Multiple Objective Optimization Using Artificial Bee Colony Algorithm For Optimal Placement And Sizing Of Distributed Generation

by

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LIST OF ABBREVIATIONS

DG	Distributed Generation
DGs	Distributed Generations
US	United State
PUHCA	Public Utilities Holding Company Act
PURPA	Public Utilities Regulatory Policy Act
QF	Qualifying Facilities
UNFCCC	United Nations Framework Convention on Climate Change
CDM	Clean Development Mechanism
ABC	Artificial Bee Colony
PSO	Particle Swarm Optimization
MATLAB	Matrix Laboratory
IEEE	Institute of Electrical and Electronics Engineers
CIGRE	International Conference on High Voltage Electric Systems
IEA	International Energy Agency
DOE	Department of Energy
DER	Distributed Energy Resource
EPRI	Electric Power Research Institute
AGA	American Gas Association
PV	Photovoltaic
CHP	Combined Heat and Power
UPS	Uninterruptible Power Supply
OECD	Organisation for Economic Co-operation and Development
TSA	Tabu Search Algorithm

ACO	Ant Colony Optimization
ACSA	Ant Colony Search Algorithm
SA	Simulated Annealing
GA	Genetic Algorithm
PSO	Particle Swarm Optimization
BCO	Bee Colony Optimization
HAS	Harmony Search Algorithm
MINLP	Mixed Integer Non-Linear Programming
Fuzzy-EP	Fuzzy-Evolutionary Programming
MOPSO	Multi-objective Particle Swarm Optimization
IDG	Implementation of Distributed Generation
MOLP	Multi-objective Linear Programming
IA	Immune Algorithm
THD	Total Harmonic Distortion
RES	Renewable Energy Sources
IDG	Implementation of Distributed Generation

LIST OF SYMBOLS

kW	Power (Kilowatt)
MW	Power (Megawatt)
%	Percentage
BTU/kWh	Energy (British thermal unit over kilowatt-hour)
kWh	Energy (Kilowatt-hour)
P_{Loss}	Real power loss
I_k	Current magnitude
R_k	Resistance at branch *I*
$f(X)$	Function of *X*
IP	Real power loss index
P_{DG}	Real power loss including the presence of DG in the distribution system
P_O	Real power loss excluding the presence of DG in the distribution system
IQ	Reactive power loss index
Q_{DG}	Reactive power loss including the presence of DG in the distribution system
Q_O	Reactive power loss excluding the presence of DG in distribution system
I	Current flowing through the electrical conductor in units of amperes
V	Potential difference measured across the electrical conductor (volts)
R	Resistance of the electrical conductor (ohms)
I_{xy}	Short circuit current in line *x* and *y*
V_x	Bus voltage at bus *x*
V_y	Bus voltage at bus *y*
Z_{xy}	Impedance between bus *x* and bus *y*
IC	Short circuit current index

I_{sc}	Short circuit current without the presence of DG in the distribution system
I_{scDG}	Short circuit current with the presence of DG in the distribution system
n	Number of nodes
$Vnom$	Nominal value for voltage
IV	Voltage profile index
nb	Number of buses
V_i	Minimum voltage magnitude among all the buses voltages magnitude
P_{SS}	Power conservation limit
P_D	Power demand (MW)
NL	Number of lines
P_{loss}	Line losses
P_{DG}	Power generated from the DG
X_i^j	Every solution of population
X_{min}^j	The minimize possible value for j^{th} variable of solution
X_{max}^j	The maximize possible value for jth variable of solution
$rand\ ()$	Uniform arbitrary number between 0 and 1
Z_i^j	New solution, the new value of j^{th} position on the state variable
X_{ka}^j	The j^{th} variable of an arbitrarily selected solution in record (indexed by *ka*)
X_i^j	The j^{th} value of the i^{th} solution in the population
j	Index of j^{th} variable that is selected arbitrarily
k	Index of random solution in population
X_k^j	Random solution selected from current population
Pi	Probability of selecting each solution
a_i	Value of ftness of i^{th} solution in population

dom_i	Number of solution in at that time of population that are dominated by solution i.
x_i	Size of DG
y_i	Location of DG
SN	Size of population
$f_V(X)$	The V dimensional vector of objective value
σ_p	Weightage values for each function
$If_1(X)$	Index of function 1
$If_2(X)$	Index of function 2
$If_3(X)$	Index of function 3
$If_4(X)$	Index of function 4
p.u	Base unit quantity (per-unit)

Pelbagai Pengoptimuman Objektif Menggunakan Buatan Algoritma Koloni Lebah Untuk Penempatan Optimum Dan Saiz Generasi Diedarkan

ABSTRAK

Pelaksanaan Alat Penjana Kuasa Pembahagian (DG) boleh membawa kepada beberapa masalah dalam sistem kuasa. Peningkatan kehilangan sistem dan tahap voltan yang tidak diingini di luar had utiliti elektrik dibenarkan boleh menyebabkan jika kuasa yang disuntik oleh unit DG adalah di tempat yang tidak sesuai. Kos rangkaian boleh meningkatkan dan memberikan hasil yang tidak diingini. Di samping itu, aliran kuasa terbalik boleh menyebabkan dan sistem penjanaan pelindung mungkin terganggu. Tujuan utama kajian ini adalah untuk menyiasat penempatan optimum dan saiz DG tunggal dan berganda dalam sistem pengagihan menggunakan kaedah pelbagai objektif. Oleh itu, kajian ini memberikan satu petunjuk prestasi pelbagai objektif berdasarkan saiz dan lokasi generasi diedarkan (KP) dalam sistem kuasa untuk menangani masalah. Penempatan dan saiz DG dipilih secara optimum oleh teknik pengoptimuman. Teknik buatan algoritma koloni lebah (ABC) telah dikaji untuk menyelesaikan masalah--objektif pelbagai masalah yang sebenar kehilangan kuasa, hilang kuasa reaktif, semasa litar pintas, dan profil voltan. Algoritma yang digunakan kemudiannya diuji pada standard IEEE 69 sistem pengagihan bas. Keputusan pengesahan keberkesanan kaedah ABC dibentangkan dan terbukti melalui perbandingan dengan lain-lain kaedah pengoptimuman seperti PSO. Ini termasuk masalah pelbagai objektif yang mempunyai impak yang besar dalam memilih saiz yang optimum dan lokasi DG, yang diwakili dari segi indeks pelbagai objektif. Nilai keseluruhan indeks pelbagai objektif yang jauh berbeza dengan nombor berbeza DG memasang ke dalam sistem tersebut dikenalpasti. Aspek kebolehpercayaan sistem pengagihan kuasa didapati diperbaiki. Akhir sekali, beberapa pemasangan DG yang akan mengurangkan bilangan indeks pelbagai objektif (IMO), dan juga akan mengurangkan masalah lain dalam sistem kuasa dikenalpasti.

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ABSTRACT

The implementation of DG may lead to several problems in power system. The increase in system losses and unwanted voltage levels outside the allowed electricity utility limits may cause by DG if the power injected by DG units is in an inappropriate place. The costs of network may increase and give the undesired outcomes. In addition, the reverse power flows may introduce and the generation protective system may be interrupted. The main aim of this research is to investigate the optimal placement and sizing of single and multiple DGs in distribution system using multi-objective method. Thus, this research presents a multi-objective performance index based on the size and location of distributed generation (DG) in power system to counter the problems. The placement and sizing of DG are selected optimally by technique of optimization. The technique of artificial bee colony algorithm (ABC) has been studied to solve these multi-objectives problems which are real power loss, reactive power loss, short circuit current, and voltage profile. The algorithm used is then tested on standard IEEE 69 bus distribution system. The validation results of the effectiveness of the ABC method are presented and proven through the comparison with other methods of optimization which is Particle Swarm Optimization (PSO). This includes the multi-objectives problems that have significant impact in choosing the optimum sizing and location of DG, which was represented in term of multi-objective index. The overall value of multi-objective index that is significantly different with different number of DGs install into the system is identified. The reliability aspect of power distribution systems is found to be improved. Finally, number of DGs installation that will reduce the number of multi-objective index (IMO), and also will reduce other problem in power system is identified.

CHAPTER 1

INTRODUCTION

1.1 Motivation

Power generated in power stations and then transmitted through transformers, overhead lines, cables and other equipment until it reached at the consumers. In power system, there are four subsystems where each of them has their own function in order to make sure that the power can be supplied to the consumer. The subsystems are generation, transmission, distribution, and utilizations.

It is fact that power generated by the power station does not match with the power that received by the consumers. Jiguparmar (2013) reported that distribution sector considered as the weakest link in the entire power sector, with the electrical power losses is approximately 50% compared to the power losses at the transmission sector which is 17% (Jiguparmar, 2013). Due to advances in technology of small generation, utilities have started to enhance their electric infrastructure by adapting small, multiple, on-site and dispersed Distributed Generations (DGs) on power system.

Distributed Generations (DGs) are small-scale generating units that are installed near to centers of the load to minimize electricity losses and inefficiencies. DG or in other name as embedded generations and dispersed generation, is expected to play an increasing role in emerging the power systems. Studies have been predicted that DG will be a significant percentage of all new generations going on lines with about 20% of new generations being installed into the power system (El-Khattam & Salama, 2004).

The widespread usage of DG nowadays because it is easier to find site for small generators, DG units are closer to customer site so that transmission and distribution costs are ignored and reduced, latest technology has made available plants ranging in capacities from 10 kW to 15 MW, usually DG plants require shorter installation times and the investment risk are not so high, and some natural gas often used as fuel in DG stations is distributed almost everywhere and stable prices are expected for it (Celli, Ghiani, Mocci, & Pilo, 2005).

Careful attention has to be paid on the placement and sizing of DG in distribution system, so that can maximize the benefits. The most effective benefits of proper location of DG units in distribution systems are the reducing the energy losses, improve the reliability and upgrades the investments deferral of the system (Shaaban & El-Saadany, 2011). The motivation of this thesis is to investigate the impact of DG's placement and sizing for single and multiple DGs using multi-objective method. Optimization has been used to get the optimum results which is minimum value of multi-objective function thus to minimize the problems. Several problems have been identified which are to find the optimal placement of DG in distribution system and optimal size of DGs.

1.2 Distributed Generation

1.2.1 Historic Overview

During the first twenty-five years which is in 1900, most customers stay within five miles from their power station. At that time, powered areas operated as electrical islands, generated less than 10 MW and not interconnected. Brown (2002) mentioned that cogeneration was common used, with 138,000 BTU/kWh of heat rate and 2.4% of efficiency (Brown, 2002). Research by Masters (2004), in 1929, 16 holding companies controlled 80% of electricity in United State (US) (Masters, 2004). However, most of the utility holding company went bankrupt during the Great Depression so that the US Congress Public Utilities Holding Company Act (PUHCA) of 1935 decided to regulate the industries of gas and electricity also with the holding companies to own a single integrated utility.

According to Brown (2002), the Public Utilities Regulatory Policy Act (PURPA) of 1978 allowed connection between the grid and ask the utility to buy electricity from Qualifying Facilities (QF) (Brown, 2002). The QF is refers to independent power generators, where it sell the generated power to the utility at equivalent price. This act allowed the utility to save the money by not generating the same amount of power with QF. The introducing of the act is the starting point of the DG industry era, where the generated electricity is sold at lower price to the utility companies.

1.2.2 Kyoto Protocol

The Kyoto Protocol to the UNFCCC is an amendment to the international treaty signed in 1992 on climate change, assigning mandatory emission limitations for the reduction of greenhouse gas emissions to the signatory nations (UNFCCC, 1998). The objective of the protocol is to stabilize the greenhouse gas concentrations in the atmosphere at certain level that can prevent dangerous of anthropogenic interference with the climate system (UNFCCC, 1998).

Flexibility Mechanisms refers to Emissions Trading, the Clean Development Mechanism and Joint Implementation. All mechanisms are defined under the Kyoto Protocol where intended to reduce the overall costs of achieving targets for emission. These mechanisms enable parties to remove carbon from the atmosphere cost effectively in other countries. While the cost of limiting emissions varies considerably from region to region, the benefit for the atmosphere is in principle the same, wherever the action is taken.

The Emissions Trading allows parties to the Kyoto-protocol to buy greenhouse gas emission permits from other countries to help meet their domestic emission reduction targets. Through the Joint Implementation, industrialized countries with a greenhouse gas reduction commitment of Annex 1 countries may fund emission reducing projects in other industrialized countries as an alternative to emission reductions in their own countries. Typically, these projects occur in countries in the former Eastern Europe.

Research by Bierbaum and Zoellick (2009) showed that Clean Development Mechanism (CDM) is an arrangement under the Kyoto Protocol allowing industrialized countries with a greenhouse gas reduction commitment of Annex 1 countries to invest in projects that reduce emissions in developing countries as an alternative to more expensive emission reductions in their own or other industrialized countries (Bierbaum & Zoellick, 2009). The most important factor of a carbon project is that it establishes that it would not have occurred without the additional incentive provided by emission reductions credits. The CDM allows net global greenhouse gas emissions to be reduced at a much lower global cost by financing emissions reduction projects in developing countries where costs are lower than in industrialized countries.

Concerns on the change in the Earth's climate, formalized in the Kyoto Protocol in 1997, stimulates research, promotion, development and increased use of renewable energy. In power systems, most of power plants are large industrial sites located at strategic locations, nearby a river or a lake for cooling water, and close to energy resources. Research by Schavemaker and Sluis (2008) stated that these large power plants are connected to the transmission network by step-up transformers and are controlled in order to take care of voltage and frequency stability of power system (Schavemaker & Sluis, 2008).

This is what we call 'centralized generation'. Nowadays, the trend is to integrate more and more 'decentralized generation' or also called as 'distributed generation (DG)' into the power system. Meaning that, small scale generators are connected to the system at lower voltage levels. Examples of DG units are solar panels and windmills.

1.2.3 Implementation of DG in Power System

By considering all the necessary way to promote the use of low carbon, distributed generation was introduced by the utility to the power system. Then, centralized power system evolved, employing transmission lines, larger scale, gave better economy, located away from cities, improve the efficiency, power dispatch and diversity advantage. Compared with the conventional power stations, for examples coal-fired, hydroelectric, and gas powered plants, are centralized and require electricity to be transmitted over long distances. DGs are connected directly to the distribution system or on the customer site of the meter. However, systems of DG are also centralized, but with more flexible technologies that located close to the load they serve.

Research by Masters (2004) stated that distributed generation also enables collection of energy from many sources and may lower the impacts on environment and at the same time improve security of the supply (Masters, 2004). There are two types of DGs which are rotating devices (synchronous or asynchronous machines) or rotating or static devices. When connected to distribution system, both technologies give impacts on the operation of the system thus affects the size and optimal placement of DG in the system. According to Gozel, Hocaoglu, Eminoglu, and Balikci (2005), it is estimated that DG would have a share of about 20% of new generating units being online (Gozel et al., 2005).

Although the concept of DG application in distribution system is not new, there is an improvement in trend towards DG application in power systems. Accelerating factors for DG application such as environmental concerns, economical consideration, technological advancements and power system deregulation are results in positive and negative side effects for both utility and customers (Fotuhi-Firuzabad & Rajabi-Ghahnavie, 2005).

1.2.4 Problem Statement

The implementation of DG in power system may lead to several advantages such as help to reduce the cost of electricity to the customer and relieve network congestion. In addition, it also promotes system technical characteristics such as loss reduction, voltage profile enhancement, and reserve mitigation. Furthermore, it require low investment cost, short construction times, reduce capital risks, improve power quality and reliability of service, greater efficiency with respect to power generation system heat loss, and able to function as standby generation.

However, there are still has problems with implementation of DG in the power system. DG may cause the increase in system losses and unwanted voltage levels outside the allowed electricity utility limits if the power injected by DG units is in an inappropriate place. This may increase the costs of network and give the undesired outcomes. In addition, this may introduce the reverse power flows and interrupt the generation protective system.

Thus, the suitable placement of DG is very important as it can increase the reliability and power quality to the customers. Special attention must be also made to DG sizing. To be clear, the problem of optimal DG placement and sizing is divided into two sub problems: where to find the optimal DG placement and what is the best method to select the most suitable size for DG? There are lots of methods proposed by many researchers to solve the problem.

1.3 Research Objectives

The main objective of this research is to investigate the optimal placement and sizing of single and multiple DGs in distribution system using multi-objective method. In order to achieve the main objective, the research has been run step by step to fulfill the following objectives:

1. To develop an optimization method to find the optimal placement and sizing of DG by using the developed multi-objective function. Few methods of optimization have been studied and found out that new application of Artificial Bee Colony (ABC) algorithm is most suitable.

2. To evaluate the impacts after installing the DG into the system by minimizing the real power loss, reactive power loss, and short circuit current, while maximizing the voltage profile.
3. To evaluate the effectiveness of Artificial Bee Colony (ABC) algorithm method by comparing with other method for example Particle Swarm Optimization (PSO).

1.4 Scope of Work

A good research produced when the work done within the scope. Thus, the first scope of work for this research is doing the literature review on the implementation of DG in distribution system. Other than implementation of DG, the problems of integration of DG also being review. The second scope of work is revisions on the multi-objective optimization method. After that, the work involves familiarization with the MATLAB software. This is because for this research, this software will be used for simulation the optimization method. Lastly, the scope of work is to determine the optimal DG location and sizing to get the effects on distribution system.

1.5 Major Contribution of Research

In this thesis, the contribution of the research involves several areas of optimization of DG in distribution systems.

1. Detailed review of past optimization methods used by researchers within a decade to find optimal placement and sizing of DGs in distribution system is presented with clear advantages and disadvantages of DG, types of DG used, objective functions, and constraints (Nur Fairuz, Azralmukmin, & Shamshul Bahar, 2012).

2. A multi-objective performance index based on the size and location of distributed generation (DG) in power system with difference preference of weightages is developed using technique of artificial bee colony algorithm (ABC) (Mohd Johan, Azmi, Rashid, et al., 2013).
3. An impact of power losses on the size and location of Distributed Generation (DG) in distribution system with difference number of population size is studied using technique of Artificial Bee Colony (ABC) algorithm and tested on standard IEEE 69 bus distribution system (Mohd Johan, Azmi, Zali, et al., 2013).
4. The impacts of power losses, short circuit currents, and voltage profile on the sizing and location of Distributed Generation (DG) in distribution system with multiple number DGs is analyzed using technique of Artificial Bee Colony (ABC) algorithm. The proposed algorithm comprises of mathematical formulation of all four objective functions to represent the objective functions in term of indices. All the indices have been combined into one multi-objective index, thus it is easier to analyze the results.
5. An ABC method and also the multi-objective optimization were developed in Chapter 4. By employing the ABC method as the main function in the simulation, the multi-objective index was reduced drastically compared to method using Particle Swarm Optimization (PSO).