VOLTAGE SAG MITIGATION BY OPTIMIZING THE LOCATION OF DISTRIBUTED GENERATION USING GENETIC ALGORITHM FOR THREE DISTRIBUTED GENERARION TYPES

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ABSTRACT

Voltage sag is considered to be one of the most serious hazards of power quality and can produce a harmful effect on electrical power system stability and most electronic devices such as personal computers, programmable logic controllers and variable speed drives. At the same time, Distributed Generation (DG) is playing an important role in power system and is widely used nowadays to improve grid performance and system flexibility and stability, and is predicted to play an increasing role in the future. Many researchers used one DG type for different purposes but few of them used two DG types to mitigate sag while none used more than two. The locations of DGs have to be optimized to improve the grid performance and to avoid degradation of power system networks using an optimization algorithm such as Genetic Algorithm (GA). The type of DG directly influences the penetration level and the placement of DG. GA is used to determine the optimum locations for three DG types namely synchronous, Wind Turbine (WT) and Photovoltaic (PV). The performance of power system for the three DG types is compared in terms of the optimum location. Effect of three DGs on voltage sag is studied in this thesis when connected to power system grid. This approach is applied on IEEE 13 bus system. Optimizing each type individually will become increasingly important because each type has different features and response. The locations of DG installation in this study are optimized using GA. GA is a capable optimization technique which is used to find the optimum solution of multi-objective functions; the objective function combines the overall number of buses experience voltage sag, the overall number of buses experience voltage drop, the overall number of buses experience voltage less than 10% and the overall number of buses experience voltage swell. Finally, it is found that the best location of each DG varies according to the type of DG and synchronous generator mitigates voltage sag better than WT and PV. Particle Swarm Optimization is used for comparative studies.

ABSTRAK

Voltan lendut dianggap sebagai salah satu masalah kualiti kuasa yang serius dan boleh memberi kesan merbahaya kepada kestabilan sistem kuasa elektrik dan kebanyakan peralatan elektrik seperti komputer peribadi, pengawal program logik dan penggerak berubah kelajuan. Pada masa yang sama, Generasi Teragih (DG) memainkan peranan penting di dalam sistem kuasa dan kini diguna secara meluas bagi memperbaiki prestasi grid dan fleksibiliti serta kestabilan sistem, dan dijangka akan lebih berperanan di masa hadapan. Ramai penyelidik telah menggunakan satu jenis DG untuk tujuan-tujuan berbeza, tetapi tidak ramai yang telah menggunakan dua jenis DG untuk mengurangkan lendut dan tiada seorang pun yang menggunakan lebih daripada dua jenis. Lokasi-lokasi DG perlu dioptimakan bagi meningkatkan prestasi grid dan mengelakkan gangguan jaringan sistem kuasa yang menggunakan algoritma optima seperti Algoritma Genetik (GA). Jenis DG secara langsung mempengaruhi tahap penetrasi dan penempatan DG. GA diguna untuk menentukan lokasi-lokasi optimum tiga jenis DG iaitu *segerak*, Turbin Angin (WT) dan *Photovoltaik* (PV). Prestasi sistem kuasa ketiga-tiga jenis DG dibandingkan atas dasar lokasi optimum. Kesan kesemua DG ke atas voltan lendut dikaji di dalam tesis ini apabila dihubungkan dengan grid sistem kuasa. Kaedah ini diaplikasikan ke atas system IEEE 13 bas. Setiap jenis dioptimakan secara individu yang menjadi semakin penting kerana setiap jenis mempunyai ciri-ciri dan tindaktalas berlainan. Lokasi pemasangan DG di dalam kajian ini dioptimakan menggunakan GA. GA ialah teknik pengoptimum yang baik yang digunakan untuk mencari penyelesaian optima bagi fungsi pelbagai objektif; fungsi objektik menggabungkan keseluruhan jumlah bas yang mengalami voltan lendut, keseluruhan jumlah bas yang mengalami kejatuhan voltan, keseluhuran jumlah bas yang mengalami voltan kurang daripada 10% dan keseluhuran jumlah bas yang mengalami voltan menggelembung. Akhirnya, didapati bahawa lokasi terbaik bagi setiap DG berbeza bergantung kepada jenis DG dan penjana kuasa *segerak* mengurangkan lendut voltan dengan lebih baik berbanding WT dan PV. *Particle Swarm Optimization* digunakan untuk kajian perbandingan.

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LIST OF ABBREVIATIONS

AHP	-	Analytical Hierarchy Process
ACO	-	Ant Colony Optimization
AC	-	Alternating Current
BESS	-	Battery Energy Storage System
CHP	-	Combined Heat and Power
DC	-	Direct Current
DEA	-	Data Envelopment Analysis
DG	-	Distributed Generation
DVR	-	Dynamic Voltage Restorer
EC	-	Evolutionary Computation
IDVR	-	Interline Dynamic Voltage Restorer
IGBT	-	Insulated Gate Bipolar Transistor
KW	-	Kilo Watt
Matlab	-	Mathematical and Programming Software
MADM	-	Muti-Attributes Decision Maker
MIMD	-	Multiple Instruction Multiple Data
MINLPs	-	Mixed-Integer Nonlinear Optimization Problems
MOSFET	-	Metal Oxide Silicon Field Effect Transistor
MW	-	Mega Watt
PC	-	Personal Computer
PSO	-	Particle Swarm Optimization
PSCAD	-	Power System Computer Aided design
PWM	-	Pulse Width Modulation
SC	-	Short Circuit
SMESS	-	Super Conducting Magnetic Energy Storage
STATCOM	-	Static Compensator
STATCON	-	Static Condenser
SARFIx	-	System Average RMS Variation
SIMD	-	Single Instruction Multiple Data
UPS	-	Uninterruptible Power supply

LIST OF SYMBOLS

c_1,c_2	-	Weighing coefficients in particle swarm
D_{ij}	-	Distance between two phases
F_{obj}	-	Objective function
$F_{fitness}$	-	Fitness function
$GMD_{\ abc}$	-	The geometrical mean diameter between phases
Gn	-	Light irradiance or nominal insolation
I_{PV}	-	The generated current due to light incident on PV
I_{SC}	-	Short circuit current
K_i, K_V	-	Current and voltage coefficient
K	-	Boltzmann constant
L	-	The transmission length in mile
n_{sag},x	-	Number of 1ph buses experience sag during fault at a specific bus
n_{drop},y	-	Number of 1ph buses experience drop during fault at a specific bus
n_{sag},z	-	Number of 1ph buses experience zero voltage during fault
n_{swell},m	-	Number of 1ph buses experience voltage swell during fault
N_{sag}	-	Overall number of 1ph buses experience sag
N_{drop}	-	Overall number of 1ph buses experience voltage drop
N_{zero}	-	Overall number of 1ph buses experience zero voltage
N_{swell}	-	Overall number of 1ph buses experience voltage swell
P	-	The wind power
q	-	Electron charge
ri	-	Resistance of the phase conductor per mile
R_s	-	Series resistance of series connected modules of PV
R_{sh}	-	Shunt resistance of the parallel connected modules of PV
s_i	-	Position of an agent in the swarm of birds
T_n	-	Solar cell nominal temperature
w	-	The weighing function in particle swarm
W	-	Electrical speed of the magnetic field
V^3	-	The wind speed cube
V_{sag}	-	Voltage sag at load bus
v_i	-	Velocity of agent in particle swarm
x1	-	Percentage of number of 1ph buses experience sag during fault
y1	-	Percentage of number of 1ph buses experience drop during fault
z1	-	Percentage of number of 1ph buses experience zero during fault
m1	-	Percentage of number of 1ph buses experience swell during fault

Z	-	Impedance of line
zii	-	Impedance of one phase
μ_1, μ_2	-	Mean of a variables
σ	-	Standard deviation
ρ	-	Air density in kg/m3

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Everybody does not agree with the use of the term power quality, but they do agree that it has become a very important aspect of power delivery especially in the second half of the 1990s [1]. There is a lot of disagreement about what power quality actual incorporates; it looks as if everyone has her or his own interpretation. Various sources use the term power quality with different meanings [1]. There are various terms of power quality; the common is the quality of power supply or voltage quality. What all these terms have in common is that they treat the interaction between the utility and the consumer or in technical between the power system and the load. Treatment of this interaction is in itself not new. The aim of power system has always been to supply smooth electrical energy to the consumers, what is new is the emphasis on this interaction.

The fact that power quality became an issue recently does not mean it was not important in the past. Utility all over the world have for decades worked on investment of what is known as power quality. And actually, even the term has been in use for rather long time already. The oldest mentioning of the term power quality is in 1969 in a study by U.S. Navy after specifications for the power required by electronic equipments [1]. This study gives a remarkably good overview of the power quality field, including the use of monitoring equipment and even suggested the use of static transfer switches. Several studies appeared soon after, which use the term power quality in relation to airborne power system. In 1970 high power quality is being mentioned as one of the aim of industrial power system design together with safety, reliable service and low initial and operating costs [1]. At the same time the term voltage quality was used in Scandinavian countries and in the Soviet Union, mainly with reference to slow variation in voltage magnitude [1].

Voltage sag is considered as one of the most serious hazard of power quality problems and can lead to significant damage in sensitive devices [2,3]. It is defined as a short reduction in RMS (Root Mean Square) voltage magnitude and can be produced due to short circuit, wind contamination on electrical insulator and starting of large motors such as large induction motors. The sag phenomena ranges from 2 cycles up to 10 cycles or 200 ms and its magnitude ranges from 0.1-0.9 [2,3]. Induction motors is accounted as 60% of the total electric load and is considered an important source that generates voltage sag [4] besides all types of faults generate sag.

Many solutions are proposed to mitigate voltage sag such DVR (Dynamic Voltage Restorer) as series and shunt configuration to inject active and reactive power to compensate the voltage [3,5]. Other solution is placement DGs (Distributed Generations) in the electrical network due to a lot of benefits such as improving protection reliability [6] and the voltage profile, reducing losses [7,8] and to mitigate voltage sag and most of them are environmentally friendly [2] .

1.2 Problem Statement

Voltage sag phenomena frequently occurs in power system and it produces a severe effect in quality of the power system in-addition to the harmful damage to most of electronic devices such as PCs, PLCs and Variable Speed Drives [1], so it is strongly helpful to propose solutions to mitigate this phenomena. Distributed Generation is used to mitigate voltage sag but the location of DG must be correctly defined and optimized using an optimization technique such as Genetic Algorithm

[2,8] so that the DG improves the performance of the electrical network not degrading the performance. Furthermore, different types of distributed generations are widely used nowadays due to lot of benefits but each of them has its own characteristics and response in the electrical network [2,7,9]. So that, it is highly important to place each type at the correct location to avoid the bad performance of the electrical network grid and these problems could lead to serious damage in the power system. For example, if the number of buses experience voltage sag increased when DGs are inserted in the electrical network grid increased than the case without DGs or there is no optimum DG location then more and more devices and equipments connected to these buses will exposed to serious damage and lot of control systems may breakdown in-addition to many operations controlled by the sensitive devices may stopped or blocked. All these problems lead to a great amount of financial loss. The failure and malfunction of sensitive equipments or the process control to the buses exposed to voltage sag lead to substantial financial losses. The end users are concerned to find such a method to characterize voltage sag and estimate accurately as possible the expected number of production interruptions then techno economical analysis will be useful to determine the estimated financial loss [4]. The problem statement summary is briefly provided in points 1 to 3.

1. Voltage sag produces severe effect on electrical network grid and harmful damage on sensitive device and can be mitigated using distributed generation. Electric network to be selected to actually, represents the real distribution network is highly requested
2. Distributed generation must be located at the optimal location for better mitigation voltage sag. And not to increase the number of buses experience voltage sag then more sensitive loads and electronic devises are exposed to damage. Incorrect placement of DGs in distribution system will generate problems in power quality such as voltage sag.
3. Different types of distributed generation are widely used due to improving the grid performance and environmental purposes and each type has its own features and impact on the electrical grid [8,9]. So, it is highly important be located at the correct location for better mitigation of voltage sag.

1.3 Research Objectives

The objectives of the research are:

i. To develop GA optimization technique to identify the optimal location for DG installation.

ii. To develop model for IEEE 13 bus system for applying the proposed approach.

iii. To develop three models for three types of DG to be used in the proposed approach.

iv. To prove that the optimum location of the three types of DGs varies according the optimum location.

1.4 Research Scope

This research focuses on three major problems voltage sag mitigation, optimizing the location of distributed generation and studying the impact of each type and optimizing their locations.

i. Voltage Sag mitigation is highly important to improve the network performance by reducing the number of buses experience voltage sag then many loads will be protected by introducing distributed generation in the grid but selecting the best location must considered because not all the location improve the grid performance.

ii. Optimizing the location of DG is highly appreciated because some location can degrade the performance of the grid, this can be achieved by choosing suitable method to optimize the DG locations, besides some locations improve the performance but these locations are not the best location then finding the optimum one is very important using an optimization technique.

iii. Many types of DGs are widely used nowadays due to several reasons such as the environmental purposes, the economical and financial purposes by reducing the large investment, improving the system reliability, losses reduction and as in this research mitigating voltage sag. In this study three DG types are connected individually in the electrical network and are optimally located, these types are synchronous generator, wind turbine and photovoltaic. Different DG type at different time.

1.5 Significance of Study

Based on the previous studies in voltage sag mitigation and distributed generation, most of researchers used optimized DG location to reduce losses and improve voltage profile. Other researchers mitigate sag by introducing DVR [3,18] (Dynamic Voltage Restorer) and STATCOM (Static Compensator) [20,22], the authors focused on the control procedure and used battery banks with limited energy stored not to use DGs or optimize the distributed generation . Another author used genetic algorithm optimization technique to mitigate voltage sag [2] but with many dropouts and disadvantages such as using combination of single phase DG and three phase DG which is not realistic to propose single phase DG with approximately 500 KW. In-addition the researcher used only general type of DG, the researcher applied three phase short circuit to simulate voltage sag too while single phase short circuit is frequently occurs, almost 80% [1], so both of them should be applied to the system. All the previously mentioned limitations are recovered in this study, this leads to better results and improved solutions. Other authors used different types of optimization techniques to reduce losses and improve the voltage profile [3,5,8,9] and many others in literature review not to mitigating voltage sag. Based on the literature, the majority of authors divided into two groups, some of them used DVR and STATCOM to inject active and reactive power at specific location. The others optimized DGs locations and size to reduce losses and improve voltage profile.

i. Since three phase and single phase short circuits are considered in this study than only three phase as proposed in the model conducted by the previous researchers. Then better results are achieved by improving the model proposed by the previous researchers then more loads are protected against damage.

ii. Furthermore, three phase DGs are used in this study not single phase DG as introduced in the model of the previous researchers. Since the proposed size of each DG is 500 KW (according to the DG penetration percentage target in US is 25% [2]), this is not realistic to propose large power DG at single phase.

iii. The objective function proposed by previous researchers is modified by excluding the repeated items such as the overall number of buses experience voltage sag and $SARFI_{90}$ because both are representing similar events.

iv. Proofing that the optimum location varies according to the type of distributed generation by introducing three different types of DGs, these types are synchronous generator wind turbine and photovoltaic.

v. Integrating the three different DG types in electrical network grid based on optimum location to mitigate the sag phenomena which is not considered till now.

vi. This research reduced the search space by proposing reference or threshold value in genetic algorithm for all solutions not just comparing the solutions by the others.

vii. This research protects sensitive devices from damage by reducing the number of buses experiences voltage sag and protects control process in industry from stoppage or blocking which leads to saving a lot of money.

viii. This research increasing the penetration level of renewable energy resources then reduction the emission of greenhouse gases.

1.6 Thesis Outline

This thesis consists of five chapters and organized as follows:

Chapter 2 covers the literature review of various distributed generation penetration targets. Reviewing the previous study methods to mitigate voltage sag and reviewing the proposed optimization techniques in these studies. Literature review of the various DGs used to mitigate the voltage sag.

Chapter 3 presents the research methodology that used to formulate and model the genetic algorithm technique to allocate the distributed generation at the optimum location and shows the flow chart of the optimization procedures.

Chapter 4 discusses results and analysis for the three types of distributed generations including their impacts on voltage mitigation and data validation using another optimization technique.

Finally, Chapter 5, conclusion of the work done in the thesis and recommendation for future work are presented.

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