MODELING OF OPTIMAL RECONFIGURABLE MICROGRID FOR ELECTRIC VEHICLE INTEGRATION

BY

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A dissertation submitted in fulfillment of the requirement for the degree of Master of Science (Computer and Information Engineering).

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ABSTRACT

The world is experiencing the impact of climate change, such as rising sea levels, extreme weather, natural disaster, and reduced food production. These issues strongly correlate with the global warming phenomenon caused by high carbon emissions; in fact, the transportation sector is recorded as one of the highest contributors. Therefore, many countries are phasing out internal combustion engine (ICE) usage by replacing them with more environment-friendly electric vehicles (EVs). However, as essential infrastructure in the EV ecosystem, the EV charging station must be installed in huge numbers at various locations. Excessive charging loads could cause challenges to the microgrid, such as harmonic distortion, voltage instability, and high-power losses. As a solution, microgrid reconfiguration modeling is needed. Hence, this research develops an optimum reconfigurable microgrid to minimize power losses and increase voltage stability. The most efficient metaheuristic method, Cuckoo Search Algorithm (CSA) is used to find the best reconfiguration as it is involved with the multi-objectives problem, in comparison to Genetic Algorithm (GA) as the second most efficient metaheuristic method and Particle Swarm Optimization (PSO) as the least most efficient metaheuristic method. The two different scales of bus networks, IEEE-33 bus, and IEEE-69 bus, are utilized as a microgrid test model in various charging conditions. The simulation results show the power losses decreased up to 99.47 %, while the voltage stability index (VSI) value increased up to 6.1386 approximately with integration of EVs load. Moreover, the compared results with GA and PSO algorithm show that the CSA performed better in terms of power loss reduction and voltage stability for all cases.

ملخص البحث

يشهد العالم تأثيرات ناتجة عن تغير المناخ، مثل ارتفاع مستوى سطح البحر، والطقس القاسي، والكوارث الطبيعية، وانخفاض الناتج الغذائي. وترتبط هذه القضايا ارتباطاً وثيقاً بظاهرة الاحتباس الحراري الناجمة عن الانبعاثات العالية للكربون؛ حيث يعدّ قطاع النقل من أكثر المساهمين في هذه الظاهرة. لذلك، تعمل العديد من البلدان على التخلص التدريجي من استخدام محركات الاحتراق الداخلي (ICE) عن طريق الاستعاضة عنها بمركبات كهربائية صديقة للبيئة (EVs). ومع ذلك، فإن محطات شحن المركبات الكهربائية، باعتبارها من ضرورات البنية التحتية للنظام البيئي لهذه المركبات، يتوجب تركيبها بأعداد كبيرة في مواقع متعددة. وبالتالي، فقد تتسبب أحمال الشحن الزائدة في حدوث تحديات للشبكة المصغرة، مثل التشوه التوافقي، وعدم استقرار الجهد، وفقدان الطاقة العالية. وكحل هذه المشاكل، هناك حاجة إلى نمذجة إعادة تكوين الشبكة الصغيرة. من هنا، فإن هذا البحث يقترح تطويراً لشبكة مصغرة قابلة لإعادة التكوين بشكل مثالي لتقليل فقد الطاقة وزيادة استقرار الجهد. لقد تم استخدام خوارزمية بحث الوقواق (CSA) باعتبارها الطريقة الأكثر فاعلية في الكشف عن أفضل إعادة تشكيل؛ لأنها تستخدم في حل المسائل متعددة الأهداف، وذلك بالمقارنة مع الخوارزمية الوراثية (GA) كثاني أكثر الطرق كفاءة وفعالية، وكذلك خوارزمية سرب الجسيمات (PSO) باعتبارها طريقة الكشف الأقل كفاءة. كما تم استخدام مقياسين مختلفين لشبكات النقل هما: (IEEE-33 bus)، و (IEEE-69 bus)، كنموذج اختبار للشبكة المصغرة في ظروف شحن مختلفة. وقد أظهرت نتائج المحاكاة أن فقد الطاقة قد انخفض بنسبة تصل إلى 99.47٪، بينما زادت قيمة مؤشر ثبات الجهد (VSI) إلى 6.1386 تقريباً، مع تكامل حمل المركبات الكهربائية. إضافة إلى ذلك، تُظهر نتائج المقارنة مع خوارزميتي

(GA) و (PSO) أن أداء خوارزمية (CSA) كان أفضل من حيث تقليل فقد الطاقة واستقرار الجهد في جميع الحالات.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science (Computer and Information Engineering).

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DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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Signature……………………………… Date: 20 February 2023

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This dissertation is dedicated to my parents for laying the foundation of what I turned out to be in life.

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LIST OF SYMBOLS

α	Step size
c_1	Cognitive parameter
c_2	Social parameter
$Gbest$	Global best
I_i	Current flow into the bus (A)
l_a	Upper bound
l_b	Lower bound
N	Iteration number
n	Number of nest
n_d	Nest dimension
n_e	Tie switch dimension
$Pbest$	Particle best
P_i	Real power (W)
P_{loss}	Power loss (W)
p_a	Discoverability probability
Q_i	Reactive power (VAR)
R	Resistance (Ω)
S_i	Apparent power (VA)
V_i	Current Bus voltage (V)
V_j	Neighbor bus voltage (V)
v_i	Velocity
w	Inertia
X	Reactance (Ω)
x	Open switch set
y_{ij}	Admittance between current bus and neighboring bus (S)

CHAPTER ONE

INTRODUCTION

1.1 OVERVIEW

The internal combustion engine (ICE) has been widely used in the automotive industry and has continuously developed since the 19th century. Modern ICEs use fossil fuels efficiently compared to older version of the ICEs. However, ICEs still use fossil fuels to generate energy to move vehicles. Fossil fuel combustion releases carbon dioxide into the air and makes detrimental to the environment. Carbon dioxides cause the effect of global warming as the gas trap heat in the atmosphere and increase the earth's surface and ocean temperature. Consequently, sea-level increases and more unstable weather are expected to occur frequently. Sea levels are expected to increase up to 30 cm to 65 cm by 2050 (Horton et al., 2005).

Fortunately, carbon dioxide reduction efforts have been encouraged worldwide since the 2000s. Most prominently, United Nations Framework Convention on Climate Change was established by United Nations as an effort to mitigate the effect of global warming. Paris Agreement was signed by 196 parties that aim to limit global warming to 2 °C below pre-industrial levels and try to take considerable action to limit temperature increase 1.5 °C below pre-industrial levels (Gao et al., 2017). Thus, one main effort of carbon dioxide emission reduction is the introduction of Electric Vehicles (EVs). EVs are considered one way to limit carbon dioxide emissions because the focus on renewable energy implementation is increasing to reduce electricity generation dependency on fossil fuels.

In EV operation, EV uses one or more electric engines or traction engines for vehicle driving. EVs are powered by electricity supplied from an energy storage device like a battery or large-scale capacitor. As the storage needs to be charged using a power outlet beforehand, numerous charging stations with the interconnection to electric grids need to be deployed strategically. Thus, it is one of the most critical infrastructures in meeting the increasing number of EVs on the road. Meanwhile, in Malaysia, one target of National Automotive Policy 2020 (NAP 2020) is Malaysia will develop EV Smart Grid Interoperability Center by 2030 (*Kementerian Perdagangan Antarabangsa Dan Industri*, n.d.). Currently, there are more than 200 public EV charging stations in peninsular Malaysia, and it is expected to accommodate 125,000 units by 2030.

1.2 PROBLEM STATEMENT

In meeting the rising number of EVs, arguably, one of the most crucial infrastructures is to have sufficient charging stations. Consequently, these charging stations are mostly connected to the power grid. Hence, those charging activities cause some negative impact on the grid. For instance, the uncoordinated charging of EVs degrades voltage profile (Rahman et al., 2022), increases peak load (Park, 2018), cause harmonic distortions (Ahmed et al., 2021), increases power losses (Deb, Kalita, et al., 2018), and equipment overloading. With these problems, the grid's reliability was being questioned. Thus, this research is aimed to utilize a reconfigurable microgrid to mitigate the impact of EV charging load on the network.

1.3 RESEARCH HYPOTHESIS

A reconfigurable microgrid can reduce power loss and increase voltage stability by finding the best path to deliver power, thus a model of a reconfigurable microgrid was needed to apply on small-scale and medium-scale microgrids. The solution of the reconfiguration is optimized as the result of the simulation is the least power loss and best voltage stability. But, to find the best solution, an algorithm was needed. It is expected that Cuckoo Search Algorithm (CSA) is a better algorithm to find the solution for reconfigurable microgrids compared with the Particle Swarm Optimization (PSO) and Genetic Algorithm (GA).

1.4 RESEARCH OBJECTIVES

i. To assess the impact of EV charging load on the microgrid.
ii. To develop an optimum reconfigurable microgrid for minimizing the power losses and increasing voltage stability by using CSA, PSO, and GA with EV charging loads integration.
iii. To apply the developed model/algorithm to small scale and medium scale microgrids.

1.5 RESEARCH METHODOLOGIES

The fisrt step to achieve research objective is assessment of the EV charging load on the microgrid. Thus, a comprehensive review of EV charging load impact on the microgrid was needed. Then, a standard IEEE-33 bus test system was used as a microgrid model. Power flow calculation was being performed using MATPOWER 6.0 toolbox in MATLAB under both conditions with and without EV charging load, respectively. The impact of EV charging loads on the microgrid was analyzed especially in terms of power loss and voltage stability. From here, objective number 1 which is to assess the impact of EV charging load on microgrids was achieved.

The second step to achieve research objectives is modeling of reconfigurable microgrid with the interconnection of EV. Thus, a reconfigurable microgrid model of the IEEE-33 bus test system with the integration of EV was formulated in a MATLAB software environment. Data of the IEEE-33 bus system which is real power and reactive power of busloads and resistance and reactance of bus system lines was loaded in the MATLAB software. The number of EV charging stations was increased as well as the charging load size and installed location was varied. Power flow calculation of the system was executed by using MATPOWER 6.0 toolbox to ensure the reliability of the system models.

The third step to achieve research objective is developing the optimum model. Thus, the result was analyzed by using a CSA and the parameters was varied to get optimum fitness function. The process was repeated until the minimum power loss and highest voltage stability are achieved. The result was compared using a GA and PSO. From here, objective 2 which is to develop an optimum reconfigurable microgrid model for minimizing the power losses and increasing voltage stability by using CSA was achieved.

Finally, to achieve research objectives is by applying optimum model on medium scale microgrid. The step is the result was validated by using medium scale test model which has a larger number of load bus which is IEEE-69 bus system with respect of IEEE-69 bus system data. From here, objective 3 which is to apply on small scale and medium scale microgrid was achieved.

1.6 RESEARCH SCOPE

The research scope of the research is microgrid. Thus, wide area synchronous grid and super grid are not in this research scope. In terms of power generations and loads, only the effect of the EV charger on the power distribution network is within the research scope and the effect of the distribution generator is not within research scope. Finally, the algorithm application is CSA in comparison with the PSO and GA. Other algorithms are not within the research scope.

1.7 DISSERTATION ORGANISATION

This dissertation contains five chapters. The organization of this dissertation is Chapter 1: Introduction, Chapter 2: Literature Review, Chapter 3: Methodology, Chapter 4: Result and Discussion, and Chapter 5: Conclusion.

In Chapter 1, introduction of overall dissertation was explained. This includes problem statement, research hypothesis, research objectives, research methodologies, research scope and dissertation organization. Meanwhile, Chapter 2 contains literature review of this dissertation. This chapter explains overview of literature revies, microgrids, loss minimization technique, electric vehicle chargers, voltage stability, optimization algorithm and related works. Chapter 3 is the methodologies of this dissertation. Power flow formulation and techniques, IEEE bus system, objective functions and cuckoo search algorithm was explained here. Chapter 4 is the result and discussion of this dissertation. The result was divided between IEEE-33 bus system and IEEE-69 bus system. Chapter 5 is the conclusion and limitation of this dissertation.

CHAPTER TWO

LITERATURE REVIEW

2.1 OVERVIEW

Microgrid is the main subject of this research. In the microgrid system, EV charging loads was integrated into microgrid at different buses. The microgrid can be reconfigurable by using CSA and the optimal configuration was found based on the minimum power loss and the most stable Voltage Stability Index (VSI) as the best result. The design to find the best solution is the model of this dissertation. The literature review covers elements of this research and views of other researchers about those elements. Literature review also covers related works of other researchers and their findings. The elements of this research are microgrid type, loss minimization techniques, EV charger types, VSI and optimization algorithm. Microgrid is divided between AC, DC, and hybrid. Loss minimization techniques cover between distributed generations allocation, capacitor allocation and network reconfiguration. EV charger types covered are slow chargers and fast chargers. VSI are categorized between line VSI, bus VSI, and overall VSI. Optimization algorithms covered are GA, PSO and CSA and other algorithms are not covered.

EVs are seen as the better solution to combat climate change and global warming due to the alternative of ICE vehicles as EVs use electricity as opposed to fuel burning. The transition from ICE vehicles to EVs has many economic and environmental benefits. However, as EVs number increase, the charging demands also increase (Deb, Tammi, et al., 2018). Thus, EV implementation and integration can cause an extra burden on the existing power grid. In other words, as shown by many researchers, EV charging loads can cause harmonic distortion (Barrero-González et al., 2019; Jiang et al., 2014; Nikitha et al., 2018), increase peak load (Arango Castellanos et al., 2019; Di Silvestre et al., 2013; Fan et al., 2013; Sehar et al., 2017), and decrease voltage profile (Dharmakeerthi et al., 2014; Zhang et al., 2016; Zhou et al., 2016). A. Ul-Haq et al. find that 60% EV penetration causes a 109% power consumption increase (Ul-Haq et al., 2015). In a study of EV penetration to North Ireland power system, only one region can support 7kW, 22kW, and 50kW, two regions can support 7kW and 22kW rating charging, eight regions can support 7kW charging and the other 12 regions cannot support any EV charging load (Zhou et al., 2016). Besides that, magnetic devices in the power system can be degraded by total harmonic distortion presented in the system, meanwhile, EV charging load also can cause total harmonic distortion (Nikitha et al., 2018). In a study by F. Barrero-González et al., EV charging station load can cause up to 26% of total harmonic distortion (Barrero-González et al., 2019).

2.2 MICROGRID

The microgrid was studied as an effort to combat dependency on fossil fuels due to environmental concerns and to achieve Sustainable Development Goals (Kumar et al., 2019). In comparison with a conventional power plant, microgrid offers renewable energy usage as power generation thus making microgrid technology more eco-friendly compared to the conventional power plant. Besides that, microgrids also may increase power system reliability, reduce network congestion, and reduce transmission power loss (Zaki Diab et al., 2019). Microgrids also can be working as autonomous networks or non-autonomously. Autonomous microgrids are microgrid networks disconnected from the power grid, meanwhile non-autonomous microgrids are interconnected with the power grid. Thus, off-grid microgrids can provide power to isolated areas like an island. But there are a few challenges to operating off-grid microgrids such as stability and load management due to their nature isolated from the main grid (Yoldaş et al., 2017).