

VOLTAGE STABILITY ASSESSMENT FOR DISTRIBUTED GENERATION IN  
ISLANDED MICROGRID SYSTEM

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For my beloved mother and father

For my lost brother '**MOHAMED**'



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## ABSTRACT

The increasing energy demands are stressing the generation and transmission capabilities of the power system. Distributed generation (DG), which generally located in distribution systems, has the ability to meet some of the growing energy demands. However, unplanned application of individual distributed generators might cause other technical problems. The microgrid concept has the potential to solve major problems arising from large penetration of DG in distribution systems. A microgrid is not a forceful system when it is compared to a power system. This project proposes a simulation approach to study voltage stability index (VSI) and voltage stability analysis in microgrid system for the improvement of the dynamic voltage stability in a microgrid in case of the dynamic voltage insufficiency. A model of IEEE-14 Bus System has been presented as a case study of an islanded microgrid system. This project also presented line voltage stability index analysis which accurately performs voltage stability analysis at each transmission line and precisely predicts voltage collapse on power systems. A formula to calculate VSI has been derived and applied on two cases on the system. To show the effectiveness of the proposed voltage stability analysis method, this approach is implemented in a microgrid test system (14-bus, 20 lines) in PSAT which is a MATLAB toolbox environment. The test system has four diesel DGs and a wind turbine connected with eleven constant loads. The dynamic simulation of the test system is carried out for various types of disturbances. Islanded mode of operation is considered in this study. Fast Voltage Stability Index (FVSI) and voltage stability analysis have been successfully implemented and analysed.

## ABSTRAK

Permintaan tenaga elektrik yang semakin meningkat telah memberi tekanan kepada sistem kuasa dari segi keupayaan penjanaan dan penghantaran tenaga. Penjanaan teragih (DG), yang terletak dalam sistem pengagihan, mempunyai keupayaan untuk memenuhi permintaan tenaga yang semakin meningkat. Walau bagaimanapun, penggunaan yang tidak terancang oleh penjana teragih tunggal mungkin menyebabkan masalah teknikal yang lain. Konsep mikrogrid mempunyai potensi untuk menyelesaikan masalah besar yang timbul daripada penembusan besar DG dalam sistem pengagihan. Mikrogrid bukanlah satu sistem yang secara paksa apabila ia dibandingkan dengan sistem kuasa. Projek ini mencadangkan pendekatan secara simulasi untuk mengkaji indeks kestabilan voltan (VSI) dan analisis kestabilan voltan dalam sistem mikrogrid bagi penambahbaikan kestabilan voltan yang dinamik dalam mikrogrid sekiranya terdapat kekurangan voltan yang dinamik. Model 14 bus sistem IEEE telah dikemukakan sebagai kajian kes bagi sistem mikrogrid yang terpulau. Projek ini juga membentangkan analisa indeks kestabilan voltan talian yang secara tepat melaksanakan analisa kestabilan voltan pada setiap talian penghantaran dan secara tepat juga meramalkan keruntuhan voltan pada sistem kuasa. Satu formula untuk mengira VSI telah diterbitkan dan digunakan pada dua kes kajian di dalam sistem. Untuk membuktikan keberkesanan kaedah penganalisan kestabilan voltan yang dicadangkan, pendekatan ini telah dilaksanakan dalam sistem ujian mikrogrid (14 bus, 20 talian) di dalam PSAT yang merupakan sebuah toolbox dalam persekitaran MATLAB. Sistem ujian ini mempunyai empat DG diesel dan satu kincir angin yang disambungkan dengan 11 beban malar. Simulasi dinamik sistem ujian dijalankan bagi pelbagai kes gangguan. Operasi mod terpulau telah dipertimbangkan dalam kajian ini. Analisis Indeks Kestabilan Voltan Pantas (FVSI) dan kestabilan voltan telah berjaya dilaksanakan dan dianalisis.

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**LIST OF SYMBOLS AND ABBREVIATIONS**

$\delta$	-	Angle difference between sending and receiving buses
DG	-	Distributed generation
MG	-	Microgrid
P	-	Active power
PQ	-	Load Buses
PV	-	Generation Buses
Q	-	Reactive power
S	-	Apparent power
X	-	Line reactance
AVR	-	Automatic Voltage Regulator
FVSI	-	Fast Voltage Stability Index
PSAT		Power System Analysis Toolbox
VSI	-	Voltage Stability Index

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## CHAPTER 1

### INTRODUCTION

#### 1.1 Project background

Since the increase of power demand is stressing the transmission and generation system capabilities that might lead to frequent power outages, engineers around the world are developing different methods to improve the reliability, protection and security of the electrical power system. These frequent power outages due to the overloaded grid will cost millions of Dollars per year. Newer technologies authorize the production of electrical energy in an efficient, reliable and secure way, causing fewer damages to the environment. One of the significant solutions is to build generation closer to the power consumption areas. This is known as distributed generation (DG) [1]. The reforms in distribution sector have given major scope for employment of DG resources which will boost the system performance. Usually, the main concentration of generation stations is near to the load or biggest demand of power. If this condition does not happen and the load is far away from the generation stations, consumers will face outage problems and drop in voltage as well.

The advantages of distributed generation can be only granted 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. Voltage profile is defined as the change in the voltage of the system as the load changes which are shown in the Figure 1.1 [2]- [3].

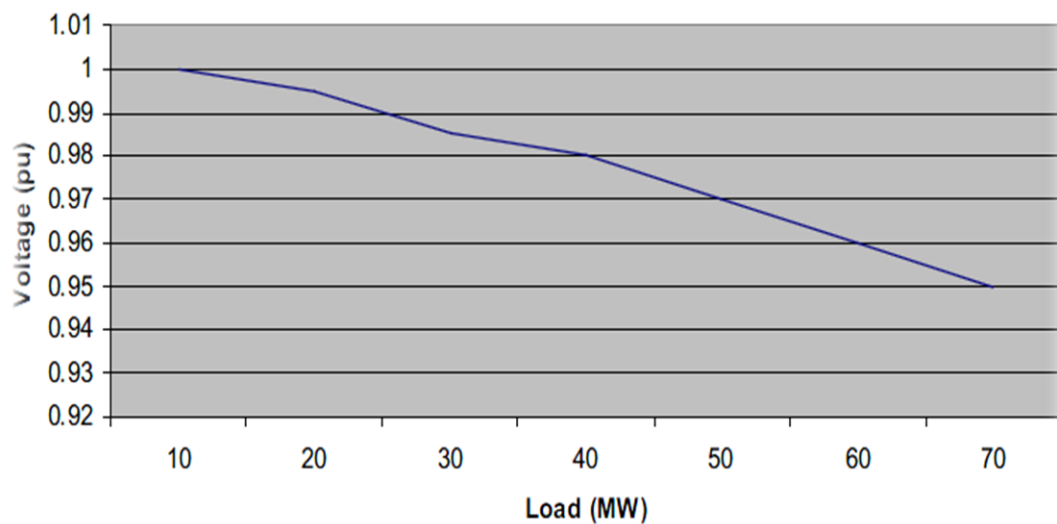


Figure 1.1: Voltage and loads characteristic

A microgrid has on-site power generation and operates as a single controllable unit in parallel to the main grid. During power outage or any disturbance, microgrids can island themselves and retain power availability, avoiding blackouts and lost productivity. Although microgrid system has advantages, it also causes some problems. Microgrid stability problem is the major issue can be faced. This issue may lead the over or under voltages and frequencies deviations as well [4]. There are three main categories of power system stability which are voltage stability, frequency stability and rotor angle stability. Figure 1.2 illustrates further on voltage stability category.

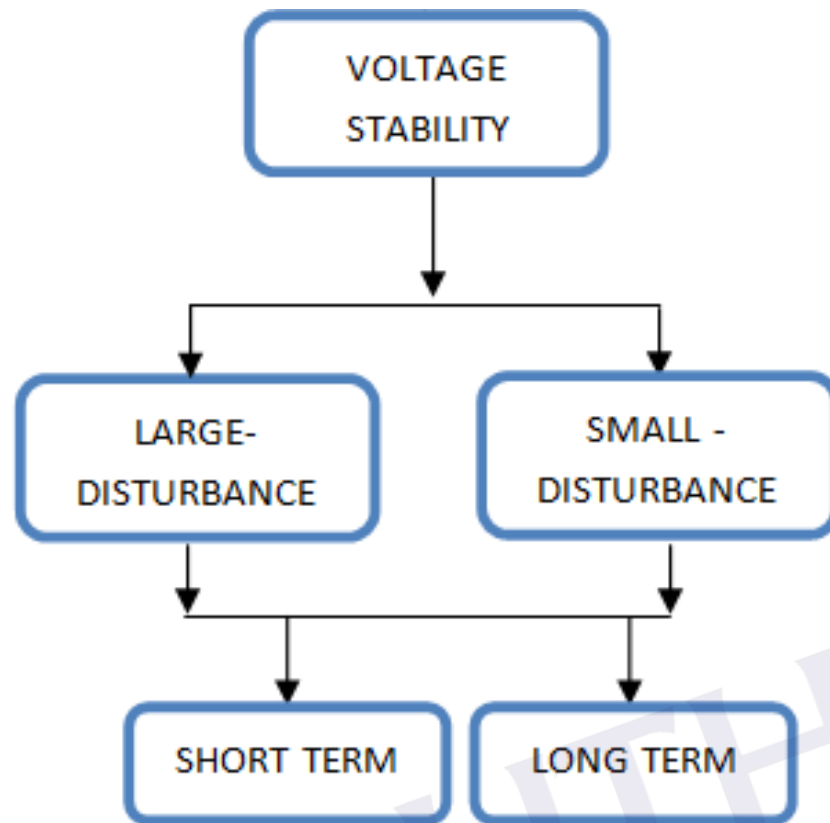


Figure 1.2: Classification of voltage stability

## 1.2 Problem statements

The large interconnected power system made the electricity distribution reliable and economical. This interconnection of multi areas exposed the entire system to be more vulnerable to various stability problems [5]. This problem is not only due to the complexity of the interconnection in a system but also due to the intermittent distributed generations and integration of other emerging technology in order to meet exponential growth of load demand beyond thermal and electrical limit of the system. The planning and operation using new ideas and new methods in solving challenging problems need to be done in fast and dependable mode. High penetrations of DGs affect the steady-state and the dynamics of the distribution system. These impacts mostly consist of power quality disturbances for customers and electricity suppliers such as voltage regulation, voltage flicker, harmonic distortion and short circuit level.



However, voltage instability problem in a microgrid network is one of the most harmful disturbances on power system. A microgrid is not a robust system when compared to a grid system. Hence, additional control strategies should be implemented for a successful operation of a microgrid. Most of the DGs (such as wind, fuel cells, PV arrays, microturbines) cannot produce reactive power. Thus, they cannot support voltage stability during dynamic state. Proper voltage controllers should be designed to maintain the voltage stability of the microgrid.

Therefore, it is necessary to consider voltage stability constraints for planning and operation of distribution systems. In addition, this can be simplified by studying islanded microgrid system to see the influence of distributed generation on the system.

### 1.3 Project objectives

The main objective of this project is to present a simulation approach to study voltage stability in a microgrid system.

The following are the measurable objectives of this project:

- i. To model microgrid and DG system for voltage system stability studies.
- ii. To analyse the impacts of DG penetration on voltage stability.

### 1.4 Project Scopes

- i. This project is only focus on the modelling of an islanded microgrid with different types of DGs (wind and diesel).
- ii. A single line diagram of the standard IEEE 14 bus test system will be used as a case study.
- iii. Three disturbances on the microgrid which are load switching, partial line outage, and three phase short circuit fault will be simulated by using Power System Analysis Toolbox (PSAT), which is a MATLAB toolbox.

## CHAPTER 2

### LITERATURE REVIEW

In the following section, a detailed literature review on the voltage stability, distributed generation concept, microgrid stability problems, and voltage stability index are introduced. Section 2.1 describes a general idea of voltage stability. Section 2.2 discusses the distributed generation. The concept of microgrid is discussed in 2.3. Some previous studies are presented in 2.4. Power-voltage (PV) analysis is defined in section 2.5. Literature on voltage stability index (VSI) is presented in 2.6. Section 2.7 discusses PV Curve of a two-bus system. Finally, standard Newton-Raphson method is highlighted in 2.8.

#### 2.1 Concept of Voltage Stability

Voltage stability analysis is currently one of the most significant fields of research in the power systems area. In the last few years, many contributions to a better knowledge of the various aspects of voltage problems have been reported in the literature, where the problem has been explored from many different points of view [6]. Voltage collapse in addition, has been an active subject of research for years [7]-[8].

In general, power system stability is the ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after

being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact [2].

Voltage stability is the ability of a power system to maintain steady state voltage at all buses in the system under normal operating condition and after the occurrence of a disturbance [9]. The main factor contributing to voltage instability is usually the voltage drops that limit the capacity of transmission networks to transfer power between buses. Increased voltage drops could be associated with the change of rotor angles. Voltage instability occurs when load dynamics try to restore power consumption beyond the capability of the transmission system and the connected generation [9].

## 2.2 Distributed generation

Various technologies are being developed to generate electrical energy close to the consumption areas (load centers). This modality is called generation IN-SUIT, disperse generation or distributed generation [10]. Distributed generation is a small scale generation or storage of electrical energy at the customer side, which permits the option of selling and buying energy to and from the electrical system, while taking advantage of the maximum efficiency of energy production [10]. Generally, the capacity range of distributed generation is between 100 kW and 10 MW. Figure 2.1 shows the differences between centralised generation and distributed generation.

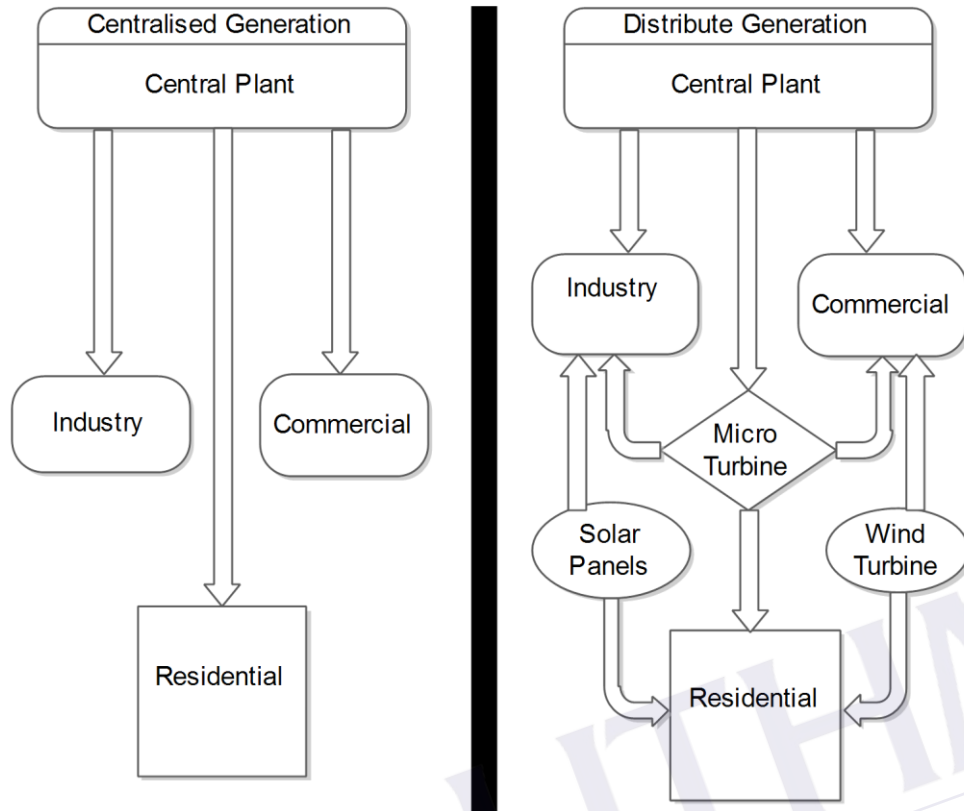


Figure 2.1: Centralized Generation and Distributed Generation

### 2.2.1 Disadvantages of distributed generation

Although DG has some advantages, it also has disadvantages and negative impacts to the power system. The disadvantages of DG are as follows:

- (a) Increased short circuit current
- (b) Increased the protection cost
- (c) Possibility of islanding is increased
- (d) Possibility of overvoltage
- (e) Possibility of voltage flicker

## 2.3 Concept of microgrid

Microgrid (MG) system can be defined as a low voltage (LV) network having loads with small modular generation systems, power electronic devices and controllers, which can ensure stable operation during faults and various network disturbances. Therefore, MG is one of the alternative in improving the stability and reliability of the overall power system.

### 2.3.1 Unbalanced voltages in microgrids

In the last two decades, several blackouts have been demonstrated with voltage instability and voltage collapse problems. It is believed that most of these blackouts occurred due to the voltage instability problems. Insufficient reactive power margin to supply the load is a major cause for voltage instability problems. A voltage decrease may lead to a reactive power consumption increase and then causing more drops in voltage. Voltage drop below an acceptable limit counteracts the process of boosting voltage by increasing reactive power. Since voltage collapse is related to system maximum load-ability limit thus, obtaining the load-ability limit or the point of collapse determination becomes essential.

Voltage unbalance can be defined as unequal voltage magnitudes at fundamental system frequency (under-voltages and over-voltages), fundamental phase angle deviation and unequal levels of harmonic distortion between the phases [11]. The voltage unbalance exists because of various reasons such as the spacing of the overhead transmission lines, three-phase loads with unbalanced impedances or a fault in the power system [12].

### 2.3.2 Microgrid islanding

Islanded microgrid refers to a small area which is disconnected from the main grid. Some distributed generations are responsible to supply the system or the loads with sufficient power. Microgrid islanding is the future of efficient and fast restoration of the power system. It allows the high penetration of distributed generation into the power system. For a microgrid to operate in autonomous mode, the islanding control strategies are very important. Two kinds of islanding control strategies for voltage source inverter (VSI) were developed for many studies, i.e. the PQ inverter control and VSI inverter control [13].

Therefore, many studies have been carried out to improve the voltage stability in microgrid power system. Moreover, this phenomenon has become one of the major challenges for the power system planners and engineers. The high penetration of distributed generation in microgrid has brought new technical challenges to the system. Some of the main problems are related to steady state and transient voltages and frequencies, protection malfunctions, increase in short circuit levels and power quality problems during events like islanding, network changes, faults and other disturbances to the system [10]. Several microgrid based research projects and test beds are currently being undertaken by Consortium for Electric Reliability Technology Solutions (CERTS) and California Energy Commission. The CERTS has an unique conception of the microgrid . In this concept, a minimum of overview control is needed for the generators. Instead, the generators are each programmed with control characteristics that allow them to function well together to provide a high quality source of power to the microgrid under a range of operating conditions [14] - [15].

### 2.3.3 Environmental benefits of microgrid system

In a microgrid, the power generation and the loads are closer to each other. So, the waste heat generated during power generation, which is generally wasted in a large

power generating station, can now be used for heating purposes. Thus, the microgrids operate at high efficiencies as illustrated in Figure 2.2 [16].

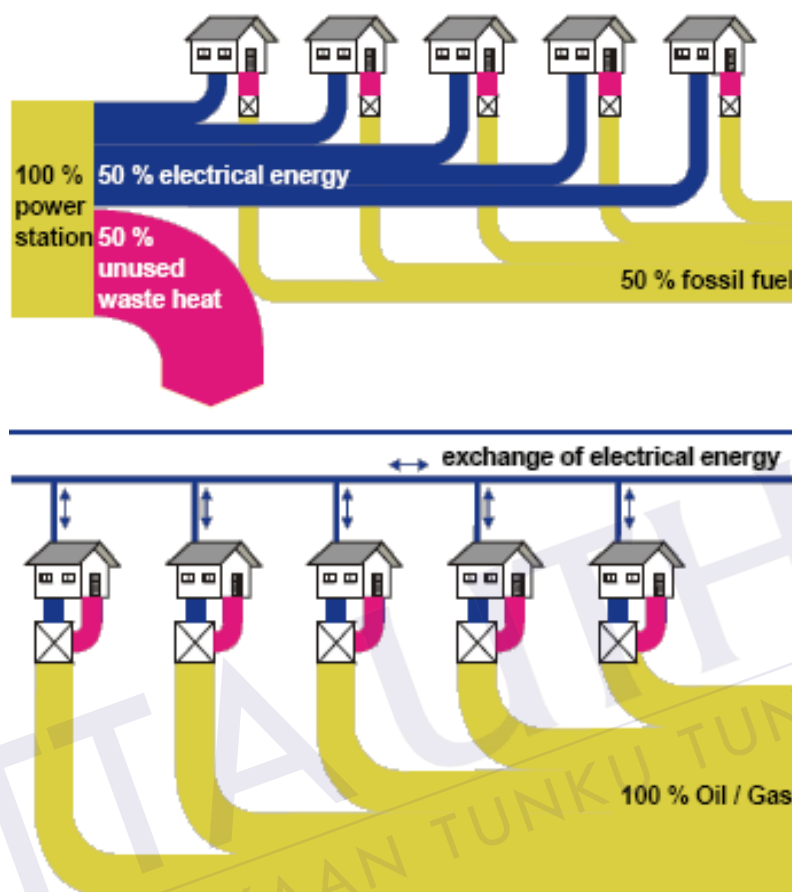


Figure 2.2: Microgrid operations

#### 2.3.4 Stability problems in Microgrid system

When any disturbances of load in system or DGs islanding changes in parameter in grid, inequality in the power generation and demand or different type of faults are occurred, microgrid stability issues might be appeared and may change the voltage and system frequency.

Studies focused on one type of distributed generator connected to microgrid should be carried out together with the investigation on several expected disturbances that might be occurred. In addition, finding the optimal size and location of DGs to maximise the grid stability is also a common study in this area.

## 2.4 Previous studies

A three phase continuation power flow for voltage stability analysis of distribution systems has been developed by Mississippi State University in 2008 [17]. The IEEE 13 nodes and IEEE 37 nodes feeders are selected as test systems because these feeders are highly unbalanced and they are closely represent actual terrestrial distribution systems. This work aimed at finding the optimal size and location of DG based on voltage support and stability. The equality constraints of the formulation are power flow equations and the inequality constraints were the voltage limits, power supplied by the DG as well as load limits at all nodes. Functions have been developed to address voltage support and voltage stability. Power flow analysis has been performed on these test cases with DG connected and it has observed that as the size of the DG is increased, the voltage profile of the system is improved. The voltages at the downstream nodes which are close to lower limit (0.95pu) have been improved; hence this increases the voltage stability margin of the system [18].

Power system stability analysis with a high penetration of distributed generation is another research in McGill University [19], clarified the impact of DG on the stability of the system and explained the various power quality problems which affected voltage stability. The approach of study is to operate DG at unity power factor for economic reasons. However, the study revealed the followings:

- (a) It is more beneficial to have DGs operating at a lagging power factor for long-term voltage stability because it improves the voltage security margin by increasing the distance to voltage collapse.
- (b) When DG operates at a leading power factor, the short-term voltage stability is generally improved because the voltage dips are reduced.
- (c) Utilities should therefore try to convince owners to let the utilities control the DGs in order to improve the stability of the system.

In 2009, a study was presented on an optimisation technique in determining the optimal capacity and location of DG [20] in order to improve system stability during and after a disturbance in the electrical system [17]. The IEEE 14 Bus Test System and the Electrical System of Puerto Rico have been used as models in the simulations.



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