ECONOMIC DISPATCH CONSIDERING OF ELECTRIC VEHICLE IN POWER SYSTEM NETWORK

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ABSTRACT

The rapid growth of electric vehicle (EV) offers the future transportation industry with high potential solution on environmental concerns. However, this also brings new challenges to the economic and reliability of power network. With the arrival of large-scale electric vehicles, the operation of the system becomes manageably arduous due to the uncontrolled charging nature of electric vehicles. This research will implement hourly economic dispatch (ED) solution considering the arrival of electric vehicles as an additional load to the system. Using recorded hourly load demand data for different weather conditions obtained from the Malaysia Energy Commission, the simulation data is able to emulate the practically of a real power system network. The hourly probability of EV connected to the network and a vehicle remains idle are used to estimate the percentage increased in load when electric vehicles are connected to the network in charging mode. The consolidated load forecasting analysis was assimilated into standard IEEE test case to solve the hourly economic dispatch problem. Different case studies were carried out to understand the effect of electric vehicles when they are connected to the network in charging mode. From the developed ED solution, it is understood that electric vehicles have a valley filling effect during non-peak hours and higher peak load during peak hours. As a measure to moderate the uncontrolled charging of EV, a control charging scheme is proposed. With this scheme, it could be observed that the total operating cost and generated power is reduced as compared to uncontrolled charging.

ABSTRAK

Kemajuan pesat kenderaan elektrik (EV) menawarkan industri pengangkutan masa depan dengan penyelesaian berpotensi tinggi terhadap kebimbangan alam sekitar. Walau bagaimanapun, ini juga membawa cabaran baru kepada ekonomi dan kebolehpercayaan rangkaian kuasa. Dengan ketibaan kenderaan elektrik berskala besar, pengendalian sistem menjadi sukar dikendalikan kerana sifat pengecasan kenderaan elektrik yang tidak terkawal. Penyelidikan ini akan melaksanakan penyelesaian penghantaran economi (ED) setiap jam dengan ketibaan kenderaan elektrik sebagai beban tambahan kepada sistem. Menggunakan data yang direkodkan setiap jam untuk keadaan cuaca yang berbeza yang diperolehi dari Suruhanjaya Tenaga Malaysia, data simulasi dapat mencontohi rangkaian sistem kuasa sebenar. Kebarangkalian setiap jam EV yang disambungkan ke rangkaian dan kebarangkalian kenderaan tetap telah digunakan untuk menganggarkan peratusan meningkat dalam beban apabila kenderaan elektrik disambungkan ke rangkaian dalam mod pengecasan. Analisis ramalan beban yang disatukan telah diasimilasikan ke dalam kes ujian IEEE untuk menyelesaikan masalah penghantaran ekonomi setiap jam. Kajian kes yang berbeza telah dijalankan untuk memahami kesan kenderaan elektrik apabila ia disambungkan ke rangkaian dalam mod pengecasan. Dari penyelesaian ED, hasil kajian menunjukkan bahawa kenderaan elektrik mempunyai kesan pengisian lembah semasa waktu tidak sibuk dan beban puncak yang lebih tinggi pada waktu puncak. Sebagai langkah untuk menyederhanakan pengecasan EV yang tidak terkawal, skim pengecasan kawalan dicadangkan. Dengan skim ini, hasil kajian menunjukkan jumlah kos operasi dan kuasa yang dihasilkan dikurangkan dibandingkan dengan pengecasan yang tidak terkawal.

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First and foremost, I would like to take this chance to thank my supervisor, Prof. Ir. Dr. Hazlie Mokhlis. With his knowledgeable technical background and strict guidance, I managed to conduct proper research methodology and technical writing along this presented work.

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LIST OF ABBREVIATIONS

GHG	Greenhouse Gas
ICE	Internal Combustion Engine
EV	Electric Vehicle
BEV	Battery Electric Vehicle
HEV	Hybrid Electric Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
IPCC	Intergovernmental Panel on Climate Change
ISO	Independent System Operator
TNB	Tenaga Nasional Berhad
V2G	Vehicle to Grid
LF	Load Flow Analysis
ED	Economic Dispatch
UC	Unit Commitment

LIST OF SYMBOLS

NB	Total number of buses
NG	Total number of generators
NEV	Total number of electric vehicles
NT	Total operational periods
λ	Lagrange multiplier
P_i	Active power of bus *i*
V_i	Voltage of bus *i*
δ_i	Voltage angle of bus *i*
$P_{gi}(t)$	Active power generated of generator *i* at time *t*
$P_D(t)$	Active power demand at time *t*
$P_L(t)$	Active power loss at time *t*
$R_i(t)$	Operating reserve *i* at time *t*

CHAPTER 1: INTRODUCTION

1.1 Overview

As global economies shift toward low carbon society, the environmental concern over drastic climate change and the production of Greenhouse Gas (GHG) have been steadily increasing. (M.E. Khodayar, Wu, & Li, 2013; M.E. Khodayar, Wu, & Shahidehpour, 2012). As more people are aware of the consequences of pollutions, environmental friendly products are gaining support at a steady pace. For example, zero carbon emission transportation such as Electric Vehicle (EV) have been receiving a lot of attentions.

This research present an hourly economic dispatch (ED) solution to effectively study the operation of power system with the additional of new components such as electric vehicle. In this research, the ED solution will consider EV as additional load when the EVs are in charging mode. At any given moment, the total generated power must be greater than or equal to the total power demand, additional power demand by electric vehicle during charging phase and the system losses.

In usual IEEE test case, only one load demand is provided for optimization. In this study, the time horizon is 1 day which consists of 24 periods of 1 hour. This is to illustrate the hourly scenario in a day. Also, due to meteorological conditions (hot in sunny day, and cold in rainy day), the hourly variations in power demand are different. Thus, a load demand profile is established based on daily log sheet reports by the Malaysia Energy Commission. These data consists of load demand at every hour in peninsular Malaysia. The daily load demand data was extracted and modeled into IEEE test system.

In order to understand the effect of EV as a load, different case scenarios was simulated in this study. At every hour, the power generated by each generator and the operating cost has been recorded and plotted in a graph. Also, the solution will then compared to the standard economic dispatch solution to understand the effect of electric vehicle as a load in the power system. To minimize the operating cost and operating cost of generators, a controlled charging scheme is also proposed. In control charging scheme, the operators is able to control the charging activities of EV.

1.2 Problem Statement

Electricity is the major energy carrier for energy consumers and an instantaneous commodity, which in principle restricted in storing large amount (Bhuiyan & Yazdani, 2012). The integration of EVs into the daily operation of power grid imposes many challenges such as voltage fluctuation (Kamiya et al., 2013) and system overload which may lead to system breakdown (Guibin, Fushuan, Zhao, & Kit Po, 2013).

Therefore, it is crucial for system operators to take an action on when and where the EVs to be judiciously connected or disconnected. With advent of large-scale EV, the operation of the system becomes manageably arduous and in some extreme cases can harshly jeopardize the normal operation conditions (Guibin et al., 2013). The challenge is to minimize operating cost for generation in power system while satisfying critical constraints such as generators limit and losses with the charging activities of EV.

To ensure the stability of the power network, proper monitoring scheme like Economic Dispatch (ED) is developed. The ED will solve the optimal generation of generators with the charging activities of electric vehicles. This, however, reforms the conventional formulation for generation scheduling problem comprising a set of new objective and constraints.

1.3 Research Objectives

The aim of this research is to develop an economic dispatch solution, which effectively consider EV as a load in the power system network. The objectives as below:

1. To implement economic dispatch with consideration of electric vehicle charging mode
2. To analyze the economic dispatch solution of generators with and without EV charging activities
3. To analyze the different load demand profile based on weather condition with and without EV charging activities

1.4 Research Scopes

This research will establish hourly economic dispatch solution considering the arrival of electric vehicles as an additional load to the system. The simulation will be conducted for mainly for two case scenario which is economic dispatch without electric vehicle (standard economic dispatch problem) and economic dispatch with electric vehicle as load. System constraints such as generation limit and power balance constraints have been taken as consideration in the simulation.

1.5 Research Outline

The research report is categorized into five chapters. In chapter one, an overview of the research background is presented along with the problem statement, research objectives and research scopes.

Chapter two mainly discussed on the literature review of the research. The current Malaysia energy outlook is discussed in details based on data obtained from the Malaysia Energy commission and the Ministry of Transport of Malaysia. In addition, electric vehicle technologies and its impact on the grid is also discussed.

In chapter three, the proposed method of implementing the simulation is presented. Also, different case studies to study the impact of EV as load are also presented.

In Chapter four, the results are tabulated from the proposed case studies and analysis are conducted to study the scheduling trend of power generators with EV and without EV as a load.

Finally, the conclusion and significant of this research are presented in chapter five. Recommendation for future research work is also discussed in this chapter.

CHAPTER 2: LITERATURE REVIEW

2.1 Electricity Generation & Distribution in Malaysia

As shown in Figure 2.1, Malaysia still greatly relies on petroleum based fuel type for electricity generation ("Fuel Input to Power Stations by Fuel Types," 2014). With the impending climate change, utilizing clean source of energy will be the key to capping carbon emission.

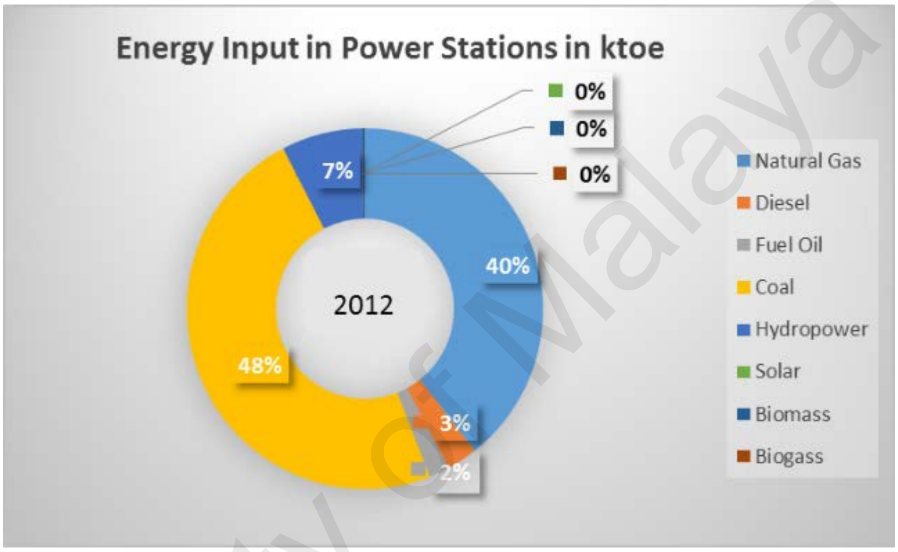


Figure 2.1: Energy Input in Power Station in ktoe

Total maximum demand in the country is currently 17,788 MW last recorded by Tenaga Nasional Berhad (TNB) in April 2016. Malaysia depends primarily on two major fuels with gas and coal contribution 49.4% and 42.6% to our power generation. This is followed by hydroelectric at 4.8% and oil/distillate at 2.5% ("Peninsular Malaysia Electricity Supply Industry Outlook 2014," 2014).

Currently, Malaysia is following the five-fuel diversification strategy plan energy mix which executed in the year 1999 (Ong, Mahlia, & Masjuki, 2011). Based on this plan, the Malaysia energy mix consist of give major sources, which are coal, oil, natural gas, hydro and renewable energy. In addition, the Malaysia government has introduced a new programme in 2001 to encourage the utilization and installation of renewable energy in the power network.

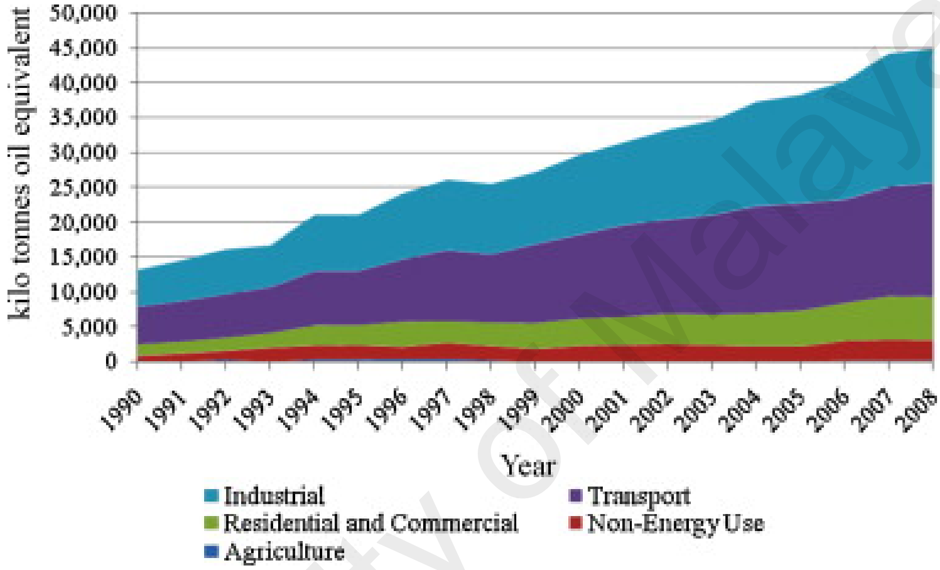


Figure 2.2: Malaysia Energy Consumption by sector

The challenge faced by the Malaysia power sector is the issue of sustainability. As shown in Figure 2.2, Malaysia is still a developing country, the electricity demand is expected to rise along with the growth of the country. Based on (Ong et al., 2011), the energy consumption has increased significantly from 1990 to 2008. This is mainly due to rapid development of the country in terms of industrialization and urbanization.

2.2 Environmental Concerns

As the public awareness of air pollution and Green House Gas (GHG) increases, the vehicle users have started to utilize more environmental friendly vehicle such as Battery Electric Vehicle (BEV) & Plug in Hybrid Electric Vehicle (PHEV) (IPCC, 2013; Labatt & White, 2007).

As shown in Figure 2.3, the Malaysian Ministry of Transport (MOT) record show that 97% of vehicles registered was an Internal Combustion Engine (ICE) vehicle (Malaysia, 2012).

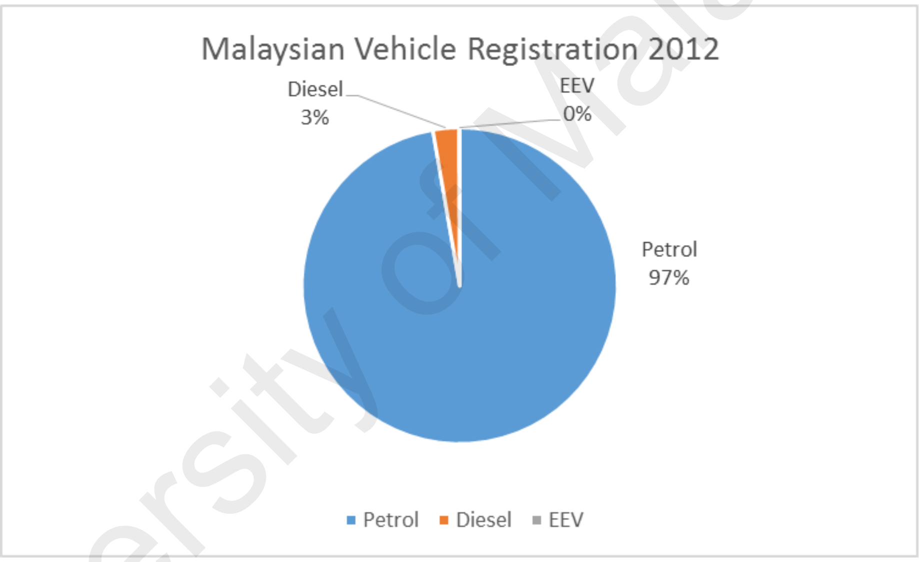


Figure 2.3: Type of Malaysian Vehicle Registration 2012

The issues with ICE vehicles are low efficiencies, harmful exhaust emissions and noise pollution. Modern petroleum or gasoline ICE can achieve a maximum efficiency of 25% from the fuel supplied (Baglione, 2007; Takaishi, Numata, Nakano, & Sakaguchi, 2008). The rest of the energy released by petroleum is used to overcome the fuel conversion inefficiencies rather than useful work. Losses are also generated through noise, vibration, and power used to cool the engine.

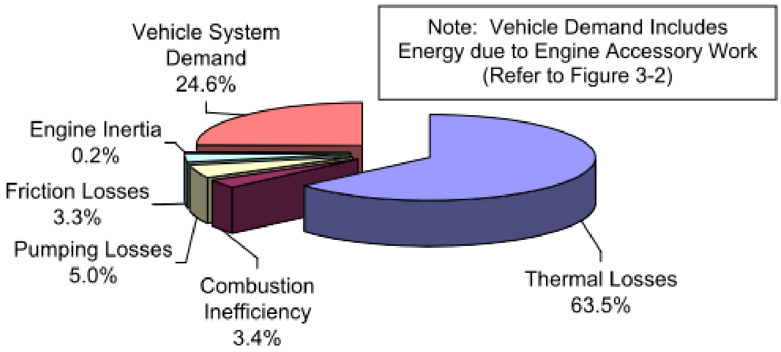


Figure 2.4: ICE energy usage (Baglione, 2007)

As shown in Figure 2.4, Diesel ICEs are more efficient compared with petroleum engines, the increased efficiencies of 40% is achieved by utilizing turbocharging technology (Hiereth & Prenniger; Takaishi et al., 2008).

However, the energy losses and the harmful combustion exhausts to the environment demonstrate ICE vehicles are not sustainable due to loss of valuable energy resource and environmental concerns.

Malaysia adopts the European standard for emission regulation. In recent news, MITI announced nationwide implementation for EURO4 Ron 97 petrol was achieved in September 2015 and sales of EURO5 Diesel in Johor have already begun and plans to distribute the cleaner fuel to other States are ongoing. However, MITI had announced EURO4 Ron 95 will be implemented by 2018 (*Updates of NAP 2014 and EURO 4*, 2014).

Although the emissions of Nitrogen Oxide (NOx), carbon monoxide, hydrocarbon, non-methane hydrocarbon, and particulates are regulated and controlled by the emission controls in both fuel and vehicle engines, the volume of vehicles entering the environment will continue to present a challenge to the GHG and environment for clean air, especially in major cities where vehicle concentration is high.

The geographical setting of Malaysian cities have always been spread over a wide surface area. Subsequently, the low penetration of public transport in the meantime has brought upon the necessity for car ownership. In future development, the recent announced “Malaysia National Automotive Policy” plans to progress Malaysia as the regional automotive hub in energy efficient vehicles (EEV) (*Malaysia National Automotive Policy*, 2014).

The government policies was successful in creating a slow shift toward public adoption of EEV. Malaysian Ministry of Transport (MOT) records showed an increase of 1% in EEVs and a corresponding drop in of ICE vehicles registered in 2013 to 96% (Malaysia, 2013).

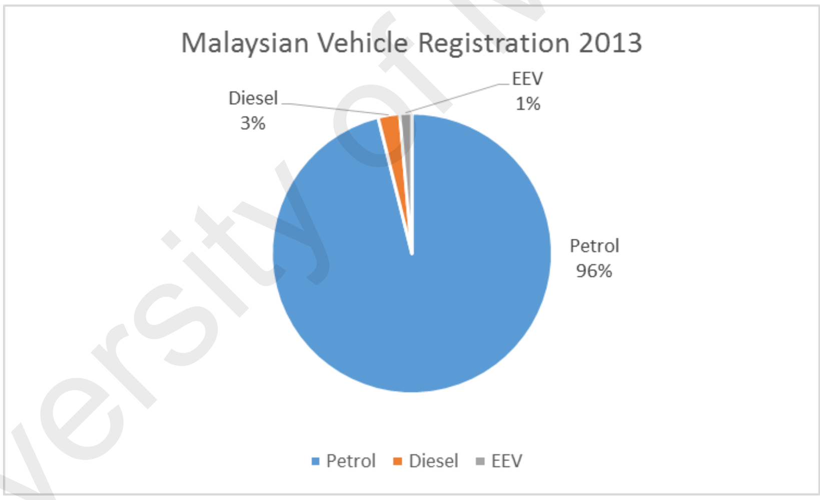


Figure 2.5: Type of Malaysian Vehicle Registration 2013

In contrast, the PHEV and BEV vehicles are able to reduce petroleum consumption and GHG by a factor shown in Table 2.1 (Elgowainy, Burnham, Wang, Molburg, & Rousseau, 2009).

Table 2.1: PHEV Petroleum use and GHG emissions compared with ICE vehicles

Fuel Mixture of PHEV	Fuel savings	Reduction in GHG emissions
petroleum fuels (gasoline and diesel)	40–60%	30–60%
blend of 85% ethanol and 15% gasoline (E85)	40–60%	40–80%
hydrogen	more than 90%	10–100%

The savings BEV (which are purely electric cars) can achieve compared with above technologies are significant. BEVs plug-in into the electric grid and their petroleum use and GHG emissions is nil. PHEV vehicles and BEVs are also known to be quiet which is a benefit to areas with high concentrations of vehicles from noise pollution point of view.

2.3 Potential of Electric Vehicle in Malaysia

In the last decade, private vehicle ownership has seen rapid growth. The Malaysian government has responded to the growing transportation needs by constructing the MRT Line 1 (Sg Buloh – Kajang) and has recently approved the MRT Line 2 (Sg Buloh – Serdang – Putrajaya) under the Greater Kuala Lumpur / Klang Valley (GKL/KV) NKEA in 2014 (Pemandu, 2014). However, these efforts are insufficient to meet the demand of the urbanization and rise in motorization in Malaysia (cars, motorcycles, public vehicles such as taxis, buses and freight vehicles). Data from the Malaysian Department of Statistics show the demand for vehicles is not abating, with 666,500 vehicles registered for year 2014 alone (*Compendium of environment statistics: Malaysia*, 2015).

Environmental anxieties over climate change and GHG production and have been gaining Government's attention on its adverse economic & environmental effect. The 2014 National Automotive Policy (NAP) has focused its attention on pursuing greener initiatives, human capital and advancement of technology, and the enhancement & expansion of the automobile industry. One of the NAP initiatives is to encourage the automotive industry to adopt advanced technologies and develop high Energy Efficient Vehicles (EEV) (*Malaysia National Automotive Policy*, 2014). Although the number of vehicles that uses electric energy as fuel is currently low, the NAP policies have the potential to change the landscape for EEV use and create a significant shift in the role of power electronics in vehicles in the possible future.

The low penetration of public transport in Malaysia has brought upon the necessity for vehicle ownership. As shown in Figure 2.6, the majority of vehicle ownership in Malaysia is motorcycles (11,383,838 units) followed by passenger vehicles (10,867,907 units) (Transport, 2014).

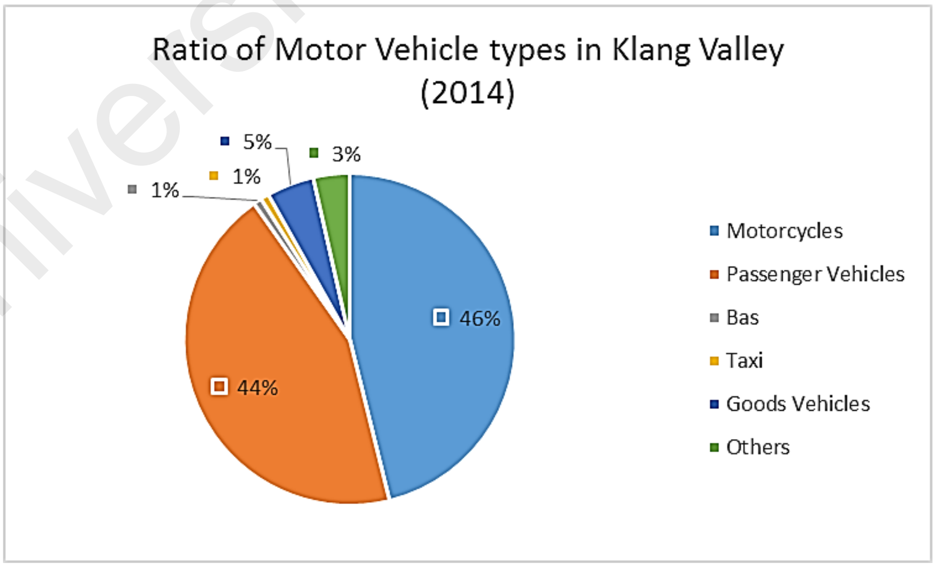


Figure 2.6: Ratio of Motor Vehicle types in Klang Valley (2014)

The 2014 Malaysian National Automotive Policy (NAP) plans to develop Malaysia as the regional automotive hub for energy efficient vehicles (EEV).

The 2014 NAP’s stated goals (*Malaysia National Automotive Policy*, 2014) are to:

- Develop a competitive and capable automotive industry domestically
- Develop Malaysia as a regional automotive hub in producing EEVs
- Increase value-added and sustainable business opportunities to support the automotive industry
- Increase exports of vehicles, parts, and services to regional manufacturing and service sectors
- Create and enhance an ecosystem of a sustainable automotive market and industry
- Improve consumer benefits with high quality and safe products with lower cost of ownership

The Malaysian Transport statistics (Malaysia, 2012) indicated the total vehicles registered in 2012 for Malaysia was 22 million vehicles. This number grew to 23.8 million vehicles in year 2013 (Malaysia, 2013) indicating a 7% growth in vehicles ownership.

During this period, PHEV contributed significantly to the growth of EEV vehicle ownership. The growth in PHEV is due in part to the Malaysian government policies of promoting PHEV vehicles through import tax and excise duty exemption incentives. The NAP 2014 import tax and excise duty exceptions for PHEV will continue to run from 1 January 2014 to 31 December 2015 and is expected to further promote market growth for PHEVs. However the subsidies for PHEVs dampened the demand for BEVs at the same time.

Table 2.2: PHEV & EV Comparison

	2012	2013	% Increase
PHEV	391	16,866	4200%
BEV	292	248	-15%

The NAP 2014 came to realize the importance of BEVs in achieving NAP's goals and has also implemented similar import tax and excise duty exception incentives to BEVs that will be effective from 1 January 2014 until 31 December 2017. This will promote the BEV market to grow.

NAP 2014 also aims to promote the development of EEV (PHEV and BEV) infrastructure and public charging facilities to achieve the penetration rates similar to those achieved by petrol stations for Internal Combustion Engine (ICE) vehicles. This will promote public adoption of EEV technology which is currently restricted by the unavailability and slow penetration rates of EEV infrastructure.

The Malaysian government is providing incentives through the NAP 2014 policies to encourage the development of automotive industry technologies for vehicle sub-systems such as power train components, transmissions, lightweight materials, batteries, and software.

The Ministry of Education (MOE) has established the Industry Centre of Excellence (ICOE) as a platform to develop human capital for the EEV industry. The ICOE will coordinate activities for research, development of standards, design, manufacturing, and testing facilities with local universities and the private industry.

The synergy created by the collaboration of universities with the automotive industry will be critical for the potential of EEV in Malaysia to take off.

One way of storing electrical energy is to convert it to another form of energy, for example pumped storage hydroelectricity or to a chemical energy in the form of battery, which is prohibitively high in cost. However, EV can change the landscape and open up new opportunities to store energy in battery equipped vehicles if they are made available to the network during peak power demand. EV acts as an electrical load during the charging and as a source of power during dispensation of power. In this case, electric vehicles are able to act as a mobile energy storage when connected to the grid supplying energy during peak power demand. (Haris, 2009). This bidirectional power flow application is considered as Vehicle to Grid (V2G) (Kanellos, 2014).

By incorporating electric vehicle with the national power network, many beneficial elements can be gained, such as reducing the likelihood of power shutdown. Furthermore, when power stations running on fossil fuel are not operating in full load, GHG emissions can be reduced greatly. This joint effort of incorporation between power sector and transportation will positively provide high efficiency gain for both organization.

2.4 Vehicle to Grid Concept

In V2G concept, EVs are linked up to the nationwide electric network in order to provide energy to the network during peak hours.(M.E. Khodayar et al., 2013; S. Wang, Zhang, Li, & Shahidehpour, 2012). The energy returned to the electricity grid is basically the same (i.e. excess energy) generated by the power grid during non-peak hours. Assimilating EV and electricity grid will enable the power system to draw on the EV power during peak hours and for EVs to charge its batteries during off-peak hours.

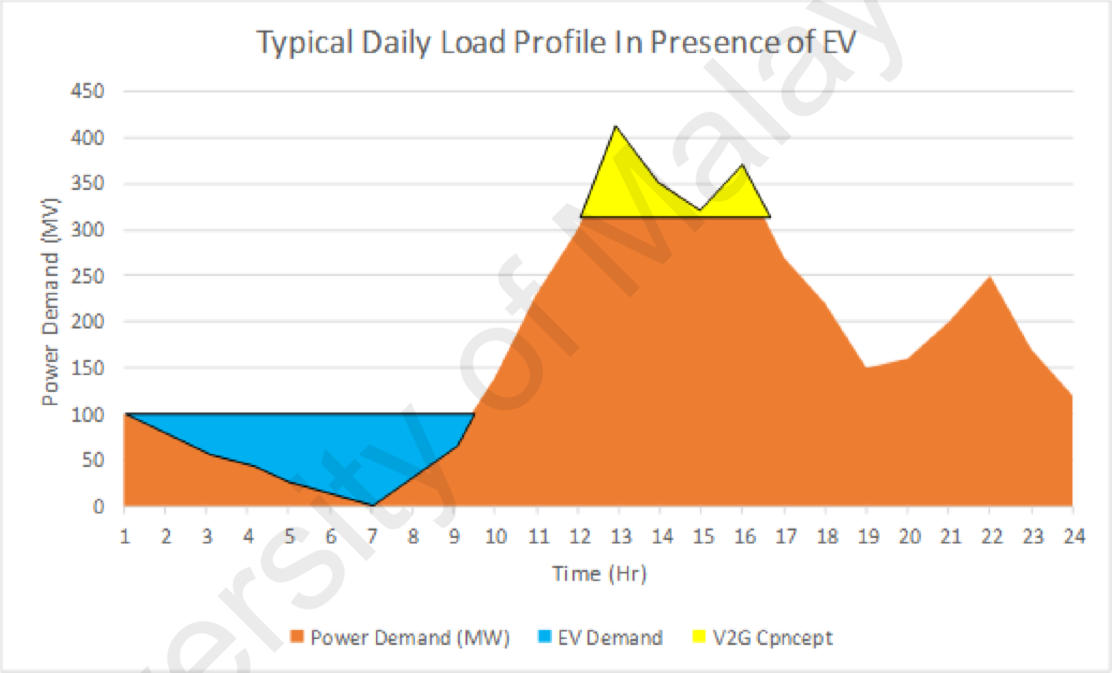


Figure 2.7: The effect of EV in daily load profile

With V2G technology, two way power flow between electrical network and EV fleets can be realised. During peak periods such as noon, EV fleets can be used to supply energy to grid to satisfy the extra power demand. In this case, EV fleets have a peak shaving effect on the load profile. During off-peak hours, electric vehicles will be programmed to charge the vehicles. This case typically has a valley filling effect on the power grid as shown in Figure 2.7.

V2G utilization is considered new to the industry but it is picking up interest in the research community. Several universities, such as the University of Delaware) have started research into (S. Wang et al., 2012; Yu, Li, & Lam, 2013) technical influences of V2G on the power network. Other research (H.Zeynal, Y.Jiazhen, B.Azzopardi, & M.Eidiani, 2014; M.E. Khodayar et al., 2012; Yu et al., 2013) are carried out to improve the efficiency of V2G operation based on different scheduling strategy (e.g. using deterministic & heuristics methods).

The key driver of V2G will come with the modernization of electrical utility using smart grid technologies. Smart grid takes advantage of the existing IT technology to adopt use of peer-to-peer communication, continuous monitoring and flexible network topology to manage power distribution. Smart grid technologies in measurement and metering are currently available to model generation and distribution networks in real time. With Feed in Tariffs, advanced tariff or energy payments systems will help accelerate technology adoption for V2G as a means to supply power back to the grid.

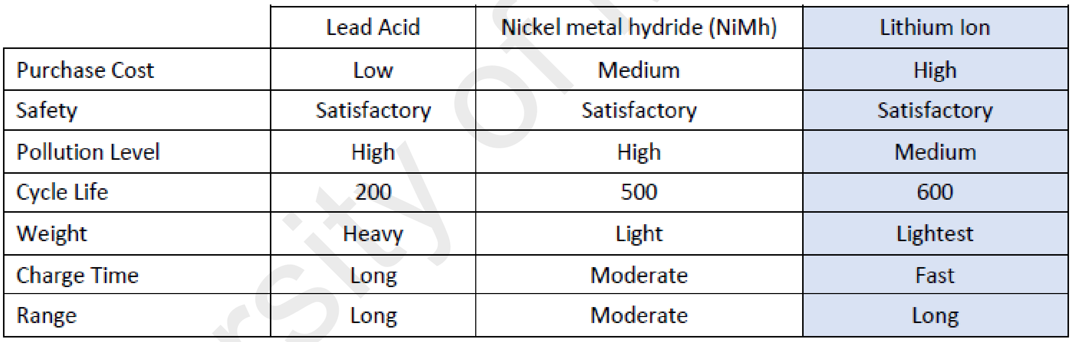
2.5 Electric Vehicle Technologies

EV technologies have evolved and advanced through the years. Currently, researchers are primarily focusing on improving the efficiency and performance of electric vehicle. (Emadi, 2011). That being said, the single most important component of the electric vehicle is the battery. As compare to batteries found in conventional vehicles; which its main function is to start up the engine, the battery of electric vehicle is to energize the entire car throughout its journey.

In recent years, many extensive research has been made to improve the performance of EV batteries. For example, large corporate company such as Google and Tesla have invested multi-millions dollar into the research of electric vehicle advancement. (Dickerman & Harrison, 2010). Likewise, conventional car manufacturers have also started making their own electric vehicle models. In the automobile market, PHEV is still the popular choice as compare to EV. This is due to the fact that EV infrastructures such as charging station are still lacking in numbers. However, the gradual implementation of smart grid infrastructures will definitely boost the numbers of EV.

Presently, lithium ion battery lead the electric vehicle battery market. Their superior performance and range per charge outclassed the other two conventional battery. Table 2.3 summarize the batteries comparison used in EV.

Table 2.3: EV Batteries Comparison



	Lead Acid	Nickel metal hydride (NiMh)	Lithium Ion
Purchase Cost	Low	Medium	High
Safety	Satisfactory	Satisfactory	Satisfactory
Pollution Level	High	High	Medium
Cycle Life	200	500	600
Weight	Heavy	Light	Lightest
Charge Time	Long	Moderate	Fast
Range	Long	Moderate	Long

From the time when automobile was invented, the fuel used to propel the vehicles have always been the internal combustion engine (ICE). Till now, the modern vehicles still utilizes the same technology.

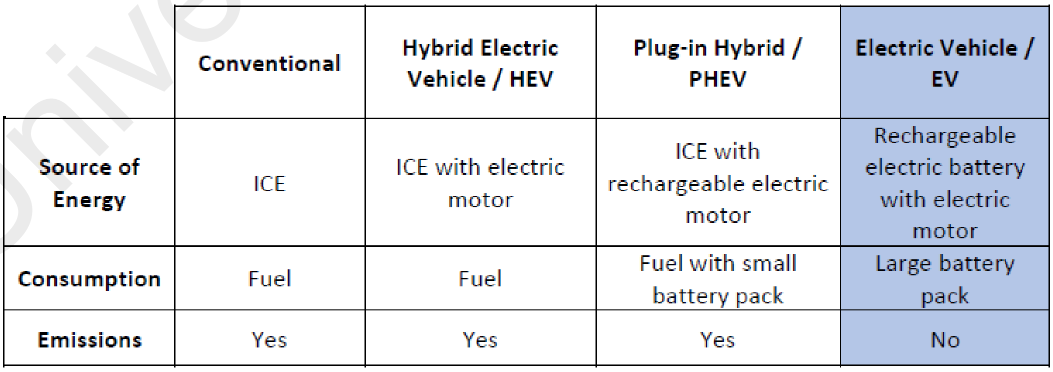
On the other hand, hybrid vehicles uses a compact electric battery on top of the conventional ICE system. A further utilization of this concept is the Plug-in Hybrid Electric Vehicle (PHEV). It uses the same internal combustion engine but with a bigger battery pack. At such, PHEV can be connected to the power network to charge and discharge according to the load profile. The utilization of both ICE and battery is able to increase fuel efficiency. However, the shortcoming of this concept is that it still produces carbon dioxide.

Battery Electric Vehicle (BEV) are operated purely on electric. At such, they are not equipped with any internal combustion engine. They are also known as Electric Vehicles (EV) in general. To compensate for the lack of internal combustion engine to propel the vehicle, electric vehicle are installed with large battery bank. Without any internal combustion engine, the vehicle emits zero carbon dioxide also.

Table 2.4 categorized the different features of different vehicles type.

References (M.E. Khodayar et al., 2013; S. Wang et al., 2012; Yu et al., 2013) primarily concentrate on EV integration while (G. Li & Zhang, 2012) focuses on both PHEV and EV. In this report, only electric vehicle, which purely operates on electric are considered in the simulation.

Table 2.4: Categorization of Different Vehicle Type



	Conventional	**Hybrid Electric Vehicle / HEV**	**Plug-in Hybrid / PHEV**	**Electric Vehicle / EV**
Source of Energy	ICE	ICE with electric motor	ICE with rechargeable electric motor	Rechargeable electric battery with electric motor
Consumption	Fuel	Fuel	Fuel with small battery pack	Large battery pack
Emissions	Yes	Yes	Yes	No

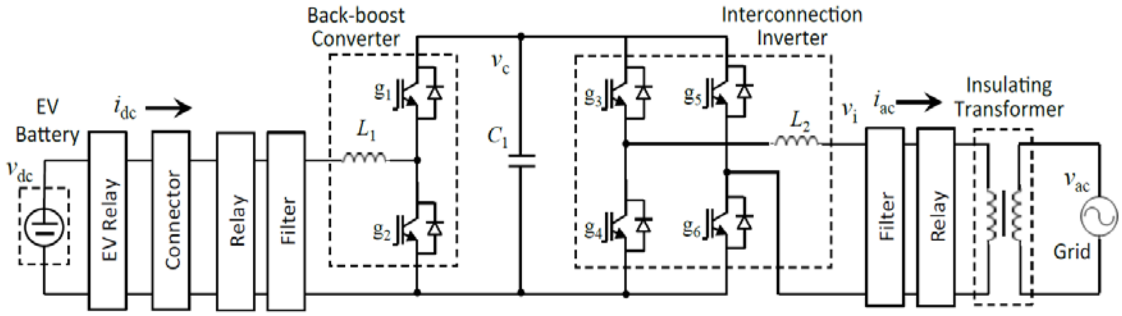


Figure 2.8: Electric Vehicle Power Electronics Topology

In V2G Operation, one important role power electronics will play is in its application for managing bidirectional flow of power between the EV's battery and grid.

Figure 2.8 illustrated the fundamental topology of V2G configuration adopted from (Ota et al., 2012). The realization of the bidirectional power flow between the EV's battery and grid is by utilizing conventional power electronics circuit which consists of a DC-DC Buck Boost Convert, Bidirectional Inverter and protection circuits (relay & filter). In order to monitor and control the incoming & outgoing voltage to protect the battery, the EV battery pack is linked to the DC-DC converter with protection layer such as analog filter to suppress ripple waves of DC current. Conversely, the bidirectional inverter manage the V2G operation when connected to the grid. The placement of harmonic filter and relay are to protect against inrush current of the insulating transformer.

In EV charging mode (G2V) (Agatep & Ung, 2011), an AC source is filtered to remove harmful harmonics, then the bidirectional inverter rectified the clean AC source into DC source. Then, the bidirectional DC-DC (Buck Boost) converter step up the voltage to equalize the voltage of the battery in order to safeguard suitable charging parameters.

Conversely, in EV discharging mode (V2G) (Agatep & Ung, 2011), the operation is then inverted. The bidirectional DC-DC converter step down battery voltage equivalent to grid parameter. Next, the bidirectional inverter modulate the DC waveform into AC waveform which is acceptable to the grid.

2.6 Generation Scheduling Problem

The optimal generation scheduling problem comprises the solution of two very different problems. The first one is a pre dispatch problem or unit commitment problem. For this, the system operator is required to select the most optimal generating sources out of the generation pool in order to meet the forecasted load in that hour. Also, a specific margin of operating reserve should be available for a specified amount of time. The second stage of the generation scheduling problem is the economic dispatch problem. For this, the system operator is required to allocate the load among the selected generating sources while considering system constraints in such a way that the operating cost is optimized.

2.6.1 Economic Dispatch Problem

To further elaborate, the economic dispatch problem can be defined as the manner of distributing generating power to the selected generating units, in such a way that the system load is fully supplied and is the most economical solution. (Grainger & Stevenson, 1994; Mahor, Prasad, & Rangnekar, 2009; Zwe-Lee, 2003). For a huge interconnecting system, it is vital to keep the operating expenses at a minimum. The objective is to regulate and control the generation of different power plants in the network such that the overall operating cost is at the most minimum level(Al-Roomi & El-Hawary, 2016). Simultaneously, the total load demand and the system losses must be fulfilled with the total generation. The algorithms of economic dispatch for different generating units at different load demands must consists of total fuel cost at the most economical cost. (Grainger & Stevenson, 1994; Mahor et al., 2009; Zwe-Lee, 2003).

2.6.2 Operating Cost of Thermal Power Plant

A thermal power plant is a generating unit which utilizes fossil fuel to drive the prime-mover of the generator. The basic principle of the mechanism is fluid dynamics. The water is heated in a boiler and the resulting steam circulate the steam turbine to provide work to the rotor shaft of the generator. After the steam passes through the turbine, it will be condensed in a huge condenser to turn it into water again. Thus, the cycle begins again with the water being heated in a boiler. The process of this can be mathematical modeled as a transfer function of fossil fuel energy to electricity.

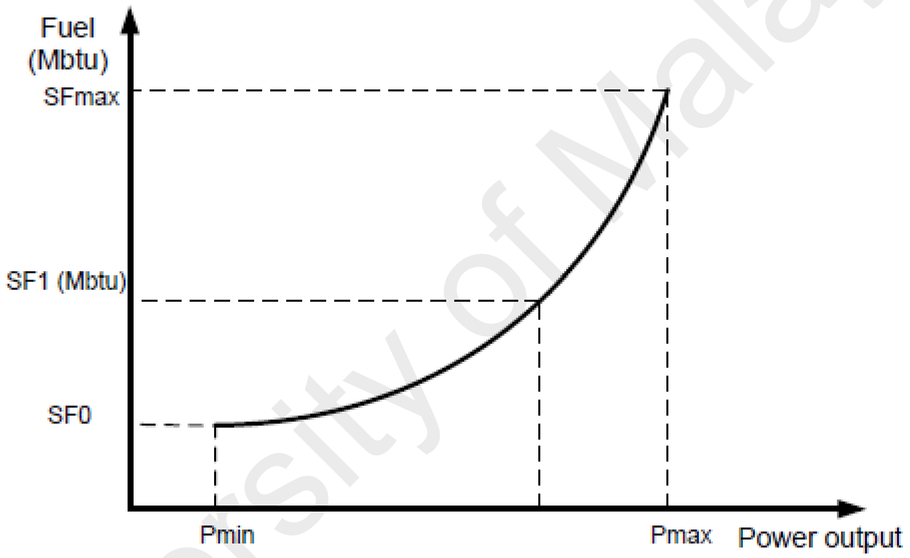


Figure 2.9: Thermal Power Plant Heat Rate Curve / Cost Function Curve

As illustrated in Figure 2.9, the generation data of a power plant can be characterized by a cost function curve. As there are many type of generators, the cost function for every generator is unique to one another. The representation of the cost function curve are influenced by a few factors, such as cost of fuel, operating efficiency of generation and losses during transmission. The British thermal unit (Mbtu) is the portion of heat rate exhausted by a generator to distribute an exact volume of power (MW).

2.6.3 System Constraints

There are numerous factors that can be modeled into the scheduling strategy. For example, generator cost functions, generator limits, transmission loss, transportation fuel, prohibited zone, ramp rate limit, and labor cost.

The Kron's loss formula can be used to calculate transmission losses or system losses in the network. The formula calculate losses utilizing Beta coefficient in which is assumed to be a constant in the network. This is usually expressed in a matrix.

The ideal power network is a system with maximum efficiency and zero loss. In such case, transmission loss that resulted from generation stage to distribution stage is ignored. Generally, this case scenario is often used as a base comparison to observe power network in operation.

In a practical network, the generation units and the distribution area are usually spread across a huge area. During transmission of power, loss of power occurs due to the long transmission line that interconnect power plants to residential or commercial area.

In this report, only the basic system constraints such as power balance constraints, generator limits and transmission loss are considered in the simulation.

2.7 Economic Dispatch considering Electric vehicle

It is estimated that the number of EVs in the world to be around 35 million by the year 2022 (Liu, Kong, Liu, Peng, & Wang, 2015). But, the high penetration of EV brings new challenges to the economic and reliability of power network. The system operators will be faced with a huge magnitude of charging demand and the operation of the system becomes manageably arduous.

Thus, research such as (Yin, Wenzhong, Momoh, & Muljadi, 2015) and (Sufen, Youbing, & Jun, 2012) implemented economic dispatch solution to investigate the random charging nature of EV and their impacts to the power network. Also, papers such as (Arias & Bae, 2016) and (Chunlin et al., 2012) developed load forecasting model based on charging activities of electric vehicle. These studies investigate the relationship between number of electric vehicles and the heavy electricity demand to the power network.

In (Mwasilu, Justo, Kim, Do, & Jung, 2014), one of the effective way to control the random charging activities of EV is by integrating renewable energy sources such as solar energy and wind energy with the EV charging infrastructures. However, renewable energy sources are often unpredictable and fluctuate over time due to the dependency of different weather conditions.

On the other hand, smart grid technologies provide bidirectional communications between power network operators and power consumers such as EVs (Tan, Ramachandaramurthy, & Yong, 2016). This will allow on-line monitoring and flexibility in power coordination. Along this line, many recent research efforts have put their attention on the possibilities of EV charging activities can be monitored and controlled by the system operator, with an economic dispatch method.

As a result, controlled charging scheme has been integrated into economic dispatch solution to regulate the charging activities of electric vehicles. Currently, as the EV penetration is still low, analysis was simulated based on high EV penetration in the country and forecasted data on number of electric vehicles and its future demand (Guibin et al., 2013). Most economic dispatch are solved using load demand profile obtained from the place of study. For example, China (Z. Wang & Wang, 2013), Japan (Qi, Tezuka, Esteban, & Ishihara, 2010) and USA (M.E. Khodayar et al., 2012).

CHAPTER 3: METHODOLOGY

The steps and methods to perform economic load dispatch considering the arrival of electric vehicle will be covered in detailed in this chapter. The simulation will be conducted in MATLAB environment.

The proposed simulation was firstly tested on a simple system and then on standard IEEE 26 bus with 6 generating units test system. Comparison was made between economic dispatch solution without EV and with EV.

The scope of this research as stated in chapter 1.4, is to simulate economic dispatch with the arrival of electric vehicle as load. This solution will then compared to the standard economic dispatch solution to understand the effect of electric vehicle as a load in the power system.

In order to understand the scheduling trend, the economic dispatch problem was solved for each hour in a day to illustrate the hourly load scenario. This will portrait the operating level of the online generating units in the system. Due to meteorological conditions (hot in sunny day, and cold in rainy day), the hourly variations in power demand are different and the load curve are very steep. Thus, the two case scenario with different weather conditions were incorporated in this simulation.

3.1 Economic Dispatch with the arrival of Electric Vehicle

With V2G technology, two way power flow between electrical network and EV fleets can be realised. During peak periods such as noon, EV fleets can be used to supply energy to grid to satisfy the extra power demand. During off-peak hours, electric vehicles will be programmed to charge the vehicles. In this simulation, EV will only serve as a load component.

The economic dispatch distributes generating power to the selected generating units in the system. In summary, the objective is to optimize the operating cost of power plants subject to system constraints.

Generally, the generator basic cost function are expressed in quadratic functions. The cost coefficient a, b, c are the indicator of the estimated curve fittings limits for the cost function. The variable NG represent the number of generating units in the system while the variable i represent the number of generators in the system. In day ahead scheduling, the variable t represent the hourly scenario. This can be mathematically express as:

$$minimize \ \ \sum_{t=1}^{NT} \sum_{i=1}^{NG} (a_i P_{gi}^2(t) + b_i P_{gi}(t) + c_i) \tag{3.1}$$

By means of a safety preventive measure and reliability requirement, power network operator have outline numerous constraints to ensure system security and to avoid critical system breakdown. Power balance constraints is expressed in Equation (3.2). At any given moment, the total generated power must be greater than equal to the total power demand and the system losses. In other words, the power balance constraints must be fulfilled to avoid system breakdown. In the equation, P_L represent the losses while P_D represent the power demand. P_G is the power generated by the generators in the system.

$$\sum_{i=1}^{NG} P_{gi} \, (t) \geq P_L(t) + P_D(t) \tag{3.2}$$

With the arrival of EV as a load, the formula is reformulated and expressed in Equation (3.3). At any given moment, the total generated power must be greater than or equal to the total power demand, the power demand by electric vehicle during charging phase and the system losses. P_{EV} represent the power demand by electric vehicle during charging phase.

$$\sum_{i=1}^{NG} P_{gi}(t) \geq P_L(t) + P_D(t) + P_{EV}(t) \tag{3.3}$$

In an economic dispatch problem, all the selected power plants are subjected to a pre-specified generation output limits which consists of maximum and minimum output bounds. In other words, generator limits constraint prevent the generators to run lower or above than the pre specified maximum and minimum capability of producing power. This is mainly due to the techno-economical limits of each generator. This limitation is expressed in Equation (3.4).

$$P_{gi}^{min} \leq P_{gi} \leq P_{gi}^{max} \tag{3.4}$$

As the influx of electric vehicle fleets are unpredictable, a safeguard mechanism must be put in place to ensure no system breakdown. A reliable approach is to keep sufficient spinning reserve to make sure that the available power generation capacity is always more than the demanded load. An operating reserve will maintain the power balance constraints at each interval of the system operation. This is to make sure the system power balance is safe from unexpected disturbance. The variable R represent the reserve power in the system.

$$\sum_{i=1}^{NG} P_{gi}(t) \geq P_L(t) + P_D(t) + R_i(t) \tag{3.5}$$

3.1.1 Flow Chart of Economic Dispatch

The proposed economic dispatch solution flow chart is depicted in Figure 3.1. In this study, a mathematical iterative approach (Newton Raphson technique) is used to solve the economic dispatch problem. Generally, mathematical iterative approaches are the typical methods to solve optimization problem. This method of sequential based solution offer accurate results in terms of optimization and computing speed for small and medium size system.

The algorithm start by reading the input data of the power system. For this study, standard IEEE test system are used in the simulation. The power demand at each hour is estimated by obtaining data from daily log sheet reports by the Malaysia Energy Commission.

To accurately calculate the losses in the system, a Load Flow Analysis (LFA) can be incorporated in the algorithm. The load flow analysis is able to check the status of the system for any minor changes in the operation and accurately calculate the transmission losses. Alternately, the losses can be represented by the Kron's loss formula as an approximated loss technique.

Next, the economic dispatch algorithms will calculate the initial values of the system. In this step, the ED solution will try to allocate the optimal generation output for each generating units in the available pool.

In (Zeynal, 2013), the author discusses that numerous optimization techniques have been developed and utilized to solve optimization problem. These include deterministic methods such as mathematical iterative approaches and derivative-based methods. Alternately, many research paper are incorporating heuristic techniques such as swarm intelligent methods and evolutionary algorithm techniques to solve optimization problem such as unit commitment, economic dispatch and load flow analysis.

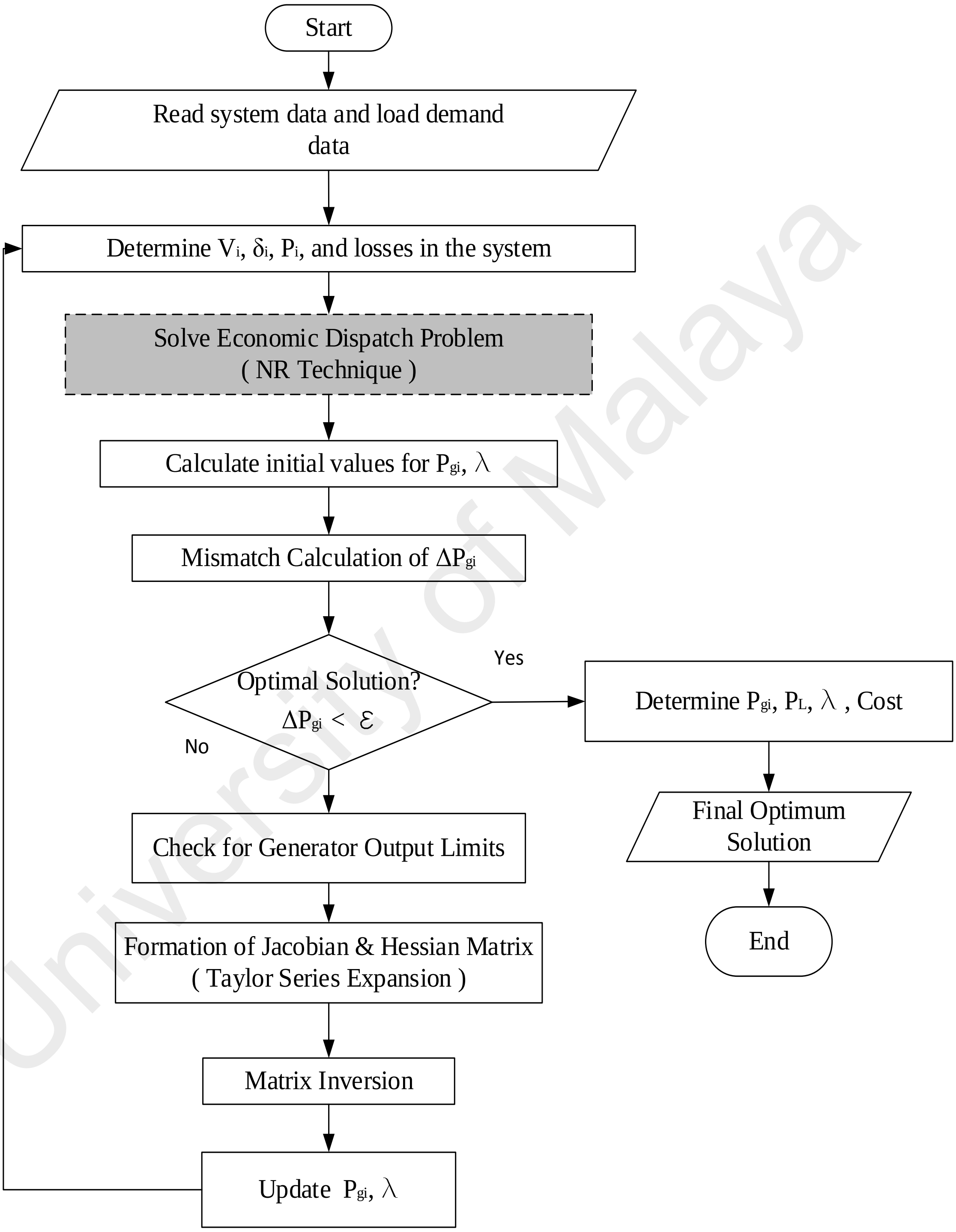


Figure 3.1: Economic Dispatch Solution Flow Chart

If the convergence do not meet the required value, a Jacobean matrix and hessian matrix is formed to update the initial values for the next iteration. The ED solution will only be interrupted if the convergence value falls within the specified tolerance. Then, the optimal generation output for each generating units will be determined.

3.2 Obtaining Data for Load Forecast Analysis

In usual IEEE test case, only one load demand is provided for optimization. However, to study scheduling trend, 24 different load demand is required to illustrate the hourly scenario. Thus, a load demand curve must be established to simulate the typical load profile in a day. Additionally, different weather condition load profile can be used.

Using the daily log sheet reports by the Malaysia Energy Commission, the daily load profile data was extracted and used in the simulation. The data consists of load demand at every hour in peninsular Malaysia. Based on the obtained data, a load demand curve can be plotted to understand the load level trend.

To study the effect EV on the power network, the daily load profile must be updated with the arrival of EV. In this study, the data was obtained from (Zhao, Wen, Dong, Xue, & Wong, 2012) as shown in Figure 3.2.

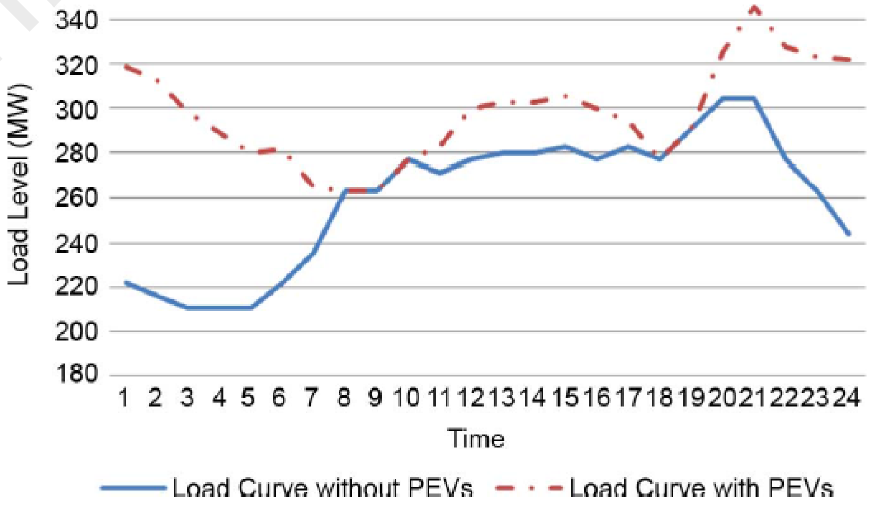


Figure 3.2: Load Curve with and without EV

In this study, two case scenario which is load curve without EV and load curve with EV are simulated. Detailed analysis on the load profile has been discussed in Chapter 5.

3.3 Type of Case Scenario Analysis

In order to understand the effect of EV as a load, different case scenario was simulated in this study. Also, the solution will then compared to the standard economic dispatch solution to understand the effect of electric vehicle as a load in the power system.

In this study, IEEE test system were used, which is the IEEE 26 Bus with 6 generating units test system. Many published papers such as (Lee & Breipohl, 1993; Selvakumar & Thanushkodi, 2007) have used these test cases in their optimization studies.

In addition, to simulate the practically of a power network, the load profile will be simulated in two weather conditions which are hot and sunny day and cloudy and rainy day. The data is obtained from daily log sheet reports by the Malaysia Energy Commission.

In a practical network, the generation units and the distribution area are usually spread across a huge area. During transmission of power, loss of power occurs due to the long transmission line that interconnect power plants to residential or commercial area. Thus, only the basic system constraints such as power balance constraints, generator limits and transmission loss are considered in the simulation.

3.4 Equipment/ Software/ System used

This research is a simulation based project, thus only a computer is required to complete the research. The computer specification is tabulated in table 3.1.

Table 3.1: Computer Specification

Operating System	Window 7 64bit
Processor	2.6 GHz or 2.6 GHz Intel Core i7-4720HQ
Memory	8.00GB

For each case scenario, the simulation is implemented in MATLAB environment and the results is tabulated.

CHAPTER 4: RESULTS AND DISCUSSIONS

In this chapter, the economic solution for different case scenario tabulated. The aim is develop an economic dispatch solution, which effectively consider EV as a load in the power system network.

The primary simulation model is the IEEE 26 bus with 6 generating units test system. In this study, 9 different type of case scenario is simulated and tabulated. The case scenario will be as follow:

1. ED Solution without EV (Hot & Sunny Day)
2. ED Solution with EV (Hot & Sunny Day)
3. ED Solution without EV (Cloudy & Rainy Day)
4. ED Solution with EV (Cloudy & Rainy Day)
5. ED Solution without EV considering losses (Hot & Sunny Day)
6. ED Solution with EV considering losses (Hot & Sunny Day)
7. ED Solution without EV considering losses (Cloudy & Rainy Day)
8. ED Solution with EV considering losses (Cloudy & Rainy Day)
9. ED Solution with EV considering losses in controlled charging scheme (Hot & Sunny Day)

In case scenario 2, 4, 6 and 8, the electric vehicles immediate start drawing power from the network once it is connected to the charging bay. This is uncontrolled charging scheme. In case scenario 9, an ED solution is solved with a controlled charging scheme for the connected electric vehicles.

4.1 Load Forecasting Analysis

Based on (Zhao et al., 2012) load forecasting model shown in Figure 4.1, the impact of electric vehicle on the daily load profile is displayed for each hour. In the studies, 90,000 electric vehicle are connected to the system, which represent 0.8% of the total registered vehicles in Malaysia for the year 2014.

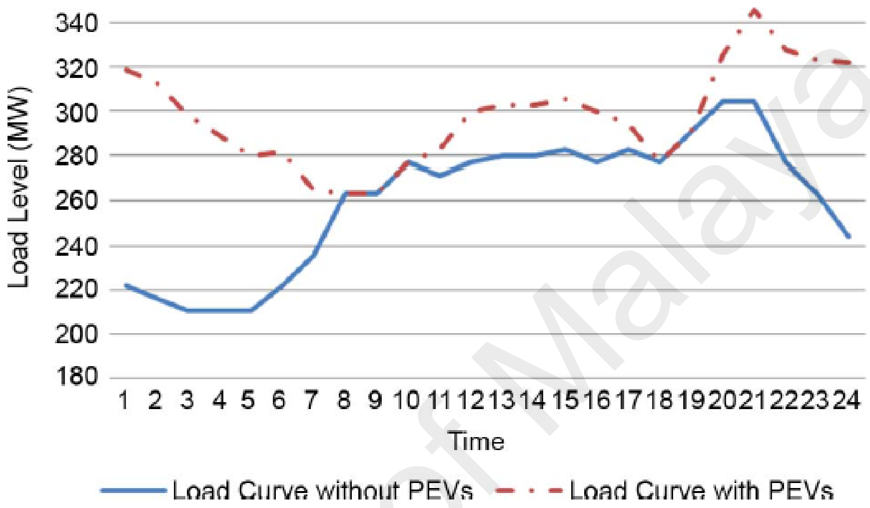


Figure 4.1: Load Curve with and without EV

As observed in the figure, the blue line indicate typical load demand in a day. In the early hour of 1:00 to 7:00, the load demand is at the minimum as everyone is asleep. During hour from 8:00, the load has been gradually increasing and a day time load profile can be observed. As seen in Figure 4.1, the peak demand take places at hour 20:00 to 21:00.

The dotted red curve illustrate the load demand in a day when electric vehicles are connected to the system. As seen in the figure, the load level from hour 20:00 to 7:00 have been increased significantly. This is mainly caused by the large number of idle electric vehicle in the charge mode. From hour 8:00 to 10:00, there is no increase in load demand as the electric vehicle is assumed to be travelling. From hour 11:00 to 17:00, the hourly load demand increased by 10% when electric vehicles are connected to the network. From hour 18:00 to 19:00, there is no increase in load demand as the electric vehicle is assumed to be travelling. As seen in Figure 4.1, the peak demand take places at hour 20:00 to 22:00 when electric vehicles are connected to the network. The hourly peak demand when electric vehicles are connected to the system is the same as the typical daily load demand without electric vehicle connected to the system. When electric vehicle are connected to the network, the daily load curve is significantly reshaped.

The two load profile in Figure 4.1 has been tabulated in Table 4.1 to observe the percentage increased in load (%) when electric vehicles are connected to the network.

Table 4.1: Analysis on percentage increased in load when EV is connected

Hour	P_D (MW) without EV	P_D (MW) with EV	Percentage increased in load (%)
1	225	320	42.222
2	218	310	42.202
3	210	300	42.857
4	210	290	38.095
5	210	280	33.333
6	220	280	27.273
7	235	265	12.766
8	260	260	0
9	260	260	0
10	278	278	0
11	265	280	5.660
12	278	298	7.194
13	280	300	7.143
14	280	305	8.929
15	285	308	8.070
16	278	300	7.914
17	282	295	4.610
18	278	278	0
19	290	290	0
20	305	325	6.557
21	305	338	10.820
22	280	330	17.857
23	265	325	22.642
24	245	320	30.612

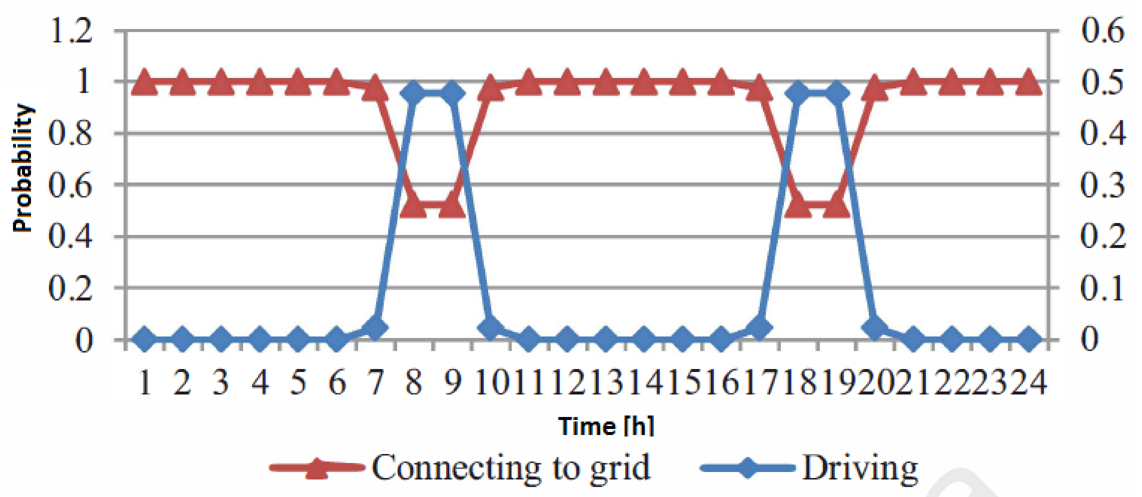


Figure 4.2: The hourly probability of EV connected to the network

As shown in Figure 4.2, the study by (Y. Li & Lukszo, 2014) shows that the electric vehicle driving profile follow a typical distribution with a normal departure time of 8:00 to 9:00 and average arrival time of 18:00 to 19:00. During the rest of the hours, the electric vehicles are assumed to be connected to the power network and are in a stationary state and charging mode.

The graph in Figure 4.2 correspond with the load curve when electric vehicles are connected to the network in Figure 4.1. During these hours, the electric vehicle are travelling therefore there is no increase in load demand.

This study demonstrated that in most of the day (over 85%), electric vehicles are parked in a parking bay connected to a charging station.

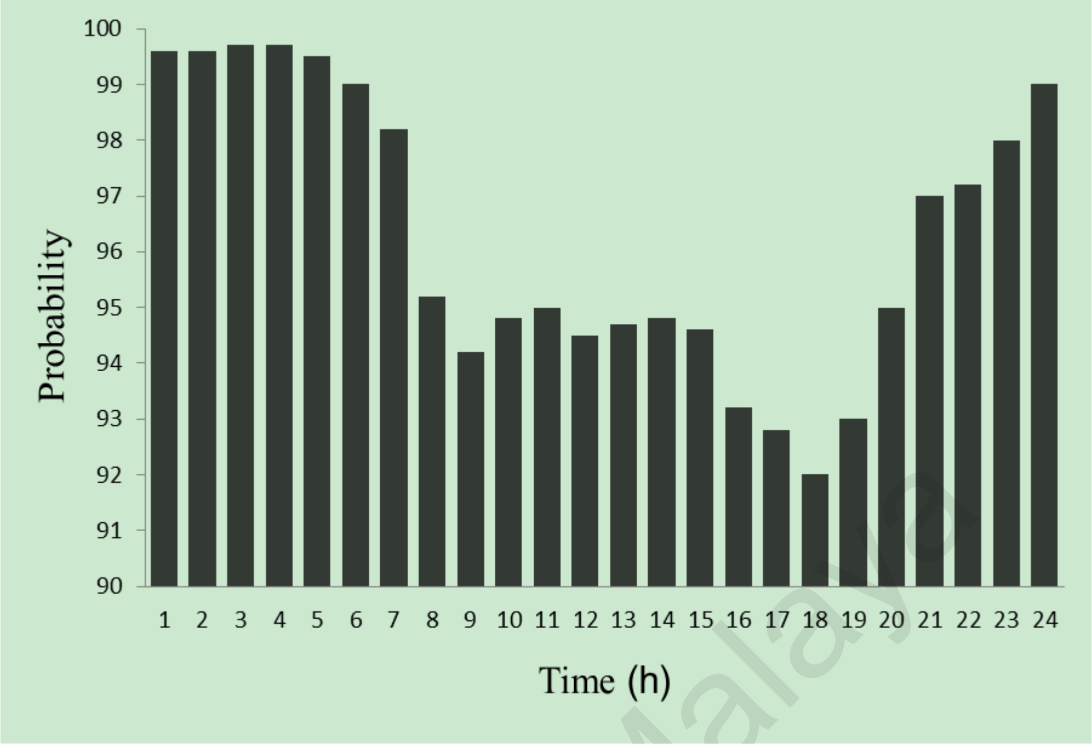


Figure 4.3: The hourly probability of a vehicle remains idle

As observed in Figure 4.3, the hourly probability of a vehicle remains idle is shown. This study conducted by (Guibin et al., 2013) illustrated that while EV users might drive differently than the conventional ICE vehicle, it is safe to assume that the driving pattern of EV drivers are similar with the typical drivers. Thus, it is further assumed that EV owners driving patterns will not significantly affect the daily travel behaviors and lifestyles. Regardless of type of vehicle, people will still have the same travelling habits as before, and will continue to drive to reach their usual destinations and perform everyday tasks. Based on this basis, EV owners will have the same probability distribution as the conventional ICE vehicles as illustrated in Figure 4.3.

All the discussed studies above proved that the hourly percentage of electric vehicle travelling is less than 15%, in which 85% of the time that electric vehicle could be connected to the network and are in a stationary state. However, this assumption only indicate an electric vehicle can only either be in driving state or stationary state.

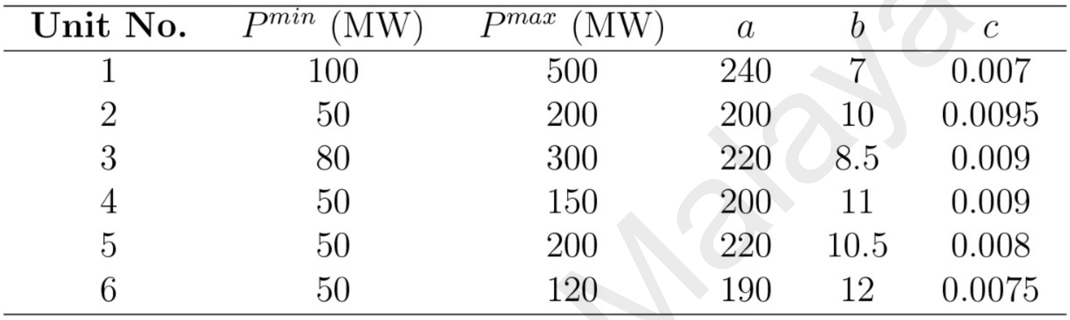
In order to perform economic dispatch on a daily load profile to understand the impact of electric vehicles when connected to the grid, an hourly load profile must first be constructed. Table 4.2 shows the hourly load profile for two case scenario which is hot & sunny day and cloudy and rainy day. These data are obtained by observing the data provided by the Malaysian Energy commission. For hot and sunny day, the actual data is obtained on 15th December 2016 while cloudy and rainy is obtained on 11th December 2016. Based on both of the load profile, it is observed that hot and sunny day has a higher hourly load demand compare to cloudy and rainy day.

Table 4.2: Load Profile on Different Weather Condition

Hour	**Hot and Sunny Day P_D (MW)**	**Cloudy and Rainy Day P_D (MW)**
1	12968	12267
2	12411	11914
3	12160	11522
4	11885	11230
5	11755	11045
6	11740	10994
7	11936	10807
8	12517	10378
9	14118	10985
10	15073	11590
11	15648	12026
12	15623	11945
13	15388	11834
14	15815	11954
15	16035	11808
16	16059	11863
17	15822	11665
18	14756	11536
19	14804	12319
20	15586	13093
21	15379	12976
22	14883	12775
23	14418	12415
24	13609	12765

4.2 IEEE 26 Bus with 6 Generating Units Test System

In this study, a typical IEEE test system is used in the simulation. The test system comprise of 26 buses with 6 generating units and 46 transmission lines. The base capacity of this system is 100MVA. The maximum generation of the system is 1470MW while the minimum generation is 380MW. In Figure 4.4, a_i, b_i and c illustrated the cost coefficient for each generating units.



Unit No.	P^{min} (MW)	P^{max} (MW)	a	b	c
1	100	500	240	7	0.007
2	50	200	200	10	0.0095
3	80	300	220	8.5	0.009
4	50	150	200	11	0.009
5	50	200	220	10.5	0.008
6	50	120	190	12	0.0075

Figure 4.4: Generating Units Cost Coefficients Data

The load demand used for this system is 1263MW. But in this study, a practical hourly load demand must be constructed to observe the impact of electric vehicles when connected to the grid. This will be further discussed later.

Figure 4.5 shows the B coefficient for the six generating units.

$$B_{ij} = \begin{bmatrix} 0.0017 & 0.0012 & 0.0007 & -0.0001 & -0.0005 & -0.0002 \\ 0.0012 & 0.0014 & 0.0009 & 0.0001 & -0.0006 & -0.0001 \\ 0.0007 & 0.0009 & 0.0031 & 0.0000 & -0.0010 & -0.0006 \\ -0.0001 & 0.0001 & 0.0000 & 0.0024 & -0.0006 & -0.0008 \\ -0.0005 & -0.0006 & -0.0010 & -0.0006 & 0.0129 & -0.0002 \\ -0.0002 & -0.0001 & -0.0006 & -0.0008 & -0.0002 & 0.0150 \end{bmatrix}$$

$$B_{0i} = 10^{-3} \times [-0.3908, -0.1297, 0.7047, 0.0591, 0.2161, -0.6635]$$

$$B_{00} = 0.056$$

Figure 4.5: B coefficient for generating units

As previously discussed, a practical hourly load demand must be constructed to observe the impact of electric vehicles when connected to the grid. Based on the tabulated results on Table 4.2, it is possible to model a similar and practical hourly load demand for the IEEE 26 bus with 6 generating unit system.

The estimated hourly load demand in Table 4.3 for hot and sunny day has similar load curve as Table 4.2. Furthermore, another set of hourly load demand is estimated when electric vehicles are connected to the network. This set of data are estimated based on percentage increased in load when electric vehicles are connected to the network in Table 4.1.

Table 4.3: Load Profile on Hot & Sunny Day with & without EV

Hour	**P_D (MW) without EV**	**Percentage increased in load (%)**	**P_D (MW) with EV**
1	1009.403	42.222	1435.593
2	966.047	42.202	1373.738
3	946.510	42.857	1352.155
4	925.104	38.095	1277.523
5	914.985	33.333	1219.977
6	913.818	27.273	1163.043
7	929.074	12.766	1047.680
8	974.298	0	974.298
9	1098.916	0	1098.916
10	1173.252	0	1173.252
11	1218.009	5.660	1286.948
12	1216.063	7.194	1303.546
13	1197.771	7.143	1283.327
14	1231.008	8.929	1340.924
15	1248.132	8.070	1348.856
16	1250.000	7.914	1348.925
17	1231.552	4.610	1288.327
18	1148.577	0	1148.577
19	1152.313	0	1152.313
20	1213.183	6.557	1292.731
21	1197.070	10.820	1326.593
22	1158.463	17.857	1365.329
23	1122.268	22.642	1376.372
24	1059.297	30.612	1383.569

The estimated hourly load demand in Table 4.4 for cloudy and rainy day has similar load curve as Table 4.2. Furthermore, another set of hourly load demand is estimated when electric vehicles are connected to the network. This set of data are estimated based on percentage increased in load when electric vehicles are connected to the network in Table 4.1.

Table 4.4: Load Profile on Cloudy & Rainy Day with & without EV

Hour	**P_D (MW) without EV**	**Percentage increased in load (%)**	**P_D (MW) with EV**
1	846.032	42.222	846.032
2	821.687	42.202	821.687
3	794.651	42.857	794.651
4	774.512	38.095	774.512
5	761.753	33.333	761.753
6	758.236	27.273	758.236
7	745.339	12.766	745.339
8	715.751	0	715.751
9	757.615	0	757.615
10	799.341	0	799.341
11	829.411	5.660	829.411
12	823.825	7.194	823.825
13	816.169	7.143	816.169
14	824.445	8.929	824.445
15	814.376	8.070	814.376
16	818.169	7.914	818.169
17	804.513	4.610	804.513
18	795.617	0	795.617
19	849.619	0	849.619
20	903.000	6.557	903.000
21	894.931	10.820	894.931
22	881.068	17.857	881.068
23	856.240	22.642	856.240
24	880.378	30.612	880.378

4.2.1 Economic Dispatch Solution without EV (Hot & Sunny Day)

Table 4.5 shows the simulation results for the developed ED solution without EV on a hot & sunny day. The results is segregated into a typical 24 hours load demand profile. The result in Table 4.5 will be used as a comparison base with ED solution with EV on a hot & sunny day. In this case scenario, transmission loss is not considered in the simulation.

Table 4.5: ED Solution without EV (Hot & Sunny Day)

Hour	P_D (MW)	P_{g1} (MW)	P_{g2} (MW)	P_{g3} (MW)	P_{g4} (MW)	P_{g5} (MW)	P_{g6} (MW)	Total Cost ($/h)
1	1009.403	393.916	132.359	223.046	84.157	125.926	50.000	12004.54
2	966.047	383.512	124.693	214.954	76.065	116.823	50.000	11465.11
3	946.510	378.824	121.239	211.308	72.419	112.721	50.000	11224.09
4	925.104	373.688	117.454	207.313	68.424	108.227	50.000	10961.49
5	914.985	371.259	115.665	205.424	66.535	106.102	50.000	10837.89
6	913.818	370.979	115.458	205.206	66.317	105.857	50.000	10823.66
7	929.074	374.640	118.156	208.053	69.165	109.060	50.000	11010.08
8	974.298	385.492	126.152	216.494	77.605	118.556	50.000	11567.28
9	1098.916	414.539	147.555	239.086	100.197	143.971	53.569	13138.13
10	1173.252	429.112	158.293	250.421	111.532	156.723	67.171	14097.47
11	1218.009	437.887	164.759	257.245	118.356	164.401	75.361	14682.40
12	1216.063	437.505	164.478	256.949	118.060	164.067	75.005	14656.86
13	1197.771	433.919	161.835	254.159	115.270	160.929	71.658	14417.23
14	1231.008	440.435	166.637	259.227	120.339	166.631	77.740	14853.32
15	1248.132	443.792	169.110	261.839	122.950	169.568	80.873	15079.17
16	1250.000	444.159	169.380	262.123	123.235	169.889	81.215	15103.86
17	1231.552	440.542	166.715	259.310	120.422	166.724	77.839	14860.48
18	1148.577	424.275	154.729	246.658	107.769	152.490	62.656	13777.35
19	1152.313	425.007	155.268	247.228	108.339	153.131	63.340	13825.71
20	1213.183	436.941	164.062	256.509	117.621	163.573	74.478	14619.07
21	1197.070	433.782	161.734	254.052	115.164	160.809	71.530	14408.07
22	1158.463	426.213	156.157	248.166	109.277	154.186	64.465	13905.40
23	1122.268	419.117	150.928	242.646	103.757	147.977	57.842	13437.86
24	1059.297	405.888	141.181	232.357	93.469	136.402	50.000	12633.14

The total operating cost for the day is 317389.66 $ while the total generated power for 24 hours is 26495.113 MW. The peak load demand for this case scenario is hour 16 with 1250 MW. The lowest load demand is hour 6 with 913.818 MW.

Figure 4.6 illustrate the simulated results for Table 4.5. Based on Figure 4.6, the generating units must deliver adequate power supply in order to satisfy the hourly power demand.

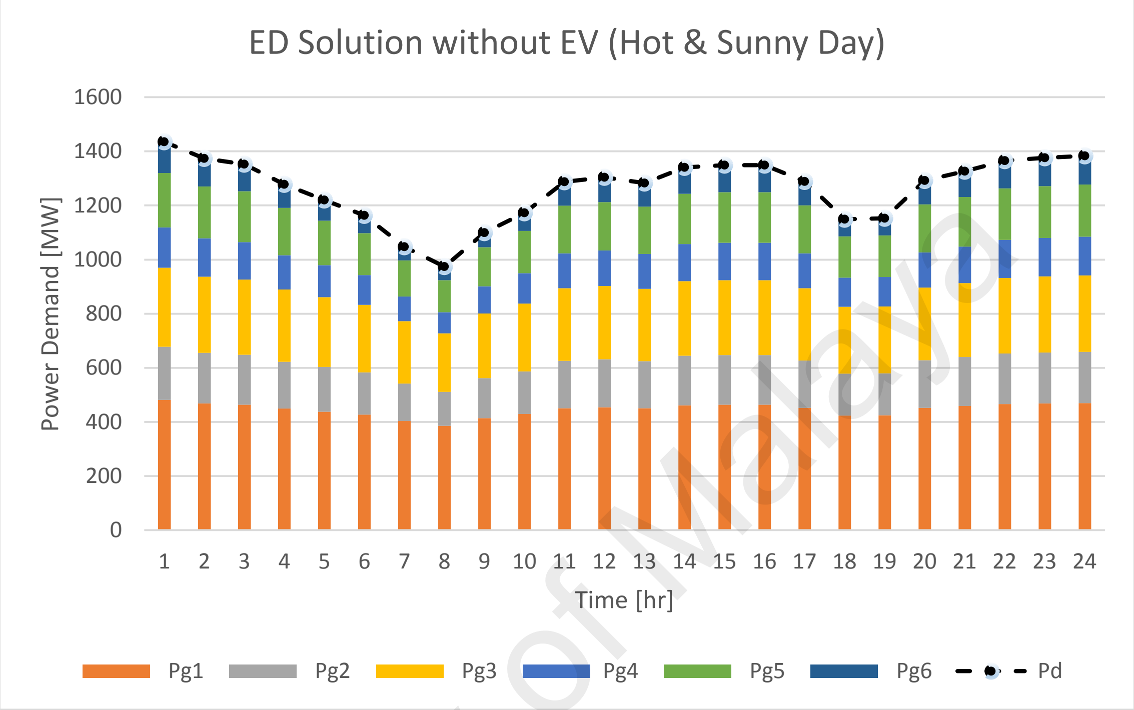


Figure 4.6: ED Solution without EV (Hot & Sunny Day)

As shown in Figure 4.6, in the early hour of 1:00 to 7:00, the load demand is at the minimum. During hour from 8:00, the load has been gradually increasing and a diurnal load profile can be observed. This is the typical daily load profile solved with economic dispatch solution.

4.2.2 Economic Dispatch Solution with EV (Hot & Sunny Day)

Table 4.6 shows the simulation results for the developed ED solution with EV on a hot & sunny day. The results is segregated into a typical 24 hours load demand profile. In this case scenario, transmission loss is not considered in the simulation.

Table 4.6: ED Solution with EV (Hot & Sunny Day)

Hour	P_D (MW)	P_{g1} (MW)	P_{g2} (MW)	P_{g3} (MW)	P_{g4} (MW)	P_{g5} (MW)	P_{g6} (MW)	Total Cost ($/h)
1	1435.593	481.490	196.887	291.159	150.000	200.000	116.057	17604.41
2	1373.738	468.418	187.255	280.991	142.103	191.115	103.856	16760.47
3	1352.155	464.186	184.137	277.700	138.811	187.413	99.907	16468.49
4	1277.523	449.555	173.356	266.320	127.431	174.610	86.251	15468.71
5	1219.977	438.273	165.043	257.545	118.657	164.739	75.721	14708.25
6	1163.043	427.111	156.818	248.864	109.975	154.972	65.303	13964.82
7	1047.680	403.101	139.127	230.189	91.300	133.963	50.000	12486.04
8	974.298	385.492	126.152	216.494	77.605	118.556	50.000	11567.28
9	1098.916	414.539	147.555	239.086	100.197	143.971	53.569	13138.13
10	1173.252	429.112	158.293	250.421	111.532	156.723	67.171	14097.47
11	1286.948	451.402	174.718	267.757	128.868	176.227	87.976	15594.12
12	1303.546	454.656	177.115	270.288	131.399	179.074	91.013	15815.58
13	1283.327	450.692	174.194	267.205	128.316	175.606	87.313	15545.91
14	1340.924	461.984	182.515	275.988	137.099	185.486	97.852	16317.06
15	1348.856	463.539	183.661	277.197	138.308	186.847	99.303	16423.97
16	1348.925	463.553	183.671	277.208	138.319	186.859	99.316	16424.90
17	1288.327	451.673	174.917	267.968	129.079	176.464	88.228	15612.49
18	1148.577	424.275	154.729	246.658	107.769	152.490	62.656	13777.35
19	1152.313	425.007	155.268	247.228	108.339	153.131	63.340	13825.71
20	1292.731	452.536	175.553	268.639	129.750	177.219	89.034	15671.20
21	1326.593	459.175	180.445	273.803	134.914	183.028	95.230	16124.34
22	1365.329	466.769	186.040	279.709	140.820	189.673	102.318	16646.56
23	1376.372	468.934	187.636	281.393	142.504	191.567	104.338	16796.19
24	1383.569	470.345	188.675	282.490	143.602	192.802	105.655	16893.89

The total operating cost for the day is 367733.34 $ while the total generated power for 24 hours is 30362.512 MW. The peak load demand for this case scenario is hour 1 with 1435.593 MW. The lowest load demand is hour 8 with 974.298 MW. It is observed that the total operating cost and total generated power is significantly higher when EVs are connected to the system.

Figure 4.7 illustrate the simulated results for Table 4.6. Based on Figure 4.6, the generating units must deliver adequate power supply in order to satisfy the hourly power demand.

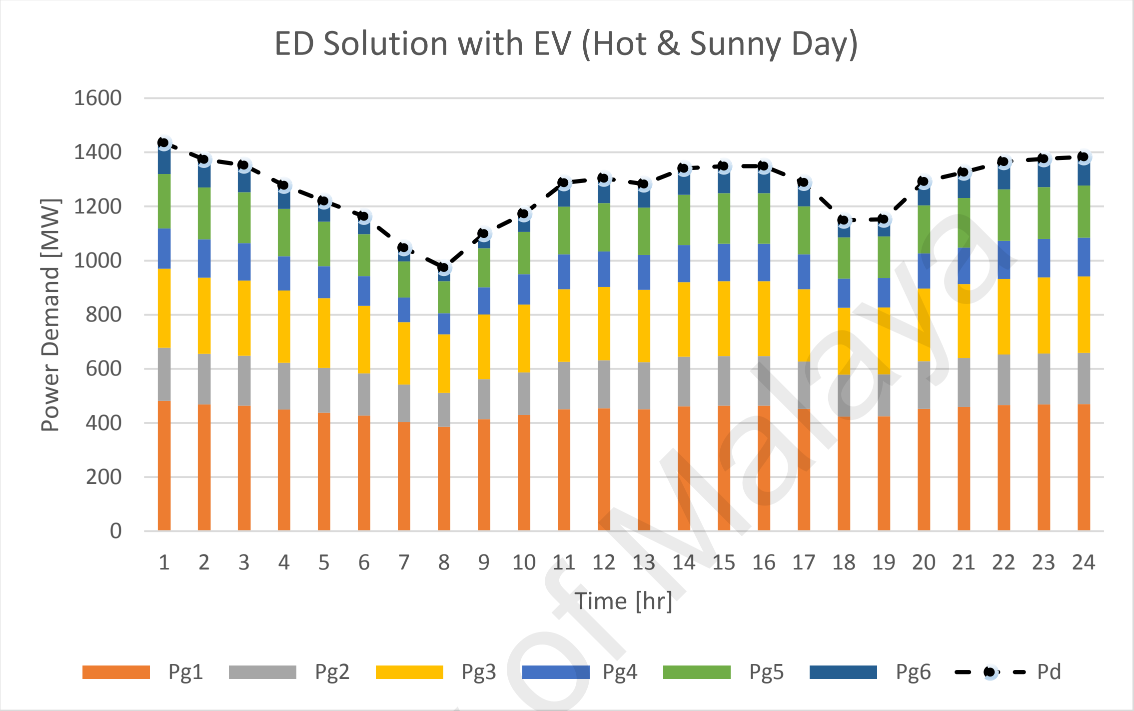


Figure 4.7: ED Solution with EV (Hot & Sunny Day)

As shown in Figure 4.7, the load level from hour 20:00 to 7:00 have been increased significantly as compare to Figure 4.6. This is mainly caused by the large number of idle electric vehicle in the charge mode.

Also, the peak demand shift from hour 16 when no EVs are connected to the network to hour 1 when EVs are connected to the network. In this case, when electric vehicle are connected to the network, the daily load curve is significantly reshaped.

4.2.3 Economic Dispatch Solution without EV (Cloudy & Rainy Day)

Table 4.7 shows the simulation results for the developed ED solution without EV on a cloudy & rainy day. The results is segregated into a typical 24 hours load demand profile. The result in Table 4.7 will be used as a comparison base with ED solution with EV on a cloudy & rainy day. In this case scenario, transmission loss is not considered in the simulation.

Table 4.7: ED Solution without EV (Cloudy & Rainy Day)

Hour	P_D (MW)	P_{g1} (MW)	P_{g2} (MW)	P_{g3} (MW)	P_{g4} (MW)	P_{g5} (MW)	P_{g6} (MW)	Total Cost ($/h)
1	846.032	354.714	103.473	192.555	53.666	91.624	50.000	10004.82
2	821.687	348.613	98.978	187.810	50.000	86.286	50.000	9714.51
3	794.651	340.637	93.101	181.606	50.000	79.307	50.000	9394.82
4	774.512	334.695	88.723	176.985	50.000	74.108	50.000	9158.64
5	761.753	330.931	85.949	174.058	50.000	70.815	50.000	9009.88
6	758.236	329.894	85.185	173.251	50.000	69.907	50.000	8968.99
7	745.339	326.089	82.381	170.291	50.000	66.578	50.000	8819.49
8	715.751	317.360	75.949	163.502	50.000	58.940	50.000	8479.10
9	757.615	329.710	85.050	173.108	50.000	69.747	50.000	8961.78
10	799.341	342.020	94.120	182.683	50.000	80.518	50.000	9450.06
11	829.411	350.725	100.534	189.453	50.564	88.135	50.000	9806.40
12	823.825	349.244	99.443	188.301	50.000	86.838	50.000	9739.92
13	816.169	346.985	97.778	186.544	50.000	84.862	50.000	9649.02
14	824.445	349.427	99.577	188.443	50.000	86.998	50.000	9747.29
15	814.376	346.456	97.389	186.132	50.000	84.399	50.000	9627.76
16	818.169	347.575	98.213	187.003	50.000	85.378	50.000	9672.74
17	804.513	343.546	95.245	183.869	50.000	81.853	50.000	9511.08
18	795.617	340.922	93.311	181.828	50.000	79.557	50.000	9406.19
19	849.619	355.574	104.107	193.224	54.336	92.378	50.000	10047.76
20	903.000	368.383	113.546	203.187	64.298	103.586	50.000	10691.95
21	894.931	366.447	112.119	201.681	62.792	101.891	50.000	10593.96
22	881.068	363.121	109.668	199.094	60.205	98.981	50.000	10426.12
23	856.240	357.163	105.278	194.460	55.571	93.768	50.000	10127.14
24	880.378	362.955	109.546	198.965	60.076	98.836	50.000	10417.78

The total operating cost for the day is 231427.2 $ while the total generated power for 24 hours is 19566.678 MW. The peak load demand for this case scenario is hour 20 with 903 MW. The lowest load demand is hour 8 with 715.615 MW.

Figure 4.8 illustrate the simulated results for Table 4.7. Based on Figure 4.8, the generating units must deliver adequate power supply in order to satisfy the hourly power demand.

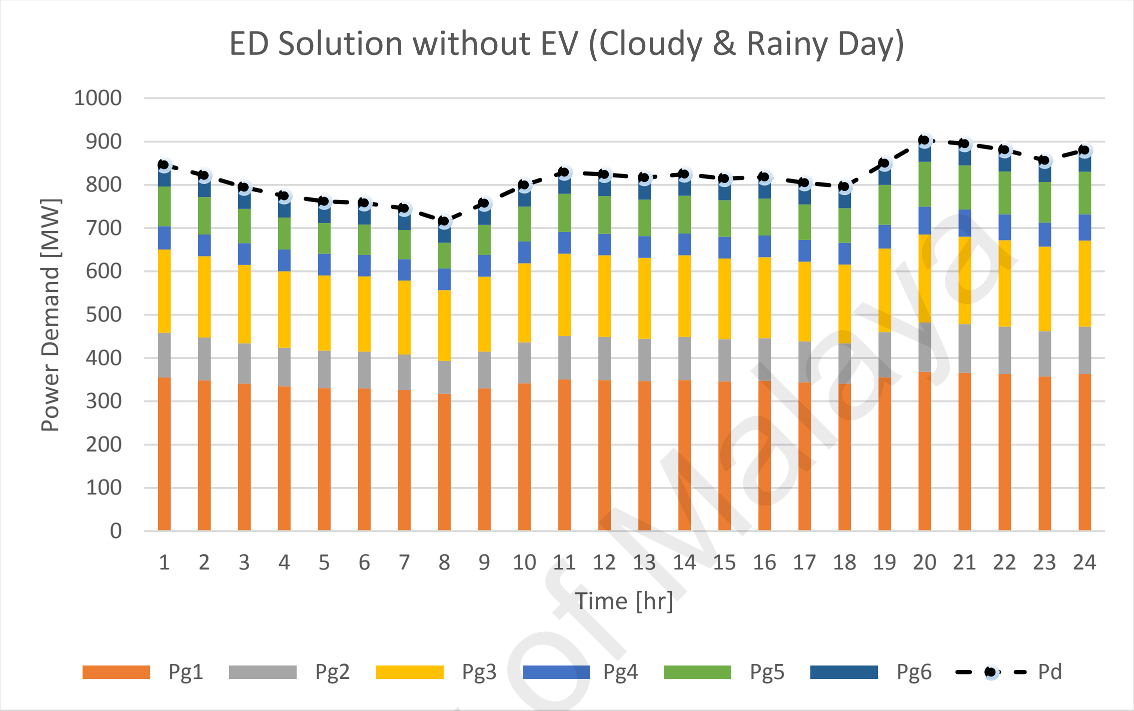


Figure 4.8: ED Solution without EV (Cloudy & Rainy Day)

As shown in Figure 4.8, in the early hour of 1:00 to 7:00, the load demand is at the minimum. During hour from 8:00, the load has been gradually increasing and a diurnal load profile can be observed. This is the typical daily load profile solved with economic dispatch solution. However, it can be observed that the average load demand is generally lower that hot and sunny day.

4.2.4 Economic Dispatch Solution with EV (Cloudy & Rainy Day)

Table 4.8 shows the simulation results for the developed ED solution with EV on a cloudy & rainy day. The results is segregated into a typical 24 hours load demand profile. In this case scenario, transmission loss is not considered in the simulation.

Table 4.8: ED Solution with EV (Cloudy & Rainy Day)

Hour	P_D (MW)	P_{g1} (MW)	P_{g2} (MW)	P_{g3} (MW)	P_{g4} (MW)	P_{g5} (MW)	P_{g6} (MW)	Total Cost ($/h)
1	1203.244	434.992	162.623	254.994	116.105	161.868	72.659	14488.83
2	1168.455	428.172	157.600	249.689	110.800	155.900	66.294	14035.11
3	1135.215	421.655	152.798	244.621	105.732	150.198	60.211	13604.69
4	1069.563	408.352	142.996	234.273	95.385	138.558	50.000	12763.52
5	1015.668	395.419	133.467	224.215	85.326	127.242	50.000	12083.02
6	965.030	383.268	124.513	214.764	75.875	116.610	50.000	11452.53
7	840.489	353.383	102.493	191.520	52.632	90.461	50.000	9938.54
8	715.751	317.360	75.949	163.502	50.000	58.940	50.000	8479.10
9	757.615	329.710	85.050	173.108	50.000	69.747	50.000	8961.78
10	799.341	342.020	94.120	182.683	50.000	80.518	50.000	9450.06
11	876.356	361.990	108.835	198.214	59.326	97.991	50.000	10369.22
12	883.091	363.606	110.026	199.471	60.583	99.405	50.000	10450.57
13	874.468	361.537	108.501	197.862	58.973	97.595	50.000	10346.44
14	898.060	367.198	112.672	202.265	63.376	102.548	50.000	10631.93
15	880.096	362.887	109.496	198.913	60.024	98.777	50.000	10414.38
16	882.919	363.565	109.995	199.439	60.550	99.369	50.000	10448.49
17	841.602	353.651	102.690	191.728	52.839	90.694	50.000	9951.84
18	795.617	340.922	93.311	181.828	50.000	79.557	50.000	9406.19
19	849.619	355.574	104.107	193.224	54.336	92.378	50.000	10047.76
20	962.210	382.591	124.015	214.238	75.349	116.017	50.000	11417.67
21	991.762	389.683	129.240	219.753	80.864	122.222	50.000	11784.29
22	1038.400	400.874	137.486	228.457	89.569	132.015	50.000	12368.85
23	1050.109	403.683	139.556	230.643	91.754	134.473	50.000	12516.76
24	1149.880	424.530	154.917	246.857	107.968	152.714	62.895	13794.21

The total operating cost for the day 269205.78 $ while the total generated power for 24 hours is 22644.56 MW. The peak load demand for this case scenario is hour 1 with 1203.244 MW. The lowest load demand is hour 8 with 715.751 MW. It is observed that the total operating cost and total generated power is significantly higher when EVs are connected to the system.

Figure 4.9 illustrate the simulated results for Table 4.8. Based on Figure 4.9, the generating units must deliver adequate power supply in order to satisfy the hourly power demand.

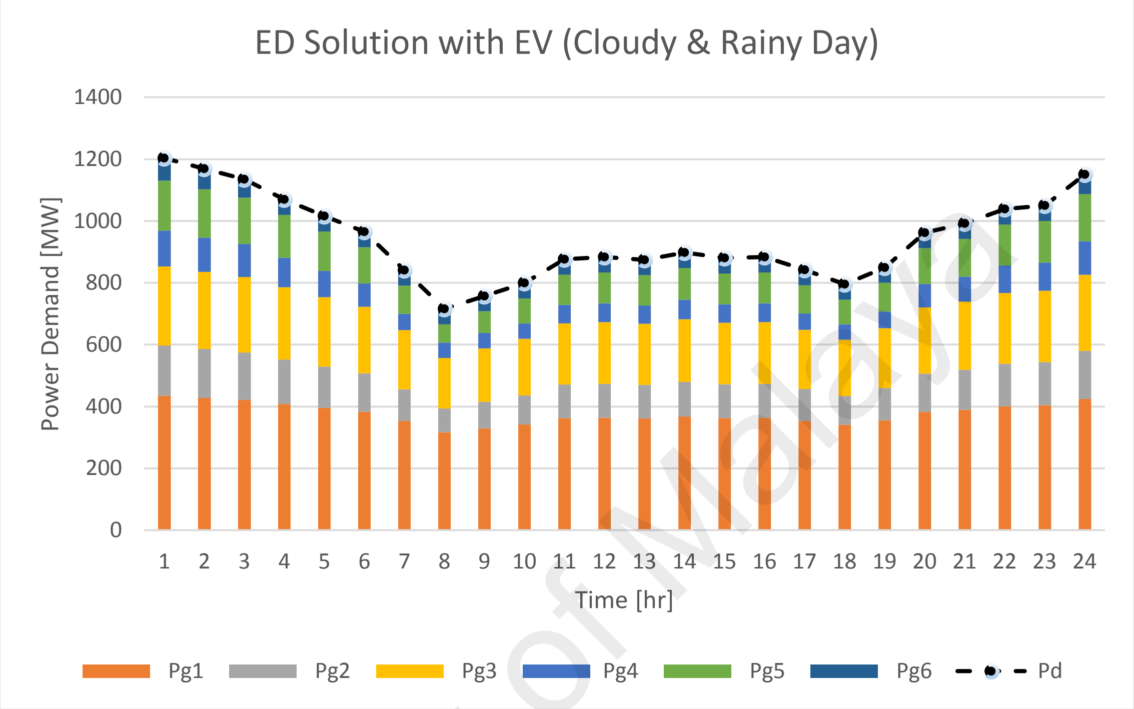


Figure 4.9: ED Solution with EV (Cloudy & Rainy Day)

As shown in Figure 4.9, the load level from hour 20:00 to 7:00 have been increased significantly as compare to Figure 4.8. This is mainly caused by the large number of idle electric vehicle in the charge mode.

Also, the peak demand shift from hour 20 when no EVs are connected to the network to hour 1 when EVs are connected to the network. In this case, when electric vehicle are connected to the network, the daily load curve is significantly reshaped.

4.2.5 Economic Dispatch Solution without EV considering transmission losses (Hot & Sunny Day)

Table 4.9 shows the simulation results for the developed ED solution without EV on a hot & sunny day. The results is segregated into a typical 24 hours load demand profile. The result in Table 4.9 will be used as a comparison base with ED solution with EV on a hot & sunny day. In this case scenario, transmission loss is considered in the simulation.

Table 4.9: ED Solution without EV considering transmission losses (Hot & Sunny Day)

Hour	P_D (MW)	P_{g1} (MW)	P_{g2} (MW)	P_{g3} (MW)	P_{g4} (MW)	P_{g5} (MW)	P_{g6} (MW)	Total Cost ($/h)
1	1009.403	395.279	134.792	222.676	96.071	124.557	50.000	12180.75
2	966.047	384.564	126.862	214.408	87.419	116.111	50.000	11631.05
3	946.510	379.739	123.292	210.684	83.525	112.302	50.000	11385.60
4	925.104	374.456	119.383	206.607	79.262	108.126	50.000	11118.29
5	914.985	371.960	117.535	204.680	77.248	106.151	50.000	10992.52
6	913.818	371.672	117.322	204.458	77.015	105.923	50.000	10978.04
7	929.074	375.436	120.108	207.363	80.052	108.901	50.000	11167.74
8	974.298	386.602	128.371	215.981	89.065	117.719	50.000	11735.13
9	1098.916	414.683	149.068	237.526	112.258	139.805	60.921	13336.51
10	1173.252	430.081	160.446	249.376	124.825	151.861	73.247	14315.31
11	1218.009	439.371	167.311	256.523	132.412	159.117	80.655	14912.90
12	1216.063	438.967	167.012	256.213	132.082	158.802	80.333	14886.79
13	1197.771	435.169	164.205	253.290	128.979	155.837	77.306	14641.91
14	1231.008	442.072	169.306	258.601	134.619	161.224	82.804	15087.63
15	1248.132	445.632	171.937	261.339	137.528	163.999	85.635	15318.60
16	1250.000	446.020	172.224	261.638	137.845	164.301	85.943	15343.85
17	1231.552	442.185	169.390	258.688	134.711	161.312	82.894	15094.95
18	1148.577	424.966	156.666	245.440	120.649	147.860	69.159	13988.51
19	1152.313	425.740	157.238	246.036	121.281	148.466	69.778	14037.87
20	1213.183	438.369	166.570	255.752	131.593	158.335	79.856	14848.16
21	1197.070	435.023	164.098	253.178	128.860	155.723	77.190	14632.55
22	1158.463	427.015	158.180	247.017	122.321	149.463	70.797	14119.22
23	1122.268	419.516	152.639	241.246	116.201	143.593	64.796	13642.15
24	1059.297	406.493	143.016	231.223	105.579	133.376	54.341	12821.81

The total operating cost for the day is 322217.84 $ while the total generated power for 24 hours is 26867.843 MW. The peak load demand for this case scenario is hour 16 with 1250 MW. The lowest load demand is hour 6 with 913.818 MW.

Figure 4.10 illustrate the simulated results for Table 4.9. Based on Figure 4.10, the generating units must deliver adequate power supply in order to satisfy the hourly power demand.

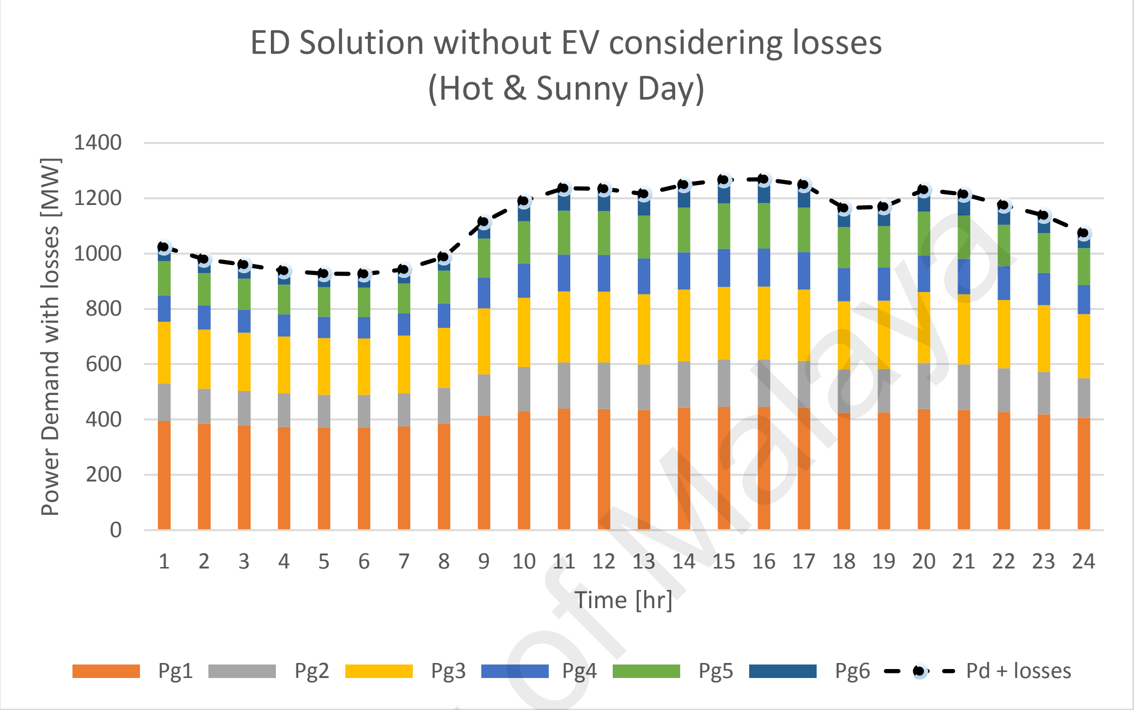


Figure 4.10: ED Solution without EV considering losses (Hot & Sunny Day)

As shown in Figure 4.10, in the early hour of 1:00 to 7:00, the load demand is at the minimum. During hour from 8:00, the load has been gradually increasing and a diurnal load profile can be observed. This is the typical daily load profile solved with economic dispatch solution.

4.2.6 Economic Dispatch Solution with EV considering transmission losses (Hot & Sunny Day)

Table 4.6 shows the simulation results for the developed ED solution with EV on a hot & sunny day. The results is segregated into a typical 24 hours load demand profile. In this case scenario, transmission loss is considered in the simulation.

Table 4.10: ED Solution with EV considering transmission losses (Hot & Sunny Day)

Hour	P_D (MW)	P_{g1} (MW)	P_{g2} (MW)	P_{g3} (MW)	P_{g4} (MW)	P_{g5} (MW)	P_{g6} (MW)	Total Cost ($/h)
1	1435.593	494.932	200.000	298.537	150.000	195.604	118.740	17911.96
2	1373.738	474.545	193.775	283.811	150.000	185.340	106.892	17041.74
3	1352.155	469.097	189.733	279.615	150.000	181.153	102.649	16741.70
4	1277.523	451.746	176.455	266.042	142.526	168.761	90.489	15717.17
5	1219.977	439.780	167.613	256.838	132.746	159.436	80.980	14939.32
6	1163.043	427.964	158.882	247.747	123.096	150.206	71.556	14179.87
7	1047.680	404.093	141.243	229.375	103.623	131.490	52.410	12671.81
8	974.298	386.602	128.371	215.981	89.065	117.719	50.000	11735.13
9	1098.916	414.683	149.068	237.526	112.258	139.805	60.921	13336.51
10	1173.252	430.081	160.446	249.376	124.825	151.861	73.247	14315.31
11	1286.948	453.708	177.905	267.551	144.131	170.287	92.045	15845.56
12	1303.546	457.165	180.459	270.210	146.958	172.976	94.784	16072.32
13	1283.327	452.954	177.348	266.972	143.514	169.701	91.447	15796.20
14	1340.924	466.264	187.632	277.433	150.000	178.974	100.441	16586.27
15	1348.856	468.265	189.116	278.973	150.000	180.513	102.001	16695.99
16	1348.925	468.282	189.129	278.987	150.000	180.526	102.014	16696.95
17	1288.327	453.995	178.117	267.772	144.365	170.511	92.273	15864.36
18	1148.577	424.966	156.666	245.440	120.649	147.860	69.159	13988.51
19	1152.313	425.740	157.238	246.036	121.281	148.466	69.778	14037.87
20	1292.731	454.912	178.795	268.478	145.115	171.224	92.100	15924.47
21	1326.593	462.652	184.953	274.650	150.000	176.194	97.621	16388.63
22	1365.329	472.422	192.200	282.176	150.000	183.708	105.240	16924.63
23	1376.372	475.210	194.269	284.324	150.000	185.850	107.410	17078.48
24	1383.569	477.029	195.618	285.724	150.000	187.247	108.824	17178.99

The total operating cost for the day is 373669.75 $ while the total generated power for 24 hours is 30804.277 MW. The peak load demand for this case scenario is hour 1 with 1435.593 MW. The lowest load demand is hour 8 with 974.298 MW. It is observed that the total operating cost and total generated power is significantly higher when EVs are connected to the system.

Figure 4.11 illustrate the simulated results for Table 4.10. Based on Figure 4.11, the generating units must deliver adequate power supply in order to satisfy the hourly power demand.

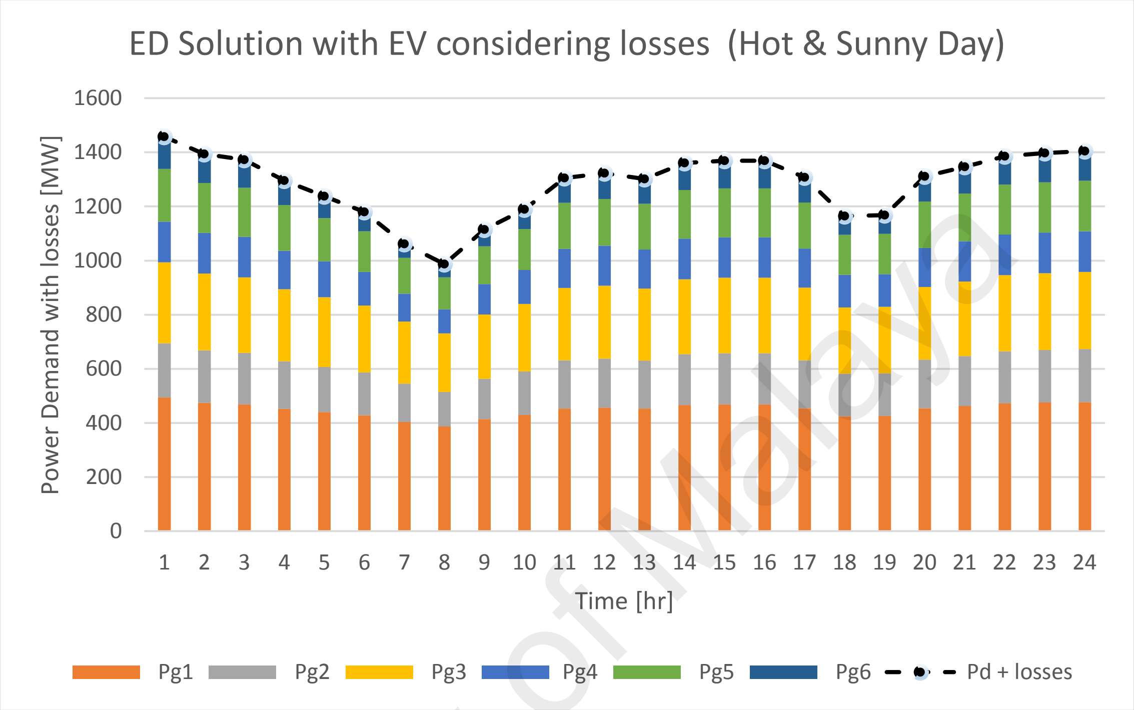


Figure 4.11: ED Solution with EV considering losses (Hot & Sunny Day)

As shown in Figure 4.11, the load level from hour 20:00 to 7:00 have been increased significantly as compare to Figure 4.10. This is mainly caused by the large number of idle electric vehicle in the charge mode.

Also, the peak demand shift from hour 16 when no EVs are connected to the network to hour 1 when EVs are connected to the network. In this case, when electric vehicle are connected to the network, the daily load curve is significantly reshaped.

4.2.7 Economic Dispatch Solution without EV considering transmission losses (Cloudy & Rainy Day)

Table 4.11 shows the simulation results for the developed ED solution with EV on a cloudy & rainy day. The results is segregated into a typical 24 hours load demand profile. The result in Table 4.11 will be used as a comparison base with ED solution with EV on a cloudy & rainy day. In this case scenario, transmission loss is considered in the simulation.

Table 4.11: ED Solution without EV considering transmission losses (Cloudy & Rainy Day)

Hour	P_D (MW)	P_{g1} (MW)	P_{g2} (MW)	P_{g3} (MW)	P_{g4} (MW)	P_{g5} (MW)	P_{g6} (MW)	Total Cost ($/h)
1	846.032	354.965	104.960	191.561	63.543	92.681	50.000	10145.47
2	821.687	348.972	100.526	186.933	58.713	87.919	50.000	9850.57
3	794.651	342.321	95.605	181.797	53.354	82.628	50.000	9525.61
4	774.512	337.211	91.947	177.912	50.000	78.256	50.000	9285.29
5	761.753	333.299	89.045	174.888	50.000	75.157	50.000	9133.89
6	758.236	332.222	88.245	174.054	50.000	74.303	50.000	9092.29
7	745.339	328.271	85.314	170.998	50.000	71.170	50.000	8940.22
8	715.751	319.215	78.595	163.994	50.000	63.978	50.000	8594.19
9	757.615	332.031	88.104	173.907	50.000	74.152	50.000	9084.95
10	799.341	343.475	96.458	182.688	54.283	83.546	50.000	9581.79
11	829.411	350.873	101.933	188.401	60.245	89.430	50.000	9943.90
12	823.825	349.498	100.915	187.340	59.137	88.337	50.000	9876.38
13	816.169	347.614	99.521	185.885	57.618	86.839	50.000	9784.03
14	824.445	349.651	101.028	187.457	59.260	88.459	50.000	9883.87
15	814.376	347.173	99.195	185.544	57.263	86.489	50.000	9762.43
16	818.169	348.107	99.886	186.265	58.015	87.231	50.000	9808.13
17	804.513	344.747	97.400	183.670	55.308	84.558	50.000	9643.84
18	795.617	342.559	95.781	181.981	53.545	82.817	50.000	9537.18
19	849.619	355.849	105.614	192.243	64.255	93.382	50.000	10189.11
20	903.000	369.004	115.348	202.398	74.863	103.812	50.000	10844.04
21	894.931	367.014	113.876	200.862	73.258	102.236	50.000	10744.37
22	881.068	363.597	111.347	198.224	70.502	99.528	50.000	10573.69
23	856.240	357.479	106.821	193.502	65.570	94.677	50.000	10269.77
24	880.378	363.427	111.221	198.093	70.365	99.394	50.000	10565.21

The total operating cost for the day is 234660.22 $ while the total generated power for 24 hours is 19837.932 MW. The peak load demand for this case scenario is hour 20 with 903 MW. The lowest load demand is hour 8 with 715.615 MW.

Figure 4.12 illustrate the simulated results for Table 4.10. Based on Figure 4.11, the generating units must deliver adequate power supply in order to satisfy the hourly power demand.

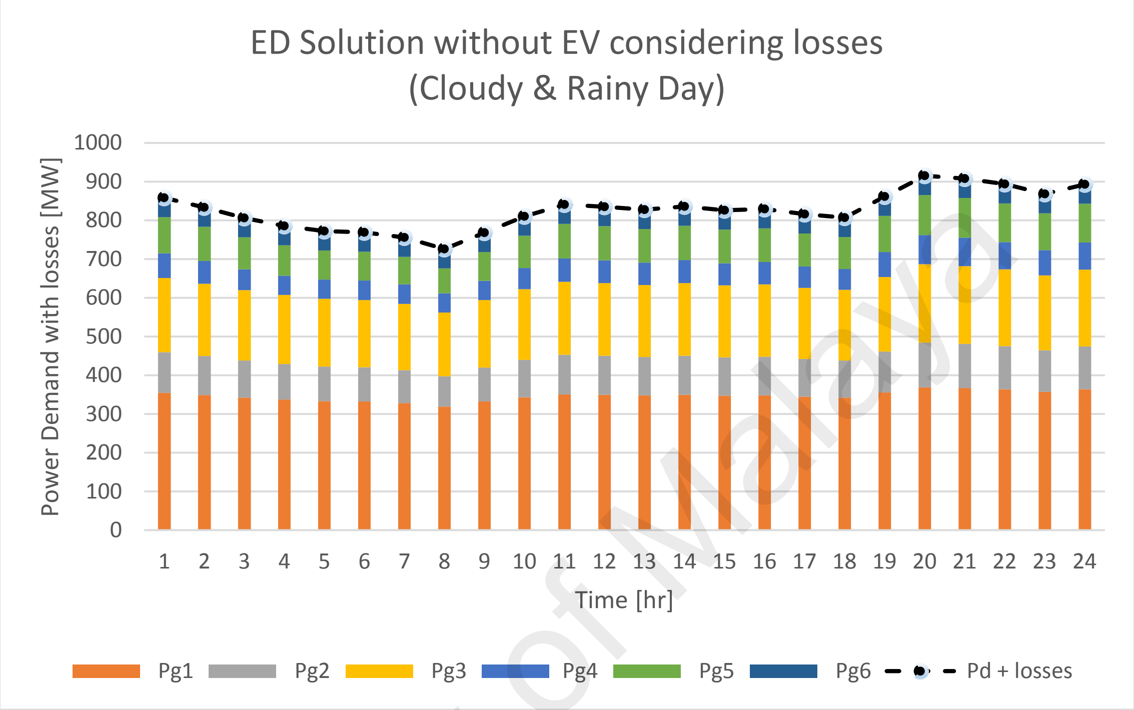


Figure 4.12: ED Solution without EV considering losses (Cloudy & Rainy Day)

As shown in Figure 4.11, in the early hour of 1:00 to 7:00, the load demand is at the minimum. During hour from 8:00, the load has been gradually increasing and a diurnal load profile can be observed. This is the typical daily load profile solved with economic dispatch solution. However, it can be observed that the average load demand is generally lower that hot and sunny day.

4.2.8 Economic Dispatch Solution with EV considering transmission losses (Cloudy & Rainy Day)

Table 4.12 shows the simulation results for the developed ED solution with EV on a cloudy & rainy day. The results is segregated into a typical 24 hours load demand profile. In this case scenario, transmission loss is considered in the simulation.

Table 4.12: ED Solution with EV considering transmission losses (Cloudy & Rainy Day)

Hour	P_D (MW)	P_{g1} (MW)	P_{g2} (MW)	P_{g3} (MW)	P_{g4} (MW)	P_{g5} (MW)	P_{g6} (MW)	Total Cost ($/h)
1	1203.244	436.305	165.045	254.165	129.907	156.724	78.212	14715.07
2	1168.455	429.087	159.711	248.611	124.012	151.084	72.452	14251.63
3	1135.215	422.197	154.620	243.309	118.389	145.693	66.943	13812.33
4	1069.563	408.614	144.583	232.855	107.309	135.042	56.046	12954.71
5	1015.668	396.828	135.938	223.871	97.323	125.776	50.000	12260.76
6	965.030	384.313	126.677	214.214	87.217	115.912	50.000	11618.24
7	840.489	353.600	103.951	190.507	62.443	91.597	50.000	10078.14
8	715.751	319.215	78.595	163.994	50.000	63.978	50.000	8594.19
9	757.615	332.031	88.104	173.907	50.000	74.152	50.000	9084.95
10	799.341	343.475	96.458	182.688	54.283	83.546	50.000	9581.79
11	876.356	362.435	110.488	197.328	69.566	98.608	50.000	10515.83
12	883.091	364.095	111.716	198.609	70.904	99.924	50.000	10598.55
13	874.468	361.970	110.143	196.968	69.190	98.239	50.000	10492.68
14	898.060	367.786	114.447	201.458	73.880	102.847	50.000	10782.99
15	880.096	363.357	111.170	198.039	70.309	99.338	50.000	10561.75
16	882.919	364.053	111.685	198.576	70.870	99.890	50.000	10596.44
17	841.602	353.874	104.153	190.718	62.664	91.815	50.000	10091.65
18	795.617	342.559	95.781	181.981	53.545	82.817	50.000	9537.18
19	849.619	355.849	105.614	192.243	64.255	93.382	50.000	10189.11
20	962.210	383.616	126.161	213.676	86.654	115.363	50.000	11582.73
21	991.762	390.917	131.564	219.311	92.549	121.121	50.000	11956.25
22	1038.400	402.177	139.827	227.900	102.061	129.984	50.866	12552.29
23	1050.109	404.595	141.614	229.761	104.032	131.885	52.813	12703.14
24	1149.880	425.236	156.866	245.648	120.869	148.072	69.375	14005.72

The total operating cost for the day 273118.12 $ while the total generated power for 24 hours is 22959.159 MW. The peak load demand for this case scenario is hour 1 with 1203.244 MW. The lowest load demand is hour 8 with 715.751 MW. It is observed that the total operating cost and total generated power is significantly higher when EVs are connected to the system.

Figure 4.13 illustrate the simulated results for Table 4.12. Based on Figure 4.13, the generating units must deliver adequate power supply in order to satisfy the hourly power demand.

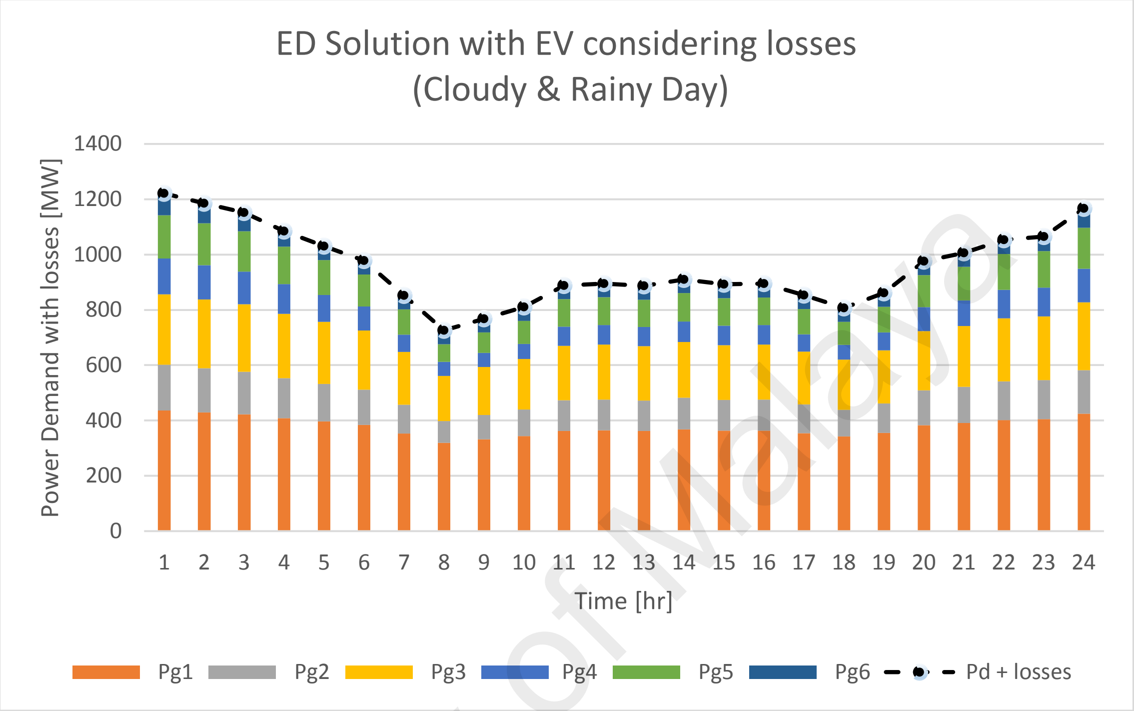


Figure 4.13: ED Solution with EV considering losses (Cloudy & Rainy Day)

As shown in Figure 4.13, the load level from hour 20:00 to 7:00 have been increased significantly as compare to Figure 4.12. This is mainly caused by the large number of idle electric vehicle in the charge mode.

Also, the peak demand shift from hour 20 when no EVs are connected to the network to hour 1 when EVs are connected to the network. In this case, when electric vehicle are connected to the network, the daily load curve is significantly reshaped.

4.3 Case Scenario Analysis

4.3.1 System Losses Analysis

Table 4.13 & Table 4.14 and Figure 4.14 & Figure 4.15 summarized the simulated results in Chapter 4.2.1 to 4.2.8. Table 4.13 and Figure 4.14 is the summarized result of Hot & Sunny Day while Table 4.14 and Figure 4.15 is the summarized result of Cloudy & Rainy Day.

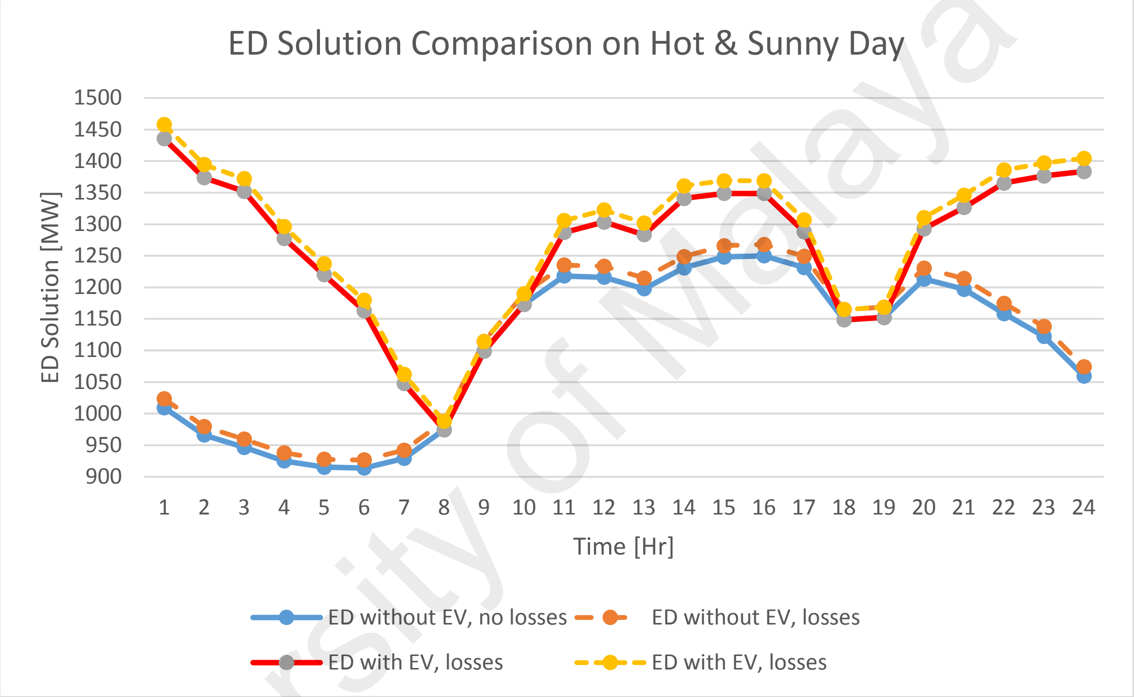


Figure 4.14: ED Solution Comparison on Hot & Sunny Day

Table 4.13: Case Scenario Analysis on Hot & Sunny Day

Case Scenarios	Total Operating Cost ($/hr)	Total Generated Power (MW)	Peak Power Demand (MW)	Lowest Power Demand (MW)
ED without EV, no losses	317389.66	26495.113	1250 at hour 16	913.818 at hour 6
ED with EV, no losses	367733.34	30362.512	1435.593 at hour 1	974.298 at hour 8
ED without EV, considering losses	322217.84	26867.843	1250 at hour 16	913.818 at hour 6
ED with EV, considering losses	373669.75	30804.277	1435.593 at hour 1	974.298 at hour 8

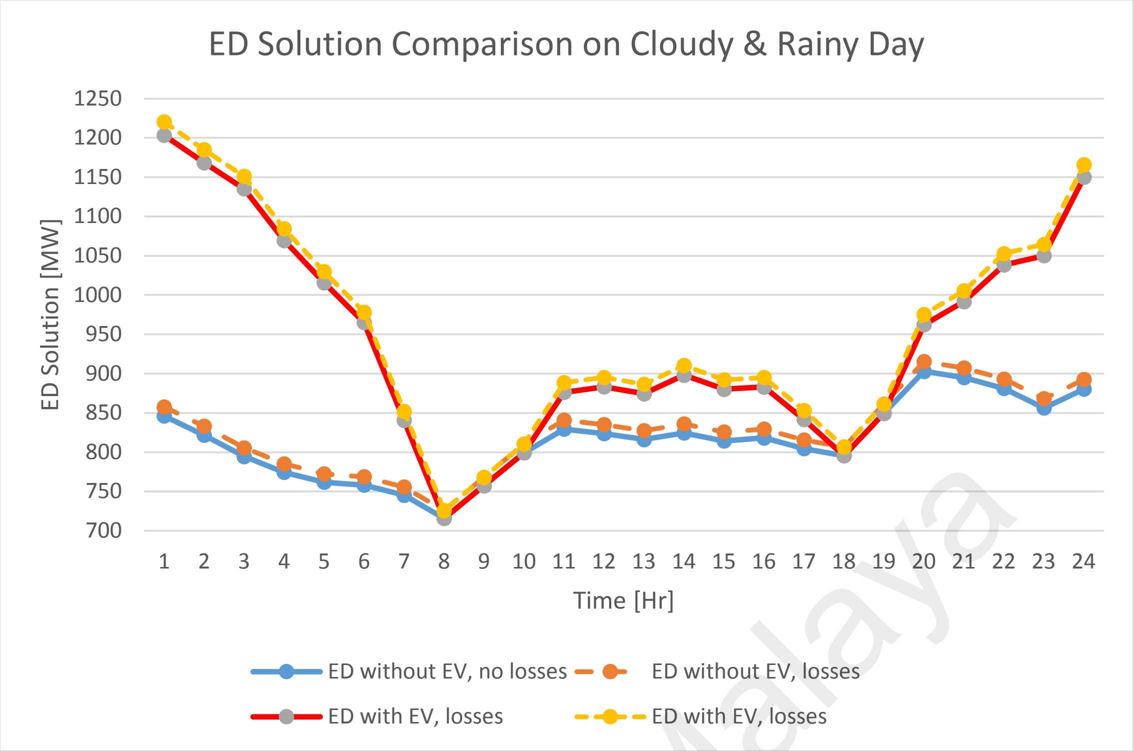


Figure 4.15: ED Solution Comparison on Cloudy & Rainy Day

Table 4.14: Case Scenario Analysis on Cloudy & Rainy Day

Case Scenario with losses	Total Operating Cost ($/hr)	Total Generated Power (MW)	Peak Power Demand (MW)	Lowest Power Demand (MW)
ED without EV, no losses	231427.2	19566.678	903 at hour 20	715.615 at hour 8
ED with EV, no losses	269205.78	22644.56	1203.244 at hour 1	715.751 at hour 8
ED without EV, considering losses	234660.22	19837.932	903 at hour 20	715.615 at hour 8
ED with EV, considering losses	273118.12	22959.159	1203.244 at hour 1	715.751 at hour 8

In the simulated model, B coefficient was used to calculate the transmission losses in the system. Based on the simulated results, transmission losses attribute to about 1.5% increase in total operating cost and total generated power. In future studies, the author suggest to perform load flow analysis on the system to precisely compute the system losses. As the system losses have minimal impact on the system, all the subsequent analysis will be based on case scenario considering losses only.

It can be observed that the total operating cost and total generated power of hot and sunny day is higher than cloudy and rainy day. This is mainly contributed by the cooling weather and less air conditioning is used.

In addition, the total operating cost and total generated power is higher when electric vehicles are connected to the network. When EV are connected to the grid, they will draw power from the network to charge its internal battery. When large EV fleets are present in the network, they will draw considerable amount of power from the network.

Also when EV fleets draw power from the network, the peak power demand duration changes significantly. Without the present of EV, the peak power demand is at hour 16 for hot and sunny day and hour 20 for cloudy and rainy day. Subsequently, when EV are connected to the network, the peak power demand shifted to hour 1 for both weather conditions. Though, the lowest power demand duration remains the same for all case scenario, which is the early morning of the day.

4.3.2 Weather Condition Analysis

Figure 4.16 displayed the ED Solution comparison based on weather condition without EV while Figure 4.17 displayed the ED Solution comparison based on weather condition with EV.

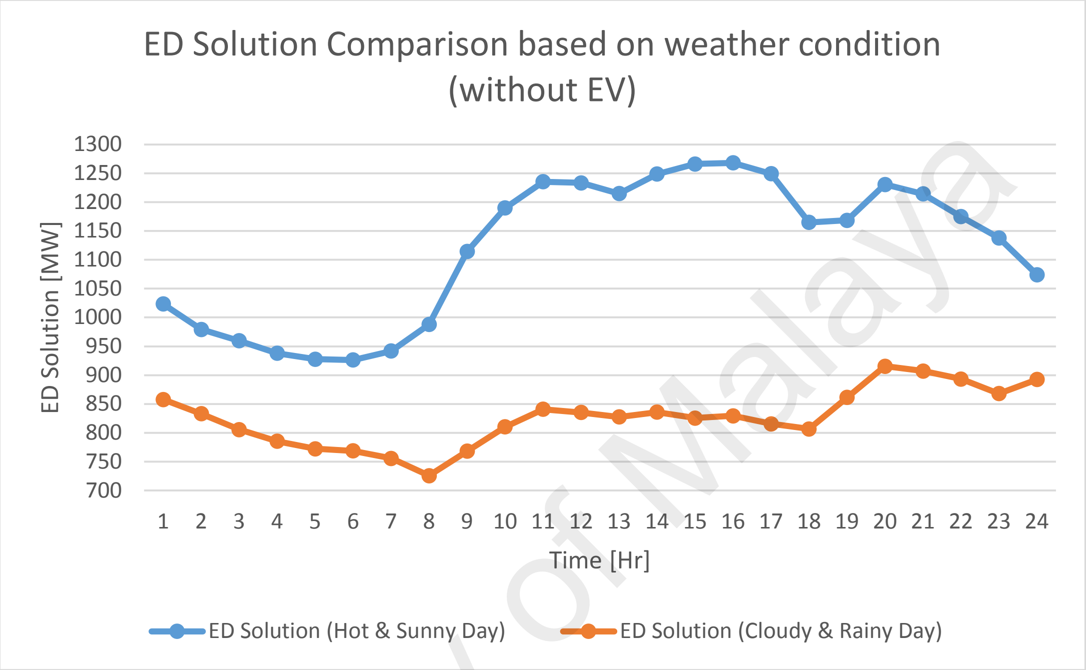


Figure 4.16: ED Solution Comparison based on weather condition (without EV)

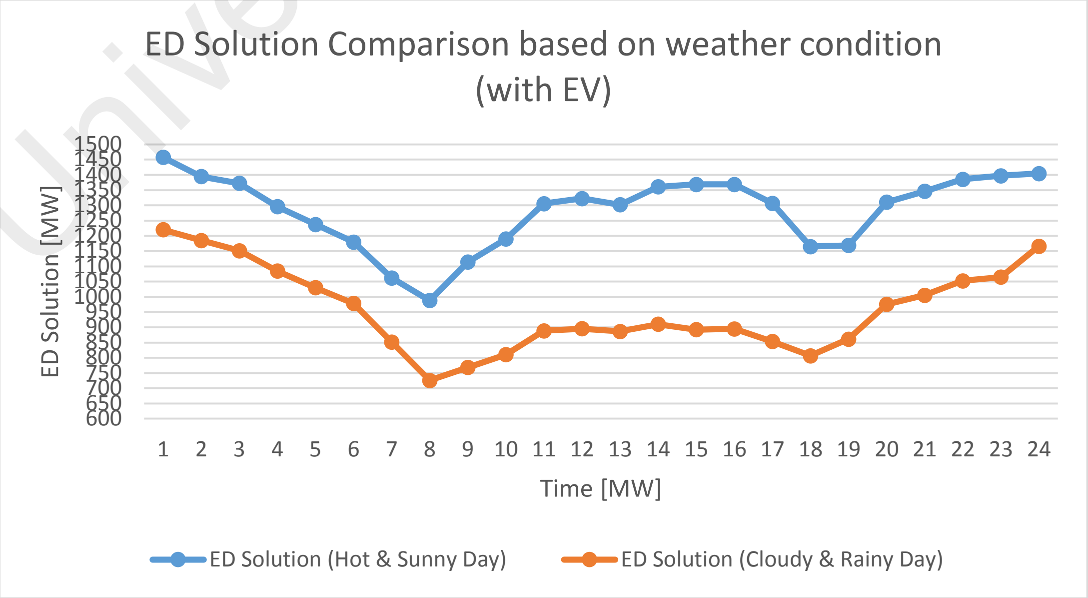


Figure 4.17: ED Solution Comparison based on weather condition (with EV)

On hot and sunny day, the operating cost is 37% higher as compare to cloudy and rainy day with and without EV charging activities. The total generated power is 35% higher as compare to cloudy and rainy day with and without EV charging activities.

In the IEEE test system, the maximum generation of the system is 1470MW. Based on Figure 4.17, the peak load demand is at hour 1 with 1435.593MW. If there is any sudden increase in load, then the system may be prone to system overload and breakdown. One of the effective way to anticipate sudden increase in load is by integrating renewable energy sources such as solar energy and wind energy with the EV charging infrastructures. However, renewable energy sources are often unpredictable and fluctuate over time due to the dependency of different weather conditions.

On cloudy and rainy day, the load demand is generally lower and generators may not run at full efficiency. EV charging activities can help to alleviate the situation by demanding additional power from the network. In such cases, system operators can lower the energy price during these non-peak period to encourage EV owner to charge to charge their EV batteries.

4.3.3 Electric Vehicle Charging Activities Analysis

Figure 4.18 displayed the ED Solution comparison with & without EV based on Hot & Sunny Day while Figure 4.19 displayed the ED Solution comparison with & without EV based on Cloudy & Rainy Day.

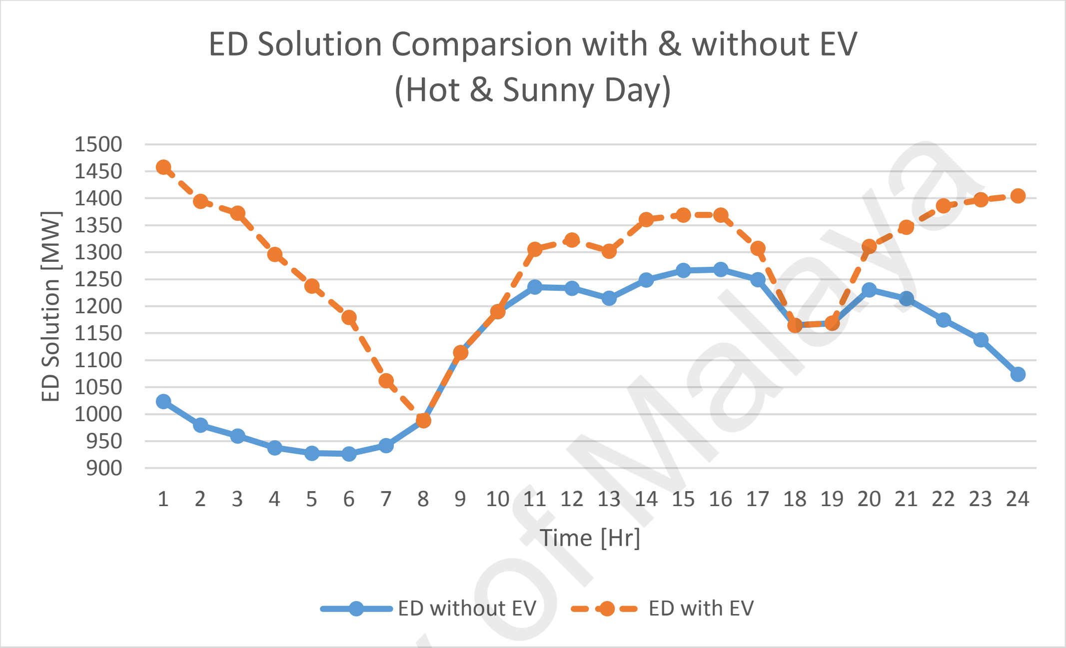


Figure 4.18: ED Solution Comparison with & without EV (Hot & Sunny Day)

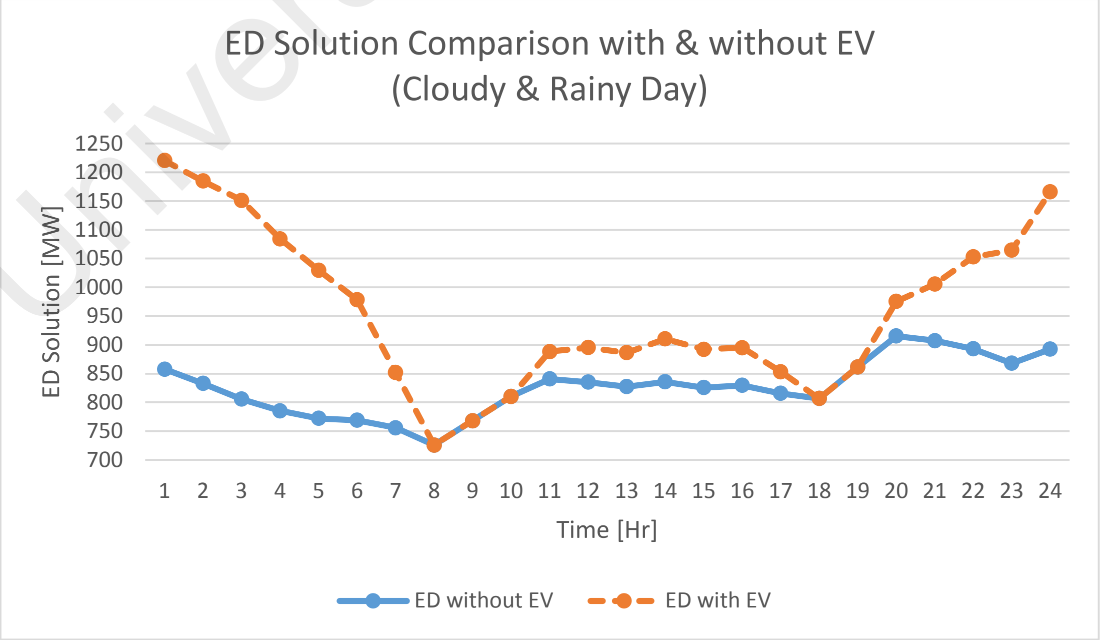


Figure 4.19: ED Solution Comparison with & without EV (Cloudy & Rainy Day)

For the standard economic dispatch solution, the load demand is at minimum during the wee hours in the morning. As the general population is fast asleep, the required power is also at minimum. For the economic dispatch solution with electric vehicle, it can be observed that the load demand spikes from hour 1 to 7. This is due to most electric vehicles charge its internal battery pack during non-peak hours to ensure the battery is at full capacity during the following commute. This will allow generating units to run at their most efficient.

Based on Figure 4.18 and Figure 4.19, it also can be observed that once electric vehicle are connected to the network, it will immediately draw power from the network to charge its internal battery. As the battery charges towards its full capacity, the load demand decreases at a steady rate. This can be observed during hour 23 to 7. Due to the uncontrolled charging nature of electric vehicle, the generating units may not operate at their highest efficiency.

As indicated in Figure 4.2 and 4.3, hour 8, 9, 10, 18 and 19 are the period when electric vehicle are travelling. Thus, the hourly load demand remains the same with or without electric vehicle.

During the peak demand period from hour 11 to 16, the load demand increases by around 10% when electric vehicle are considered to be connected to the network.

The economic dispatch solution was solved based on high EV penetration in the country and forecasted data on number of electric vehicles and its future demand. Thus, the load demand difference is huge for ED with EV as compare to ED without EV.

4.4 Proposed Control Charging Scheme

4.4.1 Economic Dispatch Solution with EV considering transmission losses in controlled charging scheme (Hot & Sunny Day)

In uncontrolled charging scheme, EV are connected to the network randomly and the power demand by EV are not always the same. Also, uncontrolled charging suggests that EVs start charging as soon as they are connected to the network. This will complicate the day ahead scheduling due to the randomness in demand response of EV.

One of the effective way to anticipate sudden increase in load is by integrating renewable energy sources such as solar energy and wind energy with the EV charging infrastructures. However, renewable energy sources are often unpredictable and fluctuate over time due to the dependency of different weather conditions.

Thus a controlled charging scheme is proposed to regulate the charging activities of electric vehicles. In addition, with controlled charging scheme, EVs plays a role of flexible load. In the controlled charging scheme of EV, system operators will monitor the hourly load demand and decide auspicious charging period for the EV.

Table 4.15 shows the simulation results for the developed ED solution with EV in proposed controlled charging scheme on a hot & sunny day. The results is segregated into a typical 24 hours load demand profile. In this case scenario, transmission loss is considered in the simulation.

Table 4.15: ED solution with EV in proposed controlled charging scheme

Hour	P_D (MW)	P_{g1} (MW)	P_{g2} (MW)	P_{g3} (MW)	P_{g4} (MW)	P_{g5} (MW)	P_{g6} (MW)	Total Cost ($/h)
1	1300.000	456.426	179.913	269.641	146.353	172.401	94.199	16023.80
2	1300.000	456.426	179.913	269.641	146.353	172.401	94.199	16023.80
3	1300.000	456.426	179.913	269.641	146.353	172.401	94.199	16023.80
4	1300.000	456.426	179.913	269.641	146.353	172.401	94.199	16023.80
5	1300.000	456.426	179.913	269.641	146.353	172.401	94.199	16023.80
6	1300.000	456.426	179.913	269.641	146.353	172.401	94.199	16023.80
7	1314.304	459.406	182.116	271.934	148.791	174.718	96.559	16219.76
8	974.298	386.602	128.371	215.981	89.065	117.719	50.000	11735.13
9	1098.916	414.683	149.068	237.526	112.258	139.805	60.921	13336.51
10	1173.252	430.081	160.446	249.376	124.825	151.861	73.247	14315.31
11	1286.948	453.708	177.905	267.551	144.131	170.287	92.045	15845.56
12	1303.546	457.165	180.459	270.210	146.958	172.976	94.784	16072.32
13	1283.327	452.954	177.348	266.972	143.514	169.701	91.447	15796.20
14	1340.924	466.264	187.632	277.433	150.000	178.974	100.441	16586.27
15	1348.856	468.265	189.116	278.973	150.000	180.513	102.001	16695.99
16	1348.925	468.282	189.129	278.987	150.000	180.526	102.014	16696.95
17	1288.327	453.995	178.117	267.772	144.365	170.511	92.273	15864.36
18	1148.577	424.966	156.666	245.440	120.649	147.860	69.159	13988.51
19	1152.313	425.740	157.238	246.036	121.281	148.466	69.778	14037.87
20	1300.000	456.426	179.913	269.641	146.353	172.401	94.199	16023.80
21	1300.000	456.426	179.913	269.641	146.353	172.401	94.199	16023.80
22	1300.000	456.426	179.913	269.641	146.353	172.401	94.199	16023.80
23	1300.000	456.426	179.913	269.641	146.353	172.401	94.199	16023.80
24	1300.000	456.426	179.913	269.641	146.353	172.401	94.199	16023.80

The total operating cost for the day is 373452.54 $ while the total generated power for 24 hours is 30802.599 MW. The peak load demand for this case scenario is hour 16 with 1348.925 MW. The lowest load demand is hour 8 with 974.298 MW.

Figure 4.20 illustrate the simulated results for Table 4.15. Based on Figure 4.20, the generating units must deliver adequate power supply in order to satisfy the hourly power demand.

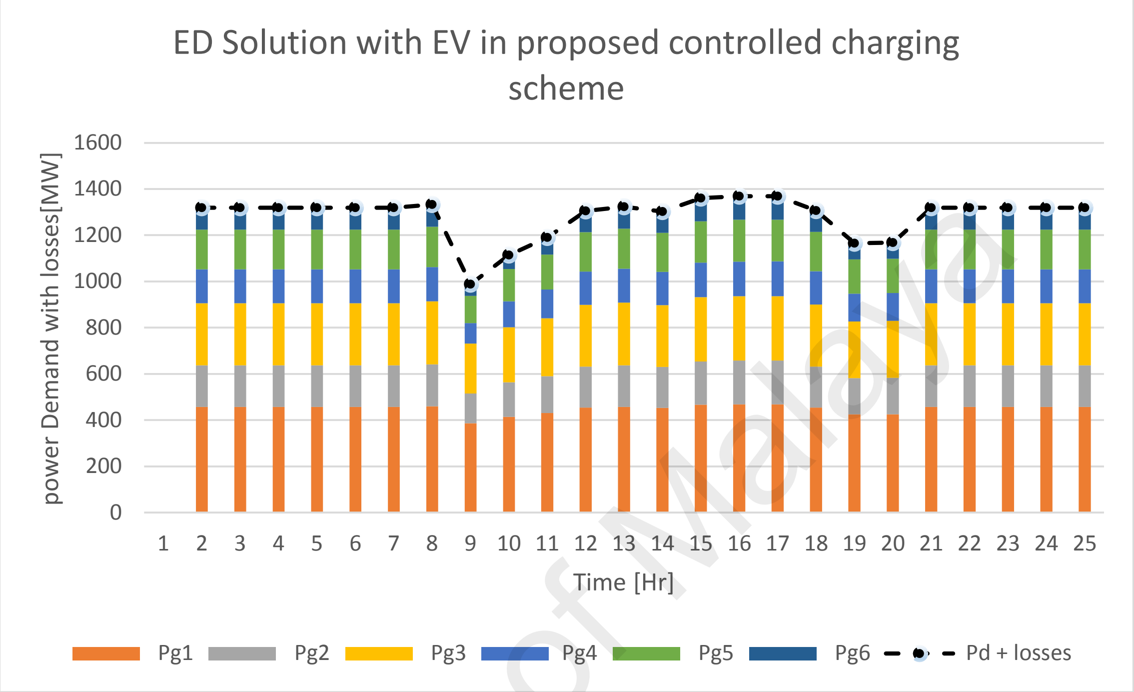


Figure 4.20: ED solution with EV in proposed controlled charging scheme

As shown in Figure 4.20, the load level from hour 21:00 to 7:00 have been regulated as compare to Figure 4.10. This is mainly caused by the large number of idle electric vehicle in the charge mode.

Also, the peak demand shift from hour 16 when no EVs are connected to the network to hour 1 when EVs are connected to the network. In this case, when electric vehicle are connected to the network, the daily load curve is significantly reshaped.

4.4.2 Case Scenario Analysis

Figure 4.21 illustrates control charging scheme compare to uncontrolled charging scheme and economic dispatch solution without considering EV integration. For the period of uncontrolled charging, the non-peak hour load curve is reformed drastically. By considering the maximum generation for this test system is 1470MW, the peak load demand for uncontrolled charging at hour 1 is 1457.713MW. If there are sudden increase in load demand, then the system will be overloaded and may collapsed.

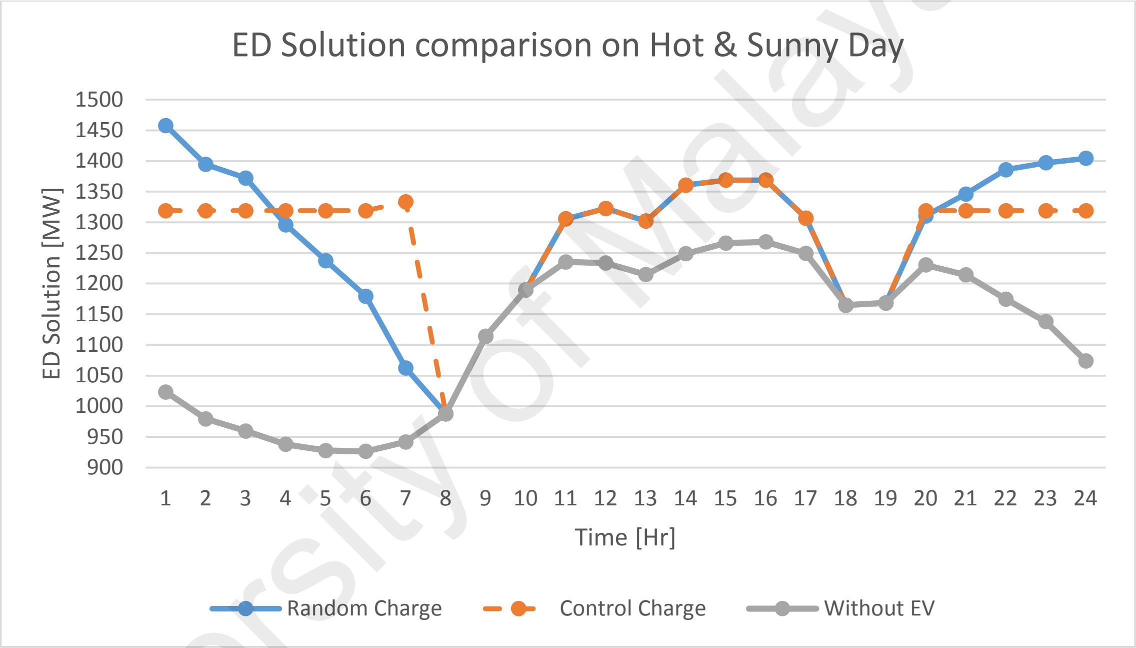


Figure 4.21: ED Solution comparison on Hot & Sunny Day

In order to mitigate this issue, a proper control charging scheme must be devised by the power system operators. In control charging scheme, the operators is able to distribute power evenly throughout the non-peak period. With the same load demand, control charging scheme is able to keep the load demand from reaching critical levels.

To further secure the operation of the network, renewable energy such as photovoltaic system can be integrated into the system. This will act as a spinning reserve.

CHAPTER 5: CONCLUSION & FUTURE WORK

5.1 Conclusion

As more people are aware of the consequences of pollutions, zero carbon emission transportation such as Electric Vehicle (EV) have been receiving a lot of attentions. With advent of large-scale EV, the system operators must accurately estimate the additional load demand from EV charging activities and allocate sufficient power to the system.

Based on the load forecasting analysis, it can be concluded that the load curve is significantly reshaped during EV charging activities. This is evident during the early hours of the day where load demand increases by an average of 30% as compare to load demand profile without EV. With the variation of weather conditions, the hourly variations in power demand are also different. By comparing both of the load profile, it is observed that hot and sunny day has a higher hourly load demand compare to cloudy and rainy day.

In order to understand the impacts of large-scale EV integration to the power network, an hourly economic dispatch solution considering EV charging activities was solved using mathematical iterative approach. As a comparison base, the hourly economic dispatch solution was also simulated for load demand profile without EV charging activities. Based on the results, electric vehicle has a “valley filling” effect during non-peak hours and higher peak load demand during peak hours.

To minimize the operating cost of generators, a controlled charging scheme is proposed. In the controlled charging scheme of EV, the variable generating cost and generated power is reduced. The key assumption is that EV charging activities can be monitored and controlled by the system operator, with an economic dispatch method.

The result of this study are limited by many assumptions such as percentage increased in load when EVs are connected to the network, estimated load demand profile and future development of EV technologies. However, to a certain extent, the results may provide reference values for future study on the widespread impact of EV on the power network, and assist the possibility of EV as controllable & manageable load.

5.2 Future Work

Amongst area of improvement that can be further perform for this study is to ensure the results take accounts into more case scenarios. For example, the hourly load demand for weekend and weekday with different weather condition or hourly load demand during festive holidays. In addition, the highest load demand of the day and lowest load demand of the day can be simulated to understand the maximum and minimum impact of electric vehicles.

Other area of interest is to simulate both charging and discharging mode of electric vehicle. This bidirectional power flow is also known as Vehicle to Grid (V2G) technologies. With V2G technology, two way power flow between electrical network and EV fleets can be realised. Assimilating EV and electricity grid will enable the power system to draw on the EV power during peak hours and for EVs to charge its batteries during off-peak hours. This was briefly discussed in Chapter 2.5.

In addition, to emulate a more practical power system network, system constraints such as generating unit’s ramp rate and prohibited zone can be included in the simulation. This will reform the optimization process that take accounts of all parameters to get better results.

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