UNIVERSITI TUN HUSSEIN ONN MALAYSIA

STATUS CONFIRMATION FOR MASTER'S PROJECT REPORT

ANALYSIS OF VOLTAGE INSTABILITY ON THE SABAH GRID SYSTEM: A CASE STUDY

ACADEMIC SESSION: 2012/2013

I, **MYJESSIE BINTI SONGKIN**, agree to allow this Master's Project Report to be kept at the Library under the following terms:

1. This Master's project Report is the property of the UniversitiTun Hussein Onn Malaysia
2. The Library has the right to make copies for educational purposes only.
3. The Library is allowed to make copies of this report for educational exchange between higher educational institutions.
4. ** Please Mark (√)

☐	CONFIDENTIAL	(Contains information of high security or of great importance to Malaysia as STIPULATED under the OFFICIAL SECRET ACT 1972)
☐	RESTRICTED	(Contains restricted information as determined by the Organization/institution where research was conducted)
☐	FREE ACCESS	

Approved by:

(WRITER'S SIGNATURE) (SUPERVISOR'S SIGNATURE)

Permanent Address:

WDT 19, JLN KOTA KINABALU
KG. MANDAP, 89157
KOTA BELUD, SABAH

Date:___________________________ Date: ________________________

NOTE:

** If this Master's Project Report is classified as CONFIDENTIAL or RESTRICTED, please attach the letter from the relevant authority/organization stating reasons and duration for such classifications

This thesis has been on date

And is sufficient in fulfilling the scope and quality for the purpose of awarding the Degree of Master of Electrical Engineering.

Chairperson:

DR. DIRMAN HANAFI
Faculty of Electrical and Electronic Engineering
Universiti Tun Hussein Onn Malaysia

Examiners:

PM DR ZAINAL ALAM BIN HARON
Faculty of Electrical and Electronic Engineering
Universiti Tun Hussein Onn Malaysia

DR KOK BOON CHING
Faculty of Electrical and Electronic Engineering
Universiti Tun Hussein Onn Malaysia

Supervisor:
IR DR GOH HUI HWANG
Faculty of Electrical and Electronic Engineering
Universiti Tun Hussein Onn Malaysia

VOLTAGE INSTABILITY ANALYSIS ON THE SABAH GRID SYSTEM: A CASE STUDY

MYJESSIE BINTI SONGKIN

A project report submitted in partial
fulfilment of the requirement for the award of the
Degree of Master in Electrical Engineering

Faculty of Electrical and Electronic Engineering
Universiti Tun Hussein Onn Malaysia

FEBRUARY 2013

I hereby declare that the work in this project report is my own except for quotations and summaries which have been duly acknowledge

STUDENT : MYJESSIE BINTI SONGKIN

DATE : 15 FEBRUARY 2013

Supervisor : IR. DR. GOH HUI HWANG

DEDICATION

To the five pillar of my life: God, my husband, my parents and my lovely daughter.
Without you, my life would fall apart.
I might not know where the road will take me, but walking with you God, through this journey has given me strength.
My husband Zubirik, you are everything to me. Without your unconditional love, support and understanding, I would not able to make it.
Mak, you have given me so much. Thanks for your faith in me and teaching me that I should never give up in life.
Bapa, you have always told me to reach my dream. Thank you for everything.
Last but not least, to my precious little girl, gift from heaven, Cherish Emerxandra.
Mummy loves you so much. This is for you my girl.

ACKNOWLEDGEMENT

First and foremost, I would like to express my gratitude to Sabah Electricity Sdn Bhd for making this study possible by providing me the data I needed for this study. Special thanks to the Operation Planning Department team; Nana, Eva and Felani for helping me compiling all the historic data, base case data and load modelling for the PSS/E studies. It has been honour to work with all of you.

My gratitude also goes to my Supervisor Ir. Dr. Goh Hui Hwang for the support and guidance throughout the year and during this study. You are the coolest lecturer I have ever known. Special thanks to the panels Dr. Kok Boon Ching and PM Zainal Alam bin Haron, and also to the Chairman, Dr. Dirman Hanafi for all the positive comments during my Master's presentation. With that, I have enhanced my studies further to achieve the project scope and objectives.

Khairul, you are always there when I need you. Your help is priceless. Thank you for the support and help in my PSS/E studies. Without you, my project will never be completed.

The most special thank goes to my best partner and friend, my husband. You gave me your unconditional support and love through all this long process. May God bless us abundantly.

ABSTRACT

With the development of the power system, voltage stability has become a major concern in planning and operating electric power system. The blackout problem has been associated with not only transient stability but also voltage stability. Voltage Instability in the Sabah Grid System has resulted in several major system failures. The recent major system failure due to the voltage instability happened on the 30th April 2012, where Sabah Grid System experienced a total collapse. This highlighted the need for detailed voltage stability studies to improve the voltage control especially during trough load period and to prevent the reoccurrence of similar incident. This report performs the analysis on the Voltage Instability study case of the 30th April 2012 event and the performance of the Sabah Grid System using the PSS/E simulator involving the load flow analysis, steady-state contingency analysis, Short circuit Studies and Transient Stability studies. This project presented several operating strategies to mitigate the voltage problems including the implementation of the new 66kV radial configuration to improve the voltage stability especially in the 66kV network which is the most critical part of Sabah Grid System. The additional of new 66kV and 132kV shunt reactor to be installed and several recommendations are proposed to maintain substation voltage to be within the specified limits. The analysis shows that the voltage in the 66kV network and the 132kV network has a significant improvement after the fast corrective action and the new 66kV radial configuration have been implemented.

ABSTRAK

Dengan pembangunan sistem kuasa, kestabilan voltan telah menjadi kebimbangan utama dalam perancangan dan operasi sistem kuasa elektrik. Masalah gangguan bekalan elektrik telah dikaitkan bukan sahaja dengan kestabilan transien tetap juga kestabilan voltan. Ketakstabilan Voltan dalam Sistem Grid Sabah telah mengakibatkan beberapa kegagalan sistem utama. Kegagalan sistem utama baru-baru ini yang berlaku pada 30hb April 2012 adalah disebabkan oleh ketidakstabilan voltan, di mana keseluruhan Sistem Grid Sabah telah mengalami gangguan bekalan elektrik. Ini menekankan keperluan untuk kajian kestabilan voltan yang lebih terperinci untuk meningkatkan kawalan voltan terutama semasa tempoh beban rendah dan untuk mencegah kejadian yang serupa berulang lagi. Laporan ini adalah kajian analisis ke atas kes ketakstabilan Voltan yang berlaku pada 30hbApril 2012 dan juga menganalisa prestasi Sistem Grid Sabah dengan menggunakan simulator PSS/E yang melibatkan analisis beban aliran, keadaan mantap analisis kontingensi, pengajian litar pintas dan kajian kestabilan transien. Projek ini membentangkan beberapa strategi operasi untuk mengurangka nmasalah voltan termasuk pelaksanaan konfigurasi baru 66kV jejarian untuk meningkatkan kestabilan voltan terutamanya pada rangkaian grid 66kV yang merupakan bahagian yang paling kritikal dalam Sistem Grid Sabah. Penambahan dan pemasangan 66kV dan 132kV *shunt reactor* yang baru telah dicadangkan untuk mengekalkan voltan pencawang berada dalam had yang ditetapkan. Analisis menunjukkan bahawa voltan dalam rangkaian 66kV dan rangkaian 132kV mempunyai peningkatan yang ketara selepas tindakan pembetulan pantas dan konfigurasi baru jejarian 66kV telah dilaksanakan.

CONTENTS

LIST OF APPENDICES

1. APPENDIX A: Single Line Diagram for Sabah Transmission Network
2. APPENDIX B: Merit order for Generation scheduling
3. APPENDIX C: System Disturbance Report on the 30th April 2012
4. APPENDIX D: Generator dynamic modelled in the PSS/E
5. APPENDIX E: Limit Checking Analysis
6. APPENDIX F: Voltage monitoring based on the Sabah Grid Code
7. APPENDIX G: Dynamic simulation results

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

ECG - East Coast Grid
WCG - West Coast Grid
kV - kilovolt
MW - Megawatt
VAR - Reactive Power
MVAr - Megavar
SVC - Static VAR Compensator
CVT - Capacitive voltage transformer
SESB - Sabah Electricity Sdn. Bhd
V_R - Voltage at receiving end
LTC - Load Tap Changer
IEEE - Institute of Electric and Electronic Engineering
TNB - Tenaga National Berhad
p.u. - per unit system
ASCC - Automatic sequencing circuit activity
X’’d - sub-transient impedance
PSS/E - Power System Study for engineer
kA - kilo ampere
CB - Circuit Breaker
CSVGN1 - SVC model
SCR - Semi-conductor controlled rectifier
CBASE - Capacitor parameter
VMAX - maximum voltage
VMIN - minimum voltage
RMIN - admittance limit
MBASE - MBA base

Tx	-	Transformer
OL	-	Overloading
DCC	-	Distribution Control Centre
GT	-	Gas Turbine
SCADA	-	Station Control Automation Data Acquisition
IPP	-	Independent Power Producer
Hz	-	Hertz
KK	-	Kota Kinabalu
HVDC	-	High Voltage Direct Current

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Project Background

The Sabah Grid System is divided into two regions namely East Coast Grid (ECG) and West Coast Grid (WCG). The ECG and WCG are interconnected through a double circuit of 275kV Kolopis – Segaliud transmission line. The 132kV network is connecting all the load center areas both in ECG and WCG except for Kota Kinabalu area that is interconnected by a 66kV network and Sandakan area is interconnected by 33kV network. The Single Line Diagram for the Sabah Grid network is given in Appendix A. The generation capacity and load demand in both ECG and WCG are summarized in Table 1.1.

Table 1.1: Generation capacity and load demand in West Coast Grid and East Coast Grid.

	West Coast Grid	**East Coast Grid**
Generation Capacity (MW)	860	404.8
Load Demand (MW)	658	222

The 275kV interconnectionlines were constructed for sending abundant energy generated in the West with a total of 770MW generation capacity to the East Coast power systems.

Due to the sizable length of the link which is about 247km, a large amount of power is transmitted through on this line and the configuration of the Sabah Grid system, the risk of voltage instability is evident.

This interconnected line is compensated by shunt reactor and Static VAR Compensator (SVC) at both sides. However, due to the imbalance generation capacity which is more generation capacity from West Coast Region, the East Coast Region frequently experience voltage instability especially during trough load period where most of the expensive generator sets in the East Coast region are stopped to reduce the operational cost. During the base load condition, the generation capacity in the west Coast Grid is exported power to the East Coast Region. The power flows from West to East is about 130MW during base load condition.

The report takes into account the latest information on the integrated system electricity demand and the existing electricity supply system. Based on this information, this projectanalyse the voltage instability of the grid network. Emerging limitations in the network are identified and possible solutions to address these limitations are discussed. This project report therefore provides input in identifying the most appropriate solution to ensure the system stability can be maintained in the face of continuing strong growth in electricity demand in Sabah.

1.2 Problem Statement

On the 30th April 2012, Sabah Grid power system experienced a total collapse due to the tripping of the largest generator set with total capacity of 190MW in the West Coast region. The problem started at 03:23Hr and lasted until 18:19Hr where the system is fully restored.

Prior to the incident, the 66kV network experienced high voltage of +10% during low load due to inadequate reactive power management control and mesh operation of the network.Figure 1.1 presented the higher than normal voltage (up to 90kV) were recorded by protection relay at the Red phase of 66kV Penampang-Inanam line 1 prior to the blackout incident for 9.175 second**.** This contributed to Capacitive Voltage Transformer (CVT) component failure and triggered the cascading tripping.

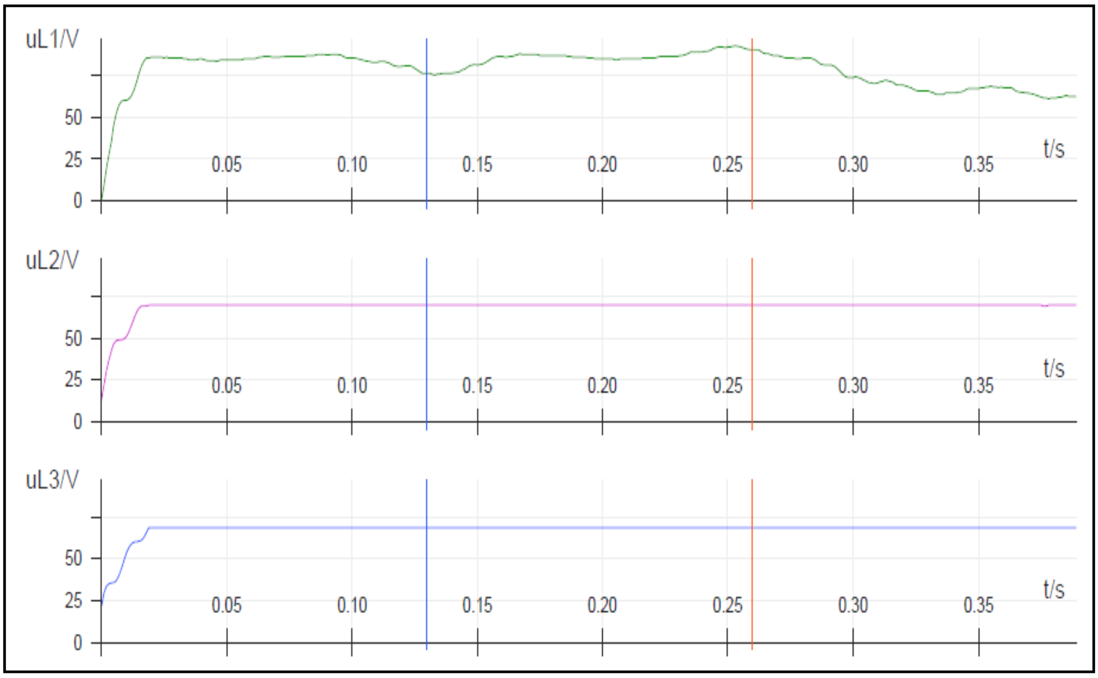

Figure 1.1: Red Phase Over voltage picked up by Protection Relay (SIEMEN Relay 7SA522) for 66kV Penampang - Inanam line 1

While the 66kV network operated with all interconnections closed will result in the highest supply security, it suffers from high fault duties, exceeding Circuit Breaker ratings at some substations, slow and uncoordinated fault clearing for backup protection operation including busbar faults and breaker failure, and manual and uncoordinated voltage control. Some of the critical physical and operational constraints experienced include outage of 90 MVA 132/66kV transformer at UMS substation, Single circuit 66kV circuits between

(i) UMS 132kV and UMS 66kV,
(ii) UMS 66kV and Tanjung Lipat,
(iii) Kota Kinabalu and Karamunsing; and
(iv) Karamunsing and Tanjung Lipat,

old switchgear with low fault ratings, and inflexible single bus configuration.

The 66kV network is the critical part in the Sabah Grid System where the major load center is located in the 66kV network. Therefore the security of the 66kV network is become the highest priority to maintain the reliable supply to the consumers.

1.3 Project Objectives

The major objectives of this research are:

a) To recommend a system improvement for the 66kV network on the Sabah Grid System by preventing the exceeding of high fault duties of Circuit Breakers ratings at 66kV substations.
b) To evaluate the performance of the Sabah Grid System in terms of voltage instability and possible voltage collapse.
c) To identify transmission system reinforcement in the Medium term.

1.4 Project Scopes and limitations

System studies are performed to evaluate of 66kV radial network configuration options and identify related operational issues in the Sabah Grid System. This study performed includes:

a) To create the case studies and scenarios developments for steady state analysis
b) To perform steady state analysis on various set configurations of option including reactive power requirement, contingency analysis and short circuit requirements.
c) To perform Dynamic stability analysis including transient stability, frequency stability, voltage stability to ensure all the planning and operation criteria are satisfied.

1.5 Thesis outline

The subsequent chapters of the thesis are organized as follows:

Chapter 1 highlights about the background of Sabah Grid Power system and the voltage stability problem that leads to the real incident where Sabah Grid System experienced total collapse on the 30th April 2012.The objectives and project scope of this thesis arealso stated in this chapter.

Chapter 2 is the literature review of this project. This chapter will give details about the theory of the Voltage stability analysis. Some previous researches are shown in this chapter.

Chapter 3 discusses about the project procedure and also approach used to implement the project is explained. Chapter 4 shows the result of the simulation and discussion of the findings.

Finally, Chapter 5 presents the project Conclusion. This chapter will also discuss about some future recommendations.

1.6 Statement of originality and contribution

This study was conducted using the mixed steady-state and dynamic analysis techniques. It is originally work except where due reference is made. All the data used for this study is a real data extracted from the SESB's operational data and it may be considered confidential. This report has not been submitted for any degree or other purposes.

I certify that all the assistance received in preparing this report and sources have been acknowledged.

CHAPTER 2

LITERATURE REVIEW

2.1 Voltage Stability theories

A power system operating condition should be stable, meeting various operational criteria, and it should also be secure in the event of any credible contingency at any point of time. However, in the present day, most of the power systems are being operated nearer to their stability limits due to economic and environmental constraints. Unlike the real power, it is extremely difficult to make a precise estimate of reactive power reserve margin. This problem becomes more complicated because of the limited extent that reactive power will flow to support the bulk transmission system voltage. Therefore, maintaining a stable and secure operation of power system is very important and challenging issue.

2.1.1 Definitions of voltage stability and instability

Voltage stability is the ability of a power system to maintain adequate voltage magnitudes. When the system nominal load that connected to a voltage stable system is increased, the power delivered to that load by the system will also increase. In a voltage stable system both power and voltage are controllable. In a voltage unstable system the system operators have lost control of both voltage magnitudes and power transfer [1].

Before continuing with definitions of voltage stability and instability, the two types of load need to be distinguished first. The nominal load is the rated load which is the MW the customer load will draw if it is operated at its nominal (or rated) voltage and frequency. The actual load is the actual MW drawn from the power system by a load. The actual load may be different than the nominal load. For example, assume a 100MW load is connected to the power system with customer voltages 5% below nominal values. 100MW is the nominal load whereby the customer load which is 5% voltage low (perhaps 97MW) is the actual load.By these definitions of nominal and actual load, the concise definition of voltage stability can be presented. In a voltage stable system when the nominal load is increased, the MW transferred to that load also increases. In a voltage unstable system when the nominal load is increased, the MW transferred to that load will decrease. Voltage instability implies an uncontrolled decrease in voltage triggered bya disturbance, leading to a voltage collapse and is primarily caused by the dynamic connected with the load.

2.1.2 Voltage collapse definition

Voltage collapse is a process in which voltage instability leads to loss of voltage in a significant part of the system. A system will enter a period of voltage instability prior to a voltage collapse. During voltage instability the power system is in danger and the system operators have lost control of system voltage and power flow. System voltage levels could be in the zone of 70% to 90% of normal voltage level. System reactive supplies are exhausted and motors may begin to stall. If voltages decline any further a voltage collapse will occur. In simple terms, a voltage collapse occurs when there is not enough reactive power available to serve the reactive power requirements of the area power system and loads. The reactive power deficiency leads to decay in voltages. If the deficiency in reactive power is great enough, system voltage will decay to a level that they are unable to recover to the normal state [1]. The theory of voltage stability and collapse is examined by describing three general types of voltage collapse:

i) Long Term Voltage Collapse
ii) Classical Voltage Collapse
iii) Transient Voltage Collapse

2.1.3 Long term voltage collapse

In a long term voltage collapse [1], a transmission path separates a system's generating sources and load areas. The transmission path used to connect the generation to the load is stressed to the point that the system can no longer maintain the voltages. Power system voltages collapse due to failure to transmit sufficient reactive power to the load area where the reactive power is needed. This type of voltage collapse may take several minutes to several hours to occur. To illustrate this long term voltage collapse, a radial power system is used.

A radial power system is a power system in which generation and load areas are separated by a transmission path. Several parallel lines may be used to connect generation sources to the load areas. Radial power systems often develop as a means to connect inexpensive sources of generation to large metropolitan load areas. In the Sabah Grid Power System, a radial power system occurs in the Kota Kinabalu load center. Figure 2.1 illustrates the 66kV radial power system in the Sabah Grid Power System.

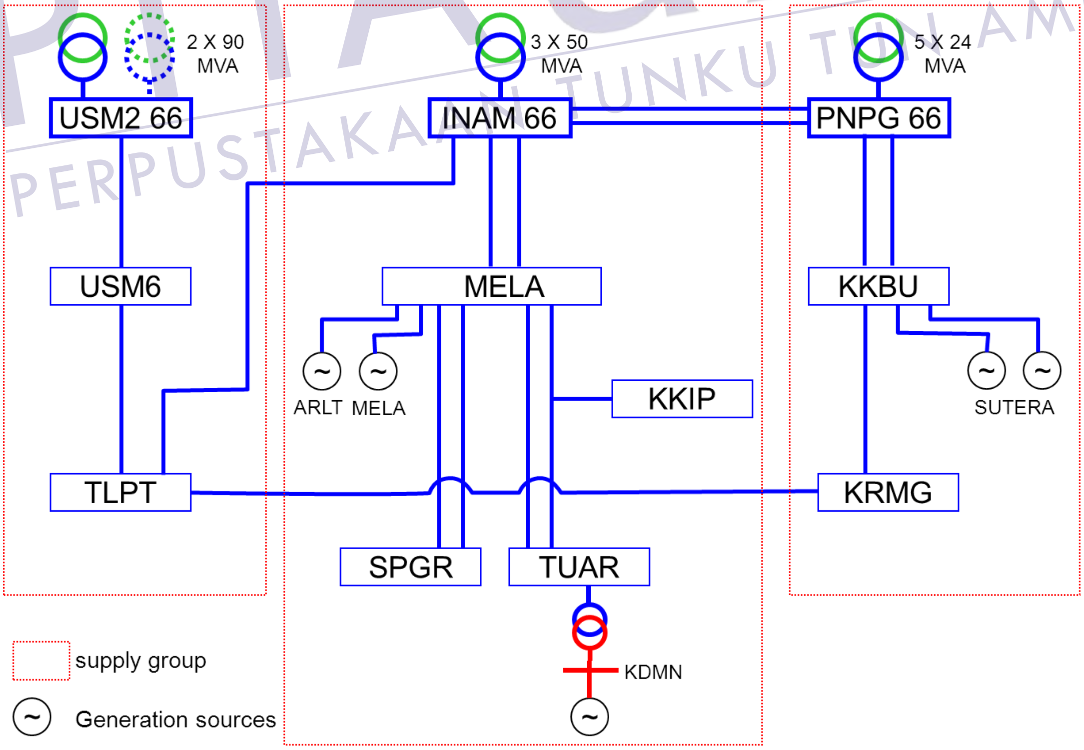

Figure 2.1: 66kV radial power system

When the MW is transferred across a radial power system a curve can be created that relates the voltage at the receiving end of the system (V_R) to the MW transferred across the system. From this curve, as the MW transfer increases across the system, the voltage at the receiving bus (V_R) slowly decreases. Any further increase in MW transfer will eventually reached to the point called the “knee” of the P-V curve. This will lead to a rapid decrease in voltage. The knee of the P-V curve is the boundary between voltage stability and voltage instability. The voltage and MW transfer levels at the knee of the curve are called the “critical” values. Once the critical values are exceeded, the system has entered a condition of voltage instability and system voltage could collapse at any time. This can be illustrated in the Figure 2.2.

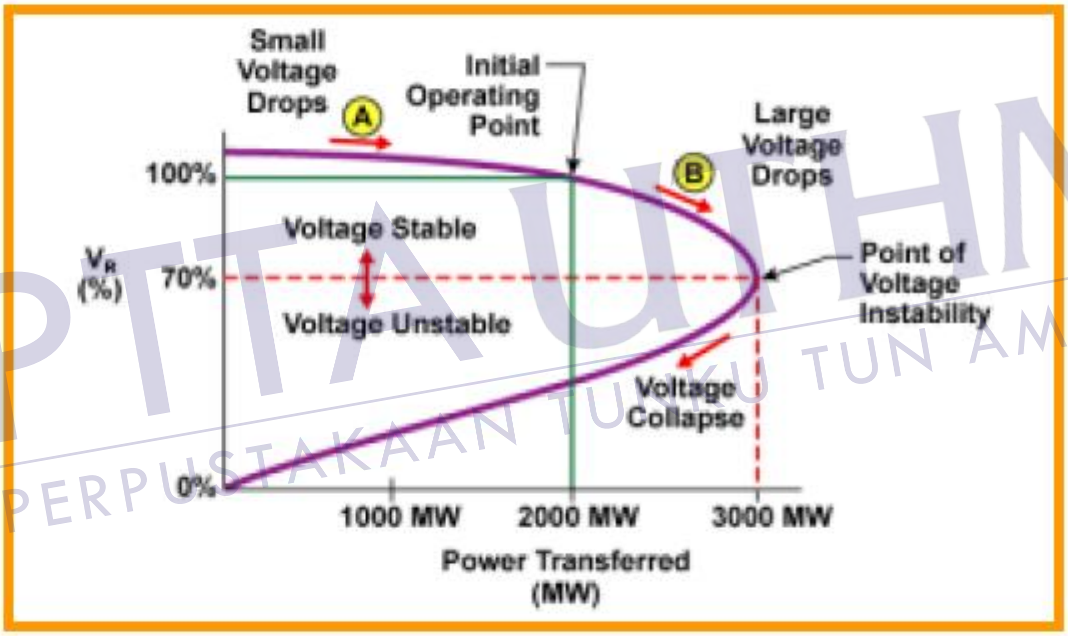

Figure 2.2: P-V curve illustration of voltage collapse.

2.1.4 Classical voltage collapse

In a classical voltage collapse [1] a strongly interconnected power system, with widely dispersed generation, does not have enough reactive power to satisfy the needs of the system and the customer load. A severe disturbance creates this insufficiency of reactive power. The greater the deficiency of reactive power, the greater the voltage decline. Eventually, the voltages decline to a point from which they cannot recover and the system will then collapse. This type of voltage collapse may take from 1 to 5 minutes following the disturbance. A power system is possibly susceptible to a classical voltage collapse if:

- Loads on the system are heavier than normal
- A contingency occurs such as the loss of a key line or generator

The long term voltage collapse also may occur during classical voltage collapse.

2.1.5 Transient voltage collapse

There are several variations to the transient type of voltage collapse [1]. The first variation involves sections of the power system pulling out-of-step from one another. During an out-of-step event, a point between the two systems will experience a voltage collapse. A second variation of transient voltage collapse involves large numbers of induction motors stalling and attempting to restart. This leads to large reactive power swings and possible voltage collapse. Both variations of a transient voltage collapse are different from the long term and classical voltage collapse that they happen very rapidly. A transient voltage collapse will normally occur in less than 15 seconds following the initial disturbance.

2.2 Voltage stability and the timeframes of interest

Power system equipment such as transformer automatic load tap changer (LTC), Static VAR compensators and automatic switched capacitor banks behave with certain time-constants that need to be considered when studying voltage stability. The following timeframes [2] are of interest when studying voltage stability:

- Short Term
- Mid-Term
- Long Term

2.3 Critical bus or busses

A key element of voltage stability studies is the determination of a critical bus or a cluster of critical busses. These busses can be monitored as they will invariably form the electrical centroid of a voltage collapse.

In radial transmission system consisting of a generator serving several loads along a transmission line, the critical or weak bus is generally located electrically and physically furthest away from the generator [3]. In a networked or meshed transmission system such as the SESB 66kV transmission network, finding the weakest bus or a cluster of weak busses is not intuitive. System Operation of Sabah Grid power system experienced that the weakest bus or set of busses are generally located in locations with reactive power deficiencies.

2.4 Static and dynamic analysis

The two most common methods employed within the electric utility for analysing power system stability are static and dynamic analysis.

1.4.1 Static analysis

Static analysis which is also referred as load-flow or steady state analysis reveals equilibrium points of a system study. The power flow equations employed in static analysis assume constant system frequency with generation output equals to demand plus losses. Voltage stability studies are frequently undertaken through the use of static analysis. A common use of this development of P-V curves as shown in the Figure 2.2.

1.4.2 Dynamic analysis

Dynamic analysis which is also referred to as time-domain analysis is commonly used in the study of power system stability to reveal the system trajectory after a disturbance. In contrast to static analysis in which equilibrium points of a P-V curve are not the time-dependent, dynamic analysis method reveals the transient and the longer-term stability of a power system study.

2.5 Descriptions of previous methods of analysis and proposed countermeasures for voltage instability

Voltage instability has been given much attention by the power system researchers and planner in recent years, and is being regarded as one of the major sources of power system threat. There is a body of literature on a voltage instability done by the power system researchers. An IEEE paper published in May 2004 [4] has proposed the following three classifications of power system stability:

- Rotor angle stability
- Frequency stability
- Voltage stability

When a particular system is undergoing system instability, more than one of the above types of instability can be present. The primary purpose of classifying power system stability phenomenon is to aid in its analysis as different techniques are employed to ferret out the underlying causes of the symptoms of a particular disturbance.

Following this general trend, on the 30th April 2012, the Sabah Grid Power System owned and operated by Sabah Electricity Sdn. Bhd (SESB) experienced a higher voltage that highlighted the need of the detailed voltage stability studies. The first study was conducted by a Task Force Group in collaboration with TNB expert group to investigate the cause of the 30th April 2012 event and it demonstrates that fast corrective actions such as performed manual load shedding need to be taken to relieve the high voltage problem [5].

As a result of this and other similar studies conducted by SESB Operation Planning Department [6], this project was launched to measure the remedial action plan to relieve the high voltage problem in the 66kV network area.

Early research concerning the general phenomenon of voltage collapse or instability at the load end of transmission links is introduced with reference to previous work by Weedy, B.M. & Cox, B.R. (1968). The power/voltage and reactive-power/voltage characteristics of power-system loads are predicted and accurately represented by polynomial expressions which are used in the analysis of radial transmission links fed from infinite busbars. It is shown from their studies that, although tap changing to raise the load voltage increases the critical length of the link, it also reduces the margin between normal operating voltage and the voltage at the onset of instability [7]. The effects of the injection of reactive power by static capacitors are also discussed, together with the effect of the induction-motor content of the loads.

The phenomenon of voltage instability and its effects are described in some detail by early researchers namely Brownell, G. & Clark, H. (1989). It is argued that controls that can steer a system away from voltage instability are feasible and badly needed. Among the control possibilities discussed are: load tap changers between the bulk and distribution systems, which play a key role in the voltage collapse process, sometimes contributing to collapse, sometimes helping avoid it; the use of generator reactive overload capability and undervoltage load shedding [8].

Lee, B.H & Lee. K. Y (1991) explained the mechanism of phenomenon of voltage collapse. [9] From their studies shown an iterative reaction of voltage drop between a dynamic load and the system network can cause voltage collapse. The dynamic phenomenon of voltage collapse is analysed on a simple power system model which includes a synchronous motor. Dynamic equations describing the mechanism of voltage collapse caused by a very small disturbance are derived, and the physical explanation of the voltage collapse mechanism is presented in detail for the case when the system is operating near the bifurcation point and its linearized system matrix has a very small negative eigenvalue. It is shown that an iterative reaction of voltage drop between a dynamic load and the system network can cause voltage collapse.

Analyzing mechanisms of voltage instability is necessary for an understanding of the physical phenomenon and a development of control actions. Vu, K. T (1992) [10] reviews some analytical properties of voltage instability as related to tap-changing operations, load dynamics, and generator excitation limits. The analytical results are related to the physical role of each mechanism and the combined effect in a voltage collapse event. This information is valuable in helping one to understand not only how a dynamic phenomenon develops but also the type of corrective control actions needed. The concept of voltage recovery region which can be used to guide control actions is also reviewed. This concept is then explored further for a system model which incorporates the effect of active power and frequency.

A group of researchers from Japan Yorino, N., Sasaki, H., Masuda, Y., Tamura, Y., Kitagawa, M., & Oshimo, A (1992) [11] have investigated the voltage stability problem based on singular perturbation theory. From their paper, possible voltage instability patterns are classified into four types, namely I, II-l, II-2S and II-2D, according to mechanism that causing voltage instability. Several features of each type of instability are studied as well as their analysis methods. Voltage instability tends to begin with type I and then lead to one of the remaining types. The load flow Jacobian can be an effective index to approximately assess types I and 11-2s instabilities, while types 11-1 and 11-2D require direct non-linear analyses and eigenvalue analyses, respectively. The validity of the classification proposed here has been verified through numerical simulations and theoretical analyses which take into account dynamic characteristics of generating units, loads and tap-changing transformers.

In the analysis and evaluation of power system voltage stability, it is necessary to accurately identify the stability margin at each load point under specific system configuration or power balance condition. The voltage stability margin can be basically identified by the multi-solution load flow calculation method. When predicted by this static analysis that voltage instability may occur, time domain simulation will be required which includes the models of various control equipment related with power system voltage profile [12]. To deal with this, the following two analytical computer codes were developed by T. Nagao, K. Tanaka & K. Takenaka (1997)

- a voltage stability static analysis computer code employing a new load flow calculation method; and
- a time-domain long-term simulation computer code for voltage stability.

These computer codes can also calculate the voltage stability index at each load point which is based on the margin to the stability power limit at each load point. The practicalities of these codes developed were verified by applying to the IEEE-118 test system.

A dynamic analysis of voltage instability in the Vietnam 500/220 kV system is presented by T. Tran-Quoc, T. Vu-Due, R. Feuillet, N. Hadjsaid, J.C. Sabonnadire, C, H. Praing, &L. Tran-Dinh' (1998) [13]. From their analysis, long-term simulation is used by taking into account dynamics of slow controllers. Time domain simulation, calculation of indicator of voltage instability risk and eigenvalue methods are presented in other to predict the voltage collapse.

The paper reports on a 1996 incident in the Greek power system that had all the characteristics of voltage instability and the subsequent analyses and countermeasures was performed by Vournas, C.D., Manos, G.A., Kabouris, J. & Cutsem, T. V (2000)Voltage stability analysis is performed by both NTUA and ULg software tools that give identical simulation results. After the upgrades performed by PPC a considerable increase in the maximum power that can be fed to the Athens area is achieved [14].

According to Cutsem, T. V (2000) [15], voltage instability takes on the form of a dramatic drop of transmission system voltages, which may lead to system disruption. He has explained the Voltage instability is caused by the maximum load power transfer from generations to load centers. Several analysis methods are also presented such a contingency analysis, Static versus time domain method, the use of load flow equations, post-contingency load flow and modified load flows. The contingency analysis and post-contingency analysis method are also used in this project because for long-term voltage stability analysis, the credible contingencies (N-1) are outages of transmission and generation facilities; the sequence of events leading to such outages does not really matter.

Urgent direct load control [16] is proposed by Liu, J., Wang, Z., Tang, X., & Liu Z. (2004) as a remedy to voltage instability. It is an overall protection scheme. Tendency analysis combines the aspects of peak load forecasting, state estimation and operation pattern. The window nodes are selected by pattern recognition to observe the entire system from different angles to point out in advance those substations in which the loads are in excess of the rated loads. It is an effective method where groups of air conditioners are selected to act as voltage control equipment during a voltage crisis.

Hasani, M. &Parniani, M. (2005) discussed the voltage stability assessment using mixed static and dynamic techniques. Using static methods, a voltage stability based ranking is carried out to specify faint buses, generators and links in power system. The system is analyzed for most severe conditions. Then, time domain simulation is performed for the conditions determined by voltage instability ranking [17]. The mixed approach benefits from advantages of both static and dynamic analyses.

Li, C., Yuan, R., & Zheng Y., (2006) discussed the relations between Mid-term and Long term voltage instability mechanisms. [18] From their paper, it can be summarized that non-constant energy load has a static-state voltage stable region at the under-side of system characteristic curve, which explains the phenomenon of system operation at low voltage. The static mechanism (the reactive power imbalance mechanism) and the dynamic one (loads and network interaction mechanism) explain the phenomenon from different point of views, using different load models. The integration will provide with a more useful and complete tool to observe and analyse the phenomenon. The imbalance of active power and reactive power are closed linked to each other and inseparable, both of them are the dominant factors of voltage instability.

The right understanding of mechanism of short-term large-disturbance voltage stability is very important for further research of voltage stability [19]. The study by Tang, Y., Ma S. & Zhong W. (2006) expounded the actuality of voltage instability and the concepts of voltage stability and voltage collapse. The influence of load on short-term large-disturbance voltage stability is analyzed on a simple power system. The results form their study show that the dynamic characters of load must be considered in analysis of short-term large-disturbance voltage stability. Through research of voltage stability and voltage collapse, a new mechanism of short-term large-disturbance voltage instability is presented from the engineering point of view. In the end, some solution measures preventing short-term large-disturbance voltage instability are given.

Estimating voltage instability of power systems is important for reduction of large blackouts [20]. Susuki, Y. & Hikihara, T. (2007) proposed to use reachability analysis of hybrid systems for predicting voltage instability of a power system. The reachability analysis is performed by computing backward reachable sets for unsafe sets of hybrid automata. The automata represent continuous voltage dynamics and discrete operations by relay devices. The unsafe sets of hybrid automata are also subsets of state space in which a system voltage shows unacceptable levels such as low or high values. With single machine-load bus (SMLB) system with controlled route switching, it is shown that voltage instability in the SMLB system can be predicted using the reachability analysis.

Yang, Z., Rajagopalan, S. & Conto, J. (2010) presented a practical method to perform Voltage Stability Analysis [21]. A Python tool developed to facilitate contingency screening and PV analysis is described. This paper also addresses issues like voltage stability criteria, cumulative errors of available voltage stability analysis tools, and identification of voltage instability regions.

CHAPTER 3

METHODOLOGY

3.1 Study methodology

The adopted methodology is based on a complete investigation into the steady state security, short circuit analysis, and dynamic stability assessment with respect to the existing transmission connection and the on going generation project. The salient point used for generation scheduling during the study years are:-

i. Full dispatch of generating resource in the Southern part of West Coast grid.
ii. The transfer of power through the East – West Interconnection link will depend on the generation merit order as stated in the Appendix B

3.2 Steady-state security analysis

3.2.1 Contingency analysis

The basic principle of the planning and operation is to ensure all the transmission equipment operates within their respective normal thermal ratings and voltage limits when the system is operating during normal condition. All the transmission equipment should also operate within its emergency thermal ratings and voltage limits immediately after a disturbance with the loss of an element without operator involvement. The system should be capable of such conditions for all times including operations during minimum and maximum forecasted load conditions. This N-1 condition is applied in both steady state and stability analyses.

Normal thermal ratings and voltage limits represent equipment limits that can be sustained indefinitely without increasing risk of failure and equipment damaged. On the other hand, emergency thermal ratings and voltage limits represent equipment limits that can be tolerated for a relatively short time, such as a few hours. Even though there is a definite risk of equipment damaged when the system is operating under emergency conditions, the increased risk is tolerable on the basis that such conditions will occur infrequently and that the system grid operators would take necessary actions to return the equipment to within normal limits promptly.

For the purpose of investigating the security of the grid system, the system will be tested for adequacy by means of the steady state (power flow) analysis and stability security using a dynamic simulation program. The system may be tested for voltage instability (voltage collapse) and overload cascading using steady state analysis tools. The steady state assessments performed will concentrate on:

- Economic operation by applying generation dispatch and scheduling according to the Merit Order.
- N-1 contingencies for the year 2012 and 2013scenarios with peak and trough load levels
- Several selected N-2 contingencies
- P-V curve Analysis during normal and contingency conditions for both West Coast grid and east Coast Grid systems.

3.2.2 Criteria used for steady-state assessment

The criteria used for the steady-state assessment is tabulated in the Table 3.1 below.

Table 3.1: The criteria used for the steady state assessment

Normal Condition	
Items	**Limit/Requirements**
Steady state voltage variation	0.95 – 1.05 p.u
Equipment Loading	
• Large Transformer	Within 100% of their Rating
• Transmission Lines	Within 100% of their Rating
Steady state conditions following contingencies	
Single Contingencies (N-1)	
Steady state voltage variation	275kV ± 10% (0.9 – 1.1 p.u)
	132kV ± 5% (0.95 p.u – 1.05 p.u)
	66kV ± 5% (0.95 -1.05 p.u)
Equipment Loading	
• Large Transformer	Emergency loading up to 130% is allowed
• Transmission Lines	Within 100% of their Rating
Double Contingencies (N-2)	
Steady state voltage variation	0.9 – 1.1 p.u
Equipment Loading	
• Large Transformer	Emergency loading up to 130% is allowed
• Transmission Lines	Within 100% of their Rating

3.2.3 Summary of model development and base cases

The methodology used in this study analysis involves the following 3 steps as described. In Step 1, the study base cases are defined.The base cases are prepared and carry two scenarios:

i. System peak load scenario
ii. System trough load scenario

Table 3.2 and table 3.3 represents the four base cases during system peak load and system trough load.

Table3.2: Cases considered during System peak and System trough for the year 2012

Case	**System Demand (MW)**
System Peak load	828
System Trough load	380

Table3.3: Cases considered during System peak and System trough for the year 2013

Case	**System Demand (MW)**
System Peak load	907
System Trough load	430

In Step 2, simulations are conducted on each base case defined in Step 1 using the PSS/E software version 32.Finally in Step 3, measures for mitigating the constraints are identified.The following general assumptions are made:

a) The SESB Grid System is modeled from 275kV down to 33kV
b) Generation dispatching is according to merit order where all the economical generator sets are in the highest order as stated in the Appendix B
c) In this study, the installed shunt capacitors, reactors and SVC are modelled.

Grid network models used for the base cases are in the form of load flow data (PSS/E version 32). Most parameters used in developing the network models are inherited from the existing PSS/E data used by Operation Planning Department, Sabah Electricity Sdn. Bhd.

In this study, the installed shunt capacitors, reactors and SVC are modelled. The full list is shown in Table 3.4.

Table 3.4: Status of shunt capacitors, reactors and SVC

No	Substations	Equipment	Size	Remarks
1	Penampang	66kV Capacitor bank	2x10MVAr	In operation
2	Penampang	11kV Capacitor bank	2x4MVAr	Available but not in operation
3	Inanam	11kV Capacitor bank	2x4MVAr	Only one is available for operation, but not operated
4	TgLipat	11kV Capacitor bank	3x4MVAr	Not operational due to control system problem
5	TgAru Old PS	11kV Capacitor bank	4 units	Not available after 2 units caught fire
6	Ranca-Ranca	132kV Bus Shunt reactor	2x16MVAr	In operation
7	PPU Mowtas	11kV Capacitor bank	2x3MVAr	Available but not in operation
8	PPU BatuSapi	11kV Capacitor bank	2x3MVAr	Available but not in operation
9	PPU Leila Road	11kV Capacitor bank	2x3MVAr	Available but not in operation
10	PPU PasirPutih	11kV Capacitor bank	2x3MVAr	Only one is in operation
11	PPU Wakuba	11kV Capacitor bank	4x3MVAr	Not operational because PPU not taking up load, problem with 33/11kV transformer
12	PPU Kubota	11kV Capacitor bank	2x3MVAr	In operation
13	PPU Balung	11kV Capacitor bank	2x3MVAr	In operation
14	PPU Seri Menanti	11kV Capacitor bank	2x3MVAr	In operation
15	Tawau PS	11kV Capacitor bank	2x3MVAr	In operation
16	Segaliud	275kV SVC	± 60MVAr	In operation
17	Dam Road	132kV SVC	± 60MVAr	In operation

3.2.4 Selection of contingency and monitored elements

The monitored elements selected are at 66kV level and above for the WCG system, and 33kV and above for the ECG system. Emergency ratings, typically 100% of normal continuous ratings, were used for all monitored branches.

The automatic contingencies lists include all valid single contingency (N-1) 33kV to 275kV branches in monitored area lists. The selected double contingencies (N-2) are given as follows:-

- 132kV Kolopis – Karambunai
- 132kV Kolopis – Penampang
- 132kV Karambunai – Kayumadang
- 132kV Karambunai – Inanam
- 132kV Kayumadang – UMS
- 132kV Penampang – Inanam
- 66kV Penampang – Inanam
- All 33kV ring circuits in Sandakan

3.2.5 N-1 contingency analysis

The main purpose of the contingency analysis is to access the reliability of a power system with respect to weaknesses in the system. Power system reliability can be evaluated from a probabilistic or deterministic standpoint, depending on the planning and operations criteria. Most of the power systems adhere to an (N-1) contingency criterion where the system can perform adequately and securely with equipment within ratings during the outage of a single major system component. It also provides critical information to the system operators on the system security in anticipation of the next possible contingency.

The preservation of the system security requires that the power system to be designed and operated under normal operating conditions where imposition of any of the credible contingencies will not result in interruption of firm load or result in hazardous conditions to bulk power system requirement.

3.2.5.1 Assumption and methodology used for N-1 contingency analysis

The initial step of the analysis is to run the load flow base cases to identify errors and violations that can cause undesirable results. All errors or violations in the cases are solved prior to the study.Results obtained from the simulation can be categorized as follows:-

- Voltage violation – any voltage that exceed the criteria used
- Loading violation – any component loading that exceed 100% of the normal loading
- Voltage collapse – any voltage collapse that occurs in the system that is indicated when power flow iteration reaches the non-divergence stage
- System islanding – when the system are isolated from the swing bus or source

3.2.6 N-2 contingency analysis

In addition to satisfactory performance of the power system network under normal system conditions (base case condition) and single contingency conditions, the power system should also be able to withstand certain severe but less probable disturbances without suffering voltage collapse or instability. Means should be provided to limit the impact of very severe disturbances, such as the loss of all transmission lines on the same right-of –way and loss of all generation units at a power station.

These principles are categorized into four (4) categories of contingencies with increasing severity:

- Single contingencies – exemplified by contingencies such as single generator, single transformer or single line outages. Only single contingencies are included among the credible (more probable) contingencies.

REFERENCES

1. Taylor, C. W.*Power System Voltage Stability*. McGraw Hill. 1994.
2. Morison, G., Gao, B. andKundur, P. Voltage stability analysis using static and dynamic approaches. *IEEE Transactions on Power Systems*. vol. 8. no.3. 1993. pp. 1159 – 1171.
3. Obadina, O. O. and Berg, G. J. Identifying electrically weak and strong segments of a power system from a voltage stability viewpoint. *IEE proceeding*. vol. 137. Pt. C. No. 3. 1990.
4. Kundur, P., Paserba, J., Ajjarapu, V., Anderson, G., Bose, A., Canizares, C., Hatziargyriou, N., Hill, D., Stankovic, A., Taylor, C., Cutsem, T. V., and Vittal, V. Definition and Classification of Power System Stability. *IEEE Transactions on Power System*. Vol.19. no.2. 2004. pp. 1387 -1401.
5. TNB - SESB Working Group Task Force. *Assessment & Review of the 30th April 2012 Event.*May 2012.Unpublished.
6. Operation Planning Department.*Voltage Stability Monitoring.*2012. Unpublished.
7. Weedy,B.M., and Cox, B.R.Voltage Stability of Radial Power Link. *Proceeding of IEE.*vol.115. No.4. 1968. pp. 528 – 536.
8. Brownell, G. and Clark, H.Analysis and Solution for Bulk System Voltage Instability. *IEEE.*1989, pp.31-35.
9. Lee, B.H. and Lee, K.Y. A study on voltage collapse mechanism in electric power systems.*IEEE Transactions on Power System*. Vol. 6. No. 3. 1991. pp. 966 – 974.

10. Vu, K. T. An Analysis of Mechanism Voltage Instability. *IEEE proceeding paper*.1992. pp.2529-2532.
11. Yorino, N., Sasaki, H., Masuda, Y., Tamura, Y., Kitagawa, M. and Oshimo, A.An investigation of voltage instability problems. *IEEE Transactions on Power System*. 1992.pp. 600 – 611.
12. Nagao, T., Tanaka, K., andTakenaka, K. Development of Static and Simulation Program for Voltage Stability Studies of Bulk Power System. *IEEE Transaction of Power System*, vol. 12. No.1. 1997. pp.273-281.
13. Tran-Quoc, T., Vu-Due, T., Feuillet, R., Hadjsaid, N.,Sabonnadire, J.C. Praing, C.H. and Tran-Dinh' L. Dynamic Analysis on the Voltage Instability in the Vietnam System.*IEEE Catalogue No: 98EX137*.1998. pp.177-182.
14. Vournas, C.D., Manos, G. A.,Kabouris, J.,and Cutsem, T. V. Analysis of Voltage Instability Incident In the Greek Power System. *IEEE Catalogue*.2000. pp.1483-1488.
15. Cutsem, T. V.Voltage Instability: Phenomena, Countermeasures, and Analysis Methods. *Proceeding of the IEEE*.vol. 88. No. 2. 2000. pp.208-227.
16. Liu J., Wang Z., Tang X., and Liu Z. An Urgent Direct Load Control Scheme Against Voltage Instability Based on Tendency Analysis. *The Institutions of Electrical Engineers*.Printed and Published by the IEE.2004. pp.623-626.
17. Hasani, M. and Parniani, M. Method of Combined Static and Dynamic Analysis of Voltage Collapse in Voltage Stability Assessment. *IEEE/PES Transmission and Distribution Conference & Exhibition, Asia & Pacific Dalian, China*.2005.
18. Li, C., Yuan R., and Zheng Y., Analysis on Mechanisms of Mid and Longer-Term Voltage Instability.*International Conference on Power System Technology*.2006.
19. Tang Y., Ma S., and Zhong W. Mechanism Research of Short-Term Large-Disturbance Voltage Stability. *International Conference on Power System Technology*.2006.
20. Susuki, Y. andHikihara, T. Predicting Voltage Instability of Power System via Hybrid System Reachability Analysis. *Proceeding of 2007 American Control Conference*.July 11-13, 2007, pp.4166-4177.

21. Yang Z., Rajagopalan, S. andConto, J. Practical Voltage Stability Analysis. *IEEE proceeding paper*.2010. pp. 1 – 7.
22. Control Operation Department.*Disturbance Report on 30th April 2012*.1st May 2012. Unpublished
23. SuruhanjayaTenaga.*Sabah and Labuan Grid Code*.Planning Criteria (PC).23 March 2011.