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SARJANA MUDA

IMPACT OF EV CHARGING ON LV NETWORKS

Lim Chen Chuan

Bachelor of Electrical Engineering (Industrial Power)

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"I hereby declare that I have read through this report entitle "*Impact of EV Charging on LV Networks"* and found that it has comply the partial fulfilment for awarding the degree of *Bachelor of Electrical Engineering (Industrial Power)*"

Signature	:	………………………………
Supervisor's Name	:	………………………………
Date	:	………………………………

IMPACT OF EV CHARGING ON LV NETWORKS

LIM CHEN CHUAN

A report submitted in partial fulfilment of the requirements for the degree of Bachelor of Electrical Engineering (Industrial Power)

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2014

I declare that this report entitle "*Impact of EV Charging on LV Networks"* is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ……..……………………………

Name : …..………………………………

Date : …..………………………………

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ABSTRACT

Global pollution is increasing tremendously which will affect human life. Electric Vehicle (EV) is one of the methods which can reduce pollution. EV does not consume fuel directly for propulsion, but charging battery for power supplying. Charging EV by connecting through power grid will cause some problems. Those problems such as voltage drop and cable overheat will bring some impacts to residential. A residential area may face power shortage when exceeding EVs are charging simultaneously. All related problems had been found and studied by some countries. This project will focus on EV charging impact towards residential LV distribution network. Those EV was considered to be charged using same supply with house load. Simulations were carried out for studying those impacts. Five simulation cases had been carried out for investigating parameters such as voltage drop, thermal limit, transformer limit and energy losses. Some prerequisite studies had been done related to the existing grid features and EV characteristic. Five levels of EV penetration, 20%, 40%, 60%, 80% and 100% were done for simulation and obtained a series of data. The method proposed to alleviate the impact of EV charging on distribution grid was controlled charging method. The simulation involving the method had been carried out as one of five cases. All data obtained was processed and analyzed.

ABSTRAK

Pencemaran global yang mempengaruhi kehidupan manusia semakin bertambah. Kenderaan Elektrik (EV) merupakan salah satu cara yang boleh mengurangkan pencemaran. EV tidak memerlukan bahan api secara langsung untuk pergerakan, tetapi perlu mengecaskan bateri untuk bekalan tenaga. Pengecasan bateri melalui gird kuasa akan menimbulkan masalah. Masalah seperti kejatuhan voltan dan keterlalupanasan kabel akan membawa impak kepada kediaman. Sesuatu kawasan kediaman mungkin menghadapi kekurangan kuasa apabila terlampau banyak EV dicaskan pada masa yang sama. Masalah berkenaan telah dijumpai dan dikaji oleh beberapa negara. Projek ini akan menumpu kepada impak pengecasan EV terhadap rangkaian pengagihan voltan rendah kediaman. Semua EV dianggap mengecas dengan bekalan yang sama dengan beban rumah. Impak tersebut dikaji dengan mengadakan simulasi. Lima kes simulasi telah dijalankan untuk menyiasat parameter seperti kejatuhan voltan, had terma, had alat pengubah dan kehilangan tenaga. Beberapa pembelajaran awal berkaitan dengan ciri-ciri grid dan EV telah dihabiskan. Lima tahap penembusan telah digunakan untuk mejalankan simulasi dan sesiri data telah didapati. Cara pengecasan secara kawalan merupakan cara yang dikemukakan untuk mengurangkan impak pengecasan EV terhadap grid pengaihan. Simulasi yang merangkumi cara tersebut telah dijalankan sebagai salah satu daripada 5 kes simulasi. Kesemua data yang didapati telah diproseskan dan dianalisasikan.

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LIST OF ABBREVIATIONS

BEV	-	Battery EV
DSO	-	Distribution system operator
EV	-	Electric vehicle
EREV	-	Extended range electric vehicles
G2V	-	Grid-to-vehicle
HEV	-	Hybrid EV
ICE	-	Internal combustion engine
km/h	-	Kilometers per hour
LV	-	Low voltage
mGen	-	Micro generator
mpg	-	Miles per gallon
NEV	-	Neighborhood EV
OpenDSS	-	Open Distribution System Simulator
PHEV	-	Plug-in hybrid EV
SCADA	-	Supervisory control and data acquisition

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Automotive is using fossil fuel to be functioned in transportation. However, fuel will produce a lot of unwanted gas and particles which may pollute the air and eventually results in global warming. As concern for global warming keep growing, several countermeasures to reduce global warming are proposed. Electric vehicle (EV) is mentioned as one of the feasible solutions among all. EVs are battery powered. Thus, pollution and global warming can be reduced since fuel is no longer been used for EV. Reduced in fossil fuel demand will extend fuel reserved. When EV is fully replaced conventional vehicles, fossil fuel will not consume directly for transportation. Table 1.1 shows the percentage reduction in global warming emissions between EV and conventional vehicles. Some EV in markets such as Toyota Prius and Honda Civic Hybrid are estimated to reduce global warming emissions for about 40% when compared to 27 mpg gasoline vehicle [1].

Table 1.1: Percentage reduction in global warming emissions for EV [1]

	Good	**Better**	**Best**
mpg of a gasoline vehicle with equivalent global warming emissions	31 – 40 mpg	41 – 50 mpg	51+ mpg
Implication of ratings about EVs' global warming emissions	EVs have emissions comparable to the best gasoline non-hybrid models available	EVs have emissions comparable to the best gasoline hybrid models available	EVs outperform the best gasoline hybrid models available
Percent reduction in global warming emissions compared with 27 mpg gasoline vehicle	11 – 33%	33 – 46%	>46%
Examples of model year 2012 gasoline and hybrid vehicle in each range	Ford Fiesta (34 mpg) Hyundai Elantra (33 mpg) Chevrolet Cruze Eco (31 mpg)	Toyota Prius (50 mpg) Honda Civic Hybrid (44 mpg) Lexus CT200h (42 mpg)	No gasoline comparisons

1.2 Problem Statement

EV is the new trend for transportation since it is environmental friendly. However, there are some constraints for EV penetration. EV will be functioned based on the battery worked as power supply. The battery can be recharged through grid connected charger. For recent grid, charging of EV is an extra load which is huge enough to affect the entire system.

To fully charge an EV battery, grid network may face issues such as voltage unbalance, cable limit or transformer limit. All those aspects need to be deliberated to ensure stable grid networks.

1.3 Objectives

EV battery can be recharged through grid connected charger which becoming an extra load that may affect the entire grid system. To fully charge an EV battery, grid network may face issues such as voltage drop, cable limit and transformer loading need to be deliberated for stable grid network. This project is carried out:

i. To investigate impacts of EV charging on low voltage (LV) networks such as voltage drop, cable thermal limit, transformer loading and energy losses.
ii. To propose and study about countermeasure for moderating impacts.

1.4 Scope

This project is expected to study about effects on LV network in Malaysia brought by EV charging for different penetration levels based on several charging patterns. EV was assumed to be charged connecting through residential grid which also considered as house load. The residential area will only use Low Voltage (LV) which is lower than 1kV. Those impacts comprise voltage drop, cable thermal limit, transformer loading and energy losses. Methods for moderating EV charging impacts are proposed and investigated. Open Distribution System Simulator (OpenDSS) was used to simulate all cases.

CHAPTER 2

LITERATURE REVIEW

2.1 Theory and Basic Principles

Electric vehicle (EV) is type of vehicle which driven by electric, uses an onboard battery as supply for electric motor to build propulsion. Differ from conventional and hybrid vehicles, EV depend totally on electricity to charge batteries. Regenerative braking is technology that help energy to flow back to the battery when brakes. EV does not need to change gear because the harder the pedal pressed, the motor turns faster and hence drive the vehicle forward. Electric delivery vehicles accelerate faster than conventional vehicles because electric motor produces high torque at any load. Moreover, EV has no gear changes which made it comparable for urban driving and sometimes even better than diesel vehicles. EV is ready for a 10-hour working time after charging for overnight. Electric vehicles involve in transportation applications presently are able to move for 100 miles before charging required [2].

There are several types of EV available in the market recently. There include battery EV (BEV), hybrid EV (HEV), plug-in hybrid EV (PHEV) and neighborhood EV (NEV). BEV, also known as the pure electric vehicle, is a type of electric vehicle that must acquire energy by connecting to an electrical source to drive the vehicle. BEVs typically move for a mileage range of 100 to 200 miles powered by batteries-fed electric motor. HEV is combination of an internal combustion engine with an electric motor for the propulsion system. The electric power-train needs for achieving better fuel economy than a conventional gasoline vehicle. HEV does not need to be recharged through electric grid. The vehicle changes to the electric motor from the ICE once vehicle is warmed; but it will remain on electric power at low speeds for less than 15 mph or about 24 km per hour. The electric motor improves the HEV to drive in urban for over 600 miles per tank of gasoline with average 88.5 km/h. PHEV is hybrid vehicle that use rechargeable batteries which can be charging by connecting to an electric power source. A PHEV is similar with HEV because it contains both internal combustion engine and electric motor. PHEV referred as “extended range electric vehicles” or EREV at times. Most PHEVs have an expected mileage range from 30 to 40 miles on electric power especially for shorter trips and ICE are appropriate for long journey. NEV is an EV which limited to speed less than 72.5 km/h speed, depending on the local law. NEV is built to have a 48.5 km/h maximum speed and 3000 pounds maximum loaded weight. It is typically designed for usage in neighborhood as stated in the name [3].

There are a lot of the benefits brought by EV. First, it does not have emissions at the point of use. It means that none of the unwanted gases release while driving an EV. Next, it brings a quiet driving experience. Since EV is giving a quiet and smooth operation, it has less noise and vibration compared to conventional vehicle which using ICE. Moreover, EV is also practical and easy to drive since it is not using conventional gear system. Thus, EV is suitable for urban driving. The traffic in urban which comprise a lot of start and stop will definitely lead regenerative braking of EV in full use. Last but not least, EV can be charged in home with electrical supply, thus avoids driver for queuing at petrol stations and save time [4].

2.2 Review of Previous Related Works

Paper [5] involves 3 types of EV charging which are dumb charging, delayed charging and smart charging. Dumb charging means that EVs are charged as soon as battery depleted without concerning any constraints. Delayed charging is often referred as grid-to-vehicle (G2V) which means that the grid operator controls the EV charging either by financial or by ripple control. Financial instrument which comprise multi tariff motivates EV owners to charge their cars during off peak hours with a lower rate. Smart charging is part of the smart grid concept. This type of charging needs continuous bidirectional communication between the EV battery management system and distribution system operator (DSO) supervisory control and data acquisition (SCADA). Since there is no smart metering infrastructure in Hungary yet, dumb charging had been using in the simulation for investigating a worst case scenario. Some assumption had been made in this study. First, the customer amount in the network is very large. Then, a single customer only consumes very tiny percentage on the performance of the network. Last, all customers are independent to decide the time for charging EV. This paper concludes that dumb charging causes an increase in transformer loading. A serious overloading may happened on transformer for 100% penetration. In addition, dumb charging also causes voltage drop. However, the voltage drop does not exceed the permissible limits which states 7.5% according to Hungarian Standard MSZ EN 50160.

Paper [6] studies the effect of EV battery charging on distribution network voltage, thermal loading and electrical line losses. A case study for different penetration levels for British distribution network had been made. The penetration levels divided into 12.5%, 33% and 71% correspond to low, medium and high EV penetration levels. Deterministic and probabilistic were used as the 2 approaches for the study. For deterministic approach, there were four findings highlighted. Voltage was out of limits for the medium and high EV penetration levels but remain normal for low level. Next, the cable supplying 96 households from LV distribution grid was found to over its nominal rating for the medium and high EV penetration levels and also normal for low penetration level. After that, the distribution transformer was found to be overloaded for all EV penetration levels. Lastly, electrical line losses in the LV cables were found to increase by 6% for the high EV penetration level.

Besides deterministic approach, there was also probabilistic approach used in this study. The first finding was voltage was out of limits for the medium and high EV penetration levels while low penetration level has 4% probability to violate limit. Besides that, the cable supplying 96 households from LV distribution grid was found to over its nominal rating for all penetration levels. Moreover, the distribution transformer was found to be overloaded for all EV penetration levels with only less than 5% probability for it to operate normally. Last finding for probabilistic approach was electrical line losses in the LV cables were found to increase by 10% for the high EV penetration level. It was obvious that deterministic approach was obtaining a better penetration level for EV charging when comparing with probabilistic approach. On the other hand, this study consists of two charging methods which are dumb and smart charging. For smart charging, the results showed that the probability of voltage violations for the low EV penetration maybe eliminated and the transformer overload probability would be reduce from 85% to 5%. Besides that, distribution network reinforcement method was investigated. The low EV penetration level may not crash any cable or voltage limit by upgrading the underground cables and the distribution transformers. However, this solution was found not sufficient for medium and high EV penetration levels. All the constraints for the medium EV penetration level can be endured by installing micro generator (mGen). When both reinforcement and installing methods applied, high EV penetration level can keep the transformer loading and the voltage limits within boundary. This paper concludes that a high EV penetration level in distribution networks needs a combination of network reinforcement, mGen installation and EV battery management.

The main questions stated in paper [7] is the impact toward transformers and cable loadings if large amount EVs are penetrated. In addition, the percentage of overloaded network components can be alleviated by implementing some kind of controlled charging is investigated. This study also researches about the financial value of controlled charging of EVs. This study is focused on the Netherlands but the research approach and conclusions are generally applicable. For the 10kW uncontrolled charging, it yields approximately 50% for transformers, 13% for cables due to overloading and 5% for cables due to voltage drop for the out of limit value. After implementing controlled charging, the percentage of exceeded threshold value had been improved compared to the 10kW uncontrolled scenario. It improves to approximately 25% for transformers, 5% for cables due to overloading and 2% for cables due to voltage drop.

Paper [8] investigates the proportion of residential LV distribution networks could be impacted by EV in Ireland. The main issues that can be predicted are excessive voltage drops and overloading of networks components such as power lines and transformers due to huge extra load. The sensitivity of these impacts to be changed in the point of connection of EVs is also analyzed for determining affordable levels of EV penetration. The voltage asymmetry also may happen since residential household connecting single phase with distribution network. For point of connection of EV, 28% penetration will violate the limit when connecting end of feeder while 42% for start of feeder. 25% penetration will violate the transformer limit and 30% penetration will violate the cable thermal limit. Since 20 to 40% of EV penetration will break the limit for components, DSO would needs to cut down the power supply for EV charging for secure reason. This paper proposed advanced metering device to be installed for alleviating the impact for EV charging with considering cost for network upgrade.

Objective of paper [9] is to investigate the impacts of electric vehicle charging on the power distribution network in the Danish island of Bornholm. The parameters involved such as voltage profile, distribution line loading, transformer loading, peak demand and system losses are analyzed for increasing in EV penetration. Two modes of EV charging which including controlled and uncontrolled are analyzed for 0 to 50% EV penetration. Uncontrolled charging made the voltage falls below the limit for more than 10% EV penetration while controlled charging can afford penetration up to more than 40%. For 50% EV penetration, uncontrolled and controlled charging shows 40% and 30% increasing in power losses respectively. For same penetration, uncontrolled had 31% higher in peak demand compared to controlled charging. For overall, only 10% of EV integration is allowed for the uncontrolled charging for the studied test distribution network. Undeniably the controlled charging is more effective than the uncontrolled charging for more EV penetration.

Paper [10] analyzed the reactive power characteristics and impact of charging stations accessing to typical distribution networks. Two types of charging method are available in charging stations which are normal-charge and fast-charge. The characteristic of charging stations accessing to four types of networks is simulated for each charging mode and charging