STATIC VOLTAGE STABILITY IN ELECTRICAL POWER SYSTEM

Mohd Firdaus B. Basir

BEKP

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"I hereby declare that I have read through this report entitle "Static Voltage Stability in Electrical Power System" and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)"

Signature : ....

Supervisor's Name : ASRI BIN MN

Date : 2 JULY 2009

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MOHD FIRDAUS BIN BASIR

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I declare that this report entitle "*Static Voltage Stability in Electrical Power System*" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature: ....

Name: MOHD FIRDAUS B. BASIR..........

Date: 2 JULY 2009..............................

To my beloved mother and father

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ABSTRACT

Electrical power system involves generation, transmission, and distribution components. Each of these components engages with voltage stability which means the ability of a power system to maintain steady voltage after a small disturbance. This study defined the static voltage stability for technical used in design power system planning as well as investigate the factors that affecting voltage stability. Loss of synchronism, loss of transmission lines, loads demand increment and insufficient generated reactive power was identified as factors affecting static voltage stability through contingencies analysis created by according to those factors. Load-flow analysis was executed using Load-flow Version 3.2.1 by ERA Technology Ltd. in ERACS Version 3.2.2 software in order to analyze the contingencies and improving methods that related to static voltage stability. Hence, the possible methods to improve voltage level at each busbars in two (2) power system network in this study had been done. Experimentally, the implemented methods were verified by ensuring the results in parallel with theoretical values. Thus, the projection of power system limit can be predicted before reaching voltage collapse situations. Moreover, appropriate methods can be applied to the system to improve static voltage stability with considerations of power system utilizations level.

ABSTRAK

Sistem kuasa elektrik terdiri daripada 3 komponen utama iaitu penjanaan, penghantaran, dan pemgagihan. Setiap komponen tersebut tersalinghubung dengan kestabilan voltan iaitu kemampuan sistem kuasa mengekalkan kestabilan voltan apabila berlaku gangguan. Kajian ini mentakrifkan kestabilan voltan statik untuk kegunaan teknikal dalam merancang rekaan serta menyelidik faktor-faktor yang mempengaruhi kestabilan voltan. Ketidakselarasan penjanaan, kehilangan talian penghantaran, perningkatan permintaan kuasa, dan kekurangan kuasa regangan terjana telah dikenalpasti sebagai faktor-faktor yang mempengaruhi kestabilan voltan statik melalui analisis ketidaktentuan yang telah direka berdasarkan faktor-faktor tersebut. Analisis aliran beban telah dilaksanakan dengan menggunakan Load-Flow Version 3.2.1 di dalam perisian ERACS Version 3.2.2 untuk menganalisa ketidaktentuan dan kaedah pembaikan yang berkaitan dengan kestabilan voltan statik. Justeru itu, kaedah yang sesuai untuk meningkatkan paras voltan pada setiap palang bas telah digunakan pada 2 buah rangkaian sistem kuasa di dalam projek ini. Secara eksperimen, pendekatan yang telah digunakan telah disahkan dengan memastikan keputusan analisis adalah selari dengan teori. Jadi, had sistem kuasa boleh dijangka sebelum berlaku kejatuhan voltan. Selain itu, kaedah yang sesuai boleh diadaptasikan pada sistem bertujuan memperbaiki kestabilan voltan statik dengan mengambil kira kadar penggunaan sistem kuasa.

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CHAPTER 1

INTRODUCTION

1.1. Introduction

The focus of this project is research of aspects that affecting voltage stability in electrical power systems. Voltage instability gives an impact to power security which is voltage collapse. Power system analysis usually analyzes using software which can simulate the real cases rather than directly analyze at the real system to avoid any disturbances. In this project actual data collected from Malaysian electrical utilities company "Tenaga Nasional Berhad" used as reliable data to run Load Flow Analysis (LFA) using appropriate software. Moreover, after the results of analyze and improvements methods can be applied to the real systems.

The LFA is a fundamental task for planning and operation of power systems. It serves primarily to determine the loading and the utilization and the voltage profiles. It is crucial to use LFA for static voltage stability study, to planning the operation of power system in present and future.

Consequently, with the static voltage stability studies, the methods to improving it can be propose without disturbing the real systems. Hence, the reliability and security of power system can be improved and the economics growth rapidly grows without any disturbances.

1.2. Problem Statements

Nowadays, utilities company which supplying the electricity receives voltage stability problems; and the static voltage included. Static voltage stability gives great effects to the falling of the voltage and overdue to voltage collapse. It is crucial to handle and manage the stabilities to avoid voltage collapse which can suffer and causing damage to the industries, economy, and quality of life. In other words, static voltage stability tolerance must be well defined according to the practice. Furthermore, appropriate methods had to be implements in order to improve and control the static voltage stability within the specified range to reduce the probability of voltage collapse.

1.3. Objectives of project

The aim of this project is to investigate all elements and factors that influencing the static voltage stability. In order to achieve the main objective, several specific objectives are defined:

a) Draw the network of power system based on reliable data and network in ERACS software Version 3.2.2.

b) Identify the factors that affecting static voltage stability.

c) Simulate and analyze related power system networks using Load Flow Version 3.2.1 in ERACS software.

d) Implement the appropriate methods in order to improve static voltage stability.

e) Compared the analyzed data with the theoretical values from the literatures and make sure both theoretical and analyzed data in parallel.

1.4. Scope of project

Scope of work is limited to simulate and analyze the static voltage stability using LFA in software package by using ERACS Power System Analysis Version 3.2.2. The voltage stability in steady-state condition is considered in analysis process. Simulation will cover three (3) components in power system networks which are generation components, transmission components and distribution components. The loads of several areas in

Malaysia are used to obtain and makes it reliable data to analyze. Additionally, dynamics voltage stability does not to be considered in this project.

Voltage stability aspects will be analyzed by consideration of voltage tolerance at every busbars whether it meet the specified voltage tolerance or vice versa.

1.5. Definition of terms

In the static voltage stability they have a few of terms which closely related to it. Here the definitions of term involve in this project presented, specifically define to make a clear understanding about this project.

1.5.1. Power system stability

Basically, power system stability is defined as characteristics for electrical power system to remain in state of equilibrium at nominal operating condition and to restore an acceptable state of equilibrium after a subjected disturbance as stated by *IEEE/CIGRE Joint Task Force on Stability Terms and Definitions* (2004).

1.5.2. Static voltage stability

After knowing about the power system stability definition, the static voltage stability closely defines as power system stability because they are integrated with each others. As stated by Repo (2001) it is ability of power system to maintain steady voltages at all busses in the electrical power system at normal operating conditions after being subjected to a disturbance. Camm and Adu (2004) also defined that static voltage stability as Repo (2001). In other words, static voltage stability referring the voltages at all buses in the specified tolerances. In addition, *IEEE/CIGRE Joint Task Force on Stability Terms and Definitions* (2004) have proposed that the effect of progressive fall and rise at buses when instability occurred.

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction

The literature review aimed to provides overall view the kind of researches that been done to date. This chapter reviews some of the works in the field of voltage stability and power system stability. In the area of voltage stability, definition of static voltage stability was studies including studies on the factors of instability occurring, methods to improve the instability. Moreover, methods that have been used by several researchers in purpose to analyze the static voltage stability also been reviewed. Then the aspects of voltage tolerance are studied to fulfill the analysis of static voltage stability, followed by reviewing Malaysian power system in order to get the reliable data for the analysis.

2.2. Importance of static voltage stability

Voltage stability has their own importance to power system networks and became major components in order to maintaining the system reliability. It is crucial to consider static voltage stability for modern power system because of dependency of economies and social factors. Moreover, Arunagiri and Venkatesh (2004) proposed that voltage stability is the major problems to the world wide electrical utilities companies in order to avoid voltage collapse that can paralyze their customer's activities.

Thus, voltage stability margin need to be ensured above the desired level. Furthermore, Lof, *et. al.* (1992) observed that most of electricity outage throughout the world caused from voltage instability. Most of literatures studied, almost all authors state that static voltage stability is the one problem of the major aspects in power system planning secure operations.

2.3. Factors influencing static voltage stability

Basically, as stated by Yome (2004) there are many factors influencing the static voltage stability and they are have relationship with each others, but the main factors is insufficient of real and reactive power generated at generation components, will slowly developing the changes in electric power system occurs that eventually lead to a shortage of reactive power and declining voltage. Next, the system approaches the maximum loading point or voltage collapse point, both real and reactive power losses increase rapidly. Consequently, the problems will affecting the others components of power system network which is transmission network and distribution network.

All aspects of power system had to be considers in order to maintain the voltage stability. Specifically, the loads also contribute to voltage instability in terms of loads demand. Furthermore, the lacks of transmission lines loadability also be the factors of instability of voltages. Basically there are several parameters in the three components of power system need to be considered to analyze static voltage stability.

2.3.1. Parameter of generation components

Taylor (1994) had introduced the parameter that must be considered is rotor angle, there are relationship between rotor angle stability and system voltage stability where small disturbance occurred to rotor angle stability gives an effect to dynamic voltage stability.

Reactive power control at the generation components also gives an effect to rotor angle stability also voltage stability. As an example, the automatic voltage regulator having a small disturbance causing the gradual addition of rotor angle values. Generator current limiter, limiting the current through the generator hence, causes an interruption of normal operations of automatic voltage regulator which brought to voltage instability.

2.3.2. Parameters of transmission components

There are three main parameters involve in transmission system which is series resistance, series reactance and shunt capacitance in transmission line. Series resistance effecting the power losses and loadability of power system.

Equation for reactance as described in equation 1.1 below:

$$X_L = \omega L = 2\omega \frac{10^{-4} \ln GMD}{GMR} \frac{\Omega}{km} \tag{2.1}$$

ω : *power system angel frequency*

GMD : *geometric mean distance between phase*

GMR : *geometric mean size conductor radius*

$$GMD = (d_{ab} + d_{ac} + d_{bc})^{1/3} \tag{2.2}$$

$GMR = 0.8r$

r : *conductor radius*

Values of GMR can be observed from conductor table. Bundled conductor which having multiple subconductor per phase, equivalent GMR is:

$$GMR_{equiv} = \left[n \times GMR \times \left\{ \frac{s}{2 \sin \frac{\pi}{n}} \right\}^{n-1} \right]^{1/n} \tag{2.3}$$

Hence, for two (2) and three (3) bundled conductors having equivalent GMR below:

$$2\ conductors \qquad (s \times GMR)^{1/2} \tag{2.4}$$

$$3\ conductors \qquad (s^2 \times GMR)^{1/3} \tag{2.5}$$

n : *numbers of conductor*

s : *distance between subconductor for bundled conductor*

There is alternative to reducing the reactance by reducing the GMD and increase values of GMR. Values of GMR reduced by addition of subconductor per phase, an example 500kV conductor build with 2, 3 and 4 subconductor per phase.

Meanwhile for the shunt reactance the equivalent equation is:

$$B = \omega C = \omega^{-6} \times \frac{1}{18 \times \ln\frac{GMD}{r}} \; s/km \qquad (2.6)$$

For bundled conductors, value of equivalent radius is:

$$R_{equiv} = \left[n \times r \times \left\{ \frac{s}{2\sin\frac{\pi}{n}} \right\}^{n-1} \right]^{1/n} \qquad (2.7)$$

Hence, equation for charging of reactive power is:

$$Q_{chg} = V^2 \times B \qquad (2.8)$$

Reactance and loading of transmission lines can be reduced with reducing the distance between conductors and numbers of bundled conductors plus it will increase the capacitance and inductive of the lines. This situation can caused increment of surge impedance loading that will improve the transmission effectiveness.

Improvement of reactive power generation caused by large values of capacitance can present small disturbance to power system at the light load. Hence, usually for extra high voltage need the shunt reactor compensator to maintain the stability of voltages.

2.3.3. Parameter in distribution components

There is several important parameters involve with static voltage stability in distribution components. One of it is impedance at transformers; most of distribution transformers have either their own tap changer or automatic voltage regulator at the secondary side.

According to Taylor (1994) impedance for heavy power transmission transformer is about 8%-10% from transformer base. Meanwhile, impedance for distribution components is about 2%-4%. Author has stated that transformers at the heavy power transmission main contributor to the impedance of distribution system. Most of the transformers at the distribution system operate at the steady-state condition.

Additionally, Dai and Xiong (2008) stated that loads uncertainty play a role to affecting voltage stability as an example the loads demand increase to the peak and decrease to lowest demand.

2.4. Functions of reactive power

As introduced from previous subchapter the reactive power plays the major role in static voltage stability, the insufficient reactive power can cause failure to transmission lines and distribution components continuously closing to voltage collapse. In this section, functions of reactive power to power system and voltage stability will be explained.

The main function of reactive power is to correct the power factor by connecting capacitor crossing the inductive loads. It can be described as capacitor generate lagging reactive power which to be supply to load. Hence the demand to power supply for lagging reactive power reduced.

Furthermore, for the transmission line cases as introduced by Taylor (1994), series capacitors also applied on shorter lines to improve voltage stability. Series compensation reduces net transmission line inductive reactance. The reactive generations (I^2X_C) compensates for the reactive consumption (I^2X) of the transmission line. Reactive power increases with the current squared, thus generating reactive power when most needed.

2.5. Methods to improves static voltage stability

After the factors that affecting the static voltage stability in electrical power system, the methods to improves it had been studied. There are many methods and alternatives to overcome or specifically control the voltage instability. It can be divided into generation part, transmission part and distribution part which including the load demand. The overall view before further explanation, there are four (4) main methods to improve static stability involving usage of synchronous compensator, shunt compensator, tap changer adjustment and load shedding as the last resort.

2.5.1. Synchronous compensators

The factors of static voltage stability proposed by *IEEE/CIGRE Joint Task Force on Stability Terms and Definitions* (2004) based on the loss of synchronism of some generators causing instability brought to the alternative of addition of synchronous compensation to maintain the voltage stability. Pradhan *et. al.* (2006) suggested to used embedded generations to reduce the dependency of local loads to transmission lines. Authors also suggested that the renewable energy source or fossil fuel generator, but in their writing they recommended the renewable energy as embedded generation. The finding of their research found that voltage stability improves with the introduction of embedded generation at the load bus and loadability enhanced. Furthermore, they suggested that embedded generation should be connected near the load buses for better performance.

This method also supported by Jaganathan, and Saha (2004) also by Gillie *et al.* (2007) which also proposed that it reduced the need of new transmission lines and distribution facilities consequently reducing overall infrastructures. Embedded generation reserves the power flow and network is no longer a passive circuit supplying loads. It became an active system with power flow and voltage determined by generation as well as the loads. Continuously, generator support excessive power to al the loads which if is connected. Finally, the embedded generation can reduce network losses with proper placement, while increase network losses if improper placement made.

Beside the addition of generators, synchronous compensator also can be a synchronous motor which can convert to generator when instability occurred. Usually it constructions in Salient pole design (6 or 8 poles) with rating of 60MVA, 13kV and interconnected with high voltage through power transformer. Moreover, synchronous motor automatically controlled to get started.

2.5.2. Shunt compensators

Shunt compensator can be describing as shunt capacitor also known as capacitor bank. Arunagiri and Venkatesh (2004) recommended using shunt capacitor that can recover the voltage stability. Researchers observed that the increased loads on a particular