SELECTION OF TRANSMISSION NETWORK CONFIGURATION FOR TRINCOMALEE POWER PLANT GRID CONNECTION - TECHNICAL AND FINANCIAL FEASIBILITY STUDY FOR 220kV/400kV CONFIGURA TIONS

G.P. Senanayake

A dissertation submitted to the Department of Electrical Engineering, University of Moratuwa in partial fulfillment of the requirements for the Degree of Master of Science

Department of Electrical Engineering

University of Moratuwa,

Sri Lanka

94844

July 2010

Abstract

According to the Long Term Generation Expansion Plan 2009-2022 published by the transmission and Generation Planning Branch of Ceylon electricity Board there will be I our 250MW and I our 300MW coal plant units in Trineomalee area by the year2020. Therefore a necessity Has arisen for identify, plan and formulaic the transmission grid connection for the above mentioned coal fired power plants. Because of the large quantity of power which has to be transmitted from the proposed trineomalee Power Station it has been decided to investigate the possibility of utilizing 400kV as the transmission voltage against the present practice of transmitting power using 220kV.

Detailed power system analysis consisting of load flow and stability studies were conducted under night peak and day peak loading conditions to identify areas where the planning criteria were violated using the Power System Simulator for Engineering' (PSS1-) software package. Conclusions of the most feasible transmission network configuration for power plant-grid connection were drawn based on all the above power system analysis results, economic analysis results and other concerns. Saudis were conducted for year 2016 based on the "Long Term Transmission Development Plan 2008-2016* and for year 2020 based on the Master Plan Study on the Development of Power Generation and Transmission System in Sri Lanka -January 2006.

It is possible to identify 220kV and 400kV transmission network configurations, which are capable of successfully transmitting 2200MW power generated at trineomalee Power Plant in year 2020. But the 220kV configuration is economically viable with compare to 400kV configuration for trineomalee Power Plant Grid Connection. By considering all the advantages and disadvantages of selected 220kVand 400kV transmission network configurations, it is recommended that 220kVconfiguration be used as the trineomalee Coal Fired Power Plant Grid Connection.

Declaration

The work submitted in this dissertation is the result of my own investigation, except where otherwise stated.

It has not already been accepted for any degree, and is also not being concurrently submitted for any other degree.

UOM Verified Signature

G.P. Senanayake

Date: ....

We/I endorse the declaration by the candidate.

UOM Verified Signature

Prof. J.R. Lucas

UOM Verified Signature

Eng.W.D.A.S. Wijayapala

Abbreviations

BSC	Breaker Switched Capacitor
cct	Circuit
CEB	Ceylon Electricity Board
D/B	Double Bus Bar
FBs	Feeder Bays
FC	Foreign Cost
GBs	Generator Bays
GIS	Gas Insulated Switchgear
GS	Grid Substation
JICA	Japan International Cooperation Agency
LC	Local Cost
LKR	Sri Lankan Rupees
LTGEP	Long Term Generation Expansion Plan
PS	Power System
PSS/E	Power System Simulator for Engineering
TF	Transformer
TL	Transmission Line
SR	Successful Reclosing
SS	System Stable/Switching Station
S/B	Single Bus Bar
USR	Unsuccessful Reclosing
3PF	Three Phase Fault

Contents

Declaration i

Abbreviations ii

Contents iii

Abstract vi

Acknowledgement vii

List of Figures viii

List of Tables ix

List of Annexes xi

1. Background and Scope 1

1.1 Background 1

1.2 Problem Statement 1

1.3 Objectives 2

1.4 Methodology 3

2. Review of Trincomalee Power Plant Grid Connection for year 2016 4

2.1 Initial Transmission Network Configuration 4

2.1.1 Power Transmission Facility Related to Trincomalee Coal-Fired Thermal Plant 4

2.1.2 Construction of Kirindiwela 220/132kV Switching Station 5

2.1.3 Construction of Arangala 220/132kV Switching Station 5

2.2 Cost Estimation of Initial Transmission Network Configuration 6

2.2.1 Base Cost Estimation of the Initial Transmission Network Configuration 7

2.2.2 Disbursement Schedules and Total Cost Estimation of the Initial Transmission Network Configuration 8

2.3 Alternative 220kV Transmission Network Configurations for year 2016 9

2.3.1 Transmission Network with the new Loads of Northern Province 10

2.3.2 Trincomalee Coal Power Plant Grid Connection – Without Kirindiwela Switching Station 11

2.3.3 Trincomalee Coal Power Plant Grid Connection – Without New Habarana Switching Station 12

2.4 Steady State Analysis of Alternative 220kV Transmission Network Configurations for year 2016 13

2.4.1 Transmission Network with the new Loads of Northern Province 13
2.4.2 Trincomalee Coal Power Plant Grid Connection – Without Kirindiwela Switching Station 14
2.4.3 Trincomalee Coal Power Plant Grid Connection – Without New Habarana Switching Station 16
2.5 Economic Analysis of Alternative 220kV Transmission Network Configurations for year 2016 17
2.5.1 Trincomalee Coal Power Plant Grid Connection – Without Kirindiwela Switching Station 17
2.5.2 Trincomalee Coal Power Plant Grid Connection – Without New Habarana Switching Station 18
2.6 Evaluation of the Results of Alternative Transmission Network Configurations for year 2016 20
2.6.1 Transmission Network with the new Loads of Northern Province. 20
2.6.2 Trincomalee Coal Power Plant Grid Connection – Without Kirindiwela Switching Station 20
2.6.3 Trincomalee Coal Power Plant Grid Connection – Without New Habarana Switching Station 20
2.7 Transient Stability Analysis of Trincomalee Coal Power Plant Grid Connection – Without Kirindiwela Switching Station 21
2.8 Final 220kV Transmission Network Configuration for year 2016 22
3. Selection of Trincomalee Power Plant Grid Connection for year 2020 24
3.1 Selected 220kV and 400kV Transmission Network Configurations for year 2020 24
3.1.1 220kV Transmission Network Configuration 24
3.1.2 400kV Transmission Network Configuration 27
3.2 Steady State Analysis of the Selected Transmission Network Configurations for year 2020 31
3.2.1 Steady State Analysis of 220kV Transmission Network Configuration 31
3.2.2 Steady State Analysis of 400kV Transmission Network Configuration 32
3.3 Transient Stability Analysis of the Selected Transmission Network Configurations for year 2020 34

3.3.1 Transient Stability Analysis of 220kV Transmission Network Configuration 34
3.3.2 Transient Stability Analysis of 400kV Transmission Network Configuration 35
3.4 Economic Analysis of the Selected Transmission Network Configurations 35
3.4.1 Base Cost Estimation of 220kV Transmission Network Configuration 36
3.4.2 Base Cost Estimation of 400kV Transmission Network Configuration 37
3.4.3 Disbursement Schedules and Total Cost Estimation of the Selected 220kV Transmission Network Configurations 38
3.4.4 Disbursement Schedules and Total Cost Estimation of the Selected 400kV Transmission Network Configurations 39
3.4.5 Economic Evaluation of Transmission Network Configurations for year 2020 39
4. Conclusions 48
References: 51
Annexes 52

Acknowledgement

First and foremost I offer my sincerest gratitude to my supervisors, Professor Rohan Lucas and Eng.W.D.A.S.Wijayapala, who had supported me by stimulating suggestions and encouraging throughout my dissertation with their patience and knowledge. Also my thanks should go to Dr. J. P. Karunadasa, Head of the Department of Electrical Engineering, and the other members of the academic staff of the Department of Electrical Engineering, for their valuable suggestions and comments.

In addition I would like to thank the officers in Post Graduate Office of the Faculty of Engineering of University of Moratuwa for helping in various ways to clarify the things related to my academic works in time with excellent cooperation and guidance. Sincere gratitude is also extended to the people who serve in the Department of Electrical Engineering office.

Especially I must be thankful very much to my colleagues in the Transmission Planning branch of Ceylon Electricity Board for providing assistance in numerous ways to carry out the studies of the project.

I express my thanks and appreciation to my family for their understanding, motivation and patience. Lastly, but in no sense the least, I am thankful to all colleagues and friends for giving their fullest co-operation throughout the time of research and writing of this dissertation.

List of Figures

Figure 2.1 Trincomalee Coal Power Plant Grid Connection According to the " Long Term Transmission Development Plan 2008-2016" 6

Figure 2.2 Network with the new Loads of Northern Province.................................. 10

Figure 2.3 Trincomalee Coal Power Plant Grid Connection-Without Kirindiwela Switching Station.. 11

Figure 2.4 Trincomalee Coal Power Plant Grid Connection without New Habarana Switching Station.. 13

Figure 2.5 Final transmission network configuration for year 2016 system for Trincomalee Power Plant grid connection... 23

Figure 3. 1 220kV transmission network configuration of Trincomalee Coal Power Plant Grid Connection According to the Master Plan Study.................... 25

Figure 3.2 The proposed 220kV transmission network configuration of Trincomalee Coal Power Plant Grid Connection for year 2020.................................... 26

Figure 3.3 Relative Rotor Angle variation. following a three-phase short circuit fault in one circuit of the 400kV three-circuit 4xZebra transmission line between Trincomalee PS and Veyangoda GS.. 28

Figure 3.4 The proposed 400kV transmission network configuration of Trincomalee Coal Power Plant Grid Connection for year 2020.................................... 29

List of Tables

Table 2.1 Base Cost Estimation of Initial Transmission Network Configuration in year 2016 7
Table 2.2 Total Cost Estimation of Initial Transmission Network Configuration in year 2016 8
Table 2.3 Additional Loads of 2016 Power System in Liberated Areas of Northern Province 14
Table 2.4 Transmission Losses with and without Kirindiwela Switching Substation 14
Table 2.5 Contingency Results for Transmission Networks with and without Kirindiwela SS -Night Peak 15
Table 2.6 Contingency Results for Transmission Networks with and without Kirindiwela SS -Day Peak 15
Table 2.7 Transmission Losses with and without New Habarana Switching Substation 16
Table 2.8 Voltage violations without New Habarana SS 16
Table 2.9 Contingency Results for Transmission Networks without New Habarana SS 17
Table 2.10 Base Cost Estimation of Transmission Network Configuration-without Kirindiwela SS in year 2016 17
Table 2.11 Total Cost Estimation of Transmission Network Configuration-without Kirindiwela SS in year 2016 in year 2016 18
Table 2.12 Base Cost Estimation of Transmission Network Configuration-without New Habarana SS in year 2016 19
Table 2.13 Total Cost Estimation of Transmission Network Configuration-without New Habarana SS in year 2016 19
Table 2.14 Transient Stability Analysis Results of Trincomalee Coal Power Plant Grid Connection – With and Without Kirindiwela Switching Station 21
Table 3.1 Allowable voltage variations 31
Table 3.2 Voltage Levels and Loading Conditions after outage of critical 220kV Transmission Lines of selected 220kV Configuration 32
Table 3.3 Voltage Levels and Loading Conditions after outage of critical 220kV and 400kV Transmission Lines of selected 400kV Configuration 33

Table 3.4 Transient Stability Analysis Results of Selected 220kV Transmission Network Configuration of year 2020 34
Table 3.5 Transient Stability Analysis Results of Selected 400kV Transmission Network Configuration of year 2020 35
Table 3.6 Base Cost Estimation of Selected 220kV Transmission Network Configuration of year 2020 36
Table 3.7 Base Cost Estimation of Selected 400kV Transmission Network Configuration of year 2020 37
Table 3.8 Total Cost Estimation of Selected 220kV Transmission Network Configuration of year 2020 38
Table 3.9 Total Cost Estimation of Selected 400kV Transmission Network Configuration of year 2020 39
Table 3.10 Calculation of Present Value of Loss Saving 42
Table 3. 11 Calculation of Present Value of Expenditures 44
Table 3. 12 Calculated Load Factor values and corresponding Cost saving calculation 46

List of Annexes

Annex A- 1 2020 Transmission Network with 220kV Trincomalee Power Plant Grid Connection Configuration (Night Peak) 53

Annex A- 2 2020 Transmission Network with 400kV Trincomalee Power Plant Grid Connection Configuration (Night Peak) 54

Annex A- 3 Rotor angle variation following a three-phase short circuit fault in one circuit of the 220kV four-circuit 4xZebra transmission line between Trincomalee PS and New Habarana SS. (220kV Network, year 2020.Night Peak) 55

Annex A-4 Rotor angle variation following a tripping of one 300MW unit at Trincomalee power station. (220kV Network, year 2020, Night Peak) 56

Annex A-5 Rotor angle variation following a three phase short circuit fault in one circuit of the 220kV two circuit 4xZebra transmission line between New Habarana SS and Veyangoda GS. . (220kV Network, year 2020, Night Peak) 57

Annex A-6 Rotor angle variation following a three-phase short circuit fault in one circuit of the 220kV four-circuit 4xZebra transmission line between Trincomalee PS and New Habarana SS. (220kV Network, year 2020.Day Peak) 58

Annex A-7 Rotor angle variation following a three phase short circuit fault in one circuit of the 220kV two circuit 4xZebra transmission line between New Habarana SS and Veyangoda GS. (220kV Network, year 2020, Day Peak) 59

Annex A-8 Rotor angle variation following a three-phase short circuit fault in one circuit of the 220kV four-circuit 4xZebra transmission line between Trincomalee PS and New Habarana SS. (400kV Network, year 2020.Night Peak) 60

Annex A-9 Rotor angle variation following a tripping of one 300MW unit at Trincomalee power station. (400kV Network, year 2020, Night Peak) 61

Annex A-10 Rotor angle variation following a three phase short circuit fault in one circuit of the 220kV two circuit 4xZebra transmission line between New Habarana SS and Veyangoda GS. (400kV Network, year 2020, Night Peak) 62

Annex A-11 Rotor angle variation following a three-phase short circuit fault in one circuit of the 220kV four-circuit 4xZebra transmission line between Trincomalee PS and New Habarana SS. (400kV Network, year 2020,Day Peak) 63
Annex A-12 Rotor angle variation following a three phase short circuit fault in one circuit of the 400kV two circuit 2xZebra transmission line between New Habarana SS and Veyangoda GS. (400kV Network, year 2020, Day Peak) 64
Annex A- 13 Planning Criteria 65

Chapter 1

Background and Scope

Background, motivations, objectives and the methodology of the study are described in this chapter.

1.1 Background

The CEB is the national utility responsible for the generation, transmission and a major portion of distribution of electrical power in Sri Lanka. The demand for electricity in Sri Lanka is grown at rate of 5.68% per annum [3]. The generating sources and primary transmission and associated grid substation facilities have to be re-enforced and strengthened in order to meet this growth in demand.

It is essential to development and strengthening of the transmission system facilities to transmit the power generated at main generating stations such as Trincomalee Coal Fired Power Plant into the main transmission system. The necessary transmission system reinforcements to maintain a satisfactory power system performance in Sri Lanka are identified by the detailed power system analysis conducted during the Long Term Transmission System Expansion Planning process. CEB completed Master Plan Studies for the development of the Transmission system in Sri Lanka with technical assistance from Japan International Co-operation Agency (JICA) in January 1997 and in January 2006 [4]. Long Term Transmission Development studies are conducted annually, based on the latest available National Load Forecast, Long Term Generation Expansion Plan and Medium Voltage Distribution Development Plan reports. Outcome of the above studies emphasized the urgency of constructing the transmission system facilities outlined in this study for the transmission of power from Trincomalee Coal Fired Power Plant.

1.2 Problem Statement

The Ceylon Electricity Board (CEB) transmission system comprises of 220 kV and 132 kV transmission networks, interconnected to grid substations (GS) and power stations (PS). The 220kV transmission system is mainly used to transmit power from Mahaweli hydro power generating stations namely Kotmale, Victoria, Randenigala and Rantembe to main load centers through Kotugoda, Pannipitiya and Biyagama grid substations. The 132kV transmission network is used to interconnect most of the grid substations and to transfer power from other power stations.

According to the "Long Term Generation Expansion Plan 2009-2022" coal fired thermal units will be added to the power system in following manner. [1]

- 2013 - 2x250MW Trinco Coal (stage 1)
- 2015 – 2x250MW Trinco Coal (stage 2)
- 2015 – 1x300MW East Coast 2 (stage 1)
- 2016 – 1x300MW East Coast 2 (stage 2)
- 2017 – 1x300MW East Coast 2 (stage 3)
- 2018 – 1x300MW East Coast 2 (stage 4)

It has been decided that two sites along the east coast of Sri Lanka be developed for coal fired power plant. One site located at 7^{th} milepost on Trincomalee- Pullmudai road (Trinco Coal) is expected to cater 1000MW of 250MW coal fired power plant units. It is also expected a site at Sampur (East Coast 2) be allocated for further 4x 300MW units of coal fired power plants units.

Because of the large quantity of power which has to be transmitted from proposed Trincomalee power stations to load center, it has been decided to consider the possibility of utilizing 400 kV as the transmission voltage be explored against the present practice of transmitting power using 220 kV as the transmission voltage.

1.3 Objectives

The main objectives of the study are.

- Selection of 400kV and 220kV transmission network configurations for Trincomalee Power Plant Grid Connection for year 2020.
- Analyse the Technical feasibility of using 400kV configuration against the 220kV configuration as the Trincomalee Power Plant Grid Connection.
- Investigate the Economic viability of 400kV and 220kV transmission network configurations for proposed Trincomalee power plant Grid Connection

1.4 Methodology

Detailed power system analyses consisting of load flow and stability studies are conducted under night peak (19.30 hours) and day peak (11.00 hours) loading conditions to identify areas where the planning criteria are violated. The Power System Simulator for Engineering (PSSE) software package is used as the study tool for that purpose.

PSSE package is comprised of a comprehensive suite of programs for studies of power system transmission network and generation performance in both steady-state and dynamic conditions. In addition to steady-state and dynamic analysis, the PSSE package also provides the user with a wide range of auxiliary programs for installation, data input, output, manipulation and preparation.

The main objective of the load flow study is to determine the steady state performance of the power system. The potential problems such as unacceptable voltage conditions and overloading of the transmission network elements are identified from load flow studies. Contingency analysis is required to identify network bottlenecks during equipment failure or unavailability.

The stability studies are performed in order to make sure that the system will remain stable following severe disturbance. Under stability studies transient behavior of the system is observed.

To select the most suitable transmission network configuration, technical as well as economic aspects are taken into consideration.

The methodology followed in this study is as follows.

- Review the 220kV Transmission network configuration of Trincomalee Power Plant Grid Connection proposed by the 'Long Term Transmission Development Plan 2008-2016'.
- Identification of 220kV Transmission network configuration for Trincomalee Power Plant grid connection for year 2020
- Identification of 400kV Transmission network configuration for Trincomalee Power Plant grid connection for year 2020
- Steady state analysis, transient stability analysis and economic analysis are used to study the advantages and disadvantages of the configurations.
- Conclusions of the most feasible configuration for power plant grid connection are drawn based on all the study results.

Chapter 2

Review of Trincomalee Power Plant Grid Connection for year 2016

"Long Term Transmission Development Plan 2008-2016" [2] proposed 220kV transmission network configuration for Trincomalee power plant Grid Connection to transmit 1600MW of power in year 2016. The main objective of this study is to select the most feasible transmission configuration for year 2020. after addition of all the coal plant units to the system. Before go for year 2020 system studies. it is necessary to review the existing configuration. Therefore in this chapter. three alternatives of 220kV Trincomalee Power Plant Grid Connections were studied based on the configuration proposed by the "Long Term Transmission Development Plan 2008-2016" for year 2016. Technical and economic evaluations were used to select the best alternative. The results of Chapter 2 studies were used when selecting transmission configuration for the Trincomalee Power Plant Grid Connection for year 2020.

2.1 Initial Transmission Network Configuration

According to the "Long Term Transmission Development Plan 2008-2016" [2]. initial transmission network configurations proposal (Figure 2.1). which is capable of transmitting 1600MW power using 220kV as the transmission voltage from Trincomalee power plant in year 2016 is in following manner.

2.1.1 Power Transmission Facility Related to Trincomalee Coal-Fired Thermal Plant

New transmission developments required to Trincomalee power plant grid connection can be summarized as below.

- Trincomalee Power Station (PS) switchyard (220kV double bus bar (D/B) arrangement with a bus coupler. 3x220kV D/B Transmission Line (TL) bays. 2x220kV D/B Transformer (T/F) bays. 2x150 MVA 220/132/33kV Transformer. 132kV double bus bar arrangement with a bus coupler. 2x132kV D/B Tf bays. 2x132kV D/B TL bays)
- Trincomalee Grid Substation (GS) (2x132kV TL bays)
- Trincomalee PS – Trincomalee GS 132kV transmission line (2 cct. 28km. Zebra)

- New Habarana Switching station (SS) (2x250MVA 220/132/33kV Tf. 9x220kV D/B TL bays. 2x220kV D/B Tf bays. 220kV double bus bar arrangement with bus coupler. 132kV double bus bar arrangement with bus coupler. 2x132kV D/B TL bays. 2x132kV Tf bays)
- Trincomalee PS – New Habarana SS 220kV transmission line (2 cct. 95km. 4xZebra)
- Veyangoda GS (4x220kV D/B TL bays)
- New Habarana SS – Veyangoda GS 220kV transmission line (2 cct. 145km. 4xZebra)

2.1.2 Construction of Kirindiwela 220/132kV Switching Station

Following transmission developments are required for Kirindiwela switching station construction.

- Kirindiwela SS (220kV double bus bar arrangement with bus coupler. 8x220kV D/B TL bays)
- Construction of Veyangoda-Kirindiwela 220kV transmission line (2cct. 14.5km. 4xZebra)

2.1.3 Construction of Arangala 220/132kV Switching Station

Transmission facilities related to Arangala switching station are listed below.

- Arangala SS (2x250MVA 220/132/33kV Tf. 6x220kV D/B TL bays. 2x220kV D/B Tf bays. 220kV double bus bar arrangement with bus coupler. 132kV double bus bar arrangement with bus coupler. 2x132kV Tf bays)
- Construction of Kirindiwela-Arangala 220kV transmission line (2 cct. 33km. 4x Zebra)
- Construction of Arangala SS -Athurugiriya GS 132kV transmission line (2cct. 3.6km. Zebra)
- Construction of Arangala SS -Kolonnawa GS 132kV transmission line (2cct. 10.4km. Zebra)

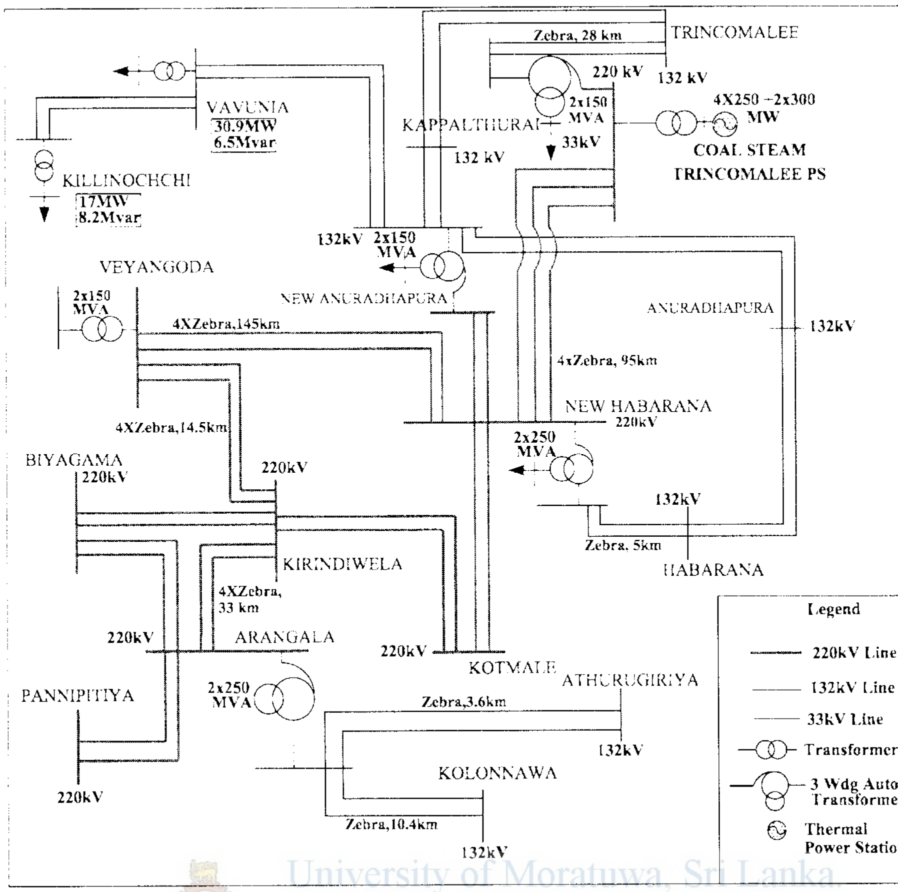


Figure 2.1 Trincomalee Coal Power Plant Grid Connection According to the " Long Term Transmission Development Plan 2008-2016"

2.2 Cost Estimation of Initial Transmission Network Configuration

All the items listed in 2.1.1, 2.1.2 and 2.1.3 were taken into account for the calculation of costs of selected transmission network configurations. Unit costs (Base Cost) were obtained from the 2008 Cost Database prepared by the Transmission Planning Branch of CEB and from the report "Master Plan Study on the Development of Power Generation and Transmission System in Sri Lanka" [4]

The best estimation of project costs can be undertaken from prices available at the time of estimation (date of evaluation). Project implementation can take many years. Hence, the actual cost of the project at the commissioning date will differ from the cost estimated at the time of planning and evaluation. This is the result of inflation and increase in price and quantities of the project components. Such variation is allowed for through the following two contingencies.

- A ***Physical Contingency*** to allow for the increase in quantities of material and equipment involved in project execution and the change of implementation method. Civil works have higher contingency than machinery. Physical contingencies usually vary up to 10% of the project base cost. Beyond this, more detailed estimation has to be undertaken in order to reduce uncertainties in project cost estimation. Physical contingencies are distributed along the project execution life as a percentage of annual cost allocation.

- A ***Price Contingency*** to allow increase in price of project components, over the base case estimation, during the construction period. It is highly dependent on inflation rates and other possible price increases.

2.2.1 Base Cost Estimation of the Initial Transmission Network Configuration

Base cost does not include the cost associated with uncertainties and risks. It comprises of two components.

- Foreign Cost (F.C.) Component is the cost of plant and equipment.
- Local Cost (L.C.) Component includes Agency Fee, Clearance charges, Document charges and Transport Charges etc.

Description	Estimated Base Cost (Million LKR)
Construction of Trinco Power Station Switchyard	1015.0
Augmentation of Trinco Grid Substation	49.5
Construction of New Habarana 220/132 kV Switching Station	1500.9
Augmentation of Veyangoda Grid Substation	205.5
Construction of Arangala 220/132kV Switching Station	1383.8
Construction of Kirindiwela 220/132kV Switching Station	465.4
Construction of Trincomalee PS -Trincomalee GS 132kV transmission line(28km)	791.2
Construction of Trinco PS - New Habarana SS 220kV transmission line(95km)	5944.0
Construction of New Habarana SS -Veyangoda GS 220kV transmission line	9072.3
Construction of double in-out connection from Biyagama-Pannipitiya 220kV Tr. Line to connect Arangala SS (0.5km)	19.3
Construction of Arangala SS -Kolonnawa GS 132kV transmission line(10.4km)	293.9
Construction of Arangala SS -Athurugiriya GS 132kV transmission line(3.6km)	101.7
Construction of Veyangoda GS -Kirindiwela-Arangala SS 220kV transmission line(47.5km)	2972.0
Total Estimated Base Cost	**23,814.5**

Table 2.1 Base Cost Estimation of Initial Transmission Network Configuration in year 2016

According to the Table 2.1 total base cost estimation of initial 220kV transmission network configuration is 23,814.5 Million LKR.

2.2.2 Disbursement Schedules and Total Cost Estimation of the Initial Transmission Network Configuration

The project execution period is considered as three years. Investment is grouped to be disbursed at 20%, 70%, 10% spread over three years starting one year after the cost estimation.

Following cost components will be added to determine the total cost estimation.

- *Price Escalation*: changes in the cost or price of specific goods or services in a given economy over a period of time. This is similar to the concepts of inflation.
- *Physical Contingencies*: To allow for the increase in quantities of material and equipment involved in project execution and the change of implementation method.
- Administrative cost: Accommodation, Communication, Transport, Training
- Levies

Description	Total		2014	2015	2016
Base Cost	F.C.	18054	3611	12638	1805
	L.C.	5761	1152	4033	576
Price Escalation	F.C.	3327	572	2364	391
	L.C.	5028	834	3579	615
Sub Total 1	**F.C.**	**21380**	**4182**	**15002**	**2196**
	L.C.	**10788**	**1986**	**7612**	**1191**
Physical Contingencies 10%	F.C.	2138	418	1500	220
	L.C.	1079	199	761	119
Sub Total 2	**F.C.**	**23518**	**4601**	**16502**	**2416**
	L.C.	**11867**	**2185**	**8373**	**1310**
Administrative Cost	L.C.	823	161	578	85
Total Before Levies	*F.C*	*23518*	*4601*	*16502*	*2416*
	L.C	*12690*	*2346*	*8950*	*1394*
Levies	L.C.	847	166	594	87
Grand Total	**F.C.**	**23518.4**	**4601**	**16502**	**2416**
	L.C.	**13537.0**	**2511**	**9544**	**1481**
	MLKR	**37,055.4**			

Table 2.2 Total Cost Estimation of Initial Transmission Network Configuration in year 2016

According to the Table 2.2 Total project cost estimation for the initial transmission network configuration in year 2016 is 37,055.4 Million LKR

2.3 Alternative 220kV Transmission Network Configurations for year 2016

Now the Transmission Planning Branch of Ceylon Electricity Board is in the process of preparing the "Long Term Transmission Development Plan 2010-2019". So it is necessary to review the existing Trincomalee Coal Power Plant Grid Connection proposal and make necessary changes to the proposal. Following options were studied to select most viable configuration for year 2016.

- Transmission Network with the new Loads of Northern Province
- Trincomalee Coal Power Plant Grid Connection – Without New Habarana Switching Station
- Trincomalee Coal Power Plant Grid Connection – Without Kirindiwela Switching Station

2.3.1 Transmission Network with the new Loads of Northern Province

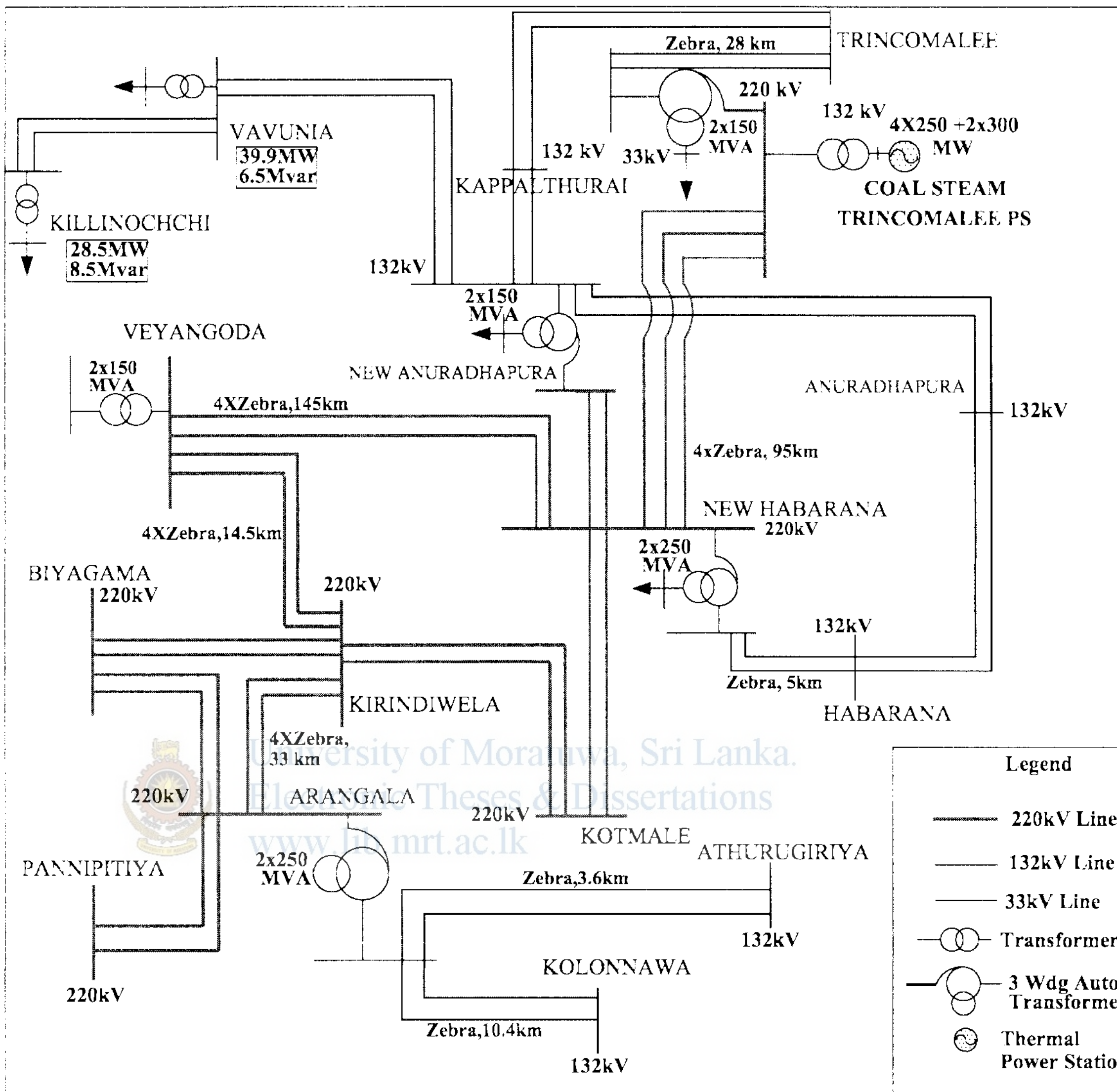


Figure 2.2 Network with the new Loads of Northern Province

With the liberation of conflict affected areas in Kilinochchi and Mullative districts during late 2008 – early 2009, development activities are gradually taken place. Resettlement has been the top priority of the Government. Thus, many humanitarian requirements like water supply project, hospitals, irrigation schemes are being initiated or under construction. They will require heavy supplies. Security/police installations also need electricity with top priority. Presently some of these installations are having Diesel Generators. According to the Ceylon Electricity Board - "Medium Voltage Distribution System Development Plan for Recently Liberated Areas of Northern Province". [8] Vavunia and Kilinochchi grid substations loads will be increased by 9MW and 11.5 MW in addition to the forecasted loads in year 2016. (Figure 2.2)

2.3.2 Trincomalee Coal Power Plant Grid Connection – Without Kirindiwela Switching Station

To prepare new Trincomalee Power Plant Grid Connection proposals for "Long Term Transmission Development Plan 2010-2019", it is necessary to review existing configuration. Therefore under this option, study was conducted for the Trincomalee power plant Grid Connection without Kirindiwela Switching Station (Figure 2.3).

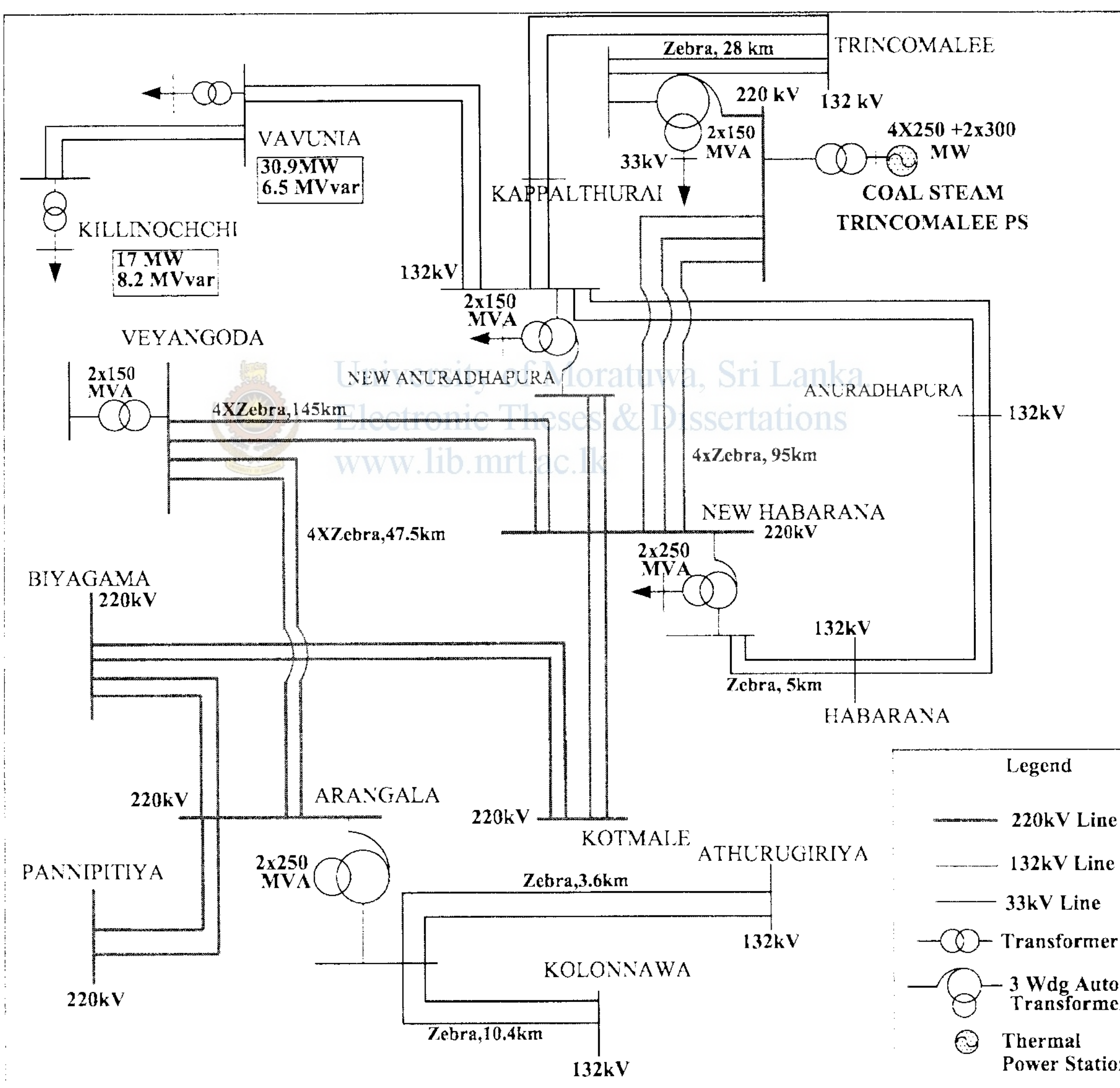


Figure 2.3 Trincomalee Coal Power Plant Grid Connection-Without Kirindiwela Switching Station

2.3.3 Trincomalee Coal Power Plant Grid Connection – Without New Habarana Switching Station

This option was investigated the possibility of removing the New Habarana SS from the existing configuration (Figure 2.4). Following additional transmission re-enforcements are necessary to overcome critical voltage and thermal criteria violations (Annex 13).

- Construction of Trincomalee PS – Veyangoda GS 220kV transmission line (2 cct. 240km. 4xZebra)
- Construction of Trincomalee PS – New Anuradhapura GS 220kV transmission line (2 cct. 103.3km. 2xZebra)
- Reconstruction of New-Anuradhapura-Anuradhapura 132kV double circuit line using Zebra conductor.
- Augmentation of New Anuradhapura GS (2x150MVA 220/132/33kV Tf to 3x150MVA 220/132/33kV Tf. 2x220kV D/B TL bays. 1x220kV D/B Tf bays. 1x132kV D/B TF bays. 1x33kV TF bay)
- Upgrade of Habarana-Anuradhapura 132kV Transmission line to operate at 75^{0}C.

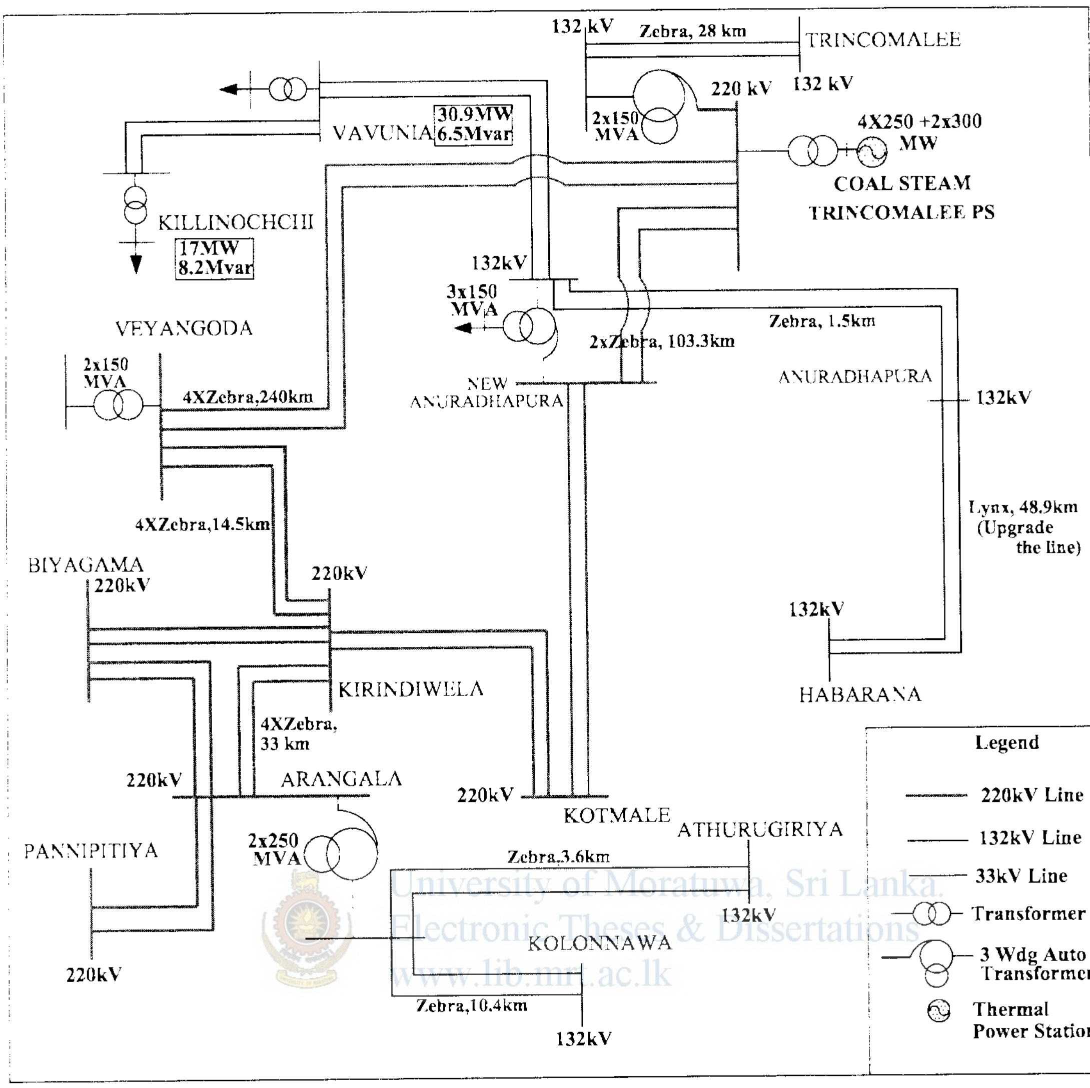


Figure 2.4 Trincomalee Coal Power Plant Grid Connection without New Habarana Switching Station

2.4 Steady State Analysis of Alternative 220kV Transmission Network Configurations for year 2016

2.4.1 Transmission Network with the new Loads of Northern Province

According to the 'Medium Voltage Distribution System Development Plan for Recently Liberated Areas of Northern Province' [8] following (Table 2.3) loads will be added to the system in 2016 in addition to the Load Forecast prepared by the Transmission Planning Branch.

Grid SS	Night Peak		Day peak	
	MW	MVar	MW	MVar
Kilinochchi	11.54	0.29	7.09	0.29
Vavunia	8.99	0.01	4.54	0.01

Table 2.3 Additional Loads of 2016 Power System in Liberated Areas of Northern Province

Load flow studies for night peak and day peak load scenarios were analyzed to check whether any modifications are necessary for the Transmission Network Configuration of Trincomalee Coal Power Plant Grid Connection according to the new load additions of Northern Province. The total addition of loads to the system according to the present Northern plan is 20.5MW. But according to the Load forecast [2], the 2016 power system Night peak is 3726.3MW. Therefore it is clear that the load center will not be changed due to new Northern loads. Load flow studies also illustrate that no changes will cause to the proposed configuration due to new northern loads.

2.4.2 Trincomalee Coal Power Plant Grid Connection – Without Kirindiwela Switching Station

System studies were conducted for Night Peak and Day Peak load scenarios considering normal and single contingency operating conditions.

Normal operating conditions

Transmission losses of the system with and without Kirindiwela SS are summarized in Table 2.4.

Option	Transmission Losses (MW)	
	Night Peak	Day Peak
With Kirindiwela SS	104.7	36.6
Without Kirindiwela SS	105.4	35.9

Table 2.4 Transmission Losses with and without Kirindiwela Switching Substation

Table 2.4 illustrate that the transmission losses are almost same for two cases. Load flow studies also confirm that the both systems consist of same overloaded equipments and voltage violations for both Day Peak and Night Peak scenarios under normal operating conditions.

Single contingency operating conditions

Loading conditions and voltage violations after outage of critical 220kV lines are shown in Table 2.5 and Table 2.6. (Annex 13 illustrate the planning criteria)

Contingency	Voltage violations (pu)		Loading on the remaining circuit	
	Without Kirindiwela SS	With Kirindiwela SS	Without Kirindiwela SS	With Kirindiwela SS
One circuit outage of Biyagama/Kirindiwela - Kotmale 220kV line	Biyagama - 0.947	Biyagama - 0.949	21%	22%
One circuit outage of Kotugoda – Biyagama 220kV line	Biyagama – 0.950 Arangala 0.935 Pannipitiya –0.931	Biyagama 0.950 Arangala - 0.935 Pannipitiya 0.931	66%	56%
One circuit outage of Biyagama - Arangala 220kV line	Arangala – 0.930 Pannipitiya– 0.926	Arangala – 0.932 Pannipitiya 0.928	90%	88%
One circuit outage of Veyangoda – Arangala/ Kirindiwela 220kV line	Biyagama – 0.947 Arangala 0.928 Pannipitiya –0.924	Biyagama - 0.950 Arangala – 0.935 Pannipitiya -0.931	22%	29%
One circuit outage of NewHabarana - Veyangoda 220kV line	Veyangoda –0.946 Biyagama - 0.943 Arangala – 0.927 Pannipitiya –0.922	Veyangoda–0.950 Biyagama – 0.943 Arangala – 0.929 Pannipitiya 0.925	44%	44%

Table 2.5 Contingency Results for Transmission Networks with and without Kirindiwela SS - Night Peak

Contingency	Voltage violations (pu)		Loading on the remaining circuit	
	Without Kirindiwela SS	With Kirindiwela SS	Without Kirindiwela SS	With Kirindiwela SS
One circuit outage of Biyagama/Kirindiwela - Kotmale 220kV line	Pannipitiya– 0.947	Pannipitiya -.948	41%	42%
One circuit outage of Biyagama - Arangala 220kV line	Arangala – 0.949 Pannipitiya - .946	Arangala 0.95 Pannipitiya .948	111%	98%
One circuit outage of Veyangoda - Arangala/ Kirindiwela 220kV line	Arangala - 0.949 Pannipitiya .946	Arangala - 0.95 Pannipitiya– .947	25%	25%
One circuit outage of NewHabarana Veyangoda 220kV line	Pannipitiya – .949	Pannipitiya .950	59%	59%

Table 2.6 Contingency Results for Transmission Networks with and without Kirindiwela SS -Day Peak

According to the above critical line contingency cases, there is small system voltage improvement with the insertion of Kirindiwela SS.

2.4.3 Trincomalee Coal Power Plant Grid Connection – Without New Habarana Switching Station

System studies were conducted for Night Peak and Day Peak load scenarios considering normal and single contingency operating conditions.

Normal operating conditions

Transmission losses according to the Load flow studies can be summarized in Table 2.7.

Option	Transmission Losses (MW)	
	Night Peak	Day Peak
With New Habarana SS	104.7	36.6
Without New Habarana SS	114.0	37.1

Table 2.7 Transmission Losses with and without New Habarana Switching Substation

According to the Table 2.7 transmission losses are high in the case of 220kV Transmission Network without New Habarana SS.

No over loading of Transmission Lines or Transformers were observed for two cases during load flow analysis. Transmission Network without New Habarana SS has following voltage violations (Table 2.8).

Equipment	Voltage violations (p.u.)	
	Night Peak	Day Peak
Pannipitiya 220kV	0.935	No Violations were Observed
Arangala 220kV	0.94	
Polonnaruwa 132kV	0.943	
Vavnia 132kV	0.94	
Chunnakum 132kV	0.946	

Table 2.8 Voltage violations without New Habarana SS

Single contingency operating conditions

Following power flow results (Table 2.9) were obtained for the single contingency operating conditions.

Operating Condition	Single Contingency	Result
Night Peak	One circuit outage of Habarana-Anuradhapura 132kV Transmission Line	The remaining Habarana-Anuradhapura 132kV Transmission Line loads to 121.8%
	One circuit outage of Anuradhapura-New Anuradhapura 132kV Transmission Line	The remaining Anuradhapura-New Anuradhapura 132kV Transmission Line loads to 125.7%
Day Peak	One circuit outage of Kappalthurai-Trinco 132kV Transmission Line	The remaining Kappalthurai-Trinco 132kV Transmission Line loads to 101%

Table 2.9 Contingency Results for Transmission Networks without New Habarana SS

There were no voltage criteria violation observed under single contingency operating conditions during Night Peak and Day Peak. (Annex 13 summarize the planning criteria)

2.5 Economic Analysis of Alternative 220kV Transmission Network Configurations for year 2016

2.5.1 Trincomalee Coal Power Plant Grid Connection – Without Kirindiwela Switching Station

Table 2.10 illustrates the base cost estimation of the transmission network configuration without Kirindiwela switching Station.

Description	Estimated Base Cost (Million LKR)
Construction of Trinco Power Station Switchyard	1015.0
Augmentation of Trinco Grid Substation	49.5
Construction of New Habarana 220/132 kV Switching Station	1500.9
Augmentation of Veyangoda Grid Substation	205.5
Construction of Arangala 220/132kV Switching Station	1383.8
Construction of Trincomalee PS -Trincomalee GS 132kV transmission line(28km)	791.2
Construction of Trinco PS - New Habarana SS 220kV transmission line(95km)	5944.0
Construction of New Habarana SS -Veyangoda GS 220kV transmission line (145km)	9072.3
Construction of double in-out connection from Biyagama-Pannipitiya 220kV Tr. Line to connect Arangala SS (0.5km)	19.3
Construction of Arangala SS -Kolonnawa GS 132kV transmission line(10.4km)	293.9
Construction of Arangala SS -Athurugiriya GS 132kV transmission line(3.6km)	101.7
Construction of Veyangoda GS -Arangala SS 220kV transmission line(47.5km)	2972.0
Total Estimated Base Cost	**23,349.1**

Table 2.10 Base Cost Estimation of Transmission Network Configuration-without Kirindiwela SS in year 2016

This option has the base cost estimation of 23,349.1 Million LKR.

The project execution period is considered as year 2014 to 2016. Investment is grouped to be disbursed at 20%, 70%, 10% spread over three years.

Description	Total		2014	2015	2016
Base Cost	F.C.	17618	3524	12333	1762
	L.C.	5731	1146	4012	573
Price Escalation	F.C.	3246	558	2307	381
	L.C.	5002	830	3561	611
Sub Total 1	**F.C.**	**20865**	**4082**	**14640**	**2143**
	L.C.	**10732**	**1976**	**7572**	**1184**
Physical Contingencies 10%	F.C.	2086	408	1464	214
	L.C.	1073	198	757	118
Sub Total 2	**F.C.**	**22951**	**4490**	**16104**	**2358**
	L.C.	**11806**	**2173**	**8329**	**1303**
Administrative Cost	L.C.	803	157	564	83
Total Before Levies	*F.C*	*22951*	*4490*	*16104*	*2358*
	L.C	*12609*	*2330*	*8893*	*1385*
Levies	L.C.	826	162	580	85
Grand Total	**F.C.**	**22951.1**	**4490**	**16104**	**2358**
	L.C.	**13435.1**	**2492**	**9473**	**1470**
	MLKR	**36,386.2**			

Table 2.11 Total Cost Estimation of Transmission Network Configuration-without Kirindiwela SS in year 2016 in year 2016

According to the Table 2.11, total project cost estimation for Transmission Network Configuration-without Kirindiwela SS in year 2016 is 36,386.2 Million LKR

2.5.2 Trincomalee Coal Power Plant Grid Connection – Without New Habarana Switching Station

Table 2.12 illustrates the base cost estimation of the transmission network configuration without New Habarana switching Station.

Description	Estimated Base Cost (Million LKR)
Construction of Trinco Power Station Switchyard	1069.9
Augmentation of Trinco Grid Substation	49.5
Augmentation of New Anuradhapura 220/132/33 kV GS	357.9
Augmentation of Veyangoda Grid Substation	205.5
Construction of Arangala 220/132kV Switching Station	1383.8
Construction of Kirindiwela 220/132kV Switching Station	465.4
Construction of Trincomalee PS -Trincomalee GS 132kV transmission line(28km)	791.2
Construction of Trinco PS - Veyangoda GS 220kV transmission line (240km)	15016.3
Construction of New Anuradhapura- Trincomlee GS 220kV transmission line(103km)	2919.1
Upgrade of Habarana-Anuradhapura 132kV Transmission Line	33.0
Construction of double in-out connection from Biyagama-Pannipitiya 220kV Tr. Line to connect Arangala SS (0.5km)	19.3
Construction of Arangala SS -Kolonnawa GS 132kV transmission line(10.4km)	293.9
Construction of Arangala SS -Athurugiriya GS 132kV transmission line(3.6km)	101.7
Construction of Veyangoda GS -Kirindiwela-Arangala SS 220kV transmission line(47.5km)	2972.0
Total Estimated Base Cost	**25,678.6**

Table 2.12 Base Cost Estimation of Transmission Network Configuration-without New Habarana SS in year 2016

This option has the base cost estimation of 25,678.6 Million LKR.

The project execution period is considered as year 2014 to 2016. Investment is grouped to be disbursed at 20%, 70%, 10% spread over three years.

Description	Total		2014	2015	2016
Base Cost	F.C.	19103	3821	13372	1910
	L.C.	6576	1315	4603	658
Price Escalation	F.C.	3520	605	2501	414
	L.C.	5739	952	4085	702
Sub Total 1	**F.C.**	**22623**	**4426**	**15873**	**2324**
	L.C.	**12314**	**2267**	**8688**	**1359**
Physical Contingencies 10%	F.C.	2262	443	1587	232
	L.C.	1231	227	869	136
Sub Total 2	**F.C.**	**24885**	**4868**	**17461**	**2556**
	L.C.	**13546**	**2494**	**9557**	**1495**
Administrative Cost	L.C.	871	170	611	89
Total Before Levies	*F.C*	*24885*	*4868*	*17461*	*2556*
	L.C	*14417*	*2664*	*10168*	*1584*
Levies	L.C.	896	175	629	92
Grand Total	**F.C.**	**24885.2**	**4868**	**17461**	**2556**
	L.C.	**15312.7**	**2839**	**10797**	**1676**
	MLKR	40,197.8			

Table 2.13 Total Cost Estimation of Transmission Network Configuration-without New Habarana SS in year 2016

According to the Table 2.13 total project cost estimation for Transmission Network Configuration-without New Habarana SS in year 2016 is 40,197.8 Million LKR

2.6 Evaluation of the Results of Alternative Transmission Network Configurations for year 2016

2.6.1 Transmission Network with the new Loads of Northern Province.

The total addition of load to the system according to the present Northern plan is 20.5MW. According to the Load forecast [1], the 2016 power system Night peak is 3726.3MW. Therefore the new northern loads are only 0.55% of estimated night peak in year 2016. Steady state analysis of Transmission Network configuration with the Loads of Liberated Areas of Northern Province reveals that no modifications to the proposed network are necessary due to addition of new Northern loads.

2.6.2 Trincomalee Coal Power Plant Grid Connection – Without Kirindiwela Switching Station

According to the Load Flow studies and contingency analysis, there were no significant differences between 220kV Transmission Network configurations with and without Kirindiwela SS. Transmission losses were almost same for two cases. Transmission network configuration with and without Kirindiwela SS has estimated total cost of 37,055.4 Million LKR and 36,386.2 Million LKR respectively. Therefore a total amount of 669.2 Million LKR (1.8 %) saves due to implementation of transmission network configuration without Kirindiwela SS. But Transient state studies should be conducted before a final conclusion.

2.6.3 Trincomalee Coal Power Plant Grid Connection – Without New Habarana Switching Station

According to the Load Flow studies and contingency analysis, there were more violations in the 220kV Transmission Network without New Habarana SS than configuration with New Habarana SS. Transmission losses were also high in the case of 220kV Transmission Network without New Habarana SS. Economic analysis reveals that the additional cost of 3,142.4 Million LKR (8.5 %) should be invested for the Transmission Network configuration without New Habarana SS. Therefore this option does not show any advantage over the original proposed configuration. Removal of New Habarana SS from the Transmission network configuration is not recommended due to above results.

2.7 Transient Stability Analysis of Trincomalee Coal Power Plant Grid Connection – Without Kirindiwela Switching Station

Transient stability of the 220kV transmission network with and without Kirindiwela Switching Station in year 2016 under night peak and day peak load operating conditions were investigated. Successful and unsuccessful clearing of three phase faults in critical lines and outage of generators as depicted in the Table 2.14 were studied and stability of the system was assessed.

Tripping sequences of Successful Re-closing (SR) and unsuccessful Re-closing (USR) of transmission circuits can be summarized as follows.

Successful Re-closing (SR) of transmission circuits sequence is.

T= 0 : Fault occurs

T=120ms : Fault cleared & circuit tripped

T=620ms : Circuit re-closed

Unsuccessful Re-closing (USR) of transmission circuits sequence is.

T= 0 : Fault occurs

T=120ms : Circuit tripped

T=620ms : Circuit re-closed with fault

T=740ms : Circuit tripped

Unless otherwise stated specifically, the circuit breaker operating time was considered as 120ms and first re-closing time is considered as 500ms.

Faulty Element	Fault Type & Location	Switching Sequence	Results			
			Day Peak		Night Peak	
			With Kirindiwela	Without Kirindiwela	With Kirindiwela	Without Kirindiwela
Trincomalee PS – New Habarana GS 220kV tx line cct 1	3ph fault at Trinc. PS end	SR	SS	SS	SS	SS
		USR	SS	SS	SS	SS
Tripping of one 250MW unit at Trincomalee PS	Machine Tripping	Not Applicable	SS	SS	SS	SS
Veyangoda – Arangala tx line cct 1	3ph fault at Veya. GS end	SR	SS	SS	SS	SS
		USR	SS	SS	SS	SS
Tripping of one 100MW unit at Kerawalapitiya PS	Machine Tripping	Not Applicable	SS	SS	SS	SS

SS- System stable SU- System unstable

Table 2.14 Transient Stability Analysis Results of Trincomalee Coal Power Plant Grid Connection – With & Without Kirindiwela Switching Station

According to the Table 2.14 no system transient stability improvement has observed with the inclusion of Kirindiwela SS.

2.8 Final 220kV Transmission Network Configuration for year 2016

Study was conducted for year 2016 system with 1600MW of coal power plant units connected to Trincomalee site, considering two different system-loading conditions. Three alternative configurations were considered for analysis. But only the configuration-without Kirindiwela option was selected after the steady state analysis and economic analysis. Even though the configuration with Kirindiwela shows slight improvement in system reliability and system loss savings no planning criteria violations can be observed without Kirindiwela configuration. As far as the transient stability is concerned both systems behave similarly, following critical system disturbances. Thus, the construction of Kirindiwela SS is not necessary for transmit power from proposed Trincomalee Coal Power Plant. Figure 2.5 shows the final transmission network configuration for year 2016 system for Trincomalee Power Plant grid connection.

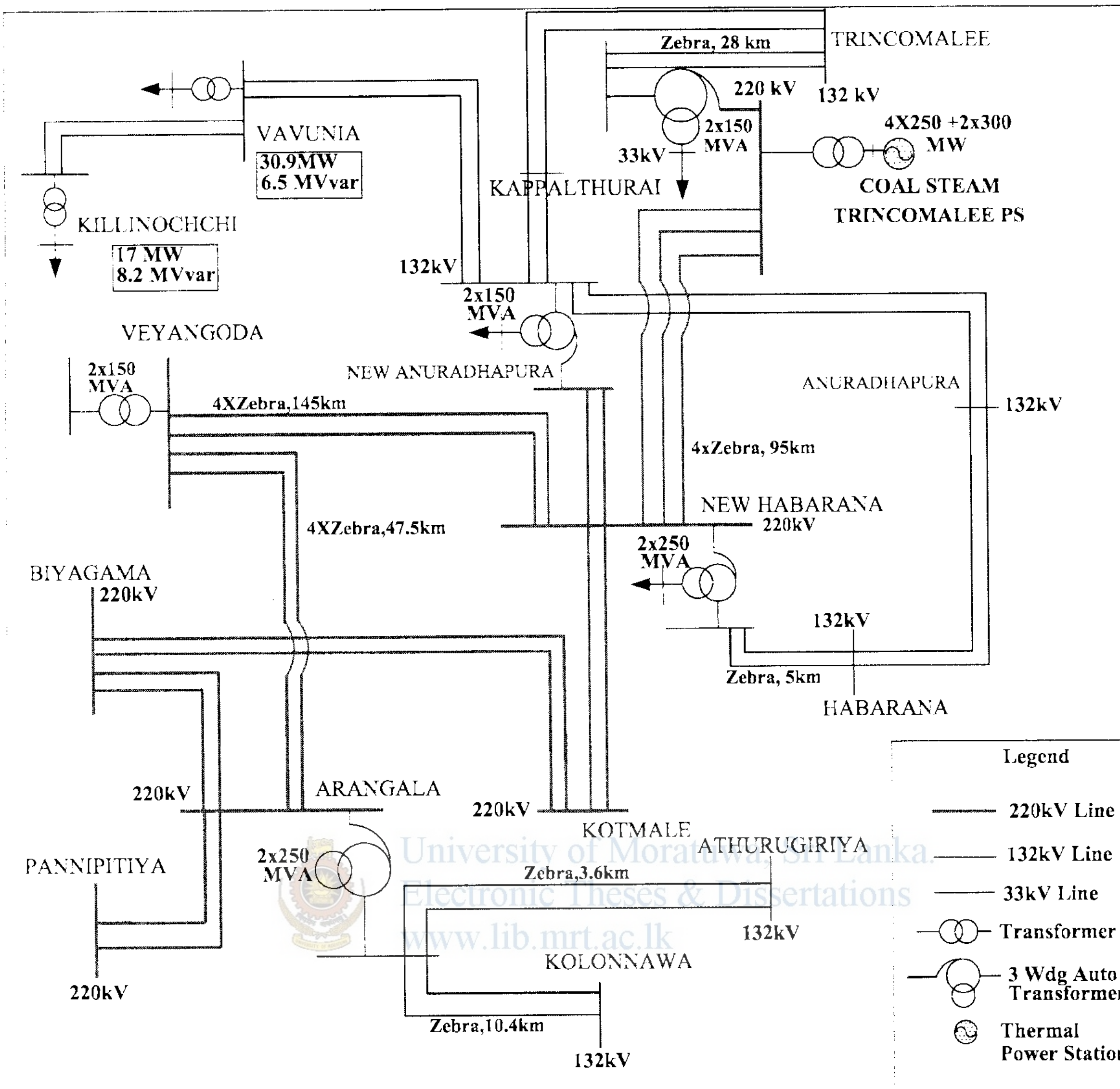


Figure 2.5 Final transmission network configuration for year 2016 system for Trincomalee Power Plant grid connection.

Chapter 3

Selection of Trincomalee Power Plant Grid Connection for year 2020

Transmission network configurations capable of transmitting 2200MW of power using 220kV and 400kV as the transmission voltage from Trincomalee Coal Power Plant in year 2020 were selected based on the "Master Plan Study on the Development of power Generation and Transmission System in Sri Lanka – January 2006'. Results from Chapter 2 were considered here when selecting transmission configurations.

Since there is a possibility of increased power flow from Puttlam PS to New Anuradhapura GS as a result of possible expansion beyond 900MW at Norochcholei site and in view of the increased capacity of the Trincomalee Power Plants, it is not feasible to construct a transmission line connection between Trincomalee Power Plant and New Anuradhapura GS. it is also not feasible to convert Valachchenai GS to 220kV or 400kV and transmit power from the Trincomale Power Plant to Valachchenai GS. Therefore, Habarana GS was considered as the main network connection point for the transmission of power from Trincomalee Power Plant.

3.1 Selected 220kV and 400kV Transmission Network Configurations for year 2020

3.1.1 220kV Transmission Network Configuration

Following modifications were done on the 220kV network configuration proposed by the 'Master Plan Study on the Development of power Generation and Transmission System in Sri Lanka – January 2006' for year 2020. Figure 3.1 is the 220kV configuration proposed by the Master Plan Study.

Figure 3.2 shows the proposed 220kV transmission network configuration of Trincomalee Coal Power Plant Grid Connection for year 2020.

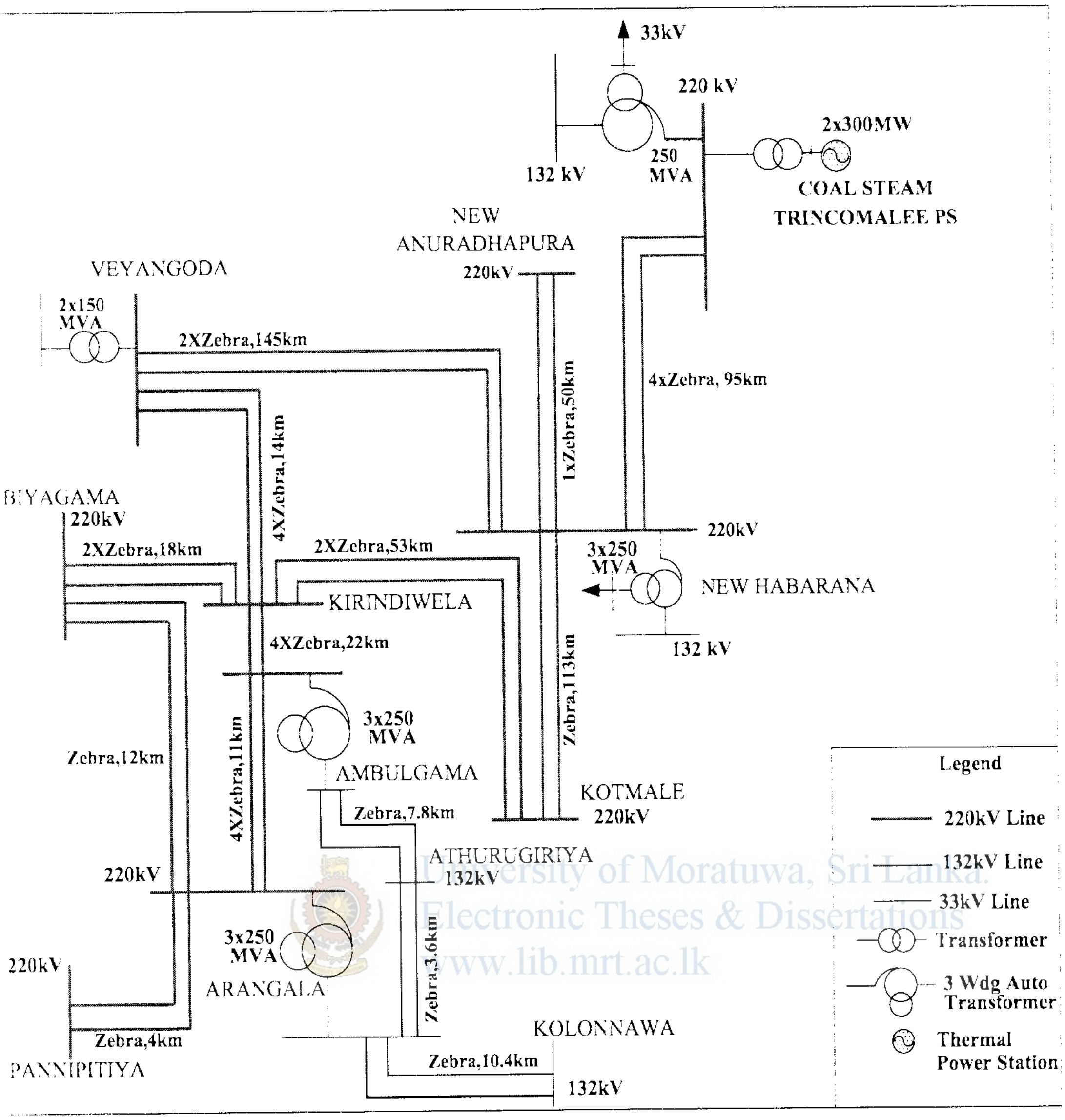


Figure 3. 1 220kV transmission network configuration of Trincomalee Coal Power Plant Grid Connection According to the Master Plan Study

According to the Figure 3.1. there are only 600 MW of coal fired power plant units at the Trincomalee Power Plant site.

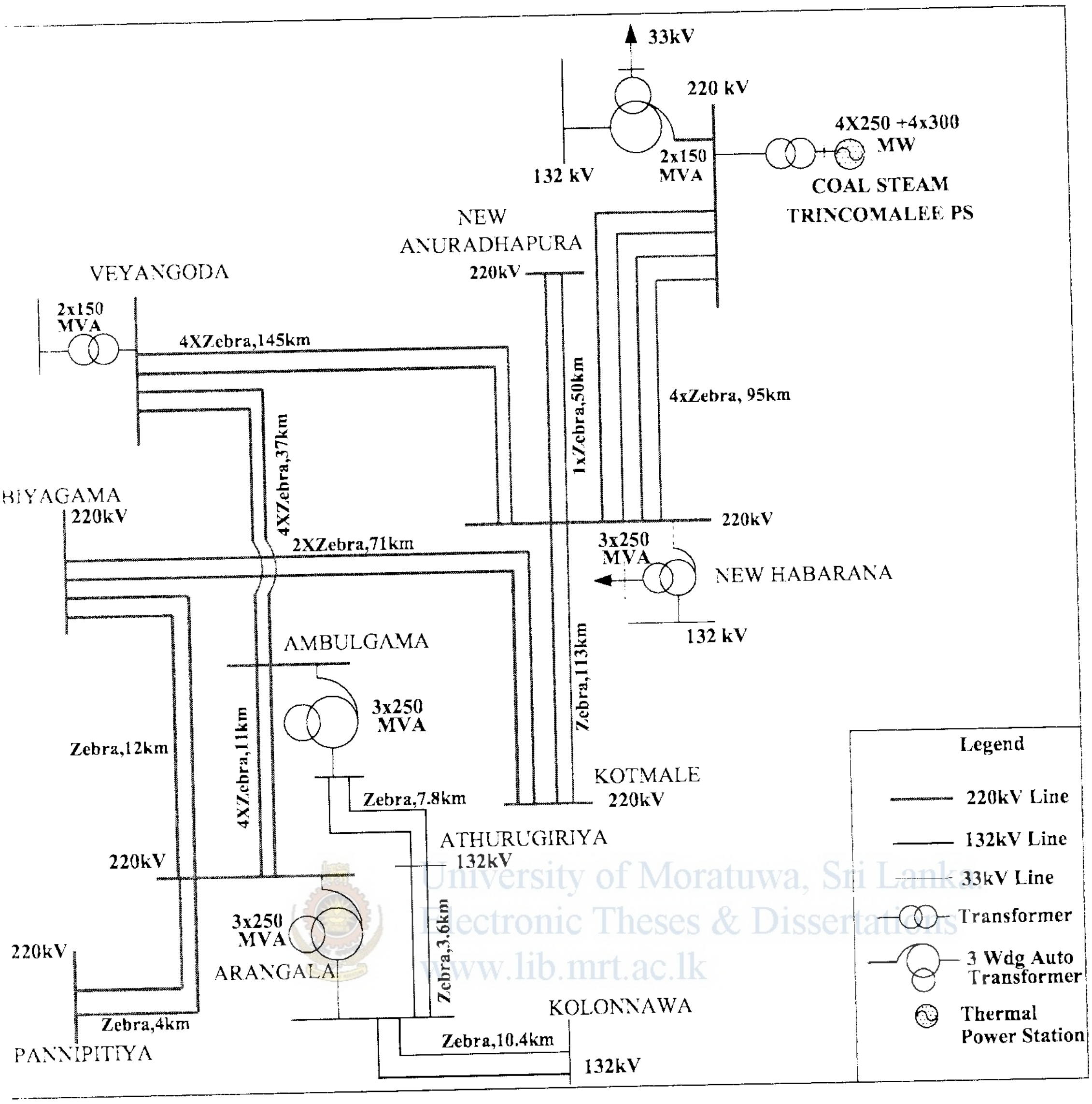


Figure 3.2 The proposed 220kV transmission network configuration of Trincomalee Coal Power Plant Grid Connection for year 2020

The scope of work for the power transmission from Trincomalee power station using 220kV as the transmission voltage can be summarized as follows.

- Construction of a 220kV Four circuit 4*Zebra, 95km length transmission line from Trincomalee power station to New Habarana switching station.
- Construction of Trincomalee PS switchyard (220 kV double bus bar arrangement with bus coupler, 4x220 kV double bus bar transmission line bays, 2x 220kV double bus bar transformer bays, 2x 150MVA 220/132 kV transformers, 132kV double bus bar arrangement with bus coupler, 2x132kV double bus bar transformer bay)

- Construction of New Habarana SS (220kV double bus bar arrangement with bus coupler. 3x 220kV double bus bar transformer bays. 10x 220kV double bus bar transmission line bays. 3x 250 MVA 220/132 kV transformers. 132kv double bus bar arrangement with bus coupler .3x 132kV double bus bar transformer bays)
- Construction of New Habarana-Veyangoda 220kV two circuit 4*Zebra. 145km length transmission line.
- Development of Veyangoda GS (4x 220kV double bus bar transmission line bays)
- Construction of Ambulgama GS(220kV double bus bar arrangement with a bus coupler. 3x250MVA 220/132 kV transformers. 3x220kV double bus bar transformer bays. 4x220kV double bus bar transmission line bays.132kV single bus bar arrangement with bus section bay. 2x132kV transmission line bays. 3x132kV transformer bays.)
- Construction of Arangalla GS (220kV double bus bar arrangement with a bus coupler. 3x250MVA transformers. 3x220kV double bus bar transformer bays. 6x 220kV double bus bar transmission line bays. 132kV Single bus bar arrangement with bus section. 4x132kV single bus bar transmission line bays. 3x 132kV transformer bays.)
- Construction of Veyangoda GS-Ambulgama GS 220kV two circuit 4*Zebra. 37km length transmission line.
- Construction of Ambulgama GS-Arangala GS 220kV two circuit 4*Zebra. 11km length transmission line.
- Construction of Ambulgama GS-Athurugiriya GS 132kV two circuit Zebra. 7.8km length transmission line.
- Construction of Arangala GS-Athurugiriya GS 132kV two circuit Zebra. 3.6km length transmission line.
- Construction of Arangala GS-Kolonnawa GS 132kV two circuit Zebra. 10.4km length transmission line

3.1.2 400kV Transmission Network Configuration

As far as the Trincomalee power station is concerned at least 2600 MVA of power has to be transmitted to the load center when all 250 MW and 300 MW generator units are in operation. Hence at least one 400kV 4xZebra three-circuit transmission line is required to transmit the power generated in Trincomalee power station to satisfy security criteria (Annex 13). Under such circumstances one possible network configuration using 4xZebra 400kV transmission line is to connect the same to Veyangoda grid substation. The other possibility is to construct a switching station at New Habarana and connect the 4xZebra 400kV transmission line from Trincomalee power station to New Habarana. However. load flow and contingency studies were ascertained that only one 400kV 2xZebra double circuit transmission line is sufficient from New Habarana switching station to Veyangoda GS for the transmission of power from Trincomalee power station and the transmission system is more stable to a short circuit faults in 4xZebra 400kV double circuit transmission line. if there is a switching station at New Habarana. Figure 3.2 illustrate the Relative Rotor angle variation between one of the Trincomalee machines and one Victoria machine without New Habarana SS. if there is a three-phase short circuit fault in one circuit of the 400kV three-circuit 4xZebra transmission line between Trincomalee PS and Veyangoda GS.

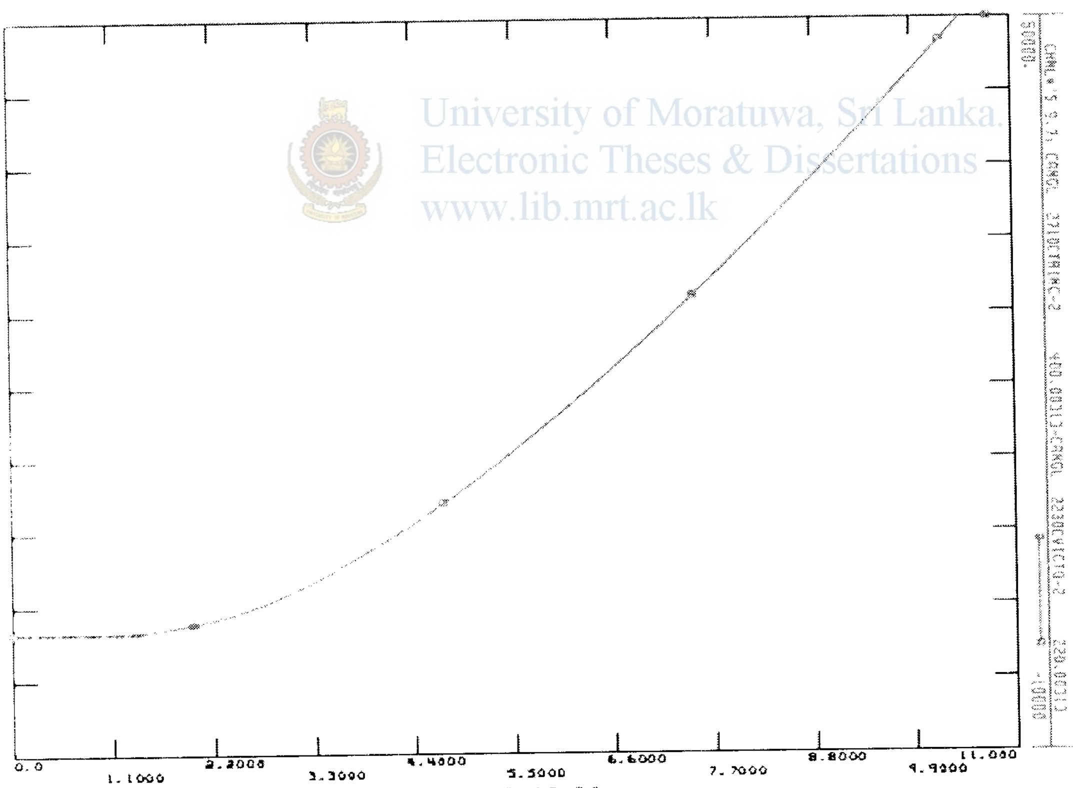


Figure 3.3 Relative Rotor Angle variation, following a three-phase short circuit fault in one circuit of the 400kV three-circuit 4xZebra transmission line between Trincomalee PS and Veyangoda GS

Thus. the 400kV transmission network configuration comprising of a switching station at New Habarana. 4xZebra 400kV three circuit transmission line between

Trincomalee power station and New Habarana switching station and a 400kV 2xZebra double circuit transmission line between New Habarana switching station and Veyangoda grid substation are selected for further studies. Figure 3.3 shows the proposed 400kV transmission network configuration of Trincomalee Coal Power Plant Grid Connection for year 2020.

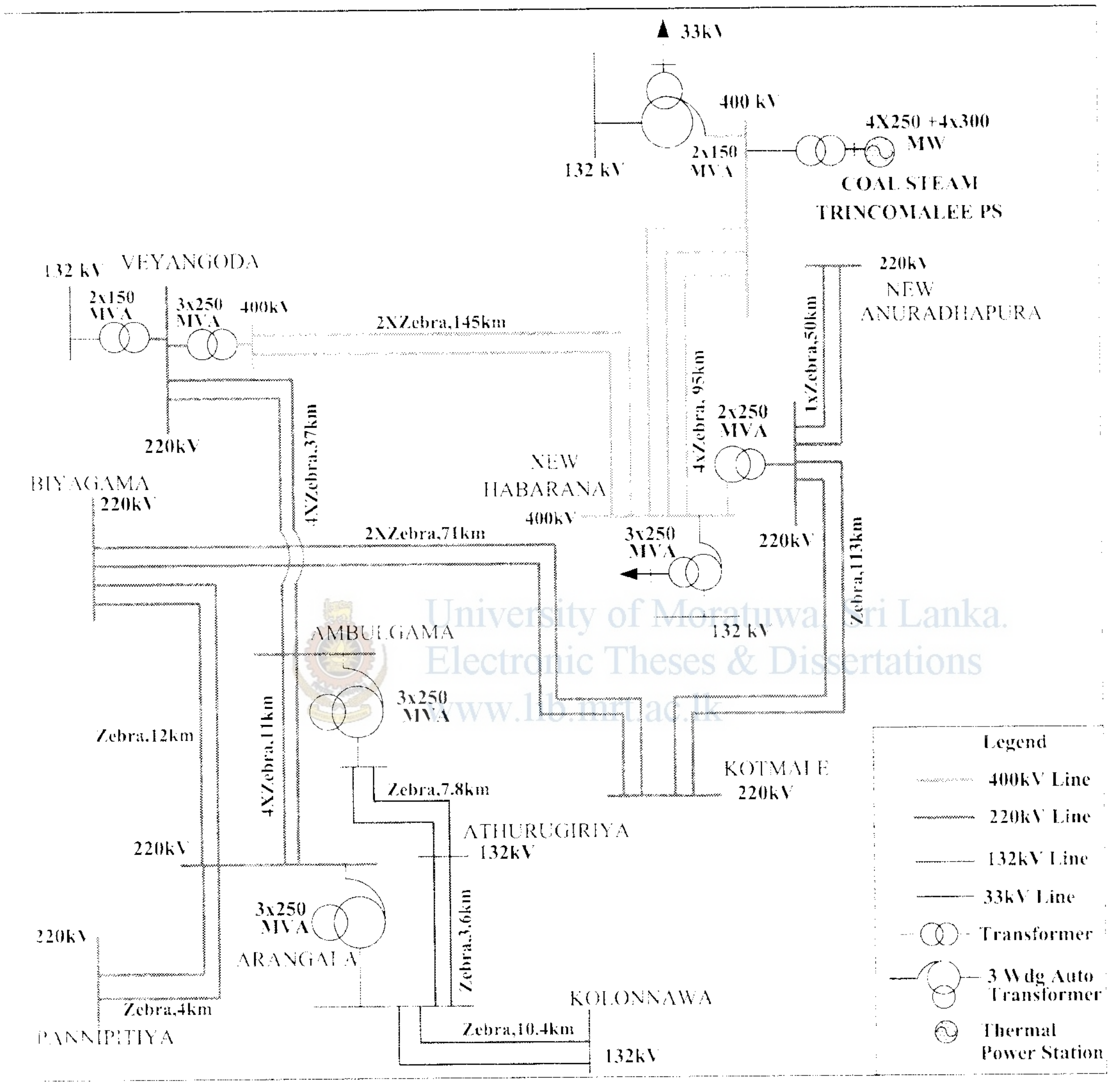


Figure 3.4 The proposed 400kV transmission network configuration of Trincomalee Coal Power Plant Grid Connection for year 2020

The total scope of work for the power transmission from Trincomalee power station. if the transmission voltage of 400kV is selected can be summarized as follows.

- Construction of a 400kV three circuit 4*Zebra. 95km length transmission line from Trincomalee power station to New Habarana switching station.
- Construction of Trincomalee PS switchyard (400 kV double bus bar arrangement with bus coupler. 3x400 kV double bus bar transmission line bays. 2x 400kV

double bus bar transformer bays. 2x 150MVA 400/132 kV transformers. 132kV double bus bar arrangement with bus coupler. 2x 132kV double bus bar transformer bay)

- Construction of New Habarana SS (400kV double bus bar arrangement with bus coupler. 2x 250 MVA 400/220 kV transformers. 5x400kV double bus bar transformer bays. 2x 220kV double bus bar transformer bays. 3x 250 MVA 400/132kV transformers. 3x 132kV double bus bar transformer bays. 5x 400kV double bus bar Transmission Line bays. 4x 220kV double bus bar Transmission Line bays. 220kV double bus bar arrangement with bus coupler. 132kV double bus bar arrangement with bus coupler)
- Construction of New Habarana-Veyangoda 400kV two circuit 2*Zebra. 145km length transmission line.
- Development of Veyangoda GS (400kV double bus bar arrangement with bus coupler. 3x250 MVA 400/220 kV transformers. 3x400kV double bus bar transformer bays. 3x 220kV double bus bar transformer bays. 2x 400kV double bus bar transmission line bays)
- Construction of Ambulgama GS(220kV double bus bar arrangement with a bus coupler. 3x250MVA 220/132 kV transformers. 3x220kV double bus bar transformer bays. 4x220kV double bus bar transmission line bays.132kV single bus bar arrangement with bus section bay. 2x132kV transmission line bays. 3x132kV transformer bays.)
- Construction of Arangalla GS (220kV double bus bar arrangement with a bus coupler. 3x250MVA transformers. 3x220kV double bus bar transformer bays. 6x 220kV double bus bar transmission line bays. 132kV Single bus bar arrangement with bus section. 4x132kV single bus bar transmission line bays. 3x 132kV transformer bays.)
- Construction of Arangala GS-Athurugiriya GS 132kV two circuit Zebra. 3.6km length transmission line.
- Construction of Arangala GS-Kolonnawa GS 132kV two circuit Zebra. 10.4km length transmission line.
- Construction of Veyangoda GS-Ambulgama GS 220kV two circuit 4*Zebra. 37km length transmission line.

- Construction of Ambulgama GS-Arangala GS 220kV two circuit 4*Zebra. 11km length transmission line.
- Construction of Ambulgama GS-Athurugiriya GS 132kV two circuit Zebra. 7.8km length transmission line

3.2 Steady State Analysis of the Selected Transmission Network Configurations for year 2020

The load flow and single contingency analysis were conducted during steady state analysis of selected transmission networks.

The main objective of the load flow study is to determine the steady state performance of the power system. The potential problems such as unacceptable voltage conditions and overloading of transmission network elements were identified from load flow studies.

The adopted contingency level for the planning purpose is N-1, i.e. after outage of any one element of the transmission system at a time, the system should be able to meet the distribution demand while maintaining the acceptable bus bar voltage levels and loading of all the elements should not exceed their emergency rating specified.

The voltage criterion defines the permitted voltage deviation at any live bus bar of the network under normal and single contingency operating conditions as given in table 3.1.

Busbar Voltage	Allowable Voltage Variation (%)	
	Normal Operating Condition	Single Contingency Condition
400kV	±5%	±5%
220 kV	±5%	-10% to +5%
132kV	±10%	±10%

Table 3.1 Allowable voltage variations

3.2.1 Steady State Analysis of 220kV Transmission Network Configuration

The load flow (Annex A-1) and single contingency analysis were illustrated that following additional transmission reinforcements are necessary for 220kV network to overcome voltage and thermal criteria violations.

- Reconstruction of 82.3km Ukuwela-Habarana 132kV double circuit transmission line using Zebra Conductor.

- Installation of 15Mvar. voltage controlled breaker switched capacitors at Kurunnagala 33kV bus.
- Reconstruction of 1.5km New Anuradhapura-Anuradhapura 132kV double circuit Lynx line using Zebra conductor.

With the above reinforcements the voltage levels and loading conditions were observed after outage of critical 220kV lines. The results are listed in the Table 3.2.

Single Contingency	Voltage on Bus Bars (p.u.)			Loading on the remaining circuit	
	Bus Bar	Day Peak	Night Peak	Day Peak	Night Peak
One circuit outage of Arangala-Pannipitiya 220kV Transmission Line	Arangala Pannipitiya	0.974 0.967	0.961 0.954	113%	96%
One circuit outage of Kotugoda-Biyagama 220kV Transmission Line	Biyagama Arangala Pannipitiya	0.982 0.978 0.975	0.970 0.962 0.959	11%	16%
One circuit outage of Biyagama-Arangala 220kV Transmission Line	Arangala Pannipitiya	0.977 0.974	0.958 0.955	47%	88%
One circuit outage of Veyangoda-Ambulgama 220kV Transmission Line	Biyagama Arangala Pannipitiya	0.981 0.976 0.973	0.966 0.958 0.954	13%	23%
One circuit outage of New Habarana-Veyangoda 220kV Transmission Line	Veyangoda Biyagama Arangala Pannipitiya	0.983 0.977 0.973 0.970	0.967 0.966 0.958 0.955	20%	25%
One circuit outage of Arangala-Ambulgama 220kV Transmission Line	Arangala Pannipitiya	0.971 0.968	0.961 0.958	28%	14%

Table 3.2 Voltage Levels and Loading Conditions after outage of critical 220kV Transmission Lines of selected 220kV Configuration

According to the results listed in Table 3.2, no planning criteria violations can be observed after outage of critical 220kV transmission lines. All the bus bar voltages and loading conditions are obeying planning criteria.

Transmission System Losses

Transmission system losses under Night peak and Day peak load scenarios are mention below.

Night Peak Load Scenario: 130.5 MW (2.55 % of Total Generation)

Day Peak Load Scenario: 55.7 MW (1.56% of Total Generation)

3.2.2 Steady State Analysis of 400kV Transmission Network Configuration

The load flow (Annex A-2) and single contingency analysis were revealed that the following additional transmission reinforcements were necessary for 400kV network to satisfy voltage and thermal criteria.

- Reconstruction of 82.3km Ukuwela-Habarana 132kV double circuit transmission line using Zebra Conductor.
- Install another 10Mvar, voltage controlled breaker switched capacitors at Pallekele 33kV bus.
- Reconstruction of 1.5km New Anuradhapura-Anuradhapura 132kV double circuit Lynx line using Zebra conductor.

With the above reinforcements, the voltage levels and loading conditions were observed after outage of critical 220kV and 400kVlines. The results are listed in the Table 3.3.

Single Contingency	Voltage on Bus Bars (p.u.)			Loading on the remaining circuit (%)	
	Bus Bar	Day Peak	Night Peak	Day Peak	Night Peak
One circuit outage of Arangala-Pannipitiay 220kV Transmission Line	Arangala Pannipitiya	0.981 0.977	0.967 0.960	71%	105%
One circuit outage of Kotugoda-Biyagama 220kV Transmission Line	Biyagama Arangala Pannipitiya	0.989 0.968 0.986	0.974 0.966 0.963	7%	15%
One circuit outage of Biyagama-Arangala 220kV Transmission Line	Arangala Pannipitiya	0.988 0.986	0.963 0.960	33%	92%
One circuit outage of Veyangoda-Ambulgama 220kV Transmission Line	Biyagama Arangala Pannipitiya	0.988 0.986 0.984	0.972 0.962 0.959	9%	23%
One circuit outage of New Habarana-Veyangoda 400kV Transmission Line	Veyangoda Biyagama Arangala Pannipitiya	0.99 0.984 0.983 0.981	0.973 0.971 0.962 0.959	24%	32%
One circuit outage of Arangala-Ambulgama 220kV Transmission Line	Arangala Pannipitiya	0.986 0.985	0.965 0.961	10%	14%
One circuit outage of 4*Zebra cct of Trinco-New Habarana 400kV Transmission Line	Veyangoda Biyagama Arangala Pannipitiya	0.983 0.986 0.985 0.983	0.974 0.973 0.964 0.961	14%	30%

Table 3.3 Voltage Levels and Loading Conditions after outage of critical 220kV & 400kV Transmission Lines of selected 400kV Configuration

No violation of busbar voltages or loading conditions can be observed after outage of critical 220kV and 400kV transmission lines with respect to planning criteria specified by the Long Term Transmission Development Plan (Annex 13).

Transmission System Losses

Transmission system losses under Night peak and Day peak load scenarios are mention below.

Night Peak Load Scenario: 116.7 MW (2.29 % of Total Generation)

Day Peak Load Scenario: 54.9 MW (1.54% of Total Generation)

3.3 Transient Stability Analysis of the Selected Transmission Network Configurations for year 2020

The transient stability studies were performed in order to make sure that the system will remain stable following a severe disturbance.

Transient stability of the 220kV and 400kV transmission network configuration in year 2020 under night peak and day peak load operating conditions were investigated. Successful and unsuccessful clearing of three phase faults (3PF) in critical lines was studied and stability of the system assessed. Both Successful Re-closing (SR) and unsuccessful Re-closing (USR) of transmission circuits and tripping of generators were taken into account for the studies. Unless otherwise stated specifically, the circuit breaker operating time is considered as 120ms and first re-closing time is considered as 500ms.

3.3.1 Transient Stability Analysis of 220kV Transmission Network Configuration

The transient stability results of the 220kV network configuration are depicted in Table 3.4 and Annex A-3 to Annex A-7.

Faulty Element	Fault Type & Location	Switching Sequence	Result in Operating Condition	
			Night Peak	Day Peak
Trincomalee PS - New Habarana GS 220kV tx line cct. 1	3 PF at Trincomalee PS end	SR	SS	SS
		USR	SS	SS
Tripping of one 300MW unit at Trincomalee PS	Machine Trip	Not Applicable	SS	SS
Veyangoda - Ambulgama 220kv tx line cct. 1	3PF at Veyangoda GS end	SR	SS	SS
		USR	SS	SS
New Habarana-Veyangoda 220kV tx. Line cct 1	3PF at New Habarana SS end	SR	SS	SS
		USR	SS	SS

SS- System stable SU- System unstable

Table 3.4 Transient Stability Analysis Results of Selected 220kV Transmission Network Configuration of year 2020

Table 3.4 and Annex A-3 to Annex A-7 illustrate the stability results in Night Peak and Day Peak loading scenarios. Stability results demonstrate that the 220kV transmission network configuration is stable.

3.3.2 Transient Stability Analysis of 400kV Transmission Network Configuration

The transient stability results of the 400kV network configuration are depicted in Table 3.5 and Annex A-8 to Annex A-12.

Faulty Element	Fault Type & Location	Switching Sequence	Result in Operating Condition	
			Night Peak	Day Peak
Trincomalee PS New Habarana GS 400kV tx line cct. 1	3 PF at Trincomalee PS end	SR	SS	SS
		USR	SS	SS
Tripping of one 300MW unit at Trincomalee PS	Not Applicable	Not Applicable	SS	SS
Veyangoda - Ambulgama 220kv tx line cct. 1	3PF at Veyangoda GS end	SR	SS	SS
		USR	SS	SS
New Habarana-Veyangoda 400kV tx. Line cct 1	3PF at New Habarana SS end	SR	SS	SS
		USR	SS	SS

SS- System stable SU- System unstable

Table 3.5 Transient Stability Analysis Results of Selected 400kV Transmission Network Configuration of year 2020

Table 3.5 and Annex A-8 to Annex A-12 demonstrate the stability results in Night Peak and Day Peak loading scenarios. These results reveal that the 400kV transmission network configuration is stable.

3.4 Economic Analysis of the Selected Transmission Network Configurations

All the items in the section 3.1.1, 3.1.2, 3.2.1, 3.2.2 were taken into account for the calculation of costs of selected transmission network configuration. All costs are in Million LKR (Sri Lankan Rupee). Unit costs were obtained from the 2008 cost database prepared by the Transmission Planning Section of CEB and References [4], [9] and [10].

Base cost does not include the cost associated with uncertainties and risks. It comprise of two components named Foreign Cost (F.C.) Component and Local Cost (L.C.) Component.

The project completion period is considered as three years and the proportion of disbursement of project costs are assumed as 20%, 70% and 10% for the first, second and third years respectively. To determine total project cost, Price Escalations, Physical Contingencies, Administrative cost and Levies will be added.

3.4.1 Base Cost Estimation of 220kV Transmission Network Configuration

Description	Estimated Base Cost (Million LKR)
220kV Transmission Connection	
Construction of Trincomalee Power Station Switchyard	1166.4
Construction of New Habarana 220/132 kV Switching Station	2042.6
Construction of Arangala 220/132 kV Grid Substation	1906.0
Construction of Ambulgama 220/132 kV Grid Substation	1730.3
Construction of Trincomalee PS - New Habarana SS 220kV Transmission Line (95km)	6787.5
Construction of New Habarana SS - Veyangoda GS 220kV Transmission Line (145km)	10359.9
Construction of Veyangoda GS - Ambulgama GS 220kV Transmission Line (37km)	2643.5
Construction of Ambulgama GS-Arangala GS 220kV Transmission Line (11km)	785.9
Construction of Ambulgama GS - Athurugiriya GS 132kV Transmission Line (7.8km)	238.6
Construction of Arangala SS - Athurugiriya GS 132kV Transmission Line (3.6km)	110.1
Construction of Arangala GS-Kolonnawa GS 132kV Transmission Line (10.4km)	318.2
Reconstruction of Ukuwela-Habarana 132kV Transmission Line	2517.8
Installation Breaker Switched Capacitors at Kurunagala GS	60.7
Reconstruction of New Anuradhapura-Anuradhapura 132kV Transmission Line	45.9
Construction of Line Bays at Veyangoda GS	221.5
Total Estimated Base Cost	**30,935.1**

Table 3.6 Base Cost Estimation of Selected 220kV Transmission Network Configuration of year 2020

According to the Table 3.6 total base cost estimation of the 220kV transmission network configuration is 30,935.1 Million LKR.

3.4.2 Base Cost Estimation of 400kV Transmission Network Configuration

Description	Estimated Base Cost (MLKR)
400kV Transmission Connection	
Construction of Trincomalee Power Station Switchyard	1511.4
Construction of New Habarana 400/220/132 kV Switching Station	3715.9
Construction of Arangala 220/132 kV Grid Substation	1906.0
Construction of Ambulgama 220/132 kV Grid Substation	1730.3
Construction of Trincomalee PS - New Habarana SS 400kV Transmission Line (95km)	16290.0
Construction of New Habarana SS - Veyangoda GS 400kV Transmission Line (145km)	12311.5
Construction of Veyangoda GS - Ambulgama GS 220kV Transmission Line (37km)	2643.5
Construction of Ambulgama GS-Arangala GS 220kV Transmission Line(11km)	785.9
Construction of Ambulgama GS - Athurugiriya GS 132kV Transmission Line (7.8km)	238.6
Construction of Arangala SS - Athurugiriya GS 132kV Transmission Line(3.6km)	110.1
Construction of Arangala GS-Kolonnawa GS 132kV Transmission Line(10.4)	318.2
Reconstruction of Ukuwela-Habarana 132kV Transmission Line	2517.8
Installation Breaker Switched Capacitors at Kurunagala GS	40.5
Reconstruction of New Anuradhapura-Anuradhapura 132kV Transmission Line	45.9
augmentation of Veyangoda GS	1935.5
Total Estimated Base Cost	**46,101.2**

Table 3.7 Base Cost Estimation of Selected 400kV Transmission Network Configuration of year 2020

According to the Table 3.7 total base cost estimation of the 400kV transmission network configuration is 46,101.2 Million LKR.

3.4.3 Disbursement Schedules and Total Cost Estimation of the Selected 220kV Transmission Network Configurations

Description	Total		2018	2019	2020
Total Base Cost of the project	F.C.	23509.6	4701.9	16456.7	2351.0
	L.C.	7425.5	1485.1	5197.8	742.5
Price Escalation	FC	6455.1	1159.8	4568.2	727.1
	LC	10832.1	1876.0	7683.6	1272.5
Sub Total 1	**FC**	**29964.7**	**5861.7**	**21024.9**	**3078.0**
	LC	**18257.6**	**3361.1**	**12881.4**	**2015.0**
Physical contingency(10%)	FC	2996.5	586.2	2102.5	307.8
	LC	1825.8	336.1	1288.1	201.5
Sub Total 2	**FC**	**32961.2**	**6447.9**	**23127.4**	**3385.9**
	LC	**20083.3**	**3697.2**	**14169.6**	**2216.5**
Administrative Cost	LC	988.8	193.4	693.8	101.6
Sub Total 3	**F.C.**	**32961.2**	**6447.9**	**23127.4**	**3385.9**
	L.C.	**21072.2**	**3890.7**	**14863.4**	**2318.1**
Taxes and Duties	L.C.	1186.6	232.1	832.6	121.9
Grand Total	**F.C.**	**32961.2**	**6447.9**	**23127.4**	**3385.9**
	L.C.	**22258.8**	**4122.8**	**15696.0**	**2440.0**
Total Cost MLKR		**55,220**			

Table 3.8 Total Cost Estimation of Selected 220kV Transmission Network Configuration of year 2020

According to the Table 3.8 Total project cost estimation for the 220kV transmission network configuration is 55.220 Million LKR.

3.4.4 Disbursement Schedules and Total Cost Estimation of the Selected 400kV Transmission Network Configurations

Description		Total	2018	2019	2020
Total Base Cost of the project	F.C.	35046.4	7009.3	24532.5	3504.6
	L.C.	11054.8	2211.0	7738.3	1105.5
Price Escalation	FC	9622.8	1729.0	6810.0	1083.9
	LC	16126.4	2792.9	11439.0	1894.4
Sub Total 1	FC	44669.3	8738.3	31342.5	4588.5
	LC	27181.2	5003.9	19177.4	2999.9
Physical contingency(10%)	FC	4466.9	873.8	3134.2	458.9
	LC	2718.1	500.4	1917.7	300.0
Sub Total 2	FC	49136.2	9612.1	34476.7	5047.4
	LC	29899.3	5504.3	21095.1	3299.9
Administrative Cost	LC	1474.1	288.4	1034.3	151.4
Sub Total 3	**F.C.**	**49136.2**	**9612.1**	**34476.7**	**5047.4**
	L.C.	**31373.4**	**5792.6**	**22129.4**	**3451.3**
Taxes and Duties	L.C.	1768.9	346.0	1241.2	181.7
Grand Total	**F.C.**	**49136.2**	**9612.1**	**34476.7**	**5047.4**
	L.C.	**33142.3**	**6138.7**	**23370.6**	**3633.0**
Total Cost MLKR		**82,278**			

Table 3.9 Total Cost Estimation of Selected 400kV Transmission Network Configuration of year 2020

According to the Table 3.9 Total project cost estimation for the 400kV transmission network configuration is 82,278 Million LKR.

3.4.5 Economic Evaluation of Transmission Network Configurations for year 2020

The capital cost could be saved using 220kV as the transmission voltage for the Trincomalee Power Plant Grid Connection instead of 400kV as the transmission voltage. But the transmission losses were low in the case of 400kV configuration than 220kV configuration. (Transmission Network with 220kV Configuration and 400kV configuration has the peak power losses of 130.5 MW and 116.7MW respectively.) Low losses reduce both the peak demand and energy loss level of the network. Therefore it was necessary to investigate the economic viability of 400kV configuration with compare to 220kV configuration. In order to determine whether additional capital expenditure to reduce system losses can be justified, the usual requirement is for the investigation to cover at least the economic life of the proposed reinforcements. For the Transmission Network reinforcements, economic life is assumed to be 40 years.

Estimation of Net Cost Saving

Loss saving of the project comprises of two components, namely Energy cost saving and Capacity Cost Saving.

Following parameters were used in this evaluation.

Peak Power Loss Saving due to 400kV Configuration – 13.8 MW

Peak Power loss saving due to implementation of 400kV configuration was assumed to be constant through out the economic life of the configuration.

Lifetime of Transmission Network Development	-	40 years
Interest rate	-	8% per annum
Discount rate	-	8% per annum
Energy Cost per kWh (Rs.)	-	8.36 [13]
Capacity Cost per kW (Rs.)	-	17.567 [13]

Load factor values were taken from 'National Power and Energy Forecast for year 2008-2027' [1]. For years outside of this period, Load Factors were assumed to be equal to the year 2027 value.

Salvage value of Transmission network development at the end of their lifetime was taken as negligible.

Table 3.10 illustrates the calculation of Net Cost Saving due to implement the 400kV configuration instead of 220kV configuration.

Energy Cost Saving

Annual Energy Cost Saving (AECS) = ALS*Energy Cost Per kWh

Where,

ALS is the Annual Loss Saving.

Annual Loss Saving (ALS) = Peak Loss Saving*LLF*24*365

Where,

Loss Load Factor (LLF) $= K*LF + (1-K)*LF^2$

K= 0.2 ('K' was taken as 0.2 for a Load Curve having a single predominant peak. To having a predominant peak, night time or day time peak should be more than 1.5 to 2 times the other. [4])

$$\text{Load Factor} = \frac{\text{Total Consumption of a year}}{(\text{Peak Load of the system}*24*365)}$$

Calculated Energy loss saving during the life time of the configuration was discounted back to present value (PV).

$PV = R_t / (1+i)^t$

Where

t - The year of the cash flow

i - The discount rate

R_t - The Energy Cost Saving during year t

Net Present Value (NPV) of Savings was calculated by summing PV of all loss savings during life time.

Capacity Cost Saving

Annual Capacity Cost Saving (ACCS) = Peak Loss Saving * Capacity Cost per kW

Net Cost Saving

Annual Cost of Saving (ACS) = AECS+ACCS

Year	Peak Loss Saving	Load Factor	LLF	ALS (MWh)	AECS (MRs.)	ACCS (MRs.)	ACS (MRs.)	NPV Factor	Present Cost Saving (MRs.)	Net Present Value (MRs.)
2020	13.8	0.587	0.393	47515.7	397.2	242.4	639.7	0.46	296.3	3879.4
2021	13.8	0.588	0.394	47653.5	398.4	242.4	640.8	0.43	274.8	
2022	13.8	0.59	0.396	47929.7	400.7	242.4	643.1	0.40	255.4	
2023	13.8	0.591	0.398	48068.1	401.8	242.4	644.3	0.37	236.9	
2024	13.8	0.592	0.399	48206.7	403.0	242.4	645.4	0.34	219.7	
2025	13.8	0.594	0.401	48484.4	405.3	242.4	647.8	0.32	204.2	
2026	13.8	0.595	0.402	48623.6	406.5	242.4	648.9	0.29	189.4	
2027	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.27	176.0	
2028	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.25	163.0	
2029	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.23	150.9	
2030	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.21	139.7	
2031	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.20	129.4	
2032	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.18	119.8	
2033	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.17	110.9	
2034	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.16	102.7	
2035	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.15	95.1	
2036	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.14	88.1	
2037	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.13	81.5	
2038	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.12	75.5	
2039	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.11	69.9	
2040	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.10	64.7	
2041	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.09	59.9	
2042	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.09	55.5	
2043	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.08	51.4	
2044	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.07	47.6	
2045	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.07	44.0	
2046	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.06	40.8	
2047	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.06	37.8	
2048	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.05	35.0	
2049	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.05	32.4	
2050	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.05	30.0	
2051	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.04	27.8	
2052	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.04	25.7	
2053	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.04	23.8	
2054	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.03	22.0	
2055	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.03	20.4	
2056	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.03	18.9	
2057	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.03	17.5	
2058	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.02	16.2	
2059	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.02	15.0	
2060	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.02	13.9	

Table 3.10 Calculation of Present Value of Loss Saving

Estimation of Total Expenditure

Total capital investment required (Without Tax) for implement 220kV configuration during year 2018, 2019 and 2020 will be 10338.6MRs, 37990.8MRs and 5704.0MRs respectively. For 400kV transmission network configuration capital investment (Without Tax) necessary for year 2018, 2019 and 2020 will be 15404.7MRs, 56606.1MRs and 8498.6MRs respectively. Therefore extra capital investment required for 400kV configuration will be 5066.1MRs, 18615.3MRs and 2794.7MRs for year 2018, 2019 and 2020.

Following parameters were used in this calculation.

Annual operation and maintenance cost was assumed to be 2% of the total investment cost.

Interest rate	-	8% per annum
Discount rate	-	8% per annum

The payments for the loan were considered, based on constant payments and constant interest rate.

Table 3.11 illustrates the calculation of present value of expenditures due to implement the 400kV configuration instead of 220kV configuration.

Year	Capital Investments (MRs)	Annuity Payment (MRs)	Annual Investments (MRs)	Annual Operation & Maintenance Cost (MRs)	Total Annual Expenditure (MRs)	Discounted values @ 8% p.a. (MRs)	NPV Cost of Expenditure (MRs)
2018	5066.2	496.6	496.6		496.6	268.3	20,419.3
2019	18615.3	1858.4	2355.1		2355.1	1178.1	
2020	2794.7	284.6	2639.7	529.5	3169.2	1468.0	
2021	-	-	2639.7	529.5	3169.2	1359.2	
2022	-	-	2639.7	529.5	3169.2	1258.5	
2023	-	-	2639.7	529.5	3169.2	1165.3	
2024	-	-	2639.7	529.5	3169.2	1079.0	
2025	-	-	2639.7	529.5	3169.2	999.1	
2026	-	-	2639.7	529.5	3169.2	925.1	
2027	-	-	2639.7	529.5	3169.2	856.5	
2028	-	-	2639.7	529.5	3169.2	793.1	
2029	-	-	2639.7	529.5	3169.2	734.3	
2030	-	-	2639.7	529.5	3169.2	680.0	
2031	-	-	2639.7	529.5	3169.2	629.6	
2032	-	-	2639.7	529.5	3169.2	582.9	
2033	-	-	2639.7	529.5	3169.2	539.8	
2034	-	-	2639.7	529.5	3169.2	499.8	
2035	-	-	2639.7	529.5	3169.2	462.8	
2036	-	-	2639.7	529.5	3169.2	428.5	
2037	-	-	2639.7	529.5	3169.2	396.7	
2038	-	-	2639.7	529.5	3169.2	367.4	
2039	-	-	2639.7	529.5	3169.2	340.1	
2040	-	-	2639.7	529.5	3169.2	314.9	
2041	-	-	2639.7	529.5	3169.2	291.6	
2042	-	-	2639.7	529.5	3169.2	270.0	
2043	-	-	2639.7	529.5	3169.2	250.0	
2044	-	-	2639.7	529.5	3169.2	231.5	
2045	-	-	2639.7	529.5	3169.2	214.3	
2046	-	-	2639.7	529.5	3169.2	198.5	
2047	-	-	2639.7	529.5	3169.2	183.8	
2048	-	-	2639.7	529.5	3169.2	170.2	
2049	-	-	2639.7	529.5	3169.2	157.6	
2050	-	-	2639.7	529.5	3169.2	145.9	
2051	-	-	2639.7	529.5	3169.2	135.1	
2052	-	-	2639.7	529.5	3169.2	125.1	
2053	-	-	2639.7	529.5	3169.2	115.8	
2054	-	-	2639.7	529.5	3169.2	107.2	
2055	-	-	2639.7	529.5	3169.2	99.3	
2056	-	-	2639.7	529.5	3169.2	91.9	
2057	-	-	2639.7	529.5	3169.2	85.1	
2058	-	-	2639.7	529.5	3169.2	78.8	
2059	-	-	2639.7	529.5	3169.2	73.0	
2060	-	-	2639.7	529.5	3169.2	67.6	

Table 3. 11 Calculation of Present Value of Expenditures

Benefit/Cost Ratio

A benefit/cost ratio is an indicator. used in the formal discipline of cost-benefit analysis. which attempts to summarize the overall value for money of a project.

Benefit/Cost Ratio = (NPV of Savings) / (NPV of Expenditures)

= (3879.4/20419.3)

= 0.189

The Benefit/Cost Ratio < 1. Therefore it is not economically viable to construct 400kV configuration with compare to 220kV configuration.

Sensitivity Analysis

Sensitivity analysis is one of the techniques used to investigate the robustness of a study when the study includes some form of uncertainties. Since the future cannot be accurately predicted there is a high probability that some of the assumptions may prove incorrect. Sensitivity analysis shows how the variation in the results can be apportioned to different sources of variation in the assumptions. This technique shows how changes of assumptions affect the Benefit to Cost Ratio.

1) Interest rate - 6% per annum

Discount rate - 6% per annum

Benefit/Cost Ratio = 0.221

2) Interest rate - 10% per annum

Discount rate - 10% per annum

Benefit/Cost Ratio = 0.165

3) Load factor values were taken from 'National Power and Energy Forecast for 2008-2027' [1]. During this analysis. years outside of the 2008-2027 periods. Load Factors were assumed to be varying according to the previous trend.

Table 3.12 illustrates the new Load Factor values and corresponding Cost Saving calculations.

Therefore the Benefit/Cost Ratio = (3933.5)/(20419.3)

= 0.193

Year	Peak Loss Saving	Load Factor	LLF	ALS (MWh)	AECS (MRs.)	ACCS (MRs.)	ACS (MRs.)	NPV Factor	Present Cost Saving (MRs.)	Net Present Value (MRs.)
2020	13.8	0.587	0.393	47515.7	397.2	242.4	639.7	0.46	296.3	3933.5
2021	13.8	0.588	0.394	47653.5	398.4	242.4	640.8	0.43	274.8	
2022	13.8	0.59	0.396	47929.7	400.7	242.4	643.1	0.40	255.4	
2023	13.8	0.591	0.398	48068.1	401.8	242.4	644.3	0.37	236.9	
2024	13.8	0.592	0.399	48206.7	403.0	242.4	645.4	0.34	219.7	
2025	13.8	0.594	0.401	48484.4	405.3	242.4	647.8	0.32	204.2	
2026	13.8	0.595	0.402	48623.6	406.5	242.4	648.9	0.29	189.4	
2027	13.8	0.597	0.405	48902.5	408.8	242.4	651.2	0.27	176.0	
2028	13.8	0.598	0.406	49052.2	410.1	242.4	652.5	0.25	163.3	
2029	13.8	0.599	0.407	49248.9	411.7	242.4	654.1	0.23	151.6	
2030	13.8	0.601	0.409	49445.9	413.4	242.4	655.8	0.21	140.7	
2031	13.8	0.602	0.411	49643.3	415.0	242.4	657.4	0.20	130.6	
2032	13.8	0.604	0.412	49841.1	416.7	242.4	659.1	0.18	121.2	
2033	13.8	0.605	0.414	50039.3	418.3	242.4	660.8	0.17	112.5	
2034	13.8	0.607	0.416	50237.9	420.0	242.4	662.4	0.16	104.5	
2035	13.8	0.608	0.417	50436.8	421.7	242.4	664.1	0.15	97.0	
2036	13.8	0.609	0.419	50636.2	423.3	242.4	665.7	0.14	90.0	
2037	13.8	0.611	0.421	50835.9	425.0	242.4	667.4	0.13	83.6	
2038	13.8	0.612	0.422	51036.0	426.7	242.4	669.1	0.12	77.6	
2039	13.8	0.614	0.424	51236.4	428.3	242.4	670.8	0.11	72.0	
2040	13.8	0.615	0.425	51437.3	430.0	242.4	672.4	0.10	66.8	
2041	13.8	0.616	0.427	51638.5	431.7	242.4	674.1	0.09	62.0	
2042	13.8	0.618	0.429	51840.1	433.4	242.4	675.8	0.09	57.6	
2043	13.8	0.619	0.430	52042.1	435.1	242.4	677.5	0.08	53.4	
2044	13.8	0.621	0.432	52244.5	436.8	242.4	679.2	0.07	49.6	
2045	13.8	0.622	0.434	52447.3	438.5	242.4	680.9	0.07	46.1	
2046	13.8	0.623	0.436	52650.4	440.2	242.4	682.6	0.06	42.7	
2047	13.8	0.625	0.437	52854.0	441.9	242.4	684.3	0.06	39.7	
2048	13.8	0.626	0.439	53057.9	443.6	242.4	686.0	0.05	36.8	
2049	13.8	0.628	0.441	53262.2	445.3	242.4	687.7	0.05	34.2	
2050	13.8	0.629	0.442	53466.8	447.0	242.4	689.4	0.05	31.7	
2051	13.8	0.630	0.444	53671.9	448.7	242.4	691.1	0.04	29.5	
2052	13.8	0.632	0.446	53877.3	450.4	242.4	692.8	0.04	27.3	
2053	13.8	0.633	0.447	54083.1	452.1	242.4	694.6	0.04	25.4	
2054	13.8	0.635	0.449	54289.3	453.9	242.4	696.3	0.03	23.6	
2055	13.8	0.636	0.451	54495.9	455.6	242.4	698.0	0.03	21.9	
2056	13.8	0.637	0.453	54702.9	457.3	242.4	699.7	0.03	20.3	
2057	13.8	0.639	0.454	54910.2	459.0	242.4	701.5	0.03	18.8	
2058	13.8	0.640	0.456	55118.0	460.8	242.4	703.2	0.02	17.5	
2059	13.8	0.642	0.458	55326.1	462.5	242.4	705.0	0.02	16.2	
2060	13.8	0.643	0.459	55534.6	464.3	242.4	706.7	0.02	15.1	

Table 3. 12 Calculated Load Factor values and corresponding Cost saving calculation

For all the cases, Benefit/Cost Ratio was less than 1. Therefore it is not economically feasible to construct 400kV transmission network configuration with compare to 220kV transmission network configuration.

Chapter 4

Conclusions

The present practice of bulk power transmission from major power stations is using 220kV transmission lines. Because of 2200 MW of power has to be transmitted from proposed Trincomalee Power Plant to load center, it has been decided to investigate the feasibility of using 400kV against the 220kV as the transmission voltage for the power transmission. The study mainly concerns the year 2016 and year 2020 transmission network configurations.

The transmission system studies for year 2016 system with 1600MW of coal power plant units were conducted for two different system loading conditions. Three alternative configurations were studied based on the "Long Term Transmission Development Plan 2008-2016". Only the configuration without Kirindiwela SS was selected after the steady state and economic analysis. Even though the configuration with Kirindiwela shows slight improvement in system reliability and system loss savings no planning criteria violations can be observed without Kirindiwela configuration. As far as the transient stability was concerned both systems behave similarly following critical system disturbances. Thus, the construction of Kirindiwela SS was not necessary to transmit power from proposed Trincomalee Coal Power Plant. Results from the year 2016 studies were used to select the year 2020 configuration.

Two feasible 220kV and 400kV transmission network configurations for year 2020 were selected for comparison based on the steady state and transient state performance. Result of the steady state analysis, transient stability analysis and economic analysis were used to study the advantages and disadvantages of the transmission configurations. No planning criteria violations were observed for both configurations under steady state operating conditions. Transmission system losses of 220kV network configuration under Night peak and Day peak load scenarios were 130.5 MW and 55.7 MW respectively. Transmission system losses of 400kV network configuration were 116.7 MW and 54.9 MW under Night peak and Day peak load scenarios. The study was illustrated that the 400kV transmission network configuration has comparatively low transmission losses with respective to 220kV transmission network configuration.

Transient stability of the 220kV and 400kV transmission network configuration in year 2020 was assessed under night peak and day peak load operating conditions for both Successful Re-closing and Unsuccessful Re-closing of transmission circuits and tripping of generators. Both selected 220kV and 400kV transmission network configurations were stable for most critical three phase faults that can appear one at a time in each connection, with circuit breaker operating time of 120ms.

Additional capital investment required for 400kV configuration with compare to 220kV configuration will be 5066.1MRs, 18615.3MRs and 2794.7MRs for years 2018, 2019 and 2020 respectively. Annual operation and maintenance cost was assumed to be 2% of the total investment cost. 8% of Interest rate and 8% of Discount rate were assumed during the calculation. The payments for the loan were considered as based on constant payments and constant interest rate. Then the Net Present Value of expenditures was 20,419.3 MRs.

Peak Power Loss Saving due to implementing the 400kV Configuration was 13.8MW. Power Loss Saving was assumed to be constant through out the economic life of the configurations. Life time of Transmission Network Developments was assumed as 40 years. Loss saving of the project comprises of two components, namely Energy cost saving and Capacity Cost Saving. Energy Cost per kWh and Capacity Cost per kW was taken as 8.36Rs and 17,567Rs respectively. Load factor values were taken from 'National Power and Energy Forecast for year 2008-2027'. For years outside of this period, Load Factors were assumed to be equal to the year 2027 value. Then the Net Cost Saving due to implement the 400kV configuration instead of 220kV configuration was 3879.4MRs.

If the ratio of the present value of the benefits to the present value of the costs greater than one then the project is worthwhile. But according to the analysis the Benefit to Cost Ratio was less than one. Therefore it is not economically viable to construct 400kV configuration with compare to 220kV configuration.

Since the future cannot be accurately predicted there is a high probability that some of the assumptions may prove incorrect. Sensitivity Analysis is used to show how changes of assumptions affect the Benefit to Cost Ratio. As the first sensitivity analysis 6% Interest rate and 6% Discount rate were assumed. Then 10% Interest rate and 10% Discount rate were assumed. Finally Load factor values for the period of 2018-2060 were calculated according to the previous trend. (Load factor values for the period of 2020-2027 were taken from 'National Power and Energy Forecast for 2008-

2027') For all the cases. Benefit/Cost Ratio was less than 1. Therefore it is not economically viable to construct 400kV transmission network configuration with compare to 220kV transmission network configuration.

Because the lack of experiences on 400kV transmission projects it is necessary to train the technical staff for both constructional and operational aspects if construct 400kV transmission network configuration. This is also an additional cost to the 400kV configuration.

By considering the above factors it is recommended that 220kV configuration be used as the Trincomalee Coal Fired Power Plant grid connection and the scope of work depicted under section 3.1.1 be implemented for transmit 2200MW of power.

According to the new draft generation planning schedule prepared by the Generation Planning Branch of the Ceylon Electricity Board. (dated 07th December 2009) only 500 MW Trincomlee Coal Fired units will be added to the power system before 2020. That unit will be added during year 2015. Therefore it necessary to re examine the proposed configuration after publishing the 'Generation Expansion Plan 2010-2029'.

References:

[1] Ceylon Electricity Board. "Long Term Generation Expansion Plan 2009-2022". May 2009

[2] Ceylon Electricity Board. "Long Term Transmission Development Plan 2008-2016". Unpublished.

[3] Ceylon Electricity Board. "Sales and Generation Data Book 2007". 2007

[4] Japan International Co-operation Agency (JICA). "Master Plan Studies for the development of the Transmission system in Sri Lanka". January 2006

[5] O. Tarkan. "Power System Planning". Lecture Notes in Power System Planning. Middle East Technical University. 1981

[6] J. Mccombe and F.R. Haigh. "Overhead Line Practice". Macdonald & Co. Ltd.. 1966

[7] P. Kundur."Power System Stability and Control". McGraw – Hill Publishing Company Limited. 1994

[8] Ceylon Electricity Board. "Medium Voltage Distribution System Development Plan for Recently Liberated Areas of Northern Province". May 2009

[9] Y.S.Rajasekhara. "One 400 KV substation to be added to each district, investment for T&D network to be doubled". *http://www.ysr.*in (Sun. 07 May 2006)

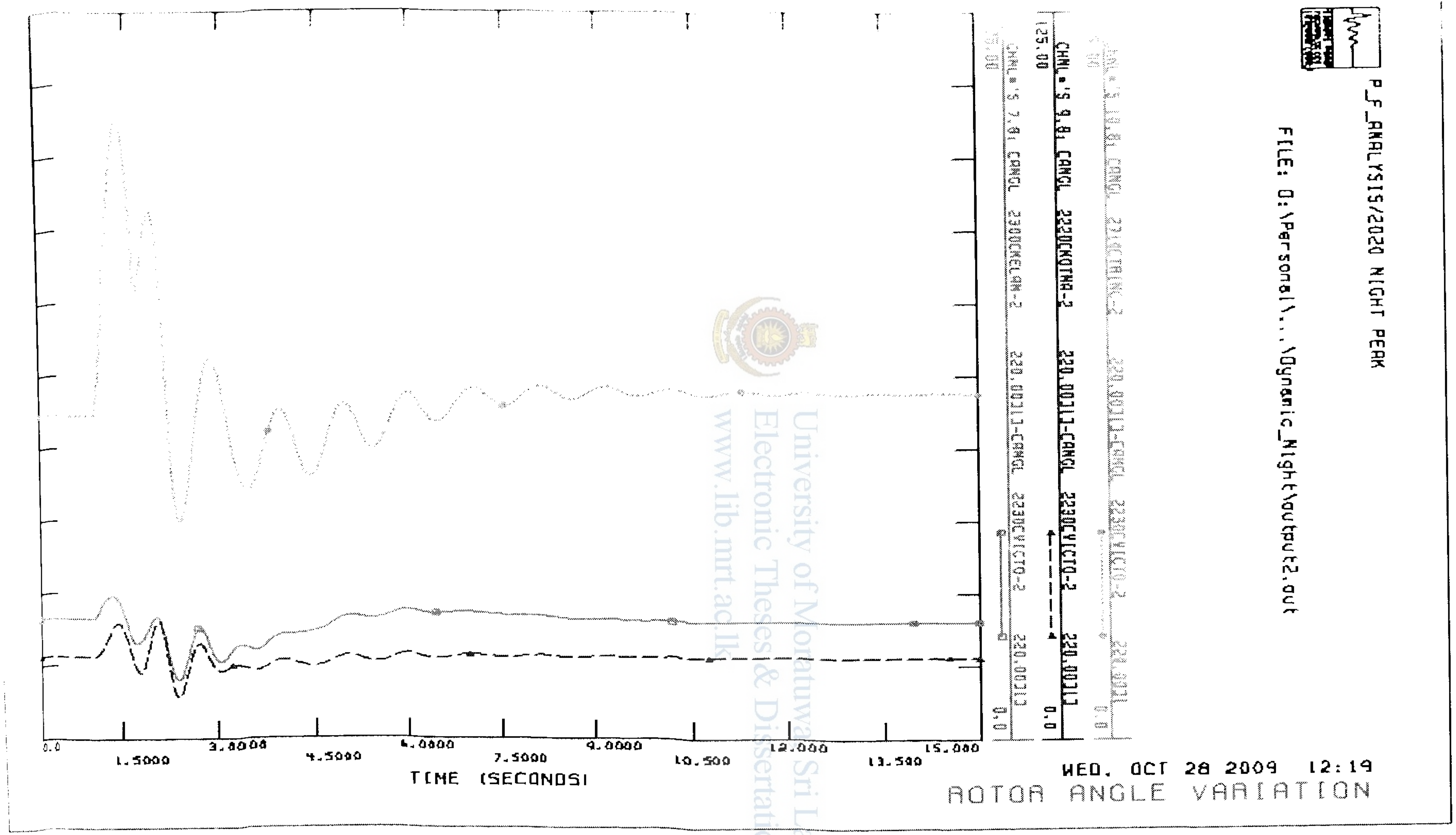
[10] Maharashtra State Electricity Transmission Co. Ltd.. "Cost data for the year 2008-09 for the transmission schemes". *http://www. mahatransco.com*

[11] Prabha Kundur. Neal J. Balu. Mark G. Lauby. "Power System Stability and Control". McGraw-Hill Professional. 1994.

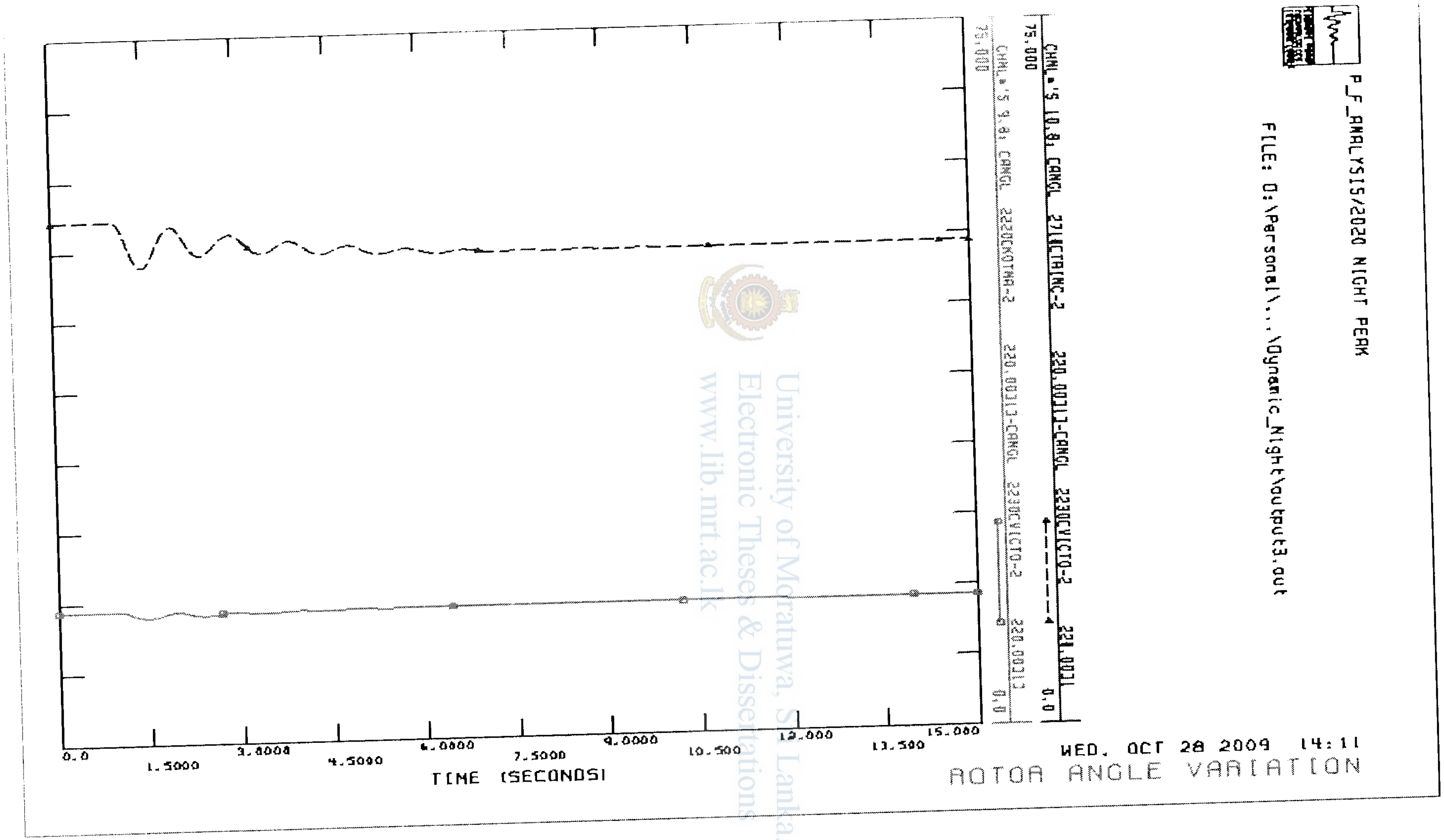
[12] Statistical Digest 2008 - Ceylon Electricity Board.

[13] Ceylon Electricity Board. CEB Total Electricity Costs by Voltage Level and Consumer Category. 2008

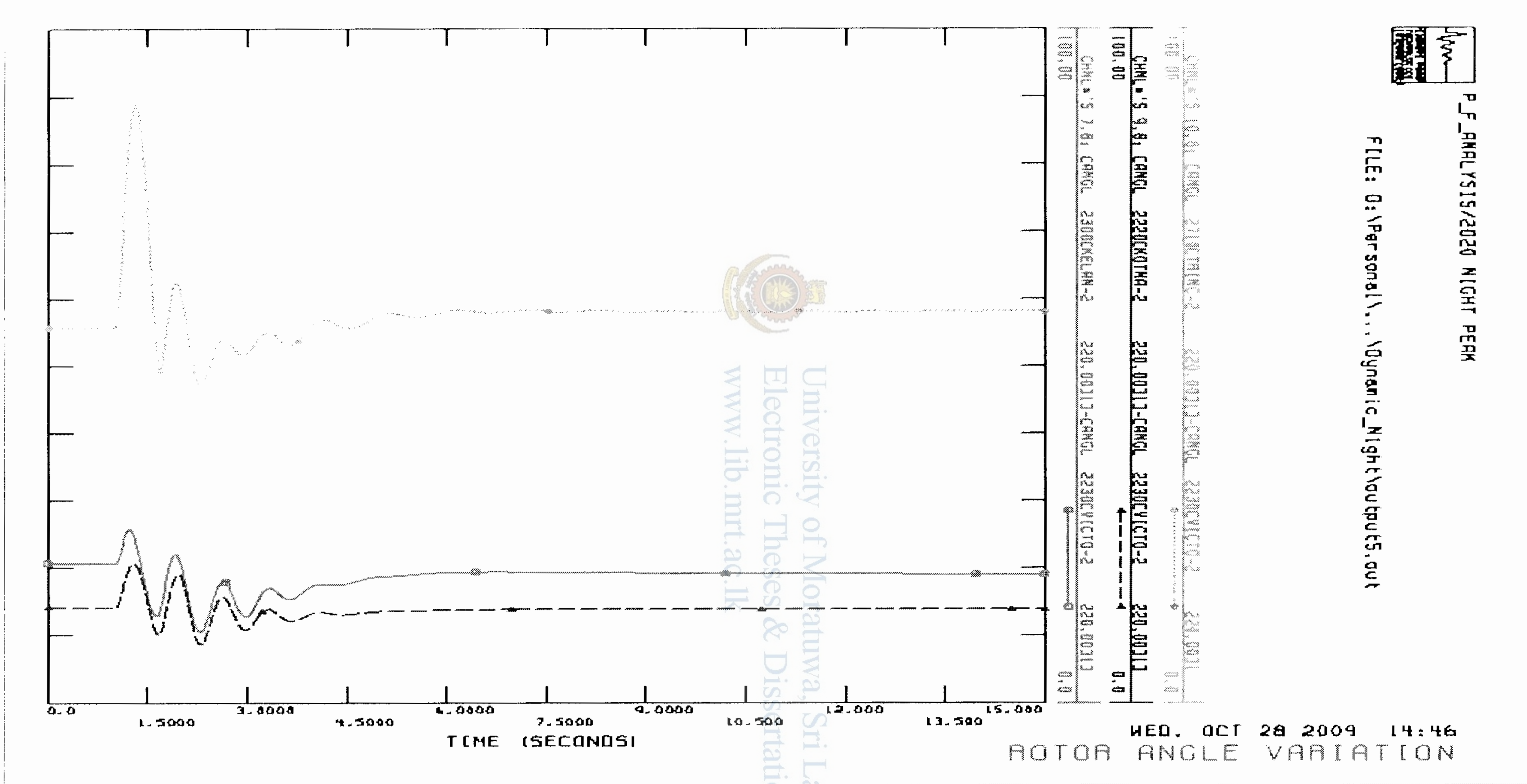
Annexes



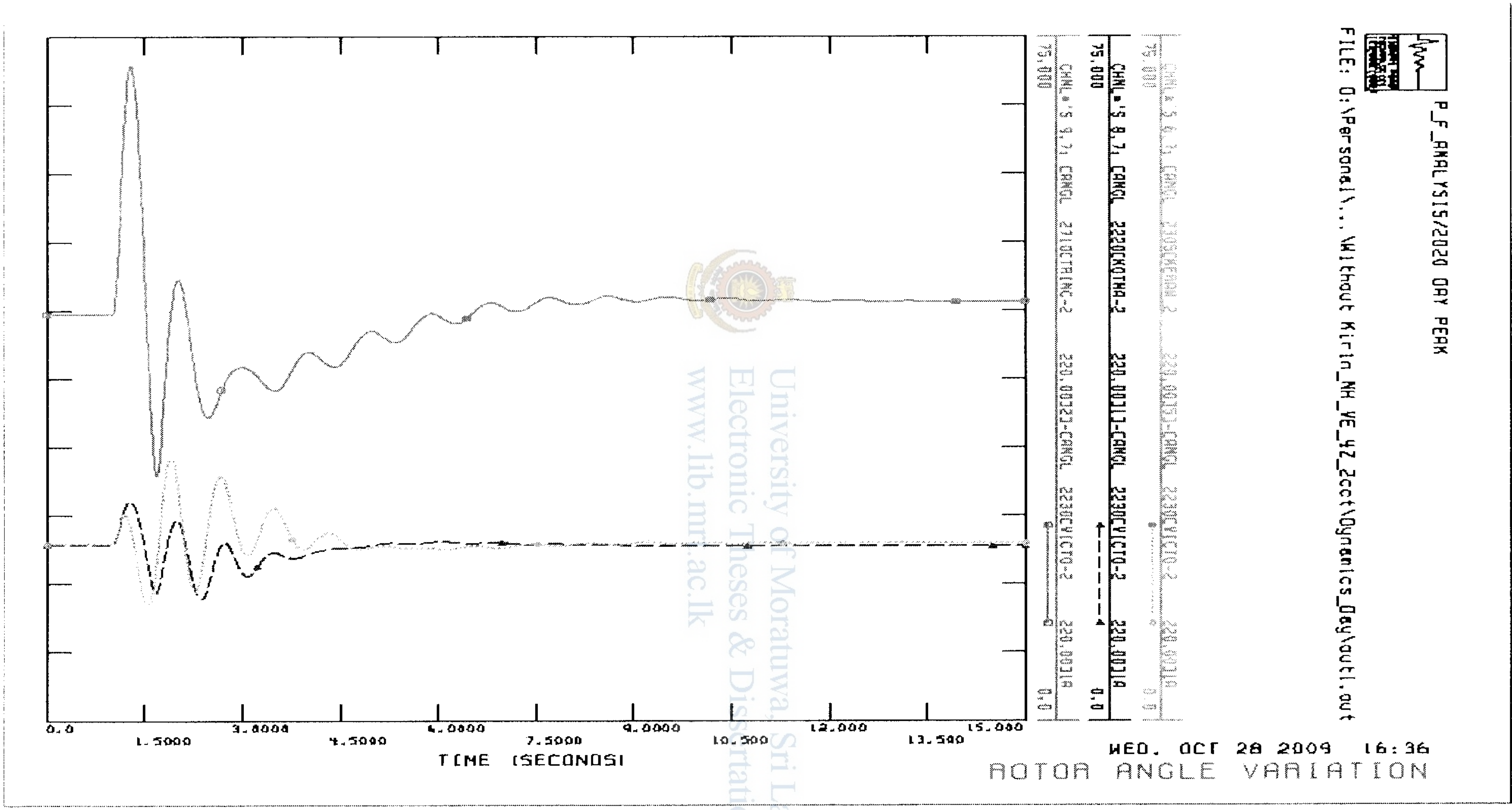
Annex A- 3 Rotor angle variation following a three-phase short circuit fault in one circuit of the 220kV four-circuit 4xZebra transmission line between Trincomalee PS and New Habarana SS. (220kV Network, year 2020,Night Peak)



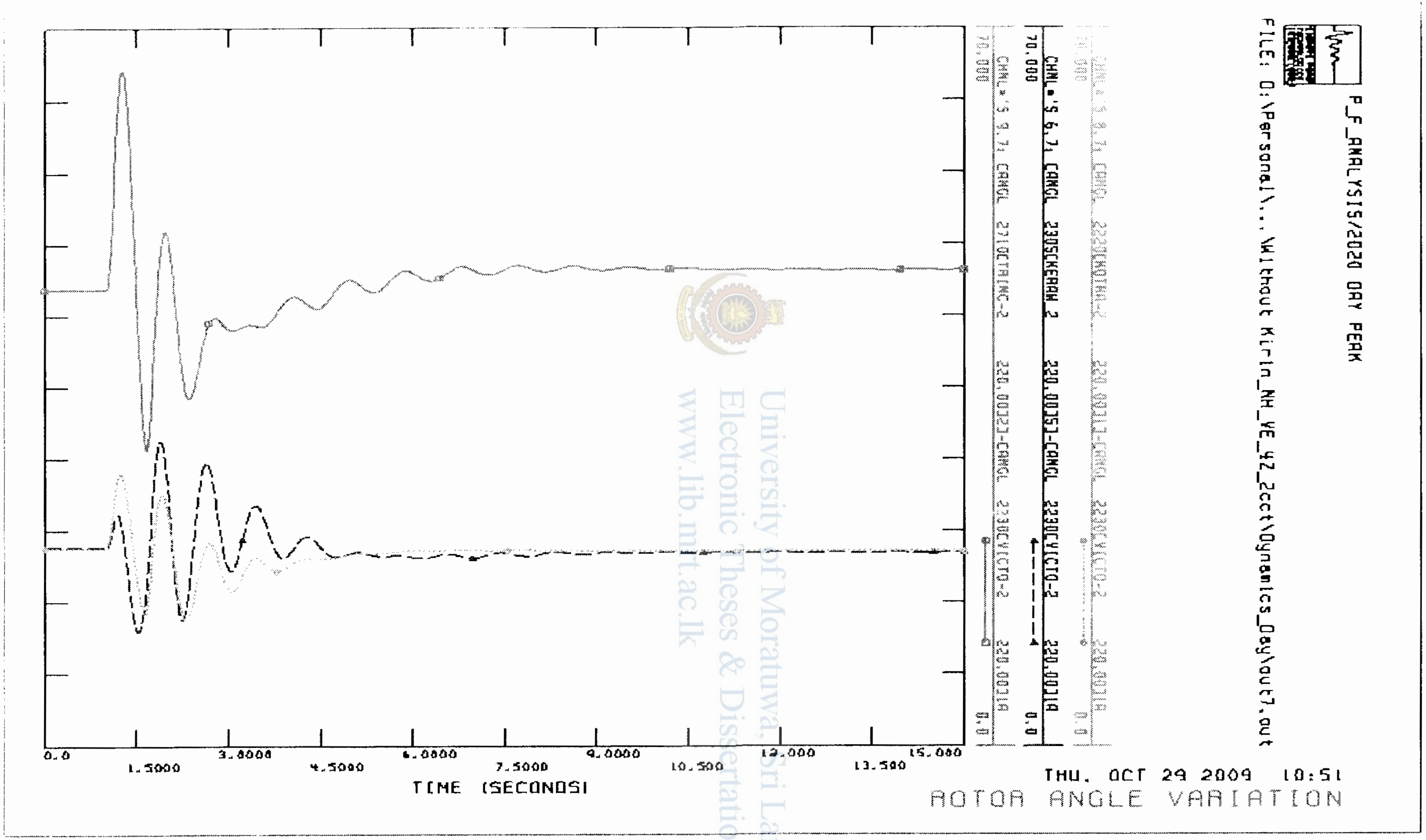
Annex A-4 Rotor angle variation following a tripping of one 300MW unit at Trincomalee power station. (220kV Network, year 2020, Night Peak)



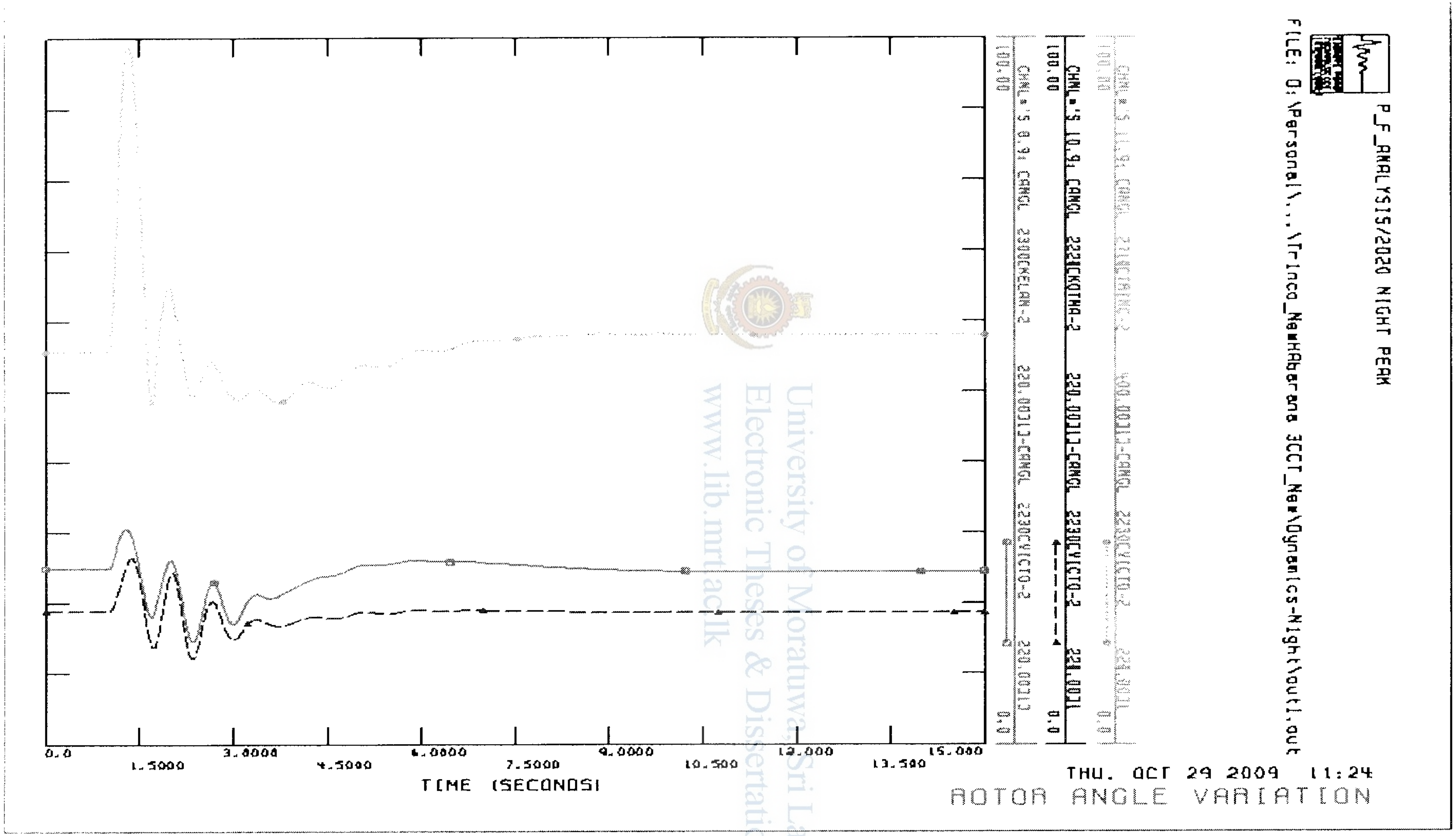
Annex A-5 Rotor angle variation following a three phase short circuit fault in one circuit of the 220kV two circuit 4xZebra transmission line between New Habarana SS and Veyangoda GS. . (220kV Network, year 2020, Night Peak)



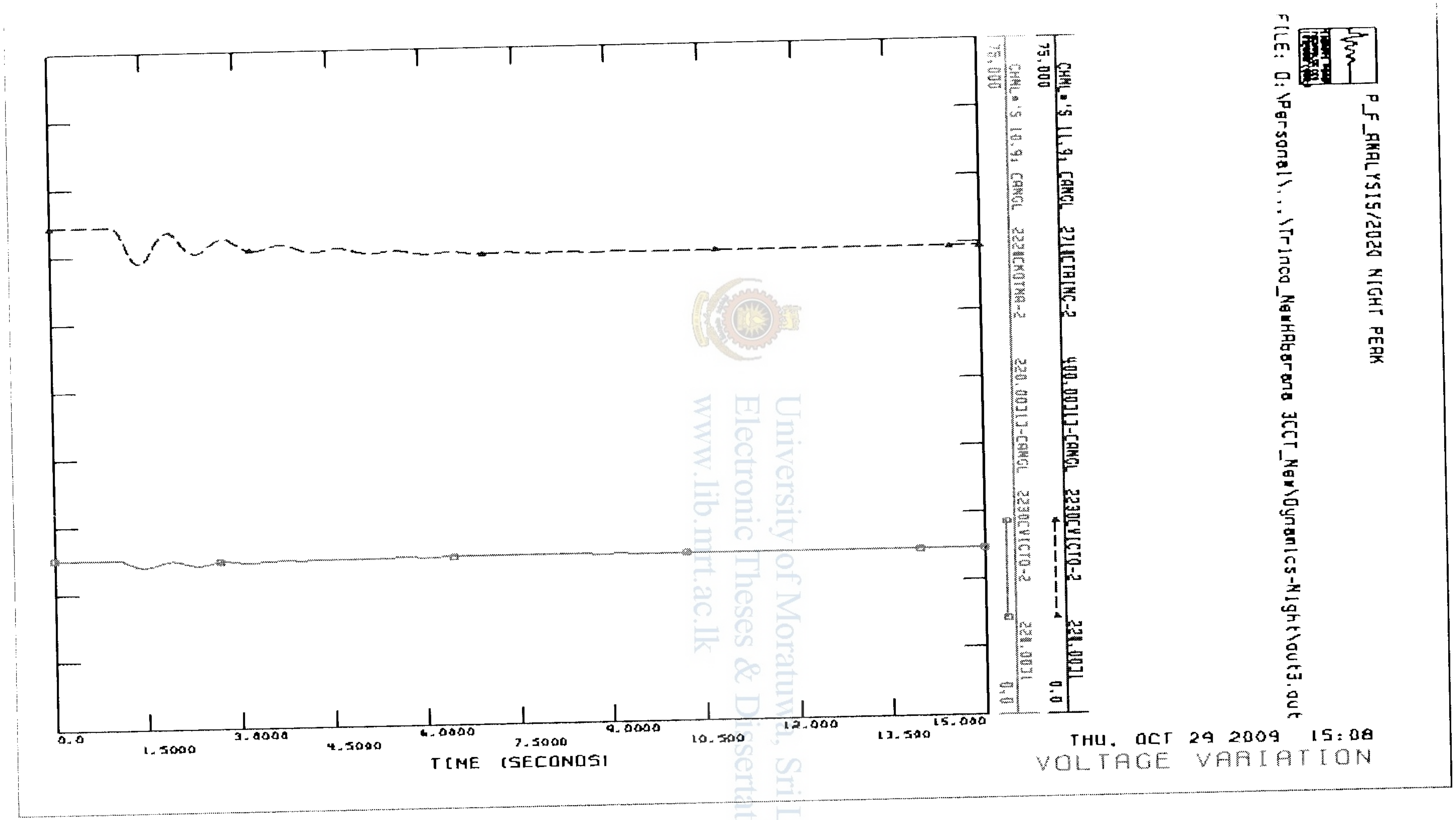
Annex A-6 Rotor angle variation following a three-phase short circuit fault in one circuit of the 220kV four-circuit 4xZebra transmission line between Trincomalee PS and New Habarana SS. (220kV Network, year 2020,Day Peak)



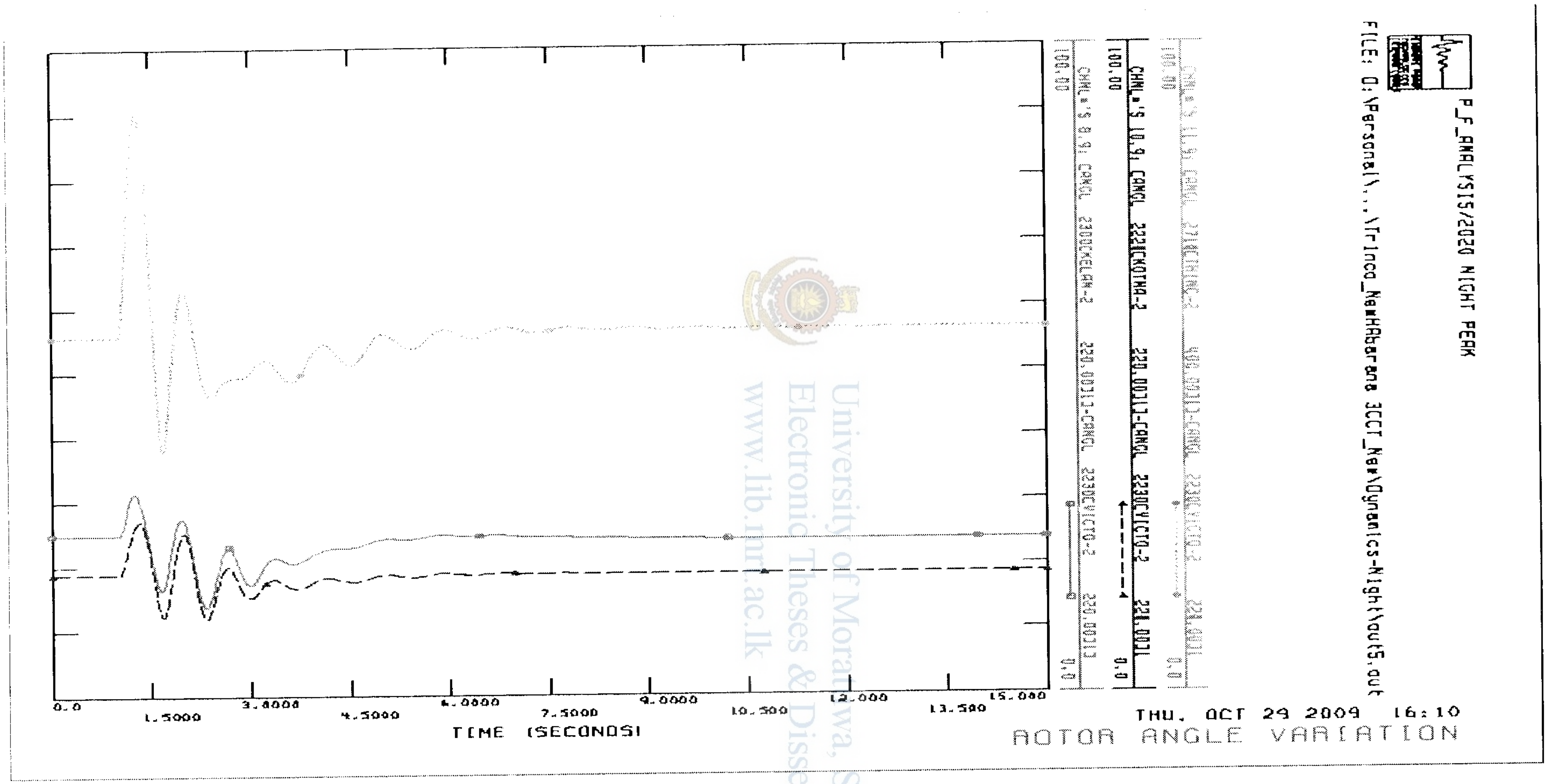
Annex A-7 Rotor angle variation following a three phase short circuit fault in one circuit of the 220kV two circuit 4xZebra transmission line between New Habarana SS and Veyangoda GS. (220kV Network, year 2020, Day Peak)



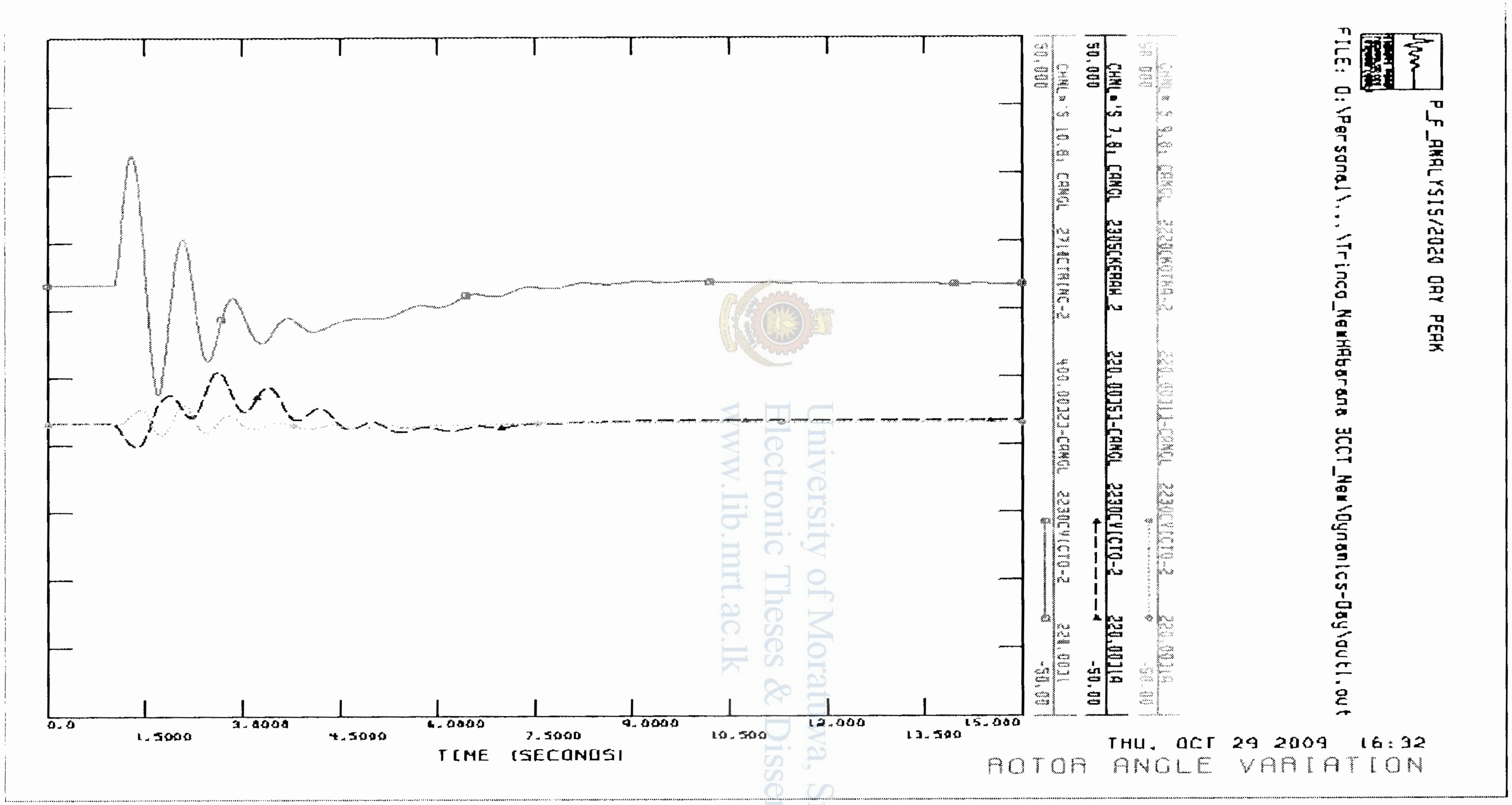
Annex A-8 Rotor angle variation following a three-phase short circuit fault in one circuit of the 220kV four-circuit 4xZebra transmission line between Trincomalee PS and New Habarana SS. (400kV Network, year 2020,Night Peak)



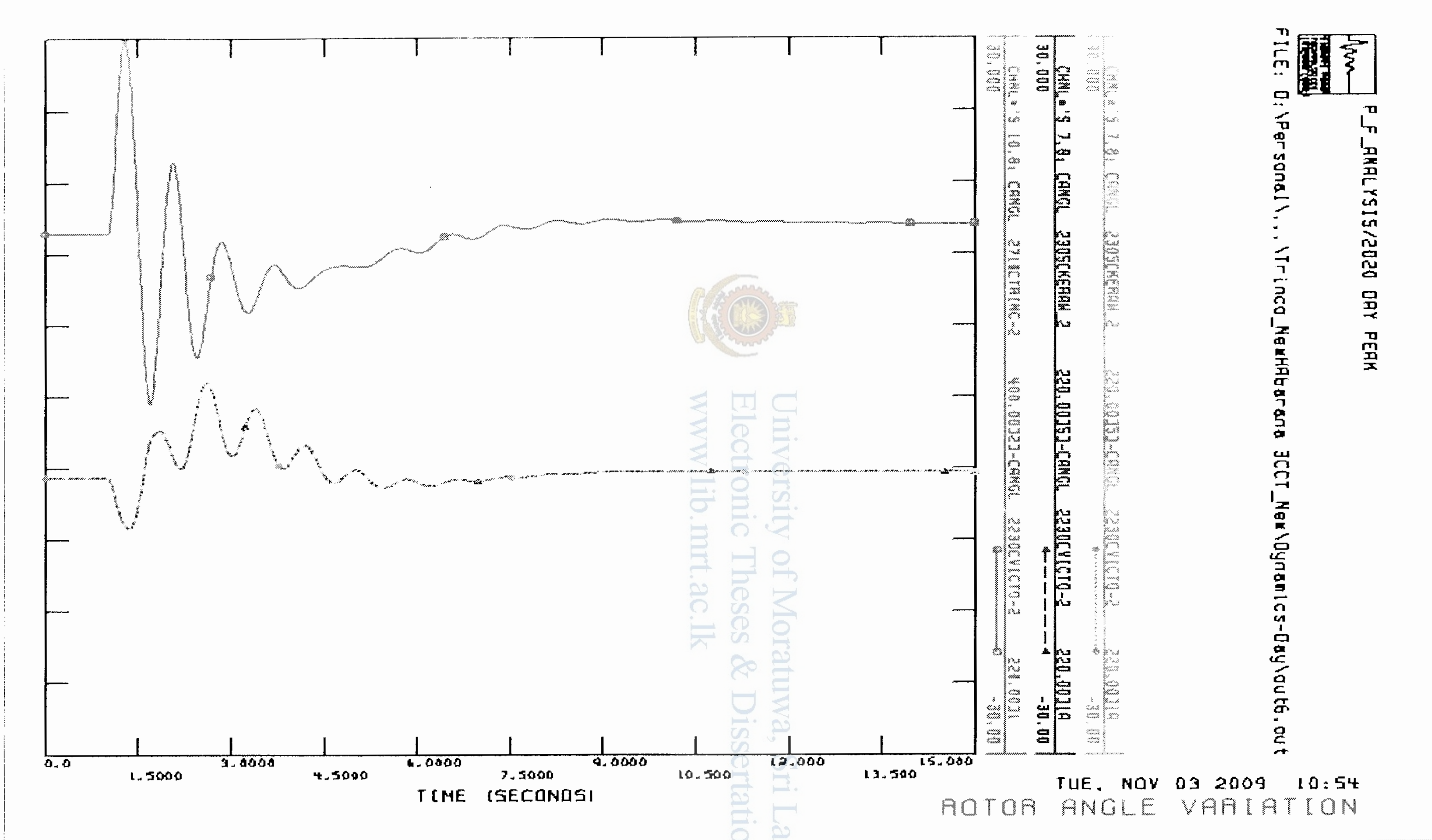
Annex A-9 Rotor angle variation following a tripping of one 300MW unit at Trincomalee power station. (400kV Network, year 2020, Night Peak)



Annex A-10 Rotor angle variation following a three phase short circuit fault in one circuit of the 220kV two circuit 4xZebra transmission line between New Habarana SS and Veyangoda GS. (400kV Network, year 2020, Night Peak)



Annex A-11 Rotor angle variation following a three-phase short circuit fault in one circuit of the 220kV four-circuit 4xZebra transmission line between Trincomalee PS and New Habarana SS. (400kV Network, year 2020,Day Peak)



Annex A-12 Rotor angle variation following a three phase short circuit fault in one circuit of the 400kV two circuit 2xZebra transmission line between New Habarana SS and Veyangoda GS. (400kV Network, year 2020, Day Peak)

Planning Criteria

During the transmission development planning, it is targeted to meet planning criteria to ensure quality and reliable supply under normal operating conditions as well as under contingencies.

Voltage criteria

The voltage criterion defines the permitted voltage deviation at any live bus bar of the network under normal operating conditions as given in table A-1.

Bus bar voltage	Allowable voltage variation (%)	
	Normal operating condition	Single contingency condition
400kV	±5%	±5%
220 kV	±5%	-10% to +5%
132kV	±10%	±10%

Table A-1: Allowable voltage variations

Thermal criteria

The design thermal criterion limits the loading of any transmission network element, in order to avoid overheating due to overload. The loading of elements should not exceed their rated thermal loading values for steady state conditions.

Security criteria

The performance of the transmission system under contingency situation is taken into consideration in the security criteria. The adopted contingency level for the planning purposes is N-1, i.e. outage of any one element of the transmission system at a time.

After outage of any one element (i.e. any one circuit of a transmission line or a transformer and without any adjustment or corrective measure), the system should be able to meet the distribution demand while maintaining the bus bar voltage levels as given in Table A-1 and loading of all the remaining elements should not exceed their emergency ratings specified.

Stability criteria

Stability criteria should ensure the system stability during and after a system disturbance.

For all pertaining equipment in service, the system should remain stable in case of:

- Three-phase fault at any one overhead line terminal, cleared by the primary protection with successful and unsuccessful auto re-closing.
- Loss of any one generation unit
- Load rejection by loss of any transformer.

Generator dispatching