



Ain Shams University
Faculty of Engineering
Electrical Power and Machines Department

RELIABILITY ASSESSMENT IN BULK POWER SYSTEM (GENERATION AND TRANSMISSION)

M.Sc. Thesis by:

Eng. Doaa Adel Hassan Sabry

B.Sc. in Electrical Power Engineering
Department of Electrical Power and Machines
Ain Shams University

A thesis Submitted to the Faculty of Engineering, Ain Shams University
in partial fulfillment of the requirements for the Degree of Master of
Science in Electrical Power and Machines Engineering

Under Supervision of:

Prof. Dr. Ahmed Rizk Abul'Wafa

Department of Electrical Power and Machines
Faculty of Engineering –Ain Shams University

Prof. Dr. Muhamed Abd Latif Badr

Department of Electrical Power and Machines
Faculty of Engineering –Ain Shams University

Cairo – Egypt
2015

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

وَقُلْ اَعْمَلُوا فَسَيَرَى اللَّهُ عَمَلَكُمْ وَرَسُولُهُ وَالْمُؤْمِنُونَ وَسَتُرَدُّونَ إِلَى عَالِمِ الْغَيْبِ وَالشَّهَادَةِ فَيُنَبِّئُكُمْ بِمَا كُنْتُمْ تَعْمَلُونَ

صدق الله العظيم

Approval sheet

For The Thesis

**RELIABILITY ASSESSMENT IN BULK POWER SYSTEM
(GENERATION AND TRANSMISSION)**

by:

Eng. Doaa Adel Hassan Sabry

B.Sc. in Electrical Power Engineering
Department of Electrical Power and Machines
Ain Shams University

A thesis Submitted to the Faculty of Engineering, Ain Shams University
in partial fulfillment of the requirements for the Degree of Master of
Science in Electrical Power and Machines Engineering

Approved by

Name

Signature

Prof. Dr. Ahmed Rizk Abul'Wafa

Department of Electrical Power and Machines
Faculty of Engineering –Ain Shams University

Prof. Dr. Muhamed Abd Latif Badr

Department of Electrical Power and Machines
Faculty of Engineering –Ain Shams University

Examiners committee

For The Thesis

**RELIABILITY ASSESSMENT IN BULK POWER SYSTEM
(GENERATION AND TRANSMISSION)**

by:

Eng. Doaa Adel Hassan Sabry

B.Sc. in Electrical Power Engineering
Department of Electrical Power and Machines
Ain Shams University

A thesis Submitted to the Faculty of Engineering, Ain Shams University
in partial fulfillment of the requirements for the Degree of Master of
Science in Electrical Power and Machines Engineering

Approved by

Name ,Title and affiliation

Signature

Prof. Dr. Adel Ali Abul'Elaa

Department of Electrical Power and Machines
Faculty of Engineering –Monofia University

Prof. Dr. Ibrahim Eldesoki Helal

Department of Electrical Power and Machines
Faculty of Engineering –Ain Shams University

Prof. Dr. Ahmed Rizk Abul'Wafa

Department of Electrical Power and Machines
Faculty of Engineering –Ain Shams University

Prof. Dr. Muhamed Abd Latif Badr

Department of Electrical Power and Machines
Faculty of Engineering –Ain Shams University

Statement

A thesis Submitted to the Faculty of Engineering, Ain Shams University in partial fulfillment of the requirements for the Degree of Master of Science in Electrical Power and Machines Engineering

The included work in this thesis has been carried out by the author at the Electrical Power and Machines Department of Ain Shams University .No part of this thesis has been submitted for a degree or qualification at any university or institution

Name: Doaa Adel Hassan Sabry

Signature:

Date:

Table of Contents

Acknowledgement	i
Abstract	ii
Table of Contents	iii
List of Tables	v
List of Figures	vi
List of Symbols and Abbreviations	viii

CHAPTER 1: Introduction

1.1 Introduction	1
1.2 Power System Reliability Evaluation	2
1.3 Bulk Power System Reliability	4
1.4 Predictive Indices and Past Performance Indices	6
1.5 Objectives of Thesis	8
1.6 Thesis Outline	9

CHAPTER 2: Composite System Adequacy Assessment

2.1 Definitions	11
2.2 Reliability Indices	12
2.2.1 Reliability Indices in HL-I	12
2.2.2 Reliability Indices in HL-II	13
2.2.3 Reliability Indices in HL-III	16
2.3 Bulk Power System Reliability Assessment Methods	17
2.3.1 Analytical and Monte Carlo Simulation Techniques	17
2.3.2 Comparison of Analytical and Monte Carlo Techniques	18
2.3.3 Analytical Technique	19
2.4 Composite System (HL-II) Adequacy Evaluation using Analytical Technique	22
2.5 Introduction to ETAP Software	22
2.6 Composite Test System	25
2.7 Base Case Studies for the RBTS	26
2.7.1. RBTS Analysis	26
2.8 Summary	28

Chapter 3: Composite System Reliability Evaluation with Station Related Maintenance Outages

3.1 Introduction	29
3.2 Model Descriptions	30
3.2.1 Basic Station Component Models	31
3.2.2 Station Component Models Including Maintenance Outages	33
3.2.3 Evaluation of Station Related Forced Outages	35
3.2.4 Station Related Maintenance Outages	39
3.3 Station Component Reliability Data	40
3.4 Analysis of Composite Test Systems with Stations	42
3.5 Comparison of The System Reliability Indices for the RBTS	51
3.8 Summary	53

Content

CHAPTER 4: Sensitivity Studies on Composite Test Systems with Stations

4.1 Introduction	54
4.2 Sensitivity Analyses of the Modified RBTS with the Four Different Station configurations	54
4.3 Summary	64

CHAPTER 5 : Conclusions

5.1 Conclusions	65
5.2 General Discussion	66
5.3 Future Work	66

References	67
-------------------	----

Appendices

Appendix A: Basic Data For The RBTS	74
Appendix B: Modified data for the RBTS with four station configuration	76
Appendix C: Customer Damage Function	80
Appendix D: Collection of Reliability Data	86

List of Tables

Table 2.1: Load bus indices for the RBTS	27
Table 2.2: System indices for the RBTS	27
Table 3.1: Load bus indices (RBTS with ring bus schemes)	47
Table 3.2: System indices (RBTS with ring bus schemes)	47
Table 3.3: Load bus indices (RBTS with double bus double breaker schemes)	48
Table 3.4: System indices (RBTS with double bus double breaker schemes)	48
Table 3.5: Load bus indices (RBTS with double bus double breaker schemes)	49
Table 3.6: System indices (RBTS with double bus double breaker schemes)	49
Table 3.7: Load bus indices (RBTS with double bus double breaker schemes)	50
Table 3.8: System indices (RBTS with double bus double breaker schemes)	50
Table 3.9: Relative impact on the system reliability indices for the RBTS due to the four different station configurations	51
Table A.1: TableA.1: Bus data for the RBTS	74
TableA.2: Line data for the RBTS	74
TableA.3: Generator data for the RBTS	74
TableA.4: Modified generator data for the RBTS with generating unit transformers	75
Table B.1: Modified line and transformer data for the RBTS with ring bus schemes	76
Table B.2: Modified line and transformer data for the RBTS with double bus double breaker schemes	77
Table B.3: Modified line and transformer data for the RBTS with one and half breaker schemes	78
Table B.4: Modified line and transformer data for the RBTS with one and one third breaker schemes	79
Table C.1: Sector CDF expressed in (\$/kW)	81
Table C.2: Assumed load compositions	82
Table C.3: CCDF in (\$/kW) for the test system	82
Table C.4: Sector peak load allocation for the RBTS	83
Table C.5: Sector peak load percentages for the RBTS	84
Table C.6: Sector energy consumption percentagesfor the RBTS	84
Table C.7: CCDF for the RBTS load buses in (\$/kW)	84

List of Figures

Figure 1.1: System reliability, adequacy and security	3
Figure 1.2: power system hierarchical levels	4
Figure 2.1: The relationship between m (MTTF), r (MTTR) and T cycle time	19
Figure 2.2: The state space diagram presentation	20
Figure 2.3: The Contingency Enumeration diagram presentation	21
Figure 2.4: Data file processing for ETAP	24
Figure 2.5: Single line diagram of the RBTS (BASE CASE)	25
Figure 3.1: state space model of a circuit breaker	31
Figure 3.2: state space model of a bus bar	32
Figure 3.3: state space model of a transformer	32
Figure 3.4: Model of two system components (including a common failure caused by station related outages)	33
Figure 3.5: Model of a circuit breaker (including maintenance outages)	34
Figure 3.6: Model of a transformer (including maintenance outages)	36
Figure 3.7: Equivalent model of a circuit breaker (without maintenance outages)	37
Figure 3.8: Model for two component overlapping forced outages	45
Figure 3.9: Single-line diagram of the RBTS with ring bus configurations	43
Figure 3.10: Single- line diagram of the RBTS with double bus double breaker configurations	44
Figure 3.11: Single- line diagram of the RBTS with one and one half breaker configurations	45
Figure 3.12: Single- line diagram of the RBTS with one and one third circuit breaker configurations	46
Figure 3.13: Relative impact on the system reliability indices for the RBTS due to the four different station configurations	52
Figure 4.1: Effect of varying the busbar failure rates in the RBTS with ring bus schemes	55
Figure 4.2: Effect of varying the circuit breaker failure rates in the RBTS with ring bus schemes	56

Content

Figure 4.3: Effect of varying the busbar failure rates in the RBTS with double bus double breaker schemes	57
Figure 4.4: Effect of varying the circuit breaker failure rates in the RBTS with double bus double breaker schemes	58
Figure 4.5: Effect of varying the busbar failure rates in the RBTS with one and one half breaker schemes	59
Figure 4.6: Effect of varying the circuit breaker failure rates in the RBTS with one and one half breaker schemes	60
Figure 4.7: Effect of varying the busbar failure rates in the RBTS with one and one third circuit breaker schemes	61
Figure 4.8: Effect of varying the circuit breaker failure rates in the RBTS with one and one third circuit breaker schemes	62
Figure 4.9: Increase rate of system EENS as a function of the circuit breaker failure rates for the modified RBTS with the four station schemes	63
Figure C.1: Reliability cost/reliability level diagram	80
Figure C.2 : Sector customer damage functions in (\$/kW)	81
Figure. C.3: Composite customer damage function in (\$/kW)	82
Figure C.4 : CCDF for the RBTS load buses in (\$/kW)	85

List of Symbols and Abbreviations

HL	Hierarchical Level
S	System state
RBTS	Roy Billinton Test System
PLC	Probability of Load Curtailment
ELC	Expected Load Curtailment
ENLC	Expected Number of Load Curtailment
EDC	Expected Damage Cost
ASAI	Average Service Availability Index
CAIDI	Customer Average Interruption Duration Index
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
MAIFI	Momentary Average Interruption Frequency Index
NERC	North American Electric Reliability Corporation
ENS	Energy Not Supplied
EENS	Expected Energy Not Supplied
IEEE	Institute of Electrical and Electronics Engineers
IEEE RTS	IEEE Reliability Test System
A	Availability
R	Reliability
U	Unavailability
λ_i	Failure rate of element i
μ_i	Repair rate of element i
f_i	Frequency of element i
P_i	Probability of element i

ACKNOWLEDGMENT

Thanks to ALLAH who gives us the power and hope to succeed.

Thanks must go to Allah the creator of this universe who ordered us to study and explore his creations in order to know him better. However, as I come to understand more, I find that there is so much more knowledge to absorb and to get to grips.

I am very grateful to all the people who have supported me during the pursuit of my Msc. degree. This work would not have been possible without their encouragement and help.

First and foremost, I would like to express my sincere appreciation and deep gratitude to my dissertation advisor, Prof. **Dr. Ahmed R. Aboul'Wafa and Prof. Dr. Mohamed Abd Latif Badr** for guidance, discussions, criticism, persistence and encouragement throughout the course of this study. Working under his supervision has been such a great pleasure. His open minded way of thinking and devotion has helped me get through several difficulties. I have learnt a lot through every discussion with him.

I would like to thank all colleagues of mine for their valuable comments, suggestions and friendship.

I would like to thank all staff members of faculty of engineering – Ain Shams University that will grant me the degree of Master of Science in Electrical Engineering

My deepest gratitude goes to all of my father ,husband and my son for their unconditional love and support.

Doaa Adel Sabry

Abstract

Electric power systems throughout the world are considerable changes due to the converging forces of degradation, technology revolution and evolving customer expectations. Quantitative reliability evaluation plays an important role in the development, design and operation of composite generation and transmission or bulk power systems.

This thesis presents research conducted on the development and examination of concepts, techniques and pertinent factors in the reliability evaluation of composite power systems.

Analytical method is used in this research to assess composite system reliability. The system reliability was measured through reliability indices output of ETAP software on reliability test system RBT (6bus) and the effects of station related outages are combined with the connected terminal failure parameters. RBTS was augmented with different configurations of substations (Ring bus-double bus double breaker- one and one half circuit breaker-one and one third circuit breaker) and reliability analysis was run for each configuration.

This thesis presents two main contributions. First, is determine the value of switching time, that is the time in hours for isolating a fault occurred at the component, on the calculation, which proved it's influential in improving reliability indices.

Second, the sensitivity analysis was run and shows the reliability indices of the RBTS with different configurations of substations. The failure parameters of the circuit breakers and bus bars are varied in order to observe this effect on the composite systems

Keywords: Bulk power system reliability, Adequacy, Contingency, ETAP simulation, Power quality and security.

Chapter 1

Introduction

This chapter provides a general background to the topic and the related research. The thesis objective and main contributions are presented.

1.1 Introduction

Modern society is highly dependent on the efficient operation of electric power systems and has developed in such a way that even a small interruption in electric power supply has a significant effect. Customers expect that electric power should be available 24 hours a day, 7 days a week without any interruption. The article *Power Cuts Can Wreck Business April 12, 1999: Fortune Magazine*, is evidence that illustrates the dependence of the world's advanced nations on electric power supply. In the early days of electricity supply, electric power was considered to be a luxury, but today it is a highly valued commodity. Although the number of electric power outages in developed nations has reduced considerably, developing nations are still coping with the problem of frequent power failures. The ability of a power system to provide customers with an adequate supply is usually designated by the term "reliability" [1].

Economic growth is highly dependent on the existence of reliable electricity supply at an affordable cost. Major electricity outages can occur due to incorrect planning and operation, equipment failures, vandalism, environmental conditions and adverse weather effects. The creation and operation of a completely reliable electric power system is technically and economically not viable. The practical way to avoid major power outages is to make a power system more reliable. This is usually accomplished by increasing the system redundancy and the capital investment.

Increasing the capital investment will result in increasing cost to the customer. Therefore, there has to be a balance between the cost and reliability of an electric power system.

Power system planners and designers sometimes find it difficult to achieve a balance between reliability and cost during the planning phase. Many electric power utilities use both deterministic and probabilistic techniques during the planning phase in order to assess power system reliability [2-12]. Probabilistic techniques can be used to incorporate a wide range of system behavior and are preferred over deterministic techniques [2]. Many probabilistic techniques are now available in the form of computer softwares for reliability analysis [5,12].

There are, however, still many unanswered problems particularly in the new deregulated environment and considerable research is in progress to address these issues.

It is important to consider the vast amount of work that has been done over the last five decades [2-12], when considering the problems that face electric power utilities at the present time. Some of the basic concepts associated with power system reliability are briefly introduced in the following section.

1.2 Power System Reliability Evaluation

Adequacy and Security:

Power system reliability assessment is primarily focused on an analysis of the healthy and failure states of a power system. Power system reliability can be subdivided in two classes as shown in Figure 1.1 [1,2].

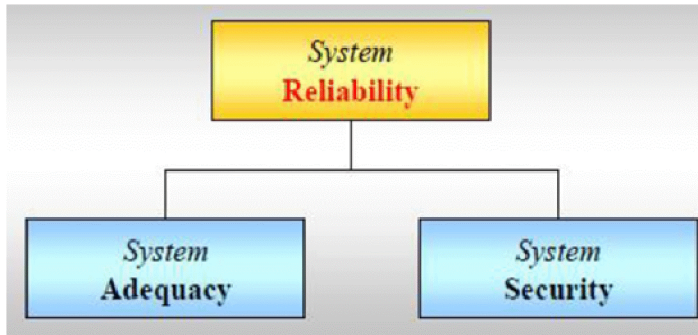


Figure 1.1: System reliability, adequacy and security

Adequacy assessment involves the determination of sufficient facilities within the system to satisfy the customer load and deals with static conditions in the power system. Power system security is the ability to respond to disturbance arising within the system and, therefore, deals with the dynamic conditions in the system.

• Adequacy:

- (i) “The existence of sufficient facilities within a power system to satisfy the customer demand”.
- (ii) “The ability of the electric system to supply the aggregate electrical demand and energy requirements of the end-use customers at all times, Taking into account scheduled and reasonably expected unscheduled outages of system elements”.