POWER LOSS AND HARMONIC MINIMIZATION AT DISTRIBUTION SYSTEM WITH ELECTRIC VEHICLE BY PASSIVE FILTER USING MODIFIED LIGHTNING SEARCH ALGORITHM

SYED NORAZIZUL BIN SYED NASIR

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Faculty of Engineering
Universiti Teknologi Malaysia

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DEDICATION

This thesis is dedicated to

My lovely parents,
Syed Nasir Bin Syed Mohsin & Nahariah Binti Abdul Hamid

My spouse,
Nur Liyana Binti Sa'ari

My son and daughters,
Sharifah Alya Damia Binti Syed Norazizul
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ABSTRACT

The drastic rise in the usage of electric vehicles (EV) in recent years has negatively impacted the distribution system, especially on the apparent losses and harmonic distortion. In order to mitigate these issues, optimal placement and sizing of multiple passive filters for medium and low voltage network are determined using proposed modified lightning search algorithm (MLSA). Weight summation approach is used to identify the best location for the filter in the design stage, while Pareto with the assistance of fuzzy technique is used to determine a suitable sizing for the passive filter switching that will operate 24 hours a day based on EV consumer behavior. In addition, the proposed method also considers fast charging station (CS) and slow CS analysis for medium and low voltages, respectively. All power system harmonic flow, load profile, EV charging pattern, passive filter, CS and battery modelling are programmed in MATLAB. The performance of MLSA is compared with other meta-heuristic techniques, such as particle swarm optimization (PSO), firefly algorithm (FA) and lightning search algorithm (LSA). From the results, the MLSA is able to minimize the apparent losses and harmonic distortion at 33 bus radial distribution system (medium voltage) by considering worst harmonic distortion scenario from all 17 units of fast CS. The MLSA has provided superior result compared to PSO, FA, and LSA. Next, the proposed method was tested at 449 bus radial distribution system (medium and low voltage) with variance load and EV charging pattern for 24 hours, with fifteen minutes interval, using slow CS. The analysis shows that the optimal placements and sizes of variable passive filters were able to reduce the maximum total harmonic distortion (THD) for voltage, current and also the total apparent losses up to 39.14%, 52.5%, and 2.96 %, respectively. Furthermore, the results prove that the variation of passive filter is able to provide superior solution compared to single sizing. Therefore, it can be concluded that the multiple passive filters with an assistance of the MLSA algorithm is suitable to be implemented in minimizing overall apparent losses and harmonic distortions. This study is very useful as a guide for distribution network owners to control the impact of large-scale CS deployment in the future distribution system.

ABSTRAK

Pertambahan drastik dalam penggunaan kenderaan elektrik (EV) dalam beberapa tahun kebelakangan ini telah memberi kesan negatif terhadap sistem pengagihan terutama kepada kerugian tenaga ketara dan herotan harmonik. Dalam usaha untuk mengurangkan isu-isu ini, lokasi dan ukuran yang optimum beberapa penapis pasif untuk rangkaian voltan sederhana dan rendah ditentukan dengan menggunakan algoritma carian petir diubah (MLSA) yang dicadangkan. Pendekatan penjumlahan berat digunakan untuk mengenal pasti lokasi terbaik untuk penapis pada peringkat reka bentuk, manakala Pareto dengan bantuan teknik kabur digunakan untuk menentukan saiz sesuai untuk penukaran penapis pasif yang akan beroperasi dalam 24 jam sehari, berdasarkan kepada kelakuan pengguna EV. Di samping itu, kaedah yang dicadangkan juga mengambil kira analisis stesen pengecasan (CS) pantas dan CS yang perlahan untuk voltan sederhana dan rendah. Semua aliran harmonik sistem kuasa, profil beban, corak pengecasan EV, penapis pasif, CS dan pemodelan bateri diprogramkan dalam MATLAB. Prestasi MLSA dibandingkan dengan teknik meta-heuristik yang lain iaitu pengoptimuman kerumunan zarah (PSO), algoritma kunang (FA) dan algoritma carian petir (LSA). Berdasarkan hasil kajian, MLSA dapat meminimumkan kehilangan tenaga ketara dan herotan harmonik pada sistem pembahagian radial 33 nod (voltan sederhana) dengan mempertimbangkan senario herotan harmonik yang paling teruk dari 17 unit CS pantas. MLSA memberikan hasil yang lebih baik berbanding PSO, FA dan LSA. Seterusnya, kaedah yang dicadangkan diuji pada sistem pembahagian radial 449 nod (voltan sederhana dan rendah) dengan beban varians dan pola pengecasan EV selama 24 jam, dengan selang lima belas minit, menggunakan CS perlahan. Analisis menunjukkan lokasi dan saiz optimum untuk penapis pasif berganda mampu mengurangkan nilai jumlah herotan harmonik maksimum (THD) untuk voltan, arus dan jumlah kehilangan tenaga ketara masing-masing sehingga 39.14%, 52.5% dan 2.96%. Tambahan pula, keputusan membuktikan variasi penapis pasif mampu memberikan penyelesaian lebih baik berbanding saiz tunggal. Oleh itu, dapat disimpulkan bahawa beberapa penapis pasif dengan bantuan algoritma MLSA sesuai untuk digunakan dalam meminimakan keseluruhan kerugian tenaga ketara dan herotan harmonic. Kajian ini berguna sebagai panduan untuk pemilik grid untuk mengawal kesan penggunaan CS berskala besar dalam sistem pembahagian pada masa hadapan.

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LIST OF ABBREVIATIONS

AC - Alternating Current
BFO - Bacterial Foraging Optimization
CO2 - Carbon Dioxide
CS - Charging Station
CSA - Cuckoo Search Algorithm
CSAR - Current Source Active Rectifier
DC - Direct Current
EV - Electric Vehicle
FA - Firefly Algorithm
GA - Genetic Algorithm
HIAF - Hybrid Inductive and Active Filtering
HSA - Harmony Search Algorithm
LSA - Lightning Search Algorithm
LV - Low Voltage
ML - Machine Learning
MLSA - Modified Lightning Search Algorithm
OCDC - Optimal coordinated discrete charging
PSO - Particle Swarm Optimization
SAIDI - System Average Interruption Duration Index
SHAPF - Shunt Hybrid Active Power Filter
SOCDC - Smooth Optimal coordinated discrete charging
STATCOM - Static Compensator
TOU - Time of Use

LIST OF SYMBOLS

Δt_k - Time interval

η - PEV efficiency

c_1 - Cognitive Coefficient (position acceleration constant)

c_2 - Social Coefficient (position acceleration constant)

C_{Filter} - Filter capacitance

$\overline{I}_h$ - Current vector matrix for h^{th} harmonic order

$\overline{I}_{ij,l,h}$ - Current that flow from bus i to bus j for h^{th} order at l^{th} line number

$\overline{I}_{ji,l,h}$ - Current that flow from bus j to bus i for h^{th} order at l^{th} line number

$I(\Delta t_k, i)$ - Charging current for the i^{th} PEV at current time slot (A)

L_i - Line inductance for i^{th} line

L_{Filter} - Filter inductance

$P_{CS}(\Delta t_k, i)$ - Consumed power for the i^{th} PEV (kW)

$P_{de}(\Delta t_k, i)$ - Delivered power for the i^{th} PEV (kW)

P_L - Load Active Power

Q_i - Rated battery ampere hour for the i^{th} PEV (Ah)

R_i - Battery equivalent internal resistance for the i^{th} node (ohm)

R_i - Line resistance for i^{th} line

R_L - Load resistance

R_{Filter} - Filter resistance

$r_1 \& r_2$ - Random Parameter

$SOC(\Delta t_k, i)$ - State of charge of the i^{th} PEV at kth time slot (%)

$SOC(\Delta t_{k+1}, i)$ - State of charge of the i^{th} PEV at next kth time slot (%)

$\overline{S}_h$ - Apparent power losses for h^{th} order

$\overline{S}_{Total}$ - Apparent power losses for overall distribution system

THD_V - Voltage Total Harmonic Distortion

THD_I - Current Total Harmonic Distortion

$V_{oc,i}$ - Open circuit voltage for i^{th} node (V)

$\overline{V}_{i,l,h}$ - Local Voltage for hth order at lth line number

$\overline{V}_{j,l,h}$ - Remote voltage for hth order at lth line number

$\overline{V_h}$ - Voltage vector matrix for hth harmonic order

V_L - Load Voltage

${v_i}^k$ - Particle Momentum

${x_i}^k$ - Particle Position

$X_{L,h}$ - Load inductance at hth harmonic order

$\overline{Y_h}$ - Admittance vector matrix for hth harmonic order

$Z_{i,h}$ - Line impedance for ith line at hth harmonic order

$Z_{L,h}$ - Load impedance at hth harmonic order

$Z_{Filter,h}$ - Filter impedance at hth harmonic order

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Overview of Electric Vehicle

The vision to have less carbon dioxide (CO_2) emissions and less dependency on natural resources has encouraged electric vehicle (EV) to become an important option compared to conventional vehicles. EV is predicted to play a major role in the future urban transportation system, to cater to the increases in urban population and need to reduce environment pollution [1]. Based on the statistics, in early 2016 there were 1.3 million units of EV produced and China aims by 2020 to boost the production of EV to about 11.9 million units [1]. Next, based on a report in 2016, around 50.21% of global crude oil is used for transportation sector [2]. Furthermore, the unstable price for crude oil has also influenced EV to become a more suitable alternative. Also, many incentives are offered by the government in most countries especially to manufacturers and customers such as tax reduction and rebate on buying EV. There are many initiatives that have been implemented globally to enable EV technology to grow into a massive production which then will lead to cheaper price to own EV [1]. Due to aggressive research on EV technology, it is predicted that between 40 million and 90 million EV units will be on the road by 2025 [1]. It is noted that EV battery must be charged using electricity from the grid, normally through a charging station (CS). Due to the need for EV to replace the conventional vehicle, this has indirectly caused many CS being installed in the distribution system [3]. Installation of CS in the network may cause problems in certain issues such as power losses increment, power quality issues. Increasing power loss and harmonic distortion in the distribution network is a vital issue, especially when dealing with an increasing number of CS in the system. The increase of CS is proportional with the increasing usage of EV. Based on the statistics, in early 2016, there are 1.3 million units of EV produced and China aims by 2020 to boost the production of EV to about 11.9 million units [1]. Therefore, the amount of power consumed by EV will increase, indirectly impacting the power system increases also.

Generally, 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. 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 [4]. The unplanned CS installation may cause high power losses especially when all EV are operated simultaneously and causing utility loss in profit. Other than that, some researchers' works have shown that the uncoordinated EV charging can introduce higher peak demand which is a drawback to the overall power losses of the grid [4,5]. Furthermore, it will also introduce harmonic distortion due to the non-linear load, which is power electronic devices that convert alternating current (ac) to direct current (dc) at CS [6-7]. This harmonic distortion will cause negative impact such as increment in heating loss, shorter insulation lifespan, increased temperature and insulation stress, decreased power factor and lower efficiency [7-8].

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 [9-16] and coordinating EV charging schedule [17-29]. Both techniques can be used to reduce losses in the distribution system. Next, filter placement [30-39] and improving CS topology [40-44] are the examples of approaches that can be used in minimizing harmonic distortion impact in the distribution system caused by CS. 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.

Therefore, installation of CS is no longer at selected places but it will be placed at almost all houses, offices, car park and many strategic places to accommodate the users' needs. The increment in electricity usage for all the places will certainly cause a burden to the existing distribution system in terms of higher losses and harmonic distortion impact. This research will focus on mitigating harmonic distortion and power loss impacts of large scale EV in the distribution system.

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 and harmonic distortion, especially for level 3 CS. Although CSs are generally equipped with harmonic filter, which is to cater to IEEE 519 standard, due to the large number of CS installed and operated at the same time to charge the EV, the proper analysis still needs to be conducted to determine the impact of EV usage towards apparent losses and harmonic distortion injection to the distribution system.

Passive filter can be used in minimizing the harmonic distortion as well as reducing power losses. However, the placement and sizing of passive filter become crucial when involving a large system and many parameters need to be considered. For example, the passive filter needs to be placed in the system with correct size range based on harmonic load flow and harmonic flow, otherwise it will cause harm to the distribution 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 passive filter are very crucial, it is important to have suitable meta heuristic technique that has the ability to explore better compared to common technique.

Since the optimum placement and sizing of the passive filter in distribution 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 passive filter. For example, multiple objectives need to be considered in finding the optimum point where the improvement for all objectives must be put as a priority to show the effectiveness of the proposed approach. Other than that, 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.

Furthermore, the harmonic produced by EV depends on battery state of charge (SOC) where normally higher SOC may produce higher harmonic distortion to the distribution system. The behaviour of customers have caused uncertainty when analysing power system condition. Due to that, harmonic load flow will have different flow depending on SOC and need to consider 24 hour load profile including CS operation behaviour. Therefore, optimal placement and sizing of passive filters will assist with new improved meta heuristic technique, which is MLSA. Other than that, multi objective solution approach was used together with MLSA to obtain the best optimal placement and sizing for multiple passive filters. The proposed method is also able to solve dynamic changes in EV load profile.

1.3 Research Objectives

The main objectives of this project are:

i. To analyse the impact of EV load profile towards power losses and harmonic distortion injection in low and medium voltage distribution network.

ii. To develop an improved meta heuristic technique, which is a modified lightning search algorithm (MLSA), by introducing the Laplacian distribution function, learning factor and updating improvement.

iii. To formulate optimal passive filter placement and sizing by considering combination weight summation approach and Pareto fuzzy approach in minimizing harmonic distortion and power losses in the distribution network.

iv. To analyse the performance of the proposed method using the variable passive filter in minimizing the apparent losses and harmonic distortion problems due to the dynamic system with large scale EV for 24 hours with 15 minute interval.

1.4 Research Scope

The scopes of work considered in this research are summarized as follows:

i. This research only focused on minimizing low harmonic order, which are 3rd, 5th, 7th and 9th in the simulation distribution system produced by CS since the impact is very significant compared to higher harmonic order. All other loads were assumed as linear load since the focus of this research is more on harmonic distortion produced by CS.

ii. A passive filter in this research was designed based on a series resistor, inductor, and capacitor which is a single tuned filter to cater to only one harmonic order. The selection of single tune filter is based on a common passive filter popularly used by the customer.

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

iv. Since the application of this research focuses in design stage, the computational time required to get a proper passive filter placement and sizing will be ignored.

v. The impact from distribution transformers that have delta connection, which normally caters for 3rd order harmonics, will be ignored since not all transformers in the practical application are using delta connection.

vi. 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.

vii. Passive filter reactive range to be placed at a medium voltage distribution system is set between 0.001 MVAr and 5 MVAr. The reactive range is chosen based on typical practical application where the value is more significantly large to cater reactively to the overall network.

viii. For a low voltage distribution system application, sizing of the variable passive filter was based on harmonic and power loss profile gathered at 15 minute interval. Passive filter reactive range to be placed at a low voltage distribution system is set between 0 kVAr and 40 kVAr. The reactive range is chosen based on typical practical application where the value normally in lower due to the size of the passive filter is small.

ix. For a low voltage distribution system application, plug-in and plug-out time are according to the customer request together with requested SOC. This assumption shows the power of customer to decide when to charge the EV. For a low voltage distribution system application, requested time for each CS must be greater than charging time required to charge the battery.

x. Since the passive filter sizing value is flexible for this research purpose, it is assumed that the passive filter is specially made for this research purpose.

xi. Voltage profile constraint at all buses is configure to be between 0.9 pu until 1.1 pu. Voltage profile for all buses will be checked before considering to install the passive filter 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 passive filter in the distribution system which can reduce harmonic distortion as well as power losses simultaneously due to large number of CS installation at medium voltage and low voltage distribution network.

Although passive filter 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 passive filters operation based on the system's needs. For example, the sizing for passive filters is different when all CS's are not operated at all compared to when all CS are in standby mode. Other than that, the harmonic distortion produced by CS depends on battery SOC, where normally low level SOC may only produce small harmonic distortion compared to high SOC level. Therefore, this research will focus on data analysis such as battery SOC and harmonic distortion injection due to charging process before proceeding with passive filter placement and sizing.

Level 3 CS, which has higher power consumption and normally connected to medium voltages buses, will give significant impact to the power losses and harmonic distortion in the distribution 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's that operate increases dramatically. The proposed method introduced in this research is able to make use of the passive filter to solve apparent losses and harmonic distortion problems using meta heuristic technique. The new proposed Modified Lightning Search Algorithm (MLSA) will assist in finding the optimal placement and sizing which will give low harmonic distortion in the overall distribution system as well as apparent losses. Other than that, multi objective function was used to give a superior solution among non-dominated solutions.

The process in achieving optimal placement and sizing of passive filter started with finding the optimal sizing using MLSA with assistance of multi objective technique, which is weight summation approach. The weight summation was chosen based on the validation from best solution from all possible combinations between all parameters. Next, with the optimal placement, optimal sizing was determined using MLSA with assistance of another evolution multi objective technique, which is Pareto fuzzy approach. The solution from Pareto technique gave improvement for all parameters.

The analysis in this research is useful as a guide for distribution network owner to control the impact of large scale CS deployment in the distribution system.

1.6 Thesis Organization

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

Chapter 2 reviews previous works by researchers throughout the world on harmonic distortion and loss reduction in distribution systems. Next, the researches on EV are discussed, such as on charging strategy. Harmonic load flow technique used in this research has also been discussed. Moreover, the research on meta heuristic technique in finding placement and sizing for specifying element are discussed. The significant findings from past works were used as guidelines in this research.

Chapter 3 describes harmonic load flow and apparent losses equation. Next, passive filter design, CS and battery modelling have also been discussed in detail. The new meta heuristic technique, which is MLSA, is developing. The basic process of finding the optimal placement and sizing are also discussed.

Chapter 4 discusses the new improved MLSA. MLSA had also been tested using mathematical benchmark function and compared with other meta heuristic technique.

Chapter 5 describes the result obtained from the analysis involving fast CS in medium voltage at the distribution system. The impact of passive filter placement and sizing is discussed with results.

Chapter 6 describes the result obtained from the analysis involving slow CS in low voltage at the distribution system. The impact of variable passive filter placement and sizing is also discussed with results.

Chapter 7 provides the thesis conclusion with recommendation for future works to improve current research.

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