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OPTIMAL LOCATION AND SIZE OF DISTRIBUTED GENERATION TO REDUCE POWER LOSSES AND IMPROVE VOLTAGE PROFILES USING DIFFERENTIAL EVOLUTION OPTIMIZATION METHOD

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By

AHMED SAHIB HAMMADI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

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DEDICATION

I dedicate this thesis to my father and my mother, loving wife, Qamar, my sons, Zain Alabdeen, Abdollah and Yusur, for continually evaluating and inspiring me to work hard in my studies; my brothers, Dr. Ayad, Dr. Haydar, Dr. Alaa and Eng. Walled and my sisters, Dr. Suhad, Awrad and Eng. Mehad and their spouses and children for their encouragement and prayers for me, without forgetting my in-laws, and particularly Eng. Zainabmy and my best friends in my country. I thank Almighty Allah every day for blessing me with you and I love you all very much.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the Degree of Master of Science

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Chairman : Associate Professor Noor Izzri Abdul Wahab, PhD
Faculty : Engineering

There are numerous advantages that can be obtained when Distributed Generation (DG) is integrated into the distribution systems. These advantages include improving the voltage profiles and reducing the power losses of the distribution system. Such advantages can be accomplished and confirmed if the DG units are optimally located and sized in the distribution systems. In fact, there are several algorithms used for optimizing the size and finding the best location to install DG units in the power system. Some existing algorithms need to be improved while others, need to add a new parameter for improving the performance of optimization methods and making it more effective and efficient. This research aimed to reduce both total real and reactive power losses and improve voltage profiles of the distribution system by proposing a differential evolution (DE) algorithm to optimize DG size and location by taking into consideration different types of DG units. The multi-objective function, which represents the summation of product five indices by corresponding weights, was utilized to identify the candidate buses to reduce the search space of the algorithm. The suggested algorithm of DE was tested using IEEE 30 bus test system and IEEE 57 bus test system taking into consideration three types of DG units. The results obtained by using the DE method were compared with those obtained by genetic algorithm (GA) method. It was observed that the DE method gives a better result in terms of improving the voltage profile and reducing real and reactive power losses compared to GA method. In the IEEE 30 bus test system, the percentages of reduction in the real power losses obtained by the DE method were 20.58 %, 22.08 % and 20.40 % compared with 15.03 %, 16.81 % and 19.66 % obtained by the GA method for type 1, type 2 and type 3 respectively, while the percentages of reduction in the reactive power losses were 23.28 %, 19.20 % and 23.14 % by using the DE method compared with 17.01 %, 14.41 % and 22.49 % by using the GA method for type 1, type 2 and type 3 respectively. The voltage profile of the system also improved after optimizing DG sizes and locations using the DE method. However, in the IEEE

57 bus test system, the percentages of reduction in the real power losses were 17.08 %, 21.53 % and 20.20 % by DE method compared with 16.72 %, 15.91 % and 16.86 % by the GA method for type 1, type 2 and type 3, while the percentages of reduction in the reactive power loss were 9.64 %, 11.67 % and 9.42 % by DE method compared with 9.32 %, 10.81 % and 9.08 % by the GA method for three types of DG units respectively.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk Ijazah Master Sains

LOKASI DEN SAIZ OPTIMUM PENJANA TERAGIT UNTUK MENINGKATKAN KEHILANGAN KUASA DAN MEMPERBAIKI PROFIL VOLTAN DENGAN MENGGUNAKAN KAEDAH EVOLUSI PENGOPTIMUMAN PENGKAMIRAN

Oleh

AHMED SAHIB HAMMADI

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Pengerusi : Profesor Madya Noor Izzri Abdul Wahab, PhD
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Terdapat banyak kebaikan yang boleh diperolehi apabila Distribution Generation (DG) disepadukan ke dalam sistem pengedaran. Kebaikan yang pailing utama adalah menambah baik penjanaan profil voltan dan mengurangkan kehilangan kuasa sistem pengagihan. Banyak kebaikan boleh dicapai dan disahkan jika unit DG diletak secara optimum dan ditempatkan dengan sistematik dalam sistem pengedaran. Malah, terdapat beberapa algoritma yang digunakan untuk mengoptimumkan saiz dan mencari lokasi yang lebih baik untuk memasang unit DG dalam sistem kuasa. Beberapa algoritma yang sedia ada perlu diperbaiki dan diubahsuai manakala yang lain perlu dinaik tarafkan dan ditambahkan dengan parameter baru untuk meningkatkan prestasi kaedah pengoptimuman dan menjadikannya lebih berkesan dan cekap. Kajian ini bertujuan untuk mengurangkan kedua-dua jumlah kehilangan kuasa sebenar dan reaktif dan meningkatkan profil voltan sistem pengagihan dengan mencadangkan algoritma pengkamiran evolusi (DE) bagi mengoptimumkan saiz DG dan lokasi dengan mengambil kira jenis unit DG. Fungsi pelbagai objektif, yang mewakili penjumlahan produk lima indeks mengikut wajaran sama telah digunakan untuk mengenal pasti kaedah 'buses' untuk mengurangkan ruang carian algoritma. Algoritma DE yang dicadangkan telah diuji menggunakan IEEE 30 'bus' sistem ujian dan sistem IEEE 57 ujian 'bus' yang mengambil kira tiga jenis unit DG. Keputusan yang diperolehi dengan menggunakan kaedah DE itu kemudiannya dibandingkan dengan keputusan diperolehi daripada kaedah algoritma genetik (GA). Kajian ini terbukti bahawa kaedah DE dapat memberikan hasil yang lebih baik dari segi meningkatkan profil voltan dan mengurangkan kehilangan kuasa sebenar dan reaktif berbanding kaedah GA. Dalam IEEE 30 'bus' sistem ujian, peratusan pengurangan kehilangan kuasa sebenar yang diperolehi dengan kaedah DE tersebut ialah 20.58%, 22.08% dan 20.40% berbanding dengan 15.03%, 16.81% dan 19.66% yang diperolehi dengan kaedah GA untuk jenis 1, jenis 2 dan jenis 3 masing-masing. Manakala peratusan pengurangan

kehilangan kuasa reaktif adalah 23.28%, 19.20% dan 23.14% dengan menggunakan kaedah DE berbanding dengan 17.01%, 14.41% dan 22.49% dengan menggunakan kaedah GA untuk jenis 1, jenis 2 dan jenis 3 masing-masing. Profil voltan sistem juga bertambah baik selepas mengoptimumkan saiz DG dan lokasi menggunakan kaedah DE tersebut. Walau bagaimanapun, dalam IEEE 57 'bus' sistem ujian, peratusan pengurangan kehilangan kuasa sebenar adalah 17.08%, 21.53% dan 20.20% dengan kaedah DE berbanding dengan 16.72%, 15.91% dan 16.86% dengan menggunakan kaedah GA untuk jenis 1, jenis 2 dan jenis 3. Manakala peratusan pengurangan kehilangan kuasa reaktif adalah 9.64%, 11.67% dan 9.42% dengan mengaplikasi kaedah DE berbanding dengan 9.32%, 10.81% dan 9.08% dengan kaedah GA bagi tiga jenis unit DG masing-masing.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

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LIST OF ABBREVIATIONS

ABC	Artificial Bee Colony
ACO	Ant Colony Optimization
AI	Artificial Intelligence
BA	Bat Algorithm
BFO	Bacterial Forging Optimization
CIGRE	International Council On Large Electricity System
CS	Clonal Selection
DE	Differential Evolution
DG	Distributed Generation
EPRI	Electric Power Research Institute
FA	Firefly Algorithm
GA	Genetic Algorithm
HPE	Harmonic Power Flow
IEA	International Energy Agency
IEEE	Institute Of Electrical And Electronics Engineers
LLCI	Line Loading Capacity Index
MOF	Multi Objective Function
MOO	Multi Objective Optimization
NN	Neural Network
OPF	Operation Power Factor
PEM	Point Estimate Method
PSO	Particle Swarm Optimization
PV	Photovoltaic
PLRI	Real Power Loss Reduction Index

QLRI	Reactive Power Loss Reduction Index
SCI	Short Circuit Index
VDI	Voltage Deviation Index

CHAPTER 1

INTRODUCTION

1.1 Background

A crucial role of an electric power system is to generate electricity to meet customer demands, with an acceptable level of reliability in an economical manner. The main functional areas in an electric power system are power generation level, transmission line level, and distribution system level. The main function of the power generation plants is to ensure enough capacity is available to meet customer demand at any time. Usually, transmission line and distribution systems need to be stable and reliable to ensure the electricity can be delivered to the consumers where it is needed and when it is needed (Singh *et al.*, 2015).

For many years, electricity distribution networks were used and designed to supply electrical energy to customers; no generation was present on the customer side or on the distribution systems and distribution systems must supply electricity to the customer at an appropriate voltage rating. In the distribution levels, the ratio of X/R is lower compared to transmission levels that cause a drop in voltage magnitude and high power losses through radial distribution lines. Approximately13% of the total power generated is wasted at the distribution level as real power losses (Kavitha *et al.*, 2014).

Nowadays, due to major changes in the electricity market in terms of the environmental policies, technological evolution and also the expansion in power markets, the new concept of allowing the electricity to be generated in small capacity generation is increasingly being added to the distribution systems of the power network (Torres *et al.*, 2014). The generating of electricity energy at the customer site or through the distribution networks is known as Distributed Generation (DG). These new technologies utilize both unconventional and conventional sources of energy. Often, it may be operated by the utility or the customer. The following reasons have brought this technology to the attention of the electricity companies (Payasi *et al.*, 2011):

- Availability of small unit generating plants.
- Ease of finding places for smaller generation units.
- Competition or deregulation policy.
- Provision of diverse energy sources.
- National power requirements.
- Lower capital costs and short building times.
- Reduced transmission costs because the generation is sited closer to the load.

The operation of DG units may be considered random depending on the customer load. The location of DG units in the distribution system and amount of power delivered from it can increase or decrease the efficiency and reliability of the system and have an effect on its operation. Technical and safety problems may be created by huge supplied power from the DG units. Depending on its size and location, DG may cause voltage oscillations, interfere with voltage-control processes, increase fault currents, increase or diminish losses. Additionally, it can reverse the direction of power flow, etc.

If the DG unit is installed at a non-optimal location in the distribution system, the amount of power may change that lead to an increase in the power losses and undesired in the voltage profiles. Therefore, suitable position and rating of the DG unit is very critical in determining system performance (Kamdar and Karady, 2014).

Basically, allocation of DG unit is a complex combinatorial optimization problem which requires synchronous optimization of several objectives such as decreasing of total active and reactive power losses, improving voltage deviation of buses and reducing the short circuit level to maximize the reliability of the network. The multi-objective optimization pattern offers an attractive option to address the complex optimization issues like optimal DG sizing and placement. Besides, it is important to measure the success of DG implementation in terms of economic feasibility and it is also important to ensure that deployment of DG units in power system improves the technical parameters of the system (Adefarati and Bansal, 2016).

Thus, many optimization techniques have been employed to solve different multi-objective optimization problems. Artificial intelligence (AI) methods have been used to solve complex DG unit problems as they can provide global or near global solutions. Artificial intelligence techniques include mainly Genetic Algorithm (GA) method, Particle Swarm Optimization (PSO) method, Artificial Bee Colony (ABC) method, Ant Colony Optimization (ACO) method, Bacterial Foraging Optimization (BFO) method, Clonal Selection (CS) method, and Firefly Algorithms (FA) method. The main advantage of the AI techniques is that they are relatively versatile for applying various qualitative constraints (Mohandas *et al.*, 2015).

1.2 Problem Statement

Day after day, power electricity demands are growing very fast and the electricity demands in a power utility service vary as a function of location depending on the types and number of consumers in each locality. The main tasks of the electricity companies is to generate electricity from new sources such as renewable energy sources or distributed generation units to overcome the new demand of energy consumption and delivering the power into the distribution system (Dahal and Salehfar, 2016). Despite the numerous benefits that are offered by the integration of the DG unit, the technical problems increase when the new generation is added at an unsuitable location in the power distribution network (Karimyan *et al.*, 2014). An unsuitable location with a non-optimal size of DG units may lead to increase of total active and reactive power losses together with adverse effect on voltage magnitude. The increase or decrease in the power flow could cause overtaking of the boundary in some of the lines, and integration of DG units may increase the short circuit current of the system depending on size, location and type of DG units.

Several researches have proposed artificial intelligence techniques (AI) for determining the optimal sizing and the best location of DG units to improve the voltage profile of buses and reduce power losses of the distribution system.

Recently, the Differential Evolution (DE) technique has attracted the attention of researchers because it provides a fast speed of convergence, ease of implementation, and higher accuracy in finding the optimal solution (Jiang *et al.*, 2013). The DE will be employed in this research with multi-objective functions in order to determine optimal allocation of DG units in terms of reduction of total power losses and improvement of the network's voltage profile.

1.3 Research Objectives

The present study aims to find the optimal size and location of different types of DG units to reduce power losses and improve voltage profile of the distribution system.

The specific objectives of this study are:

1) To formulate a multi-objective function for solving the optimal DG placement and sizing problem by considering various indices like real and reactive power loss reduction index, voltage deviation index, line loading capacity index, and short circuit index.
2) To propose a Differential Evolution (DE) technique for optimizing DG size and location in the distribution system.
3) To investigate the effect of penetration three types of DG unit (type1, type2 and type3) on the power losses and the voltage profiles of power system and validate the results with those obtained by genetic algorithm (GA).

1.4 The Scope of Work

The current research focuses on finding the best location and optimal size of different DG unit models which can improve the stability of distribution networks and maximize the benefits of significant penetration. Technical issues that arise when connecting the DG unit to distribution systems are taken into consideration.

The technical challenges presented in this research are minimization of losses, improving voltage profile, and reducing the short circuit level, also taking into consideration the line loading capacity. The technique presented in this work involves determining the optimal plan for integration of DG unit by using a DE optimization algorithm, then comparing the results with those obtained from the application of genetic algorithm. The limitations and technical constraints in power system operations are considered to ensure a good result. The algorithm is tested on both medium size (IEEE 30-bus) and large test systems (IEEE 57-bus) to demonstrate the extensiveness and applicability of the technique.

1.5 Organization of the Thesis

The thesis is organized as follows:

Chapter 1 provides information about distributed generation (DG) and its effects on power systems. Also, it gives an overview on the research background and statement of the research problem with regard to the importance of optimal sizing and the best placement of DG units to ensure voltage stability exists in the network at all times. The objectives of the study as well as the scope of work are also presented in this chapter.

Chapter 2 reviews previous studies in three sections: the first section is a summarized introduction to the chapter, follow by a description and discussion of the distributed generation and its impact on the power networks, while, the multi-objective evolutionary Algorithm is discussed in the second section. In the last section, the highlights on optimization approaches for location and sizing of DG are presented.

Chapter 3 describes the methodology and development of the proposed algorithm for best placement and optimal sizing of DG units in the distribution system. Some theoretical backgrounds of corresponding artificial intelligence (AI) techniques are introduced here. The GA and selected AI technique (DE) are combined in the overall optimization algorithm.

Chapter 4 shows the implementation of the proposed optimization technique in two widely-used test systems. Test results are analyzed and discussed to verify the applicability of the proposed technique.

Chapter 5 presents the conclusions and recommendations for future work.

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