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FINAL REPORT

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INTELLIGENCE BASED TECHNIQUES FOR ASSESSMENT AND CONTROL OF VEHICLE-TO-GRID (V2G) IN POWER SYSTEM

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ABSTRACT

Due to growing global interest towards alternative energy resources and environmental concerns, Electric Vehicle (EVs) has proved to be the best alternative and are fast developing in recent 21st century. An increase in EV integration with an electric grid raises concerns about the health of the electrical grid due to increase of charging load. Electric vehicles have the potential to play the Vehicle-to-Grid (V2G) role as the vehicle becomes an asset in a smart grid with bi-directional chargers. V2G which achieves bidirectional power flow between the Electric Vehicle and power grid, will bring new applications for optimal operation of power systems. One of the most important application is to provide frequency regulation service. Moreover, it has been calculated that 92% of the total vehicles stay parked even during the peak hours or about 20 hours a day for the vehicle remain static. This increase the chance for the vehicle being available for V2G.

This paper evaluates the capability of the Vehicle-to-Grid to provide ancillary service for frequency regulation. In addition, there are 3 main case studies that have been conducted to evaluate the impact of V2G as frequency regulator in a micro grid area. These case studies are the possible event that might be occurred in micro grid system and cause disturbance of the system frequency.

The first case study is to investigates the impact of sudden increase of residential peak load due to the Plug-in Hybrid Vehicle (PHEV) charging load to the system frequency of the micro grid. The PHEV Charging Load Profile (PCLP) was analysed based on real the data from National Household Travel Survey 2017. The second case study is to implement the V2G system when there are 3 power system disturbances occur in Micro Grid system. These disturbances will definitely disturb the normal system frequency of the micro grid. The third case study is to evaluate the frequency regulation when there was partial shading occurred during noon that effect the solar panel output power. In this project, the simulation of Vehicle-to-grid system was simulated using model in MATLAB SIMULINK software. The results proved that the V2G system can greatly improve the stability of system frequency.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ANNMILES	Annual Miles
BEV	Battery Electric Vehicle
D	Distance Driven
DC	Direct Current
DER	Distributed Energy Source
DOD	Depths Of Discharge
E_{max}	Energy Capacity
EPM	Energy Per Mile
ESS	Energy Storage System
EV	Electric Vehicle
G2V	Grid-To-Vehicle
GHG	Greenhouse Gas
Hz	Herts
HOUSEID	House Identity
ICE	Internal Combustion Engine
N	PHEV Numbers
PCLP	PHEV Charging Load Profile
PHEV	Plug-In Hybrid Electric Vehicle
PV	Photovoltaic
r	Charging Rate
RES	Renewable Energy Systems
SO	System Operator
SOC	State Of Charge
T	PHEV Type
THD	Total Harmonic Voltage
ts	Arrival Time
V2G	Vehicle-to-Grid
VEHID	Vehicle Identity
VEHTYPE	Vehicle Type
ZEV	Zero Emission Vehicles

CHAPTER 1

INTRODUCTION

1.1. Background of the Study

Increased of Electric Vehicles penetration into the vehicle sector will have the impact and interaction to the system scale in terms of sector generation, transmission, distribution and demand of electricity, resources, technology and waste related to energy and battery storage, also in terms of interaction with end user and consumer. Furthermore, there are some other potential technical barriers or challenges to secure EV use which widely available in the future that must be addressed.

Mostly, the previous researchers only carried out research on grid-to-vehicle (G2V), or one-way power flow. Nowadays, the latest attraction in the field of EVs is Vehicle-to-Grid (V2G) and the unification of EVs with power grid network. Based on this occurrence, the bidirectional flow of electric power is need to be considered. That is, Electric vehicles can be charged during peak-off hour, where the power is supplied by the grid. In the meantime, during peak hour, the Electric vehicles can supply power back to the grid in order to minimize the utility load. In addition, a huge number of electric vehicles (EVs) remain parked even during peak periods and on still sate most of the day. This idea can increase the chance of Electric Vehicles to be available in facilitating V2G technology. Furthermore, the plugged-in Electric Vehicle is beneficial in providing ancillary services for utilities like spinning reserves, peak shafts, load levelling, frequency and voltage regulation.

1.1.1. Overview of Electric Vehicle

After about a century of internal combustion engines conquering the private convey sector, in recent clear that motor vehicles are on the edge of abrupt growth for both evolve and expanding vehicle markets. Extensive electric vehicle carriers can bring significant changes to the community regarding not just the technology we employ for personal transportation, besides also to drive our economy from petroleum and to study environmental footprint of transport.

Combustion engines diminish the reserved fossil fuel as well as caused pollution to the environment. This problem attracted the researcher's attention since the 1900s. In order to address this issue, there are a lot of solution and method that have been evaluated and reviewed in past. In recent decades, the advances of technology related to batteries and power system have facilitated researchers to change their focus to introduce, plan and implement electric vehicles [1].

Electric Vehicles (EVs) are electric motor- powered vehicles, not an internal combustion engine (ICE), and motors functioning by utilizing the power stored in the battery. The battery must be regularly charged by connecting any major power supply (120 V or 240 V). EVs were seen soon after the first DC- powered motorcycles were introduced by Joseph Henry in 1830. The first known electric car was a small model that Professor Stratingh built in 1835 in the Netherlands town of Groningen. The first EV was built in 1834 in the United States by Thomas Davenport, and in 1847 by Moses Farmer, who built the first EV of two passengers. At this time there was no rechargeable battery [2].

Electric vehicles are known as zero emission vehicles (ZEVs) and are much eco-friendlier than petroleum or LPG. Since EV has less moving parts, there is also little maintenance. No oil changes, no adjustment or time and no exhaust. EV is also considerably more energy efficient than gasoline engines and operates very quietly [2]. In recent years, EVs have obtained considerable popularity and in the near future this trend seems to further grow so most transport sectors comprise Electric Vehicles, in line with new policies establish by several governments around the world [3]. The electric transport sector emerges to be an ideal solution and method for reducing greenhouse gas

(GHG) emissions from combustion engines, besides electrical utilities to enhance the quality of energy by using Electric Vehicle batteries as a distributed energy source (DER).

Since EV trends on the road are growing tremendously, it creates a new challenge to control its growth. The execution of fast charging station to avoid customer emergency and the increase of load on electrical grids are among the most important challenges. To deal with this problem and ease development of this growing trend towards increasing electric utilities and EV owners, the effective strategies in the management system is needed in order to facilitate productive EV integration with the power grid network, and not just focus on the technical development [1].

1.1.2. Moving towards an EV future and Vehicle to grid overview

1.1.2.1 The Impact of High Penetration of EV

Increased EV penetration into the vehicle sector will have the impact and interaction of the system scale in terms of sector generation, transmission, distribution and demand of electricity, resources, technology and waste related to energy and battery storage, besides with respect to consumer and end-user interaction. Furthermore, there are other difficulties and potential technical barriers that must also be tackled to ensure that EV use is widely available in the future.

The first and perhaps most noticeable impact on the EV increment is the impact of increasing electricity demand due to EV and the following changes needed for supply, transmission and distribution. Nonetheless, the impact of the require for electrical peak loads on this demand will not be a significant leap. On the other hand, any need for additional capacity generation will be greatly influenced by the recharge of the battery and the use of Vehicle-to-Grid(V2G) technologies at home, workplace or elsewhere where the EV battery can be recharged.

This technology offers the possibility to change the way EV interacts with the electric grid, so that customers can use the energy stored in their vehicle battery to make up for some of the peak demand if they do not plan to drive on that particular day. In the meantime, there are important technical, safety and environmental concern regarding of the batteries used in EV during and subsequent vehicle operations. There is a briskly increasing area of research and advancement of battery technology, especially in respect of rising energy density and recharge speed, recharging options and interaction with users and the electricity grid via V2G. Furthermore, these technologies and operations require a certain degree of standardization, particularly if their use is compatible and consistent.

The probability is that, the rapid evolution of various EV market components without adequate standardization will ultimately affect the acquisition of Electric Vehicle and the advantage of society that can be accomplished with the extensive use of EV.

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1.1.2.2 Introduction to Vehicle to Grid

V2G technology can be clarified as a technology where there is ability of controllable, the flow of bi-directional electrical energy between a vehicle and the power grid. In order to charge the vehicle, the electrical energy is flowing from the grid to the vehicle.

The electrical energy will flow in the other direction when the grid needs the energy, to contribute peaking power or "spinning reserves", for example. It has been calculated that 92% of the total vehicles stay parked even during the peak hours or about 20 hours a day for the vehicle remain still state [4]. This, Increase the chance for the vehicle being available for V2G.

Electric vehicles have the potential to play the V2G role as the vehicle becomes an asset in a smart grid with bi-directional chargers. By using the V2G network, public utilities can provide a more stable and better service to meet the sudden demand in load and save energy for future use when the offer is high. The V2G system can also provide financial benefits to the owner, thereby reducing the overall cost of purchasing electric vehicles. Vehicles to the Grid system allow vehicle owners to generate income from selling back power to the grid [5].

In order to maintain the stability and reliability of the power system, an intelligent charging schedule is required. EV aggregator caries an essential role in integrating the EV fleet into the power system by managed the charging of batteries and taking part in the electricity market [9], [10]. The vehicles connected to the aggregator are alternatively charged or discharged from the grid operator to meet the required power and charge their batteries. Since the current state of charge and the expected charging duration of each vehicle differ from each other, it will be useful to develop a systematic aggregator that contribute to regulatory services in the best possible way and charges each vehicle within a certain period of time.

Depending on the system price, the EV battery can have three modes which are waiting mode, charge mode and discharging mode. Moreover, the waiting mode can be set to inhibit high price hours, and requests for charges can be changed to peak times. In the grid to vehicle (G2V) also knows as charging mode, batteries are charged by purchasing electricity from the grid. Figure 1.1 shows the framework of the operation of the Vehicle to the Grid System.

The discharging mode or known as the vehicle to the grid (V2G) can restore the energy stored back to the grid. EV aggregators interact with system operators (SO) to decide EV mode in order to minimize system losses, reduce costs, increase voltage profiles and provide ancillary services such as regulatory and operational reserves by monitoring system and market conditions in real time [11], [12]. EV is considered to be a burden impaired or delivering capable resources within the power system. EV can thus be one of the energy storage applications. Bidirectional technology and EV instantaneous response can enhance the flexibility of an integrated power system with high implementation of renewable energy systems(RES).

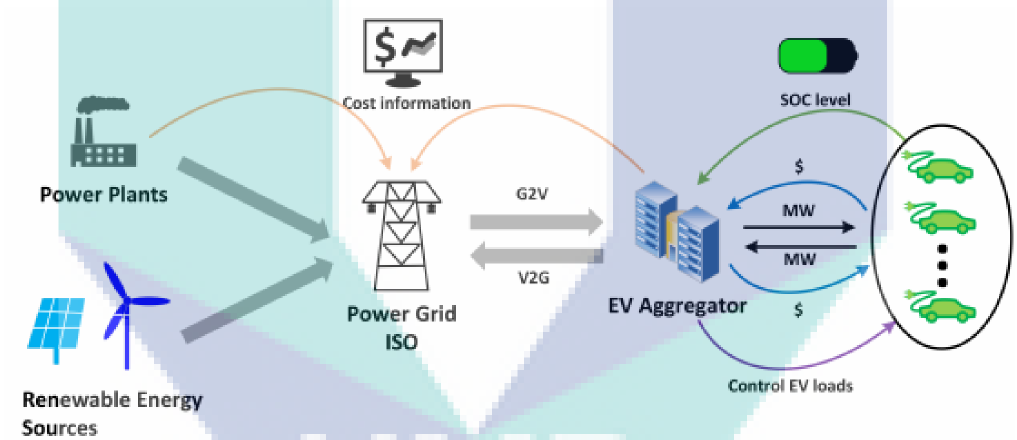


Figure 1.1 The Framework of Vehicle-to-grid system

Since Kempton and Letendre proposed the concept of vehicle to grid (V2G) firstly in 1997 [6]. V2G has shown great applications such as spinning reserve [7], load peak shifting [8], voltage regulation [9], and frequency regulation [10]. Specifically, considerable attention was paid to grid frequency regulation. Frequency must be controlled within the limits permitted by its standard frequency by controlling power sources such as generators, as one of the important indexes in the operation of the power system. This standard frequency is the frequency that all devices in the grid are synchronized and are designed to operate on. If the frequency deviates from regular frequency, the equipment may be damaged. Generators can sustain damage to turbines because it speeds up too fast or sub-synergies. And finally the protection relay will trip out of the generator, line, and transformer if frequency deviation is too severe. Transformers can heat up and spoil themselves if the current through them becomes too high that can occur during contingency events due to frequency issues. Even your consumer device is designed only to handle certain frequencies and may experience high or low frequency damage. Due to the rapid response feature, the EV fleet that participates in frequency regulation has a natural benefit over other ancillary services.

1.2. Problem Statements

Based on the forecasts of the International Energy Agency, the number of electric vehicles on the road worldwide will reach between 3.1 million and 125 million by 2030 [18]. Nevertheless, the Electric Vehicles cannot penetrate to the grid without being controlled and well manage. If the grid is in peak load periods, it would cause serious damage to the grid with a high demand for electric vehicles. Therefore, Vehicle-to-Grid systems helps to even out peak load demand and provide frequency stabilization in the grid. Moreover, there are a lot of other power system disturbances that could affect the efficiency and stability of the power grid. The solution to stabilize and improve the efficiency is needed. So, basically the spinning reserve is use to maintain the system frequency stability by providing additional generating capacity that can supply power rapidly. But, the capital cost of these reserves are higher. Thus, the implementation of Vehicle-to-Grid will definitely provide a solution to minimize the need of spinning reserves.

1.3. Objectives and Scopes

According to the problem statement, here are the objectives for this researched project:

i. To investigate the impact of Electric Vehicles integration in the power system network with different type of charging power.
ii. To analyze the system frequency before and after the implementation of V2G system during an events or disturbances occur in the Grid system.
iii. To evaluate whether V2G System can greatly improve the system frequency stability.

As mentioned and explained in previous section, Vehicle-to-Grid system can provide ancillary services for utilities, such as, spinning reserves peak shafts, power quality improvements, and frequency and voltage regulation. In order to address problem as stated in problem statement, we mainly focus the function of the Vehicle-to-Grid as a frequency regulator in a micro grid area. Thus, the analysis regarding the impact of Grid System Frequency with the implementation of V2G and without the implementation of V2G for 4 types charging rate level to prove that V2G System can greatly improve grid stability were discussed in this researched project. There are 3 case study that have been conducted to evaluate the credibility of Vehicle-to-Grid to improve the performance of system frequency. The type of Electric Vehicle that contributed in the analysis of V2G system is Plug-in Hybrid Electric Vehicle (PHEV).

CHAPTER 2

LITERATURE REVIEW

2.1. BACKGROUND

In the automotive market, a large number of electric vehicles (EVs) and spreading worries about harmful pollutants in the environment have attracted research and development centres around the world. At the same time, an increase in EV integration with an electric grid raises concerns about the health of the electrical grid due to increased load. To handle this additional load, the utility must install an intelligent system without resulting generation and distribution problems.

Nevertheless, the newest upgraded in EV technology have persuaded electrical utilities to join the EV market, in which EV can contribute to additional services for electrical utilities. In the initial stages, the idea of the involvement of utilities is the potential to increase the amount of EV to facilitate the promotion of electricity. This concept is known as grid technology (V2G). Utility can take part by providing EV battery power at peak times and take power from EV battery at peak time. To implement this idea, the utility needs to create a smart charging strategy to shave the peaks, fill the valley and increase the load that will improve the overall grid state.

This chapter will discuss the types of electric vehicles available in the market. Moreover, the researcher's studies about the impacts of Electric Vehicles penetration on power system network, the possible application and benefits that can be performed by Vehicle-to-Grid system and impacts of V2G as a frequency regulator in a power system network also will be reviewed and deeply discussed.

2.2. Types of Electric Vehicles

2.2.1. Battery Electric Vehicle (BEV)

Electric vehicles are known as Battery Electric Vehicles (BEV) with only batteries that supply power to the drive train. BEVs have to depend wholly on the energy stored in their battery packs; therefore, the distance driven ranges of such vehicles depends directly on the battery capacity. Regularly, they can cover 100 km–250 km on single charge [11], while the top-tier models can go much further, from 300 km to 500 km [11]. These ranges rely on driving condition and style, road conditions, vehicle configurations, climate, type and age of the battery. Once drained, if compared to refuelling a conventional ICE vehicle, charging the battery pack draws a lot of time It can take up to 36 hours to fulfil the batteries to 100% od State of Charge (SOC) [12].

The duration of charging relies on the configuration, infrastructure and operating power level of the charger. The benefits of Battery Electric Vehicles are their simple operation, construction and convenience. This type of vehicle does not emit any greenhouse gas (GHG), make no noise and hence environmentally friendly. Instant and high torques are provided by electric propulsion at low speeds. The standard examples of Battery Electric Vehicles are all type of Tesla’s products, such as the Model S or Model X in the high- end luxury car segment. Chevrolet Bolt, Ford Focus Electric, Hyundai Ioniq or the Volkswagen E-Golf could be the most affordable alternatives. We consider Mitsubishi i-MiEV or Smart Electric Drive from the low cost segment, for example [6].

2.2.2. Hybrid Electric Vehicle (HEV)

Hybrid electric Vehicles are powered by electric and internal combustion engines, while gasoline or diesel drives the second. The prevailing internal combustion engines and electric motors only function as an addition. The vehicle is therefore fitted with a smaller battery and it is also powered by combustion engines coupled with energy derived from regenerative brakes.

Compared to BEVs, this battery cannot be charged via a battery station because it has a small capacity and the hybrid car does not have a plug configuration. The objective of hybrid electric vehicles is to achieve a better fuel economy and improve the efficiency of the car. Furthermore, this vehicle is unique in urban traffic, where electric motors reduce idling and increase the ability of the vehicle to stop and move. Additionally, electric motors assist or contribute entirely to low speed and low speed driving. In addition, the vehicle range is much higher due to the addition of combustion engines when the electric motor battery is exhausted [6].

2.2.3. Plug-In Hybrid Electric Vehicle (PHEV)

Just like HEV, the plug - in hybrid vehicle is fit with an electric engine and internal combustion. The main contrast is the charging method, in which the battery can be charged from the electrical grid via the vehicle plug, apart from the regenerative braking and energy generated from the internal combustion engine. Due to this, vehicle batteries are much larger and can also drive electrically for a few miles by themselves. After the discharged of the battery the combustion engine takes place. This makes PHEV very functional for longer journeys without the batteries being recharged [6].

On the contrary, the vehicle runs in a full electric regime and emits zero exhaust gas as well as does not make air pollution in worse cities. This fact is an interesting alternative to the changing market of cars, while providing the advantage for both, the electric engine and the combustion world. However, we cannot deny that plug - in hybrid vehicles have several negative aspects, such as the complexity of two different propulsion units in vehicle dimensions, whereas this complexity leads to higher maintenance costs

[6]. Figure 2.1 illustrates the of United States forecasting Electric Vehicle Sales for each types up to year 2050. According to the figure, the PHEVs sales increase tremendously begin at year 2020 compare to BEV while the sales for HEV types are quite constant from year 2015 and starting to fall at year 2045. Therefore, in the next 10-30 years later, PHEV are expected to dominate the Electric Vehicle market [13].

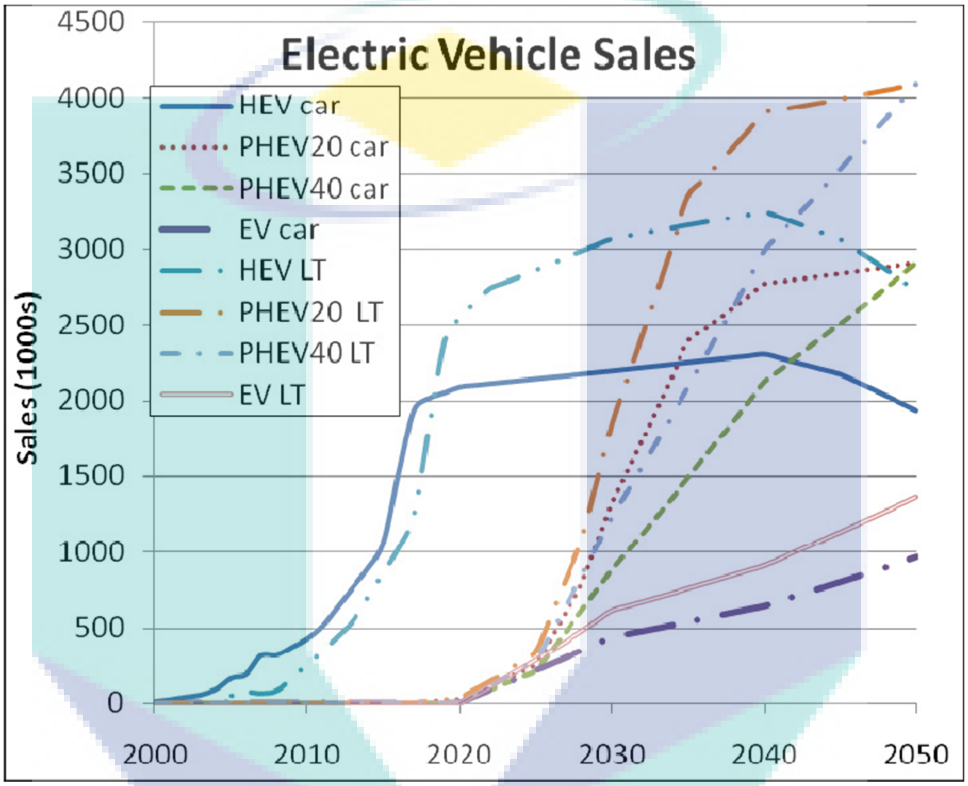


Figure 2.1 United States Electric Vehicle Sales for each types up to year 2050

2.3. The impacts of Electric Vehicles penetration on power system network

In addition to the many advantages of electric vehicles, there are concerns about grid conditions caused by the wider market for electric vehicles that will spread in the future. It is inevitable that large electric vehicle fleets are integrated into the power system network for charging electric vehicle batteries that have a negative impact on grid power and utilities. These effects must be taken into consideration in the design and use of V2G systems. Impact on electric grids caused by many electric vehicles in distribution networks, including phase imbalances, voltage decreases, harmonics, energy demand, power system load and stability [19]. This section highlights potential threats to the utility and electricity grid due to the large number of electric vehicles included in the electricity grid.

2.3.1. Load profile and system component

EV integration in power distribution networks adds to the electric grid additional loads. Power supply is a set of demand - based criteria. When electric vehicles connect to a grid to charge the battery, there is an additional demand that electrical utilities must be supplied to the user. If electric vehicles are charged without any proper plan, i.e. uncontrolled charging, the owner of electric vehicles can charge the battery of electric vehicles at any time during the day because their mood is determined. This presents a potential risk of increased load during peak loading periods. Increasing peak power requires more generation to meet the demand, which can cause an electricity problem. A number of studies are presented in the peak load area due to uncontrollable charging of electric vehicles in current and future scenarios.

The EV impact charged on the German grid is shown in " The effect of the use of various electric vehicle scenarios in the German grid in 2030, " as Germany has taken a major step towards moving most road transport in the near future [20]. Likewise, in the article, "Impact of hybrid electric vehicle plug-in on hourly electric demand in the United States", Claire Weiller explains the impact of EV charging on the hourly load profile of the United States [21]. This study shows that the load will double if the charging of electric vehicles is not controlled. From the results of both study, its present that additional loads caused by large EV fleets integrated with the electric grid will affect the grid reliability without any management and planning of the filling schedule.

The system components in the power distribution network are developed and accomplished in accordance with some of the criteria. This criterion is resolved by demand and supply of electricity. Additional demand from the generation side is required to add a large number of EVs to the distribution network. This extra power is provided in the distribution network using the similar system components. It is easy to overload existing system components because they are not designed to bring this additional power to the EV charging system. Analysis has been carried out on the impact of EV charging on the power distribution system [22]. We can make a conclusion, the widen penetration of Electrics Vehicles cause negative impact on the lifetime of the transformer. Without appropriate load management and network planning strategies, apparently, it is inescapable for EVs to overload components in the distribution network in the future.

2.3.2. Harmonics

As previously established, the charger carries a significant function in the EV system. The composition of the EV charging station includes power electronics. Throughout operation, changing the power electronic of the Electrical Vehicles charging operation could result negative consequence on the quality of the electrical grid power caused by the resulting harmonic [14].

According to researched paper by Bass, Richard Harley, Ronald Lambert, Frank Rajasekaran, and Vinod in [15], the total harmonic voltage (THD) due to the EV charging process lower than one percent, hence the harmonic injection does not influenced the quality of the energy. This idea also supports in “Method to assess the power quality impact of plug-in electric vehicles" [16], using Montecarlo based simulation method for simulation, the resulting harmonic which influences the electrical grid during EV charging is acceptable. Nevertheless, the harmonic injection into the electric grid is significant when rapid charging is used for EV charging [25]. Again, several factors that influence this study have led to different results from different studies. however, the solution is provided to recompense for the harmonized injection like filter devices.

2.3.3. Stability

Power system stability is described as the quality of the electrical grid to restore operation to a stable state in the event of interferences or perturbations [19]. Stability holds high marks in the power reliability supplied by the electric grid. Electric vehicle is a comparatively recent load for the electric grid and stability concerns have alerted many researchers to investigate the impact of electric vehicle charging on the power system's stability. Onar, Omer C. Khaligh, and Alireza discussed that, if the huge amount of Electric Vehicles penetrates into the electric grid, the whole operation begins more prone to interference or perturbations and it takes more time to back to a steady state [26].On the contrary, research on “Transient Stability Analysis of SMES for Smart Grid with Vehicle-to-Grid Operation” study on the "Transient Stability Analysis of SMES for Smart Grid with Vehicle-to-Grid Operation" indicates that integration of electric vehicles could improve the stability of the power grid by managing the system [27].

From the above literature on the consequences of the EVs charging on the power network, we can conclude that one-way power flow in Electric Vehicle charging, whereas the flow of power from the electric grid to the Electric Vehicle battery, can lead to major issues in the electrical grid and the power system network. Nevertheless, if properly designed and accomplished, the V2G system, whereas bidirectional energy flow, can reduce this problem and improve the quality of the electricity grid. Therefore, with the Electric Vehicle market increase, vehicle technology awareness of Vehicle to Grid system is not merely a benefit but instead requirement for distribution and operation of a stable power in the future.

2.4. The application and benefits of Vehicle-to-grid in Power System Network

Electric vehicles have the potential to play the Vehicle-to-Grid role as the vehicle becomes an asset in a smart grid with bi-directional chargers. By using the Vehicle-to-Grid system, public utilities can provide a more stable and better service to meet the sudden demand in demand and save energy for future use when the offer is high. The V2G system can also provide financial benefits to the owner, thereby reducing the overall cost of purchasing electric vehicles. As mentioned from the above section, if properly planned and accomplished, the V2G system, which is bidirectional energy flow, could reduce this problem and improve the quality of the electricity grid.

The most efficient method is to use the optimize algorithm for the charging schedule. This will enable electric vehicles to involve in various services available to electrical utilities in return for inducement for services allocated to EV owners. Definitely, the type of service provided by the optimization model depends on the aims function of the optimization technique that has been set. Some EV services that can provide electrical utilities are briefed in this section.

2.4.1. Regulation Services

The regulations are used to control the frequency of grid by the corresponding generation to load the request. The regulations must be under the direct real-time control of the grid operator, with generating units capable of receiving signals from the grid operator's computer and responding in one minute or less by increasing or lowering the generator output. Some markets divide the regulation into two elements which are one for the ability to increase power generation from the base level, and the other goes down from the baseline. This is usually referred to as " regulation up" and " regulation down", respectively [17].

Regulations are controlled automatically, with direct connections from grid operators. If compared to spinning reserves, regulation is called more often, requires faster response, and is required to continue functioning for a shorter period of time [17].

Frequency regulation are very important among all ancillary services. During the disturbance or interruption of load, the system frequency drops and the grid experiences a transient state. If the reduction in frequency is among the acceptable limits, there is no need for compensation. Otherwise, the regulatory process is required to return the frequency to its nominal value. In conventional power networks this process is done by a generator unit. However, this process is hard and costly to regulate the power supplied by the huge generator to the load demand. The other solution is to employ the energy storage system (ESS) and inject active power into the grid. The need for a control system to adjusts the power flow rate to frequency deviations or load fluctuations is the difficulty of this method. The plug-in electric vehicle (PEV) has the potential to be used as an energy storage device [18].

Regulatory services are the first possible steps for V2G due to the high market value and minimal pressure on vehicle power storage systems. V2G make promising alternative to frequency regulation because of fast charging and discharge of electric vehicle batteries rates [19]. Voltage regulation is employed to balance supply and demand for reactive power. PEVs can react quickly to regulatory signals that can be controlled independently by each of the PEV. Voltage controls can be inserted into the battery charger. By properly selecting the current phase angle, the charger can compensate inductive or capacitive reactive power. Vehicle charging may stop when the grid voltage becomes too low while when it gets high, charging can start [19].

2.4.2. Peak shaving and load levelling

The reserved battery energy can be utilized in providing power to balance load by charging the vehicle at night when low demand (valley filling) and offering power back to the electrical grid when demand is high (peak shaving). Moreover, the reduction of unwanted factors such as delay transmission, line losses, and transmission losses are additional advantages peak shaving could provide. It also assists in reducing the operating pressure of the power system, thereby increasing its longevity in terms of lasting. This leads to the avoidance of heavy investments in power plants. Power regulatory authorities have better ability to predict peak loads (mostly during the summer due to AC loads) [20].

By employing hybrid vehicles as storage distributed performs as a vigorous alternative to capital demanding and expensive 'peaking plant' generators. In general, power-seeking bodies buy electricity through long term contracts with generation companies or from the electricity market in the short term. Application of the peak shaver PHEV fleet is reducing the cost of electricity at peak hours. The saved money in this case is beneficial to further mobilize PHEV utilities by funding in research facilities and enlarging their horizons. The average benefit of V2G EV participation is approximated to range from $ 392 to $ 561 per year per vehicle [21].

Hence, PHEVs provide the power system with a controllable, flexible load and could functioning as load levelling during peak-off periods [22].

2.4.3. Spinning Reserves

The spinning reserve is known as the additional generating capacity provided by converting the additional generator that has been connected to the grid. These supplementary power supplies are accessible within a short period of time upon request. Nevertheless, the capital cost of these reserves is quite high. The merger of V2G solves this problem by fulfilling the sudden request for power. Connecting the vehicle to the grid can go a long way in eliminating the need to maintain a spinning reserve [20].

At any factory or workstation, in which there is a possibility of a sudden peak requirement, a vehicle that can become an employee will continue to be connected to the grid and may be called upon to supply extra power supplies. This provide a win-win situation for both workplaces and employees. Moreover, employees may get their electric vehicles re-charged at unobtrusive times and can also be paid a certain amount for the usage of the vehicle [23]. Vehicle-to-Grid technology has the capability to assist recovery failure as well as diminish backup generation capacity and minimize costs for utilities [24]. Thus, V2G can indeed provide solutions to reduce the need for spinning reserves.

2.4.4. Renewable energy storage and backup

The most important contribution for V2G may eventually be in the emerging power market to support renewable energy. Photovoltaic (PV) and wind turbines which are the two largest renewable sources that may be widely used in the near future, are both intermittent. Renewable energy intermittency can be operated by existing mechanisms for managing supply fluctuations and load at low penetration levels.

However, when renewable energy exceeds 10-30% of the power supply, additional resources are needed to adjust the variable supply to the already fluctuating load. The irregularity can be managed either with backup or storage. "Backup" refers to a generator that can be turned on to supply power when the renewable resources are insufficient. "Storage" has the added advantage of absorbing excessive energy, but adding restraining power is duration-limited [25].

In Vehicle-to-Grid, fuel cell electric vehicles and hybrid electric vehicles can provide backup while plug-in hybrid electric vehicles (PHEV) and battery electric vehicles (BEV) can offer storage. The capacity of one electric vehicle is limited and does not affect the electric power system and only represents noise on the grid scale. However, if we consider the large quantities of electric vehicles in the future, the grid impact or a set of potential services by a group electric vehicles can attract a lot of focus. Therefore, electric vehicles need to be aggregated to be able affect the power grid. Imagine a long-term role for V2G, with perhaps a quarter to half of the fleet that serves as backup storage and storage for renewable energy, bringing us to the overall re-conceptualization of the energy system [17].

2.5. Impacts of V2G as a Frequency Regulator in a Power System Network

Aleksandar Dimovski and Snezana Cundeva have conducted an analysis regarding the V2G system used to regulate the frequency of a microgrid. Different potential scenarios, for different grid shading renewable energy, different residential load sizes and different EV numbers, are taken into consideration. The results show that in island operation of a micro Grid with a lower spin-reserve, V2G concept can deliver efficient control of primary frequency [26]. Besides that, in paper 'Vehicle-to-grid Systems for Frequency Regulation in an Islanded Danish Distribution Network', it examined the effective frequency regulation of V2G system in islanded Danish Distribution Network that contribute with the huge wind energy. The results of the simulation demonstrate that V2G systems provide a more rapid and stable frequency control than standard generating units. In future electrical energy systems, V2G systems can be regarded as a dynamic frequency regulation solution [27].

Furthermore, Hitesh Dutt Mathur and Yogesh Krishan Bhateshvar have studied the performance of V2G in frequency regulation at multi-generation power system. APSO (adaptive particle swarm optimization) which an optimized fuzzy logic controller has been utilized to smartly restrain frequency and power line. The result of V2G providing frequency and power balance has been achieved [28]. Moreover, an analysis of participation of V2G system in signal area grid network model and linked two-area model and a study of V2G performance in secondary frequency regulation based on area control error (ACE) have been investigated by Wenqi Tian, Jinghan He, and Liyong Niu. The results show that V2G can effectively reduce the frequency deviation and tie-line flow deviation, lower system reserve capacity. The results illustrated that V2G can lower the deviation in frequency and power flow and reduce spinning reserve efficaciously [29].

2.6. Summary

This section has described different types of electric vehicles which are Battery Electric Vehicle (BEV), Hybrid Electric Vehicle (HEV), Plug-In Hybrid Electric Vehicle (PHEV). But, for this thesis, only a deep analysis on the impact of Plug-In Hybrid Electric Vehicle (PHEV) penetration in power system network will be discussed in Chapter 3 and Chapter 4. This is due to in next 10 to 30 years, PHEVs will be dominating the market of Electrics Vehicles. Furthermore, there a lot of Vehicle-to-Grid advantages and application have been studied in this chapter. This thesis will mainly focus the application of V2G in frequency regulation. Moreover, there are a lot of analysis regarding the participation of Vehicle-to-grid system in frequency regulation have been investigated by the other researchers. But, the research only specific to one case study only in specific power system area. This thesis will be analysed 3 types of case studies which an events that will disturb the stability of the frequency in micro grid area and how the credibility of the V2G system to regulate the system frequency back to the allowable frequency variation. This case study will be discussed more in next chapter.

CHAPTER 3

METHODOLOGY

3.1. Introduction

The following section describes the method used in order to conduct analysis based on the research objectives. There are three case studies that have been conducted to meet the problem statements of this project. These case studies are the possible event that might be occurred in micro grid system and cause disturbance of the system frequency. With the intention of the disturbance, vehicle-to-grid is one of the solution to improve the frequency stability. An analysis to study the impact of implementation or without implementation of V2G as frequency regulator has been executed. In this project, the simulation of Vehicle-to-grid system was simulated using model in Mat Lab Simulink software. This model is based on 24-hour Simulation of a Vehicle-to-Grid (V2G) System which is one of the MATLAB example [30].

The first case study that have been conducted is to study the impact of sudden increase of residential peak load due to the PHEV charging load to the system frequency of the micro grid. The PHEV Charging Load Profile (PCLP) was analysed based on real the data from **National Household Travel Survey 2017**. In order to develop PCLP, there are some data need to be obtained and involved some calculation. These data were processed using three software which are Minitab, Excel and Mat Lab Programming. In addition, the analysis of PHEV Charging Load Profile (PCLP) have been develop with 4 different type of charging level which are charging level 1, charging level 2, and 2 types of DC fast charging and 4 different number of PHEV penetrations. The second case study is to implement the V2G system when there are 3 power system disturbances occur in

Micro Grid system. These disturbances will definitely disturb the normal system frequency of the micro grid. The third case study is to evaluate the frequency regulation when there is partial shading occur during noon that effect the solar panel output power.

3.2.Developing PHEV charging load profile (PCLP)

3.2.1. Introduction to PHEV charging load profile (PCLP)

The aggregate power required by PHEV in a particular region at a given time is noted to as the PHEV charging load profile (PCLP). This PCLP predictions are fundamental to any assessment of how the power system will interacted to PHEV. PCLP could cause damage on various aspects of the electrical grid impact analysis such as transformers and cables, generation rate, overloading, under voltage, power losses, power system utilization, and the electricity market. In addition, PCLP is beneficial for studying the effect of PHEV on emissions of greenhouse gas. PCLP makes it practicable to study the release of marginal power plants, for example, coal, fired natural gas, based on the amount of additional load and time distribution [31].

The basic data required to obtain the PCLP are the number and types of PHEVs, their all-electric range (AER), driving patterns, and miles driven daily. Besides that, the other factors that affect the PCLP are charging start time and charging level. Hence, the developing of the PCLP requires this knowledge which are the time of when each vehicle begins to be charged, how much energy is required to charge it, and what level of charge is available. The miles driven and vehicle type will determine the total energy required while charging level determines the charging time duration. The information needed in building the PCLP can be represented as a prism, as shown in Figure 3.1. The sides on the base are the vehicle type, driven mileage and charging start time. These factors are mostly statistical or probabilistic. The height of the prism is the charging level, which is depends on the power grid distribution system and the sides of the base are determined by the driver‘s behaviour [31].

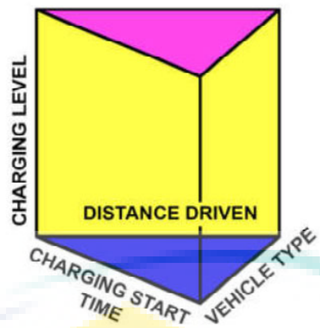


Figure 3.1 Prism of the information required in developing the PHEV charging load profile

3.2.2. 2017 National Household Travel Survey

This section analyse the extraction of practical data from transport data where the purpose is to produce PCLP. The National Household Travel Survey website consists of comprehensive transportation data of collected between April 2016 and May of 2017. The 2017 NHTS provides detailed data regarding the travel and transportation and are used to explore topics about travel behaviour, traffic safety, congestion, environment, energy consumption, demographic trends, bicycle and pedestrian studies, mobility economic sharing, and transit planning for basic planning and applications in the United States. This Survey was sponsored by the US Department of Transportation [32].

NHTS 2017 was conducted through interviews by telephone, and sampling is based on a random number-list of phone numbers. But group hotels, motels and quarters are excluded from this list. The target in the 2017 NHTS was to acquire completed surveys from 129,112 households, which consists of a national sample of 26,000 households and 103,112 additional add-on partner samples purchased by thirteen States or Metropolitan Planning Organization (MPO) area. Data reflected day trips within 24 hours, and they are gathered for all trips, all destinations, all long trips, and the country areas, both in urban and rural areas. Each household, person and vehicle at NHTS 2017 has an individual ID number. This ID applicable tools for merging any two data files [33].

The 2017 NHTS data comprises of five big databases. Since the PCLP extraction involves a vehicle, not a person, this section is primarily concerned with data relating to the travel of a vehicle, rather than a person's travel. However, data extraction that is viable requires considerations of people's travel as well. Hence, two Microsoft Excel files of the 2017 NHTS: i) TRIPPUB.csv and ii) VEHPUB.csv can be used for the researches presented here.

i. TRIPPUB.csv: This file comprises of data associated with 923,572 person trips, each of which has 104 attributes. There are four attributes that mainly focused in this study: household ID number (HOUSEID), vehicle ID number (VEHID), travel day trip end time (ENDTIME), and type of vehicle (VEHTYPE). The four vehicle types that are appropriate in this study are listed in Table 3.1 [33].

Table 3.1 Definition of VEHTYPE Values

VEHTYPE: Type of vehicle	
01	Automobile/car/station wagon
02	Van (mini, cargo, passenger)
03	Sports utility vehicle
04	Pickup truck

ii. VEHPUB.csv: This file represents information about 256,115 vehicles and each of vehicle has 54 elements. The specific interest here are HOUSEID, VEHID, VEHTYPE, and ANNMILES. ANNMILES illustrates the vehicle miles driven in the last 12 months.

As explained above, ANNMILES refer to the annual vehicle mileage. Based on [33], annual mileage is get by multiplying the daily mileage of 365. The daily mileage is acquired during the survey based on weekdays, weekends, and seasonal factors. Therefore, in our analysis study the ANNMILES was divided by 365.

The differentiation of these two files describes, in advance, that TRIPPUB refers to trips while VEHPUB address to the vehicle. Secondly, the attributes of HOUSEID, VEHID, and VEHTYPE are common for both files and can be utilize to merge both. To give an example, to specify the arrival time of the vehicle designated in VEHPUB, it is necessary to locate the vehicle in TRIPPUB, then search for ENDTIME in rows and columns associated with the TRIPPUB spreadsheet. Similarly, to determine the mileage of certain vehicles in TRIPPUB, it is necessary to locate a vehicle in VEHPUB, then search for ANNMILES in rows and columns associated with the VEHPUB spreadsheet.

The objective is to create a single file, each row dedicated to the trip of the vehicle. This file comprises attributes like vehicle type, day-driven mileage, and the last arrival time. Both files are merged based on their general attributes. The resulting file consists of several numbers vehicle trips with attributes of VEHTYPE, ANNMILES, and ENDTIME. In 2017, the average annual electricity consumption for a U.S. residential utility customer was 10,399 kilowatt-hours (kWh), an average of 867 kWh per month, 29 kWh per day and 1.2kWh per hour [34]. Based on the normal residential charging curve, the peak load is 10MW. Therefore, the average number of residential is 8333 residential. Each of the residential is assumed to own one vehicle per house. From 8333 vehicles, around 20-30 percent of the vehicle are assumed to be Plug-in Hybrid Electric Vehicle (PHEV). The PLCP was develop for 4 different number of PHEV penetration according to the assumed percentage which are 1500, 2000, 2500 and 3500 of PHEV. The PCLP also have been develop according to different charging level which are charging level 1, level 2, and two types of DC fast charging as shown in Table 3.2 [35]. From the table, the charger power for DC fast charging is 45 kW. The second type of DC Fast charger power that was used in this analysis is DC Fast charger 25 kW. In order to develop the PCLP, there are two important data analysis that need to be obtained from the NHTS 2017 data which are Vehicle Daily Mileage Analysis and Vehicle Arrival Time Analysis.

Table 3.2 Electric Vehicle Charging Level data

Charging Level	Power Supply	Charger Power	Miles of Ranger per Hour of Charge	Charge Times from Empty to Full	
				BEV	PHEV
Level 1	120VAC Single Phase	1.4 kW, 12 A	~3-4 Miles	~17 Hours	~7 Hours
Level 2	240VAC Single Phase	3.3 kW	~8-10 Miles	~7 Hour	~3 Hours
		6.6+ kW	~17-20 Miles	~3.5 Hours	~1.4 Hours
DC Fast Charge	200-450 VDC up to 90kW (200 Amp)	45 kW	~50-60 Miles (~80% per 0.5hr charge)	~30-45 Minutes (to ~80%)	~10 Minutes (to ~80%)

3.2.3. Vehicle Daily Mileage Analysis

Vehicle Daily Mileage Analysis is one of the important factor to build the PHEV Charging Load curve which consist of the daily mileage travel by each of vehicle. Based on VEHPUB.csv file, the attribute of ANNMILES for 1500, 2000, 2500 and 3000 are tabulated in Minitab Software to process the data. This data was then divided by 365 in order to obtain the daily distance driven. The range of the miles driven was categorised using Recode function as shown in Figure 3.2. This function will categorised each of the distance driven data according to the desired miles range. Besides using Minitab, this data also can be categorised by using MATLAB coding, but for this data analysis, Minitab Software is chosen since it is easier and have straightforward function.

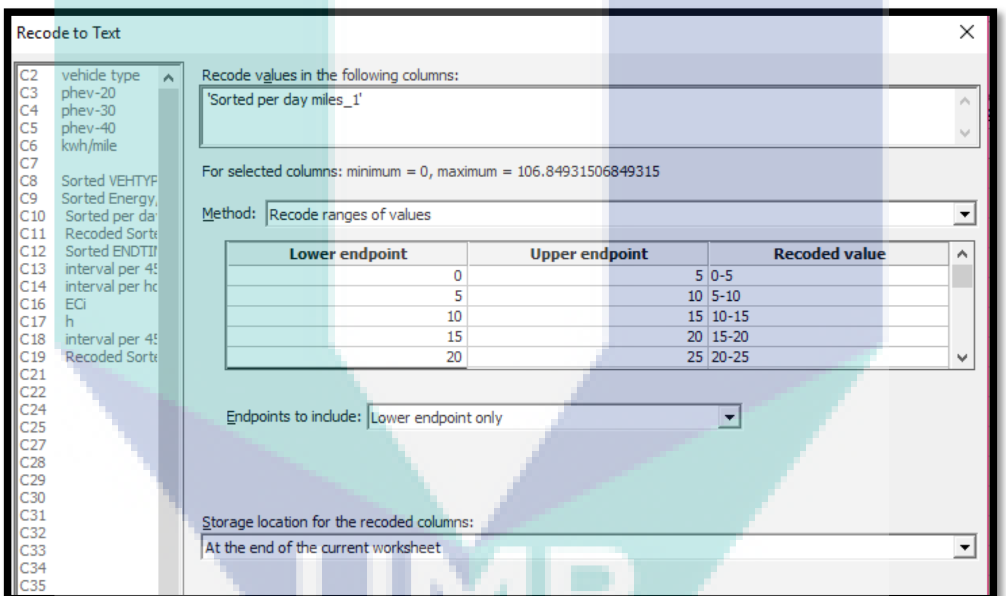


Figure 3.2 The Recode to Text function in Minitab Software.

After that, all the data was then tabulated in Excel. By using function 'COUNTIN' in excel, we can obtain the number of vehicle for each of the categorised miles driven. Table 3.3 shows the result of total number of vehicle according the distance driven in miles based on the random 1500, 2000, 2500 and 3000 total data of vehicle from the NHTS 2017.

Table 3.3 Number of Vehicle According to the Daily Distance Driven (Miles)

Distance Driven (Miles)	Number of PHEV			
	1500	2000	2500	3000
0-5	110	148	185	378
5-10	118	151	193	355
10-15	144	183	223	451
15-20	108	151	193	381
20-25	172	242	315	654
25-30	271	350	424	818
30-35	158	221	293	581
35-40	87	115	132	278
40-45	85	120	147	289
45-50	58	73	88	188
50-55	69	86	107	222
55-60	14	16	19	35
60-65	20	24	26	54
65-70	28	39	50	109
70-75	6	9	13	25
75-80	3	7	10	19
80-85	21	27	35	61
85-90	7	9	11	18
90-95	3	4	5	14
95-100	14	18	22	55
>100	4	7	9	15

From the vehicle daily mileage analysis data, a bar graph then was plotted using Mat Lab Software for four different total number of vehicles as mention before. The resulting bar graph will be shown and discussed in Chapter 4. The coding involved to develop the bar graph are as shown in Appendix I. Figure shows the flowchart of the above process.

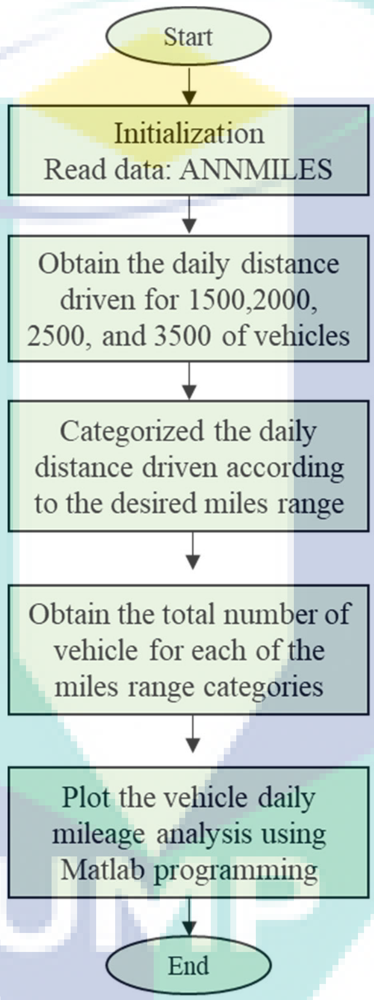
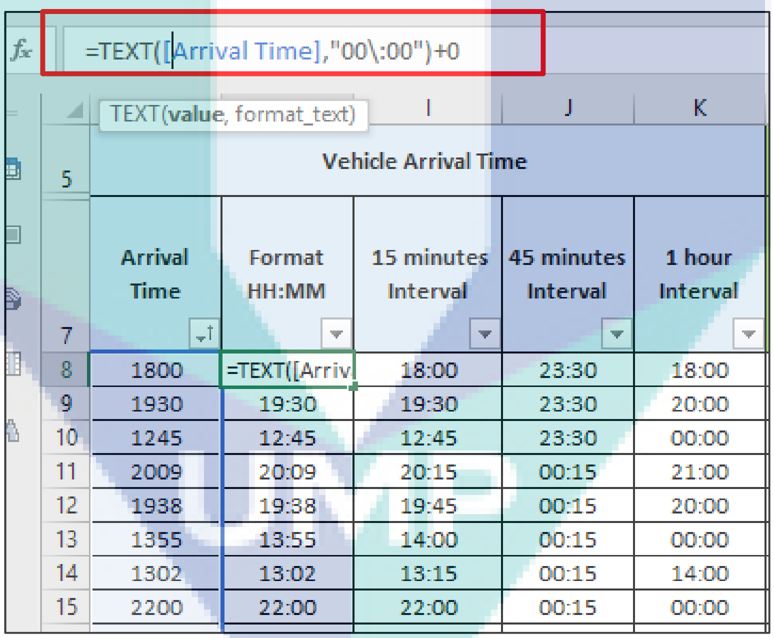


Figure 3.3 The flow chart to develop Vehicle Daily Mileage Analysis

3.2.4. Vehicle Arrival Time Analysis

Furthermore, the second factor to configure the PCLP prism (see Figure 3.1) is charging start time. The time at which the vehicle is charged cannot be accurately determined, but the vehicle's last travel time gives some information. People can depend on the ENDTIME attribute according to the assumption that the owner will plugged in their vehicle when they arrive. The data of last arrival time of each vehicle is extracted from the 2017 NHTS data, and the data are tabulated in Excel file. The given data are in 'HHMM' format. In order to process the arrival time data, each of the data were converted to HH:MM format using excel formula as shown in Figure 3.4. The arrival time data then was round up to nearest 15 minutes, 45 minutes and 1 hour using formula shown in Figure 3.5. The result of the arrival data was tabulated in excel and Figure 3.6 illustrates some of data.


=TEXT([Arrival Time],"00\:00")+0

TEXT(value, format_text)

	Vehicle Arrival Time				
	Arrival Time	Format HH:MM	15 minutes Interval	45 minutes Interval	1 hour Interval
8	1800	=TEXT([Arriv	18:00	23:30	18:00
9	1930	19:30	19:30	23:30	20:00
10	1245	12:45	12:45	23:30	00:00
11	2009	20:09	20:15	00:15	21:00
12	1938	19:38	19:45	00:15	20:00
13	1355	13:55	14:00	00:15	00:00
14	1302	13:02	13:15	00:15	14:00
15	2200	22:00	22:00	00:15	00:00

Figure 3.4 Excel Formula to convert HHMM format into HH:MM

=ROUNDUP([@[Format HH:MM]]*(24*60/15),0)/(24*60/15

ROUNDUP(**number**, num_digits)

	Vehicle Arrival Time			J	K
7	Arrival Time	Format HH:MM	15 minutes Interval	45 minutes Interval	1 hour Interval
8	1800	18:00	=ROUNDUP([@	23:30	18:00
9	1930	19:30	19:30	23:30	20:00
10	1245	12:45	12:45	23:30	00:00
11	2009	20:09	20:15	00:15	21:00
12	1938	19:38	19:45	00:15	20:00
13	1355	13:55	14:00	00:15	00:00
14	1302	13:02	13:15	00:15	14:00

Figure 3.5. Excel formula to round up the arrival to the nearest 15 minutes, 45 minutes and Hour

Vehicle Arrival Time				
Arrival Time	Format HH:MM	15 minutes Interval	45 minutes Interval	1 hour Interval
1800	18:00	18:00	23:30	18:00
1930	19:30	19:30	23:30	20:00
1245	12:45	12:45	23:30	00:00
2009	20:09	20:15	00:15	21:00
1938	19:38	19:45	00:15	20:00
1355	13:55	14:00	00:15	00:00
1302	13:02	13:15	00:15	14:00
2200	22:00	22:00	00:15	00:00
1731	17:31	17:45	00:15	18:00
1500	15:00	15:00	01:00	15:00
830	8:30	8:30	01:00	09:00
1245	12:45	12:45	01:00	01:00
2100	21:00	21:00	01:00	21:00
1635	16:35	16:45	01:00	17:00
1900	19:00	19:00	01:00	01:00
1500	15:00	15:00	01:00	01:00
1405	14:05	14:15	01:00	15:00
1645	16:45	16:45	01:00	17:00

Figure 3.6. Some of the arrival time data in Excel

From the 15-minutes interval of arrival time analysis, a bar graph was plotted using MATLAB programming for 1500, 2000, 2500 and 3500 total number of vehicles. In order to obtain the number of vehicle for each 15-minutes interval of arrival time in 24-Hour, a MATLAB programming was developed. The arrival time format was first convert from HH:MM format to Hours using Excel. The 1500 data of arrival time in Hours that have been round up to the nearest 15-minutes was then import to the MATLAB using function ‘xlsread’ and was sort from lower to higher value using function ‘sort’. Besides using function ‘xlsread’, a ‘readtable’ function also can be used in order to import data from excel to MATLAB.

Afterwards, by using function ‘unique’, the unique value of hour for 1500 arrival time data was obtained. A loop function ‘for’ was implement to count the number of unique value in the arrival time data. Finally, total number of each unique value represent the total number of vehicle arrived at that arrival time. Table 3.4 shows part of the results for total number of vehicles at each arrival time.

Then, a bar graph of arrival time and the number of vehicle was plotted using function ‘bar (x-axis, y-axis)’. The label for x-axis was set in HH:MM format but in 30-minutes interval starts from 00:00 until 23:30. The same MATLAB programming was repeated to plot the bar graph of arrival time for 2000, 3500 and 3000 total number of vehicle. The resulting bar graph will be explained in chapter 4. Figure 3.7 shows the flow chart of the development process of the Vehicle Arrival Time Analysis. Based on the flow chart, ‘N’ is equal to number of arrival time data which is the number of examined vehicles. The MATLAB programming involved to develop the bar graph are shown in Appendix II.

Table 3.4 Part of the Result for the Total Number of Vehicle at Each Arrival Time

Arrival Time	Number of PHEV			
	1500	2000	2500	3000
0:00	0	0	0	1
0:15	3	4	5	5
0:30	0	0	1	1
0:45	0	0	0	0
1:00	1	1	1	1
1:15	0	0	0	0
1:30	1	1	2	3
1:45	1	1	1	1
2:00	1	1	2	2
2:15	1	1	2	2
2:30	0	0	0	0
2:45	0	0	0	0
3:00	0	0	0	0
3:15	1	1	1	1
3:30	0	0	0	1
3:45	0	0	0	0
4:00	0	0	0	0
4:15	0	0	0	1
4:30	0	1	2	2
4:45	1	2	2	3

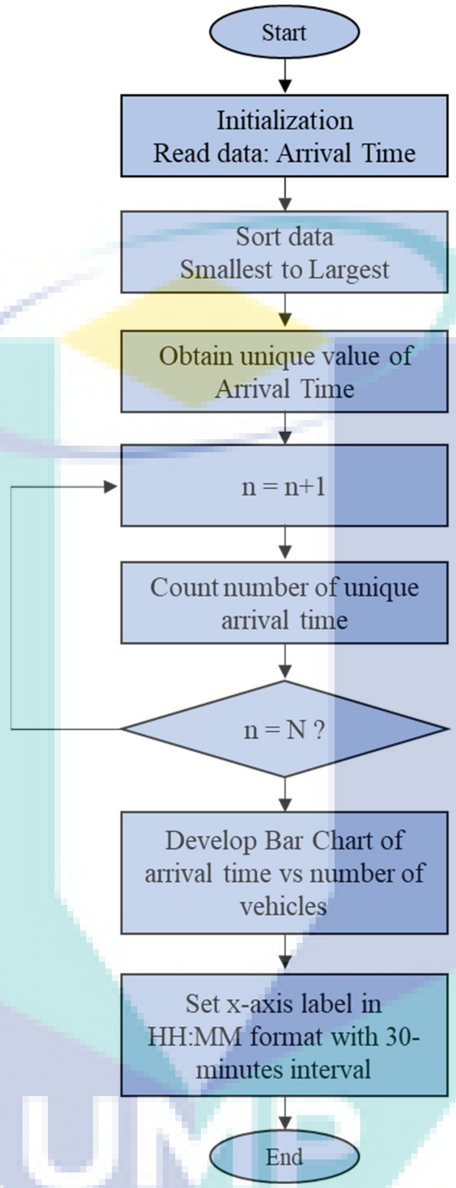


Figure 3.7. The flow chart of the development process of the Vehicle Arrival Time Analysis

3.2.5. Vehicles Type Analysis.

The third part of the PCLP prism base (see Figure 3.1.), vehicle type, is determined from the VEHTYPE field in NHTS 2017. Types 1, 2, 3, and 4 (see Table 3.1) are the focus of this analysis. Different PHEVs require different energy levels based on the type and the last SOC on the final arrival. Based on [36], Table 3.5. proposes the energy required for four types of PHEV to complement their all-electric ranges (AERs). The power required for each kwh (kWh/mile) for each type of vehicle are shown in Table 3.5.

Table 3.5. Energy Requirement for Four Types of PHEV

Type	**Total kWh**	**kWh/mile**
Compact Sedan	6.51	0.3255
Mid-size Sedan	7.21	0.3605
Mid-size SUV	8.75	0.4375
Full-size SUV	10.15	0.5075

3.2.6. PHEV Load Charging Profile

The following section describe the proposed method to develop the PHEV Load Charging Profile for 4 different number of PHEV which are 1500, 2000, 2500 and 3000. The number of PHEV used for this analysis are assumed to be the total number of Electric Vehicle that will be used in micro grid area. The PCLP also have been develop according to 4 different charging level which are charging rate level 1, level 2, and two types of DC fast charging as shown in Table 3.2. Figure show the flow chart of steps to build this PCLP. These steps are the summarize method of how to develop the programming in MATLAB. The MATLAB programming used in developing PHEV are shown in Appendix III. The steps and the formula involve are [37]:

1) Initialization process starts with collecting all required data; PHEV numbers (N), PHEV Type (T), distance driven (D), arrival time(ts), charging rate (r), energy capacity (E_{max}) and energy per mile (EPM).

2) Calculate the energy consumed, Ec_i by each PHEV:

$$Ec_i = D_i \times EPM_i \qquad 0 \leq Ec_i \leq E_{max} \qquad (1)$$

3) Calculate the duration (hours, h_i) needed by each PHEV to fulfil its SOC to 100%, E_{max} :

$$h_i = \frac{Ec_i}{r} \qquad 0 \leq Ec_i \leq E_{max} \qquad (2)$$

4) Develop the VCLP for hi hours based on the 15-minute time frame and based on arrival time of each of the PHEV:

$$Ec_i = Ec_{i,1} + Ec_{i,2} + \ldots\ldots Ec_{i,m} \qquad (3)$$

$$Ec_i = \sum_{t=1}^{m} Ec_{i,t} \qquad 1 \leq t \leq m \qquad (4)$$

Where *m*, is number of frame, which is m=96

5) So, the total 24-hour in 15-minutes interval PCLP based on the individual PHEV's charging at each step t is the calculated by:

$$E_{TC_t} = Ec_{1,t} + Ec_{2,t} + \ldots\ldots Ec_{i,t} \quad (5)$$

$$E_{TC_t} = \sum_{t=1}^{m} Ec_{i,t} \qquad 1 \leq t \leq m \quad (6)$$

6) The flow chart for above steps are as below [37]:

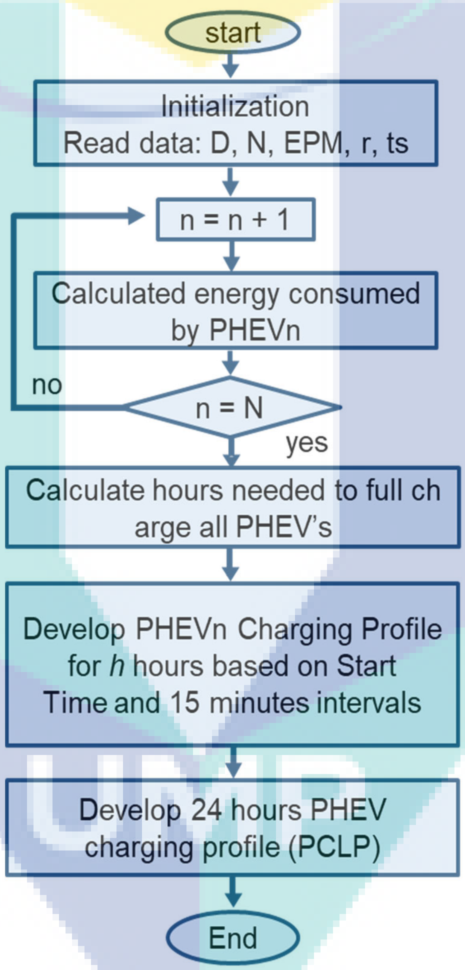


Figure 3.8. Flowchart of PCLP Development Process

According to the flow chart and the steps, the charging rate use for this analysis are Charging Rate Level 1, Level 2, and two types DC Fast Charging according to the Table 3.2. The charging level has a direct impact on the charging time. For example, using higher levels will reduce the time required to fulfil the SOC level to 100%. The MATLAB programming in developing the PCLP are shown in Appendix. The resulting PCLP will be shown and discussed in Chapter 4. After the PCLP for each for charging rate level with different penetration of PHEVs were obtained, the charging load was then added to the original residential load from the MATLAB Simulink to analyze its impact towards the power system network. This analysis was one of the case study to simulate the impact of V2G as frequency regulator in Micro grid. The process of the simulation will be discussed in next section.

3.3. MATLAB Simulation

This section involves simulation of vehicle to grid system in a Micro Grid model using MATLAB Simulink software. This model is based on 24-hour Simulation of a Vehicle-to-Grid (V2G) System which is one of the MATLAB example [30]. This assumed model is analysed as an isolated power system. In this example, the system frequency is regulate using the vehicle-to-grid system when a specific events occur during a full day. There are 3 case studies that have be analysed using this MATLAB Simulink in order to study the impact of Vehicle-to-Grid as a frequency regulator in a micro grid system. The model description and the events occur will be discussed later. The phasor mode of Specialized Power Systems allows a fast simulation of a 24-hour scenario. Figure 3.9 shows the Simulink model of 24-hour Simulation of a Vehicle-to-Grid (V2G) System.

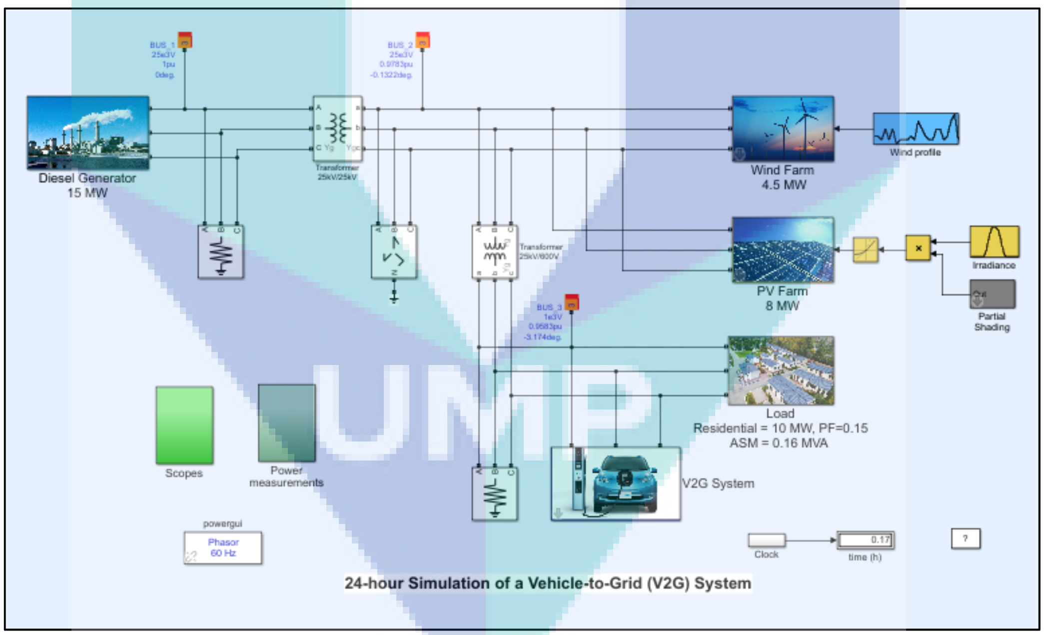


Figure 3.9. 24-hour Simulation of a Vehicle-to-Grid (V2G) System [30]

3.3.1. Model description

This studied Micro grid is divided into four important part which are Diesel Generator, acting as a base power generator; PV farms are combined with wind farms in order to produce renewable energy, the load which is composed of residential load and an asynchronous machine and the V2G system is installed next to the last part of the system. The details for the following parts are explained in the section below:

3.3.1.1. Diesel Generator

This model consists of 15 MW nominal power, 25 kV line-to-line voltage and 60 Hertz system frequency diesel generator. This generator is a swing generator and acts as base power generator. Figure 3.10 shows the model of diesel generator. The diesel generator balances the power used and the energy generated. The grid frequency deviation can be specifying by looking at the rotor speed of the synchronous machine. The *Gain* parameter have been added along with the rotor speed scope in order to obtain the real value of the frequency from the per unit of the synchronous machine rotor speed. The signal of the rotor speed from the diesel generator synchronous machine was set to be received by the Grid Regulation Control in the V2G system.

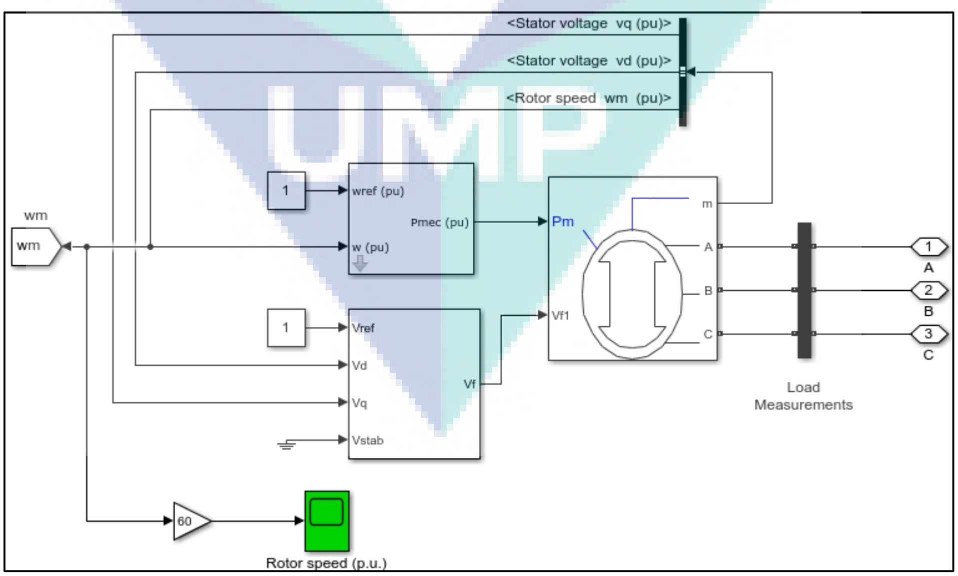


Figure 3.10. Diesel Generator model

3.3.1.2. Renewable Energy

This micro grid contains two sources of renewable energy which are Photovoltaic (PV) based on a fleet of solar panels which generate energy from solar, and wind farm which consist on wind turbine, the rated capacity of PV farm is 4.5 MW, and wind turbines capacity is 8 MW. A photovoltaic farm produces energy in proportion to three factors: area size covered by the photovoltaic farm, solar panel efficiency, and irradiance data.

On the other hand, a simplified wind farm model generates electrical power by following the linear relationship between the nominal wind speed and nominal power. The nominal power is produced by the wind farm if the nominal value of the wind is reached. When the wind speed is between the nominal speed and the maximal value, the power is fixed to 1 per unit. Once the wind speed exceeds the maximum wind value, the wind farm disconnect from the grid until the wind gets back to its rated value.

The block parameter for PV Farm and the Wind Farm are shown in Figure 3.11. The 24-Hour irradiance data of the PV Farm and wind profile of the Wind Farm can be set in lookup table. The partial shading (signal disturbance) of the PV Farm as shown in Figure 3.12 represents the reduction factor which is the fraction of the PV Farm's output. The start time and the duration of the partial shading also can be set.

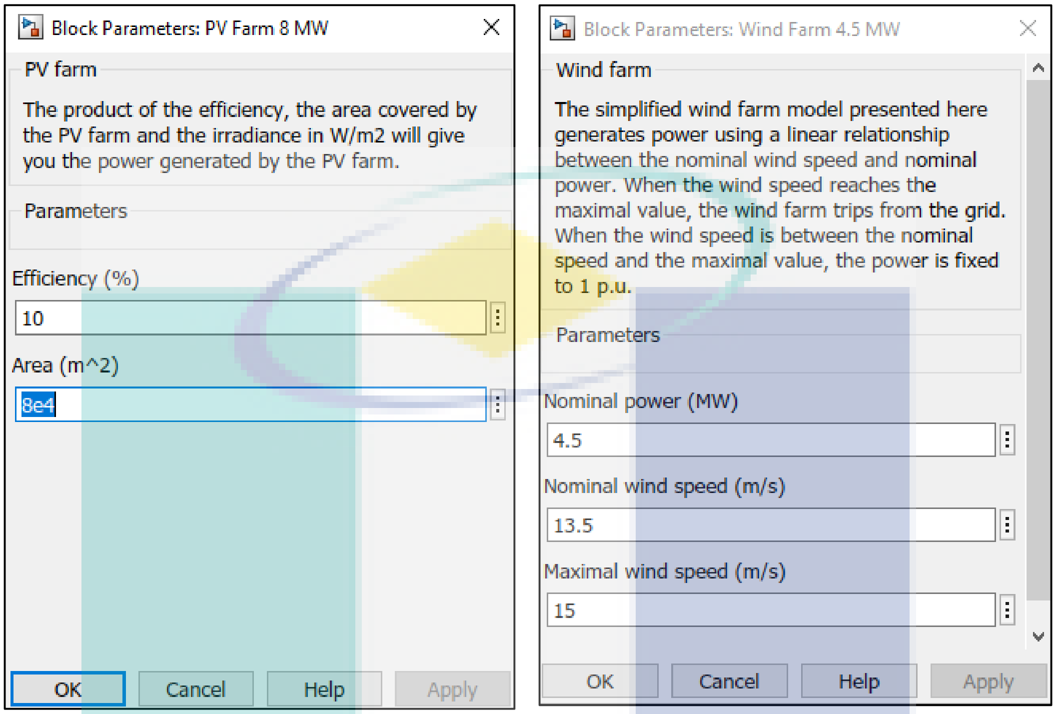


Figure 3.11 The block parameter of the PV Farm and Wind Farm

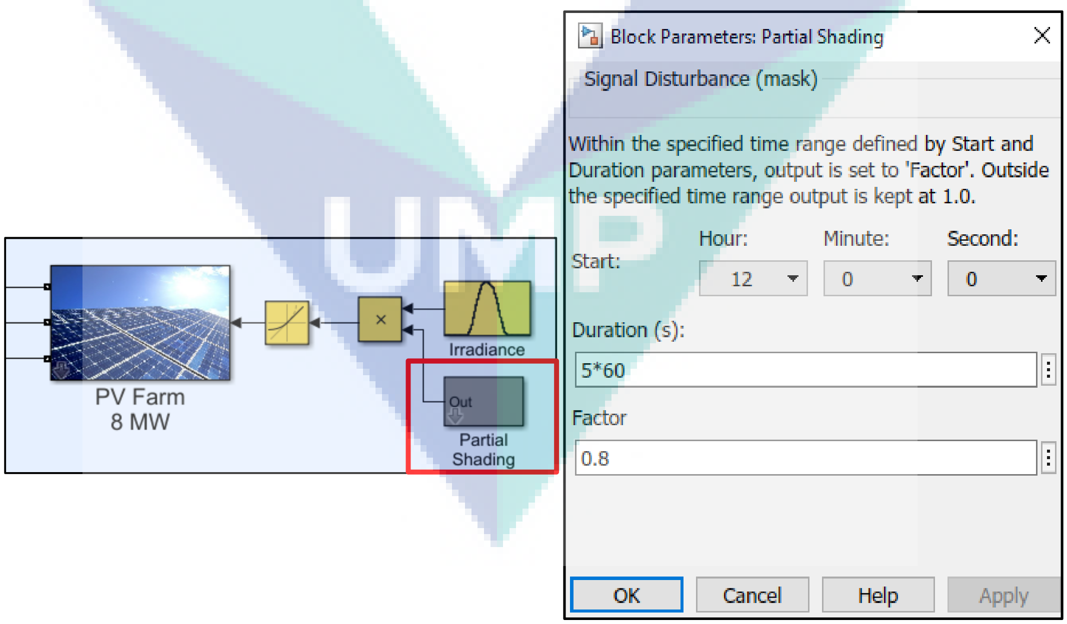


Figure 3.12. Block Parameter of the PV Farm Partial Shading

3.3.1.3. Load

The load in this simulation comprise 10 MW residential load and 0.16 MVA asynchronous machines as shown in Figure 3.13. The asynchronous machines are used to represent the impact of industrial inductive loads such as ventilation systems, on micro grids. Residential load follows the same pattern as the use of ordinary households. Its use is low during the day and rises to the peak in the evening, and slowly decreases at night. Residential load follows a usage profile with the given power factor. The residential load consumption can be modified in lookup table. Asynchronous machines are controlled by rectangular connections between rotor speeds and mechanical torque.

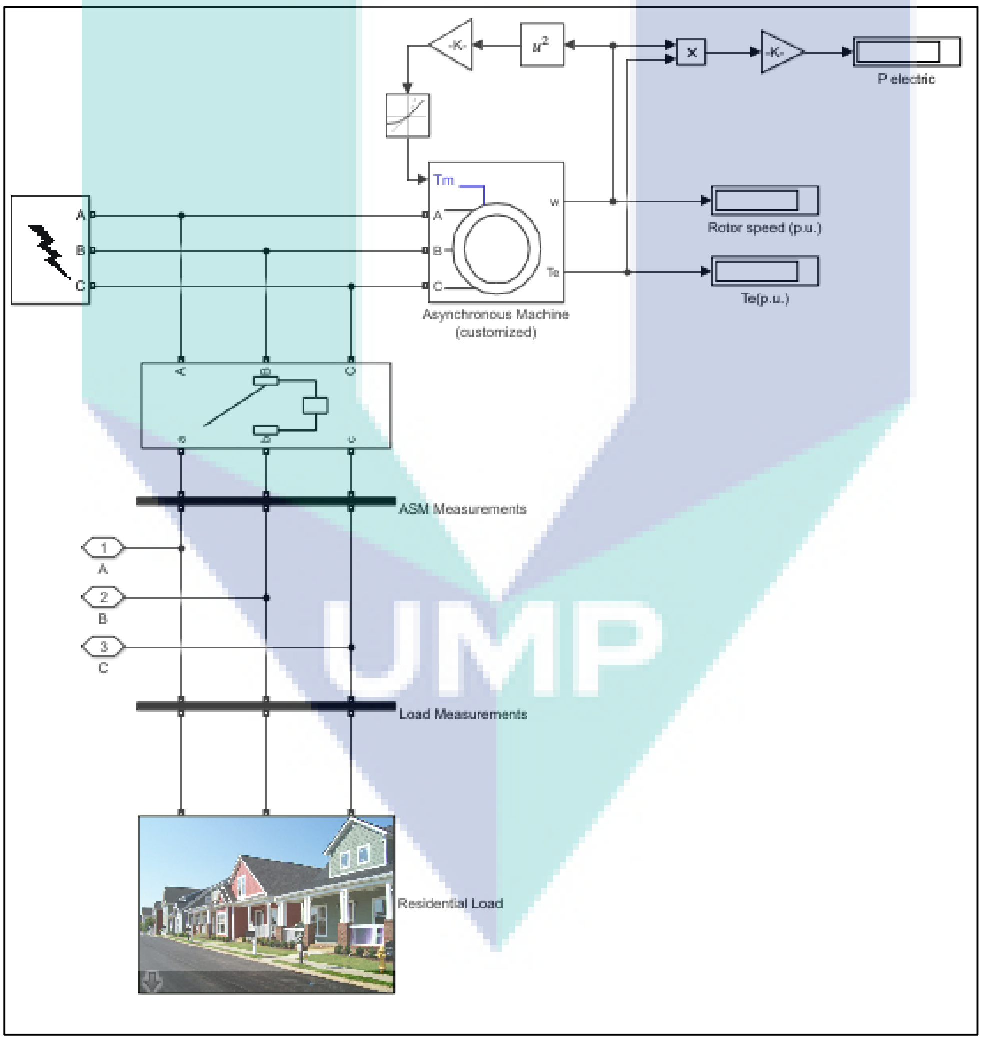


Figure 3.13. The Micro grid load model

3.3.1.4. Vehicle-to-Grid System

The V2G System model consist of 5 different profiles that can be modified under the mask by changing the plug and the state of charge (SOC) lookup tables of each profile as shown in Figure 3.14. The number of vehicles following each type of profile, rated capacity, the rated power and the efficiency of the power converter can also be decided in the Block Parameter as illustrated in Figure 3.15. V2G system in this simulation will have two important function which are controls the charge of the batteries connected to it and uses the available power to regulate the grid when an event occurs during the day. The signal of the rotor speed from the diesel generator synchronous machine was set to be received by the Grid Regulation Control in the V2G system. Therefore, the V2G system will regulate the grid if the system frequency is unstable. If the SOC of car profile is higher than 85% the, the PHEV is ready to regulate the grid while if the SOC of car profile lower than 85%, the charging mode is on.

The total amount of PHEV connected to the V2G system is subject to change. Power rated of charging stations are based on 4 different charging rate which are Level 1, Level 2, and two types of DC Fast charging as shown in Table 3.2. There are 5 different PHEV user profiles in this simulation, all of which are considered to have charging stations in their homes. In order to obtain the different PHEV user profile, the different user profile features are as follows [30]:

- Profile #1: People going to work from 8 a.m. to 4 p.m. drive their PHEVs over 2 hours with available charging stations close to offices and homes, which accounts for 35% of the total EVs

- Profile #2: People going to work from 8 a.m. to 4 p.m. and drive their PHEVs for 3 hours during this period with available charging stations close to offices and homes which accounts for 35% of the total PHEVs

- Profile #3: People employed from 8 to 4pm, and drive their PHEVs for 2 hours during this period with no possibility charging stations near their offices which accounts 10% of the total PHEVs

- Profile #4: People who do not drive their PHEVs for the whole day and their cars keep connected to the grid for 24hours which accounts 20% of total PHEVs

- Profile #5: People employed from 8pm to 4am, and drive their PHEVs for 2 hours during this period with no possibility charging stations near offices represents 10% of the total PHEVs

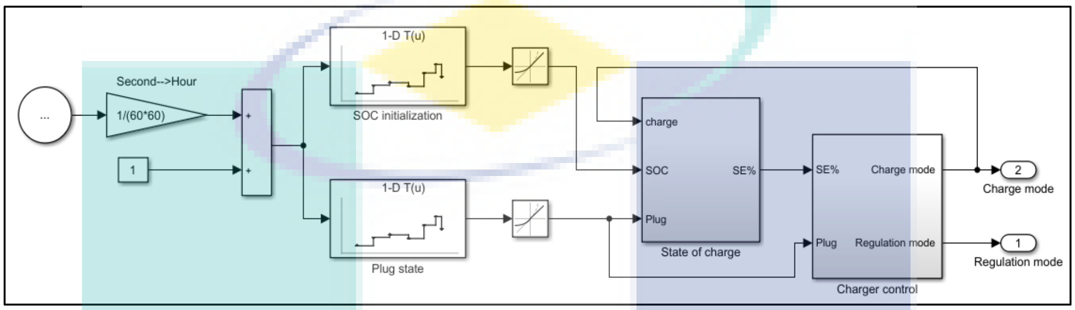


Figure 3.14. The model of Car Profile 1

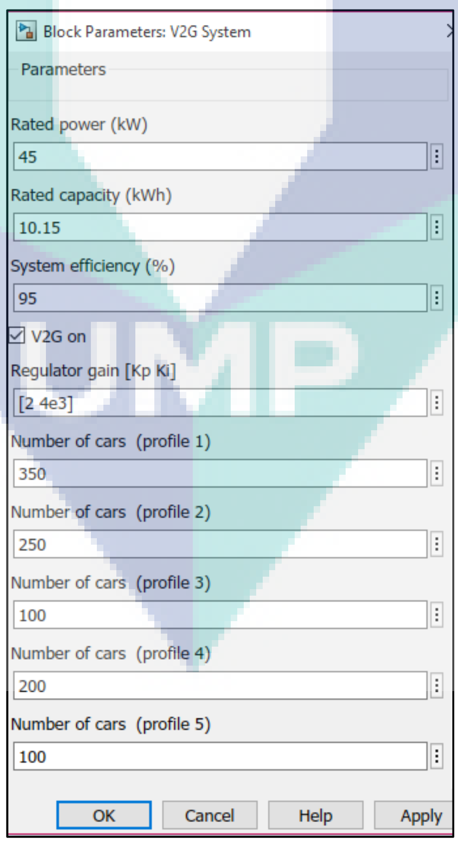


Figure 3.15. V2G system Block Parameter

3.3.2. Simulation Analysis

There are 3 case studies that have been conducted to analyse the frequency regulation and to evaluate the vehicle to grid system as the frequency regulator. These three case studies were simulated in 24-hour Simulation of a Vehicle-to-Grid (V2G) System using MATLAB Simulink. The case study involved in this research analysis are:

3.3.2.1. Case Study 1: Increase on Residential Load due to the PHEV Charging Load

Based on the PHEV Charging Load Profile that have been developed using Mat Lab programming, the charging load for each 1500, 2000, 2500 and 3000 total number of Vehicles with 4 different charging level was then added along with the original residential load in micro grid system thus increase the total peak load. This residential load in the Mat Lab Simulink was modified by updated the residential load to the new total load. The pattern of 24-hour load was changed in the Simulink lookup table. The increase of load above the normal load cause instability of the system frequency. The function of Vehicle to Grid system as frequency regulator will be evaluated here. For this case, the State of Charge for each of 5 car's profiles was set to 90% and its plug state was assumed to remain connected to the V2G system throughout the day. These car's profiles were modified based on assumption that all the PHEVs were ready to regulate the grid and to avoid any increase of load due to the charging mode of the V2G system. The result will be discussed in Chapter 4.

3.3.2.2. Case study 2: Disturbances in the Micro Grid Power System Network

In 24-hour Simulation of a Vehicle-to-Grid (V2G) System, there are 3 types of disturbances, that respectively happen at different times of the day. These disturbances are the possible event occur in micro grid system and could cause the diesel generator to suddenly generates more power in order to balances the system. The sudden change of the rotor speed of the synchronous machine will definitely cause deviation of the system frequency since the rotor speed is proportional to the system frequency. The function of Vehicle to Grid system as frequency regulator will be evaluated here. The description of the 3 types of disturbances are as the below:

i) The starting of the asynchronous machine in the initial of the third hour

The asynchronous machines are used to represent the impact of industrial inductive loads such as ventilation systems, on micro grids. Asynchronous machines are controlled by rectangular connections between rotor speeds and mechanical torque. For this case, the starting of the asynchronous machine was set at 3 a.m. in the Mat Lab simulation. The motor will draw a very high initial current, if the motor is switched on directly from the main supply. The current at start up is basically between five and seven times from what the motor normally draws at full load, but only possess a torque of between 1.5 and 2.5 times the torque at full load. The large start up current leads to a huge voltage drops in the supply line, and this may cause instabilities in the line and affect the equipment connected in the same circuit. Moreover, the kick-off of the asynchronous machine also leads to the frequency regulation. Hence, the impact of the system's frequency is evaluated when different number of PHEV are used in V2G system with 4 different charging rate. The pattern of 5 car's profile were set according to the scenario that have been discussed in section 3.3.1.4. The results of the system frequency with and without the implementation of V2G were discussed in Chapter 4.

ii) A partial shading at noon influencing the production of PV output power

The partial shading (signal disturbance) of the PV Farm represents the reduction factor which is the fraction of the PV Farm's output. For this case, the nominal PV output cause by the partial shading was reduced to 0.7. The event starts at 12 noon and the duration of the partial shading event was set for 5 minutes. The impact of the system's frequency is evaluated when different number of PHEV are used in V2G system with 4 different charging rate. The pattern of 5 car's profile were set according to the scenario that have been discussed in section 3.3.1.4. The results of the system frequency with and without the implementation of V2G were discussed in Chapter 4.

iii) A wind farm trip at 10 p.m. if the wind exceeds the maximum permitted wind power

The Rated capacity of the Wind Turbines is 8 MW. The simplified wind farm model generates electrical power by following the linear relationship between the nominal wind speed and nominal power. The nominal power is produced by the wind farm if the nominal value of the wind is reached. When the wind speed is between the nominal speed and the maximal value, the power is fixed to 1 per unit. Once the wind speed exceeds the maximum wind value, the wind farm disconnect from the grid until the wind gets back to its rated value. The sudden tripping of the wind turbines causes disturbance of the system frequency. The impact of the system's frequency is evaluated when different number of PHEV are used in V2G system with 4 different charging rate. The pattern of 5 car's profile were set according to the scenario that have been discussed in section 3.3.1.4. The results of the system frequency with and without the implementation of V2G were discussed in Chapter 4.

3.3.2.3. Case study 3: Different of Solar Panel Farm Output due to fractional Shading at noon

Different values of grids frequency have been analyses when the partial shading happens. The nominal rated power of the PV Farm was set to be reduced from 90% to 10%. The reduced of PV panel output due to the fractional shading will affect the system frequency stability. The event starts at 12 noon and the duration of the partial shading event was set for 5 minutes. The impact of the system's frequency is evaluated when different number of PHEV are used in V2G system with 4 different charging rate. The pattern of 5 car's profile were set according to the scenario that have been discussed in section 3.3.1.4. The results of the system frequency with and without the implementation of V2G were discussed in Chapter 4.

3.3.3. Summary

In order to analyze the impact of V2G as frequency regulator, there are 3 case studies that have been utilized. The first case study required real data of charging load in the need to develop PHEV charging load profile (PCLP) and to analyzed its impact to the power system network. The real data was extracted form 2017 National Household Travel Survey where the important files that have been imported are TRIPPUB.csv VEHPUB.csv. The basic data required to obtain the PCLP are the number and types of PHEVs, their all-electric range (AER), driving patterns, and miles driven daily. Besides that, the other factors that affect the PCLP are charging start time and charging level. The resulting PHEV charging load was added along with the MATLAB Simulink original residential load and the impacts to the system frequency was examined. The second case study is to implement the V2G system when there are 3 power system disturbances occur in Micro Grid system. These disturbances will definitely disturb the normal system frequency of the micro grid. The third case study is to evaluate the frequency regulation when there is partial shading occur during noon that effect the solar panel output power. The impact of the system's frequency was evaluated when different number of PHEV were used in V2G system with 4 different charging rate. The results of the system frequency with and without the implementation of V2G were discussed in Chapter 4.

CHAPTER 4

RESULTS AND DISCUSSION

4.1. Introduction

The following section describes the results of the analysis that have been explained in Chapter 3. There are three case studies that have been executed to meet the objectives and problem statements of this project. These case studies are the possible event that might be occurred in micro grid system and cause instability of system frequency. The first case study that have been conducted is to study the impact of sudden increase of residential peak load due to the PHEV charging load to the system frequency of the micro grid. The second case study is to implement the V2G system when there are 3 power system disturbances occur in Micro Grid system. These disturbances will definitely disturb the normal system frequency of the micro grid. The third case study is to evaluate the frequency regulation when there is partial shading occur during noon that effect the PV farm output power.

The first case study required real data of charging load in the need to develop PHEV charging load profile (PCLP) and to analyzed its impact to the power system network. The PHEV Charging Load Profile (PCLP) was analysed based on real the data from 2017 National Household Travel Survey. Two important analysis from the 2017 National Household Travel Survey which are Vehicle Daily Mileage Analysis and Vehicle Arrival Time Analysis were first discussed in this section.

Next, the results of MATLAB simulation regarding the case studies were tabulated and explained. The impact of the events to the system frequency of the Micro grid for each of the study case was tabulated and discussed. The impact of implementation of V2G system for each study case was also tabulated and analysed.

4.2 Distance Driven Mileage and Arrival Time Analysis

This section describes the results of two important analyses in order to study the pattern of PHEV throughout a day. As mention in *4.1.Introduction,* this analysis was built by extracting real data from 2017 National Household Travel Survey. Besides that, this analysis also contributes in developing the PCLP.

4.2.1 Vehicle Daily Mileage Analysis

Vehicle Daily Mileage Analysis is one of the important factor to build the PHEV Charging Load curve which consist of the daily mileage travel by each of vehicle. Based on VEHPUB.csv file, the attribute of ANNMILES for 1500, 2000, 2500 and 3000 are tabulated in Minitab Software to process the data. This data was then divided by 365 in order to obtain the daily distance driven. As discussed in the Chapter 3, the data was process using Minitab, Excel and Mat lab programming in order to build the bar graph of Vehicle Daily Mileage Analysis for each of the total vehicle. The result of travelled distance for 1500, 2000, 2500 and 3000 total of vehicles are shown below:

i. Travelled Distance of 1500 Vehicles

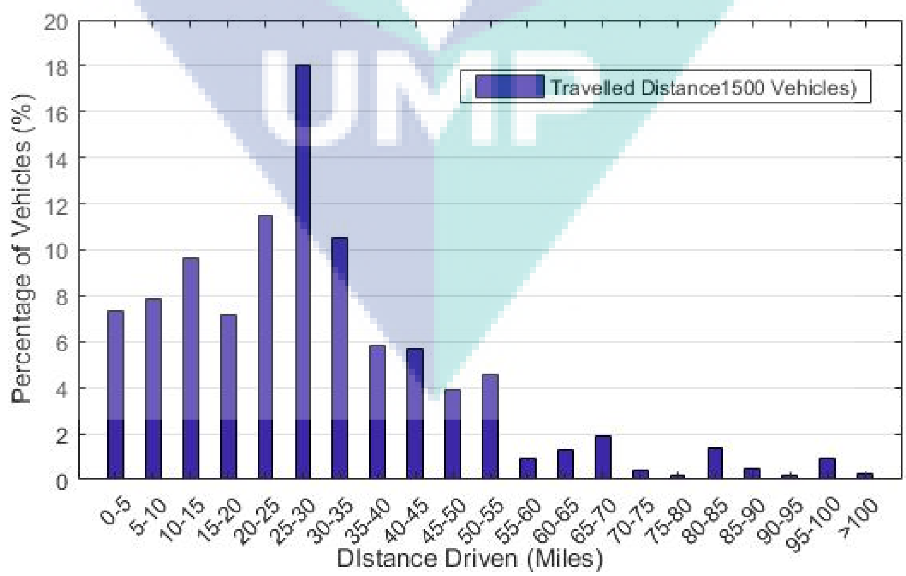


Figure 4.1. Percentage of 1500 vehicles versus their daily distance driven(miles)

ii. Travelled Distance of 2000 Vehicles

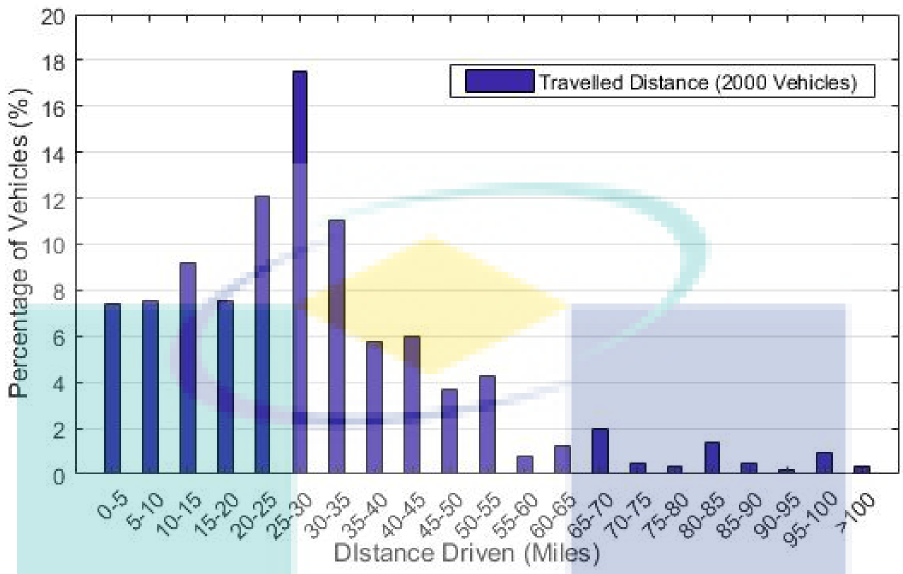


Figure 4.2. Percentage of 2000 vehicles versus their daily distance driven(miles)

iii. Travelled Distance of 2500 Vehicles

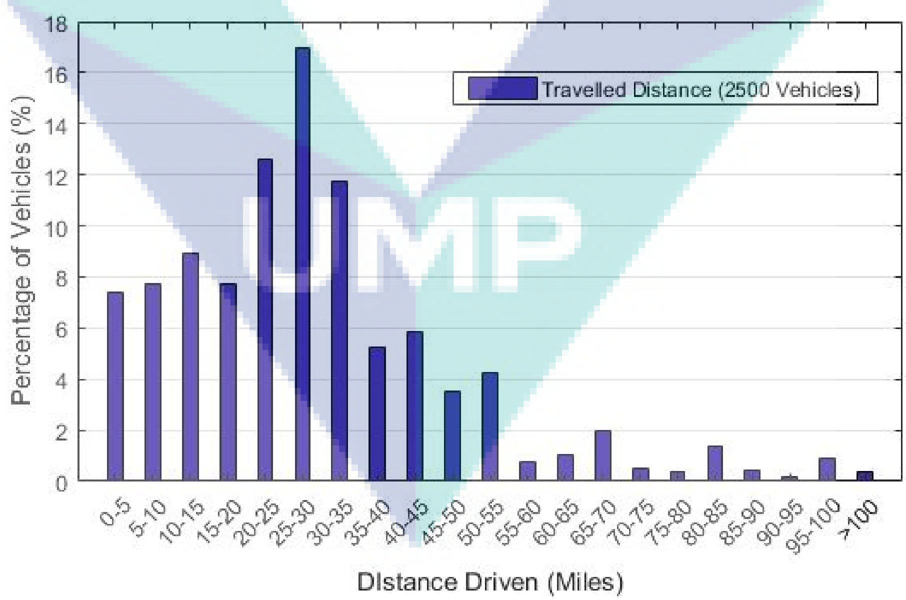


Figure 4.3. Percentage of 2500 vehicles versus their daily distance driven(miles)

iv. Travelled Distance of 3000 Vehicles

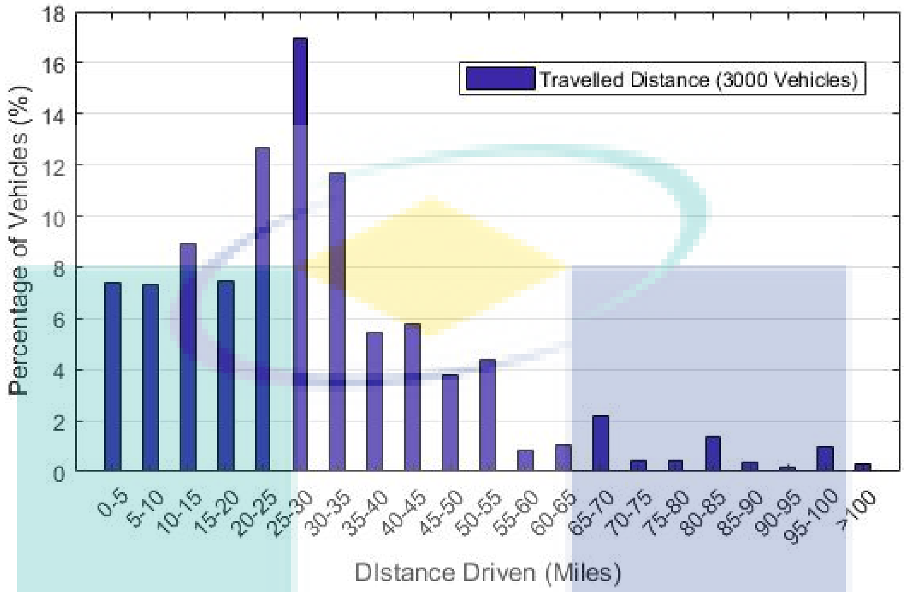


Figure 4.4. Percentage of 3000 vehicles versus their daily distance driven(miles)

Figure 4.1 to Figure 4.4 illustrate the bar graph of percentage of 1500, 2000, 2500 and 3000 vehicles versus their daily distance driven in miles. As what shown in the figures, the pattern of distance driven in miles for all 4 different number of total vehicles are quite similar. Most of the vehicle travelled between 25 to 30 miles throughout the day with percentages 16% to 18% of the total vehicles. The percentage of vehicle decrease as the distance driven in mile increase. From the figures, it is concluded that more than 70% the vehicles travelled for distance below than 35 miles per day or 56 kilometre per day. The PHEV's SOC and the energy necessary for charging the battery depend on the miles driven by vehicle. The longer the distance driven, the lower the percentage of SOC. Hence, more energy is required to fulfil the PHEV’s battery back to SOC of 100%.

4.2.2 Vehicle Arrival Time Analysis

Besides Vehicle Daily Mileage Analysis, the second important factor to configure the PCLP is charging start time. The time at which the vehicle is charged cannot be accurately determined, but the vehicle's last travel time gives some information. People can depend on the ENDTIME attribute according to the assumption that the owner will plugged in their vehicle when they arrive. The bar graph of Vehicle Arrival Time Analysis have been plotted using MATLAB programming with 4 different total number of vehicles. The results of the bar graph are as follow:

i. Vehicle Arrival Time of 1500 PHEV

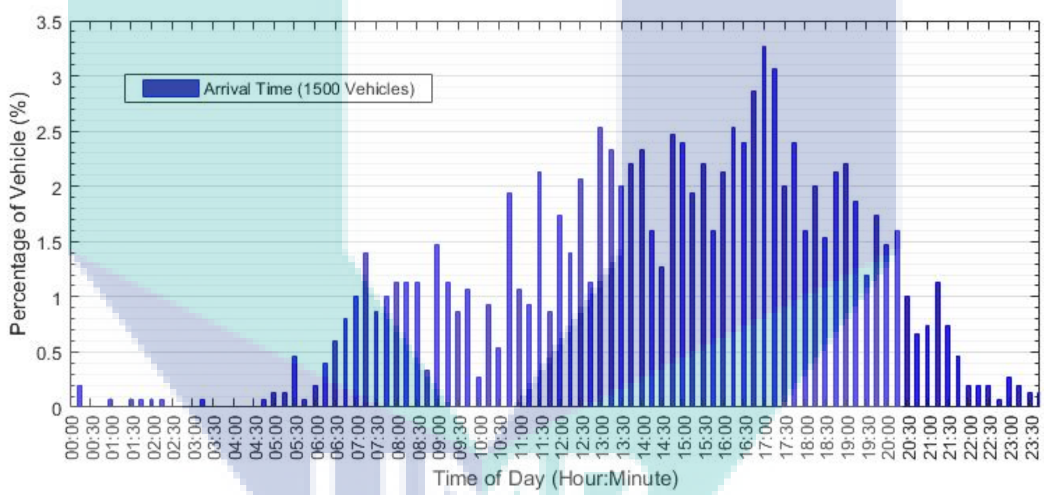


Figure 4.5. Percentage of 1500 vehicles versus their final arriving time

ii. Vehicle Arrival Time of 2000 PHEV

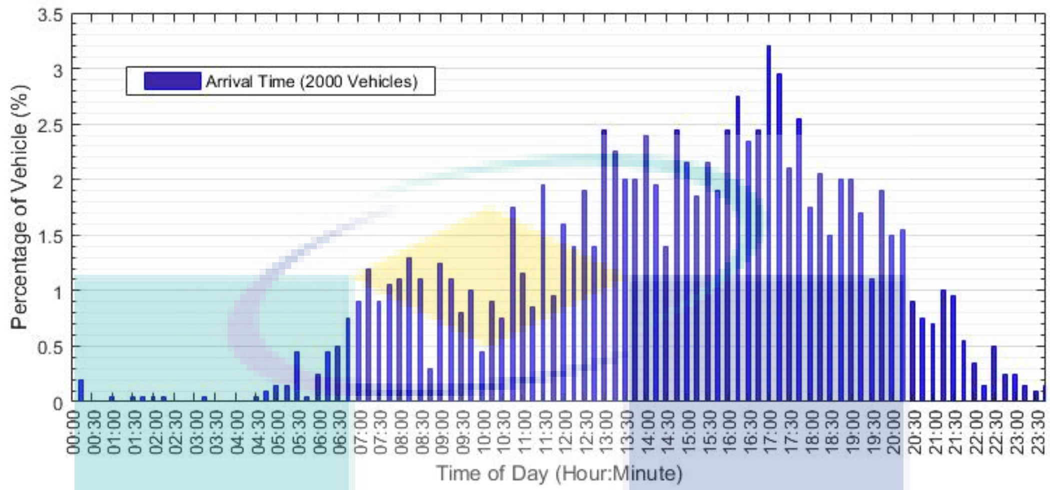


Figure 4.6. Percentage of 2000 vehicles versus their final arriving time

iii. Vehicle Arrival Time of 2500 PHEV

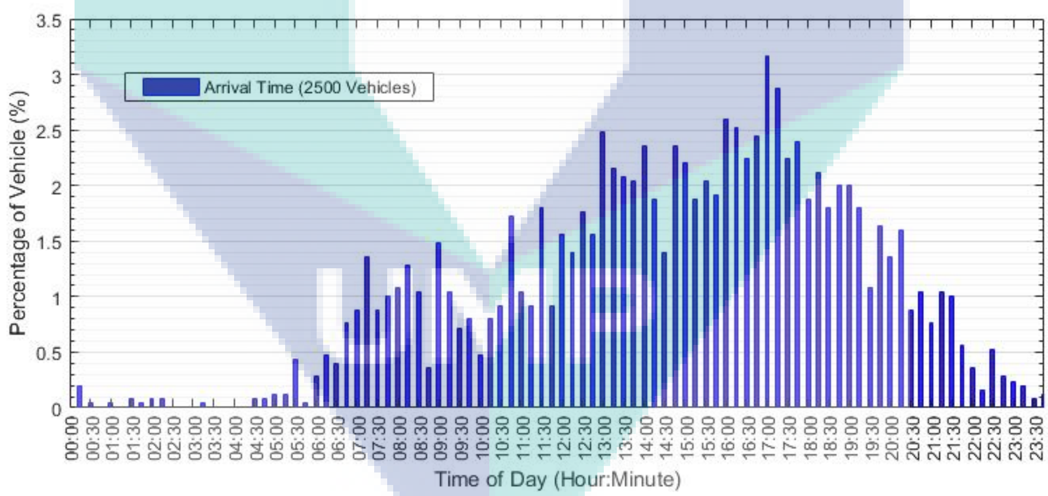


Figure 4.7. Percentage of 2500 vehicles versus their final arriving time

iv. Vehicle Arrival Time of 3000 PHEV

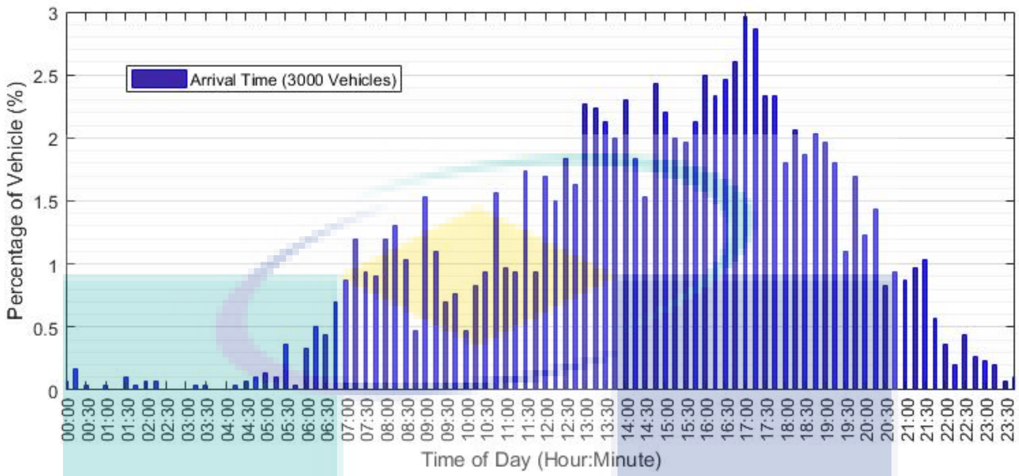


Figure 4.8. Percentage of 3000 vehicles versus their final arriving time

Figure 4.5 to Figure 4.8 illustrate the bar graph of percentage of 1500, 2000, 2500 and 3000 vehicles versus their final arriving time. Based on figures the pattern of arrival time throughout the day for all 4 different number of total vehicles are quite similar. The percentage of vehicles arrived seems low at early morning and further increase toward evening and again low during late night. The peak arrival time of the vehicles are between hours 17:00 to 17:30 with percentage 3 to 3.4 percent. From these results, the first assumption can be concluded where since the peak arrival time of the vehicles are between hours 17:00 to 17:30, this also the peak time for the vehicles start to charge their vehicle. Hence, at this hour, there will be a tremendous increase of load due to high penetration of PHEV charging their vehicles. The impact of PHEVs charging load with different type of charging rate to the system frequency have been discussed in next section.

4.3. Case study 1: Increase of Residential Load due to the EV Charging Load

According to the Mat Lab Simulink 24-hour Simulation of a Vehicle-to-Grid (V2G) System [45], the normal residential load is 10 MW. The PHEV Load Charging Profile (PLCP) have been developed based on the real data from National Household Travel Survey 2017 to study the pattern of PHEV charging in 24-Hour. In 2017, the average annual electricity consumption for a U.S. residential utility customer was 10,399 kilowatt-hours (kWh), an average of 867 kWh per month, 29 kWh per day and 1.2 kWh per hour. The 24-Hour residential load curve is shown in Figure 4.9. Based on the normal residential curve, the peak load is 10 MW. Therefore, the average number of residential is 8333 residential. Each of the residential is assumed to own one vehicle per house. From 8333 vehicles, around 20-30 percent of the vehicles are assumed to be Plug-in Hybrid Electric Vehicle. The PLCP was develop for 4 different number of PHEV penetration according to the assumed percentage which are 1500, 2000, 2500 and 3500 of PHEV. The PCLP also have been develop according to different charging level.

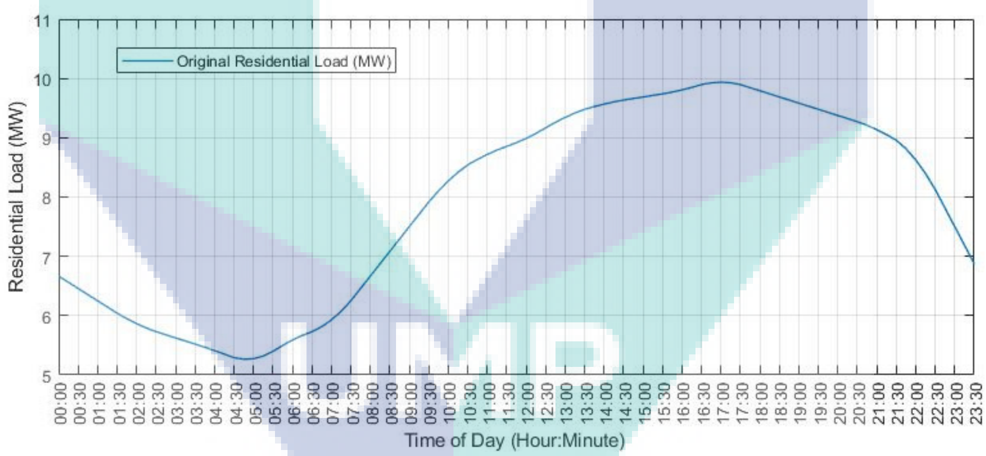


Figure 4.9. Original Residential Load (MW)

4.3.1 PHEV Load Charging Profile (PLCP)

The aggregate power required by PHEV in a particular region at a given time is noted to as the PHEV charging load profile (PCLP). This PCLP predictions are fundamental to any assessment of how the power system will interacted to PHEV. PCLP could cause damage on various aspects of the electrical grid impact analysis such as transformers and cables, generation rate, overloading, under voltage, power losses, power system utilization, and the electricity market. In addition, PCLP is beneficial for studying the effect of PHEV on emissions of greenhouse gas. PCLP makes it practicable to study the release of marginal power plants, for example, coal, fired natural gas, based on the amount of additional load and time distribution [31].

The PHEV Load Charging Profile for 4 different number of PHEV which are 1500, 2000, 2500 and 3000 have been developed. The number of PHEV used for this analysis are assumed to be the total number of Electric Vehicle that will be used in micro grid area. The PCLP also have been utilized according to 4 different charging level which are charging rate level 1, level 2, and two types of DC fast charging. The results of PCLP with 4 different charging level are as below:

4.3.1.1. PHEV Charging duration

Table 4.1 to 4.4 show the result of charging time and duration for the first 15 PHEV data with 4 different types of charging rate level. According to the results, the maximum charging duration to fulfil the PHEV battery capacity for charging level 1, charging level 2, DC fast charging (25 kW) and DC Fast Charging (45 kW) are around 7 hours, 1 hour and 30 minutes, 24 minutes and 13 minutes. It can be concluded that as the charger power increase, the time taken to charge the PHEV and fulfil its battery capacity is shorter.

Table 4.1. PHEV's Charging time and duration for Charging Level 1

CHARGING LEVEL 1 (1.4 kW)					
Start Charging		Charging Duration	End Charging		
HH:MM	in Hours		HH:MM	round to 15 min nearest	in Hours
18:00	18	0:00	18:00	18:00	18
19:30	19.5	7:03	2:33	2:45	26.75
12:45	12.75	7:15	20:00	20:00	20
20:15	20.25	2:58	23:13	23:15	23.25
19:45	19.75	1:42	21:27	21:30	21.5
14:00	14	7:15	21:15	21:15	21.25
13:15	13.25	3:11	16:26	16:30	16.5
22:00	22	7:15	5:15	5:15	29.25
17:45	17.75	7:15	1:00	1:00	25
15:00	15	5:26	20:26	20:30	20.5
8:30	8.5	7:15	15:45	15:45	15.75
12:45	12.75	7:15	20:00	20:00	20
21:00	21	6:26	3:26	3:30	27.5
16:45	16.75	7:15	0:00	0:00	24
19:00	19	4:16	23:16	23:30	23.5

Table 4.2. PHEV's Charging time and duration for Charging Level 2

CHARGING LEVEL 2 (6.6 kW)					
Start Charging		Charging Duration	End Charging		
HH:MM	in Hours		HH:MM	round to 15 min nearest	in Hours
18:00	18	0:00	18:00	18:00	18
19:30	19.5	1:29	20:59	21:00	21
12:45	12.75	1:32	14:17	14:30	14.5
20:15	20.25	0:37	20:52	21:00	21
19:45	19.75	0:21	20:06	20:15	20.25
14:00	14	1:32	15:32	15:45	15.75
13:15	13.25	0:40	13:55	14:00	14
22:00	22	1:32	23:32	23:45	23.75
17:45	17.75	1:32	19:17	19:30	19.5
15:00	15	1:09	16:09	16:15	16.25
8:30	8.5	1:32	10:02	10:15	10.25
12:45	12.75	1:32	14:17	14:30	14.5
21:00	21	1:21	22:21	22:30	22.5
16:45	16.75	1:32	18:17	18:30	18.5
19:00	19	0:54	19:54	20:00	20

Table 4.3. PHEV's Charging time and duration for DC Fast Charging (25 kW)

FAST CHARGING (25 kW)					
Start Charging		Charging Duration	End Charging		
HH:MM	in Hours		HH:MM	round to 15 min nearest	in Hours
18:00	18	0:00	18:00	18:00	18
19:30	19.5	0:23	19:53	20:00	20
12:45	12.75	0:24	13:09	13:15	13.25
20:15	20.25	0:10	20:25	20:30	20.5
19:45	19.75	0:05	19:50	20:00	20
14:00	14	0:24	14:24	14:30	14.5
13:15	13.25	0:10	13:25	13:30	13.5
22:00	22	0:24	22:24	22:30	22.5
17:45	17.75	0:24	18:09	18:15	18.25
15:00	15	0:18	15:18	15:30	15.5
8:30	8.5	0:24	8:54	9:00	9
12:45	12.75	0:24	13:09	13:15	13.25
21:00	21	0:21	21:21	21:30	21.5
16:45	16.75	0:24	17:09	17:15	17.25
19:00	19	0:14	19:14	19:15	19.25

Table 4.4. PHEV's Charging time and duration for DC Fast Charging (45 kW)

FAST CHARGING (45 kW)					
Start Charging		Charging Duration	End Charging		
HH:MM	in Hours		HH:MM	round to 15 min nearest	in Hours
18:00	18	0:00	18:00	18:00	18
19:30	19.5	0:13	19:43	19:45	19.75
12:45	12.75	0:13	12:58	13:00	13
20:15	20.25	0:05	20:20	20:30	20.5
19:45	19.75	0:03	19:48	20:00	20
14:00	14	0:13	14:13	14:15	14.25
13:15	13.25	0:05	13:20	13:30	13.5
22:00	22	0:13	22:13	22:15	22.25
17:45	17.75	0:13	17:58	18:00	18
15:00	15	0:10	15:10	15:15	15.25
8:30	8.5	0:13	8:43	8:45	8.75
12:45	12.75	0:13	12:58	13:00	13
21:00	21	0:12	21:12	21:15	21.25
16:45	16.75	0:13	16:58	17:00	17
19:00	19	0:07	19:07	19:15	19.25

4.3.1.2. Charging Level 1 (1.4 kW)

Figure 4.10 illustrates the result of PHEV Charging Load Profile (PCLP) for 4 different number of PHEVs penetration with Charging rate level 1. It can clearly be seen that there has been a huge increase of charging load starting from 6 a.m. morning and rise to peak at 5 p.m. From the curve, it can be concluded that, most of the PHEV's owner charged their vehicle during evening. Moreover, the higher number of PHEVs penetration, the higher the charging load. The peak charging load for 1500, 2000, 2500 and 3000 PHEVs penetration are 0.86436 MW, 1.17348 MW, 1.45152 MW, and 1.74944 MW. The impact of charging load with charging rate level 1 to the system frequency have been discussed in next section.

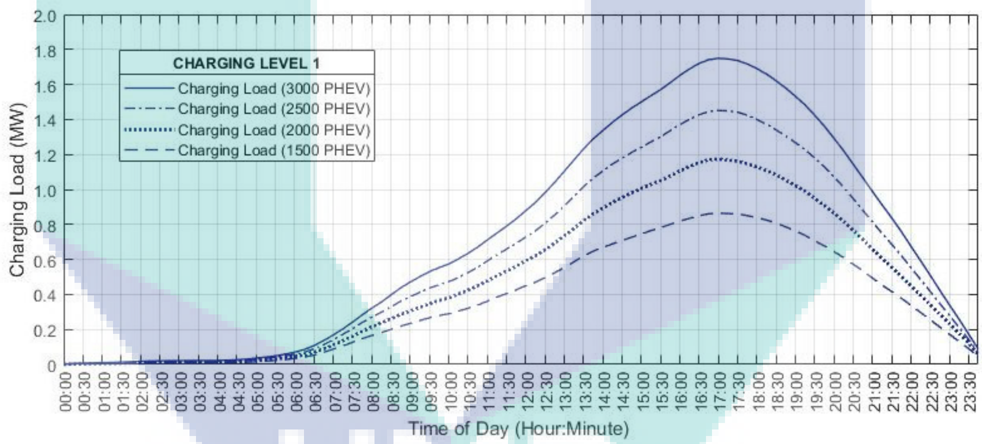


Figure 4.10. The PHEV Charging Load for charging rate Level 1

4.3.1.3. Charging Level 2 (6.6 kW)

Figure 4.11 illustrates the result of PHEV Charging Load Profile (PCLP) for 4 different number of PHEVs penetration with Charging rate level 2. As shown in figure, the charging load curve is not as smooth as Charging load with charging rate level 1. This is because, the time taken for the PHEV with charging rate level 2 to fulfil its State of Charge (SOC) to 100% or full are shorter than charging rate level 1. In contrast, the peak charging load for charging rate level 2 is greater than charging rate level 1 for all case of PHEV penetration. Based on the charging load curve, the peak charging load is at 5.30 p.m. to 6 p.m. The peak charging load for 1500,200,2500 and 3000 PHEVs penetration are 1.526 MW, 2.05 MW, 2.5278 MW, and 3.0796 MW. The impact of charging load with charging rate level 2 to the system frequency have been discussed in next section.

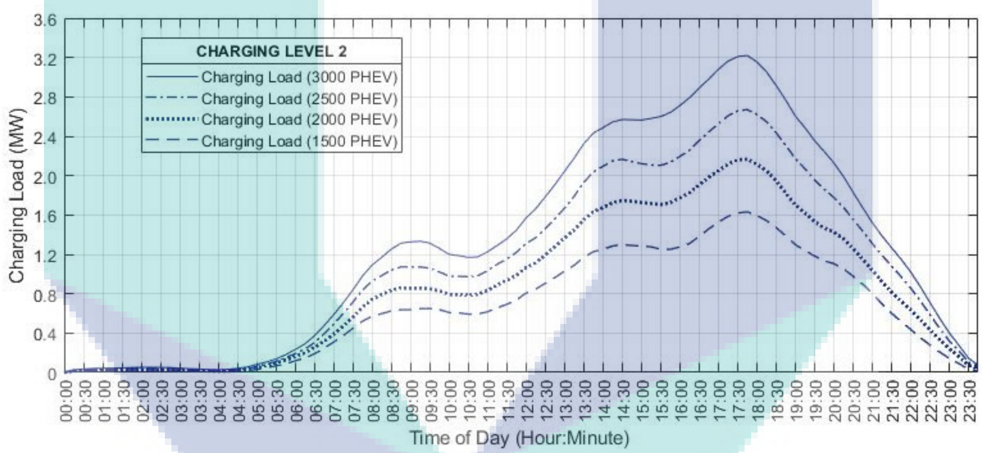


Figure 4.11. The PHEV Charging Load for charging rate Level 2

4.3.1.4. DC Fast Charging (25 kW)

Figure 4.12. illustrates the result of PHEV Charging Load Profile (PCLP) for 4 different number of PHEVs penetration with DC Fast Charging (25 kW). As shown in figure, the charging load curve is not as smooth as Charging load with charging rate level 1. This is because, the time taken for the PHEV with DC Fast Charging (25 kW) to fulfil its State of Charge (SOC) to 100% or full are shorter than charging rate level 1. In contrast, the peak charging load for DC Fast Charging (25 kW) is greater than charging rate level 1 and level 2 for all case of PHEV penetration. Based on the charging load curve, the peak charging load is at 5.30 p.m. to 6 p.m. The peak charging load for 1500, 2000, 2500 and 3000 PHEVs penetration are 2.735 MW, 3.58 MW, 4.41 MW, and 5.335 MW. The impact of charging load with DC Fast Charging (25 kW) to the system frequency have been discussed in next section.

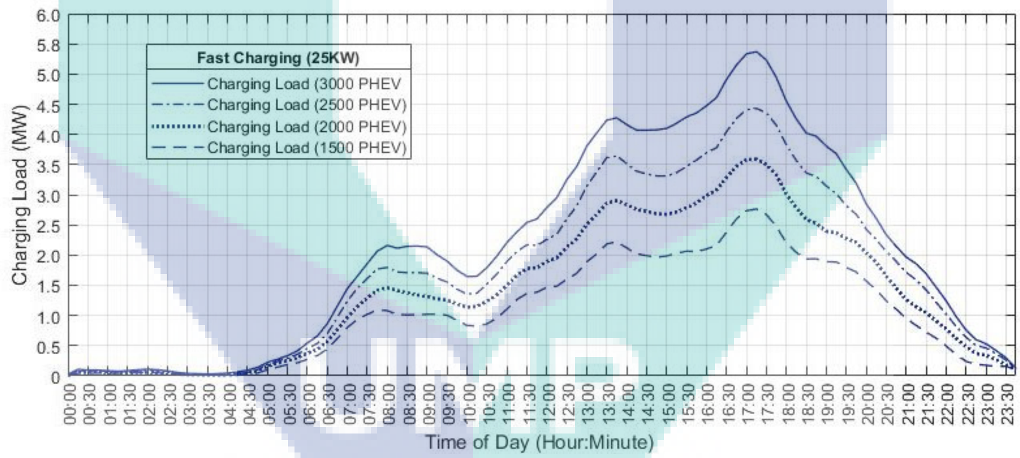


Figure 4.12. The PHEV Charging Load for DC Fast Charging (25 kW)

4.3.1.5. DC Fast Charging (45 kW)

Figure 4.13. illustrates the result of PHEV Charging Load Profile (PCLP) for 4 different number of PHEVs penetration with DC Fast Charging (45 kW). As shown in figure, the charging load curve is not as smooth as Charging load with charging rate level 1. This is because, the time taken for the PHEV with DC Fast Charging (45 kW) to fulfil its State of Charge (SOC) to 100% or full are shorter than charging rate level 1. In contrast, the peak charging load for DC Fast Charging (45 kW) is greater than charging rate level 1 and level 2 for all case of PHEV penetration. Based on the charging load curve, the peak charging load is at 5.30 p.m. to 6 p.m. The peak charging load for 1500, 2000, 2500 and 3000 PHEVs penetration are 3.6 MW, 4.608 MW, 5.742 MW, and 6.957 MW. The impact of charging load with DC Fast Charging (45 kW) to the system frequency have been discussed in next section.

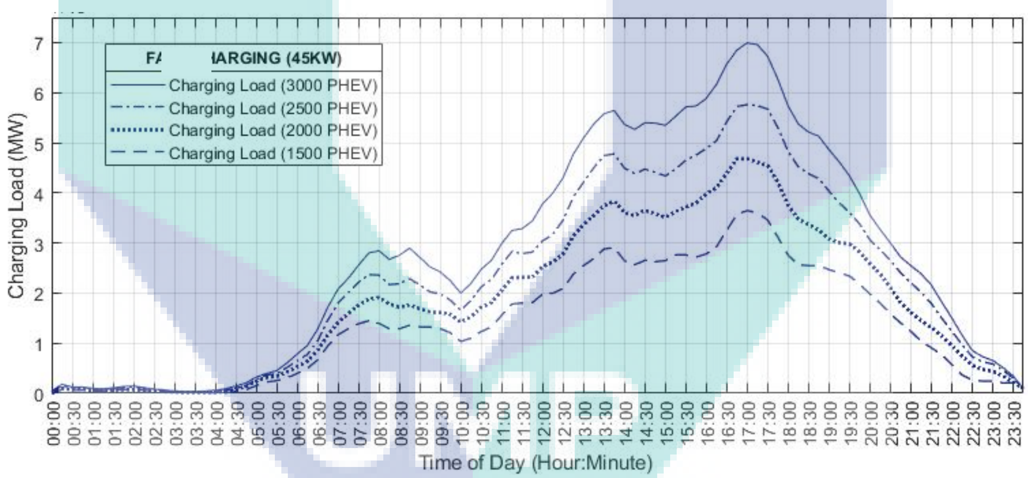


Figure 4.13. The PHEV Charging Load for DC Fast Charging (45 kW)

4.3.2 Total Residential Load for different Charging Level and its impact to the system frequency stability

For the first case study, the charging load for each of the charging level with different total number of PHEV penetration have been added to the original 24-Hour residential load of the micro grid. The total residential load will definitely exceed the normal residential load. The increase of load will cause the diesel generator that act as the base power, to generate more power in order to the balance the supply and output power. This will cause sudden change of speed of rotor of the synchronous machine and lead to the frequency deviation since the speed of rotor is proportional to the frequency. The frequency deviation for each case of charging level has been discussed in this section. As the objective of this research to improve the stability of the frequency, the implementation of V2G system is analysed to prove its ability to maintain the stability of power system.

4.3.2.1. Charging Level 1 (1.4 kW)

This section discussed the result of total residential load for 4 different number of PHEVs penetration with charging rate Level 1. Furthermore, the sudden increase of residential load due to the charging load affects the system frequency of the micro grid. The result of the system frequency from MATLAB Simulink with and without implementation of V2G have been tabulated and explained in this section.

i. Total Residential Load

Figure 4.14. show the curve of total residential load for 4 different PHEVs penetration with charging level 1 after the 24-hour PHEV charging loads was added along with the normal 24-hour residential load. As illustrated in Figure 4.14, the total load exceeds the normal load 10 MW. Moreover, it is found that the peak of the residential load caused by 4 different PHEVs penetration as charging load was at hour 17:00. The percentage of load increment at this hour for 1500, 2000, 2500 and 3000 PHEVs penetration are 7.76%, 10.82%, 11.45% and 16.56%. The percentage of load increment is rise as the total

number of PHEV penetration is increase. This increment of total residential load will definitely effect the power system stability. The diesel generator needs to generate more power in order to balance the system and cause the frequency deviation occurs.

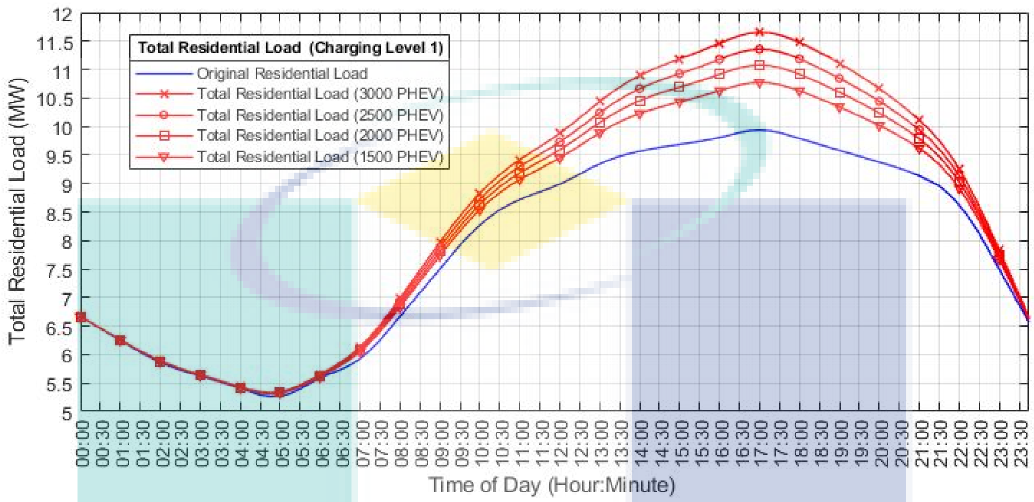


Figure 4.14. The total residential load for charging rate Level 1

ii. The impact to the system frequency

Table 4.5 to Table 4.8 show the result of the system frequency after the increment of residential load due to the 1500, 2000, 2500 and 3000 penetration of PHEVs as charging load. The result was taken during the time of day where the load starts to exceed the normal residential load. As illustrated in table, the number of PHEV acts as V2G system were varied from zero which is the condition of system without the V2G implementation and have been increase until 1000 of PHEVs connected on V2G system. But, since the frequency for 4 PHEVs penetration are normal, there is no V2G implementation needed for case charging level 1. Hence, the PHEV charger of type level 1 was suitable in micro grid system for 20-30 % penetration of PHEVs with 10 MW residential load.

Table 4.5. System Frequency after 1500 PHEVs penetration at Charging Level 1 with V2G Implementation

Charging Level 1 (1.4 kW)						
System Frequency With V2G Implementation (Hz) Charging Load = 1500 PHEVs						
Time (during peak load)	Number of V2G					
	0	200	400	600	800	1000
13:00	60	-	-	-	-	-
13:15	60	-	-	-	-	-
13:30	60	-	-	-	-	-
13:45	60	-	-	-	-	-
14:00	60	-	-	-	-	-
14:15	60	-	-	-	-	-
14:30	60	-	-	-	-	-
14:45	60	-	-	-	-	-
15:00	60	-	-	-	-	-
15:15	60	-	-	-	-	-
15:30	60	-	-	-	-	-
15:45	60	-	-	-	-	-
16:00	60	-	-	-	-	-
16:15	60	-	-	-	-	-
16:30	60	-	-	-	-	-
16:45	60	-	-	-	-	-
17:00	60	-	-	-	-	-
17:15	60	-	-	-	-	-
17:30	60	-	-	-	-	-
17:45	60	-	-	-	-	-
18:00	60	-	-	-	-	-
18:15	60	-	-	-	-	-
18:30	60	-	-	-	-	-

Table 4.6. System Frequency after 2000 PHEVs penetration at Charging Level 1 with V2G Implementation

Charging Level 1 (1.4 kW)						
System Frequency With V2G Implementation (Hz) Charging Load = 2000 PHEVs						
Time (during peak load)	Number of V2G					
	0	200	400	600	800	1000
13:00	60	-	-	-	-	-
13:15	60	-	-	-	-	-
13:30	60	-	-	-	-	-
13:45	60	-	-	-	-	-
14:00	60	-	-	-	-	-
14:15	60	-	-	-	-	-
14:30	60	-	-	-	-	-
14:45	60	-	-	-	-	-
15:00	60	-	-	-	-	-
15:15	60	-	-	-	-	-
15:30	60	-	-	-	-	-
15:45	60	-	-	-	-	-
16:00	60	-	-	-	-	-
16:15	60	-	-	-	-	-
16:30	60	-	-	-	-	-
16:45	60	-	-	-	-	-
17:00	60	-	-	-	-	-
17:15	60	-	-	-	-	-
17:30	60	-	-	-	-	-
17:45	60	-	-	-	-	-
18:00	60	-	-	-	-	-
18:15	60	-	-	-	-	-
18:30	60	-	-	-	-	-

Table 4.7. System Frequency after 2500 PHEVs penetration at Charging Level 1 with V2G Implementation

Charging Level 1 (1.4 kW)						
System Frequency With V2G Implementation (Hz) Charging Load = 2500 PHEVs						
Time (during peak load)	Number of V2G					
	0	200	400	600	800	1000
13:00	60	-	-	-	-	-
13:15	60	-	-	-	-	-
13:30	60	-	-	-	-	-
13:45	60	-	-	-	-	-
14:00	60	-	-	-	-	-
14:15	60	-	-	-	-	-
14:30	60	-	-	-	-	-
14:45	60	-	-	-	-	-
15:00	60	-	-	-	-	-
15:15	60	-	-	-	-	-
15:30	60	-	-	-	-	-
15:45	60	-	-	-	-	-
16:00	60	-	-	-	-	-
16:15	60	-	-	-	-	-
16:30	60	-	-	-	-	-
16:45	60	-	-	-	-	-
17:00	60	-	-	-	-	-
17:15	60	-	-	-	-	-
17:30	60	-	-	-	-	-
17:45	60	-	-	-	-	-
18:00	60	-	-	-	-	-
18:15	60	-	-	-	-	-
18:30	60	-	-	-	-	-

Table 4.8. System Frequency after 3000 PHEVs penetration at Charging Level 1 with V2G Implementation

Charging Level 1 (1.4 kW)						
System Frequency With V2G Implementation (Hz) Charging Load = 3000 PHEVs						
Time (during peak load)	Number of V2G					
	0	200	400	600	800	1000
13:00	60	-	-	-	-	-
13:15	60	-	-	-	-	-
13:30	60	-	-	-	-	-
13:45	60	-	-	-	-	-
14:00	60	-	-	-	-	-
14:15	60	-	-	-	-	-
14:30	60	-	-	-	-	-
14:45	60	-	-	-	-	-
15:00	60	-	-	-	-	-
15:15	60	-	-	-	-	-
15:30	60	-	-	-	-	-
15:45	60	-	-	-	-	-
16:00	60	-	-	-	-	-
16:15	60	-	-	-	-	-
16:30	60	-	-	-	-	-
16:45	60	-	-	-	-	-
17:00	60	-	-	-	-	-
17:15	60	-	-	-	-	-
17:30	60	-	-	-	-	-
17:45	60	-	-	-	-	-
18:00	60	-	-	-	-	-
18:15	60	-	-	-	-	-
18:30	60	-	-	-	-	-

4.3.2.2. Charging Level 2 (6.6 kW)

This section discussed the result of total residential load for 4 different number of PHEVs penetration with charging rate Level 2 and its charger power 6.6 kW. In addition, the sudden increase of residential load due to the charging load affects the system frequency of the micro grid. The result of the system frequency from MATLAB Simulink with and without implementation of V2G have been tabulated and explained in this section.

i. Total Residential Load

Figure 4.15. show the curve of the total residential load for 4 different PHEVs penetration with charging rate level 2 after the 24-hour PHEV charging load was added along with the normal 24-hour residential load. As what illustrated in Figure 4.15, the total load exceeds the normal load 10 MW. Moreover, it is found that the peak of the residential load caused by 4 different PHEVs penetration as charging load was about an hour 17:00 to 18:00. The percentage of load increment at peak hour for 1500, 2000, 2500 and 3000 PHEVs penetration are 14.31%, 19.60%, 24.35% and 29.81%. The percentage of load increment is rise as the total number of PHEV penetration is increase. This increment of total residential load will definitely effect the power system stability. The diesel generator needs to generate more power in order to balance the system and cause the frequency deviation occurs.

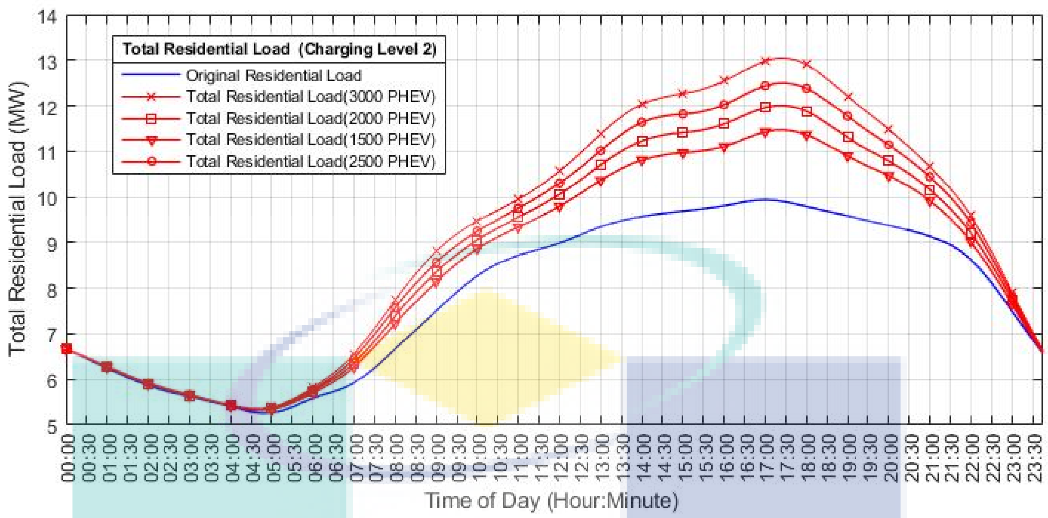


Figure 4.15. The total residential load for charging rate Level 2

ii. The impact to the system frequency

Table 4.9 to Table 4.12 show the result of the system frequency after the increment of residential load due to the 1500, 2000, 2500 and 3000 penetration of PHEV as charging load. The result was taken during the time of day where the load starts to exceed the normal residential load. As illustrated in the tables, the number of PHEV acts as V2G system were varied from zero which is the condition of system without the V2G implementation and have been increase until 1000 of PHEVs connected on V2G system.

By referring to Table 4.9 and Table 4.10, the system frequency for 4 PHEVs penetration were still normal. Therefore, there were no V2G implementation needed for case 1500 and 2000 penetration of PHEVs. In Table 4.11, the system frequency started to drop at time 17:00 until 18:30. The lowest system frequency drop cause by the sudden increase of residential load is 59.75 Hz or about -0.41% from the nominal system frequency. For country with nominal grid frequency of 60 Hz, the percentage of allowable frequency variation is +/- 1 percent.

Meanwhile, the system frequency for 3000 PHEVs penetration also drop from time 15:45 to 19:15 as illustrated in Table 4.12. The lowest system frequency drop is 59.60 Hz or about -0.67 % from the nominal system frequency. In the case of 2500 and

3000 PHEVs penetration as charging load, the grid frequency varied by -0.41% and -0.67% in which still below that -1% and it is acceptable. But, since the V2G system in the MATLAB SIMULINK will response to any frequency deviation, the system Grid Regulator Control will activate the V2G system to regulate the frequency. From 59.75 Hz and 59.60 Hz, both of the frequency was improved to 59.97 Hz with percentage of increment were 0.37% and 0.62%.

Table 4.9. System Frequency after 1500 PHEVs penetration at Charging Level 2 with V2G Implementation

Charging Level 2 (6.6 kW)						
System Frequency With V2G Implementation (Hz) Charging Load = 1500 PHEVs						
Time (during peak load)	Number of V2G					
	0	200	400	600	800	1000
13:30	60	-	-	-	-	-
13:45	60	-	-	-	-	-
14:00	60	-	-	-	-	-
14:15	60	-	-	-	-	-
14:30	60	-	-	-	-	-
14:45	60	-	-	-	-	-
15:00	60	-	-	-	-	-
15:15	60	-	-	-	-	-
15:30	60	-	-	-	-	-
15:45	60	-	-	-	-	-
16:00	60	-	-	-	-	-
16:15	60	-	-	-	-	-
16:30	60	-	-	-	-	-
16:45	60	-	-	-	-	-
17:00	60	-	-	-	-	-
17:15	60	-	-	-	-	-
17:30	60	-	-	-	-	-
17:45	60	-	-	-	-	-
18:00	60	-	-	-	-	-
18:15	60	-	-	-	-	-
18:30	60	-	-	-	-	-
18:45	60	-	-	-	-	-
19:00	60	-	-	-	-	-
19:15	60	-	-	-	-	-

Table 4.10. System Frequency after 2000 PHEVs penetration at Charging Level 2 with V2G Implementation

Charging Level 2 (6.6 kW)						
System Frequency With V2G Implementation (Hz) Charging Load = 2000 PHEVs						
Time (during peak load)	Number of V2G					
	0	200	400	600	800	1000
13:30	60	-	-	-	-	-
13:45	60	-	-	-	-	-
14:00	60	-	-	-	-	-
14:15	60	-	-	-	-	-
14:30	60	-	-	-	-	-
14:45	60	-	-	-	-	-
15:00	60	-	-	-	-	-
15:15	60	-	-	-	-	-
15:30	60	-	-	-	-	-
15:45	60	-	-	-	-	-
16:00	60	-	-	-	-	-
16:15	60	-	-	-	-	-
16:30	60	-	-	-	-	-
16:45	60	-	-	-	-	-
17:00	60	-	-	-	-	-
17:15	60	-	-	-	-	-
17:30	60	-	-	-	-	-
17:45	60	-	-	-	-	-
18:00	60	-	-	-	-	-
18:15	60	-	-	-	-	-
18:30	60	-	-	-	-	-
18:45	60	-	-	-	-	-
19:00	60	-	-	-	-	-
19:15	60	-	-	-	-	-

Table 4.11. System Frequency after 2500 PHEVs penetration at Charging Level 2 with V2G Implementation

Charging Level 2 (6.6 kW)						
System Frequency With V2G Implementation (Hz) Charging Load = 2500 PHEVs						
Time (during peak load)	Number of V2G					
	0	200	400	600	800	1000
13:30	60	60	60	60	60	60
13:45	60	60	60	60	60	60
14:00	60	60	60	60	60	60
14:15	60	60	60	60	60	60
14:30	60	60	60	60	60	60
14:45	60	60	60	60	60	60
15:00	60	60	60	60	60	60
15:15	60	60	60	60	60	60
15:30	60	60	60	60	60	60
15:45	60	60	60	60	60	60
16:00	60	60	60	60	60	60
16:15	60	60	60	60	60	60
16:30	60	60	60	60	60	60
16:45	60	60	60	60	60	60
17:00	59.79	60	60	60	60	60
17:15	59.75	59.99	59.99	60	59.97	59.97
17:30	59.75	59.97	59.97	59.97	59.97	59.97
17:45	59.76	59.97	59.97	59.97	59.97	59.97
18:00	59.8	59.97	59.97	59.97	59.97	59.97
18:15	59.84	59.97	59.97	59.97	59.97	59.97
18:30	59.87	59.99	59.99	59.99	59.99	59.99
18:45	60	60	60	60	60	60
19:00	60	60	60	60	60	60
19:15	60	60	60	60	60	60
19:30	60	60	60	60	60	60
19:45	60	60	60	60	60	60

Table 4.11. shows the system frequency after 2500 PHEVs penetration at Charging Level 2. The system frequency started to drop at time 17:00 until 18:30. After the implementation of V2G, the system frequency improved to 59.97 Hz.

Table 4.12. System Frequency after 3000 PHEVs penetration at Charging Level 2 with V2G Implementation

Charging Level 2 (6.6 kW)						
System Frequency With V2G Implementation (Hz) Charging Load = 3000 PHEVs						
Time (during peak load)	Number of V2G					
	0	200	400	600	800	1000
13:30	60	60	60	60	60	60
13:45	60	60	60	60	60	60
14:00	60	60	60	60	60	60
14:15	60	60	60	60	60	60
14:30	60	60	60	60	60	60
14:45	60	60	60	60	60	60
15:00	60	60	60	60	60	60
15:15	60	60	60	60	60	60
15:30	60	60	60	60	60	60
15:45	59.97	59.97	59.97	59.97	60	60
16:00	59.72	59.97	59.97	59.97	59.97	59.97
16:15	59.69	59.97	59.97	59.97	59.97	59.97
16:30	59.66	59.97	59.97	59.97	59.97	59.97
16:45	59.63	59.97	59.97	59.97	59.97	59.97
17:00	59.61	59.97	59.97	59.97	59.97	59.97
17:15	59.6	59.97	59.97	59.97	59.97	59.97
17:30	59.6	59.97	59.97	59.97	59.97	59.97
17:45	59.61	59.97	59.97	59.97	59.97	59.97
18:00	59.63	59.97	59.97	59.97	59.97	59.97
18:15	59.66	59.97	59.97	59.97	59.97	59.97
18:30	59.71	59.97	59.97	59.97	59.97	59.97
18:45	59.74	59.97	59.97	59.97	59.97	59.97
19:00	59.82	59.97	59.97	59.97	59.97	59.97
19:15	59.97	59.97	59.97	59.97	59.97	59.97
19:30	60	60	60	60	60	60
19:45	60	60	60	60	60	60

Table 4.12. shows the system frequency after 3000 PHEVs penetration at Charging Level 2. The system frequency started to drop at time 15:30 until 19:15. After the implementation of V2G, the system frequency improved to 59.97 Hz.

4.3.2.3. DC Fast Charging (25 kW)

This section discussed the result of total residential load for 4 different number of PHEVs penetration with DC Fast Charging and its charger power 25 kW. In addition, the sudden increase of residential load due to the charging load affects the system frequency of the micro grid. The result of the system frequency from MATLAB Simulink with and without implementation of V2G have been tabulated and explained in this section.

i. Total Residential Load

Figure 4.16. show the curve of the total residential load for 4 different PHEVs penetration with DC Fast Charging (25 kW) after the 24-hour PHEV charging load was added along with the normal 24-hour residential load. As what illustrated in Figure 4.16, the total load exceeds the normal load 10 MW. Moreover, it is found that the peak of the residential load caused by 4 different PHEVs penetration as charging load was about an hour 17:00. The percentage of load increment at peak hour for 1500, 2000, 2500 and 3000 PHEVs penetration are 25.47%, 34.02 %, 42.18 % and 51.16 %. The percentage of load increment is rise as the total number of PHEV penetration is increase. This increment of total residential load will definitely effect the power system stability. The diesel generator needs to generate more power in order to balance the system and cause the frequency deviation occurs.

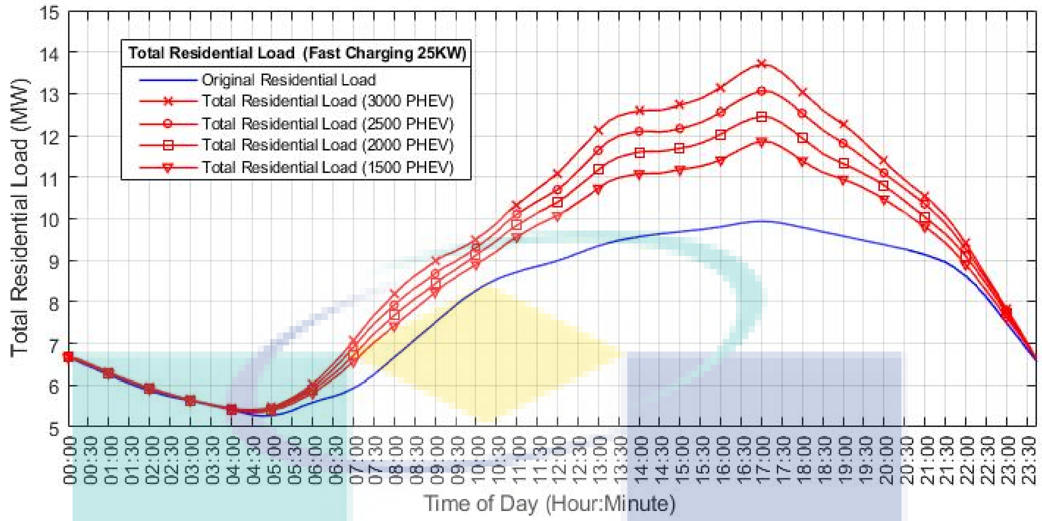


Figure 4.16. The total residential load for DC Fast Charging (25kW)

ii. The impact to the system frequency

Table 4.13 to Table 4.16 show the result of the system frequency after the increment of residential load due to the 1500, 2000, 2500 and 3000 penetration of PHEV as charging load. The result was taken during the time of day where the load starts to exceed the normal residential load. As illustrated in the tables, the number of PHEV acts as V2G system were varied from zero which is the condition of system without the V2G implementation and have been increase until 1000 of PHEVs connected on V2G system.

According to all tables, there were frequency deviation occurred resulting from the penetration of 1500, 2000, 2500 and 3000 PHEVs as charging load. In Table 4.13, the system frequency started to drop at time 16:45 until 17:45. The lowest system frequency drop cause by the sudden increase of residential load is 59.73 Hz or about -0.45% from the nominal system frequency. For country with nominal grid frequency of 60 Hz, the percentage of allowable frequency variation is +/- 1 percent.

Meanwhile, the system frequency for 2000 PHEVs penetration also drop from time 15:00 to 19:00 as illustrated in Table 4.14. The lowest system frequency drop is 59.52 Hz or about -0.8 % from the nominal system frequency which is occurred at hour 17:00. The frequency drop for case 1500 and 2000 PHEVs penetration were still below than 1% and it is acceptable. But, since the V2G system in the MATLAB SIMULINK will response to any frequency deviation, the system Grid Regulator Control will activate the V2G system to regulate the frequency.

Furthermore, the system frequency for 2500 PHEVs penetration drop from time 13:30 to 19:45 as illustrated in Table 4.15. The lowest system frequency drop is 59.38 Hz or about -1.033 % from the nominal system frequency which is occurred at hour 17:00. On the other hand, the system frequency for 3000 PHEVs penetration drop from time 13:00 to 20:00 as illustrated in Table 4.16. The lowest system frequency drop is 59.24 Hz or about -1.27 % from the nominal system frequency which is occurred at hour 17:00. From both Table 4.15 and 4.16, the duration of system frequency deviation occurred were longer compared to the previous table. Moreover, the system frequency for both table also exceed permitted frequency variation allowed which 1%. Hence, for 2500 and 3000 number of PHEVs penetration as charging load with DC Fast Charging (25kW) in micro grid system were quite worrying due to the significant impact to the system frequency. But, the V2G system has proved it credibility as frequency regulator and managed to improve the system frequency to 59.97 Hz for both cases.

Table 4.13. System Frequency after 1500 PHEVs penetration at DC Fast Charging (25 kW) with V2G Implementation

Fast Charging (25 KW)						
System Frequency With V2G Implementation (Hz) Charging Load = 1500 PHEVs						
Time (during peak load)	Number of V2G					
	0	200	400	600	800	1000
13:00	60	60	60	60	60	60
13:15	60	60	60	60	60	60
13:30	60	60	60	60	60	60
13:45	60	60	60	60	60	60
14:00	60	60	60	60	60	60
14:15	60	60	60	60	60	60
14:30	60	60	60	60	60	60
14:45	60	60	60	60	60	60
15:00	60	60	60	60	60	60
15:15	60	60	60	60	60	60
15:30	60	60	60	60	60	60
15:45	60	60	60	60	60	60
16:00	60	60	60	60	60	60
16:15	60	60	60	60	60	60
16:30	60	60	60	60	60	60
16:45	59.99	60	60	60	60	60
17:00	59.73	59.97	59.97	59.97	59.97	59.97
17:15	59.73	59.97	59.97	59.97	59.97	59.97
17:30	59.77	59.97	59.97	59.97	59.97	59.97
17:45	59.85	59.98	59.98	59.99	59.99	59.99
18:00	60	60	60	60	60	60
18:15	60	60	60	60	60	60
18:30	60	60	60	60	60	60
18:45	60	60	60	60	60	60
19:00	60	60	60	60	60	60
19:15	60	60	60	60	60	60
19:30	60	60	60	60	60	60

Table 4.13 shows system frequency after 1500 PHEVs penetration at DC Fast Charging (25 kW). The system frequency started to drop at time 16:45 until 17:45. After the implementation of V2G, the system frequency improved to 59.97 Hz.

Table 4.14. System Frequency after 2000 PHEVs penetration at DC Fast Charging (25 kW) with V2G Implementation

Fast Charging (25 KW)						
System Frequency With V2G Implementation (Hz) Charging Load = 2000 PHEVs						
Time (during peak load)	**Number of V2G**					
	0	200	400	600	800	1000
13:00	60	60	60	60	60	60
13:15	60	60	60	60	60	60
13:30	60	60	60	60	60	60
13:45	60	60	60	60	60	60
14:00	60	60	60	60	60	60
14:15	60	60	60	60	60	60
14:30	60	60	60	60	60	60
14:45	60	60	60	60	60	60
15:00	59.98	60	60	60	60	60
15:15	59.76	59.99	60	60	60	60
15:30	59.72	59.97	59.97	59.97	59.97	59.98
15:45	59.69	59.97	59.97	59.97	59.97	59.97
16:00	59.65	59.97	59.97	59.97	59.97	59.97
16:15	59.61	59.97	59.97	59.97	59.97	59.97
16:30	59.57	59.97	59.97	59.97	59.97	59.97
16:45	59.54	59.97	59.97	59.97	59.97	59.97
17:00	59.52	59.97	59.97	59.97	59.97	59.97
17:15	59.52	59.97	59.97	59.97	59.97	59.97
17:30	59.55	59.97	59.97	59.97	59.97	59.97
17:45	59.59	59.97	59.97	59.97	59.97	59.97
18:00	59.65	59.97	59.97	59.97	59.97	59.97
18:15	59.71	59.97	59.97	59.97	59.97	59.97
18:30	59.79	59.97	59.97	59.97	59.97	59.97
18:45	59.86	59.98	59.98	59.98	59.98	59.99
19:00	59.99	60	60	60	60	60
19:15	60	60	60	60	60	60
19:30	60	60	60	60	60	60

Table 4.14. shows system frequency after 2000 PHEVs penetration at DC Fast Charging (25 kW). The system frequency started to drop at time 15:00 until 19:00. After the implementation of V2G, the system frequency improved to 59.97 Hz.

Table 4.15. System Frequency after 2500 PHEVs penetration at DC Fast Charging (25 kW) with V2G Implementation

Fast Charging (25 KW)						
System Frequency With V2G Implementation (Hz) Charging Load = 2500 PHEVs						
Time (during peak load)	Number of V2G					
	0	200	400	600	800	1000
12:30	60	60	60	60	60	60
12:45	60	60	60	60	60	60
13:00	60	60	60	60	60	60
13:15	60	60	60	60	60	60
13:30	59.65	59.97	59.97	59.97	59.97	59.97
13:45	59.61	59.97	59.97	59.97	59.97	59.97
14:00	59.6	59.97	59.97	59.97	59.97	59.97
14:15	59.6	59.97	59.97	59.97	59.97	59.97
14:30	59.61	59.97	59.97	59.97	59.97	59.97
14:45	59.61	59.97	59.97	59.97	59.97	59.97
15:00	59.6	59.97	59.97	59.97	59.97	59.97
15:15	59.58	59.97	59.97	59.97	59.97	59.97
15:30	59.56	59.97	59.97	59.97	59.97	59.97
15:45	59.53	59.97	59.97	59.97	59.97	59.97
16:00	59.5	59.97	59.97	59.97	59.97	59.97
16:15	59.47	59.97	59.97	59.97	59.97	59.97
16:30	59.43	59.97	59.97	59.97	59.97	59.97
16:45	59.4	59.97	59.97	59.97	59.97	59.97
17:00	59.38	59.97	59.97	59.97	59.97	59.97
17:15	59.38	59.97	59.97	59.97	59.97	59.97
17:30	59.39	59.97	59.97	59.97	59.97	59.97
17:45	59.43	59.97	59.97	59.97	59.97	59.97
18:00	59.47	59.97	59.97	59.97	59.97	59.97
18:15	59.53	59.97	59.97	59.97	59.97	59.97
18:30	59.58	59.97	59.97	59.97	59.97	59.97
18:45	59.62	59.97	59.97	59.97	59.97	59.97
19:00	59.67	59.97	59.97	59.97	59.97	59.97
19:15	59.72	59.97	59.97	59.97	59.97	59.97
19:30	59.8	59.97	59.97	59.97	59.97	59.97
19:45	59.92	60	60	60	60	60
20:00	60	60	60	60	60	60
20:15	60	60	60	60	60	60

Table 4.15. shows system frequency after 2500 PHEVs penetration at DC Fast Charging (25 kW). The system frequency started to drop at time 13:30 until 19:45. After the implementation of V2G, the system frequency improved to 59.97 Hz.

Table 4.16. System Frequency after 3000 PHEVs penetration at DC Fast Charging (25 kW) with V2G Implementation

Fast Charging (25 KW)						
System Frequency With V2G Implementation (Hz) Charging Load = 3000 PHEV						
Time (during peak load)	Number of V2G					
	0	200	400	600	800	1000
12:30	60	60	60	60	60	60
12:45	60	60	60	60	60	60
13:00	59.61	59.97	59.97	59.97	59.97	59.97
13:15	59.53	59.97	59.97	59.97	59.97	59.97
13:30	59.48	59.97	59.97	59.97	59.97	59.97
13:45	59.46	59.97	59.97	59.97	59.97	59.97
14:00	59.45	59.97	59.97	59.97	59.97	59.97
14:15	59.45	59.97	59.97	59.97	59.97	59.97
14:30	59.45	59.97	59.97	59.97	59.97	59.97
14:45	59.45	59.97	59.97	59.97	59.97	59.97
15:00	59.44	59.97	59.97	59.97	59.97	59.97
15:15	59.43	59.97	59.97	59.97	59.97	59.97
15:30	59.42	59.97	59.97	59.97	59.97	59.97
15:45	59.4	59.97	59.97	59.97	59.97	59.97
16:00	59.38	59.97	59.97	59.97	59.97	59.97
16:15	59.34	59.97	59.97	59.97	59.97	59.97
16:30	59.3	59.97	59.97	59.97	59.97	59.97
16:45	59.27	59.97	59.97	59.97	59.97	59.97
17:00	59.24	59.97	59.97	59.97	59.97	59.97
17:15	59.24	59.97	59.97	59.97	59.97	59.97
17:30	59.26	59.97	59.97	59.97	59.97	59.97
17:45	59.3	59.97	59.97	59.97	59.97	59.97
18:00	59.35	59.97	59.97	59.97	59.97	59.97
18:15	59.4	59.97	59.97	59.97	59.97	59.97
18:30	59.45	59.97	59.97	59.97	59.97	59.97
18:45	59.5	59.97	59.97	59.97	59.97	59.97
19:00	59.53	59.97	59.97	59.97	59.97	59.97
19:15	59.58	59.97	59.97	59.97	59.97	59.97
19:30	59.63	59.97	59.97	59.97	59.97	59.97
19:45	59.71	59.97	59.97	59.97	59.97	59.97
20:00	59.81	59.97	59.97	59.97	59.97	59.97
20:15	60	60	60	60	60	60

Table 4.16. shows system frequency after 3000 PHEVs penetration at DC Fast Charging (25kW). The system frequency started to drop at time 13:00 until 20:00. After the implementation of V2G, the system frequency improved to 59.97 Hz.

4.3.2.4. DC Fast Charging (45 kW)

This section discussed the result of total residential load for 4 different number of PHEVs penetration with DC Fast Charging and its charger power 45 kW. In addition, the sudden increase of residential load due to the charging load affects the system frequency of the micro grid. The result of the system frequency from MATLAB Simulink with and without implementation of V2G have been tabulated and explained in this section.

i. Total Residential Load

Figure 4.17. show the curve of the total residential load for 4 different PHEVs penetration with DC Fast Charging (25 KW) after the 24-hour PHEV charging load was added along with the normal 24-hour residential load. As what illustrated in Figure 4.16, the total load exceeds the normal load 10MW. Moreover, it is found that the peak of the residential load caused by 4 different PHEVs penetration as charging load was about at hour 17:00. The percentage of load increment at peak hour for 1500, 2000, 2500 and 3000 PHEVs penetration are 33.94%, 44.62 %, 55.56 % and 66.74 %. The percentage of load increment is rise as the total number of PHEV penetration is increase. This increment of total residential load will definitely effect the power system stability. The diesel generator needs to generate more power in order to balance the system and cause the frequency deviation occurs.

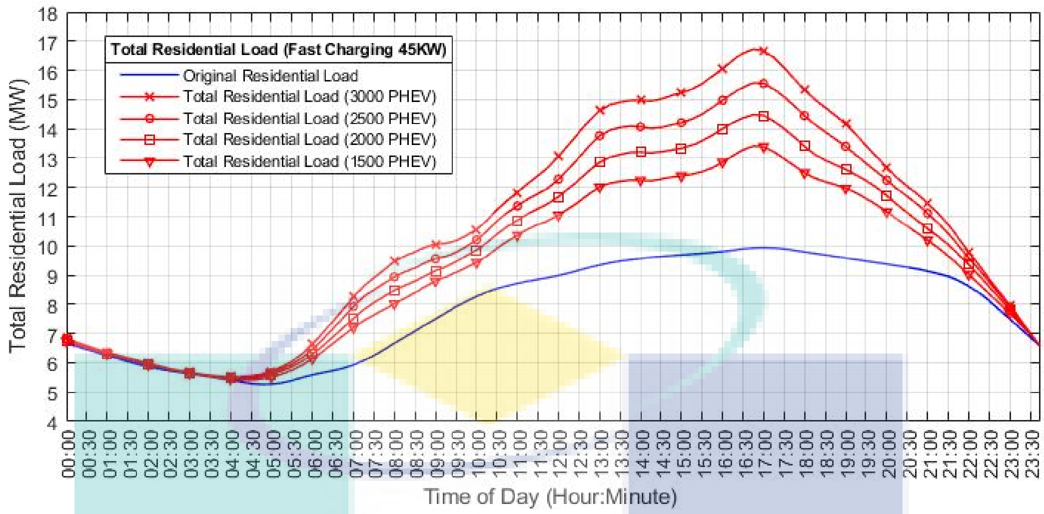


Figure 4.17. The total residential load for DC Fast Charging (45kW)

ii. The impact to the system frequency

Table 4.17 to Table 4.20 below show the result of the system frequency after the increment of residential load due to the 1500, 2000, 2500 and 3000 penetration of PHEV as charging load. The result was taken during the time of day where the load starts to exceed the normal residential load. As illustrated in the tables, the number of PHEV acts as V2G system were varied from zero which is the condition of system without the V2G implementation and have been increase until 1000 of PHEVs connected on V2G system.

According to all tables, there were frequency deviation occurred resulting from the penetration of 1500, 2000, 2500 and 3000 PHEVs as charging load. In Table 4.17, the system frequency started to drop at time 15:15 until 18:45. The lowest system frequency drop cause by the sudden increase of residential load is 59.52 Hz or about -0.80% from the nominal system frequency. For country with nominal grid frequency of 60 Hz, the percentage of allowable frequency variation is +/- 1 percent. The frequency drop for case 1500 PHEVs penetration were still below than 1% and it is acceptable. But, since the V2G system in the MATLAB SIMULINK will response to any frequency deviation, the system Grid Regulator Control will activate the V2G system to regulate the frequency

Meanwhile, the system frequency for 2000 PHEVs penetration also drop from time 13:15 to 19:30 as illustrated in Table 4.18. The lowest system frequency drop is 59.34 Hz or about -1.1 % from the nominal system frequency which is occurred at hour 16:45 to 17:00. Furthermore, the system frequency for 2500 PHEVs penetration drop from time 12:30 to 20:00 as illustrated in Table 4.19. The lowest system frequency drop is 59.18 Hz or about -1.37 % from the nominal system frequency which is occurred at hour 16:45 to 17:00. On the other hand, the system frequency for 3000 PHEVs penetration drop from time 12:00 to 20:15 as illustrated in Table 4.20. The lowest system frequency drop is 59.01 Hz or about -1.65 % from the nominal system frequency which is occurred at hour 17:00.

From Table 4.18, 4.19 and 4.20, the duration of system frequency deviation occurred were longer compared to the previous table. Moreover, the system frequency for both table also exceed permitted frequency variation allowed which 1%. Hence, for 2000, 2500 and 3000 number of PHEVs penetration as charging load with DC Fast Charging (45kW) in micro grid system were quite worrying due to the significant impact to the system frequency. But, the V2G system has proved it credibility as frequency regulator and managed to improve the system frequency to 59.97 Hz for both cases.

Table 4.17. System Frequency after 1500 PHEVs penetration at DC Fast Charging (45 kW) with V2G Implementation

Fast Charging (45 kW)						
System Frequency With V2G Implementation (Hz) Charging Load = 1500 PHEVs						
Time (during peak load)	Number of V2G					
	0	200	400	600	800	1000
12:30	60	60	60	60	60	60
12:45	60	60	60	60	60	60
13:00	60	60	60	60	60	60
13:15	60	60	60	60	60	60
13:30	60	60	60	60	60	60
13:45	60	60	60	60	60	60
14:00	60	60	60	60	60	60
14:15	60	60	60	60	60	60
14:30	60	60	60	60	60	60
14:45	60	60	60	60	60	60
15:00	60	60	60	60	60	60
15:15	59.98	60	60	60	60	60
15:30	59.73	59.97	59.97	59.97	59.97	59.97
15:45	59.69	59.97	59.97	59.97	59.97	59.97
16:00	59.64	59.97	59.97	59.97	59.97	59.97
16:15	59.59	59.97	59.97	59.97	59.97	59.97
16:30	59.55	59.97	59.97	59.97	59.97	59.97
16:45	59.52	59.97	59.97	59.97	59.97	59.97
17:00	59.52	59.97	59.97	59.97	59.97	59.97
17:15	59.56	59.97	59.97	59.97	59.97	59.97
17:30	59.61	59.97	59.97	59.97	59.97	59.97
17:45	59.68	59.97	59.97	59.97	59.97	59.97
18:00	59.75	59.97	59.97	59.97	59.97	59.97
18:15	59.81	59.97	59.97	59.97	59.97	59.97
18:30	59.86	60	60	60	60	60
18:45	59.94	60	60	60	60	60
19:00	60	60	60	60	60	60
19:15	60	60	60	60	60	60
19:30	60	60	60	60	60	60
19:45	60	60	60	60	60	60
20:00	60	60	60	60	60	60
20:15	60	60	60	60	60	60

Table 4.17. shows system frequency after 1500 PHEVs penetration at DC Fast Charging (45 kW). The system frequency started to drop at time 15:15 until 18:45. After the implementation of V2G, the system frequency was improved to 59.97 Hz

Table 4.18. System Frequency after 2000 PHEVs penetration at DC Fast Charging (45 kW) with V2G Implementation

Fast Charging (45 kW)						
System Frequency With V2G Implementation (Hz) Charging Load = 2000 PHEVs						
Time (during peak load)	Number of V2G					
	0	200	400	600	800	1000
12:30	60	60	60	60	60	60
12:45	60	60	60	60	60	60
13:00	60	60	60	60	60	60
13:15	59.72	59.97	59.97	59.97	59.97	59.97
13:30	59.59	59.97	59.97	59.97	59.97	59.97
13:45	59.57	59.97	59.97	59.97	59.97	59.97
14:00	59.56	59.97	59.97	59.97	59.97	59.97
14:15	59.57	59.97	59.97	59.97	59.97	59.97
14:30	59.56	59.97	59.97	59.97	59.97	59.97
14:45	59.55	59.97	59.97	59.97	59.97	59.97
15:00	59.54	59.97	59.97	59.97	59.97	59.97
15:15	59.52	59.97	59.97	59.97	59.97	59.97
15:30	59.48	59.97	59.97	59.97	59.97	59.97
15:45	59.46	59.97	59.97	59.97	59.97	59.97
16:00	59.43	59.97	59.97	59.97	59.97	59.97
16:15	59.39	59.97	59.97	59.97	59.97	59.97
16:30	59.36	59.97	59.97	59.97	59.97	59.97
16:45	59.34	59.97	59.97	59.97	59.97	59.97
17:00	59.34	59.97	59.97	59.97	59.97	59.97
17:15	59.37	59.97	59.97	59.97	59.97	59.97
17:30	59.41	59.97	59.97	59.97	59.97	59.97
17:45	59.46	59.97	59.97	59.97	59.97	59.97
18:00	59.52	59.97	59.97	59.97	59.97	59.97
18:15	59.58	59.97	59.97	59.97	59.97	59.97
18:30	59.62	59.97	59.97	59.97	59.97	59.97
18:45	59.66	59.97	59.97	59.97	59.97	59.97
19:00	59.69	59.97	59.97	59.97	59.97	59.97
19:15	59.75	59.97	59.97	59.97	59.97	59.97
19:30	59.82	59.97	59.97	59.97	59.97	59.97
19:45	59.99	60	60	60	60	60
20:00	60	60	60	60	60	60
20:15	60	60	60	60	60	60

Table 4.18. shows system frequency after 1500 PHEVs penetration at DC Fast Charging (45 kW). The system frequency started to drop at time 13:15 until 19:45. After the implementation of V2G, the system frequency was improved to 59.97 Hz.

Table 4.19. System Frequency after 2500 PHEVs penetration at DC Fast Charging (45 kW) with V2G Implementation

Fast Charging (45 kW)						
System Frequency With V2G Implementation (Hz) Charging Load = 2500 PHEVs						
Time (during peak load)	Number of V2G					
	0	200	400	600	800	1000
11:45	60	60	60	60	60	60
12:00	60	60	60	60	60	60
12:15	60	60	60	60	60	60
12:30	59.78	59.97	59.97	59.97	59.97	59.97
12:45	59.52	59.97	59.97	59.97	59.97	59.97
13:00	59.43	59.97	59.97	59.97	59.97	59.97
13:15	59.4	59.97	59.97	59.97	59.97	59.97
13:30	59.38	59.97	59.97	59.97	59.97	59.97
13:45	59.38	59.97	59.97	59.97	59.97	59.97
14:00	59.38	59.97	59.97	59.97	59.97	59.97
14:15	59.4	59.97	59.97	59.97	59.97	59.97
14:30	59.4	59.97	59.97	59.97	59.97	59.97
14:45	59.39	59.97	59.97	59.97	59.97	59.97
15:00	59.38	59.97	59.97	59.97	59.97	59.97
15:15	59.36	59.97	59.97	59.97	59.97	59.97
15:30	59.34	59.97	59.97	59.97	59.97	59.97
15:45	59.31	59.97	59.97	59.97	59.97	59.97
16:00	59.28	59.97	59.97	59.97	59.97	59.97
16:15	59.25	59.97	59.97	59.97	59.97	59.97
16:30	59.21	59.97	59.97	59.97	59.97	59.97
16:45	59.18	59.97	59.97	59.97	59.97	59.97
17:00	59.18	59.97	59.97	59.97	59.97	59.97
17:15	59.21	59.97	59.97	59.97	59.97	59.97
17:30	59.24	59.97	59.97	59.97	59.97	59.97
17:45	59.29	59.97	59.97	59.97	59.97	59.97
18:00	59.37	59.97	59.97	59.97	59.97	59.97
18:15	59.39	59.97	59.97	59.97	59.97	59.97
18:30	59.44	59.97	59.97	59.97	59.97	59.97
18:45	59.48	59.97	59.97	59.97	59.97	59.97
19:00	59.53	59.97	59.97	59.97	59.97	59.97
19:15	59.58	59.97	59.97	59.97	59.97	59.97
19:30	59.64	59.97	59.97	59.97	59.97	59.97
19:45	59.72	59.97	59.97	59.97	59.97	59.97
20:00	59.82	59.97	59.97	59.97	59.97	59.97
20:15	60	60	60	60	60	60
20:30	60	60	60	60	60	60
20:45	60	60	60	60	60	60
21:00	60	60	60	60	60	60

Table 4.19. shows system frequency after 2500 PHEVs penetration at DC Fast Charging (45 kW). The system frequency started to drop at time 12:30 until 20:00. After the implementation of V2G, the system frequency was improved to 59.97 Hz

Table 4.20. System Frequency after 3000 PHEVs penetration at DC Fast Charging (45 kW) with V2G Implementation

Fast Charging (45 kW)						
System Frequency With V2G Implementation (Hz) Charging Load = 3000 PHEVs						
Time (during peak load)	Number of V2G					
	0	200	400	600	800	1000
11:45	60	60	60	60	60	60
12:00	59.91	59.97	60	59.97	60	59.97
12:15	59.51	59.97	59.97	59.97	59.97	59.97
12:30	59.41	59.97	59.97	59.97	59.97	59.97
12:45	59.33	59.97	59.97	59.97	59.97	59.97
13:00	59.26	59.97	59.97	59.97	59.97	59.97
13:15	59.24	59.97	59.97	59.97	59.97	59.97
13:30	59.23	59.97	59.97	59.97	59.97	59.97
13:45	59.23	59.97	59.97	59.97	59.97	59.97
14:00	59.23	59.97	59.97	59.97	59.97	59.97
14:15	59.24	59.97	59.97	59.97	59.97	59.97
14:30	59.24	59.97	59.97	59.97	59.97	59.97
14:45	59.23	59.97	59.97	59.97	59.97	59.97
15:00	59.23	59.97	59.97	59.97	59.97	59.97
15:15	59.21	59.97	59.97	59.97	59.97	59.97
15:30	59.19	59.97	59.97	59.97	59.97	59.97
15:45	59.16	59.97	59.97	59.97	59.97	59.97
16:00	59.31	59.97	59.97	59.97	59.97	59.97
16:15	59.35	59.97	59.97	59.97	59.97	59.97
16:30	59.32	59.97	59.97	59.97	59.97	59.97
16:45	59.16	59.97	59.97	59.97	59.97	59.97
17:00	59.01	59.97	59.97	59.97	59.97	59.97
17:15	59.05	59.97	59.97	59.97	59.97	59.97
17:30	59.1	59.97	59.97	59.97	59.97	59.97
17:45	59.16	59.97	59.97	59.97	59.97	59.97
18:00	59.21	59.97	59.97	59.97	59.97	59.97
18:15	59.27	59.97	59.97	59.97	59.97	59.97
18:30	59.31	59.97	59.97	59.97	59.97	59.97
18:45	59.36	59.97	59.97	59.97	59.97	59.97
19:00	59.4	59.97	59.97	59.97	59.97	59.97
19:15	59.46	59.97	59.97	59.97	59.97	59.97
19:30	59.52	59.97	59.97	59.97	59.97	59.97
19:45	59.59	59.97	59.97	59.97	59.97	59.97
20:00	59.68	59.97	59.97	59.97	59.97	59.97
20:15	59.79	59.97	59.97	59.97	59.97	59.97
20:30	60	60	60	60	60	60
20:45	60	60	60	60	60	60
21:00	60	60	60	60	60	60

Table 4.20. shows system frequency after 3000 PHEVs penetration at DC Fast Charging (45 kW). The system frequency started to drop at time 12:00 until 20:15. After the implementation of V2G, the system frequency was improved to 59.97 Hz.

4.3.3. Analysis Summary for Case Study 1

Table 4.21 shows the summary table percentages increment of total residential load at peak hour 5 P.M for 4 different number of PHEV penetration and with 4 different type of charging level. The percentages increment of total residential was rise as the number of PHEV rise as well as the charging rate level. From the previous result at section 4.3.2, it shows that for all number of PHEVs penetration with charging level 1, there was no any frequency deviation occurred. Not only that, for case 1500 and 2000 PHEVs penetration with charging level 2, the system frequency was still normal even though with the added of charging load. By referring to Table 4.21, the percentages of peak load increment for these cases was below than 20%. Hence, for increment of residential load that below than 20%, the system frequency was still normal and did not require any V2G implementation. On the other hand, if the residential load exceeds 20% from its normal load, the system frequency need to be regulate by the Vehicle-to-grid system.

Figure 4.18 show the result of V2G regulation load from the MATLAB Simulink. V2G regulation load is the total amount of power from the PHEVs that have been used to regulate the system frequency. The higher the amount of frequency drop, the more regulation load from the V2G needed. Figure 4.19 to 4.22 show the simulation result of system frequency of 3000 PHEVs penetration for 4 different type of charging rate and with and without the implementation of V2G system. As what have been discussed before, the system frequency for PHEVs penetration at charging rate level 1 was normal. The duration of system frequency deviation occurred was depended on the PHEV charging load. The time at which the total residential load exceeds 20% from the normal load, was the time of system frequency started to deviate. While, Figure 4.23 illustrate the Bar Graph of the percentage of frequency improved after V2G system Implementation during peak hour. According to the Bar Graph, the percentage of frequency improvement increased as the charger power increased.

Table 4.21. Percentages increment of total residential load at peak hour 5 P.M for 4 different number of PHEV penetration and with 4 different type of charging level

PERCENTAGES OF PEAK RESIDENTIAL LOAD INCREASED (during 5 P.M.)				
Charging Rate Level	**Number of PHEV Penetration**			
	1500	**2000**	**2500**	**3000**
Charging Level 1 (1.4kw)	7.76 %	10.82 %	13.60 %	16.55 %
Charging Level 2 (6.6kw)	14.3 %	19.60 %	24.35 %	29.81 %
DC Fast Charging (25kw)	25.47 %	34.02 %	42.18 %	51.16 %
DC Fast Charging (45kw)	33.94 %	44.62 %	55.56 %	66.74 %

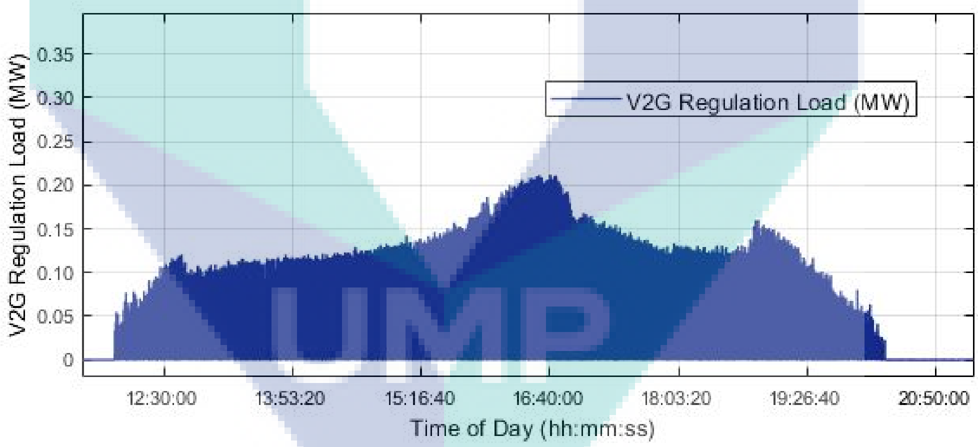


Figure 4.18 Vehicle-to-Grid Regulation Load

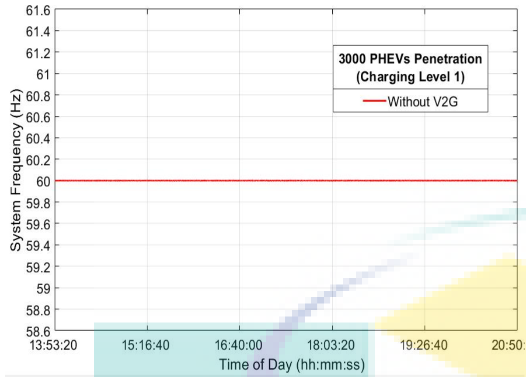


Figure 4.19. System frequency of 3000 PHEVs penetration with charging level 1

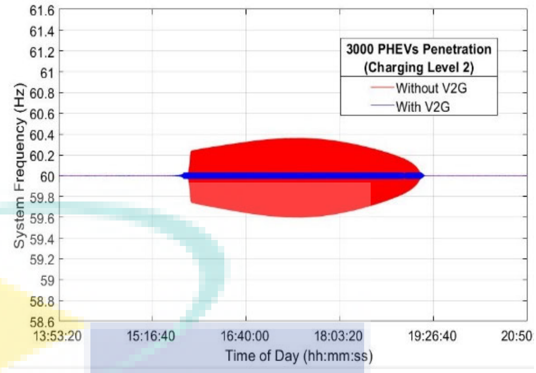


Figure 4.20. System frequency of 3000 PHEVs penetration with charging level 2

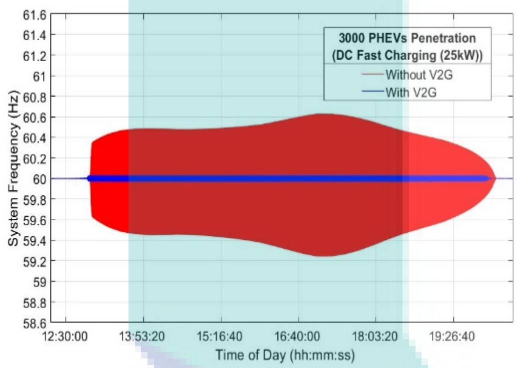


Figure 4.21. System frequency of 3000 PHEVs penetration with DC Fast Charging (25kW)

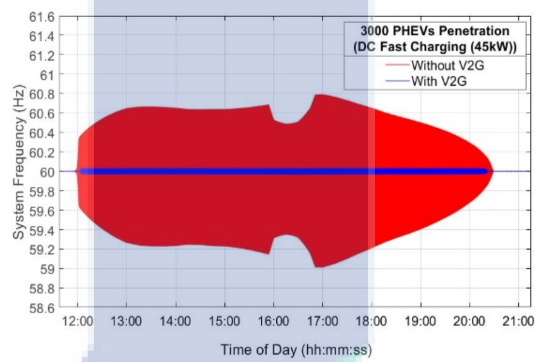


Figure 4.22. System frequency of 3000 PHEVs penetration with DC Fast Charging (45kW)

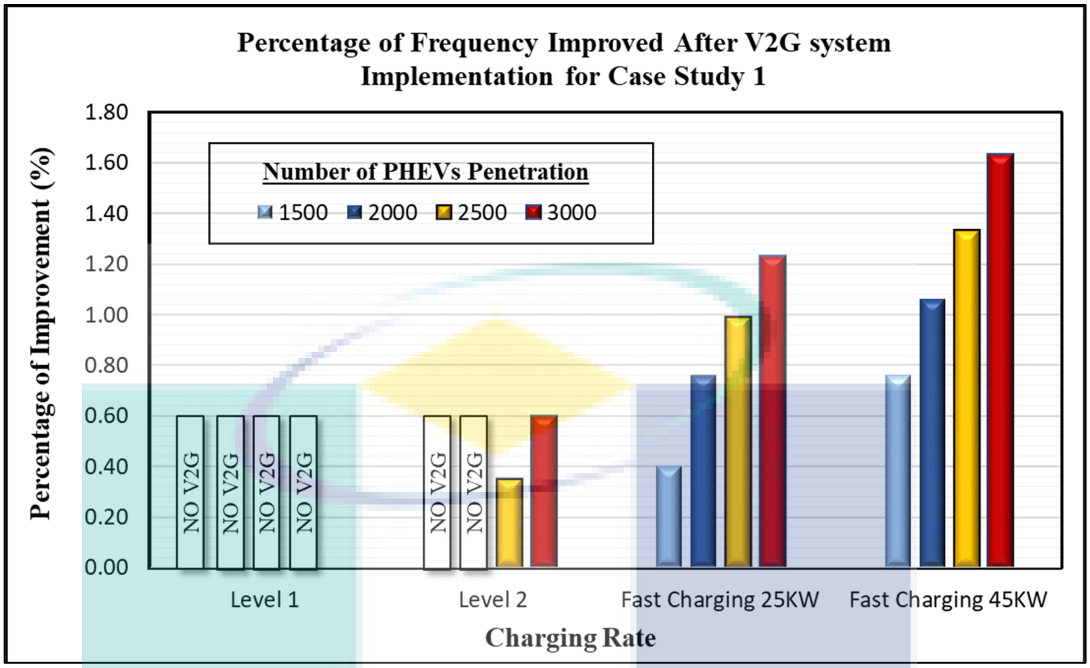


Figure 4.23 The Bar graph of the percentage of frequency improved after V2G system Implementation during peak hour

4.4. Case Study 2: Disturbances in the Micro Grid Power System Network

In 24-hour Simulation of a Vehicle-to-Grid (V2G) System, there are 3 types of disturbances that have been simulated, which directly affect each of the 3 generators in the electrical network respectively to different times of the day. Each of the disturbances will expose in the following items.

a) The starting of the asynchronous machine in the initial of the third hour

b) A partial shading at noon influencing the production of solar power

c) A wind farm trip at 22 hours if the wind exceeds the maximum permitted wind power

The impacts of these disturbance to the system frequency have been analyzed and the result are as follows:

4.4.1. The Starting of the Asynchronous Machine in the Initial of the Third Hour

For this case, the starting of the asynchronous machine was set at 3 a.m. in the Mat Lab simulation. The motor will draw a very high initial current, if the motor is switched on directly from the main supply. The current at start up is basically between five and seven times from what the motor normally draws at full load. The impact of the system's frequency is evaluated when different number of PHEVs are used in V2G system with 4 different type of charging rate.

Table 4.22. shows the tabulated results of the system frequency caused by starting of the Asynchronous Machine in the initial of the third hour. The minimum frequency reached when the disturbance occurred was 59.93Hz or with percentage drop -0.12% from nominal system frequency while the maximum frequency reached was 60.05 Hz or with percentage 0.08%. Different number of PHEVs connected to the V2G system with 4 different type of charger power was implemented to evaluate the performance of V2G as frequency regulator and the results was tabulated in Table 4.22. Since the impact of the starting of asynchronous was not too severe, there were just small of amount of

frequency that need to be regulated. Table 4.23 shows the results of percentage improvement of frequency after implementation of V2G. Even though there were different number of PHEVs connected to V2G System and with different types of charger power, the maximum percentage of frequency improved for the lower limit was only 0.05% while for the upper limit was 0.07%. For country with nominal grid frequency of 60 Hz, the percentage of allowable frequency variation is +/- 1 percent. The percentage of frequency variation caused by the disturbance was still below that -1% and it is acceptable. But, since the V2G system in the MATLAB SIMULINK will response to any frequency deviation, the system Grid Regulator Control will activate the V2G system to regulate the frequency.

Table 4.22. Results of the impact of starting of the asynchronous machine to system frequency with and without implementation of V2G

Asynchronies Machine Disturbance			
Charging Rate Level	**Number of V2G**	**Minimum Frequency reached (Hz)**	**Maximum Frequency reached (Hz)**
NO V2G		59.93	60.05
Level 1	100	59.95	60.02
	200	59.96	60.01
	400	59.96	60.01
	600	59.96	60.01
	800	59.96	60.01
Level 2	100	59.96	60.01
	200	59.96	60.01
	400	59.96	60.01
	600	59.96	60.01
	800	59.96	60.01
Fast Charging (25KW)	100	59.96	60.01
	200	59.96	60.01
	400	59.96	60.01
	600	59.96	60.01
	800	59.96	60.01
Fast Charging (45KW)	100	59.96	60.01
	200	59.96	60.01
	400	59.96	60.01
	600	59.96	60.01
	800	59.96	60.01

Table 4.23. Percentage improvement of frequency after implementation of V2G

Asynchronies Machine Disturbance			
Charging Rate Level	**Number of V2G**	**Frequency Improved for the Lower Limit (%)**	**Frequency decreased for the Upper Limit (%)**
Level 1	100	0.03	0.05
	200	0.05	0.07
	400	0.05	0.07
	600	0.05	0.07
	800	0.05	0.07
Level 2	100	0.05	0.07
	200	0.05	0.07
	400	0.05	0.07
	600	0.05	0.07
	800	0.05	0.07
Fast Charging (25KW)	100	0.05	0.07
	200	0.05	0.07
	400	0.05	0.07
	600	0.05	0.07
	800	0.05	0.07
Fast Charging (45KW)	100	0.05	0.07
	200	0.05	0.07
	400	0.05	0.07
	600	0.05	0.07
	800	0.05	0.07

The waveform of system frequency during Starting of the Asynchronous Machine event at 3 A.M with different number of PHEVs connected to V2G System and with different type of charging rate level were illustrated in Figure 4.24 to 4.27. From these waveform, it clearly shown that, the system frequency was improved after the implementation of V2G system. Different type of charging rate level contributed to different discharging power for the PHEVs to supply back its electrical energy to the grid. Furthermore, for DC Fast charging, the time taken required for the V2G to obtain the full capacity of power from the PHEV is shorter than charging level 1. Hence. the transitory time of the system frequency deviation also shorter. Moreover, the duration for the charger to fulfil the battery State of Charge (SOC) back to 100% are faster.

a) Charging Level 1 (1.4 kW)

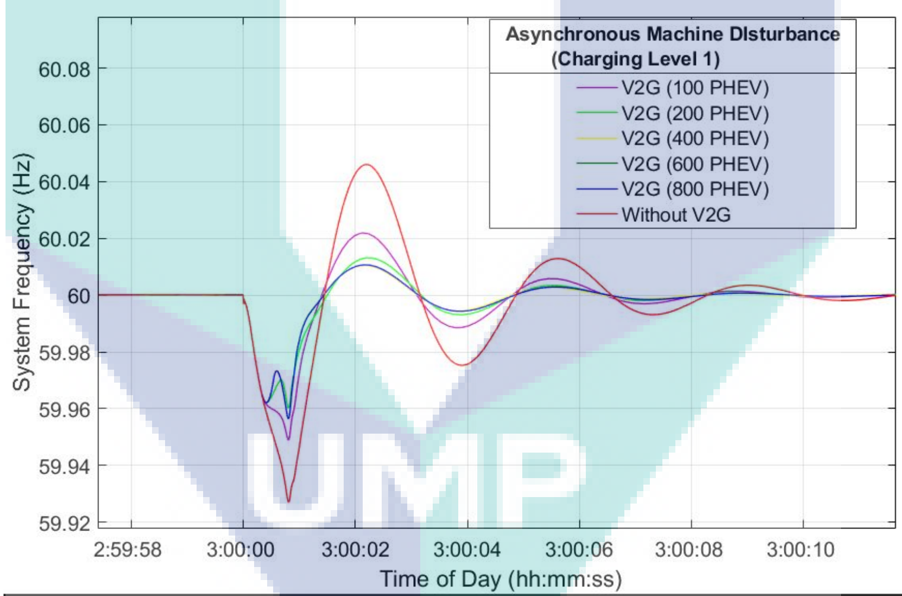


Figure 4.24. The system frequency during Starting of the Asynchronous Machine event with different number of PHEVs connected in V2G and with charging rate Level 1

b) Charging Level 2 (6.6 kW)

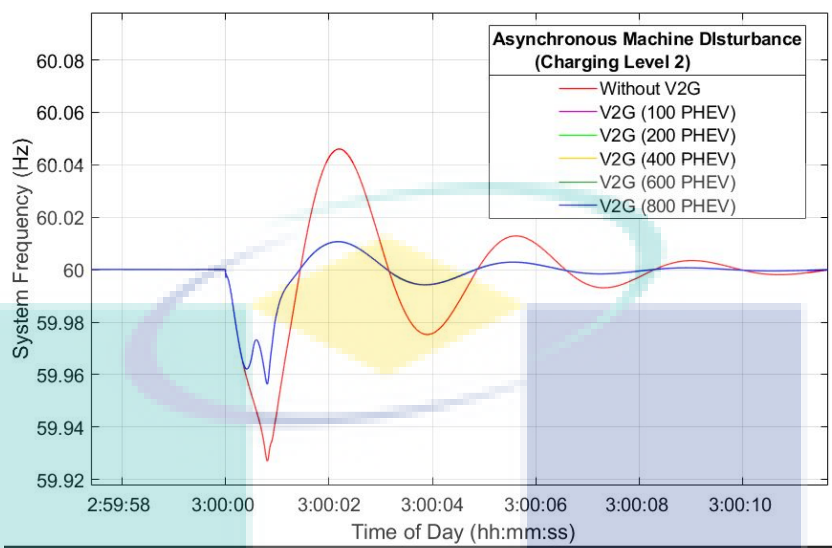


Figure 4.25. The system frequency during Starting of the Asynchronous Machine event with different number of PHEVs connected in V2G and with charging rate Level 2

c) DC Fast Charging (25 kW)

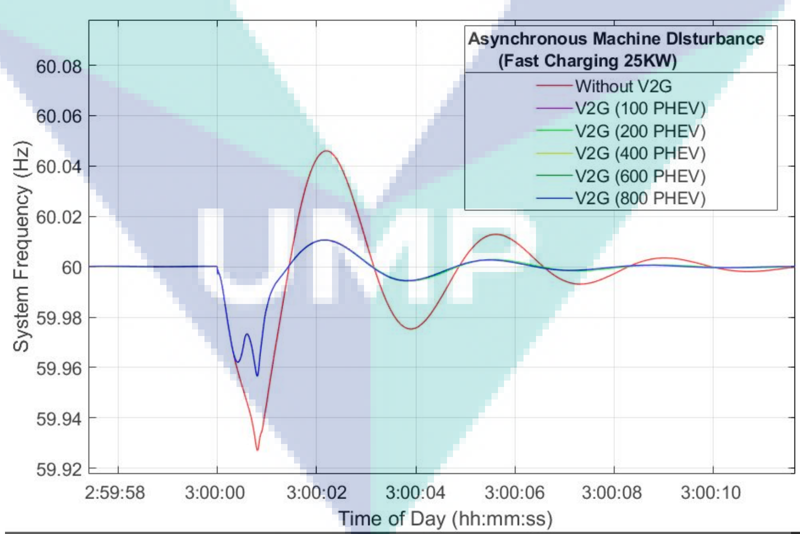


Figure 4.26. The system frequency during Starting of the Asynchronous Machine event with different number of PHEVs connected in V2G and with DC Fast Charging (25 kW)

d) DC Fast Charging (45 kW)

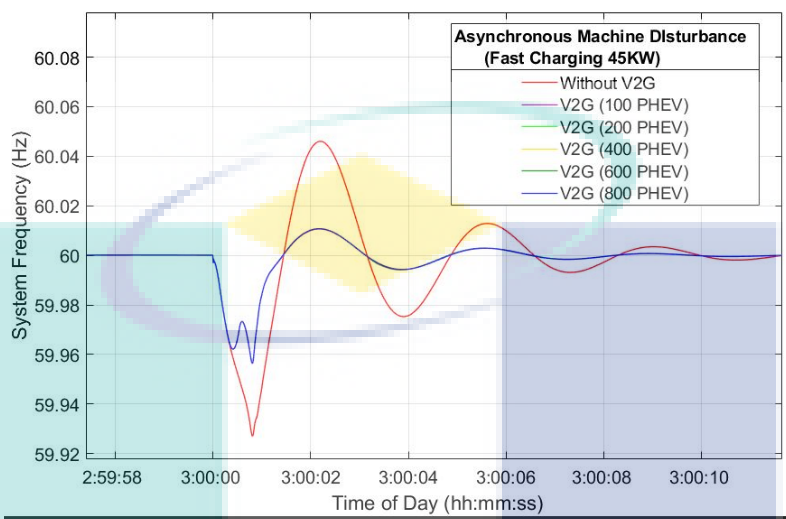


Figure 4.27. The system frequency during Starting of the Asynchronous Machine event with different number of PHEVs connected in V2G and with DC Fast Charging (45 kW)

4.4.2. A Partial Shading at Noon Influencing the Production of Solar Power

The partial shading (signal disturbance) of the PV Farm represents the reduction factor which is the fraction of the PV Farm's output. For this case, the nominal PV output cause by the partial shading was reduced to 0.7. The event starts at 12 noon and the duration of the partial shading event was set for 5 minutes. The impact of the system's frequency is evaluated when different number of PHEV are used in V2G system with 4 different charging rate. During the fractional shading event, the PV Farm output power was reduced to 70% from its nominal rated power. Hence, the Diesel Generator that act as base generator need to generate more power in order to balance the generating supply and the demand. This will influent sudden change of rotor speed and resulting the frequency to deviate.

Table 4.24. shows the tabulated results of the system frequency caused by the fractional shading of PV Solar Farm at noon. The minimum frequency reached when the disturbance occurred was 59.74 Hz or with percentage drop -0.43% from nominal system frequency while the maximum frequency reached was 60.27 Hz or with percentage 0.45%. Different number of PHEVs connected to the V2G system with 4 different type of charger power was implemented to evaluate the performance of V2G as frequency regulator and the results was tabulated in Table 4.24. The impact of the fractional shading of PV Solar Farm was more severe than the impact of the starting of asynchronous.

Table 4.25 shows the results of percentages improvement of frequency after implementation of V2G. As the number of PHEVs connected to the V2G system increased, the percentage improvement of the system frequency also increased. According to the table 4.25, the maximum percentage of frequency improved for the lower limit was only 0.23% while for the upper limit was 0.27%. For country with nominal grid frequency of 60 Hz, the percentage of allowable frequency variation is +/- 1 percent. The percentage of frequency variation caused by the disturbance was still below that -1% and it is acceptable. But, since the V2G system in the MATLAB SIMULINK will response to any frequency deviation, the system Grid Regulator Control will activate the V2G system to regulate the frequency.

Table 4.24. Results of the partial shading at noon influencing the production of solar power to the system frequency with and without implementation of V2G

Solar Farm Disturbance			
Charging Rate Level	**Number of V2G**	**Minimum Frequency reached (Hz)**	**Maximum Frequency reached (Hz)**
NO V2G		59.74	60.27
Level 1	100	59.77	60.24
	200	59.79	60.21
	400	59.84	60.16
	600	59.87	60.12
	800	59.88	60.12
Level 2	100	59.85	60.15
	200	59.88	60.11
	400	59.88	60.11
	600	59.88	60.11
	800	59.88	60.11
Fast Charging (25KW)	100	59.88	60.11
	200	59.88	60.11
	400	59.88	60.11
	600	59.88	60.11
	800	59.89	60.11
Fast Charging (45KW)	100	59.88	60.11
	200	59.88	60.11
	400	59.88	60.11
	600	59.88	60.11
	800	59.89	60.11

Table 4.25. Percentage improved of frequency to nominal value after implementation of V2G

Solar Farm Disturbance			
Charging Rate Level	**Number of V2G**	**Frequency Improved for the Lower Limit (%)**	**Frequency decreased for the Upper Limit (%)**
Level 1	100	0.05	0.05
	200	0.08	0.10
	400	0.17	0.18
	600	0.22	0.25
	800	0.23	0.25
Level 2	100	0.18	0.20
	200	0.23	0.27
	400	0.23	0.27
	600	0.23	0.27
	800	0.23	0.27
Fast Charging (25KW)	100	0.23	0.27
	200	0.23	0.27
	400	0.23	0.27
	600	0.23	0.27
	800	0.25	0.27
Fast Charging (45KW)	100	0.23	0.27
	200	0.23	0.27
	400	0.23	0.27
	600	0.23	0.27
	800	0.25	0.27

The waveform of system frequency during fractional shading of PV Solar Farm event at noon with different number of PHEVs connected to V2G System and with different type of charging rate level were illustrated in Figure 4.28 to 4.31. From these waveform, it clearly shown that, the system frequency was improved after the implementation of V2G system. Different type of charging rate level contributed to different discharging power for the PHEVs to supply back its electrical energy to the grid. Furthermore, for DC Fast charging, the time taken required for the V2G to obtain the full capacity of power from the PHEV is shorter than charging level 1. Hence. the transitory time of the system frequency deviation also shorter. Moreover, the duration for the charger to fulfil the battery State of Charge (SOC) back to 100% are faster.

a) Charging Level 1 (1.4 kW)

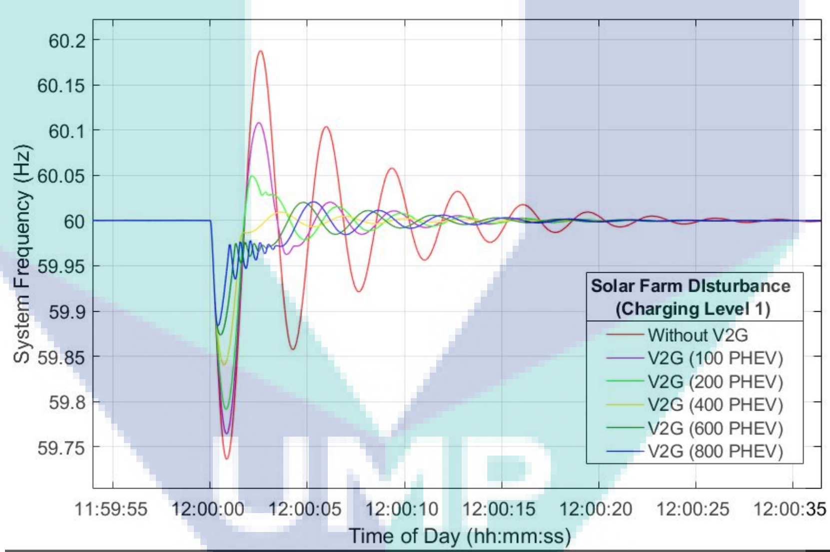


Figure 4.28. The system frequency during PV Farm fractional shading event with different number of PHEVs connected in V2G and with charging rate Level 1

b) Charging Level 2 (6.6 kW)

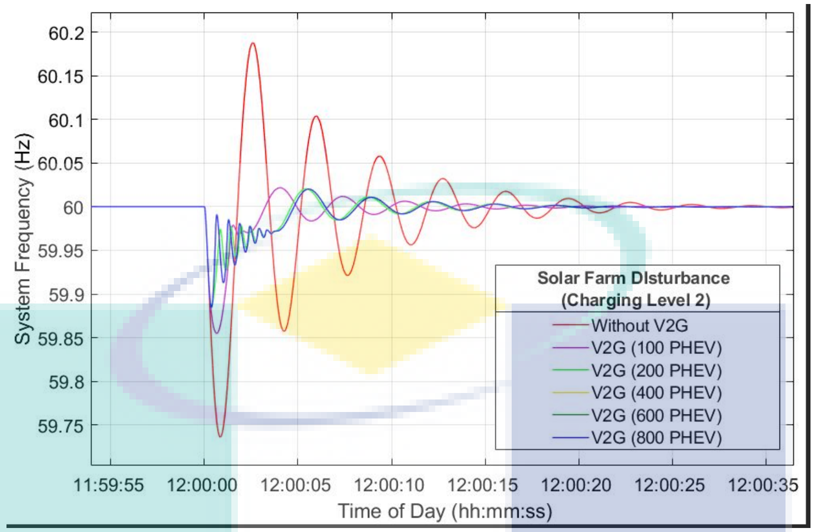


Figure 4.29. The system frequency during PV Farm fractional shading event with different number of PHEVs connected in V2G and with charging rate Level 2

c) DC Fast Charging (25 kW)

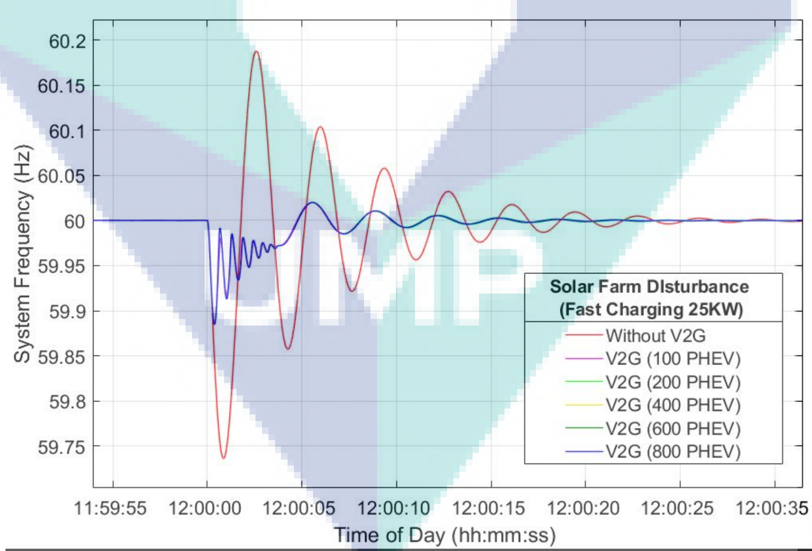


Figure 4.30. The system frequency during PV Farm fractional shading event with different number of PHEVs connected in V2G and with DC Fast Charging (25 kW)

d) DC Fast Charging (45 kW)

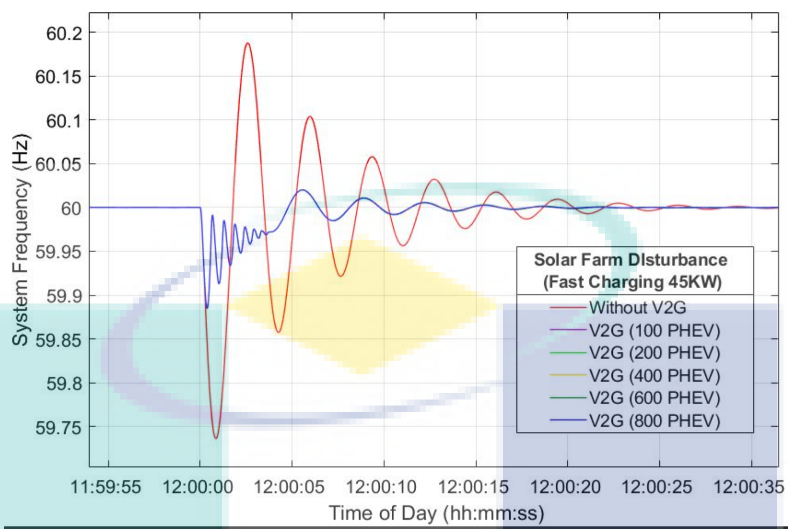


Figure 4.31. The system frequency during PV Farm fractional shading event with different number of PHEVs connected in V2G and with DC Fast Charging (45 kW)

4.4.3. A wind farm trip at 22 hours if the wind exceeds the maximum permitted wind power

The Rated capacity of the Wind Turbines is 8 MW. The simplified wind farm model generates electrical power by following the linear relationship between the nominal wind speed and nominal power. The nominal power is produced by the wind farm if the nominal value of the wind is reached. When the wind speed is between the nominal speed and the maximal value, the power is fixed to 1 per unit. Once the wind speed exceeds the maximum wind value, the wind farm disconnect from the grid until the wind gets back to its rated value. The sudden tripping of the wind turbines causes disturbance of the system frequency. Diesel Generator that act as base generator need to generate more power in order to balance the generating supply and the demand. This will influent sudden change of rotor speed and resulting the frequency to deviate. The impact of the system's frequency is evaluated when different number of PHEV are used in V2G system with 4 different charging rate.

Table 4.26. shows the tabulated results of the system frequency caused by the wind farm trip at 10 P.M. The minimum frequency reached when the disturbance occurred was 59.25 Hz or with percentage drop -1.25% from nominal system frequency while the maximum frequency reached was 60.99 Hz or with percentage 1.65%. Different number of PHEVs connected to the V2G system with 4 different type of charger power was implemented to evaluate the performance of V2G as frequency regulator and the results was tabulated in Table 4.26. The impact of wind farm trip at 22 hours if the wind exceeds the maximum permitted wind power was more severe than the impact of the fractional shading of PV Solar Farm and the impact of the starting of asynchronous. For country with nominal grid frequency of 60 Hz, the percentage of allowable frequency variation is +/- 1 percent. The percentages of frequency variation caused by this disturbance exceed -1% it was quite worrying due to the significant impact to the system frequency. But, the V2G system has proved it credibility as frequency regulator and managed to improve the system frequency.

Table 4.27 shows the results of percentages improvement of frequency after implementation of V2G. As the number of PHEVs connected to the V2G system increased, the percentage improvement of the system frequency also increased.

According to the Table 4.27, the maximum percentage of frequency improved for the lower limit was only 0.61% while for the upper limit was 0.97%.

Table 4.26. Results of the wind farm trip at 22 hours if the wind exceeds the maximum permitted wind power to the system frequency with and without implementation of V2G

Wind Farm Disturbance			
Charging Rate Level	**Number of V2G**	**Minimum Frequency reached (Hz)**	**Maximum Frequency reached (Hz)**
NO V2G		59.25	60.99
Level 1	100	59.26	60.96
	200	59.28	60.94
	400	59.32	60.89
	600	59.35	60.83
	800	59.39	60.78
Level 2	100	59.33	60.87
	200	59.41	60.74
	400	59.56	60.51
	600	59.61	60.41
	800	59.61	60.4
Fast Charging (25KW)	100	59.52	60.57
	200	59.61	60.4
	400	59.61	60.4
	600	59.61	60.4
	800	59.61	60.4
Fast Charging (45KW)	100	59.61	60.4
	200	59.61	60.4
	400	59.61	60.4
	600	59.61	60.4
	800	59.61	60.4

Table 4.27. Percentage improved of frequency to nominal value after implementation of V2G

Wind Farm Disturbance			
Charging Rate Level	**Number of V2G**	**Frequency Improved for the Lower Limit (%)**	**Frequency decreased for the Upper Limit (%)**
Level 1	100	0.02	0.05
	200	0.05	0.08
	400	0.12	0.16
	600	0.17	0.26
	800	0.24	0.34
Level 2	100	0.14	0.20
	200	0.27	0.41
	400	0.52	0.79
	600	0.61	0.95
	800	0.61	0.97
Fast Charging (25KW)	100	0.46	0.69
	200	0.61	0.97
	400	0.61	0.97
	600	0.61	0.97
	800	0.61	0.97
Fast Charging (45KW)	100	0.61	0.97
	200	0.61	0.97
	400	0.61	0.97
	600	0.61	0.97
	800	0.61	0.97

The waveform of system frequency during wind farm trip event at 10 P.M. with different number of PHEVs connected to V2G System and with different type of charging rate level were illustrated in Figure 4.32 to 4.35. From these waveform, it clearly shown that, the system frequency was improved after the implementation of V2G system. Different type of charging rate level contributed to different discharging power for the PHEVs to supply back its electrical energy to the grid. Furthermore, for DC Fast charging, the time taken required for the V2G to obtain the full capacity of power from the PHEV is shorter than charging level 1. Hence. the transitory time of the system frequency deviation also shorter. Moreover, the duration for the charger to fulfil the battery State of Charge (SOC) back to 100% are faster.

a) Charging Level 1 (1.4 kW)

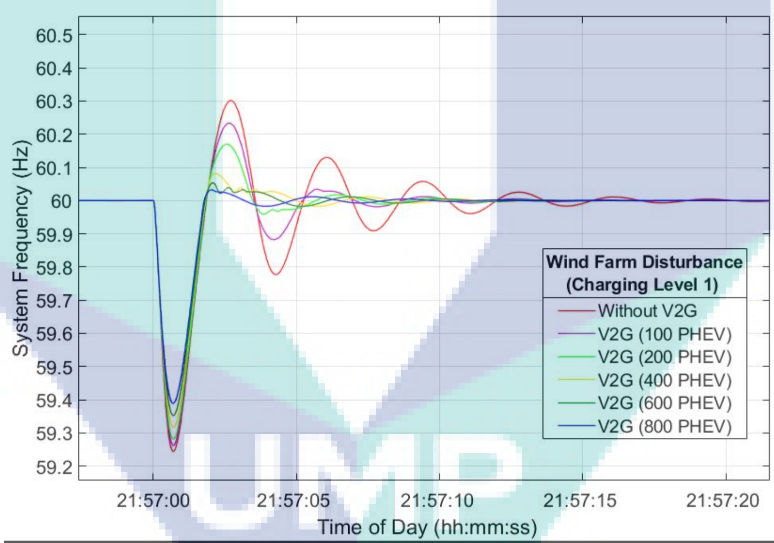


Figure 4.32. The system frequency during wind farm trip event with different number of PHEVs connected in V2G and with charging rate Level 1

b) Charging Level 2 (6.6 kW)

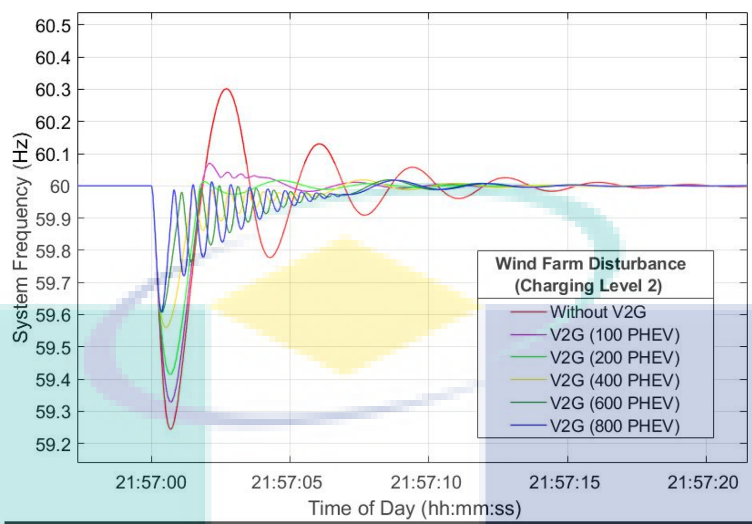


Figure 4.33. The system frequency during wind farm trip event with different number of PHEVs connected in V2G and with charging rate Level 2

c) DC Fast Charging (25 kW)

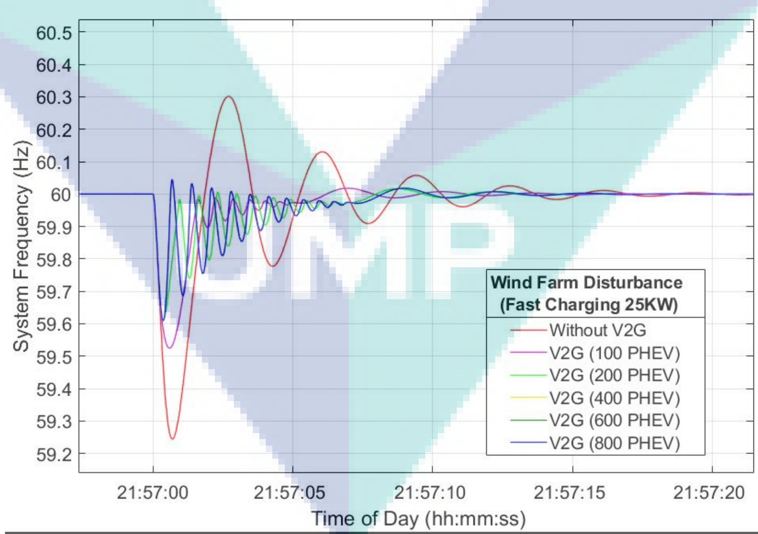


Figure 4.34. The system frequency during wind farm trip event with different number of PHEVs connected in V2G and with DC Fast Charging (25 kW)

d) DC Fast Charging (45 kW)

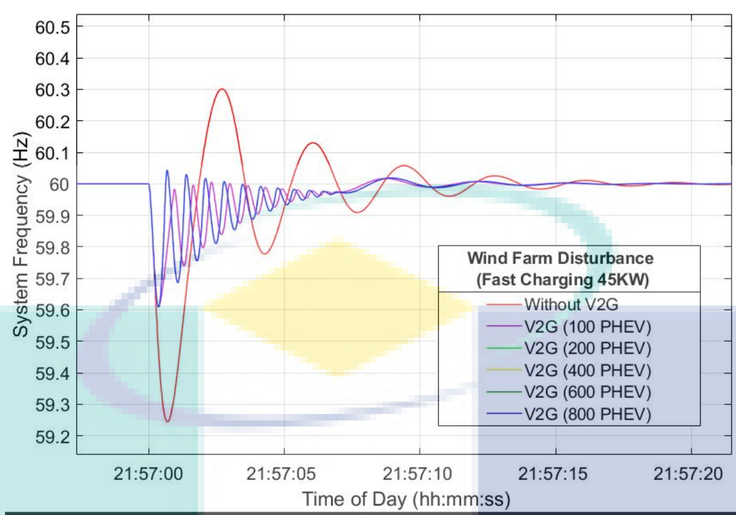


Figure 4.35. The system frequency during wind farm trip event with different number of PHEVs connected in V2G and with DC Fast Charging (45 kW)

4.4.4. Analysis Summary for Case Study 2

Figure 4.36. illustrate the result of 24-Hour system frequency when 3 types of disturbances occurred in micro grid system. These 3 types of disturbances are starting of the asynchronous machine in the initial of the third hour, a partial shading at noon influencing the production of PV output power and a wind farm trip at 10pm if the wind exceeds the maximum permitted wind power. According to the Figure 4.36, the red line is the system frequency without the V2G system while the blue line is the system frequency with the implementation of V2G system. The wind farm trip event at 10 P.M give severe impact to the system frequency compare to the other disturbances. It can be concluded that, the Vehicle-to-Grid system can greatly regulate and improve the system frequency when these disturbances occurred.

Table 4.28 show the V2G Regulation Load (MW) for each of disturbance with different number of PHEV connected in V2G system and with different type of charging rate level. This regulation load is the amount of total power discharged from the PHEV in order to regulate the system frequency. The higher the amount of frequency drop, the more regulation load from the V2G needed. The total regulation load also increases as the number of PHEV connected to the system frequency is increase as well as charging rate level. For wind farm trip events, the highest amount of V2G regulation power for DC fast charging reached 8.1 MW while for charging rate level 1 the V2G regulation power only 1.087MW. This is because in just less than 15 minutes, the V2G system with DC Fast charging is able to supply full energy capacity from the PHEV battery storage. In this V2G MATLAB simulation, the battery capacity for one PHEV was set to 10.15 kW. If 800 number of PHEVs connected to the V2G system, the amount of electrical energy they can discharge are around 8.1 MW. Therefore, in order to receive fast regulation response, DC fast charging are more suitable in V2G system.

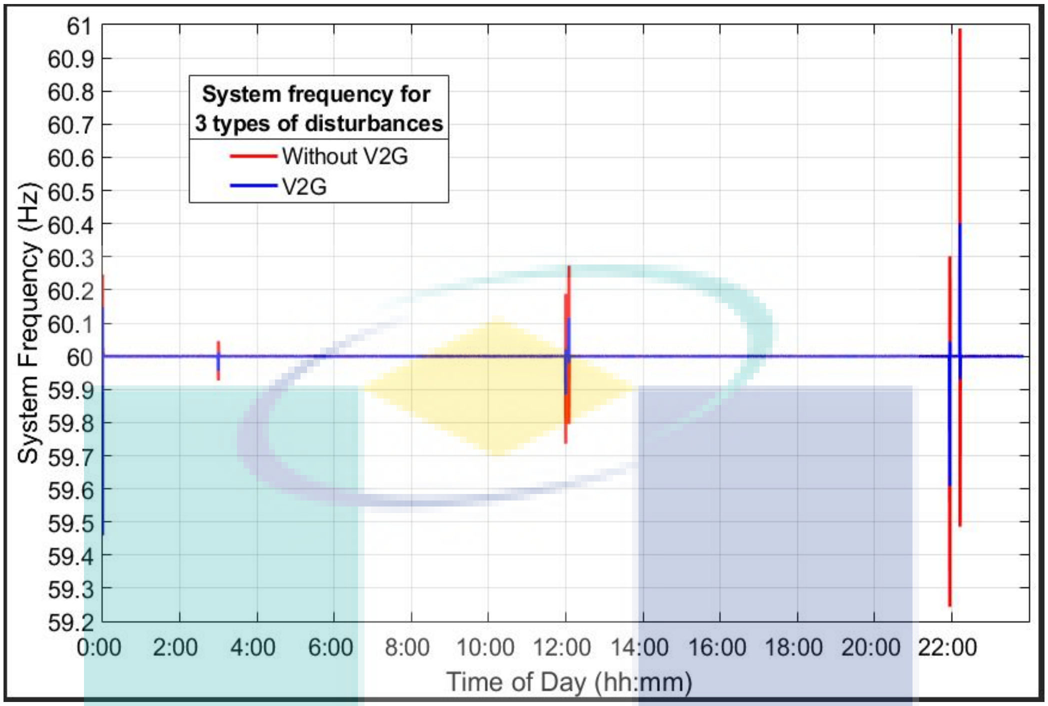


Figure 4.36. 24-hour system frequency for 3 types of disturbances before and after the implementation of V2G

Table 4.28 V2G Regulation Load (MW) for each of disturbance with different number of PHEV connected in V2G system and with different type of charging rate level

Charging Rate Level	Number of V2G	V2G Regulation Load (MW)		
		Asynchronies Machine Disturbance	Solar Farm Disturbance	Wind Farm Disturbance
Level 1	100	0.1411	0.1388	0.1396
	200	0.2532	0.2824	0.2834
	400	0.3441	0.5562	0.5345
	600	0.3853	0.838	0.7753
	800	0.3907	1.117	1.087
Level 2	100	0.3806	0.65	0.6383
	200	0.3904	1.312	1.304
	400	0.3906	2.148	2.618
	600	0.3899	2.236	3.868
	800	0.3895	2.239	5.215
Fast Charging (25KW)	100	0.382	1.871	2.447
	200	0.3757	1.779	4.948
	400	0.3903	2.24	8.114
	600	0.3902	2.225	8.103
	800	0.3903	2.029	8.128
Fast Charging (45KW)	100	0.3904	2.24	4.312
	200	0.3903	2.24	7.603
	400	0.3903	2.24	7.714
	600	0.3902	2.225	8.103
	800	0.3897	2.239	8.11

4.5. Case Study 3: Different of Solar Farm Output due to fractional Shading at noon

Different values of grids frequency have been analysed when the partial shading happens. The nominal rated power of the PV panel was set to be reduced from 90% to 10%. The reduced of PV panel output due to the fractional shading will affect the system frequency stability. This is due to the diesel generator needs to generate more energy in order to balance the generation supply and the demand. This cause the synchronous machine in the generator to rotate at different rotor speed. The impact of the system's frequency is evaluated when different number of PHEVs are used in V2G system with 4 different type of charging rate. The assumed number of Electric Vehicle that contribute to V2G system were varied from 100, 400, 700 and 1000. Different type of charging rate level contributed to different discharging power for the PHEVs to supply back its electrical energy to the grid. Furthermore, for DC Fast charging, the time taken required for the V2G to obtain the full capacity of power from the PHEV is shorter than charging level 1. Hence. the transitory time of the system frequency deviation also shorter. Moreover, the duration for the charger to fulfil the battery State of Charge (SOC) back to 100% are faster.

4.5.1 V2G Contribution to the System Frequency with Charging Rate Level 1 at different PV Farm Reduced Factor

This section analyse the impact of V2G Contribution to the System Frequency with Charging Rate Level 1 at different PV Farm Reduced Factor. The charger power for this type of charging level is 1.4 kW. Table 4.29 show the results of system frequency due to the partial shading that cause the nominal rated power of the PV Farm to be reduced from 90% to 10%. From the results, the system frequency drop was more severe as the percentage of PV Farm output was reduced. The minimum system frequency reached is 59.3 Hz. For country with nominal grid frequency of 60 Hz, the percentage of allowable frequency variation is +/- 1 percent. Therefore, the minimum allowable system frequency is 59.4 Hz. For percentage of PV Farm output reduced lower than 30%, the system frequency exceeded the allowable frequency variation which is -1 percent from the nominal system frequency. Hence, the implementation of V2G system is needed in order to regulate the system frequency back to the permitted frequency. Table 4.29 also show the result of system frequency after the implementation of V2G system with different number of PHEV connected to it. For case PV Farm output lower than 30%, at least 700 PHEVs are needed in order to regulate the system frequency back to permitted value which is higher than 59.40 Hz.

Meanwhile, the system frequency with PV Farm output 30% and higher were still in allowable frequency variation. But, since the V2G system in the MATLAB SIMULINK will response to any frequency deviation, the system Grid Regulator Control will activate the V2G system to regulate the frequency. Table 4.30 illustrate the result percentage of improvement of frequency after the implementation of V2G system. As shown in the table, the higher number of PHEVs contributed to the V2G system, the higher the percentage of frequency improvement. In addition, Table 4.31 show the result of V2G regulation load with different number of PHEVs connected in V2G system and with different PV Farm reduced factor. This regulation load is the amount of total power discharged from the PHEV in order to regulate the system frequency. The higher the amount of frequency drop, the more regulation load from the V2G needed. The total regulation load also increases as the number of PHEVs connected to the system frequency was increased. The highest V2G regulation power was about 1.39 MW for 1000 PHEVs or near to 1.4 KW per PHEVs since the V2G system was connected to charging rate level 1 with charger power 1.4 kW.

Table 4.29. V2G contribution to the system frequency with charging rate level 1

CHARGING RATE LEVEL 1					
PV Farm Reduced Factor	System Frequency (Hz)				
	Without V2G	Number of V2G Connected			
		100 PHEV	400 PHEV	700 PHEV	1000 PHEV
0.9	59.91	59.94	59.95	59.95	59.95
0.8	59.82	59.85	59.91	59.92	59.92
0.7	59.74	59.76	59.84	59.88	59.88
0.6	59.65	59.68	59.79	59.82	59.85
0.5	59.58	59.6	59.68	59.75	59.8
0.4	59.5	59.53	59.6	59.67	59.73
0.3	59.43	59.45	59.52	59.59	59.66
0.2	59.36	59.38	59.45	59.52	59.58
0.1	59.3	59.32	59.38	59.45	59.51

Table 4.30. Percentage improved of frequency after the implementation of V2G with charging rate level 1

CHARGING RATE LEVEL 1				
PV Farm Reduced Factor	Percentage of Frequency Improved (%)			
	Number of V2G Connected			
	100 PHEV	400 PHEV	700 PHEV	1000 PHEV
0.9	0.05	0.07	0.07	0.07
0.8	0.05	0.15	0.17	0.17
0.7	0.03	0.17	0.23	0.23
0.6	0.05	0.23	0.28	0.34
0.5	0.03	0.17	0.29	0.37
0.4	0.05	0.17	0.29	0.39
0.3	0.03	0.15	0.27	0.39
0.2	0.03	0.15	0.27	0.37
0.1	0.03	0.13	0.25	0.35

Table 4.31. V2G Regulation Load for charging level 1 and with different PV Farm reduced factor

CHARGING RATE LEVEL 1				
PV Farm Reduced Factor	**V2G Regulation Load (MW)**			
	Number of V2G Connected			
	100 PHEV	**400 PHEV**	**700 PHEV**	**1000 PHEV**
0.9	0.1397	0.4935	0.3759	0.6735
0.8	0.1387	0.5886	0.9106	1.024
0.7	0.1388	0.5562	0.9756	1.373
0.6	0.1398	0.5513	0.9698	1.354
0.5	0.1394	0.5446	0.9746	1.394
0.4	0.1379	0.5371	0.9518	1.389
0.3	0.1385	0.5525	0.9704	1.378
0.2	0.1384	0.5578	0.9685	1.363
0.1	0.1377	0.5398	0.9576	1.341

4.5.2 V2G Contribution to the System Frequency with Charging Rate Level 2 at different PV Farm Reduced Factor

This section analyse the impact of V2G Contribution to the System Frequency with Charging Rate Level 2 at different PV Farm Reduced Factor. The charger power for this type of charging level is 6.6 kW. Table 4.32 show the results of system frequency due to the partial shading that cause the nominal rated power of the PV Farm to be reduced from 90% to 10%. From the results, the system frequency drop was more severe as the percentage of PV Farm output was reduced. The minimum system frequency reached is 59.3 Hz. For country with nominal grid frequency of 60 Hz, the percentage of allowable frequency variation is +/- 1 percent. Therefore, the minimum allowable system frequency is 59.4 Hz. For percentage of PV Farm output reduced lower than 30%, the system frequency exceeded the allowable frequency variation which is -1 percent from the nominal system frequency. Hence, the implementation of V2G system is needed in order to regulate the system frequency back to the permitted frequency. Table 4.32 also show the result of system frequency after the implementation of V2G system with different number of PHEV connected to it. For case PV Farm output lower than 30%, only at least 400 PHEVs are enough to regulate the system frequency back to permitted value which is higher than 59.40 Hz compared to V2G system with charger power 1.4 kW that needed 700 of PHEVs.

Meanwhile, the system frequency with PV Farm output 30% and higher were still in allowable frequency variation. But, since the V2G system in the MATLAB SIMULINK will response to any frequency deviation, the system Grid Regulator Control will activate the V2G system to regulate the frequency. Table 4.33 illustrate the result percentage of improvement of frequency after the implementation of V2G system. As shown in the table, the higher number of PHEVs contributed to the V2G system, the higher the percentage of frequency improvement. In addition, Table 4.35 show the result of V2G regulation load with different number of PHEVs connected in V2G system and with different PV Farm reduced factor. This regulation load is the amount of total power discharged from the PHEV in order to regulate the system frequency. The higher the amount of frequency drop, the more regulation load from the V2G needed. The total regulation load also increases as the number of PHEVs connected to the system frequency was increased. The highest V2G regulation power was about 6.138 MW for 1000 PHEVs or near to 6.14 kW per PHEVs since the V2G system was connected to charging rate level 1 with charger power 6.6 kW. Both percentages of frequency improved and V2G regulation load for charging rate level 2 are better than charging rate level 1.

Table 4.32. V2G contribution to the system frequency with Charging rate level 2

CHARGING RATE LEVEL 2					
PV Farm Reduced Factor	System Frequency (Hz)				
	Without V2G	Number of V2G Connected			
		100 PHEV	400 PHEV	700 PHEV	1000 PHEV
0.9	59.91	59.95	59.95	59.95	59.95
0.8	59.82	59.92	59.92	59.92	59.92
0.7	59.74	59.85	59.88	59.88	59.88
0.6	59.65	59.78	59.85	59.85	59.85
0.5	59.58	59.7	59.81	59.81	59.81
0.4	59.5	59.62	59.78	59.78	59.78
0.3	59.43	59.54	59.74	59.74	59.74
0.2	59.36	59.47	59.7	59.71	59.71
0.1	59.3	59.4	59.65	59.67	59.67

Table 4.33. Percentage improved of frequency after the implementation of V2G with charging rate level 2

CHARGING RATE LEVEL 2				
PV Farm Reduced Factor	**Percentage of Frequency Improved (%)**			
	Number of V2G Connected			
	100 PHEV	**400 PHEV**	**700 PHEV**	**1000 PHEV**
0.9	0.07	0.07	0.07	0.07
0.8	0.17	0.17	0.17	0.17
0.7	0.18	0.23	0.23	0.23
0.6	0.22	0.34	0.34	0.34
0.5	0.20	0.39	0.39	0.39
0.4	0.20	0.47	0.47	0.47
0.3	0.19	0.52	0.52	0.52
0.2	0.19	0.57	0.59	0.59
0.1	0.17	0.59	0.62	0.62

Table 4.34. V2G Regulation Load for charging level 2 and with different PV Farm reduced factor

CHARGING RATE LEVEL 2				
PV Farm Reduced Factor (% of standard power)	**V2G Regulation Load (MW)**			
	Number of V2G Connected			
	100 PHEV	**400 PHEV**	**700 PHEV**	**1000 PHEV**
0.9	0.5309	0.3893	0.2635	0.3827
0.8	0.654	1.464	1.144	1.402
0.7	0.6534	2.231	2.171	2.206
0.6	0.6548	2.479	2.945	2.221
0.5	0.6442	2.403	3.265	3.569
0.4	0.64	2.595	4.142	4.403
0.3	0.6304	2.608	4.367	4.529
0.2	0.6399	2.603	4.478	5.886
0.1	0.6454	2.581	4.273	6.138

4.5.3 V2G Contribution to the System Frequency with DC Fast Charging (25 kW)

This section analyse the impact of V2G Contribution to the System Frequency with DC Fast Charging at different PV Farm Reduced Factor. The charger power for this type of charging level is 25 kW. Table 4.35 show the results of system frequency due to the partial shading that cause the nominal rated power of the PV Farm to be reduced from 90% to 10%. From the results, the system frequency drop was more severe as the percentage of PV Farm output was reduced. The minimum system frequency reached is 59.3 Hz. For country with nominal grid frequency of 60 Hz, the percentage of allowable frequency variation is +/- 1 percent. Therefore, the minimum allowable system frequency is 59.4 Hz. For percentage of PV Farm output reduced lower than 30%, the system frequency exceeded the allowable frequency variation which is -1 percent from the nominal system frequency. Hence, the implementation of V2G system is needed in order to regulate the system frequency back to the permitted frequency. Table 4.35 also show the result of system frequency after the implementation of V2G system with different number of PHEV connected to it. For case PV Farm output lower than 30%, only at least 100 PHEVs are enough to regulate the system frequency back to permitted value which is higher than 59.40 Hz compared to V2G system with charger power 1.4kW that needed at least 700 of PHEVs and charger power 6.6 kW that needed 400 of PHEVs.

Meanwhile, the system frequency with PV Farm output 30% and higher were still in allowable frequency variation. But, since the V2G system in the MATLAB SIMULINK will response to any frequency deviation, the system Grid Regulator Control will activate the V2G system to regulate the frequency. Table 4.36 illustrate the result percentage of improvement of frequency after the implementation of V2G system. As shown in the table, the higher number of PHEVs contributed to the V2G system, the higher the percentage of frequency improvement. In addition, Table 4.37 show the result of V2G regulation load with different number of PHEVs connected in V2G system and with different PV Farm reduced factor. This regulation load is the amount of total power discharged from the PHEV in order to regulate the system frequency. The higher the amount of frequency drop, the more regulation load from the V2G needed. The total regulation load also increases as the number of PHEVs connected to the system frequency was increased. The highest V2G regulation power was about 6.857 MW for 1000 PHEVs or near to 6.86 kW per PHEVs. Even though the V2G system was connected to DC Fast

Charging with charger power 25 kW, the maximum electrical energy discharged from the 1000 PHEVs to regulate the frequency is near to 7 MW. Both percentages of frequency improved and V2G regulation load for DC Fast Charging are way better than previous type of charging rate level.

Table 4.35. V2G contribution to the system frequency with DC Fast Charging (25 kW)

DC FAST CHARGING 25 kW					
PV Farm Reduced Factor	System Frequency (Hz)				
	Without V2G	Number of V2G Connected			
		100 PHEV	400 PHEV	700 PHEV	1000 PHEV
0.9	59.91	59.95	59.95	59.95	59.95
0.8	59.82	59.92	59.92	59.92	59.92
0.7	59.74	59.89	59.89	59.89	59.89
0.6	59.65	59.85	59.85	59.85	59.85
0.5	59.58	59.82	59.82	59.82	59.82
0.4	59.5	59.78	59.78	59.78	59.78
0.3	59.43	59.74	59.74	59.74	59.74
0.2	59.36	59.69	59.71	59.71	59.71
0.1	59.3	59.64	59.67	59.67	59.67

Table 4.36. Percentage improved of frequency after the implementation of V2G with DC Fast Charging (25 kW)

DC FAST CHARGING (25 kW)				
PV Farm Reduced Factor	Percentage of Frequency Improved (%)			
	Number of V2G Connected			
	100 PHEV	400 PHEV	700 PHEV	1000 PHEV
0.9	0.07	0.07	0.07	0.07
0.8	0.17	0.17	0.17	0.17
0.7	0.25	0.25	0.25	0.25
0.6	0.34	0.34	0.34	0.34
0.5	0.40	0.40	0.40	0.40
0.4	0.47	0.47	0.47	0.47
0.3	0.52	0.52	0.52	0.52
0.2	0.56	0.59	0.59	0.59
0.1	0.57	0.62	0.62	0.62

Table 4.37. V2G Regulation Load for DC Fast Charging (25 kW) and with different PV Farm reduced factor

FAST CHARGING 25 kW				
PV Farm Reduced Factor	V2G Regulation Load (MW)			
	Number of V2G Connected			
	100 PHEV	400 PHEV	700 PHEV	1000 PHEV
0.9	0.379	0.6687	0.6554	0.6673
0.8	0.9113	1.003	1.459	1.463
0.7	1.871	2.198	2.069	1.921
0.6	2.221	2.845	3.001	1.939
0.5	2.2219	3.635	3.338	2.845
0.4	2.2476	4.547	4.051	2.983
0.3	2.476	5.257	4.192	4.503
0.2	2.451	6.053	6.088	5.676
0.1	2.406	6.283	6.595	6.857

4.5.4 V2G Contribution to the System Frequency with DC Fast Charging (45 kW)

This section analyse the impact of V2G Contribution to the System Frequency with DC Fast Charging at different PV Farm Reduced Factor. The charger power for this type of charging level is 45 kW. Table 4.38 show the results of system frequency due to the partial shading that cause the nominal rated power of the PV Farm to be reduced from 90% to 10%. From the results, the system frequency drop was more severe as the percentage of PV Farm output was reduced. The minimum system frequency reached is 59.3 Hz. For country with nominal grid frequency of 60 Hz, the percentage of allowable frequency variation is +/- 1 percent. Therefore, the minimum allowable system frequency is 59.4 Hz. For percentage of PV Farm output reduced lower than 30%, the system frequency exceeded the allowable frequency variation which is -1 percent from the nominal system frequency. Hence, the implementation of V2G system is needed in order to regulate the system frequency back to the permitted frequency. Table 4.38 also show the result of system frequency after the implementation of V2G system with different number of PHEV connected to it. For case PV Farm output lower than 30%, only at least 100 PHEVs are enough to regulate the system frequency back to permitted value which is higher than 59.40 Hz compared to V2G system with charger power 1.4 kW that needed at least 700 of PHEVs and charger power 6.6 kW that needed 400 of PHEVs.

Meanwhile, the system frequency with PV Farm output 30% and higher were still in allowable frequency variation. But, since the V2G system in the MATLAB SIMULINK will response to any frequency deviation, the system Grid Regulator Control will activate the V2G system to regulate the frequency. Table 4.39 illustrate the result percentage of improvement of frequency after the implementation of V2G system. As shown in the table, the higher number of PHEVs contributed to the V2G system, the higher the percentage of frequency improvement. In addition, Table 4.40 show the result of V2G regulation load with different number of PHEVs connected in V2G system and with different PV Farm reduced factor. This regulation load is the amount of total power discharged from the PHEV in order to regulate the system frequency. The higher the amount of frequency drop, the more regulation load from the V2G needed. The total regulation load also increases as the number of PHEVs connected to the system frequency was increased. The highest V2G regulation power was about 6.857 MW for 1000 PHEVs or near to 6.86 kW per PHEVs. Even though the V2G system was connected to DC Fast

Charging with charger power 25 kW, the maximum electrical energy discharged from the 1000 PHEVs to regulate the frequency is near to 7 MW. When compare the result of percentages of frequency improved and V2G regulation load for DC Fast Charging 45 kW, it is same as result for V2G system with DC Fast Charging 25 kW. This is due to the V2G regulation load already reached its maximum electrical energy discharge for 1000 PHEVs connected to V2G system. Both percentages of frequency improved and V2G regulation load for DC Fast Charging are way better than previous type of charging rate level.

Table 4.38. V2G contribution to the system frequency with DC Fast Charging (45 kW)

FAST CHARGING 45 kW					
PV Farm Reduced Factor	System Frequency (Hz)				
	Without V2G	Number of V2G Connected			
		100 PHEV	400 PHEV	700 PHEV	1000 PHEV
0.9	59.91	59.95	59.95	59.95	59.95
0.8	59.82	59.92	59.92	59.92	59.92
0.7	59.74	59.88	59.89	59.89	59.89
0.6	59.65	59.85	59.85	59.85	59.85
0.5	59.58	59.81	59.82	59.82	59.82
0.4	59.5	59.78	59.78	59.78	59.78
0.3	59.43	59.74	59.74	59.74	59.74
0.2	59.36	59.71	59.71	59.71	59.71
0.1	59.3	59.67	59.67	59.67	59.67

Table 4.39. Percentage improved of frequency after the implementation of V2G system with DC Fast Charging (45 kW)

FAST CHARGING 45 kW				
PV Farm Reduced Factor	Percentage of Frequency Improved (%)			
	Number of V2G Connected			
	100 PHEV	400 PHEV	700 PHEV	1000 PHEV
0.9	0.07	0.07	0.07	0.07
0.8	0.17	0.17	0.17	0.17
0.7	0.23	0.25	0.25	0.25
0.6	0.34	0.34	0.34	0.34
0.5	0.39	0.40	0.40	0.40
0.4	0.47	0.47	0.47	0.47
0.3	0.52	0.52	0.52	0.52
0.2	0.59	0.59	0.59	0.59
0.1	0.62	0.62	0.62	0.62

Table 4.40. V2G Regulation Load for DC Fast Charging (45 kW) and with different PV Farm reduced factor

FAST CHARGING 45 kW				
PV Farm Reduced Factor	V2G Regulation Load (MW)			
	Number of V2G Connected			
	100 PHEV	400 PHEV	700 PHEV	1000 PHEV
0.9	0.5112	0.6687	0.6554	0.6673
0.8	1.455	1.003	1.459	1.463
0.7	2.239	2.198	2.069	1.921
0.6	2.232	2.845	3.001	1.939
0.5	3.441	3.635	3.338	2.845
0.4	3.86	4.547	4.051	2.983
0.3	3.696	5.257	4.192	4.503
0.2	4.278	6.053	6.088	5.676
0.1	4.306	6.283	6.595	6.857

4.5.5 Analysis Summary for Case Study 3

Figure 4.37. show the results of system frequency for variation of PV farm output factor without the V2G system implementation from MATLAB Simulink. According to the figure, the lower the PV Farm output, the higher the frequency drop. This is due to the diesel generator needs to generate more energy in order to balance the generation supply and the demand. This cause the synchronous machine in the generator to rotate at different rotor speed resulting the system frequency to deviate. The minimum system frequency reached is 59.3 Hz. For country with nominal grid frequency of 60 Hz, the percentage of allowable frequency variation is +/- 1 percent. Therefore, the minimum allowable system frequency is 59.4 Hz. For percentage of PV Farm output reduced lower than 30%, the system frequency exceeded the allowable frequency variation which is -1 percent from the nominal system frequency. Hence, the implementation of V2G system is needed in order to regulate the system frequency back to the permitted frequency.

From the analysis results, the higher number of PHEVs contributed to the V2G system, the higher the percentage of frequency improvement. Besides that, the higher the amount of frequency drop, the more regulation load from the V2G needed. The total regulation load also increases as the number of PHEVs connected to the system frequency was increased. Different types of charging rate level connected to the V2G system also resulting different amount of PHEVs needed to regulate the system frequency back to the allowable frequency. For case PV Farm output lower than 30%, only at least 100 PHEVs are enough to regulate the system frequency back to permitted value which is higher than 59.40 Hz compared to V2G system with charger power 1.4 kW that needed at least 700 of PHEVs and charger power 6.6 kW that needed 400 of PHEVs. Therefore, in order to receive fast regulation response, DC fast charging are more suitable in V2G system. Figure 4.38 illustrate the results of system frequency for variation of PV farm output factor with the V2G system implementation from MATLAB Simulink. This results shows the system frequency with implementation of 1000 PHEVs connected to the DC Fast Charging V2G system. Based on the figure, it can be concluded that, the implementation of V2G system can greatly regulate and improve the system frequency. The time taken for the frequency deviation back to the nominal system frequency also faster which is less than 9 seconds.

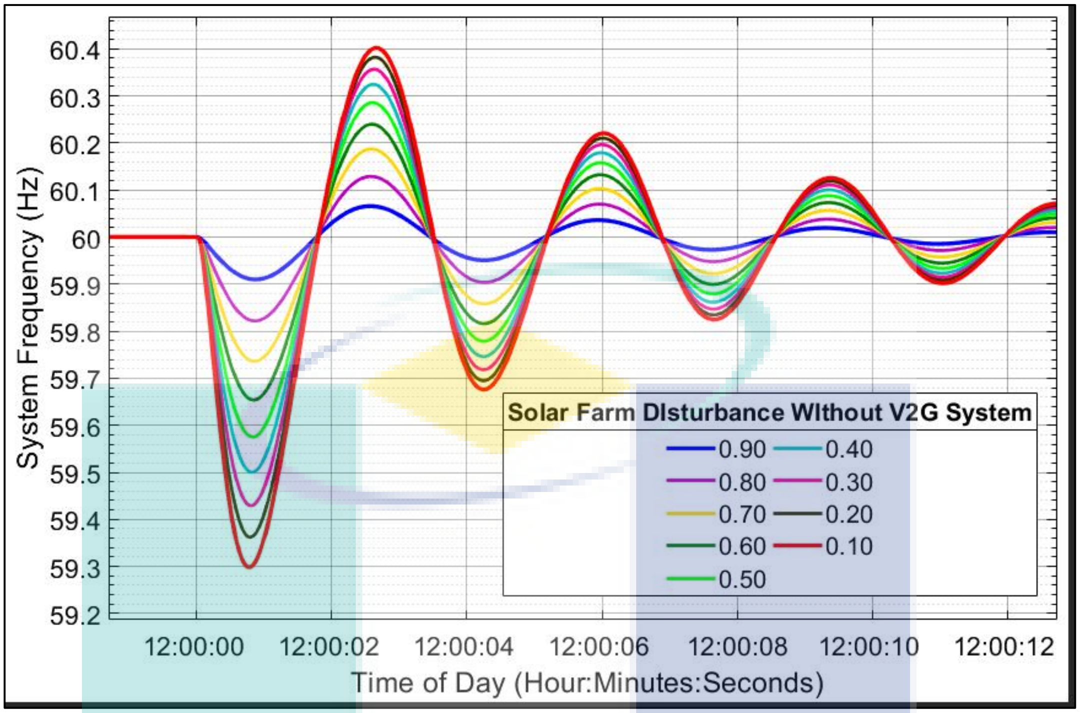


Figure 4.37. System frequency without V2G implementation

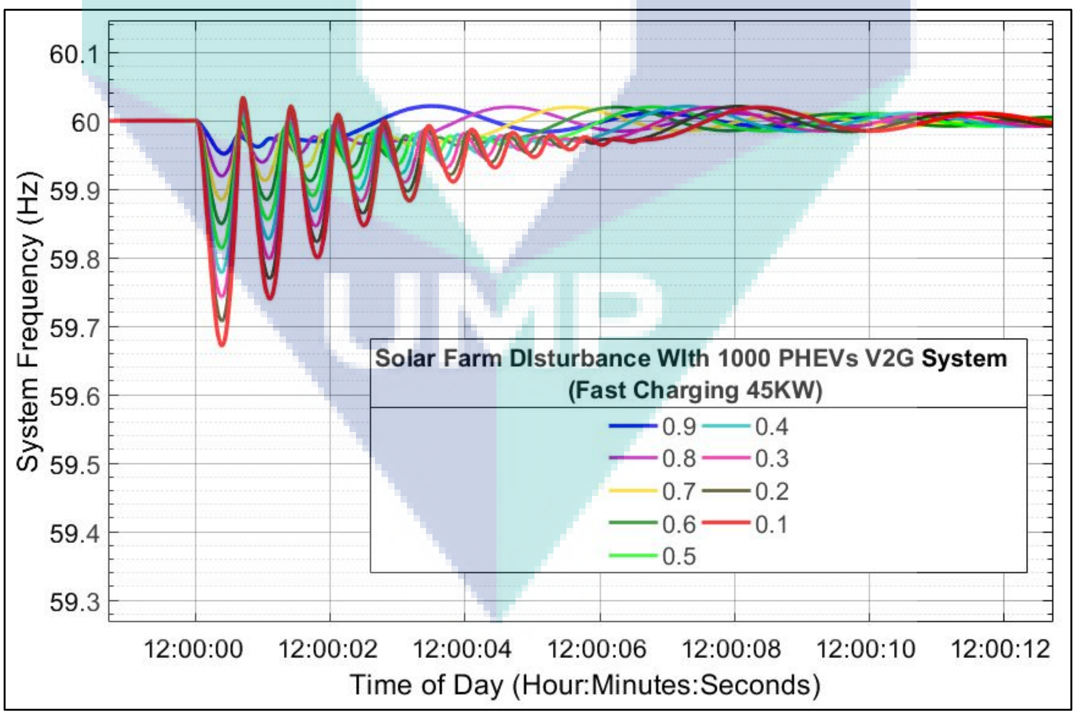


Figure 4.38. System frequency after 1000 V2G implementation with DC fast charging (45kW)

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In the automotive market, a large number of electric vehicles (EVs) and spreading worries about harmful pollutants in the environment have attracted research and development centres around the world. At the same time, an increase in EV integration with an electric grid raises concerns about the health of the electrical grid due to increased load. To handle this additional load, the utility must install an intelligent system without resulting generation and distribution problems. Nevertheless, the newest upgraded in EV technology have persuaded electrical utilities to join the EV market, in which EV can contribute to additional services for electrical utilities.

This thesis has evaluated the capability of the Vehicle-to-Grid to provide ancillary service for frequency regulation. In order to examine the performance of Vehicle-to-Grid as frequency regulation in a power system network, a deep analysis on three case studies have been conducted and discussed. These case studies are the possible event that might be occurred in micro grid system and cause disturbance of the system frequency. From the first case study, it can be concluded that for increment of residential load that below than 20%, the system frequency was still normal and did not require any V2G implementation. On the other hand, if the residential load exceeds 20% from its normal load, the system frequency need to be regulate by the Vehicle-to-grid system.

Meanwhile, for case study 2 and 3, different number of PHEVs connected to the V2G system with 4 different type of charger power was implemented to evaluate the credibility of V2G as to regulate the system frequency from the impact of disturbances in a power system. Different type of charging rate level contributed to different discharging power for the PHEVs to supply back its electrical energy to the grid. Furthermore, for DC Fast charging, the time taken required for the V2G to obtain the full capacity of power from the PHEV is shorter than charging level 1. Hence. the transitory time of the system frequency deviation also shorter. Moreover, the duration for the charger to fulfil the battery State of Charge (SOC) back to 100% are faster. Furthermore, V2G regulation load also one of the important part that have been analysed. This regulation load is the amount of total power discharged from the PHEV in order to regulate the system frequency. The higher the amount of frequency drop, the more regulation load from the V2G needed. The total regulation load also increases as the number of PHEVs connected to the system frequency was increased. For case study 2, the wind farm trip event at 10 P.M give severe impact to the system frequency compare to the other disturbances. For case study 3, the lower the PV Farm output, the higher the frequency drop. This is due to the diesel generator needs to generate more energy in order to balance the generation supply and the demand. This cause the synchronous machine in the generator to rotate at different rotor speed resulting the system frequency to deviate. According to these three case studies, it can be concluded that, the Vehicle-to-Grid System can greatly improve and regulate system frequency.

V2G has shown great applications in ancillary service, specifically to grid frequency regulation. Frequency must be controlled within the limits permitted by its standard frequency by controlling power sources such as generators, as one of the important indexes in the operation of the power system. This standard frequency is the frequency that all devices in the grid are synchronized and are designed to operate on. If the frequency deviates from regular frequency, the equipment may be damaged. Generators can sustain damage to turbines because it speeds up too fast or sub-synergies. And finally the protection relay will trip out of the generator, line, and transformer if frequency deviation is too severe. Transformers can heat up and spoil themselves if the current through them becomes too high that can occur during contingency events due to frequency issues. Even your consumer device is designed only to handle certain frequencies and may experience high or low frequency damage. Due to the rapid response feature, the EV fleet that participates in frequency regulation has a natural benefit over other ancillary services.

5.2 Future Recommendation

The economic costs and benefit associated with Vehicle-to-grid have not been taken into consideration in this thesis. The capability of the V2G fleets should be correlate with static battery energy storage and the typical power generation. In future effort, the ability of V2G to participate in power generation and storage and its implementation in strategic vehicles should be ascertained.

Nevertheless, before integrating a huge fleet of electric vehicles in the power system in the foreseeable future, there are particular challenges in the Vehicle-to-Grid technology have to be concerned and resolved. Among of the challenges are the depths of discharge (DOD) that could reduce the EV's battery life, the high investment cost of the V2G system, the need of smart bidirectional charging and discharging system and the complexity of power electronics in the bidirectional flow of electrical energy. In the upcoming future, as the price of electricity falls, a huge fleet integration of the Electric Vehicle will affect the energy market.

Moreover, in the near future, an integrated smart mapping system for all the charging station or rest stops of Electrical Vehicle should be build and expertise. Some of the locations or buildings can be used as charging stations and on-board map systems allow people to choose their charging point by using this integrated smart mapping system, specifically at public or private charging points. Nevertheless, in order to make the energy system more adaptable and dependable, safety cautions must be examined to protect the proprietor of the EV and the grid system.

Depending on the system price, the EV battery can have three modes which are waiting mode, charge mode and discharging mode. Moreover, the waiting mode can be set to inhibit high price hours, and requests for charges can be changed to peak times. In the grid to vehicle (G2V) also knows as charging mode, batteries are charged by purchasing electricity from the grid. 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.

5.3 Impacts to Society and/or Environment

The integration of Vehicle-to-Grid will definitely give advantages to both the grid operator and also the Electric Vehicle owners. Furthermore, it will also provide benefits to the environment in the future.

The energy from the battery storage can be utilized to meet local demand for an electricity supply that contributes to peak shaving. The additional benefits of peak shaving comprise reduction of transmission obstruction, losses on line, late investments in transmission and reduction of stressful system operation. Load service companies purchase electric power through long-term agreements with the generation company and short-term spot electricity markets in a deregulated market. The application of Electric Vehicle as peak shaving could provide reduction of electricity costs.

Electric vehicles have the potential to play the V2G role as the vehicle becomes an asset in a smart grid with bi-directional chargers. By using the V2G network, public utilities can provide a more stable and better service to meet the sudden demand in load and save energy for future use when the offer is high. The V2G system can also provide financial benefits to the owner, thereby reducing the overall cost of purchasing electric vehicles. Vehicles to the Grid system allow vehicle owners to generate income from selling back power to the grid [5].

Electric vehicles are known as zero emission vehicles (ZEVs) and are much eco-friendlier than petroleum or Liquefied Petroleum Gas (LPG). Since EV has less moving parts, there is also little maintenance. No oil changes, no adjustment or time and no exhaust. EV is also considerably more energy efficient than gasoline engines and operates very quietly [2]. In recent years, EVs have obtained considerable popularity and in the near future this trend seems to further grow so most transport sectors comprise Electric Vehicles, in line with new policies establish by several governments around the world [3]. The electric transport sector emerges to be an ideal solution and method for reducing GHG emissions from combustion engines, besides electrical utilities to enhance the quality of energy by using Electric Vehicle batteries as a distributed energy source (DER).

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APPENDIX A

MATLAB PROGRAMMING FOR DAILY DISTANCE DRIVEN

```
close all;
clc;
clear;

DT= xlsread('Charging and Distance.xlsx',1); % Distance Driven data
from excel

X=1:1:21,1; % x-axis

A=DT(1:21,1)'; %data for 1500 vehicles
B=DT(1:21,2)'; %data for 2000 vehicles
C=DT(1:21,3)'; %data for 2500 vehicles
D=DT(1:21,4)'; %data for 2500 vehicles

label={'0-5' '5-10' '10-15' '15-20' '20-25' '25-30' '30-35'
    '35-40' '40-45' '45-50' '50-55' '55-60' '60-65' '65-70'
    '70-75' '75-80' '80-85' '85-90' '90-95' '95-100' '>100'}; %x-axis
Label

%plot distance driven bar graph for 1500 vehicle data
figure(1)
bar(X,A)
set(gca,'xtick',[1:21],'xticklabel',label) %set x-axis label

%plot distance driven bar graph for 2000 vehicle data
figure(2)
bar(X,B)
set(gca,'xtick',[1:21],'xticklabel',label)%set x-axis label

%plot distance driven bar graph for 2500 vehicle data
figure(3)
bar(X,C)
set(gca,'xtick',[1:21],'xticklabel',label)%set x-axis label

%plot distance driven bar graph for 3000 vehicle data
figure(4)
bar(X,D)
set(gca,'xtick',[1:21],'xticklabel',label)%set x-axis label
```

APPENDIX B

MATLAB PROGRAMMING FOR ARRIVAL TIME ANALYSIS

```
close all;
clc;
clear;


a= xlsread('Charging and Distance 1.xlsx',11); %arrival time data
b=a(1:3000,4);

b = sort(b);  %sort the arrival time data
xx = unique(b);   % obtain the unique value of the arrival time data



t = zeros(size(xx)); % build a matrix contain zero value follow the
arrival data size

% to obtain frequency for each arrival time value

for i = 1:length(xx)
    t(i) = sum(b == xx(i)); %total the number of unique value
end

t1=t/3000 *100;

%convert the format from hour to HH:MM
k=datestr(hours(xx),'HH:MM');
Time=datetime(k,'Format', 'HH:mm');

%plot the arrival time bar graph
bar(Time,t1)

%read data of 30 minutes interval from 00:00 until 23:30 in Hours
format for the axis label

axis=xlsread('Charging and Distance 1.xlsx',11);
axis=a(1:48,7);

%convert the axis data to HH:MM format
axis1=datestr(hours(axis),'HH:MM');
axis2=datetime(axis1,'Format', 'HH:mm');

%set the axis label
set(gca,'XTick',axis2)
dateformat = 'HH:MM';
datetick('x',dateformat,'keepticks')
```

APPENDIX C

MATLAB PROGRAMMING FOR PHEV CHARGING LOAD PROFILE (PCLP)

```
close all;
clc;
clear;

CD = xlsread('Charging and Distance.xlsx',3); %import data from excel

START =CD(2:1501,1); %charging start time column
END=CD(2:1501,2);  %charging end time column


num_EV=1500; %Number of Vehicles

F=zeros(num_EV, 96);
G=ones(num_EV, 96);


for i=1:num_EV
    for j=START(i,1):END(i,1) %build a charging schedule matrices of
                              15-minutes interval (96 time frame)
        F(i,j)=1;
        G(i,j)=0;
    end
end


Z=F(:,1:96);
Y=G(:,1:96);

S=sum(Z) %add the total charging vehicle at each time frame
S1=S';

C=S*1.4*10^3; %get the charging load
C1=C';

x=1:96;
figure;
yy_1(:,1)=C;

yi = smooth(yy_1) ;

Hour=CD(1:96,4);
k=datestr(hours(Hour),'HH:MM');
Time=datetime(k,'Format', 'HH:mm'); %convert x-axis in HH:MM format
plot(Time,yi) %plot the vehicle charging load curve


axis=CD(1:48,5);

axis1=datestr(hours(axis),'HH:MM');
axis2=datetime(axis1,'Format', 'HH:mm'); %set the x-axis label
```

```
set(gca,'XTick',axis2)
dateformat = 'HH:MM';
datetick('x',dateformat,'keepticks')

ylabel('Charging Load (MW)');
xlabel('Time of Day (Hour:Minute) ');
```