CRITICAL POINT STUDY IN THE SABAH POWER GRID FOR CASCADING FAILURE BLACKOUTS

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fulfillment of the requirement for the award of the
Degree of Master of Electrical Engineering

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For my beloved wife

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ABSTRACT

Sabah System Grid is made up of 66kV, 132kV and 275kV which link up all major towns in Sabah and Federal Territory of Labuan. As the Grid Owner, SESB is responsible for the development, management and operation of the Sabah System Grid. All activities pertaining to the System Grid are bounded by the Sabah and Federal Territory Labuan Grid Code. As demand grows, the network also gradually becomes larger, the transmission line are now operated closer to their limit. As a result, the networks are more vulnerable to the disturbance than before. In April and May 2012, two blackout events took place successively in the power grid of Sabah, which led to the major blackout. Currently, faulty issues in the system can lead to the cascaded failure to the system grid. These issues also can affect the rotor angle of generation motor and cause a loss of generation in the system grid. In this project, the conceptual of Sabah system grid was design for simulation purposes. Then, the identified potential point to be the weakest point was further study. The overall of Sabah system grid is designed and simulated using a PSSE. After that, the potential location to be the weakest point in the Sabah Grid is simulated and analyse. Based on the study conducted, the 132kV northern grid and 275kV interconnection between west coast and east coast is the weakest point in the Sabah system grid. In addition, both interconnections are source from the same substation which is Kolopis substation. Loss of Kolopis substation can lead to the total blackout of Sabah system grid. Finally, the weakest point in the Sabah system grid was successfully identified.

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ABSTRAK

Grid Sistem Sabah terdiri daripada 66kV, 132kV dan 275kV yang menghubungkan semua bandar utama di Sabah dan Wilayah Persekutuan Labuan. Sebagai pemilik grid, SESB bertanggungjawab untuk membangunkan, menguruskan dan mengendalikan Sistem Grid Sabah. Semua aktiviti yang berkaitan dengan Sistem Grid SESB adalah kawal selia Kod Grid Sabah dan Wilayah Persekutuan Labuan. Saban tahun, permintaan beban semakin meningkat maka rangkaian talian juga secara beransur-ansur menjadi semakin besar. Ini akan menyebabkan talian penghantaran kini beroperasi hampir kepada had maksimum. Hasilnya, rangkaian akan lebih terdedah kepada gangguan daripada sebelumnya. Pada bulan April dan Mei 2012, dua peristiwa gangguan bekalan berlaku secara berturut-turut dalam grid kuasa Sabah, yang membawa kepada blackout utama. Pada masa ini, isu-isu yang kerosakan yang berlaku didalam sistem grid boleh membawa kepada kegagalan operasi dan menyebabkan masalah ini disebarkan kepada pencawang lain yang berdekatan. Isu-isu ini juga boleh mengganggu kepada kestabilan mesin penjanaan dan boleh menyebabkan kehilangan penjanaan dalam grid sistem. Di dalam projek ini, sistem grid Sabah akan direka dan bagi tujuan simulasi. Kemudian, titik potensi yang dikenal pasti untuk menjadi titik paling lemah dipilih untk kajian lebih lanjut. Keseluruhan grid sistem Sabah direka dan disimulasi menggunakan perisian PSSEBerdasarkan kajian yang dijalankan, grid utara 132kV dan 275kV sambungtara diantara pantai barat dan pantai timur merupakan titik yang paling lemah dalam sistem grid Sabah. Di samping itu, kedua-dua talian sambungtara ini mendapat sumber daripada pencawang yang sama iaitu pencawang masuk utama Kolopis. Apabila berlaku gangguan atau kerosakan pada pencawang masuk utama Kolopis, ia boleh membawa kepada gangguan bekalan berskala besar pada sistem grid Sabah. Akhir sekali, titik yang paling lemah dalam sistem grid Sabah telah berjaya dikenal pasti.

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LIST OF SYMBOLS AND ABBREVIATIONS

ADRS	-	Adaptive Distance Relay Scheme
CCU	-	Central Control Unit
ECG	-	East Coast Grid
GSF	-	Generation Shift Factors
GUI	-	Graphical User Interface
IEEE	-	Institute of Electrical and Electronics Engineer
KK	-	Kota Kinabalu
kV	-	KiloVolt
LODF	-	Line Outage Distribution Factors
p.u	-	Per unit
P2P	-	Peer To Peer
PSSE	-	Power System Simulator for Engineer
QoS	-	Quality of Service
RCU	-	Regional Control Units
SESB	-	Sabah Electricity Sendirian Berhad
TSPWG	-	TNB-SESB Planning Working Group
UTHM	-	Universiti Tun Hussein Onn Malaysia
WCG	-	West Coast Grid

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CHAPTER 1

INTRODUCTION

1.1 Project Background

The SESB Gris is made up of 66kV, 132kV and 275kV which link up all major towns in Sabah and Federal Territory of Labuan. As the Grid Owner, SESB is responsible for the development, management and operation of the Sabah Grid. All activities pertaining to the SESB Grid are bounded by the Sabah and Federal Territory Labuan Grid Code.

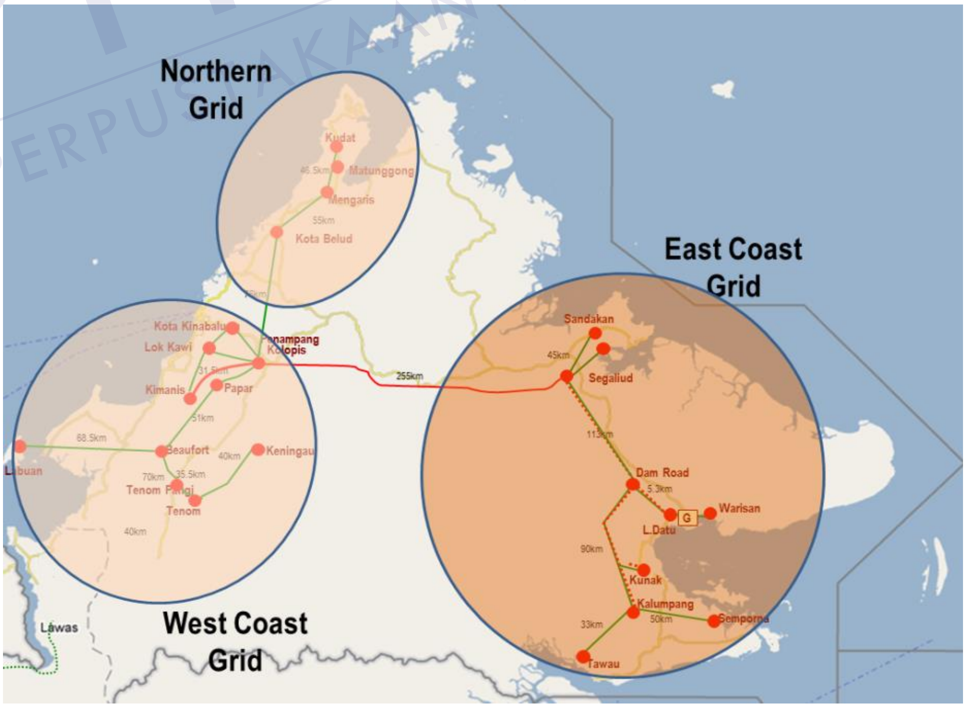

Figure 1.1: Sabah system grid

The SESB Grid is essentially divided into three; West Coast Grid (WCG), Northern Grid and East Coast Grid (ECG) as in figure 1.1, with the bulk of the generation and load in the WCG. Currently, these two areas are linked via a 275kV transmission line crossing the mountainous Crocker range. The topological of the Sabah grid is in figure 1.2.

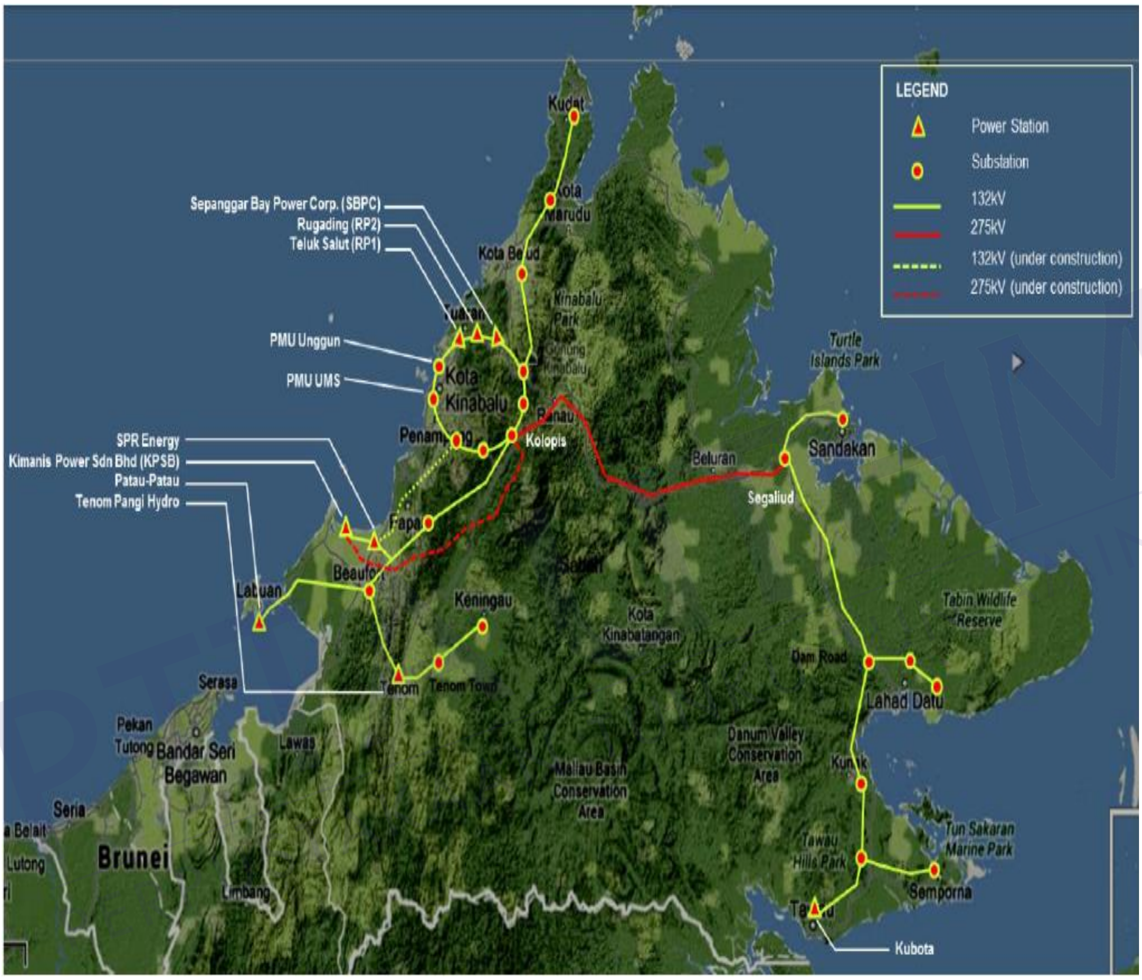

Figure 1.2: Topological of the Sabah grid

Power market is growing continuously and the utility networks are in a large-scale network to meet the market demand. Every utility company in the world is facing the same scenarios.

As demand grows, the network also gradually becomes larger, the transmission line are now operated closer to their limit [1]. As a result, the networks are more vulnerable to the disturbance than before. It will increase the possibility that the interconnection network may lose its stability and leading to the regional and even causes a total blackout [1].

As the demand continuously grows, the existing power grid cannot cater for the new demand. The existing power grid will operate closer to its limits. Without handling this new demand, the possibility of unstable condition in power grid can occur. This problem will disturb the frequency system which will lead to power grid failure.

The capability of the power grid to transfer power for a long distance also enables the propagation of local failures into the network. The power grid operates as a typical infrastructure network with vital concern of the society and the human lives. If a cascading failure happens in the power system, the bigger the network, the impact of the cascading failure will be at large-scale.

In recent years, there are many blackouts caused by cascading failures in the power system throughout the world. In April and May 2012, two blackout events took place successively in the power grid of Sabah, which led to the major blackout.

In April 2012, state-spread blackouts happened to the Sabah system grid. The fault was started at one of the 66kV substation in KK area and cascaded to the neighbouring substation. At the same time, loss of several large generating units makes the voltage at the system grid low and subsequently collapses the system frequency which led to the blackout. As seen, cascading failure was the severe case that could happen and will give a big impact to the utility power grid. A proper study has been conducted after this event happened. A task force investigation team has been created to investigate the causes of the failure and to avoid the same event to occur in the future.

Another event happened to the state of Sabah was in May 2012, faulty at 66kV in KK area led to the cascading failure which had affected the neighbouring transmission line. At this time, several big generations are also tripped and cause the power grid to become unstable. In order to stabilize the power grid and avoid widespread of cascading failure, some of the KK areas was operated in islanded mode until the power grid was stable.

In this proposal, an analysis to the Sabah power grid will be analysed to figure out the critical point that will lead to the power cascading failure. Finally, some findings and information for future planning to Sabah Power Grid for its reliable operation will also be analysed and discussed.

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1.2 Problem Statements

Sabah Electricity Sdn. Bhd is a utility company based in Sabah. As a utility company, the core business is to sell electricity to the consumer. Every year, the load demand in the state is continuously increasing. As the trending of load demand grows, the demand and expectation from the consumer to SESB also become high. The consumers are expecting reliable power will be supplied to them every day without fail.

To meet the demand and expectation, proper future planning is important. All equipment that being constructed have their own limitation. The existing equipment in the transmission line will operate closer to its limitation. This will make the system vulnerable to disturbance and the power grid to be unstable. This unstable condition will lead to power grid collapse and subsequently to cascading failure. Since the transmission line has no contingency, failure in another line will cause the other transmission line to be overloaded and tripped.

Another factor that contributes to the cascading failure is loss of generation in the power grid. As demand grows, a generation in the system should also be able to carry the load. Insufficient generation in the system will force the generator to run to its limits and created a thin reserve margin in the system. Sufficient reserve margin means the system is able to stabilize again when largest block of generation is trip in the system. Thin reserve margin will contribute instability in the system. Loss of generation occurs if there is a cascading failure in the power grid and make the system frequency fluctuated and also system voltage become low which will lead the generator to trip. Loss of generation in power grid will also disturb the system stability and can cause blackout.

1.3 Project Objectives

In a large-scale power grid system, more and more failure may occur during its operation. In this project, the major objective of this research is to analyse the operation of Sabah power Grid system.

Its measurable objectives are as follows:

i. To figure out the critical point that will lead to the power transmission cascading failure.

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ii. To propose future planning to Sabah power grid for its reliable operation

1.4 Project Scopes

This project is primarily concerned with the cascading failure. When cascading failure occurs, possibility of total blackout may happen in the power grid.

The scopes of this project are:

a) To do stability analysis of Sabah power transmission network.
b) Modelling the Sabah power transmission network.
c) Collect the transmission line data.
d) To give future planning power grid for reliable operation

1.5 Thesis Structure

In this thesis, it contains five chapters. For the chapter 1 is discussing on the introduction of this project. The introduction tell about the cascading event occur in the Sabah system grid. When cascading event occurs in the system, the system is at risk of total black out.

Chapter 2 is the literature of review. Previous study conducted and journals are selected as a reference for this project. The enhancement proposed in the previous study is taking into account to be implemented if necessary.

Chapter 3 discussed about the methodology. In this chapter, procedures to conduct a study using PSSE software are written. Using this software, few case study are built to be perform in chapter 4.

Chapter 4 are discussing on the result and analysis. Further elaboration is discussed in this chapter. This chapter contain four cases study to determine the weakest point in the system.

Chapter 5 is more to conclusion and future works to enhance and strengthening the Sabah System grid to its reliable operation.

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Chapter 2 is about the literature review on the previous studies conducted by other researchers. In this chapter, few technology and method were compared and summarized.

2.2 Theory

From Saadat [22], the tendency of a power to develop restoring forces equal to or greater than the disturbing forces to maintain the state of equilibrium is known as stability. If the forces tending to hold machines in synchronism with one another are sufficient to overcome the disturbing forces, the system is said to remain stable [22].

In stability, the concerned is the behaviour of the synchronous machines after a disturbance. Steady state stability refers to the ability of power grid to regain synchronism after small or slow disturbances, such as increase of load in the system of loss of generation.

$$\frac{H}{\pi f_0}\frac{d^2\delta}{dt^2} = P_m - P_{max}\sin\delta \tag{2.1}$$

The equation above is a nonlinear function of the power angle. However, for small disturbances, the equation may be linearized with little loss of accuracy as follows. Consider small deviation $\Delta\delta$ in power angle from the initial operating point δ_0.

$$\delta = \delta_0 + \Delta\delta \tag{2.2}$$

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Substituting to (1), we get

$$\frac{H}{\pi f_0}\frac{d^2(\delta_0+\Delta\delta)}{dt^2} = P_m - P_{max}\sin(\delta_0 + \Delta\delta) \qquad (2.3)$$

The above equation reduces to linearized equation in term of incremental changes in power angle.

$$\frac{H}{\pi f_0}\frac{d^2\Delta\delta}{dt^2} + P_{max}\cos\delta_0\Delta\delta=0 \qquad (2.4)$$

The quantity $P_{max}\cos\delta_0$ is the slope of the power angle curve at δ_0. It is known as the synchronizing power coefficient, denoted as P_s. This coefficient plays an important part in determining the system stability and is given by

$$P_s = \left.\frac{dP}{d\delta}\right|_{\delta_0} = P_{max}\cos\delta_0 \qquad (2.5)$$

Substituting in (5), we have

$$\frac{H}{\pi f_0}\frac{d^2\Delta\delta}{dt^2} + P_s\Delta\delta = 0 \qquad (2.6)$$

The solution of the above second –order differential equation depends on the roots of the characteristic equation given by

$$s^2 = -\frac{\pi f_0}{H}P_s \qquad (2.7)$$

When P_s is negative, we have one root in the right-half s-plane and the response is exponentially increasing and stability is lost. When P_s is positive, we have two roots on the j-w axis and the motion is oscillatory and undamped. The system is marginally stable with natural frequency of oscillation given by

$$W_n = \sqrt{\frac{\pi f_0}{H}}P_s \qquad (2.8)$$

It can be seen from figure 1 that the range where P_s is positive lies between 0 to 90° with a maximum value at no-load ($\delta_0 = 0$).

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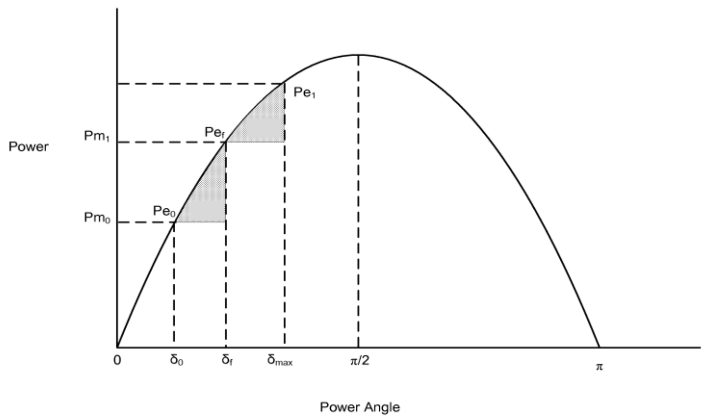

Figure 2.1: Power-angle curve

The gradual increase of the generator power output until the maximum electrical power is transferred as in figure2.1. This maximum power is referred to as the steady-state stability limit and occurs at angular displacement of 90°.

2.2.1 Power System Operation

Electric Power Systems can be defined as the transformation of other types of energy into electrical energy and the delivery of this energy to the points of consumption. The basic power system is the combination of 3 major components which are generation (energy conversion), transmission/distribution and load/consumption as shown in Figure 2.2 below.

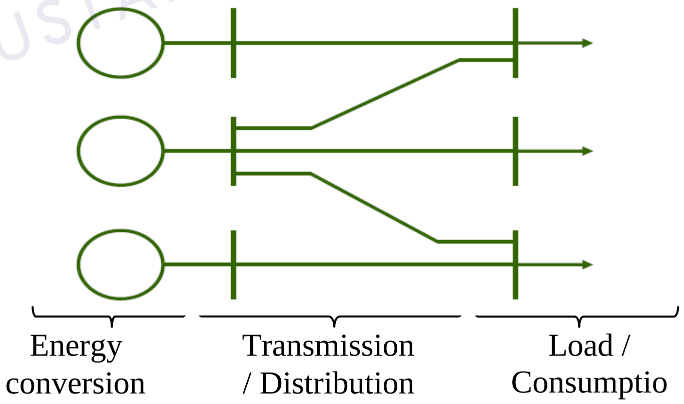

Figure 2.2: 3 major components in system grid

When the basic power systems are connected together through transmission or distribution lines/equipment, they become an interconnected power system. The objective of power system operation is to keep the electrical flows and bus voltage magnitudes and angles within acceptable limits (in a viable region of the state space), despite changes in load or available resources. Security may be defined as the probability of the system's operating point remaining in a viable state space, given the probabilities of changes in the system (contingencies) and its environment (weather, demand, etc.)

2.2.2 Dynamic and Stability

In power system, dynamic is about the study of the behaviour (trajectory, response and movement) of the power system states and controls following disturbances. Dynamic describes the behaviour, i.e., always changing or not remaining the same which sometime can be large and small. Since the power system is dynamic following a disturbance, states and controls will automatically adjust according to certain trajectories.

Stability is the ability of the states and controls to return to certain operating equilibrium following the disturbance. Stability describes the consequence of the dynamic behaviour, i.e., its ability to regain a state of equilibrium after a certain dynamic changes. Frequency stability concerned with the ability of a power system to maintain steady frequency within a nominal range following a severe system upset resulting in a significant imbalance between generation and load.

2.2.3 Reliability and Security

The degree of performance of the elements of the bulk electric system that results in electricity being delivered to customers within accepted standards and in the amount desired. Reliability may be measured by frequency, duration, and magnitude of adverse effects on electric supply. Electric system reliability can be addressed by considering two basic functional aspects of the electric system, which are adequacy and security.

System security is a subset of power system reliability which comprises of two components which are related to the time-frame of power system dynamics:

1) Adequacy
    - the ability of the power system to supply the aggregate electric power and energy requirements of the customers within component ratings & voltage limits, taking into account planned and unplanned component outages.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

REFERENCES

[1] J C Tan, P A Crossley, P G McLaren P F Gale, I Ha11, J Farre114 (2002).“Application of a wide area back-up protection expert system to prevent cascading outages”*IEEE transactions on power delivery, vol. 17, no2.*

[2] B. S. Bernstein and E. L. Brancato (2003).“Aging of Equipment in the Electric Utilities” *IEEE Transactions on Electrical Insulation VoJ.28 No.5*

[3] KeSun,Zhen-Xiang Han. (2005. “Analysis and Comparison on Several Kinds of Models of Cascading Failure in Power System” *IEEE/PES Transmission and Distribution Conference & Exhibition: Asia and Pacific Dalian, China*

[4] Seong-Il Lim, Chen-Ching Liu,Seung-Jae Lee,Myeon-Song Choi, and Seong-Jeong Rim. (2008). “Blocking of Zone 3 Relays to Prevent Cascaded Events”. *transactions on power systems, vol. 23, no. 2.*

[5] Jaime De La Ree, Yilu Liu, LamineMili, Arun G. Phadke, AndLuizDasilva (2002).catastrophic failures in power systems: causes, analyses, and countermeasures. *IEEE*

[6] G. Andersson, P. Donalek, R. Farmer, N. Hatziargyriou, I. Kamwa, P. Kundur, N. Martins, J. Paserba, P. Pourbeik, J. Sanchez-Gasca, R. Schulz, A. Stankovic, C. Taylor, and V. Vittal.(2005) “Causes of the 2003 Major Grid Blackouts in North America and Europe, and Recommended Means to Improve System Dynamic Performance” IEEE *transactions on power systems, vol. 20, no. 4*

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

[7] Qiming Chen,Chuanwen Jiang,WenzhengQiu, James D. McCalley. (2006)“Probability Models for Estimating the Probabilities of Cascading Outages in High-Voltage Transmission Network” *IEEE transactions on power systems, vol. 21, no. 3*

[8] Badrul H. Chowdhury, SushantBaravc,(2006). “Creating Cascading Failure Scenarios in Interconnected Power Systems”.*IEEE*

[9] U.S.-Canada Power System Outage Task Force,(2004). “Final Report on theAugust 14, 2003 Blackout in the United States and Canada: Causes andRecommendations,”*North American Electric Reliability Council,www.nerc.com.*

[10] G. Andersson, P. Donalek., R. Farmer, N. Hatziargyriou, I. Kamwa, P.Kundur, N. Martins, J. Paserba, P. Pourbeik, J. Sanchez-Gasca, R. Schulz,A. Stankovic, C. Taylor, V. Vittal, (2005).“Causes of the 2003 Major GridBlackouts in North America and Europe and Recommended Means toImprove System Dynamic Performance,” *IEEE Transactions on PowerSystems, vol. 20, no. 4.*

[11] Yi Jun, Zhou Xiaoxin, Xiao Yunan.(2006). “Model of Cascading Failures in Power Systems".*International Conference on Power System Technology*

[12] HuiRen, Ian Dobson,*(2008.)* “Using Transmission Line Outage Data toEstimate Cascading Failure Propagation inan Electric Power System”*IEEE transactions on circuits and systems: express briefs, vol. 55, no. 9.*

[13] Task Force on Understanding, Prediction, Mitigation and Restoration of Cascading Failures IEEE PES Computer and Analytical Methods Subcommittee. (2009).“Vulnerability Assessment for Cascading Failuresin

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

Electric Power Systems" *IEEE Power and Energy Society Power Systems Conference and Exposition, Seattle, WA*

[14] Xiaona Wang and Xusheng Wu XiaoguangYang, XiweiZai, Chan Li and Youping Fan Wu.(2009). "Distributed Model Predictive Control EmployingTrajectory Sensitivities for Cascading Failures".*IEEE*

[15] John Alejandro Sanchez, Mario Alberto Rios, Baisser Antonio Jimenez. (2009). Simulation of Cascade Contingencies in PowerSystems.*IEEE*

[16] XinZou, Lin Cheng, Yuanzhang Sun. (2010). "Evaluation of Cascading Failure in Power System Based on the Operational Reliability Theory". *IEEE*

[17] Yun Wang, Bo Wang, and Ming Liang.(2010). "A Smart Power System Cascading FailureAccident Prediction Model Basedon Probability Analysis". *International Conference on Power System Technology*

[18] Zhongying Shi, Libao Shi, Yixin Ni. (2011). "Identifying Chains of Events During Power SystemCascading Failure".*IEEE*

[19] NurAshidaSalim, Muhammad Murtadha Othman, Ismail Musirin, Mohd SallehSerwan. (2011). "Cascading Collapse Assessment Considering Hidden Failure"*First International Conference on Informatics and Computational Intelligence*

[20] Daniel Bienstock. (2011). "Optimal Control of Cascading Power Grid Failures" *.50th IEEE Conference on Decision and Control and European Control Conference (CDC-ECC), Orlando, FL, USA,*

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

[21] Weijing Du, JunmingZhang,Yang Zhang, ZhaomingQian.(2013). "Stability Criterion for Cascaded System With Constant Power Load" *IEEEtransactions on power electronics, vol. 28, no. 4*

[22] HadiSaadat. *Power System Analysis*.Second Edition McGraw Hill. (2004).

[23] Karl A. Homburg, Short-Circuit, Coordination, and Arc-Flash Studies for Data Centers: Best Practices and Pitfalls. *PE, Staff Power Systems Engineer, Square D Engineering Services Copyright © 2009 Schneider Electric. All Rights Reserved.*

[24] Xueguang Wu, Joseph Mutale, Nick Jenkins and GoranStrbac (2003).*An investigation of Network Splitting for Fault Level Reduction*

[25] Arief Ibrahim Wuller, Anita Pharmatrisanti. *Transmission Line Assessment* 2012 IEEE International Conference on Condition Monitoring and Diagnosis 23-27 September 2012, Bali, Indonesia

[26] D. O. Koval, FIEEE A. A. Chowdhury. (2009)*Assessment of Transmission Line Common Mode, Station Originated and Fault Types Forced Outage Rates*

[27] Sérgio Kurokawa,Afonso J. Prado, Carlos M. Portela, Maria Cristina Tavares, José Pissolato Filho. Behavior of Overhead Transmission Line Parameterson the Presence of Ground Wires.*IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 20, NO. 2, APRIL 2005*.ms1669-1675

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH