IMPACT OF ELECTRICAL VEHICLE CHARGING ON DISTRIBUTION NETWORK

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Electrical Engineering (Industrial Power) with Honours.

By

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

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MOHAMAD TARMIZI BIN MOHD SALEH

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2017

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I declare that this report entitle “Impact of Electrical Vehicle Charging on Distribution Network” 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 : Mohamad Tarmizi Bin Mohd Saleh

Date : …….....

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Dedicated to my beloved mother and father.

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ABSTRACT

Nowadays, Electrical Vehicle (EV) is getting popular in our daily life to reduce global pollution. It is one of the solution to keep human stay healthy without affect the human life. EV use charging battery as power supply because it does not use fuel directly. It is a new concept to introduce people about economic clean transportation technology. Charging an EV at residential area is one of the distribution network problem that may lead a disturbance of the system. In this studies, it begin to create model the Low Voltage (LV) residential network due to urban, semi urban and rural area. Charging the EV will bring about a few impact through the power grid connection and also for the load. There have several impact such as cable overload and voltage drop to residential network system. Every single related issue had been found and analysed by several countries. The aim of this project is about impact of EV charging on distribution network. Those effects can be determine using simulation software. A simulation case was considered to analyse several parameter contains voltage drop and energy losses. Some essential reviews had been done identified with the current framework components and EV characteristic. In simulation software, there have 5 stages with 20%, 40%, 60%, 80% and 100% of EV penetration. This project will divided into two part which are results without EV penetration and results with EV penetration. All information acquired was processed and analysed.

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ABSTRAK

Pada masa kini, kenderaan elektrik (EV) semakin terkenal dalam kehidupan seharian kita untuk mengurangkan pencemaran global. Ia adalah salah satu cara penyelesaian untuk manusia kekal sihat tanpa menjejaskan kehidupan seharian. EV menggunakan pengecasan bateri sebagai bekalan kuasa kerana ia tidak menggunakan bahan api secara langsung. Ia merupakan satu konsep baru untuk diperkenalkan kepada orang ramai mengenai teknologi pengangkutan yang bersih dan ekonomi. Mengecas EV di kawasan perumahan merupakan salah satu masalah rangkaian pengagihan yang boleh membawa kepada gangguan sistem. Dalam kajian ini, ia bermula dengan membuat model rangkaian voltan rendah kesan terhadap kediaman di bandar, pinggir bandar dan luar bandar. Mengecas EV akan memberi beberapa impak malalui sambungan grid kuasa dan juga terhadap beban. Ia mempunyai beberapa kesan seperti beban kabel dan kejatuhan voltan terhadap sistem rangkaian kediaman. Setiap isu yang berkaitan telah dijumpai dan dianalisis oleh beberapa buah negara. Tujuan projek ini adalah mengenai kesan pengecasan EV pada rangkaian pengagihan. Kesan-kesan tersebut boleh ditentukan dengan menggunakan perisian simulasi. Satu simulasi telah dijalankan untuk menyiasat parameter seperti kejatuhan voltan dan kehilangan tenaga. Beberapa ulasan penting telah dilakukan seperti komponen rangka kerja semasa dan ciri-ciri EV. Dalam perisian simulasi, terdapat 5 peringkat penembusan EV iaitu sebanyak 20%, 40%, 60%, 80% dan 100%. Projek ini akan dibahagikan kepada dua bahagian iaitu keputusan tanpa penembusan EV dan keputusan dengan penembusan EV. Semua maklumat yang diperolehi telah diproses dan dianalisis.

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LIST OF ABBREVIATIONS

AC	-	Alternative Current
BEV	-	Battery EV
DC	-	Direct Current
DSO	-	Distribution System Operation
EV	-	Electric Vehicle
G2V	-	Grid-To-Vehicles
HEV	-	Hybrid EV
ICE	-	Internal Combustion Engine
Km/h	-	Kilometres Per Hour
LV	-	Low Voltage
MD	-	Maximum Demand
NEV	-	Neighbourhood EV
OpenDSS	-	Open Distribution Simulation Software
PEV	-	Plug-in Electric Vehicle
PHEV	-	Plug-in Hybrid EV
SCADA	-	Supervisory Control and Data Acquisition
TNB	-	Tenaga Nasional Berhad
T_x	-	Transformer

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The transportation sector has been identified about 25% of global carbon emissions from fossil fuels [1]. This situation is getting worse by the inefficiency of the transportation sector. To achieve a sustainable and green economy development towards a green transportation sector, the government must have several strategies for it. For example, introducing electrical – based vehicle towards the Malaysia consumer is the alternative to reduce CO_2 emission and the dependency on petroleum. According to the government statistics, car ownership in Malaysia is the third highest in the world at a whopping 93% with 53% of households having more than one car. By using electric cars, it is one of the ways to support the government's initiative to achieve a reduction of 40% towards the greenhouse gas emissions by the year 2030 and reduces the reliance on fossil fuels as the resources are depleting. According to Malaysian Green Technology Corporation (MGTC), switching to EV could save up to 69% in fuel and 64% in maintenance. Using EV as the battery and also acts as the power supply, it can be charged at home or public locations through standard electrical power outlets [2]. Moreover, the phenomena of charging EV battery in the houses in this country is still new. In this project, it will focuses on the impact of EV charging on the distribution of network.

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1.2 Research Background

An Electrical Vehicle (EV) is also known as an electric drive vehicle. An EV is more energy efficient as compared with an Internal Combustion Engine (ICE) vehicle as it does not have any transmission losses. The increasing price of fuel and cares about the environment issue encourage the citizens to buy EV. An EV contains low carbon emission during operation that led to the reducing of air pollution and less contribution towards the greenhouse gases. Besides that, sales of EV is growing fast nowadays [3]. These EVs are available in the Malaysia market with the purpose of green technology and energy saving. The use of green technology and renewable energy is an integral part of the government agendas. Power source for an EV comes from the electricity collector system which is self – contained with battery or a generator to convert fuel to electricity. Consumers can charge at any location that provides electrical socket. This charging location is most common at home and in the workplace. Furthermore, during a critical situation, it may be a challenge in Malaysia to charge an EV because there are just few of the electrical charging stations only such as in Johor, Melaka, Penang and Klang Valley. In addition, installing Electrical Vehicle (EV) charging at Malaysia residential locations which consists of the urban, semi urban and rural area will give some impacts such as voltage drop or energy losses. The modelling network system for their impact of EV charging in residential areas are based on local power utility which is Tenaga Nasional Berhad (TNB) standard [4]. Due to the popularity of EV charging on electricity distribution network, it will give impacts on the planning and operation of the power system network. However, high penetrations of Electrical Vehicle (EV) may lead to technical impacts on connections to the residential system networks [5].

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1.3 Problem Statement

In the modern days, the EV is getting popular as a transportation because it is one of the environmental friendly automobiles. The battery acts as a power supply for moving the EV. The energy of the EV battery can be added through swapping the battery or getting it recharged through grid connected charger. In the morning, during the working hour period from 8 am to 5 pm, the residential consumer demand is low as compared to the evening hour until midnight. This scenario occurs when people are out from their home for school or work. Residential consumer demand begin to rise in the evening at 5 pm until midnight due to the high demand occurs at that time when people go back from work and charge their EV at home. When extra load is used to charge the EV, it will affect the distribution network system. To reduce the grid network issues such as voltage unbalance, cable limit or transformer limit, are needed to be discuss to ensure stable grid distribution network.

1.4 Objectives

The objectives of this project are:

i. To model and determine the technical parameters of the low voltage (LV) distribution network in Malaysia.
ii. To determine the impacts of Electrical Vehicle (EV) integration of Malaysia's distribution network.

1.5 Scope

This project will focus on the impacts of Electrical Vehicle (EV) charging on the distribution network based on LV network for the Malaysian power distribution system. It involves the simulation of software studies. A software simulation has been developed in DIgSILENT Power Factory of 15.1 software. It is to model LV network for their impacts of EV charging in semi – urban residential area. In this project, those impacts comprises of voltage drop, cable thermal limit, transformer loading and energy losses.

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1.6 Report Outline

This report will cover 5 chapters with its own content. Hopefully this report can show the ideas and understanding of the whole system designed to the reader after reviewing each chapter.

Chapter 1 gives a briefing about the introduction of this project, the research background, the problem statement, the objective, the scope and report outline for each chapter in this report.

Chapter 2 will discuss about all the literature reviews needed. In the literature review, it will elaborate about the theory and basic concepts of the project and comparison between previous researchers. This chapter also explains the previous project that are related about the impacts of Electrical Vehicle (EV) charging on the distribution network.

Chapter 3 explains the methodology used in this project. All the parameters and types of modelling will be explained in detail. It also includes the project's progress that considers simulation modelling and flow chart.

In chapter 4, it highlights the result and analysis for this project. The analysis includes the existing system and the improved ones on the proposed system.

Chapter 5 explains the conclusion of this project about impacts of Electrical Vehicle (EV) charging on the distribution network. It also includes the future recommendations of the project.

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will describe the literature review based on the information from lecturers, reference book, information from internet web page and previous researches that are relevant to this project. This chapter consists of several sub – topics such as Electrical Vehicle (EV) charging theory, review of related work and summary of the related work.

2.2 System and Theory of Electrical Vehicle

Electrical Vehicle produce less pollution than Internal Combustion Engine (ICE). So, EV are an environmentally friendly especially in urban area. EV depend only on electricity to charge batteries compared with conventional and hybrid vehicles. EV technology which is regenerative braking help energy to flow back to the battery when brakes. Moreover, the harder the pedal pressed will make the motor rotate faster because EV does not need to change the gear. EV get power from the rechargeable batteries installed inside the vehicle. These batteries are not only used for power vehicles but also used for the functioning of radio, light, air conditioning and others. Since the EV has controller inside, it acts as a regulator to control the amount of energy received from the batteries so the motor does not damage or burn when the motor was running. However, the EV power source battery acts like a “gas tank” and give energy to the electrical motor vehicle rotate [6].

Battery EV (BEV), hybrid EV (HEV), plug-in hybrid EV (PHEV) and neighbourhood EV (NEV) are several types of EV available in the market. BEV is a type of EV that must need energy by connecting to an electrical source to drive the vehicle. It is also

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known as the pure EV. Battery electric motor of BEVs can move about 100 to 200 miles on the road. Combination between an electrical motor for the propulsion system and an internal combustion engine (ICE) is known as HEV. The electric power-train is better fuel economy compared with a conventional gasoline vehicle. HEV can save our electrical bills because it does not need to be recharged through electric grid. The electric motor improves the HEV to drive in urban area for over 600 miles per tank of gasoline with average 88.5 km/h. Vehicle that use rechargeable batteries connecting with electric power source is called PHEV. A PHEV and HEV is same because it has both of electric motor and combustion engine. PHEVs have an expected mileage range from 30 to 40 miles on electric power for shorter trips compared with ICE for long journey. NEV is an EV have a 48.5 km/h maximum speed and 3000 pounds maximum loaded. NEV is typically designed for usage in neighbourhood as stated in the name [7].

There are three types electric motor in the market such as DC brushless with top speed, permanent magnet motor and AC induction with the good performance. Besides that, there are three main component in EV which is battery, controller and electric motor. When the vehicle are turn on, the current will flow from the battery and the controller will take energy from the battery to send energy to the electric motor. Table 2.1 shows types of EV batteries [8].

Table 2.1: Types of EV batteries.

Types of Batteries	Description
Lithium ion batteries.	• Gives extra performances, range and carries highest price tag. • Lighter than lead acid and nickel metal. • Also used to store data in smart phone.
Lead acid batteries.	• Most popular. • Cheapest and 97% recyclable.
Nickle metal hydride batteries.	• Cost much more than lead acid but provides higher output and better performances.

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There are many environmental benefits and personal benefits for having an EV such as no oil consumption. Next, creates less noise pollution. These because EV engine made low noise compared with combustion engine. Besides that, the maintenance of EV are more easy and cheaper. Since EV is giving affordable price to maintenance, they have fewer moving parts compared to conventional vehicle which using ICE. Moreover, EV very suitable for urban driving since it is not using conventional gear system and it so practical to handle. Furthermore, most electric motors can travel up to 150 until 180 km at full charge of battery.

2.3 Review of Related Work

Objective of paper [9] is to explore the affect proportion of residential LV distribution networks in Ireland by EV. Besides that, this study consists of two main issues which are excessive voltage drops and overloading of networks components. For example, large over load of transformer and power lines. Since, residential household in single phase connection, the voltage asymmetry will occurs on distribution network. Choose suitable levels of EV penetration for point connection of EV. Besides that, 28% penetration will over the limit when connecting end of feeder while 42% for start of feeder for point connection of EV. Then, 25% and 30% penetration will over the limit of transformer and the cable limit respectively. Distribution System Operation (DSO) cut down the power supply for EV charging, since 20% to 40% of EV penetration will over the limit for components safety. It can be conclude that installed smart metering device will upgrade impact for EV charging.

Paper [10] study the impacts of electric vehicle charging on the power distribution network in the Danish island of Bornholm. On the other hand, this study consist of five parameters to increase EV penetration such as system losses, peak demand, transformer loading, distribution line loading and voltage profile. Furthermore, EV charging have two modes consists controlled and uncontrolled are analysed for 0% until 50% EV penetration. These uncontrolled charging made the voltage drop below the limit more than 10% while controlled charging can increase EV penetration up more than 40%. It was obvious that the controlled charging is the best performance in EV penetration compared with the uncontrolled charging.

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Numerous studies have attempted to explain about impact of EV charging on distribution network. Paper [11] found that the network sample was done on a residential area supplied by local Distribution System Operation (DSO). This studies aim to investigate the case study about newly developed and matured networks. For this studies, matured network has ten years experienced compared to newly developed network. This studies also research about safe penetration level for EV charging network. For example, penetration level on grid limit consist of voltage drop, transformer limit and voltage unbalanced. On the other hand, this studies consist of three scenarios such as unbalance EV charging, evenly distributed EV charging and controlled EV charging. For the first scenario, which also considered as a worst case. Transformer does not be over limit with 80% for new network and 30% for matured network. For voltage limit, penetration for new network is 40% while matured network is 20% can be safely restrain by residential grid. Both network, new and mature network was considered 20% of penetration level was safe for voltage unbalance. 30% and 10% of penetration level for new and matured network respectively due to cable thermal limit. Next, for the second scenario, which acted as balanced load. 100% penetration for newly developed network will constant for save minimum voltage unbalance and voltage limit while for matured network same penetration level can supported for voltage unbalance. Lastly, the third scenario is the best charging method among the others. It control the charging time with higher penetration level. Newly developed network can provide full EV penetration. It was obvious that potential of using different charging pattern.

Voltage unbalance create by uneven distribution network of EV penetration level among the stage were concentrates in paper [12]. 3 levels of battery charging technique such as Level 1, Level 2 and Level 3 to recharge the PEV batteries. Level 1 and Level 2 are single phase while Level 3 is 3 phase. In United State, Level 2 charger was use in this studies. It typically charges 208V to 240V and drawn many current up to 80A. PEV charging used high loads demand that influence energy consumption increase and can bring power losses and voltage unbalanced. Voltage unbalance increased by 0.181% for off-peak and 0.165% for on-peak demand due to 10% penetration of EV. Next, increased by 0.277% for off-peak and 0.262% for on-peak demand due to 30% EV penetration. Furthermore, for 50% penetration, voltage unbalance increased by 0.404% and 0.38% for off-peak demand and on-peak demand respectively. Last EV penetration is 80%. Voltage unbalance increased by 0.926% for off-peak demand and for on-peak demand increased by 0.917%. Since the higher EV penetration contribute voltage unbalance increase. Smart or coordinate charging, grid

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reinforcements, grid optimization are the new technologies method without give more impact on the EV charging system.

Three types of EV charging such as dumb charging, delayed charging, and smart charging were involved in paper [13]. Dumb charging means that EVs are charged like battery depleted without concerning any constraints. Delayed charging is like grid-to-vehicle (G2V) where the grid operator control the EV charging either by ripple control or by financial. Financial instrument motivates EV owners to charge their vehicles during off peak hours with a lower tariff rated. Smart charging needs continuous bidirectional communication between EV battery management system and distribution system operator (DSO) supervisory control and data acquisition (SCADA). Dumb charging had been using in the simulation for investigating a worst case scenario in Hungary. Dumb charging was used because no smart metering infrastructure in Hungary yet. Some assumption has been made in this study such as the customer amount in the network is very large, all customers are independent to decide the time for charging EV, and a single customer only consumes very small percentage on the network performance. Thus, paper concluded that dumb charging causes on increase in transformer loading. When 100% penetration was applied on transformer it may cause serious overloading. Furthermore, dump charging also cause voltage drop but it does not exceed the permissible limits which states 7.5% according to Hungary Standard MSZ EN 50160.

When large value penetration on EVs on the network system it will cause impact toward transformer and cable loading as stated in paper [14]. However, the percentage of overloaded network system instruments can be alleviated by implementing some kind of controlled charging. This study is focused in the Netherlands and also researches about the financial value of controlled charging of EVs. For the 10KW uncontrolled charging, it yields approximately 50% for transformer, 13% for cables due to overloading and 5% for cables due to voltage drop for the out of limit value. After used controlled charging, the percentage of exceeded threshold value had been improved compared to the 10KW uncontrolled scenario. It improve to approximately 25% for transformers, 5% for cables due to overloading and 2% for cables due to voltage drop.

All the paper studied had involved with the impact of EV charging. The EV charging will bring impact such as transformer overload, voltage drop or line losses. Table 2.2 shows the summary of previous research.

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Table 2.2: Summary of previous research.

Authors	Field of Study	Project Description	Research Gap
P. Richardson, D Flynn, and A. Keane.	Impact Assessment of Varying Penetrations of Electric Vehicles on Low Voltage Distribution Systems.	This paper explores the potential effect to EV when charging on distribution network. This project was used DIgSILENT Power Factory to build a model of LV distribution network. Using unbalanced load flow calculations method to explore details about steady-state performance by changing the thermal loading levels and voltage at different parts of the system. Then the data was collected.	This research does not consider tap-changing capabilities for LV substation transformer in Ireland.
J. R. Pillai and B. Bak-Jensen.	Impact of Electric Vehicle Loads on Power Distribution Systems.	The main purpose in this project is to examine the impact of EV charging on the power distribution network in the Danish island of Bornholm due to voltage profile, transformer loading, distribution line loading, peak demand and line losses. Using DIgSILENT software to model EV charging profile and load flow analysis performance. 2 types of plug-in EV (uncontrolled & controlled).	The network data that has been analyse is difficult to find in the Danish Island of Bornholm.
Csaba Farkas, Kristof I. Szabo, Laszlo Prikler.	Impact assessment of electric vehicle charging on a LV distribution system.	Focus on dumb charging type of EV charging in Hungary. DigSILENT had been using in the simulation for investigating a worst case scenario in Hungary. This paper conclude that dumb charging causes on increase in transformer loading and voltage drop.	The analysis on this paper only shows the standard parameters which are relevant to the Hungary setting.

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