Faculty of Electrical Engineering

FIREFLY ANALYTICAL HIERARCHY ALGORITHM FOR OPTIMAL ALLOCATION AND SIZING OF DISTRIBUTED GENERATION IN RADIAL DISTRIBUTION NETWORK

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in fulfillment of the requirements for the degree of
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DECLARATION

I declare that this thesis entitled "Firefly Analytical Hierarchy Algorithm for Optimal Allocation and Sizing of Distributed Generation in Radial Distribution Network" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Date : 12 Oktober 2022

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Doctor of Philosophy.

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Supervisor Name : Professor Ir. Dr Marizan Bin Sulaiman

Date : 12 Oktober 2022

DEDICATION

Specially dedicated to Zara Sakina binti Mohammad Zuhaidi

ABSTRACT

The presence of DG in the electrical distribution network provides some benefits, such as power loss reduction, improvement of voltage profile and voltage stability. There is a need to achieve optimality in allocating and sizing of DG in the distribution system network. Although numerous studies have been conducted regarding this topic, recent trends indicate that further improvements can be achieved using the multi-objective meta-heuristic optimisation method. Hence, this research reviews and analyses different meta-heuristic optimisation techniques to determine an effective approach to locating and sizing the DG based on single and multi-objective functions. In addition, the voltage stability index (VSI) has been considered by researchers as one of the key parameters in analysing voltage stability in this field of study. Therefore, this research also investigates and compares the two different VSIs that are widely used to determine the most suitable VSI that gives much better optimisation results. The objective functions considered in this research are voltage deviation, power loss and voltage stability index. As for multi-objective functions associated with the optimisation problem, a weight-sum method is typically used to determine each objective function's coefficient factors (CF). However, there are no exact calculations behind the weight-sum method. On the other hand, this research proposes an Analytical Hierarchy Process (AHP) for obtaining more reliable weights *(w1, w2, w3)* or coefficient factors based on priority rank. The simulations of single and multi-objective function optimisations have been carried out using MATLAB for meta-heuristic techniques on the IEEE 33-bus and 69-bus radial distribution networks. The results showed that the Firefly Algorithm (FA) performs much better for the optimal allocation and sizing of DG compared to the other metaheuristic techniques, particularly based on convergence characteristics and standard deviation. Finally, an AHP was integrated with FA to form Firefly Analytical Hierarchy Algorithm (FAHA) to automatically calculate the weight of each objective function based on the load flow outputs followed by the optimisation process. In the load flow analysis, the optimisation and development of FAHA was implemented on the IEEE 118-bus radial test network. The optimisation using FAHA was carried out with the regulated voltage at the DG location during the load flow. The AHP was also found to yield accurate weights of the coefficient factors for each objective function compared to the weight-sum method generally used in studies. Moreover, the empirical results obtained showed that incorporating the AHP into Firefly Algorithm improved the accuracy of weight calculations in the multi-objective formulation of the optimisation process. Practically, this FAHA has great potential applications for the optimal allocation and sizing of DG in the radial distribution network.

ALGORITMA HIERARKI ANALITIKAL KELIP-KELIP BAGI PERUNTUKAN PENSAIZAN OPTIMUM JANAKUASA TERAGIH DALAM RANGKAIAN PENGAGIHAN JEJARI

ABSTRAK

Kehadiran DG dalam rangkaian pengagihan elektrik memberikan beberapa faedah, seperti pengurangan kehilangan kuasa, penambahbaikan profil voltan dan kestabilan voltan. Oleh itu, terdapat keperluan untuk penentuan dan pensaizan DG yang optimum dalam rangkaian sistem pengagihan elektrik. Walaupun banyak kajian telah dijalankan mengenai topik ini, perkembangan terkini menunjukkan penambahbaikan boleh dicapai dengan menggunakan kaedah pengoptimuman meta-heuristik berbilang objektif. Oleh itu, kajian ini mengkaji dan menganalisa beberapa teknik pengoptimuman meta-heuristik untuk menentukan lokasi dan saiz DG berdasarkan fungsi tunggal dan berbilang objektif. Selain itu, indeks kestabilan voltan (VSI) telah diambilkira sebagai salah satu parameter utama dalam menganalisis kestabilan voltan dalam bidang kajian ini. Oleh itu, kajian ini menyelidik dan membandingkan dua VSI berbeza yang digunakan untuk menentukan VSI yang paling sesuai dalam memberikan hasil pengoptimuman yang lebih baik. Fungsi objektif yang dipertimbangkan dalam penyelidikan ini ialah sisihan voltan, kehilangan kuasa dan indeks kestabilan voltan. Bagi fungsi berbilang objektif yang dikaitkan dengan masalah pengoptimuman, kaedah jumlah berat biasanya digunakan untuk menentukan faktor pekali (CF) setiap fungsi objektif. Walau bagaimanapun, tiada pengiraan tepat di sebalik kaedah jumlah berat tersebut. Sebaliknya kajian ini mencadangkan Analytical Hierarchy Process (AHP) untuk mendapatkan pemberat (w1, w2, w3) atau faktor pekali yang lebih dipercayai. Simulasi bagi pemgoptimuman fungsi tunggal dan berbilang objektif telah dijalankan menggunakan MATLAB untuk teknik meta-heuristik pada rangkaian pengagihan jejari IEEE 33-bus dan 69-bus. Keputusan menunjukkan bahawa Firefly Algorithm (FA) berprestasi jauh lebih baik untuk peruntukan dan saiz DG yang optimum berbanding teknik metaheuristik yang lain, terutamanya berdasarkan ciri penumpuan dan sisihan piawai. Akhir sekali, AHP telah disepadukan ke dalam FA untuk menjadi Firefly Analytical Hierarchy Algorithm (FAHA) untuk mengira secara automatik berat setiap fungsi objektif berdasarkan keluaran aliran beban diikuti dengan proses pengoptimuman. Dalam analisis aliran beban, pengoptimuman dan pembangunan FAHA diuji ke atas rangkaian IEEE 118-bus. Pengoptimuman menggunakan FAHA telah dijalankan dengan voltan-terkawal di lokasi DG semasa aliran beban. AHP juga menghasilkan pemberat tepat bagi factor pekali setiap fungsi objektif berbanding kaedah jumlah berat yang biasanya digunakan dalam kajian. Selain itu, keputusan empirikal yang diperoleh menunjukkan bahawa menyepadukan AHP dan voltan-terkawal ke dalam FA dapat meningkatkan ketepatan pengiraan berat dalam rumusan pengoptimuman pelbagai objektif. Secara praktikal, FAHA ini mempunyai potensi aplikasi untuk penentuan lokasi dan saiz DG yang optimum ke dalam rangkaian pengagihan jejari.

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LIST OF ABBREVIATION

AHP	-	Analytical Hierarchy Process
ANSI	-	American National Standards Institute
AM	-	Analytical Method
CSA	-	Cuckoo Search Algorithm
DEA	-	Differential Evolutionary Algorithm
DER	-	Distributed Energy Resource
CF	-	Coefficient Factor
CMSFS	-	Chaotic Maps Integrated Stochastic Fractal Search
CSA	-	Cuckoo search algorithm
DERs	-	Distributed Energy Resources
DG	-	Distributed Generation
DSP	-	Distribution System Planning
FA	-	Firefly Algorithm
FAHA	-	Firefly Analytical Hierarchy Firefly Algorithm
FVSI	-	Fast Voltage Stability Index
GA	-	Genetic Algorithm
GSA	-	Gravitational Search Algorithm
GOA	-	Grasshopper Optimization Algorithm
GWO		Grey Wolf Optimizer

HSA	-	Harmony Search Algorithm
HAS-PABC	-	Harmony Search and Particle Artificial Bee Colony Algorithm
IEEE	-	Institute of Electrical and Electronics Engineers
IWO	-	Invasive Weed Optimization
IGSA	-	Improved Gravitational Search Algorithm
LSS	-	Large Scale Solar
MATLAB	-	Matrix Laboratory
MFO	-	Moth Flame Optimization
MOF	-	Multi-objective Function
MW	-	Megawatt
NFL	-	No Free Lunch
POF	-	Probability of Failure
PSO	-	Particle Swarm Optimization
TWO-STAGE BBO	-	Two-stage Biogeography-based Optimization

LIST OF SYMBOLS

F	-	Force
M	-	Mass
P	-	Real/ active power
V	-	Voltage
V_{DG}	-	Voltage at the location of DG
kV	-	Kilo Volt
p.u	-	Per unit
f	-	Fitness
δ	-	Phase angle
$\circ$	-	Degree
$\vert V \vert$	-	Voltage magnitude
$P_{min} \vert$	-	Minimum real power
P_{max}	-	Maximum real power
P_{best}	-	Personal best
G_{best}	-	Global best
V_{Dev}	-	Voltage deviation
$P_{DGtotal}$	-	Total power of DG
P_{DGmin}	-	Minimum power of DG
P_{DGmax}	-	Maximum power of DG

V_{min}	-	Minimum voltage limit
V_{max}	-	Maximum voltage limit
Q	-	Reactive power
$\|V\|$	-	Voltage magnitude
$w1$	-	Weight of objective function number one
$w2$	-	Weight of objective function number two
$w3$	-	Weight of objective function number three

LIST OF PUBLICATIONS

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1. **Bujal, N.R.,** Abdul Kadir, A.F., Sulaiman, M., Manap, S., and Sulaima, M.F., 2022. Firefly analytical hierarchy algorithm for optimal allocation and sizing of DG in distribution network. *International Journal of Power Electronics and Drive Systems (IJPEDS)*, 13(3), p.1419 **(SCOPUS)**.

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CHAPTER 1

INTRODUCTION

This chapter provides an introductory background to the fundamental electric power system and the application of distributed generation (DG). It also explains the objectives and motivations behind the presented research. In addition to that, the research contributions are highlighted in this chapter, followed by the organizational structure of the thesis.

1.1 Background of research

The growing demand for energy has increased electricity production much closer to its capacity limit. Nonetheless, the power utilities must maintain sufficient reserve margins of existing power generation. The conventional power plants have their limitations and one of the issues is the long transmission distance, which leads to power losses (Muthukumar and Jayalalitha, 2016; Fathi et al., 2019). Recently, utility providers have been actively planning to expand their distribution and transmission networks to accommodate the increased demand for electrical power. However, today's economic and environmental factors impose several restrictions on network expansion in the worldwide electricity industry, even as power demand rises (Pesaran H.A et al., 2017). Besides, the constant increase in demand will reduce the voltage profile and affect system stability, resulting in power system network failure due to stressed conditions (Saadati, 2017; Mustaffa et al., 2019). Developing new substations or extensions of those currently available is a typical and conventional solution.