MINIMIZING POWER LOSSES IMPACT AT DISTRIBUTION NETWORK SYSTEM CONSIDERING MASSIVE ELECTRIC VEHICLE LOAD BY INSTALLING CAPACITOR BANKS

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DEDICATION

This thesis is dedicated to

My lovely parents,
Wan Yusoff Bin Wan Jaafar & Mek Binti Abdul Rahman

My lovely wife,
Dr. Nurul Izzah Binti Mohamad

My lovely sons and daughter,
Wan Muhammad Alif Umar Bin Wan Yusrizal
Wan Muhammad Akif Zikry Bin Wan Yusrizal
Wan Alisha Zahraa Binti Wan Yusrizal
Wan Muhammad Ali Muqri Bin Wan Yusrizal

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for being very supportive in keeping me going, enduring the ups and downs
during the completion of this thesis.

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ABSTRACT

As a member of the Paris Agreement, Malaysia is committed to transform the country into low-carbon society. Malaysian government is aiming to reduce the Greenhouse Gas (GHG) emission by 45% by year 2030 in relation to our 2005 Gross Domestic Product (GDP). As such, Malaysian government is promoting the Energy Efficient Vehicle (EEV), including Electric Vehicle (EV) and is aiming to have 100% of EEV on- road by the year 2030. With the implementation of EV policies in Malaysia, these policies will act as a catalyst for mass adoption of EV in Malaysian market. From the viewpoint of power system, these EVs are additional loads when they connect to the power grid to receive charging. The massive penetration of electric vehicles (EV) load have negatively impacted the distribution network system, especially on the power losses. Hence, this situation has led to the need for a set of unifying rules for the power grid to accommodate this additional charging demand. In order to mitigate these issues, optimal placement and sizing of multiple capacitor banks for medium and low voltage distribution network system are optimized by using the Lightning Search Algorithm (LSA). Distribution network system, EV Charging Station and capacitor banks, are modelled by using PSS Adept software and programmed in MATLAB. The performance of LSA is then compared with Modified Lightning Search Algorithm (MLSA). Based on the simulation, the MLSA method will be the best method to minimize the power losses at 69 bus radial distribution network system. The research has proven that the optimal placement and sizing of variable capacitor banks were able to minimize the power losses. Furthermore, the results prove that the variation of capacitor banks are able to provide superior solution compared to single size. Hence, it can be concluded that the multiple capacitor banks with an assistance of the MLSA method is the most suitable to be implemented in minimizing power losses in distribution network system due to the massive penetration of electric vehicles load.

ABSTRAK

Malaysia yang merupakan ahli kepada Perjanjian Paris beriltizam untuk berubah kepada negera dengan masyarakat karbon rendah. Kerajaan Malaysia mensasarkan untuk mengurangkan pembebasan gas hijau kepada 45% pada tahun 2030 secara relatif kepada Pengeluaran Kasar Dalam Negara 2005. Oleh yang demikian, kerajaan Malaysia mempromosikan kenderaan cekap tenaga termasuklah kenderaan elektrik dan mensasarkan untuk memiliki 100% kenderaan cekap tenga menjelang 2030. Dengan perlaksanaan polisi kenderaan elektrik di Malaysia, polisi ini akan menjadi pemangkin utama kepada penggunaan kenderaan elektrik secara besar-besaran di Malaysia. Menerusi sudut pandang system tenaga, kenderaan elektrik ini adalah merupakan pertambahan beban ketika disambungkan ke grid tenaga semasa mengecas. Kemasukan secara besar-besaran beban kenderaan elektrik telah memberikan impak negative kepada system rangkaian pembahagian terutamanya kehilangan tenaga. Jadi, keadaan ini memerlukan satu set peraturan kepada grid tenaga untuk menerima pertambahan beban pengecasan. Penempatan secara optima dan pemilihan saiz bank kapasitor bagi voltan sederahan dan rendah system rangkaian pembahagian akan dilaksanakan menggunakan kaedah *Lightning Search Algorithm* (LSA). Sistem rangkaian pembahagian, stesen pengecas kenderaan elektrik dan bank kapasitor dimodelkan dengan menggunakan perisian PSS Adept dan diprogramkan menggunakan perisian MATLAB. Prestasi LSA dibandingkan dengan *Modified Lightning Search Algorithm* (MLSA). Berdasarkan simulasi, kaedah MLSA adalah kaedah terbaik untuk meminimakan kehilangan tenaga pada 69 bus jejari system rangkaian pembahagian. Penyelidikan ini membuktikan bahawa penempatan secara optima dan kepelbagaian pemilihan saiz bank kapasitor dapat memberikan keputusan yang lebih baik berbanding satu saiz sahaja. Adalah disimpulkan bahawa beberapa bank kapasitor dengan bantuan kaedah MLSA adalah paling sesuai untuk dilaksanakan bagi tujuan mengurangkan kehilangan tenaga dalam system rangkaian pembahagian akibat daripada kemasukan kenderaan elektrik secara besar-besaran.

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LIST OF ABBREVIATIONS

AC	-	Alternating Current
CS	-	Charging Station
DC		Direct Current
EV	-	Electric Vehicle
EEV		Energy Efficient Vehicle
EVSE	-	Electric Vehicle Supply Equipment
GHG	-	Greenhouse Gas
ICEV	-	Internal Combustion Engine Vehicle
IEEE	-	Institute of Electrical and Electronics Engineers
LSA	-	Lightning Search Algorithm
MD	-	Maximum Demand
MLSA	-	Modified Lightning Search Algorithm
PCC	-	Point of Common Coupling
PSO	-	Particle Swarm Optimization
SOC	-	State of Charge

LIST OF SYMBOLS

AP_L	-	Additional power loss
C	-	Capacitance
f	-	frequency
I	-	Current
kW	-	Kilo Watt
kVar	-	Kilo Var
Pt	-	Total power losses
Q	-	Reactive Power
R	-	Resistance of feeder
TPL_{EV}	-	Total power loss when EVs are connected
TPL_{origin}	-	Total power loss with no EV load connected
V	-	Voltage
X_C	-	Reactance of Capacitor Bank
X_T	-	Total Reactance

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CHAPTER 1

INTRODUCTION

1.1 Background of the Problem

As a member of the Paris Agreement, Malaysia is committed to transform the country into low-carbon society. Malaysian government is aiming to reduce the Greenhouse Gas (GHG) emission by 45% by year 2030 in relation to our 2005 Gross Domestic Product (GDP) [1]. This agenda is reflected in the latest National Transport Policy (NTP 2019-2030), which has the vision of “Advance Toward Green Transport Ecosystem” [2]. As such, Malaysian government is promoting the Energy Efficient Vehicle (EEV), including Electric Vehicle (EV) and is aiming to have 100% of EEV on-road by the year 2030 [3].

With the implementation of EV policies in Malaysia, these policies will act as a catalyst for mass adoption of EV in Malaysian market. From the viewpoint of power system, these EVs are additional loads when they connect to the power grid to receive charging. Hence, this situation has led to the need for a set of unifying rules for the power grid to accommodate this additional charging demand. The interaction of EV and utility power grid can be in various types, such as vehicle to home as shown in Figure 1.1 and vehicle to vehicle as shown in Figure 1.2 [4-5].

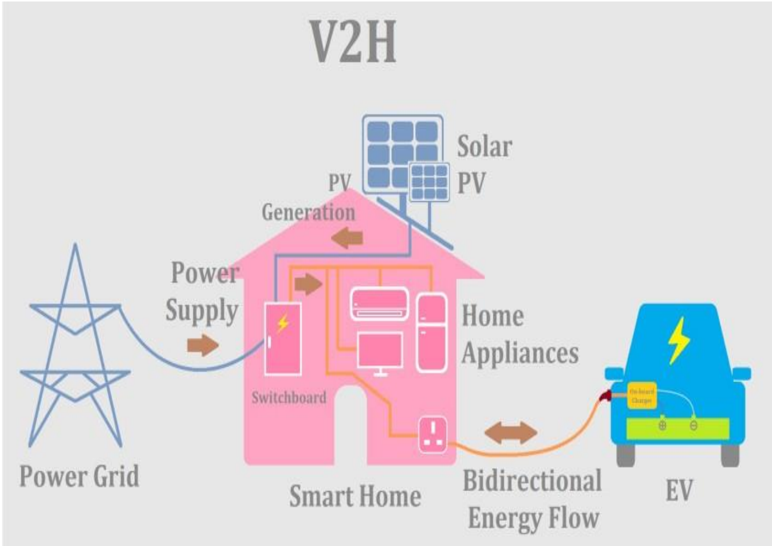

Figure 1.1: A diagram of Vehicle to Home Framework [5]

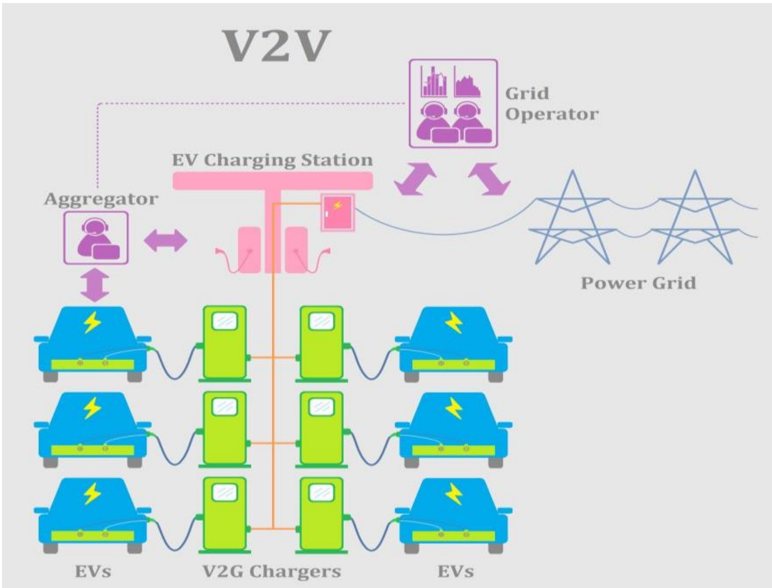

Figure 1.2: A diagram of Vehicle to Vehicle Framework [5]

EV has many advantages over the standard Internal Combustion Engine Vehicle (ICEV). EV is not only beneficial to the vehicle user, but also advantageous to the power grid and environment. There are benefits offered by EVs. Firstly, EV is more energy efficient because the use of electric motor, which has higher efficiency than combustion engine [6]. Secondly, EV is easier and cheaper to maintain because it has fewer moving parts than conventional ICEV, such as exhaust systems, fuel system, radiator, starter motor, etc. Thirdly, EV is more environmentally friendly, especially when it is recharged using renewable energy. EV is able to reduce the sound pollution and it can be used as a mobile energy storage to improve power grid reliability and sustainability.

The development of EV industry in Malaysia is still facing some challenges from various aspects. These challenges include its expensive initial vehicle cost. For an EV to travel a reasonable distance, a large battery storage is required [6]. The current EV battery is still relatively costly. Range anxiety is the fear of EV vehicle users that their vehicles have insufficient energy capacity to reach the planned destination. EV has limited travel range and requires long time to recharge the vehicle battery. EV charging infrastructure: A well-developed EV charging infrastructure with accessibility within short travel range and fast charger facilities are important to support the advancement of EV market. Nevertheless, the charging infrastructure is still insufficient in Malaysia.

Power losses can also increase when a large amount of unplanned charging station (CS) is mounted. Based on SAE standards as shown in Table 1.1, there are three categories of CS, which are CS Level 1, Level 2 and Level 3. Level 1 and 2 CSs are considered as having a slow charging characteristic which are normally installed at low voltage distribution system. CS Level 3 has a fast charging characteristic which has higher power consumption and normally installed at medium voltage network. Meanwhile, Table 1.2 shows an IEC 62196 Standards for types of Electric Vehicle Charger. Normally, when many CS are installed in the distribution system, total load will be increased, causing the distribution transformer to transfer extra amount of power to EV customer [7]. The unplanned CS installation may cause high power losses especially when all EV are operated simultaneously and causing utility loss in profit.

Table 1.1: SAE Standard for types of chargers [8]

Type of charger	Power (kW)	Current (A)	Connection	Charging time
Level 1	1.92	16	AC Single Phase	6-14 h
Level 2	2.5 to 19.2	12 to 60	AC Single Phase	3-4 h
Level 3	11.6 to 120	Up to 350	DC	20-30 min

Table 1.2 IEC 62196 Standards for types of Electric Vehicle Charger [8]

Type of Charger	Power (kW)	Current (A)	Connection	Charging Time
Mode 1	3.3	16	AC single phase	6-8 hours
Mode 2	10	16	AC three phase	2-3 hours
Mode 3	7	32	AC single phase	3-4 hours
Mode 4	22	32	AC three phase	1-2 hours
Mode 4	43	63	AC three phase	20-30 minutes
Mode 4	50	Up to 125	DC	20-30 minutes

There are many approaches to overcome these problems in improving the distribution system performance. In the case of power loss problem, the most popular approaches currently are by placing a capacitor bank [9,10] and coordinating EV charging schedule [11]. Both techniques can be used to reduce losses in the distribution system. Other than that, due to the complexity of the distribution system at present, especially after the rapid development of EV and presence of distributed generation, the method to solve the problems has become critical and unique for every problem. It is important to have an effective tool to determine the optimal solution which will give maximum benefits to the utility and user.

1.2 Problem Statement

Worldwide projection shows that the usage of EV is increasing annually and this has caused the installation of CS to increase. CS generally draws higher power consumption, especially for level 3 CS. Hence, the proper analysis needs to be conducted to determine the impact of EV usage towards apparent losses injection to the distribution system [7].

Furthermore, capacitor banks can be used in minimizing the power losses. However, the placement and sizing of capacitor banks become crucial when involving a large system and many parameters need to be considered. For example, the capacitor banks need to be placed in the system with correct size range based on load flow. Otherwise, it will cause harm to the distribution network system. Based on literature review, meta heuristic is the most popular technique used around the globe to assist in finding placement and sizing of proposed element. Since the placement and sizing of the capacitor banks are very crucial, it is important to have suitable meta heuristic technique that can explore better compared to common technique [10].

Since the optimum placement and sizing of the capacitor banks in distribution network system involve complex parameters, especially for large scale system, it is important to have an appropriate approach to explore the optimum placement and sizing of the capacitor banks. The practicality of the proposed approach must be considered such as the ability to find better optimal value. Therefore, it is important to have a superior optimization algorithm for ensuring the optimal results can be obtained. Therefore, optimal placement and sizing of capacitor banks will assist with improved meta heuristic technique, which is Modified Lightning Search Algorithm (MLSA).

1.3 Research Objectives

The main objectives of this project are:

i. To evaluate the impact of EV CS load profile towards power losses in IEEE 69 bus medium voltage distribution network system.

ii. To analyze the impact of capacitor banks in minimizing the power losses in IEEE 69 bus medium voltage distribution network system due to massive penetration of EV CS into distribution network system.

iii. To optimize the capacitor banks placement and sizing by considering improved meta heuristic technique which is a LSA and MLSA.

1.4 Research Scopes

The scopes considered in this research are summarized as follows:

i. This research focused on minimizing power losses in the simulation distribution network system produced by EV CS including power losses from the existing distribution network system.

ii. Specification of capacitor banks in this research is 11kV 50Hz rated at minimum of 0.1 MVar and maximum of 5 MVar adjustable value.

iii. The number of capacitor bank units allowed in this research was based on distribution system size. The capacitor banks installed in the network is based on minimum number required to improve all objective functions in distribution network.

iv. This research ignored the transformer and cable overload issues in the distribution system by considering loading for new EV can be borne by existing network.

v. Voltage profile constraint at all buses is configured to be between ±5%. Voltage profile for all buses will be checked before considering installing the capacitor banks in the network.

1.5 Significance of the Research

The main enthusiasm from this research is to determine the optimal placement and sizing for the capacitor banks in the distribution network system which can minimize power losses due to massive penetration of EV CS installation at IEEE 69 bus medium voltage distribution network system. Although capacitor banks can improve the power system, it is also capable to harm the system if placed at wrong places with wrong sizing. It is important to coordinate capacitor banks operation based on the system’s needs. For example, the sizing for capacitor banks is different when all EV CS is not operated at all compared to when all EV CS are in standby mode.

Level 3 CS, which has higher power consumption and normally connected to medium voltages buses, will give significant impact to the power losses in the distribution network system. Meanwhile, Level 1 CS, which has minimal impact on the distribution system due to low power consumption, somehow will create tremendous impact if the number of CS that operate increases dramatically. The proposed method introduced in this research is able to make use of the capacitor banks to solve power losses issues using meta heuristic technique. The Lightning Search Algorithm (LSA) and Modified Lightning Search Algorithm (MLSA) will assist in finding the optimal placement and sizing which will give minimum power losses. The process in achieving optimal placement and sizing of capacitor banks started with finding the analyzing existing IEEE 69 bus distribution network system. The analysis in this research is useful as a guide for distribution network to control the impact of massive penetration of EV loads deployment in the distribution network system.

1.6 Thesis Organization

The thesis is organized into five chapters. The outline of these chapters is as follows:

Chapter 2 reviews previous works by researchers throughout the world on minimizing power losses in distribution network systems. Then, the researches on EV will be discussed on the standards, the impact etc. Load flow technique used in this research also will be discussed. Furthermore, the research on meta heuristic technique on optimization of the location and sizing will be discussed. The significant contribution from previous research were used as guidelines in this research.

Chapter 3 describes the details of the research methodology adopted in this study. Research framework and flow chart are then clearly explained. Then, distribution network system power losses will be discussed including. Furthermore, EV CS modelling and capacitor bank design will be discussed in detail. The meta heuristic technique, which is LSA and MLSA that will be used in the process of finding the optimal placement and sizing are also discussed.

Chapter 4 describes the result obtained from the analysis involving Level 1, Level 2 and Level 3 of the EV Charging Station in IEEE 69 bus medium voltage at the distribution network system. The impact of installing the capacitor banks by optimization of the placement and sizing is discussed with results in this chapter. All of the results which are obtained in the simulation will be further analyzed.

Chapter 5 provides the research conclusions. Then, recommendation for future works to improve current research will be elaborate further.

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