Faculty of Electrical Engineering

MODELLING AND ANALYSIS OF THE DYNAMIC BEHAVIOR OF THE POWER SYSTEM DURING LARGE – SCALE CONTINGENCY

Bashar Sabeeh Abdulraheem

Master of Electrical Engineering (Industrial Power)

2016

MODELLING AND ANALYSIS OF THE DYNAMIC BEHAVIOR OF POWER SYSTEM DURING LARGE – SCALE CONTINGENCY

BASHAR SABEEH ABDULRAHEEM

A dissertation submitted
In partial fulfilment of the requirements for the degree of Master of Electrical Engineering (Industrial Power)

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2016

DECLARATION

I declare that this dissertation entitled "Modelling and Analysis of the Dynamic Behavior of Power System During Large - Scale Contingency" is the result of my own research except as cited in the references. The dissertation has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	....
Name	:	Bashar Sabeeh Abdulraheem
Date	:	....

APPROVAL

I hereby declare that I have read this dissertation and in my opinion this dissertation is sufficient in terms of scope and quality for the award of Master of Electrical Engineering (Industrial Power).

Signature : ....

Name : Assoc. Prof. Dr. Gan Chin Kim

Date : ....

DEDICATION

I dedicate my dissertation work to my family and many friends. A special feeling of gratitude to my loving parents, Widad Salman and Sabeeh Abdulraheem whom words of encouragement and a push for tenacity to improve myself throughout all my walks of life. Thank you for giving me a chance and I love you.

I also dedicate this dissertation to my beloved children's Raya and Abdullah. And my brothers Dr. Ammar and Ethar and my sisters Dr. Noor and Dr. Shams who have supported me through my life. I always miss and I cherish the memories that we had. I love all of you.

I do not forget to dedicate this work to my sweetheart Istabraq Sabah who has always been with me in overcoming difficult times in my life. His patience is the meaning of love, kindness and gentle soul, thus I love you.

ABSTRACT

The main variables that ensure the power system stability of any electrical network are system frequency and voltage profile. To provide sufficient power, it is necessary to extend the electrical power network by adding either new generating units or transmission lines. Due to economic and environmental constraints for new installation, and consequent growth of loads that create overload situation due to extremely loaded network or increased transmission lines flow on existing transmission lines, power system stability has become more susceptible to various disturbances and outages. This dissertation presents investigation on the dynamic behavior of power system in terms of system frequency and voltage profile during extreme contingencies such as loss of single generator units, extremely loaded network, loss of a single transmission line, and occurring island grids. This paper also presents investigation on system frequency sensitivity for various severity levels (light, medium, and heavy) of these contingencies and implemention of load shedding scheme at predetermined frequency in order to restore the system frequency and voltage profile within acceptable limits. IEEE 39 bus has been modeled as a test case by using DigSILENT power factory software, and the results has been validated with IEEE reference case. The test case has been used to perform the contingencies events. To evaluate the impact of these contingency events on transmission system in terms of system frequency and voltage profile, the system behavior has been observed before and after implementing load shedding scheme. The results show that a deficit in power system due to loss of generator unit having larger capacity will cause severe drop in system frequency and voltage profile. Meanwhile, increasing load demand with insufficient generation within specific electrical network will create overload situation, leading to decline system frequency and voltage profile. The severity of decline increases with the increase of the severity of overload. The results for loss of a single transmission line show minor change in system frequency and voltage. In addition, the critical branches based on generator has been identified in IEEE 39 bus system, and the results show that loss of these critical branches causes the system to behave exactly similar to loss of a single generator unit in terms of system frequency and voltage. The results also show that creating island grid with large amount of exchange power with neighbouring zones also causes severe decline in system frequency and voltage. System behavior has been observed after implementing load shedding scheme for above contingencies events, and the results show improvement in system frequency and voltage behavior within acceptable limits and has regained power system stability. This research study provides an insight into the need of delicate balance between electricity generation and load demand, and the consequences of rapid disturbances in electrical power system.

ABSTRAK

Frekuensi sistem dan profil voltan merupakan pembolehubah utama yang berfungsi memastikan kestabilan sistem tenaga untuk jaringan elektrik. Untuk membekalkan tenaga yang mencukupi, jaringan tenaga elektrik perlu dikembangkan sama ada dengan menambahkan unit janakuasa atau dawai transmisi baru. Disebabkan kekangan ekonomi dan alam sekitar untuk pemasangan baru, dan seterusnya penambahan bebanan yang akan mengakibatkan lebih muatan akibat jaringan yang terlalu padat atau penambahan dawai pada dawai transmisi yang sedia ada, kestabilan sistem tenaga terdedah kepada pelbagai gangguan dan putus bekalan. Kertas kajian ini membincangkan siasatan ke atas tingkahlaku dinamik sistem tenaga dalam terma frekuensi sistem dan profil voltan semasa kontijensi ekstrem, sebagai contoh kehilangan unit janakuasa tunggal, lebihmuatan jaringan, kehilangan dawai transmisi tunggal dan grid pulau. Kertas ini juga memaparkan siasatan ke atas sensitiviti sistem frekuensi untuk pelbagai tahap sensitiviti kontijensi (ringan, sederhana, berat) dan pelaksanaan skim susutan beban pada frekuensi pra-tentuan untuk mengembalikan sistem frekuensi dan profil voltan dalam had yang sesuai. Bas IEEE 39 telah digunakan sebagai model untuk kes ujian, dengan menggunakan perisian DigSILENT, dan hasil ujian telah disahkan dengan kes rujukan IEEE. Kes ujian ini telah digunakan untuk menjalankan kontijensi. Untuk menilai kesan kontijensi ke atas sistem transmisi dalam aspek frekuensi sistem dan profil voltan, tingkahlaku sistem telah dipantau sebelum dan selepas pelaksanaan skim susutan beban. Keputusan menunjukkan terdapat defisit dalam frekuensi sistem dan profil voltan. Manakala, menambahkan permintaan beban dengan janaan yang kurang dalam jaringan spesifik elektrik akan mengakibatkan situasi lebihmuatan, dan menjurus kepada penyusutan frekuensi sistem dan profil voltan. Keterukan penyusutan meningkat dengan peningkatan keterukan lebihmuatan. Keputusan untuk kehilangan dawai transmisi tunggal menunjukkan sedikit perubahan dalam frekuensi sistem dan voltan. Tambahan pula, cawangan kritikal berdasarkan penjanaan telah dikenalpasti dalam sistem bas IEEE39, dan hasil keputusan menunjukkan bahawa kehilangan cawangan kritikal ini akan menyebabkan sistem menunjukkan tingkahlaku yang sama seperti kehilangan unit janakuasa tunggal dalam terma sistem frekuensi dan voltan. Keputusan juga menunjukkan kewujudan grid pulau dengan penukaran tenaga yang besar dengan zon bersebelahan akan menjurus kepada susutan yang teruk dalam sistem frekuensi dan voltan. Tingkahlaku sistem telah dipantau selepas pelaksanaan skim susutan beban untuk kontijensi yang telah dinyatakan, dan keputusan menunjukkan penambahbaikkan dalam tingkahlaku sistem frekuensi dan voltan dalam had yang sesuai, dan kestabilah sistem tenaga dapat dikembalikan. Kajian ini memperlihatkan keperluan keseimbangan di antara penjanaan elektrik dan permintaan beban, dan seterusnya kesan gangguan yang pesaat dalam sistem tenaga elektrik.

AKNOWLEDGMENT

In completing this dissertation, I am indebted to so many people, researchers, academicians and industrial practitioners. They have contributed towards my understanding and skills in successfully carrying out this dissertation. In particular, I wish to express my sincere appreciation to my main supervisor, I must thank Assoc. Prof. Dr. Gan Chin Kim with all of my heart who gave me encouragement, guidance and support from the initial to the final level of my project.

I am also very thankful to lectures and professors in Universiti Teknikal Malaysia Melaka (UTeM) for their guidance, advices and motivations. Many thanks to my teachers in the first degree in AL- Mustansiriya University, College of Engineering. I appreciate their continued support and interest in my course study.

My gratitude also to Universiti Teknikal Malaysia Melaka (UTeM). They deserve special thanks for the assistance in supporting students by conferences, technical talks and workshops.

Many thanks to fellow postgraduate students whom also should be recognised for their support. My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. I am grateful to all my family members.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

AIEE	-	American Institute of Electrical Engineers
AEMC	-	Australian Energy Market Commission
AVR	-	Automatic Voltage Regulator
DigSILENT	-	Digital Simulation and Electrical Network
ENTSO-e	-	European Network of Transmission System Operators for Electricity
EGAT	-	Electricity Generating Authority of Thailand
GOV	-	Governors
GW	-	Gigawatts
GE	-	General Electric Company
HZ	-	Hertz
IEEE	-	Institute of Electrical and Electronics Engineers
MTSO	-	Malaysian Transmission System Operator
MW	-	Megawatts
NERC	-	North American Electric Reliability Corporation
NEMMCO	-	National Electricity Market Management Company Limited

PSS	-	Power System Stabilizer
PES	-	IEEE Power and Energy Society
PF	-	Power Factory Software
PSDPC	-	IEEE Power System Dynamic Performance Committee
P.U	-	Per Unit
RENAC	-	Renawables Academy
TNB	-	Tenaga Nasional Berhard
SESCO	-	Sarawak Energy Supply Corporation
SNKO	-	Senoko City Symbol
SCS	-	Stability Control System
UCTE	-	Union for the Coordination of the Transmission of Electricity

LIST OF APENDENCES

CHAPTER 1

INTRODUCTION

1.1 Research Background

For every country, electrical power systems represent the heart of industrial growth and socioeconomic development. Modern power systems, which encompass generating stations, transmission and distribution electric energy, represent the largest and most expensive man–made system in the 20^{th} century (Makvand, 1999). The accomplishments of each modern nation depend upon electric energy. Electrical power is typically generated at frequency 50 or 60 Hz. In developing industries, their growing infrastructures have fatigued the power industry to provide sufficient power. The increase in generation capacity should continuously match the increase in load demand. Large power transfers across the grid lead to the operation of the transmission lines close to their limits. Additionally, generation reserves are minimal, short circuits, mechanical problems in cooling and fuel system, and problems in protection system etc., hence the power generated is insufficient to satisfy the load demands (Joshi, 2007). For this reason, electrical power systems become more susceptible to outage and disturbances.

The power system operation may be subjected to various contingencies vary in their severity level. The emergency circumstances faced by the electrical power system operation may adversely affect the performance of electrical power system operation. Sometimes the power system exposed to extreme contingences exceeds the severity of normal design contingencies (Kundur, 1994). The extreme contingencies according to (Stevenson Jr., 1989; Kundur, 1994; Anderson and Fouad, 2003) are explained as follows:

i. Loss of the entire capability of generation station.
ii. Loss of critical transmission lines which isolate parts of the transmission networks from the rest of the electrical system and create islanding network with an individual generating station or group of stations with insufficient plant capacity to carry out the local demand.
iii. Sudden dropping of a large load or major load center.

Consequently, these various contingencies make the electrical power system to become unstable. System frequency and voltage are the main variables that affect the power system stability, thus the study of these behavior during various contingencies is a very important issue. The main concern of this research is to investigate the system frequency and voltage profile behavior under certain load conditions and unit plant capacity limitations during different contingencies events in an electrical system. The study is hoped to provide insights into many aspects of problems associated with system frequency and voltage profile decay during operation of power systems.

The stability of system frequency in AC electrical systems is considered a good evaluation for system equilibrium. Figure 1.1 illustrates the delicate balance between load demand and production. Low frequency in general associated with increasing load demand with insufficient power generation and rising frequency associated with dropping load and create over-power generation. Frequency is the number of times that a full sine wave occurs per second in the grid, the global unit denoted for the frequency is hertz (Hz) or cycle per second (cps) (Klimstra, 2014). The normal value of the frequency depends on global location e.g for Japan and United State of America, their electrical grid operate using 60 Hz, while other countries of the rest of world e.g Malaysia, their electrical grid operate at 50 Hz. System frequency in the electrical networks is a measure for the rotational speed of power generators (ENTSO-e, 2015). According to the formula (1.1) given below, where f is system frequency, Ns is synchronous speed and p is number of poles. The synchronous speed of generator unit is linearly proportional with system frequency, if speed slow down system frequency decline and synchronous speed increase as the system frequency increase

$$Ns = \frac{120 * f}{p} \quad (1.1)$$

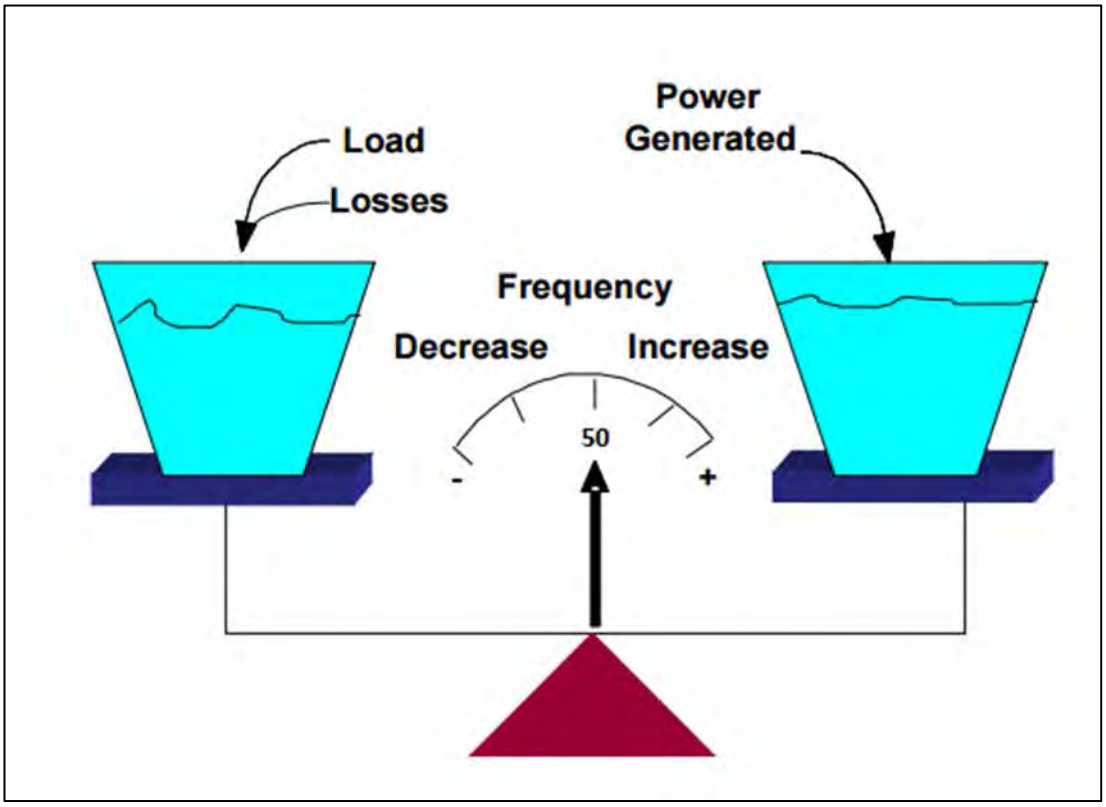

Figure 1.1: Balance between Electricity Production and Load Demand

(North American Electric Reliability Corporation, 2011).

If the load demand exceeds the power delivered by synchronous generators, the rotational speed will decrease for generator units within the system and it lead to deviate system frequency from their nominal value. Loss of a single generator will lead to a deficit in power generation system. Other generators in the system are not able to ramp up the power required instantaneously. Inability of power system generation to provide the required power necessary to meet the load demand causes a decline in system frequency, and increase in the decline depends on the severity of deficit in power system generation. Since system frequency linearly proportional with active power.

At the same time, voltage drop will occur due to inability of power system to meet the load demand in reactive power. Voltage drop occur when active and reactive power flow through inductive reactance associated with the transmission network. The severity of voltage drop increase when excessive current pass through the main load buses. Besides, if the load demand decreases, the system frequency will also increase. System frequency is mainly affected by active power, while the voltage is mainly affected by the reactive power (Joshi, 2007). Specifically, the study provides a valuable insight to the need of delicate balance between electricity generation and load demand, consequences of rapid disturbances in the electrical systems. Moreover, system frequency and voltage profile behavior are affected by the differences between electricity generation and load demand (Joshi, 2007).

To ensure stable operation for electrical systems the frequency and voltage at all buses, all components must be maintained within strict limits according to standards. These standards vary from one country to another. In Malaysia, Tenaga Nasional Berhad (TNB) has developed standards for acceptable system frequency and voltage profile limits, in which the system frequency of the electrical grid shall normally operate at 50 Hz, and be