UNIVERSITI PUTRA MALAYSIA

OPTIMAL PLACEMENT AND SIZING OF DISTRIBUTED GENERATION IN RADIAL DISTRIBUTION NETWORKS USING PARTICLE SWARM OPTIMIZATION AND FORWARD BACKWARD SWEEP METHOD

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By

SANI MOHAMMED LAWAL

Thesis submitted to the school of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirement for the Degree of Master of Science

September 2012

DEDICATION

This thesis work is dedicated my parents, late Father **Mal. Mohammed Lawal** & **Hajia Zainab Mohammed Lawal**, and also my immediate family (**My Wife & Kids**) for their patients, prayers and understanding throughout the period of the study.

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

OPTIMAL PLACEMENT AND SIZING OF DISTRIBUTED GENERATION IN RADIALDISTRIBUTION NETWORKSUSING PARTICLE SWARM OPTIMIZATION AND FORWARD BACKWARD SWEEP METHOD

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SANI MOHAMMED LAWAL

September 2012

Chairman: Hashim Hizam, PhD

Faculty: Engineering

Among major concerns of the conventional electrical power generation systems, are the issues related to emission and the environmental hazards, as well as the economic viability of building new ones. Distributed Generation (DG) has become one of the options in electrical power provision, in order to curtail or reduce the problems posed by the conventional power systems. As DG is becoming increasingly popular with high level of acceptability, the problem of optimum placement of DG with the correct capacity are the main challenges for power utilities. To address these issues, this thesis focuses mainly on the optimal placement and sizing of DG in the distribution networks. Electrical distribution network systems normally include distribution feeders,which are arranged or configured either in mesh or radial pattern and they are mainly fed by a utility substation. However, distribution networks have been found to be exhibiting

significant voltage drop, due to their high R/X ratio that could cause substantial power losses along the feeders. In light of this aforementioned problem, installation of DG within the distribution level, will have an overall positive impact towards reducing the power loss and voltage deviation as well as improving the networks voltage profiles.

Voltage deviation is an important factor that needs an immediate attention in the power system, which is affecting the operating conditions of the present day power systems. The evaluation and minimizing voltage deviation will reduce the problems power quality and bring about stability in the nominal voltage. The minimization of this fluctuation that leads to derailing from the nominal voltage need to be emphasized.

To achieve the set target, particle swarm optimization (PSO) is used as an optimization technique. PSO is among the meta-heuristics search methods like Genetic Algorithm (GA) but has been found to be computationally efficient, because it uses less number of functions for evaluation compared to GA that has genetic operators (Selection, crossover and mutation) and also the computational effort (time) required by PSO to arrive at high quality solutions is less than the effort required to the same high quality solutions by other heuristic search methods. The output indicates that, PSO algorithm technique shows an edge over other types of meta-heuristics search methods due to its effectiveness and computational efficiency.

The proposed PSO algorithm is used to determine optimal placement and size of DG in radial distribution networks, where Forward Backward Sweep Method (FBSM) of distribution load flow analysis was used, to determine the actual power loss in the system. FBSM is adopted in this work due to its advantages over other conventional load flow studies such as Newton raphson, Gauss-siedal and fast decoupled load flow methods, these conventional methods are found not to be suitable for distribution load flow analysis due to high R/X ratio. FBSM offers better solutions, faster and high level of accuracy. The computational time of building the Jacobian matrix, LU factorization, and backward/forward substitution needed for Newton's method are no longer required in FBSM. The FBSM is proven to be robust and to have the lowest CPU execution time when compared with other conventional methods.

The proposed method is tested on the standard IEEE 34-bus test systems. Results indicate that the sizing and location of DG are system dependent and should be optimally selected before installing the distributed generators in the system. Improvements in the voltage profile, power loss and voltage deviation reduction have been achieved.

Abstrak tesis ini dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master sains

PENEMPATAN DAN PENSAIZAN OPTIMA PENJANAAN TERAGIH DALAM RANGKAIAN PENGAGIHAN JEJARI MENGGUNAKAN PENGOPTIMUMAN KAWANAN ZARAH DAN KE HADAPAN / BELAKANG SAPU KAEDAH

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Antara isu yang menjadi kebimbangan utama tentang sistem penjanaan kuasa elektrik konvensional ialah masalah pelepasan dan ancaman terhadap persekitaran, serta keupayaan ekonomi bagi membina sistem jana kuasa baharu. Sistem Penjanaan Teragih *(Distributed Generation (DG))* adalah salah satu pilihan yang boleh diambil dalam sistem kuasa untuk mengurangkan permasalahan yang timbul. Ketika populariti dan kadar penerimaan terhadap sistem ini semakin meningkat, cabaran utama yang dihadapi ialah masalah penempatan optimum DG dengan kapasiti yang tepat. Untuk menangani isu ini, penempatan dan pensaizan optima DG dalam rangkaian pengagihan akan menjadi fokus utama tesis ini.

Sistem rangkaian pengagihan elektrik lazimnya merangkumi penyuap pengagihan yang telah disusun atau dikonfigurasi dalam bentuk kekisi atau jejari dan kebiasaannya disuap oleh

pencawang utiliti. Walau bagaimanapun, rangkaian pengagihan didapati telah menunjukkan penurunan kadar voltan yang ketara lantaran nisbah R/X yang tinggi yang boleh menyebabkan kehilangan kuasa yang besar sepanjang penyuap. Oleh sebab itu, pemasangan DG pada peringkat pengagihan akan dapat memberikan kesan yang positif ke arah pengurangan kehilangan kuasa dan sisihan voltan serta memperbaiki profil voltan rangkaian secara keseluruhannya. Sisihan Voltan adalah faktor penting yang memerlukan perhatian segera dalam sistem kuasa yang mempengaruhi keadaan operasi sistem kuasa semasa hari. Penilaian dan meminimumkan sisihan voltan akan mengurangkan kualiti masalah kuasa dan membawa kestabilan dalam voltan nominal. Pengurangan ini turun naik yang membawa kepada menggelincirkan daripada voltan nominal perlu diberi penekanan

Untuk mencapai sasaran ini, pengoptimuman kawanan zarah (PSO) digunakan sebagai teknik pengoptimuman. PSO mempunyai komputasi yang cekap kerana penggunaan fungsinya yang kurang dalam memberikan penilaian berbanding teknik-teknik yang lain seperti algoritma genetic (GA) dan ia juga menyediakan penyelesaian yang berkualiti dalam masa yang lebih singkat berbanding kaedah heuristik lain dalam memberikan penyelesaian yang setara kualitinya.

Algoritma PSO yang dicadangkan digunakan dalam penentuan penempatan dan saiz optima DG dalam rangkaian pengagihan yang mana kaedah sapuan hadapan / belakang digunakan untuk menentukan kehilangan kuasa sebenar dalam sistem. Keputusan mengandaikan bahawa teknik algoritma PSO menunjukkan kelebihan berbanding kaedah carian meta heuristik yang lain kerana kecekapan dan keberkesanannya.

Algoritma PSO yang dicadangkan digunakan untuk menentukan penempatan optimum dan saiz DG dalam rangkaian pengedaran jejarian, mana Sapu hadapan / belakang Kaedah (FBSM) pengagihan analisis aliran beban telah digunakan untuk menentukan kehilangan kuasa sebenar dalam sistem.Yang FBSM diguna pakai dalam kerja-kerja ini kerana kelebihan ke atas kajian konvensional yang lain aliran beban seperti Newton Raphson, Gauss-siedal dan cepat beresonan kaedah aliran beban, ini kaedah konvensional didapati tidak sesuai untuk pengedaran analisis aliran beban kerana R tinggi /X nisbah. FBSM menawarkan penyelesaian yang lebih baik, lebih cepat dan tahap ketepatan yang tinggi. Masa pengiraan membina matriks Jacobian, LU pemfaktoran, dan ke belakang / hadapan penggantian yang diperlukan untuk kaedah Newton tidak lagi diperlukan dalam FBSM. FBSM terbukti menjadi teguh dan mempunyai masa CPU pelaksanaan terendah jika dibandingkan dengan konvensional yang lain.

Kaedah yang dicadangkan diuji berdasarkan piawaian sistem penilaian IEEE 34-bas dan disahkan dengan rangkaian pengagihan. Dapatan menunjukkan bahawa pensaizan dan lokasi DG adalah bergantung kepada sistem dan harus dipilih secara optimal sebelum pemasangan penjana teragih dibuat dan peningkatan dalam profil voltan dan penurunan kehilangan kuasa telah dicapai.

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First and foremost I must be grateful to The Al-Mighty Allah for sparing my life up to this time and also given me the opportunity to carry out this wonderful research work, on which without Allah's guidance and protection nothing would be possible. The research journey would not have been successful without the immense moral support of my family, in this regardsI wouldlike extend my sincere thanks to my family members for the support and cooperation rendered to me throughout my studies period.

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I certify that a Thesis Examination Committee has met on 24th September, 2012 to conduct the final examination of Sani Mohammed Lawalon his thesis entitled "Optimal Placement and Sizing of Distributed Generation in Radial Distribution Networks using particle swarm optimization and Forward/Backward Sweep Method" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.Members of the Thesis Examination Committee were as follows:

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This thesis was submitted to the Senate of 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

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institutions.

SANI MOHAMMED LAWAL

Date: 24th September 2012

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LIST OF ABBREVIATIONS

BIBC Branch Injection Bus Current

BCBV Branch Current Bus Voltage

DG	Distributed Generation
DS	Distribution System
FBSM	Forward Backward Sweep Method
GA	Genetic Algorithm
GHG	Green House Gas
IEA	International Energy Agency
IEO	International Energy Outlook
OECD	Organization
PSO	Particle Swarm Optimization
PSAT	Power System Analysis Toolbox
PSS	Power System Simulation
R/X	Resistance/Reactance
RDS	Radial Distribution System
RDPFA	Radial Distribution Power Flow Algorithm
UNFCCC	United Nation Frame work Convention Climate Change

CHAPTER 1

INTRODUCTION

1.1 General Introduction

The electrical power generation unit is expected to function as reliable as possible in both voltage and frequency stability of the network by avoiding all unnecessary disturbances which can jeopardize the electrical system performance [1]. The transmission aspect of power system network transfers the bulk energy generated through a long distance to the distribution network and is used to interconnect neighboring utilities which allow the economic dispatch of power within regions during normal conditions [1]. The distribution systems otherwise known as medium or low voltage systems transfer the energy to the consumer or load centers as the end user based on the nominal voltage of the energy generated. This type of generation is called the conventional or centralized system of electrical power generation, and the generation plant can be thermal power, hydro power station, nuclear power station etc. But due to general concern for the environment and also conservation of fossil fuels, alternative sources are now being considered so as to preserve and minimize the negative impact caused by these conventional power generating plants to the environment [2]. This alternative source of power generation option is known as Distributed Generation.

1.2 Distributed Generation

Distributed Generation (DG) is an idea of decentralizing the electrical power generation by locating small generating units at the customer site or near the load center. Conventionally the electric power is being generated at the generating plants and supplied to the loads through transmission and distribution systems, but the need for more flexible electric power systems, changing regulatory and economic scenarios, energy savings, environmental impact and the need to protect sensitive loads against network disturbances are providing impetus to the development of dispersed generation and storage systems based on variety of technologies [3].

The term DG, implies the use of any modular technology that is sited throughout a utility's service area (interconnected to the distribution or sub-transmission system) to lower the cost of service. DG may comprise of diesel and internal combustion engines, small gas turbines, fuel cells and photovoltaic. The purpose of the distributed generation plants is to cope with the growing demand for electricity in certain areas and also render certain activities of self-sufficient in terms of electric power generation thus achieving energy savings compared to conventional or centralize power generation station [4].

The conventional or centralize power generating plants are found to be causing problems in the process of electrical power generation by emitting gases that are not friendly to the environment and causes ozone depletion in atmosphere due to carbon dioxide, green house gas (GHG) and also polluting the environment [5]. However, air pollution from oil and coal-fired thermal plants, is generating a lot of concern over the environmental problem and global climate change increase, this might be an important constraint in supplying power demand in future [6].

Therefore, air pollution of thermal power plant is likely to be a major impediment to generating electricity couple with the issue of GHG emission that is seriously affecting the climate, avoidance of the construction of new transmission circuits and large generating plants [3]. In order to mitigate or reduce all these menace or threat exhibited by the central generating plant, the United Nation instituted an agreement called Kyoto protocol based on the climate changes and general global warming affecting the world. Kyoto protocol is one of the highest profile agreements reached in United Nation Frame work Convention on Climate Change (UNFCCC) in order to tackle the issue of GHG emission which believed to be contributing to present worries of the global warming. These agreements brought out the basis for reducing the emissions of GHG from the industrialized countries referred to as "Annex I Party" (Developed Countries) by 5.2% based on the 1990 emission levels and these ratification has a commitment period between 2008 and 2012 [7]. While the non-Annex I parties (Developing Countries) are not mandated to reduce their emission but they are encouraged to do so [8]. In line with the Kyoto protocol on which European countries agreed and said that by the year 2010, the European Union should reduce total greenhouse gas emissions on the average of 8% as against those of 1990. (Countries like Germany, England, Austria, Belgium, Denmark, Italy, Luxembourg and Holland has succeeded in reducing their emission by 21%, 12.5%, 13% 7.5%, 21%, 6.5%, 28%, and 6% respectively, where as other countries such as Greece, Ireland, Portugal, Spain, and Sweden are countries that are eligible to increase their emission by 25%, 13%, 27%, 15%, and 4% respectively [1]).

The world energy-related carbon dioxide emissions rise from 29.7 billion metric tons in 2007 to 33.8 billion metric tons in 2020 and 42.4 billion metric tons in 2035, an increase of 43% over the projection period. The solid form of fossil fuel such as coal provides energy for many industrial inventions, coal provided fuel for steam engines in the late eighteenth century and it was used to produce gas for lights in many cities. With the development of electric power in the late nineteenth century, coal's future became closely tied to electricity generation that is why most of the electricity in the world today is being generated from coal [9].

The energy demand is expected to increase worldwide over the next 24 years as stated by International Energy Outlook, 2004. Therefore, both the industrial countries and the developing Countries like Malaysia in Asian continent where rapid economic growth is expected. Energy demand in Malaysia increases rapidly almost 20% within last 3 years (from 1999 to 2002) and the energy demand is expected to increase up to 18,000MW by the year 2010 [10]. Now that there is need to tackle the issue of this energy demand increase and the conventional energy generation plants are pause with the above mentioned problem, DG can serve as an important alternative option to curtail the menace in energy demand. Malaysia has advantage of the abundant natural renewable sources; such as solar, wind, biomass, ocean and small hydropower energy sources. These resources can be harness and used to generate energy in a distributed form both in urban and rural areas.

1.2.1 Definition of Distributed Generation (DG)

The whole world has turn to a new trend that has less or no negative impact to human lives and the environment, this new trend is the Distributed or Embedded or Decentralized or the

Dispersed Power Generation System. A survey of the literature shows that there is no consensus in the definition of this term. But in broad term, DG is an electric power generation source connected directly to the distribution network or on the consumer side of the meter, using different types of technologies, which include renewable (Solar, biomass, Wind, Hydro, Geothermal, etc) and non-renewable (Fuel cells, Diesel engine, Gas turbine etc) energy generation technologies [11]. IEEE defines DG as the generation of electricity by facilities that are sufficiently smaller than central generating plant (conventional plant) so as to allow interconnection at nearly any point in a power system [12].

DG includes both renewable and non-renewable energy and related with the use of small generating units facilities installed in strategic areas of the electric power system distribution network close to the load centers. DG can be use in an isolated manner, supplying the customer's local demand, or in an integrated manner, by supplying the left over energy to the grid system called the feed- in tariff system [13]. DG encourages independent producers within a locality especially the site where the central generation is located has a lot of disadvantages such as cost of construction, long distance of power transfer and electromagnetic emission in the transmission system.

DG has gained increasing popularity as a viable element of electric power systems. DG, as small scale generation sources located at or near load center, is usually deployed within the Distribution System (DS). Deployment of DG has many positive impacts such as reducing transmission and distribution network congestion, deferring costly upgrades, and improving the overall system performance by reducing power losses and enhancing voltage profiles. To achieve the most from DG installation, the DG has to be optimally placed and sized [14].

1.3 Optimal Location and Sizing of DG; the need in Power System

The size of DG is defined as the total power supplied by all the DG's connected to the system to the total load of the system. The size of the DG is expressed in terms of percentage penetration (% DG) [15-16].The DG can be placed at any possible locations in the distribution network. There are different nodes feeders in the distribution system, the possible placement of the DG can be based on the selected node within the network. The advantages of DG can be achieved only by choosing the proper size of the DG and connecting it at the appropriate location in the system. DG has significant impact on the voltage profile of the system [13]. The presence of DG improves the voltage profile which is beneficial especially in rural areas where voltage swings and outages are more common. There are possibilities that over currents may be induced in the system due to over sizing and improper location of DG leading to undesired voltage profiles. The voltage stability of the system mainly depends on the voltage profiles and it is very essential that the power system should be stable at all times for reliable operation. Presence of DG in the system may improve or worsen the stability. It is essential to choose proper size and location of DG. Thus, there is a need for investigation of the DG impact on voltage stability [15].

1.4 Problem Statement

Research on optimal placement and sizing of DG in electrical distribution network systems using different optimization methods has been generating a lot of concern, due to high level power loss found within the distribution feeders, that has been arranged or configured either in mesh or radial pattern and it is mainly fed by a utility substation. Therefore, distribution networks has been found to be exhibiting significant voltage drop due to their high R/X ratio that could cause substantial power losses along the feeders. Previous works shows that a lot has been done

Most of the PSO technique used to solve the problem, focuses on the power loss minimization and voltage profile improvement, not minding the issue voltage deviation that normally effect the system, and made the system to derail from it nominal voltage. Also lacking, is the use of effective load flow solutions for distribution networks. This lacking in the proper combination between optimization technique and load flow solutions, bring about less accuracy and slow in the execution time. However, looking at the aforementioned problems, it became an impetus in this area of research to be look into.

Therefore, research work is needed to focus on optimal placement and sizing of DG using Particle Swarm Optimization (PSO) and Forward/Backward Sweep Method (FBSM) in a single run. Also less work has been done related to the voltage deviation, voltage profile improvement and overall power loss which is also a major concern of the power systems. This work aims at finding the optimal placement and sizing of the DG in a distribution networks such that voltage deviation and power loss can be minimize with an improved the voltage profile using particle swarm optimization.

1.5 Research Objectives

The objectives of this research work are as follows;

1. To determine the optimal placement and sizing of DG in distribution networks using particle swarm optimization and forward backward sweep method
2. To minimize the active power system loss and voltage deviation of the distribution networks.

1.6 Scope of Work and Contributions

The scope of work includes carrying out a radial load flow analysis on standard 34-bus IEEE distribution network systems. An effective method of radial distribution system called Forward Backward Sweep Method will be use for the load flow solutions. Also it shall involve the development of algorithm for optimal placement and sizing of the DG system in the distribution networks using an optimization technique, validation of the algorithm with other types of approaches will be conducted, and finally come out with a technique on optimal placement and sizing of distribution generation in a distribution networks for power loss minimization, voltage deviation and voltage profile improvement in the system.

The target contribution in this research work will be; the integration of particle swarm optimization technique with forward backward sweep method of load flow solutions for the minimizations of active power loss and voltage deviation, as against other approaches where only voltage profile improvement and power loss minimization were considered.

Limitation in this research work, are the issues of total cost that will be involved for the DG installation based on the chosen location and size. Where a cost function will included as part of the objective function. Also not considered is the sensitivity analysis, which can used to determine the weakest bus in the power system networks.

1.7 Thesis Organization

In this thesis, chapter one contains the general introduction of the proposed research where a brief about electrical power system, the DG, and the major factors that brought about the evolution of the DG in the electrical power system where certain issue of negative impact cause by conventional power generation plant with respect to the environment, climate change, market liberalization based on different DG technologies for an effective and reliable electricity supply that can take care of the increase in the customer's demand. The main problem statement and the objectives of the research has been highlighted so as to give a little insight on the possible goal that is to be achieved at the end of this research while abiding by the scope of work as mentioned in this chapter.

Chapter two contains the general literature review where other similar research work has been carried out before now with their types of different approach in order to have an inside on what has been done before with possible new findings.

Chapter three contains the main methodology and approach adopted in this research so as to achieve the main target. This Chapter described the logical steps involved in designing the methodology.

Chapter four contains all the necessary output result of the analysis, simulation, developed algorithm and finally discussion on the output result.

Chapter five contains the final conclusion, observation for future area of research and also possible recommendations on how improve the system that can make it better.

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