid uses renewable energy sources like wind turbine, solar cell, fuel cell etc.

b. Military Base Microgrids

These grids are deployed overseas or installed near military base for the purpose of power generation by the military, for defense purpose. Generally, diesel generators are used for producing electricity power. These grids are reliable as they do not depend upon macrogrid.

c. Commercial and Industrial (C&I) Microgrids

These types of grids are used for distributing power within the industrial complex. There is no fix standard throughout the world. These grids are highly reliable as interruption of the power will lead to high revenue losses.

4.2 Thermal Power Station

Thermal power station is the major power generation technique used around the world. The system consists of a turbine, governor and generator. The generator is responsible for the

frequency for the power generated. The boiler uses fuel like coal, gas or oil to heat the water which gets converted to super-heated steam, which then gets compressed by the compressor and flows over the blades of the turbine. This turbine is connected to the governor whose sole purpose is to control the speed or the rotation of the turbine, the governor can be both analog and digital. The generator which is connected the geared shaft converts this mechanical power to the electricity power. The poles of the generator are responsible for the frequency which is given by the formula:

$$f = \frac{P \times N}{120} \quad (4.1)$$

Where;

f = frequency in Hz,

P = number of poles,

N = speed of generator in RPM.

When the load increases during the peak load time the power demand increases and the chances of frequency drop becomes great so to overcome this frequency deviation, droop speed control comes into play. This droop speed control is a reference which is calculated in percentage and can be given by the formula:

$$Droop \% = \frac{No\ load\ speed - Full\ load\ speed}{No\ load\ speed} \quad (4.2)$$

In order to increase the power output in this mode, the prime mover speed reference is increased, hence increasing all the related parameters like steam flow, speed of generator etc.

The droop can only control the frequency up to certain level or for a short amount of time this time may depend upon the load on the main grid. More the load harder it is for the power generation house to compensate for the power required by the grid). After that, load shedding begin to happen as discussed above to avoid the load shedding the grid may contact from other power generation sources to make the grid stable. It is important that the other power sources are in sync with the main power generation house, i.e. the frequency should be the same may be 50 Hz or 60 Hz depending on the country or the region.

4.3 Wind Farm

Wind farm is the integration of many wind turbines at one place. It is one of the popular renewable sources of energy production. The power generated when the wind at certain speed hit the blades of the wind turbine which is further connected to a geared shaft. The gear shaft is connected to the rotor of the generator which when rotates produce electricity. These blades are aerodynamically designed so to get the maximum rotation at low speed of wind. Power generated by the wind turbine is given by the formula;

$$Power = \frac{1}{2} C \rho A V^3 \tag{4.3}$$

Where;

C = Coefficient of performance

A = Frontal area of blade

V = Velocity of the wind

ρ = Air density

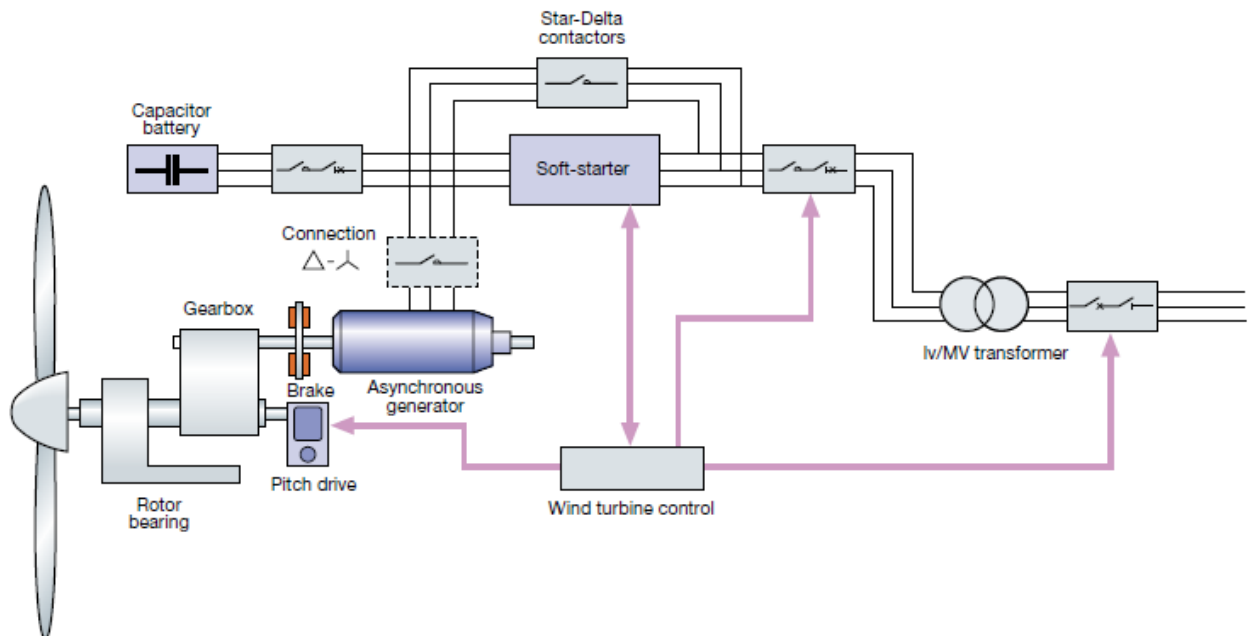


Figure 4.1: Schematic layout of wind turbine

4.4 PV Solar Cell

Solar panels are widely used for of renewable form of power generation which convert the solar radiation into electricity. This panel is an array of photo-voltaic cell generally in the configuration of 16×2 meaning which is commonly known as PV solar panel. The collection of many panels is called as solar farm.

These PV cells contain two semiconductor n-type and p-type separated by a substrate, a glass lens is used to encapsulate the entire package providing protection from external jerks, and also the glass lens focuses the sunray to the panel. When the sunrays hit on the glass lens of the solar panel the electron gets energized by absorbing the photons (small bundles of energy) in the sunrays and starts to move and eventually recombining with holes present on the other side of the panel and hence electron flow become continuous which generates electricity. The power generated from this solar farm is DC and to connect it to the grid, the power is to be converted into AC with the help of inverter for the purpose of either to power the home or in a larger scale for connection to the grid. The power conversion takes place during the day and stops at the night. The efficiency of the power conversion from the solar panel is 16 % to 22%. The Figure 4.2 shows a collection of PV devices to form a solar cell.

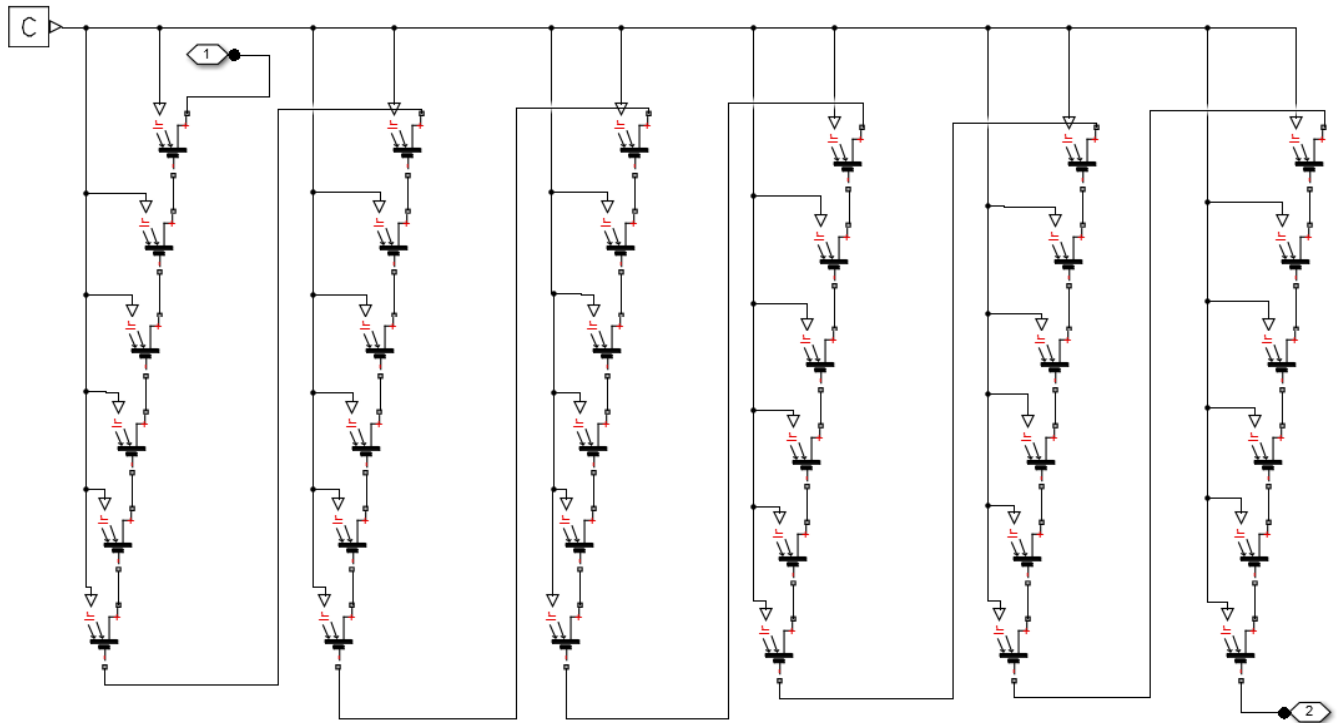


Figure 4.2: Collection many PV devices to form a solar panel

4.5 Simulation Tools and Parameters

For the purpose of validation and simulation of the work we have used **MATLAB** (also known as **matrixlaboratory**), Simulink is a part of MATAB because this software allows graphical multi-domain simulation and model-based design for dynamic and embedded systems. It is clear that our main concern is frequency control and grid stability, which is validated by this simulation software.

CHAPTER – 5

RESULTS & DISCUSSION

5.1 Background

Figure 5.1 shows the simulation model of the system under consideration. The two grids namely Grid A which is a major grid generating a total power of 600 MVA at 60 Hz and Grid B is a micro-grid, which is powered by the PV solar farm and Wind farm. The total power generation of Grid B is of 60 MVA working at 50 Hz, which is connected to neighboring homes. Both the grids are connected by a V2G system to deliver the power to the Grid B when the power generation is not enough to support the load connected to the grid. The V2G block consists of an EV fleet of several vehicles connected together, mimicking a huge power storage device. These vehicles are plugged at parking station, which is continuously connected to the grid through an aggregator. Table 5.1 shows the different parameters of the system.

TABLE 5.1 Grid parameters

Parameters	Grid A	Grid B
Power capacity	600 MVA	60 MVA
Grid Frequency	60 Hz	50Hz
Working voltage	110 V	240 V
Load	Includes homes, offices, neighborhoods, industry etc.	Small Household or a mini industry

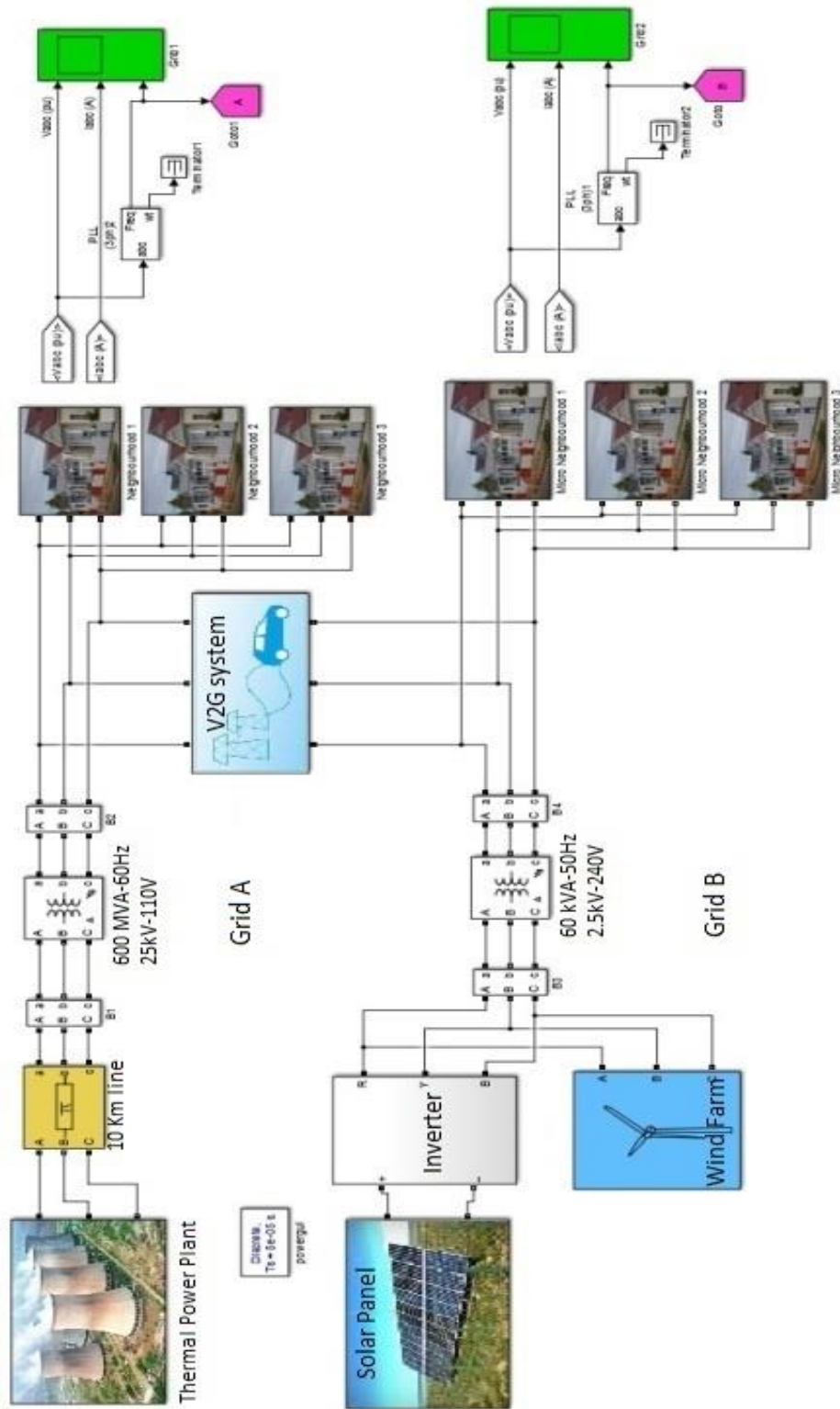


Figure 5. 1: Simulation of two grid networks connected through V2G system

5.1.1 Input Characteristic of Wind Turbine

The figure 5.2 shows the different power output of wind turbines at different wind speed at zero pitch angle. The power output is calculated by equation 4.3.

The model of the wind turbine is based on the GE 1.5XLE by General Electricals. Here in this simulation, we have used 6 turbines, producing total power of 9MW. The figure 5.3 shows the power generated by the turbine considering the nominal wind speed between 8 m/s to 9 m/s. The figure 5.4 shows the power frequency response which is 50 Hz.

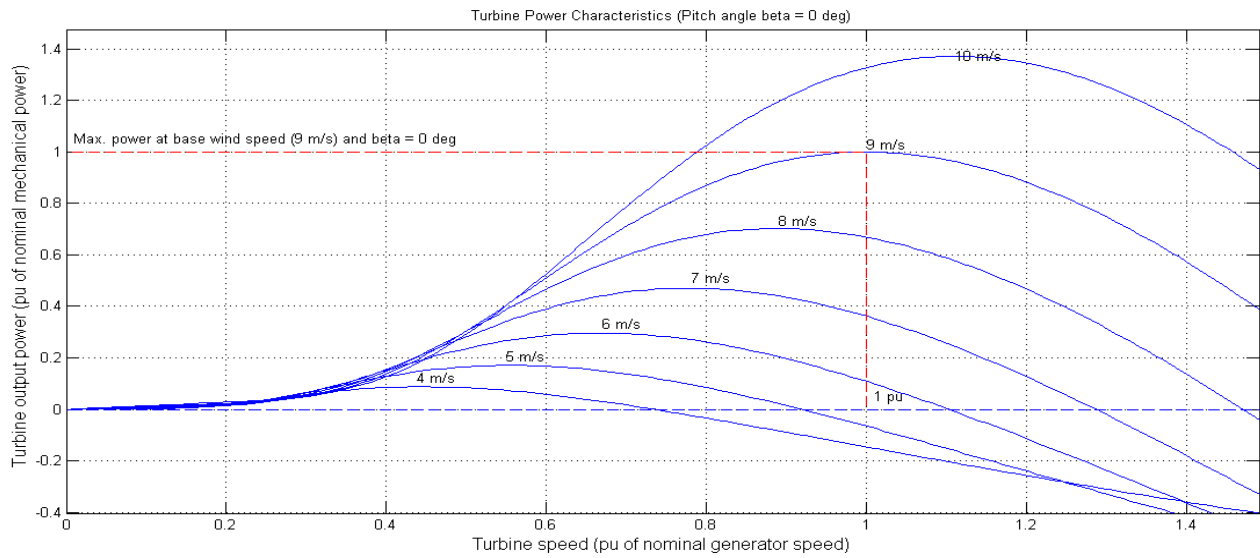


Figure 5.2: Plot between turbine output power vs turbine speed

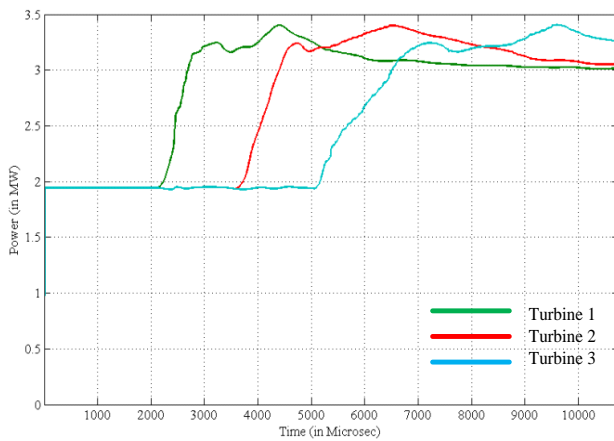


Figure 5.3: Power generation curve by three different wind turbine

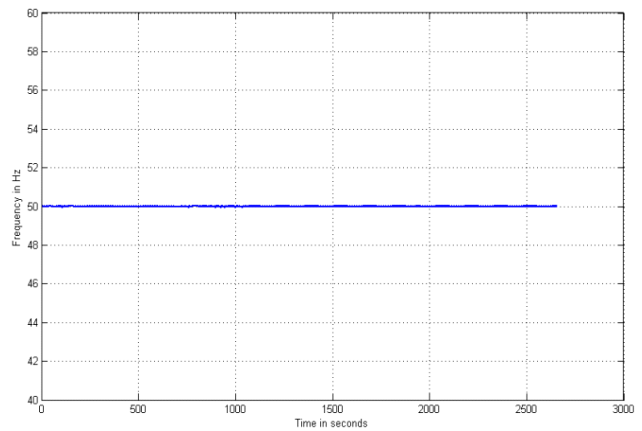


Figure 5.4: Frequency of power generated by wind turbine

5.1.2 Input Characteristics of Solar Panel

The solar panel used in the simulation consists of various small PV solar cells rated at 21.6 V at 25° C. The figure 5.5 shows a one of the many solar cells used for making a single solar panel. Here 36 solar cells are used to form a single solar panel, for this simulation total of ten solar panels are combined to make a solar farm, producing a total power of 30 MW. Moreover the power generation of the solar panel is temperature dependent.



Figure 5.5: A typical solar cell

Figure 5.6 shows a graph of the power generated in watts vs. time in seconds. Here in the graph a delay of one second is shown; it is due to the fact that the solar cells need some time to generate the power, this time delay is needed by the electrons in the n-type semiconductor to leave their respective place in the crystal lattice by absorbing the energy packet present in the sunlight (known as photons).

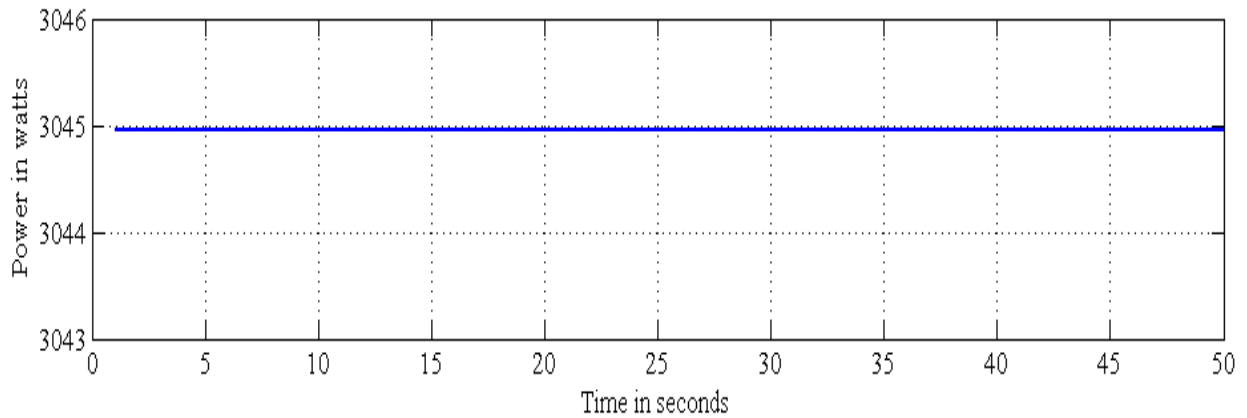


Figure 5.6: Power generated by a single solar panel

5.1.3 Input Characteristic of V2G System

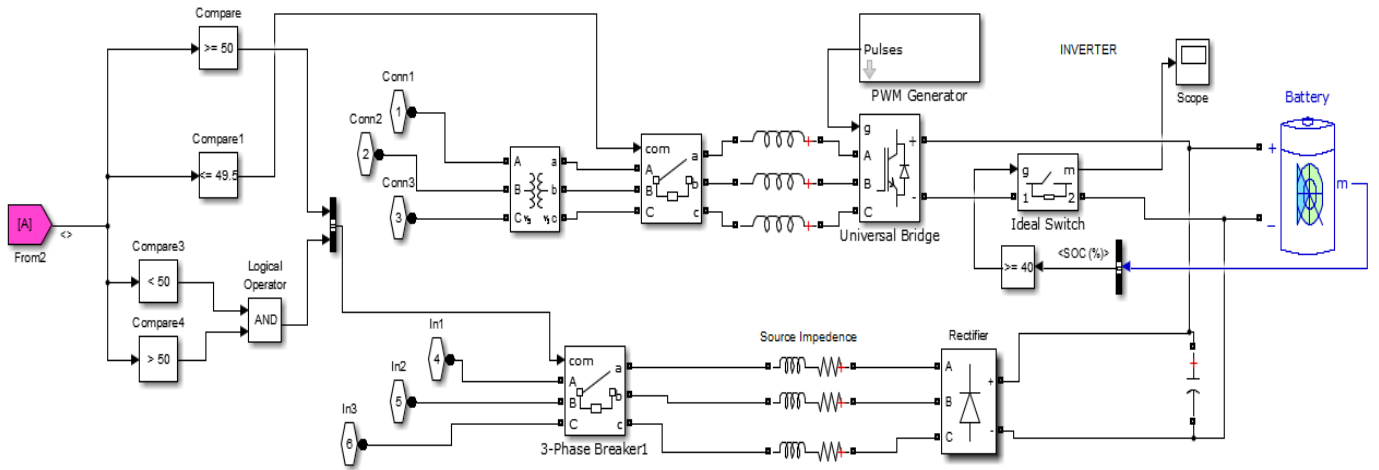


Figure 5.7: Simulation Model of V2G system

The Figure 5.8 shows the discharge curve with respect to time and figure 5.9 shows the power contributing time to the grid form 25A, 50A and 100A depending on the grid.

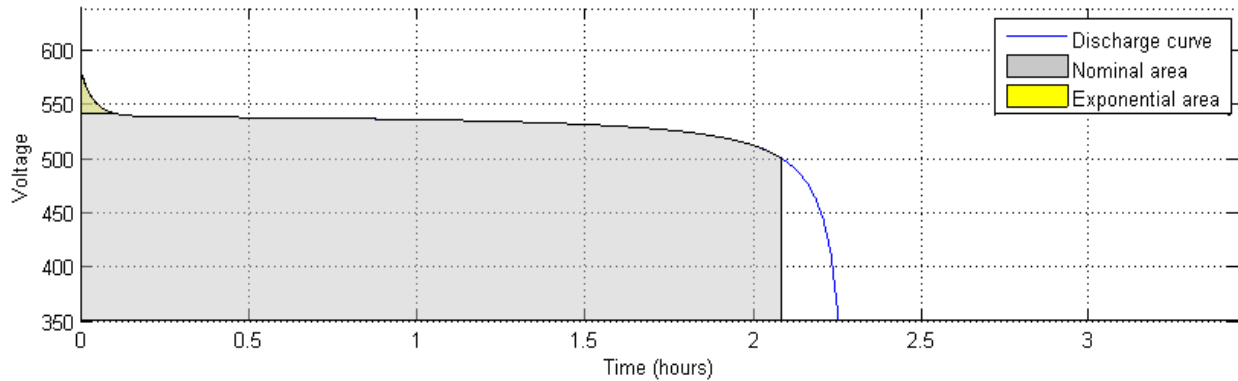


Figure 5.8: Battery discharge curve

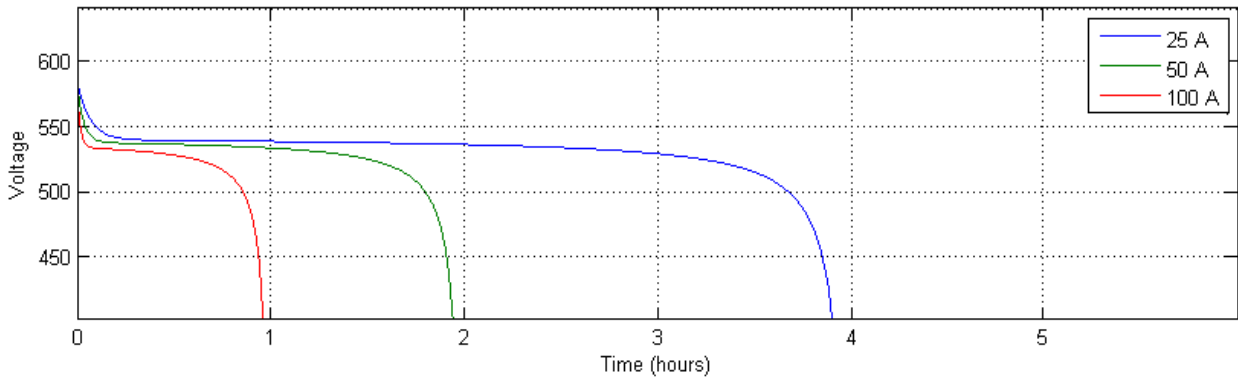


Figure 5.9: Battery discharge time for different current ratings

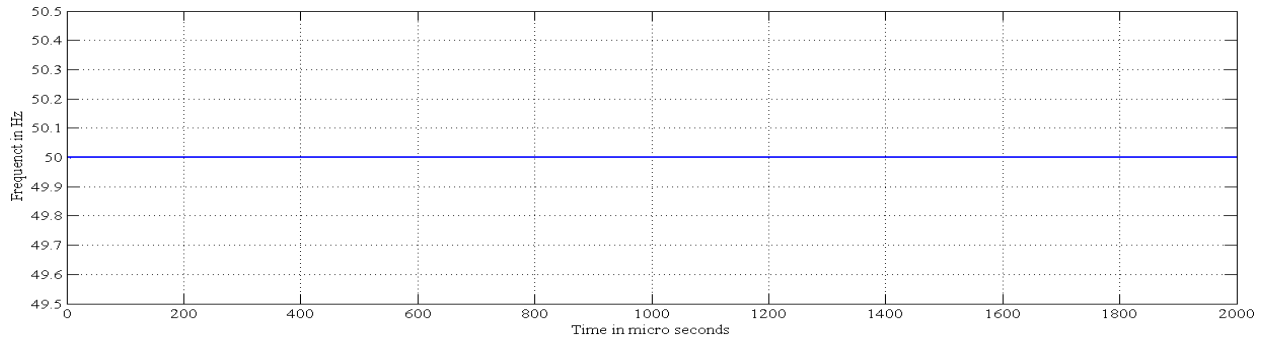


Figure 5.10: Frequency of V2G system

The figure 5.10 shows frequency response of the V2G system

5.2 Frequency Output from Grid A and Grid B without V2G System

Grid A which is a major grid working on the 60 Hz frequency, during the peak loading time the power demand rises as the day passes, to supply this power demand the frequency deviate to overcome this, droop system of power house try to maintain the frequency. If the load is continuously increased for a longer time period the frequency is going to deviate below the nominal value. Frequency response of grid A is shown in the figure 5.11.

Grid B is a micro-grid, which means it fails to generate constant power as the micro-grid is using renewable power generation which is dependent on many factors like wind speed, duration of the day, the season of the year and the amount of sunlight during the day. Grid B frequency drops during the peak demand time and as shown in the figure 5.12. The frequency is not getting back to normal after the delay of 2 seconds, which is likely the case if the power is delivered from the power station by droop control system. Since it will take some time to get back to normal, this is not likely in real scenario since the load on the grid will constantly increase, which can lead to instability of the grid during the peak demand time. So most probably the frequency is going to deviate from its original value that is 50 Hz in this case.

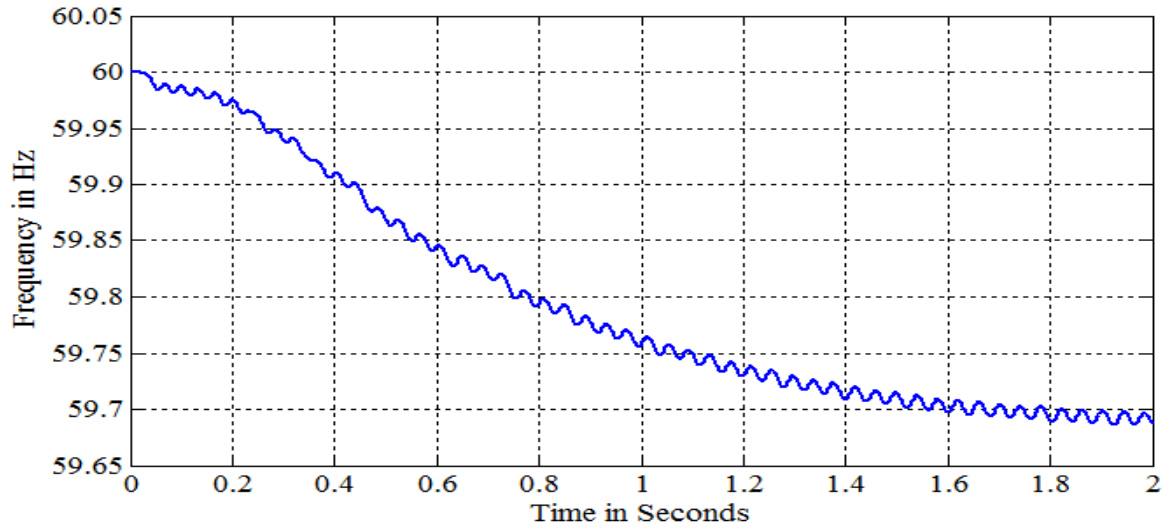


Figure 5.11: Grid A frequency response without V2G

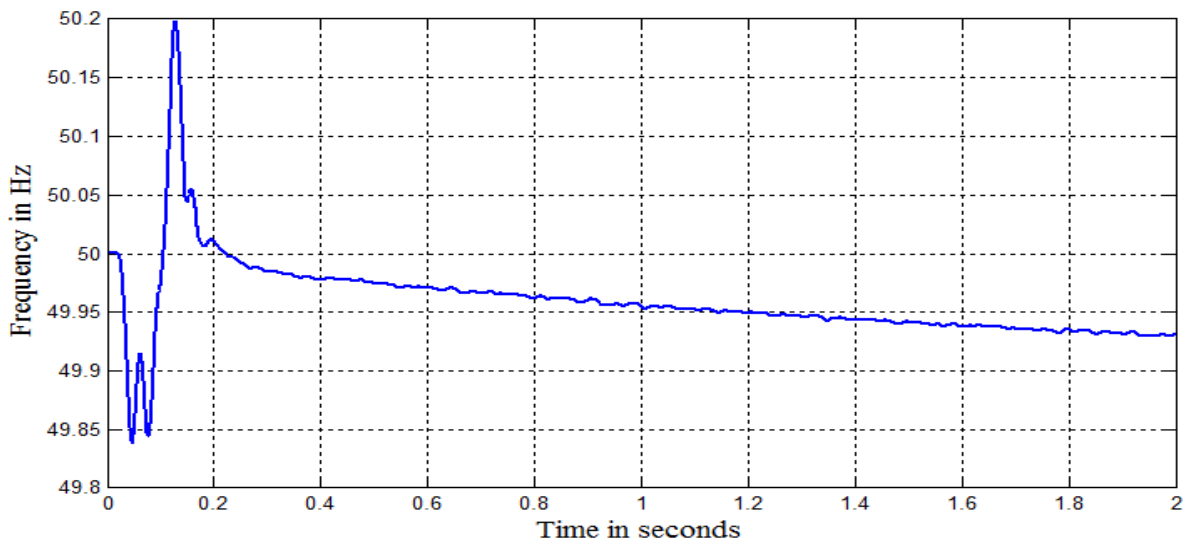


Figure 5.12: Grid B frequency response without V2G

5.3 Frequency Output from Grid A and Grid B with V2G system

Figure 5.13 and figure 5.14 shows the frequency of grid A and grid B respectively, with the integration of V2G system for frequency stabilization. In the graphs it is shown that there is a sudden hike in the frequency due to the power injected by the V2G system. In this scenario the power from grid A is used to charge the V2G system and because both of the grids are working on a different frequency, the system will convert 60 Hz (grid A) to 50 Hz (for grid B). The

graphs are showing the frequency is limited between the permissible value, which is 59.4 Hz to 60.6 Hz for grid A and 49.5 Hz to 50.5 Hz for grid B, which is allowed by the governing body.

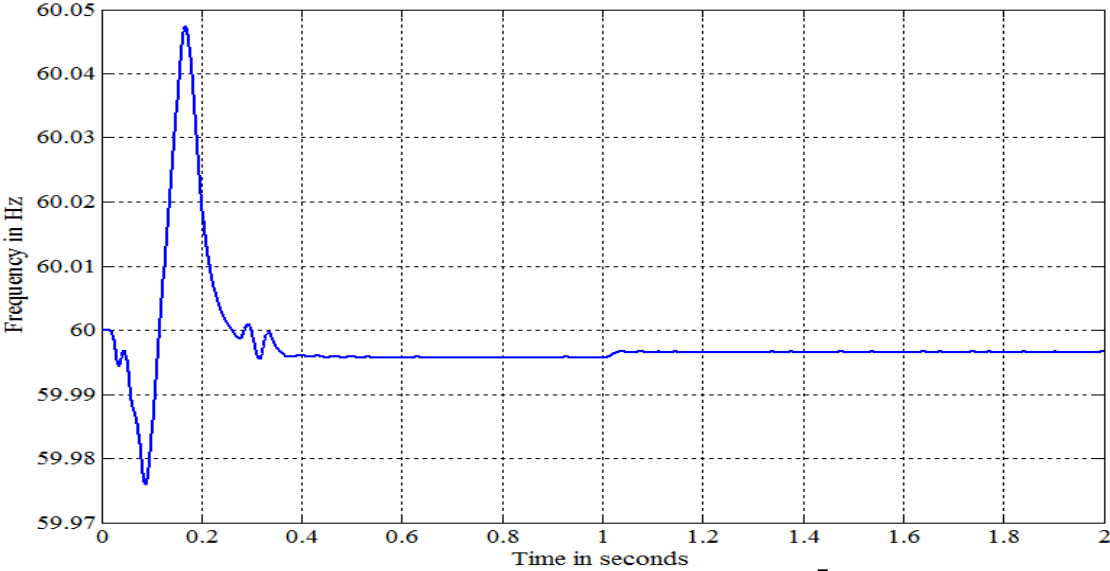


Figure 5.13: Grid A frequency response with V2G system

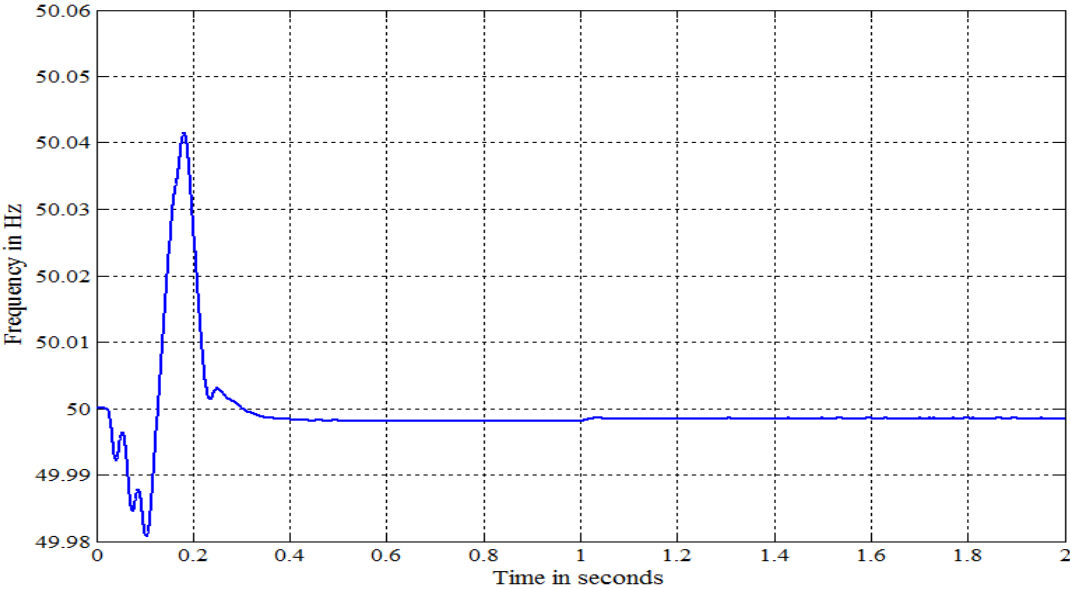


Figure 5.14: Grid B frequency response with V2G system

5.4 Fuzzy logic controller with V2G system

The implementation of fuzzy logic controller with V2G system optimizes the output power and then frequency can be controlled. A strict control over the V2G output is being imposed by considering the grid frequency, time and battery SOC. Also by applying the fuzzy logic controller the charging as well as discharging of EVs battery is optimized. The arrangement of fuzzy logic controller with V2G system is shown in Figure 4.3.

The figure 5.15 and figure 5.16 shows the frequency response of both the grids, within the nominal limit. However, it can be further controlled by optimizing the V2G system output and controlling the charging and discharging of the system. The figure 5.15 shows the frequency of both the grids as per the standard. As the graph indicates the frequency of the grid is controlled. Figure 5.15 shows the grid frequency after V2G is implemented with a fuzzy logic controller. Figure 5.16 shows the charging and discharging vs. time for the V2G system the negative value shows that the charging is taking place while the positive curve shows discharge from the system. As the grid frequency is exceeded by 50 Hz the charging process takes place and as the grid frequency decreases the discharging of the system takes place. It is clear from the figure 5.15 and 5.16 that the fuzzy logic is continuously charging the discharging the system, but there is no change in the frequency in both grids.

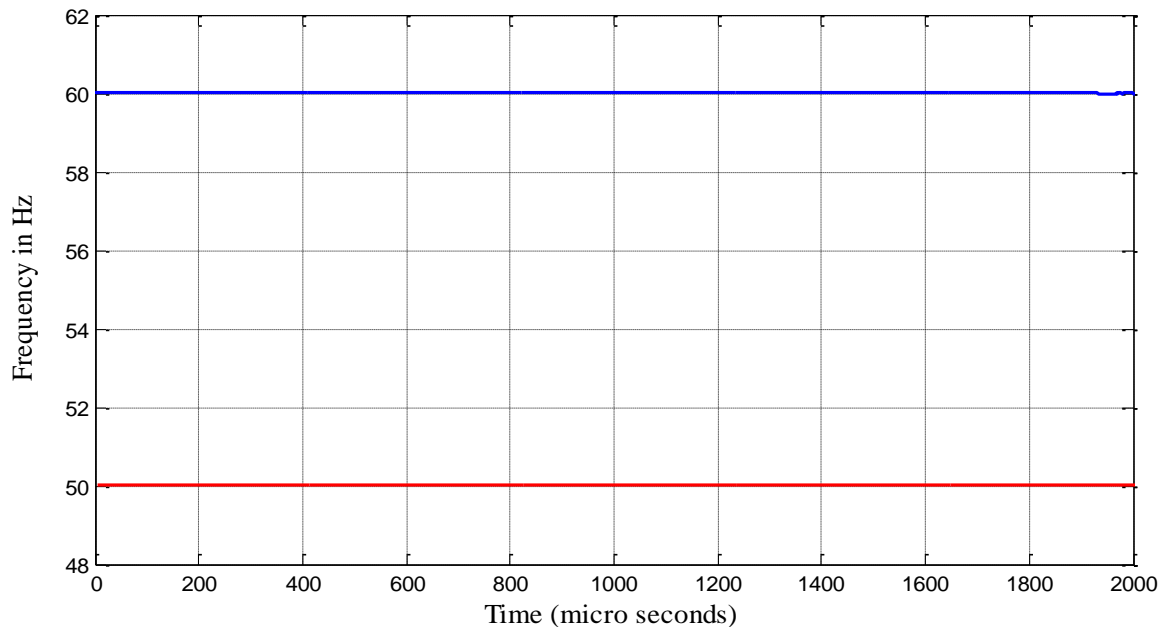


Figure 5.15: Grid frequency response with fuzzy controlled V2G system

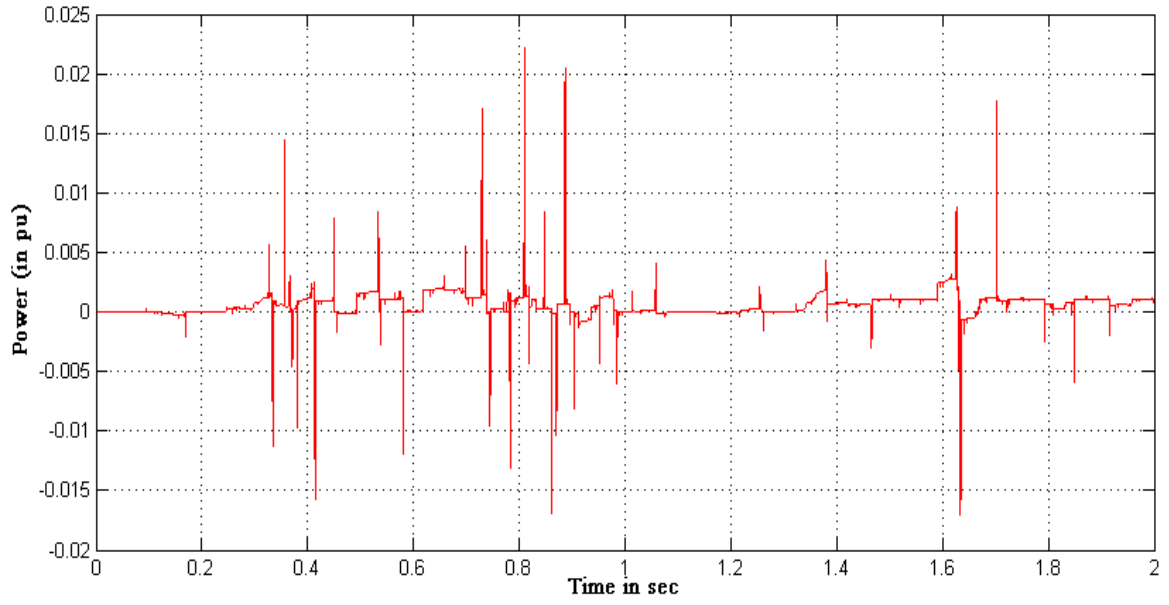


Figure 5.16 Charging and discharging of V2G system with respect to time

CHAPTER - 6

CONCLUSION & FUTURE SCOPE

6.1 Conclusion

By studying the output from the grid and by analyzing the grid frequency we came to know that by increasing the load on the grid the frequency tends to decrease, to counter this problem power has to be externally delivered to the grid. The V2G system works on peak load time and peak shaving time and acts as a power storage device. However, more researches are being performed like making a grid connection only for EV's so as to eliminate the shortage of power in the vehicles. Fuzzy logic is one of the best control strategies available to give a controlled and optimized output from the V2G system and to control the grid frequency.

6.2 Future Scope

The V2G system can be integrated with multiple grids of different frequency. The more versatile controller can be used for proper charging and discharging scheduling process on the output from the V2G system.

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