Faculty of Electrical Engineering

IMPROVED GRAVITATIONAL SEARCH ALGORITHM FOR OPTIMAL PLACEMENT AND SIZING OF DISTRIBUTED GENERATION FOR POWER QUALITY ENHANCEMENT

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SA'ADAH BINTI DAUD

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DECLARATION

I declare that this thesis entitled "Improved gravitational search algorithm for optimal placement and sizing of distributed generation for power quality enhancement" 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.

Signature	:	....
Name	:	Sa'adah binti Daud
Date	:	....

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 Master of Science in Electrical Engineering (Energy Efficiency and Renewable Energy).

Signature : ....

Name : Dr. Aida Fazliana binti Abdul Kadir

Date : ....

DEDICATION

To my beloved husband, father, mother and the whole family.

May Allah bless them and elongate their live in his obidience.

ABSTRACT

Distributed generation (DG) is one of the foremost elements in distribution planning. DG units play a significant role in distribution system stability and to enhance its power quality. Numerous benefits can be attained by the integration of DG unit in distribution networks, such as power loss reduction and improvement in voltage profiles and power quality. Such advantages can be accomplished and elevated if the DG units in the systems are optimally located and sized. Inappropriate placement and sizing of DG units would lead to negative impacts such as further loss in the system original power and system realibility. Meanwhile, power quality issues such as harmonic distortion and voltage dip have gained interest especially in power system researches. Therefore, this study deals with inverter-based DG with renewable source, which is the photovoltaic-based distributed generation (PVDG). In this research, a method for determining the optimal sizing and location of single and multiple PVDG in distribution systems is presented. A multi-objective function is formed to minimize total real losses and average voltage deviation, voltage total harmonic distortion and voltage dip magnitude. In this study, three-phase fault has been generated and injected to all the bus in the distribution systems for the voltage dips assessment. The optimization problem is generated using a weighted sum method. In order to obtain the best compromise solution, a novel heuristic algorithm based on improved gravitational search algorithm (IGSA) is proposed as an optimization technique. IGSA has the ability to search for the best solutions and it executes faster. The IGSA performances has then been compared with other heuristic algorithm such as particle swarm optimization (PSO) and GSA. The load flow algorithms from MATPOWER, harmonic load flow and method of fault position has been integrated in MATLAB environment to solve the multi-objective function. Single and multiple PVDG installation cases have been examined and compared to cases without PVDG. A comparison of the performances has also been made using optimization techniques when PVDG units are fixed at critical buses. The optimization techniques have been tested on two radial distribution systems, which are IEEE 33-bus and IEEE-69 bus with several scenarios and case studies. The overall results show that IGSA outperforms PSO and GSA in obtaining the best fitness value and has the fastest average computational time.

ABSTRAK

Penjana teragih (PT) merupakan antara satu elemen penting dalam sistem pengagihan elektrik. PT memainkan peranan penting dalam memastikan kestabilan sistem pengagihan elektrik sekaligus meningkatkan kualiti kuasa elektrik. Terdapat banyak kelebihan yang dapat diperoleh melalui integrasi PT dalam sesuatu sistem pembahagian elektrik, seperti mengurangkan kehilangan kuasa dan meningkatkan profil voltan dan kualiti kuasa. Namun begitu, kelebihan-kelebihan ini hanya boleh dicapai dan ditingkatkan seandainya PT dipasang di tempat yang optimum dengan saiz yang optimum dalam sesuatu sistem. Ketidaksesuaian lokasi dan saiz PT dalam sesebuah sistem akan menjurus kepada kesan-kesan negatif seperti memburukkan lagi kehilangan kuasa asal sistem dan mengurangkan kebolehpercayaan sesuatu sistem. Pada masa yang sama, isu kualiti kuasa seperti herotan harmonik dan voltan lendut telah meraih minat untuk dipertimbangkan terutamanya dalam kajian-kajian sistem kuasa. Sehubungan itu, kajian ini dilaksanakan menggunakan PT yang berdasarkan sumber yang boleh diperbaharui iaitu fotovolta PT (PTFV). Dalam kajian ini, satu kaedah telah dibentangkan untuk menentukan saiz dan lokasi yang optimum untuk satu unit dan beberapa unit PTFV dalam sistem. Fungsi pelbagai objektif telah dihasilkan untuk mengurangkan jumlah kehilangan kuasa, purata sisihan voltan, voltan jumlah herotan harmonik dan magnitud kelendutan voltan. Dalam kajian ini, kerosakan tiga fasa dihasilkan dan disuntik ke dalam sistem pembahagian sebagai cara untuk menganalisa voltan lendut. Masalah pengoptimuman dilaksanakan melalui penggunaan kaedah jumlah wajaran. Untuk mendapatkan hasil yang terbaik, satu algoritma heuristik berdasarkan algoritma carian graviti yang diperbaiki (ACGD) dicadangkan sebagai teknik terbaik. ACGD mempunyai kebolehan dalam mencari penyelesaian terbaik dan penyelaksanaannya lebih pantas. Prestasi ACGD telah dibandingkan dengan algoritma heuristik yang lain iaitu pengoptimuman kuruman zarah (PKZ) dan ACG. Algoritma-algoritma aliran beban dari MATPOWER, aliran beban harmonik dan kaedah kedudukan kerosakan disepadukan dalam MATLAB. Kes pemasangan PTFV tunggal dan berbilang telah dikaji dan dibandingan dengan kes sistem tanpa PTFV. Perbandingan prestasi juga telah dilakukan menggunakan teknik pengoptimuman ditetapkan pada bas kritikal. Teknik-teknik ini telah diuji pada dua sistem jejari iaitu IEEE 33-bas dan IEEE 69-bas dengan beberapa senario dan kajian kes. Secara kesuluruhan, ACGD menunjukkan prestasi yang terbaik berbanding PKZ dan ACG dalam mendapatkan nilai optimum dan purata pengiraan masa yang paling pantas.

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LIST OF ABBREVIATIONS

ABC	–	Artificial bee colony
ACO	–	Ant colony optimization
BA	–	Bat algorithm
BFA	–	Bacterial foraging algorithm
CS	–	Cuckoo search
DP	–	Dynamic programming
DP	–	Distributed generation
FA	–	Firefly algorithm
FPM	–	Fault position method
GA	–	Genetic algorithm
GSA	–	Gravitational search algorithm
HSA	–	Harmony search algorithm
HPF	–	Harmonic power flow
IVSI	–	Improved voltage stability index
NLP	–	Non-linear programming
OO	–	Ordinal optimization
OPF	–	Optimal power flow
PSO	–	Particle swarm optimization
PVDG	–	Photovoltaic distributed generation
SARFIx	–	System average RMS frequency index
SAVDA	–	System average voltage dip amplitude
SAVDM	–	System average voltage dip magnitude
SFLA	–	Shuffled frog leaping algorithm
SQP	–	Sequential quadratic programming
TCL	–	Total connected load
THD	–	Total harmonic distortion

LIST OF SYMBOLS

a	–	Acceleration
F	–	Force
G	–	Gravitational force = $6.67 \times 10^{-11} NM^2/kg^2$
kg	–	Kilogram
M	–	Meter
N	–	Newton
x	–	Distance

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LIST OF PUBLICATIONS

Journal

1) **S. Daud**, A. F. A. Kadir, C. K. Gan, A. Mohamed and T. Khatib, "A comparison of heuristic techniques for optimal placement and sizing of photovoltaic based distributed generation in a distribution system," Solar Energy, Vol. 140, 219-226, 2016.
2) **S. Daud**, A. F. A. Kadir, M. Y. Lada, and C. K. Gan, " A review: optimal distributed generation planning and power quality issues," International Review of Electrical Engineering, Vol. 11, N.2, 208-222, 2016. (*Scopus Indexed*).
3) **S. Daud**, A. F. A. Kadir, C. K. Gan, A. R. Abdullah, M. F. Sulaima, and N. H. Shamsudin, "Optimal placement and sizing of renewable distributed generation via gravitational search algorithm," Applied Mechanics and Materials, Vol. 785 (2015): 556-560, 2015. (*Scopus Indexed*).

Conference

1) **S. Daud**, A. F. A. Kadir, and C. K. Gan. "The impact of distributed photovoltaic generation on power distribution network losses," in IEEE Student Conference on Research and Development (SCORED) 2015, pp. 11-15.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Distributed generation (DG) units is emerging as a new paradigm that supplies and introduces highly reliable and quality electric power (Guerrero et al., 2010). DG units, also known as embedded generator or dispersed energy, are small-scale generating machine directly integrated to the distribution network or onto meter of the consumer (Georgilakis and Hatziargyriou, 2013). Since the last fifteen years, DG units have drawn the interest of many researchers due to their availability in modular units, simplicity in finding areas for smaller generators, shorter construction times and lower in cost (Silvestri et al., 1999; Georgilakis & Hatziargyriou, 2013). The installation of DG units is becoming more prominent in distribution networks, due to the positive impacts that are injected to the systems. They benefit the environment by contributing in the application of competitive energy approaches, reducing non-peak operating cost, diversifying of energy resources, lowering the losses thus improving the overall system, deferring network upgrades, and reducing the expansion as well as congestion of transmission and distribution network, and potentially increasing the service quality to the end-consumer (AlRashidi and AlHajri, 2011).

Basically, electrical power generated by power stations is delivered through complex networks such as transformers, cables and equipments before being delivered to loads and consumers. However, there is a difference in the power generated and power received by the end users due to transmission and distribution losses. Technically, the electrical energy produced is not fully utilized effectively, and these losses will not be paid for by the consumers. Modern electrical apparatus are designed to function within a specific range of voltages since they can only deal with voltage fluctuations in certain time. There is a high possibility of equipment damage if the voltage is unstable for a longer period of time. In distribution systems, the voltage drop may be due to many different reasons such as line impedances, mismatch of reactive generation and the growing demand at user's sides and a long radial feeder that forbid the transmission of power at the loads. In order to justify the stability of the voltage, voltage deviation term is introduced, which is defined as the difference between the nominal voltage and actual voltage. The voltage deviation must be minimized to ensure better voltage condition of the system (Le et al., 2005). Consequently, installing DG unit is by far the best option to tackle these problems since it only needs smaller area, shorter time and low operational cost.

DG can be classified into two categories, namely inverter based DG and non-inverter based DG. They can also be grouped into four types according to their characteristics. The first type is the inverter based DGs that inject renewable source energy. This type of DG units, for example photovoltaic distributed generation (PVDG), injects only active power into the networks. Secondly is DG units that inject reactive power only, such as induction generators. Thirdly is DG units that inject active power, but absorb reactive power, for instance, induction motor. The fourth type is DGs that inject both active and reactive power, such as synchronous generator (Willis, 2000; Nguyen Cong et al., 2013). The most significant elements in distribution system networks are the DG sizes or capacities, types and locations of DG to be installed. In order to increase the benefits as well as minimize their negative effects on the power system, the locations for installation and amount of capacities must be optimized (Nguyen Cong et al., 2013). Improper location of DG units would lead to increment in system losses, operating cost and network capital.

It would also lead to the injection of harmonic disturbance, probability of reverse power flow, uncertainty of the linemen's safety and complex controlling scheme (AlRashidi and AlHajri, 2011). Therefore, appropriate placement and sizing of DG units are needed to stregthen the voltage profile, reduce system losses and enhance the power quality of the supply (Georgilakis and Hatziargyriou, 2013).

In reaction to climate change, governments around the world aim to increase the role of renewable energy, minimize greenhouse gas emissions from electricity generation and reduce global warming. Substituting the conventional productions based on fossil fuels such as gasoline, oil and coal by green energy such as solar and wind energy will lessen the discharge of carbon dioxide. Hence, a specific type of DG based on renewable source such as photovoltaic (PV) can be utilized to enhance the power quality in the distribution system, as well as to increase the stability and reliability of energy to be delivered to the load and consumers. Power quality has become the most popular topic in power system studies and earned a great deal of involvement in recent years. Non-linear residential loads that produce non-sinusoidal currents are increasing in numbers from days to days due to the production of unwanted frequency components, or known as harmonic distortion that is drawn by home appliances. Higher level of harmonic distortion in a distribution system will reduce the efficiency of a system network since the line and transformer losses increase (Farooq et al., 2013). Other power quality issues in the distribution system are voltage dip. This sudden temporary reduction in the supply voltage magnitude is caused either by short circuit faults, overload or starting a large motor. This phenomenon will also can cause malfunction of power system equipment.

In order to reduce power losses, minimize voltage total harmonic distortion (THDv), improve voltage of the system and the system's voltage dip, appropriate planning of power system with the presence of DG unit is required. Various deliberations need to be taken into account, such as the type of technology to be utilized, the number and size of DG units, optimal locations and type of network connection. Thus, optimization techniques are progressively being applied to identify the optimal location and sizing of DG units in a given distribution system network.

1.2 Problem Statement

Many studies have been conducted to determine the optimal DG placement and sizing by considering the reduction of real power loss in a distribution system and voltage improvement as the objective (Dias et al., 2012; Nekooei et al., 2013; Rachtchi and Darabian, 2012; Yammani et al., 2011; Abu-Mouti and El-Hawary, 2011; Mistry et al., 2012). However, only few studies regarding optimal DG location and sizing have considered the reduction of harmonic distortion and voltage dips improvement as the objective function. Most of them focused on harmonic distortion, and applied particle swarm optimization (PSO) and genetic algorithm (GA) to solve the multi-objective function (Pandi et al., 2013; Heydari and Golamian, 2013; Abdelsalam and El-Saadany, 2013; Biswas et al., 2014; Kavitha et al., 2014; Jahromi et al., 2007; Farashbashi-Astaneh and Dastfan, 2010; Amanifar and Golshan, 2012). Heuristic optimization techniques such as GA, PSO, ant colony optimization (ACO), artificial bee colony (ABC), bat algorithm (BA), and bacterial foraging algorithm (BFA) are widely used in defining the optimal placement and sizing of DG unit in a distribution system (Akorede et al., 2010; Niknam, 2009; Lingfeng and Singh, 2008; Yammani et al., 2013; Abu-Mouti and El-Hawary, 2011). However, the mentioned heuristic optimization techniques come with several weaknesses. Gravitational search algorithm (GSA) is an optimization technique with some drawbacks. Thus, there is a need to explore a more effective heuristic optimization technique to optimally place and size DG unit in a distribution system by considering minimization of total real power loss, average voltage deviation, voltage total harmonic distortion and improving the voltage dips.

To optimize planning of DG units, several studies have focused on determining the optimal location first, by placing the DG based on the voltage stability index (Parizad et al., 2010; Aman et al., 2012; Jamian et al., 2013). However, there is no comprehensive study to date which compare the performance of optimal DG placement method with the voltage stability index method. Hence, a comparative study must be carried out to identify the performance of both methods to determine the optimum DG placement and sizing in a distribution system. The problem statements of this research can be summarized and concluded as follows:

1. Inappropriate placement and sizing of DG would inject negative impacts into the distribution system network, increase the power loss, worsen the power quality and lessen the reliability of energy projected. Thus, there is a need to explore a more problem formulation for effective heuristic optimization technique to identify the optimal placement and sizing of DG units in a distribution system by considering minimization of total real power loss, voltage total harmonic distortion, average voltage deviation and improving the voltage dips of the system.
2. Only some studies have considered power quality issues for the DG planning. Among all, the most popular power quality event focused in the researches is harmonic distortion, and most of them applied PSO and GA to solve the problem. Hence, it is essential to compare the performance of the improved technique with the original GSA and with the commonly used technique such as PSO.