OPTIMAL PLACEMENT AND SIZING OF DISTRIBUTED GENERATION UNIT BY LOADING MARGIN APPROACH FOR VOLTAGE STABILITY ENHANCEMENT

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A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical-Power)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

JANUARY 2015

Thanks to my beloved husband

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to my supervisor, Prof. Ir. Dr. Mohd Wazir Mustafa, for his guidance, encouragement, support, and constructive suggestions throughout my study. Without his understanding, this project report would not have become a reality.

To my lovely daughter, *Wan Safiyyah Irdina* her joy makes me feels relief and complete family. Thank to my siblings and parent in law for their encouragement and moral support. Finally, my deepest thanks go to my mother *Hajah Zaimah Said* for her unconditional love, understanding, and support.

ABSTRACT

In the recent times, as the concern of continues and huge energy demand worldwide anticipated for future will be unrealistic if only governed by the central generation to transfer the huge power over the long distance. Parallel reason due to the increasing of interest on the alternative energy such as solar, wind, hydro, biomass, geothermal, tidal, wave and etc., the number of studies on integration of distributed resources to the grid has rapidly increased. Distributed Generation (DG) was known as generation which comprise of distributed resources and also local supply that close to the consumer or distribution network has the capability on aforementioned scenario. Further with the fluctuate costs of fuel and rigorous environmental regulations are the reasons for the construction of large power stations to meet rising energy demands economically unattainable. The penetration of DG presents a new set of conditions to distribution networks. One of the advantages of it is the ability to provide voltage support for better system stability. In other word it is like the reactive compensation system. However during DG installation, it may encounter other technical problem. One of the problems is improper placement of DG may actually increase the network losses and impact the voltage profile of the system. The DG problem can be solved by applying Loading Margin and Analytical approaches based on Newton-Raphson power flow to optimize the placement and size of DG and to enhance the voltage stability margin of power system to mitigate the risk of voltage collapse. There are three test system from IEEE 6-bus, IEEE 14-bus and IEEE 30-bus for the verification on the effectiveness of the methods applied. This project report concludes with appropriately locate and size of DG is the great options for voltage stability enhancement and system reactive power compensation.

ABSTRAK

Sejak kebelakangan ini, kebimbangan berterusan dan permintaan tenaga yang besar di seluruh dunia dijangka untuk masa depan akan menjadi tidak realistik jika hanya dikawal oleh generasi pusat untuk memindahkan kuasa besar dari suatu jarak yang panjang. Penjanaan teragih yang dikenali sebagai generasi yang terdiri daripada sumber yang diagihkan dan juga bekalan tempatan yang hampir kepada rangkaian pengguna atau pengedaran mempunyai keupayaan untuk senario yang dinyatakan di atas . Lanjutan mengenai kos bahan api yang tidak menentu dan peraturan alam sekitar yang ketat juga merupakan satu faktor utama bahawa teknologi penjanaan teragih diperlukan atas sebab penjanaan kuasa pusat tidak boleh dicapai dari segi ekonomi . Penyambungan penjanaan teragih membawa ciri baru kepada sistem rangkaian pengedaran dan juga memberi kelebihan kepada sistem di mana ia di pasang. Salah satu kelebihan ia adalah keupayaan untuk menyediakan sokongan voltan untuk kestabilan sistem yang lebih baik . Dengan kata lain ia adalah seperti sistem pampasan yang reaktif . Walau bagaimanapun semasa pemasangan penjanaan teragih ini, ia mungkin akan menghadapi masalah teknikal yang lain. Masalah yang paling kritikal dialami adalah lokasi yang tidak sesuai untuk penjanaan teragih sebenarnya boleh meningkatkan kerugian rangkaian dan kemudiannya merosot corak voltan sistem kuasa. Dalam projek ini , masalah penjanaan teragih boleh diselesaikan dengan menggunakan muatan margin dan Analisis pendekatan untuk mengoptimumkan lokasi dan penentuan saiz untuk penjanaan teragih dan secara tidak langsung menaikkan margin kestabilan sistem kuasa untuk mengurangkan risiko kejatuhan voltan . Terdapat tiga model sytem uji yang terdiri dari IEEE 6- bas , 14-bas dan 30-bas untuk pengesahan pada keberkesanan kaedah yang digunakan . Hasil prestasi kedua-dua kaedah simulasi menggunakan perisian Power World telah membuktikan dengan lokasi dan penentuan saiz penjanaan teragih yang tepat mejadikan ia pilihan yang hebat untuk meningkatkan kestabilan voltan dan sistem pampasan kuasa reaktif.

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DG	-	Distributed Generation
PV	-	Power-Voltage
QV	-	Reactive-Voltage
HV	-	High Voltage
MV	-	Medium Voltage
LV	-	Low Voltage
PSO	-	Particle Swarm Optimization
CPF	-	Continuation Power Flow
MA	-	Modal Analysis
SOFC	-	Solid Oxide Fuel Cell
Pf	-	Power Factor
DC	-	Direct Current
AC	-	Alternative Current
SHP	-	Small Hydropower
CHP	-	Combustion Heat and Power
CCGT	-	Combined Cycle Gas Turbines
GT	-	Gas Turbines
ICE	-	Internal Combustion Engine
LCZ	-	Load Concentration Zone
AEMC	-	Australian Energy Market Operator
RE	-	Renewable energy
SSSI	-	Steady State Stability Index
PQ	-	Real Power-Reactive power

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CHAPTER 1

INTRODUCTION

1.1 Background

In the past 4 years, the Survey of Electricity Demand Management was provided a detailed about scale of Distributed Generation in Australia. According to a survey, Australian Energy Market Operator (AEMO) approximated that on February 2012, the sums up capacity been set up was 1450 MW and observed that by 2020 the demand expected to reach 5100 MW and by 2031 it forecasted to install close to 12 000 MW[1]. The huge capacity demand forecasted for future will be unfeasible if only governed by the central generation to supply the huge power over the long distance. Furthermore, with the instable price of fuel and concern on the global warming impact was brought DG more established as the attractive alternative instead of central generation to overcome the problems [3].

Distributed or Embedded generation (DG/EG) commonly defined as generation located close to the distribution network and linked closely to the consumer instead of far distance of central plant [2]. Currently, for certain countries the policy of energy conservation progressively promoted the alternative energy sources, namely solar, wind, biomass, hydro, or nuclear. The energy that generated by DG is cover variety of technologies such as micro-turbines, gaseous fuel, solar, wind, biomass and fuel cells [3].Typically, DG can be classified from micro to large scale which is range up from less than 2 kW and greater than 5MW and the rating also can be available up to 50MW, especially from heavy industrial scale use combustion heat and power (CHP) or co-generation plants [37]. Table 1.1 illustrates the classification of DG capacity requirement from the source of Australian Energy Market Commission (AEMC).

Table 1.1: AEMC classification of distributed generation units [37]

Classification	Technical definition	Typical installation
Micro	Less than 2 kW and connected to low voltage network	Rooftop solar PV
Mini	Greater than 2 kW and up to 10 kW single phase or 30 kW three phase	Fuel cells; combined heat and power systems
Small	Greater than 10 kW single phase or 30 kW three phase, but no more than 1 MW	Biomass, small hydro
Medium	Greater than 1 MW but no more than 5 MW	Biomass, hydro, local wind generating units
Large	Greater than 5 MW	Co-generation, hydro, solar thermal

The importance of DG able to produce both real and reactive power and parallel boost up the power system efficiency by minimizing system losses as well as function as contingency reserves to the network. The new transmission line also may not require since DG schemes are grid independent thus distribution facilities consequently decreasing overall infrastructure costs. Nevertheless, there are some critical factor needs to be considered prior connecting DG to the distribution system, especially location and size as well as characteristic of the DG itself. If DG not properly handled, it may lead to high losses and affect the voltage regulation of the power system. DG characteristics have specified that it is privately own and of course the energy sources might be inconsistent such solar, wind, tidal and etc., the above-mentioned conditions will not be promising to meet the requirement [6].

In the last 5 decades, the advance and innovative electrical power systems remain in challenging mode and risky transferred power from high voltage to low voltage and normally intended to activate without any back up generation [5]. DG insertion expressively improves power flow and voltage profiles at both end user and also distribution station. One of the advantages of DG to be discussed in this project is the ability of DG to provide voltage support for better system stability [4]. There were many researches have been done by introducing multiple of DG placement algorithms using analytic or experimental approaches [7]. Only a few works have been focused on optimizing the effect DG in voltage stability improvement.

In many researches done, there are numerous techniques offered for DG allocation for instance in primary feeder which employed CPF method to classify the weakest bus prone to voltage instability [8]. The other technique applied modal analysis discussed by B. Gao, G. K. Morrison, and P. Kundurl [9], which gives the idea of proximity to voltage collapse. In [10] optimal DG allocation has been identified, which is based on the modal analysis and compared the effectiveness of the method to the CPF method. Application of different optimization techniques in DG placement problem were also discussed in literature. Genetic algorithm also one of the methods introduced in [11] and DG placement by using Particle Swarm Optimization (PSO) algorithm, based on Continuation Power Flow and Modal Analysis [7].

1.1.1 Conventional Power Systems Concept

At the first level, bulk power generated in centralize power station which typically positioned in rural area. The second level is transmission network system that operated at higher voltage level. And the final stage is electricity distribution to customers. Distribution stage is vital part of power transfer for determining power quality[16]. The power demand is continuously growth especially in develop countries, therefore the generation of it also must be parallel to meet the demands. Figure 1.1 shows the conventional concept of energy flow in power system. The conventional concept consist of four level and currently only level 1 is highly concentrate. This concept were economically unfeasible since the power flow only in in one way direction and power delivered via a large passive distribution [17].

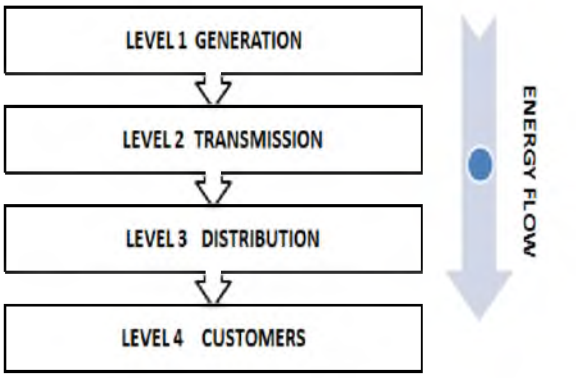

Figure 1.1: Conventional concept of energy flow [17]

1.1.2 Modern Power Systems Concept

Many years ago, advance in technologies totally changed the structure of power system [17]. The modern concept basically focus on distribution instead generation. Figure 1.2 demonstrates the modern concept of the energy flow. The new concept having two additional level compared to conventional which are distribution and distribution generation. The characteristic of new concept were no longer in passive flow but upgrade to active flow whereby both generation and load also can supply the power to meet the demand requirement.

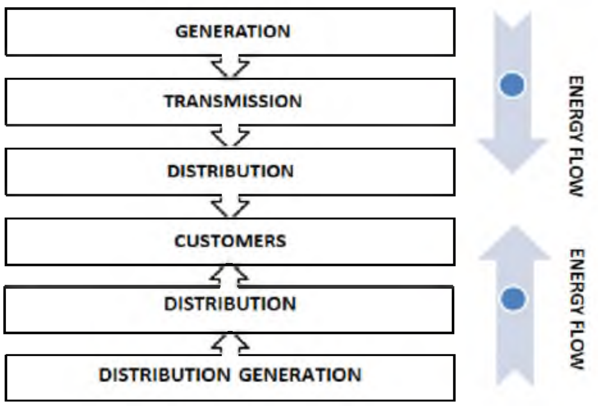

Figure 1.2: Modern concept of energy flow [17]

1.1.3 Distributed Generation Technologies

Recently, advance in electricity extraction from many energy sources has create more advance DG technologies. The main energy source used by the DG will determine the output characteristic and the required grid connection types. Two classification of DG defined, either dis-patchable or non dis-patchable based on controllability of energy source to obtain desired DG output power. In contrast, the DG is considered as non dis-patchable, if controlling energy source is not possible, which normally the source is based on renewable energy that is not consistent.

There are various of DG technologies can be attached directly to the grid via rotational support to synchronous AC generators and induction generators or utilizing inverter system to convert DC source to AC [6][19][20]. DG with rotational support to synchronous generator usually comes with thermal based energy for steam generation, while DG that utilized power electronic converters extensively applied in solar PV generation, fuel cell, micro-turbines, and wind power.

1.1.3.1 Micro-Turbines

Micro-turbines were built in small scale and most of the time used in transportation applications. The main advantage of it is extreme high rotational speed and can generate high frequency ac power. The conversion of high frequency is executed by power electronic device. The rating power of micro-turbine is ranges from 30 - 200 kW. The noise generated from micro-turbines using natural gas is better than turbine [23]. The short track record and expensive price make it worse than combustion engine.

1.1.3.2 Wind Power

Currently many countries especially German, Spain and Denmark 78% have deployed Wind energy as alternative to fuel and keep growing. Total about 48,500 MW wind power size developed in Europe [26]. In every country worldwide, all are hunting the unpolluted power energy to reduce environmental effect [25]. The fluctuation and inconstant of wind speed are the main barrier to achieve high power quality. It is known that wind power production is natural forces bases, incapable to support power on demand. Yet, the grid must deliver per capacity requirement. Another key challenge of wind source is the location of the plant is further away to the transmission line.

1.1.3.3 Solar Thermal

The source of solar energy mainly produced from sunlight and depends on the geographical and climate factor of the area. The high storage of solar energy can be generated when solar radiation is high. Solar thermal process quite simple compared to photovoltaic system in term of heat collection [22]. This process make solar thermal is economically feasible and the ranges available from small kW up to 100 MW [16]. Recent year, encouragement on the alternative energy system is arising greatly which promoted the thorough study on the renewable energy source [17]. Solar thermal also can be made hybrid with grid utility for energy cost savings.

1.1.3.4 Fuel Cell

Fuel cells develop primary from hydrogen source and the behavior of it are comparable with battery and being recharged continuously. Basically it involves the chemical reaction from air and oxygen to generate electricity [9]. Fuel Cell DGs have many merits, compared to other power plants such as high productivity, zero pollution impact and flexible modular structure. Fuel Cells have the benefit when integrated with DG which positioned close to the consumer. Generally, Fuel Cell

DGs are connected locally by consumers to improve the voltage profile and active power injection. When compared to other renewable sources like wind and solar, the certainty in availability of power from Fuel Cell DG is extra advantage which improves the power system stability and reliability [29]. Figure 1.3 illustrates the schematic of fuel cell.

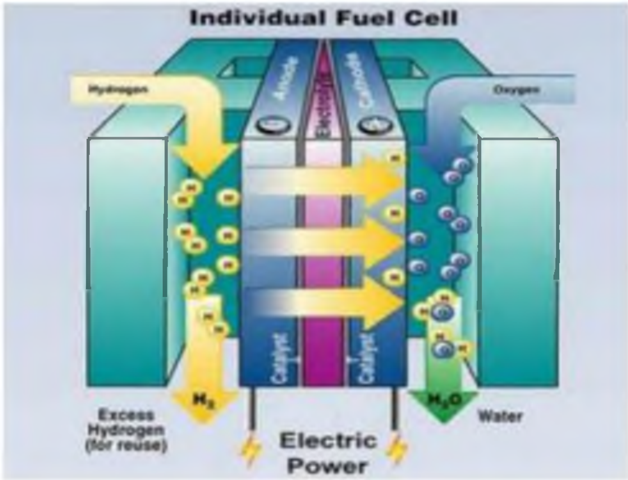

Figure 1.3: Schematic diagram of a fuel cell [29]

1.1.4 Impact of Distribution Generation on Power Grid

Attaching a DG to existing distribution system will impact the operation in the network. The new performance is depending on the DG itself and the size. The effects will be explained detail in the next sub section.

1.1.4.1 Power Flows

The positive outcomes of DG divert the power flow and the system is no longer a passive circuit supplying loads. Since the power can supply from both generator and load, the system is actually transform to active circuit [6]. In this scenario, the generator transfers excess power to all connected loads. The excess power is relocated to a higher voltage system.

1.1.4.2 Network Losses

The primary concern of DG installation is feeder losses. Allocating a DG is crucial and required depth understanding, analysis and simulation in order to improve network operations [15]. Proper action must be determined to troubleshoot DG problems or else it results in losses. A correct allocation of DG able to decrease losses, but, inappropriate allocation may surplus losses [15], at the same time there is possibility to obtain free available capacity to transmit power and minimize the equipment load. As compared to capacitor bank, DG is capable of providing both active and reactive powers, hence, slight dispersion of optimally located DG that has relative output a tenth of feeder demand will provide substantial reduce in losses[15].

1.1.4.3 Steady Sate Voltage Variations

For the network impedance, normally resistance of the synchronous is negligible as reactance is very high compared to resistance, reactive power has direct relationship with voltage level for same bus. If an adjacent load absorbs the output from DG then the effect on the distribution network voltage is likely to be beneficial. Nevertheless, if it is essential to transfer the power via the network then the steady-state voltage fluctuation may unpleasantly become uncontrolled [9].

1.2 Problem Statement

Large interconnected power system cannot escape from power stability issue. Power system considers in condition of voltage insecure whenever the voltage magnitude uncontrollable drop example progressive in consumer demand. An abnormally high or low voltage also may occurs when reactive power resource could not afford to meet power system requirement, reactive sources (generators) are too far from load centers, transmission line loading is too high, generator terminal voltages are too low, inadequate load reactive compensation and others. Without any action taken on this problem the worst case, the system may lead to voltage collapse.

Distributed Generation (DG), which commonly located in distribution system, can solve this problem. Nevertheless, unplanned application of individual DG might cause other technical problems. One of the problems is improper placement of DG may actually increase the network losses and impact the voltage profile of the system. The strategically allocate and sizing DG only then can effectively improve the voltage stability issue.

1.3 Objectives

There are two main objectives of this project which are to optimize the placement and sizing of DG and enhance the voltage stability margin of power system in order to mitigate the risk of voltage collapse with DG. The sub-objectives below needed in order to accomplish the main objectives above:

(i) To identify the candidate or weakest bus prone to voltage stability
(ii) To gain the high efficiency by reduce the system losses
(iii) To increase active power margin and reactive power margin with different type operation mode of DG

1.4 Scope of Work

This project is covered static method to analyze steady state voltage stability using Newton-Raphson power flow algorithm with aid of PowerWorldTM Simulator. This project also introduced main concept of voltage stability using loadability margin approach to approximate voltage collapse in the power system. PV-QV curve method is executed to define the collapse margin of the power system at weakest bus. The limitation of this project using P-V curve method is only consider the upper part of the curve. Another method based on analytical based algorithm also is applied to optimize the location of DG. The system modeled will be evaluated to validate and tested the applied method are working well to achieve the objectives. The operation mode of DG for all three test system in this project only considers when DG operates with unity power factor [34].

1.5 Report Organization

This project report contains of six chapters. Chapter 1 will explain about the current energy status in the world and interest of DG as well as the problem statement, objectives and scope of this project. Chapter 2 is about the literature review from few authors on the techniques used for DG placement and voltage enhancement as well as how to optimize DG in distribution system. Chapter 3 will describe about the modeling of system and DG and theory of voltage stability in power system and voltage indices to be used in order to approximate the voltage instability issue. Next Chapter 4 is about the methodology proposed to accomplish the main objectives of this project. Chapter 5 will present the result and discussion of the methods applied. Chapter 6 will provide the conclusion and future works to further improve the gap found in current technique.

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