INTELLIGENT LOAD SHEDDING MECHANISM FOR CEB NETWORK

Rajapaksha Vithanage Dona Hansi Nilanka Rajapaksha

(109246F)

Dissertation submitted in partial fulfillment of the requirements for the degree of Master of Science

Department of Electrical Engineering

University of Moratuwa

Sri Lanka

May 2015

DECLARATION OF THE CANDIDATE AND SUPERVISORS

I declare that this is my own work and this dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my dissertation, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

…………………………..

Signature of the candidate Date:

(R. V. D. H. N. Rajapaksha)

The above candidate has carried out research for the Masters dissertation under my supervision.

……………………………

Signature of the supervisor Date:

(Prof. H. Y. R. Perera)

ACKNOWLEDGEMENTS

Foremost, I would like to express my sincere gratitude to my supervisor Prof. H.Y.R. Perera for the continuous support given for the research, for the motivation, enthusiasm and immense knowledge.

My sincere thanks go to Mr. Eranga Kudahewa, Electrical Engineer in System Control branch in transmission division for enlightening me the first glance of the research and extending all the assistance required and giving technical instructions.

Furthermore I must thank Mr. H. D. S. Thimothies, Deputy General Manager(System Control) and all Engineers in System Control branch in transmission division and all Engineers in Protection Development branch in transmission division for the guidance and assistance they have given during my research period.

Further, I would like to pay my gratitude to all the lecturers engaged in the MSc course sessions for making our vision broader and providing us with the opportunity to improve our knowledge in various fields.

Moreover technical staff working in Grid sub stations who have helped me in providing exact data on my request during failure analysis done by myself.

My sincere thanks also should go to Mrs. Dhammika Tilakasena, Deputy General Manager (Asset Management(transmission)), Mr. G.W.V. Priyantha, Chief Engineer(Maintenance Planning) and my colleague Engineers who work with me in Asset Management(transmission) branch and all the office staff there who always gave their co-operation to conduct my research work.

It is a great pleasure to remember the kind cooperation of all my colleagues who have helped me in this Post Graduate programme by extending their support during the research period.

My special thanks go to my parents Mr. and Mrs. Piyatilake Rajapaksha, my husband Asanka, my sisters and brother for supporting me spiritually throughout my life and tolerating my engagement on this work.

R. V. D. H. N. Rajapaksha

ABSTRACT

Load Shedding plays a major role as the guard which protects the power system from a disturbance-induced collapse. In Sri Lanka, Ceylon Electricity Board being the major power network authorizer practice 'under-frequency load shedding' with the support of under-frequency load shedding relays.

There are some drawbacks of this under frequency load shedding scheme which promotes power system authorizers to shift into a computerized power management system to form an 'automated load shedding scheme'.

An intelligent load shedding system can provide faster and optimal load relief by utilizing actual operating conditions and knowledge of past system disturbances [1]

As the first step in this study, a research survey was done about present load shedding system practiced in Ceylon Electricity Board. Past failure analysis was done to identify major drawbacks of the system.

During literature survey characteristics of an intelligent load shedding system were observed and the way of forming an intelligent load shedding system in a power network was studied.

Through selection of southern part of CEB network including seven grid substations, two major hydro power plants, two thermal power plants and three mini hydro power plants, model was designed using MATLAB software.

Initially a data bank was formed including load data, generation data for the selected network. Load data at each grid substation for a week day, Saturday and for Sunday were formed based on the load equations derived depending on the time of the day (off-peak, day-peak, night-peak). Generation data was adjusted according to the total load requirement. Feeders that can be shed were selected considering the category of load

connected at each feeder and categorization by System Control center as high priority feeders and low priority feeders.

Coding was built up in MATLAB software after importing excel sheets consisting all the data collected and modeled to create a ‘Graphical User Interface’(GUI). Further code was extended for the load shedding process which activates once a power imbalance occurs between generation and demand. Simulation was done for tripping of major hydro power plants which contribute to load shedding process.

Further comparisons were done between existing load shedding mechanism which is under frequency load shedding(UFLS)and Intelligent Load Shedding (ILS) mechanism in Power System Simulator for Engineering(PSS/E) software which is the software used by System Control Center branch in transmission division for analyzing and simulating power system performance.

It is concluded that reasonable improvements can be achieved through application of intelligent load shedding mechanism to CEB network which contributes to quality of uninterrupted supply to consumers.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Abbreviation	Description
CEB	Ceylon Electricity Board
UFLS	Under Frequency Load Shedding
ILS	Intelligent Load Shedding
PSS/E	Power System Simulator for Engineering
GUI	Graphical User Interface
GSS	Grid Sub Station
PS	Power Station
GIS	Gas Insulated Substation
DFR	Digital Fault Recorder
KCCP	Kelanitissa Combined Cycle Power plant
SCADA	Supervisory Control and Data Acquisition
PLC	Programmable Logic Controller
MH	Mini Hydro
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
STM-1	Synchronous Transport Module level-1
SDH	Synchronous Digital Hierarchy management
ITU-T	International Telecommunication Union- Telecommunication Standardization Sector

LIST OF APPENDICES

Chapter 1

INTRODUCTION

1.1 Background

Considering the benefits from electric power systems to the human life, it is a sole responsibility of the utility to secure reliability of this electric power system in every possible way. Through power system blackouts a large group of consumers is left without electrical energy for some time duration. At any critical situation operator has to shed down excess load to gain power system stability. This process is called "load shedding" which keeps the system stable until the fault is cleared. Requirement for shedding the optimum amount of load is high nowadays which results in minimum interruptions due to a contingency.

1.2 Requirement of the load shedding scheme

Mainly due to a generation loss through tripping of any generator connected to the system or excess generation through tripping of transmission lines, system frequency deviates from the permissible range. In Sri Lanka permissible range of system frequency is between 49.5 Hz and 50.5Hz. Without activation of load shedding mechanism, it may lead to total system collapse which will affect a large number of customers and it will take longer time period for the system recovery. Governors cannot respond quickly for sudden imbalances in generation and load. Therefore load shedding mechanism should get activated in a proper way to reduce system blackouts.

1.3 Motivation

Initially I studied the existing load shedding mechanism which is Under Frequency Load Shedding (UFLS) mechanism used by CEB. Further I studied some partial system failures and a major system failure occurred in recent past to identify the loop holes in the existing load shedding mechanism.

Through my study I found out major weaknesses of the existing load shedding mechanism as follows;

1. Excessive load shedding.
2. Inadequate load shedding which may lead to system collapse.
3. Occurrence of more feeder interruptions.
4. Same pre-defined load shedding table is used for off-peak, day-peak and night-peak (independent of time of the day).
5. Reactive power produced at each feeder is not taken into consideration.

Considering above major weaknesses, necessity for a more accurate load shedding mechanism is identified which can make a fast, optimum and reliable load shedding decision. The "intelligent load shedding" is a means enabling to improve power system stability, by providing a real time adapted load control and load shedding, in situations where the power system otherwise would go unstable[1].

In recent decades, the advantages of a fast development in the computer and communication technology have been successfully harvested in the majority of technological areas for updating various mechanisms and processes. Power system control and protection is no exception [6].

The outcome of this project is developing a load shedding mechanism to make an optimum and reliable load shedding activity.

1.4 Objectives

1. To devise a load shedding mechanism to handle contingency situations more effectively.
2. To build knowledge database for the selected CEB network in MATLAB software.
3. To model an algorithm to monitor system frequency and frequency deviation rate and to update optimal load shedding tables in MATLAB software.
4. To develop the algorithms to make an optimum and reliable load shedding activity through intelligent load shedding application to CEB network.
5. To analyze and compare the proposed load shedding mechanism-'intelligent load shedding' mechanism with existing load shedding mechanism-UFLS in 'Power System Simulator for Engineering'(PSS/E).

1.5 Methodology

1. Analyzing failures occurred in recent past and how the system has responded in such failure events.
2. Selecting a reduced network from CEB network to form a model in MATLAB software.
3. Collecting data related to the network and modeling data for the uploading purpose in MATLAB software.
4. Extracting load data of the feeders that can be shed.
5. Importing modeled data into MATLAB software.
6. Designing Graphical User Interface (GUI) in MATLAB software.
7. Developing the coding to update optimal load shedding tables and to activate load shedding through monitoring system frequency and frequency deviation rate.
8. Application of case studies in MATLAB software.
9. Analyzing results of existing load shedding scheme (UFLS) in Power System Simulator for Engineering (PSS/E) software tool.
10. Application of intelligent load shedding(ILS) in Power System Simulator for Engineering(PSS/E) software tool.
11. Result analysis through comparison of the results obtained for UFLS and ILS.

Validation of the proposed load shedding mechanism- ‘intelligent load shedding’ was done mainly through the results obtained through PSS/E as existing load shedding mechanism – ‘under frequency load shedding’ mechanism was also applied for the same case studies in PSS/E. After completion of SCADA system for the CEB network, application of intelligent load shedding is a possible action to be taken to improve system reliability.

Chapter 2

ANALYSIS OF EXISTING LOAD SHEDDING SCHEME

Under normal operating conditions total generation equals to total demand plus total loss. Under this balanced condition system operates at 50 Hz of system frequency. Whenever this balanced state is disturbed system frequency varies and sometimes it may vary beyond the permissible range.

The decline in frequency is due to insufficient amount of generation to meet the load demand. This will cause load to acquire power from the stored kinetic energy in a rotating system and causes the slowing rotation. Slowing rotation causes the frequency to decline. Any frequency violation may cause damage to the machines. In situations where the spinning reserve is insufficient or slow load shedding is the best alternative response to prevent the system breakdown extension. Consequently the stresses that influence power system are minimized [2].

Load shedding mechanism applied in CEB network at present is 'Under Frequency Load Shedding' (UFLS). Theoretical explanation for UFLS is disconnecting some selected loads so that the system frequency does not drop below lowest acceptable limit. Relay used in UFLS detects rapid change in frequency (frequency-wise and frequency deviation rate-wise) and initiates operation of circuit breakers installed at loads that can be shed. Several stages are included in UFLS scheme where at a certain stage relay waits a predetermined amount of time which named as 'time delay' and rechecks system frequency before tripping the load breakers.

Even the system frequency has not recovered, relay has to wait for the next stage where another frequency limit and a time delay are specified to trip another set of load breakers. This process continues until system frequency is recovered or all the frequency relays have operated.

2.1 Existing Load Shedding Scheme

Table 2.1: Existing Load shedding scheme in CEB

Stage	Load to be Tripped (%)	Remarks	Tripping Criteria	Load to be Reconnected (%)	Reconnection Criteria
I	5		48.75 Hz + t = 100 ms	0	None
II	5		48.5 Hz + t = 500 ms	0	None
III	10	7% load on only frequency based 3% load on frequency based + df/dt based	48.25 Hz + t = 1 s OR 49 Hz AND df/dt = 0.85 Hz/sec	5	Freq. > 50 AND df/dt= 0.2 Hz/sec
IV	10	7% load on only frequency based 3% load on frequency based + df/dt based	48.00 Hz + t = 1.5 s OR 49 Hz AND df/dt= 0.85 Hz/sec	7	Freq. > 51 AND df/dt= 0.2 Hz/sec
V	10	6% load on only frequency based 4% load on frequency based + df/dt based	47.5 Hz + t = inst OR 49 Hz AND df/dt = 0.85 Hz/sec	0	None
VI	10	10% load on df/dt based	49 Hz AND df/dt = 0.85 Hz/sec	0	None

Under frequency load shedding scheme applied in CEB at present consists of six load shedding stages as tabulated above. As per the scheme 50% load of the total load at the time of failure will be shed if all six load shedding stages get operated. A reconnection criterion was introduced for the load shedding stages III and IV.

Some percentage of loads falling under stage III, IV and V also get rejected when frequency deviation rate is 0.85 Hz/s. If frequency deviation rate is about 0.85 Hz/s when system frequency is 49 Hz, it implies that system frequency is getting reduced very quickly, so that a quick and noticeable response is required from load shedding scheme. This results in rejecting a considerable amount of load in the system to make frequency stable.

System response under this load shedding scheme was studied and described below for three historical failures occurred in the system.

2.2 Historical Failure Analysis

Two partial failures and one major failure occurred in the system in recent past are analyzed;

1. Partial failure occurred on 06th May 2013.
2. Partial failure occurred on 29th October 2013.
3. Major failure occurred on 07th December 2007.

2.2.1 Analysis of partial failure occurred on 06th May 2013 at 20:41 hours

A failure has occurred on 06th May 2013 at 20.41hrs involving 132kV transmission lines, power stations and 132 kV grid sub stations. Following five grid sub stations were affected;

1) Kelaniya Grid Sub Station(GSS)
2) Maradana GSS
3) Havelocktown GSS
4) Dehiwala GSS
5) Sapugaskanda GSS

Following six power stations were affected;

1) Norochcholai Power Station(PS)
2) Wimalasurendra PS
3) Kukule PS
4) Asia Power
5) AES – Kelanitissa
6) Berge Power

First I analyzed the frequency plot and Digital Fault Records obtained at this time. Through analyzing frequency plot it is possible to identify each load shedding stage that was activated after this failure.

Then I studied the reports prepared about this failure. As per the event records at Kelaniya and Sapugaskanda GSS's, there has been an earth fault at 20.41 hours. During that time, only the circuit breaker at Sapugaskanda GSS of Sapugaskanda – Kelaniya line 1 has tripped due to Distance Protection relay operation. The Circuit Breaker of above line 2 at Kelaniya end has tripped due to operation of backup protection. Meantime, all lines connected to Kelaniya GSS have tripped by operation of breaker failure protection causing the Kelaniya GSS to be dead.

Sapugaskanda GSS has tripped operating ‘Over Current Protection’, since Sapugaskanda GSS has been unable to feed the load connected to the GSS due to Kelaniya GSS being dead.

During the failure, power system frequency has dropped to 47.7Hz and it has resulted in tripping of six power stations including Norochcholai power station. Due to earth fault detection at Maradana GSS, Maradana – Kolonnawa line has tripped during the failure causing Maradana, Havelock town and Dehiwala GSS to be dead.

Following mentioned figure is of the frequency plot of 132kV Sub C feeder at Kolonnawa GIS on 06th May 2013 at 20.41 hours.

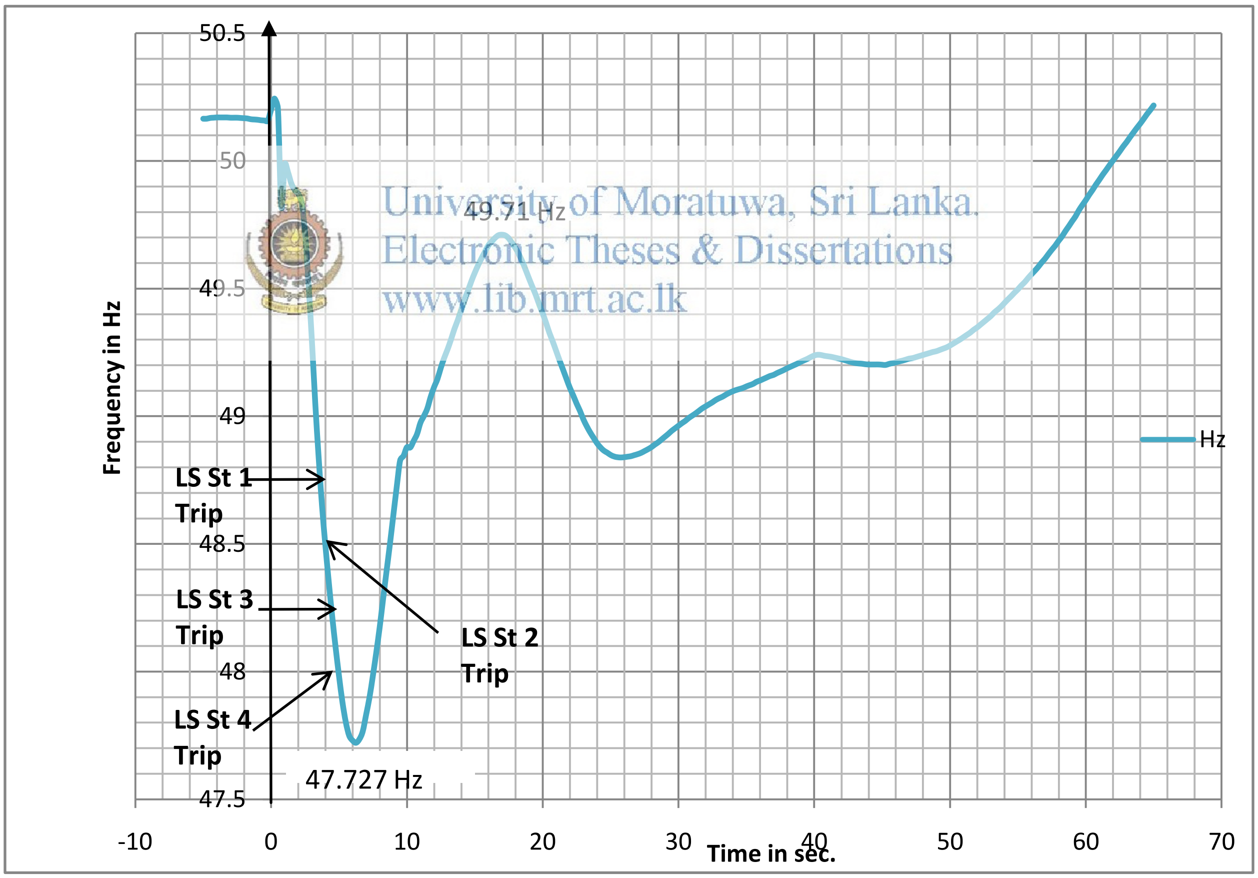


Figure 2.1 Frequency plot of 132kV Sub C feeder at Kolonnawa GIS on 06th May 2013 at 20:41:39 hrs

DFR records at Kotugoda GSS and at Norochcholai power station were also observed which are mentioned below;

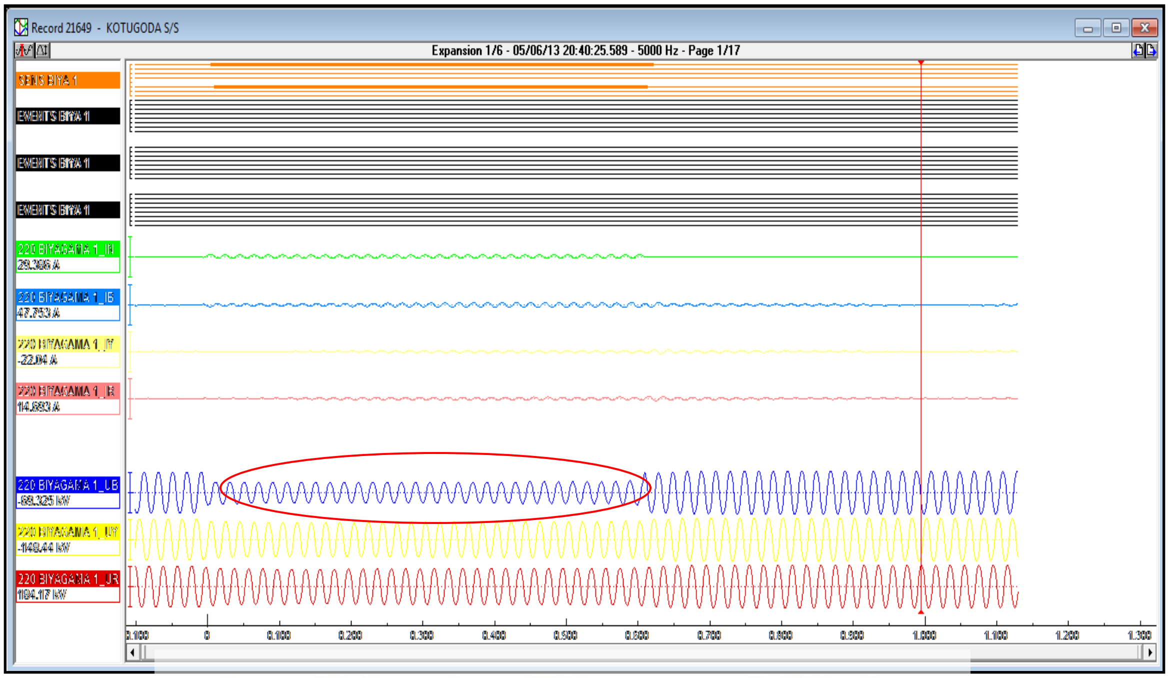


Figure 2.2   DFR record at Kotugoda GSS at 20:41 hrs

In the above records, voltage variation in phase B can be noticed.

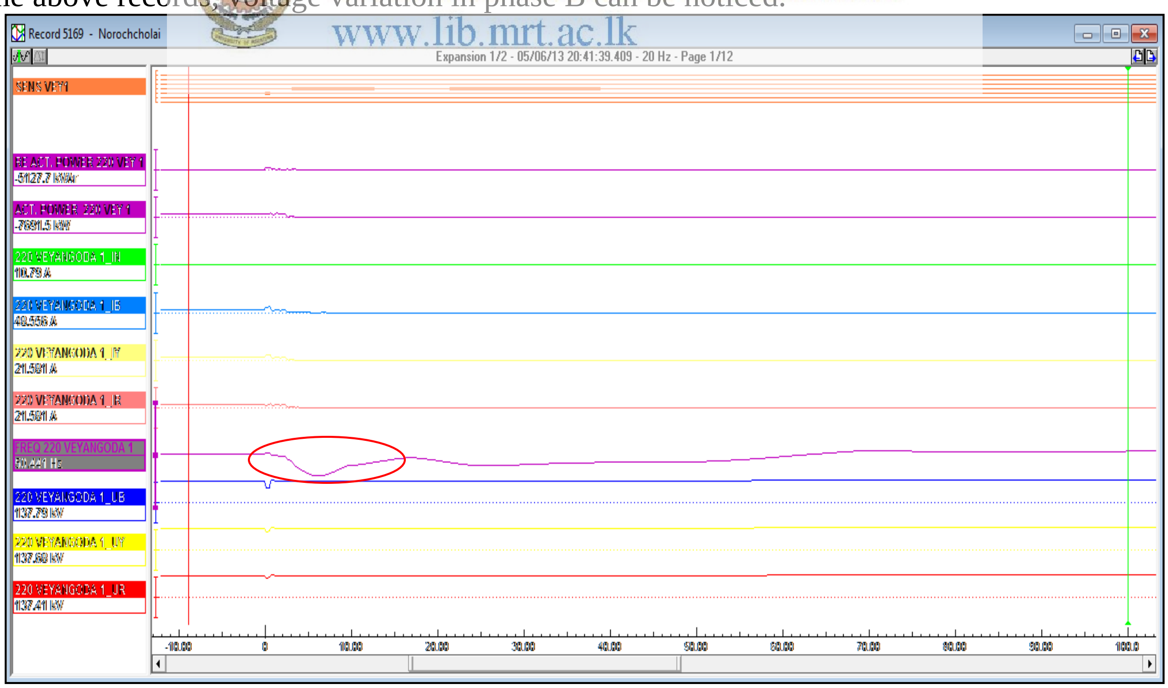


Figure 2.3   DFR record at Lakvijaya power station at 20:41 hrs

Frequency fluctuation during the failure has indicated in the DFR record at Norochcholai power station at 20.41 hours.

After obtaining MW value of each power station and grid substation which were affected just prior to the failure and MW value of each load shed under existing UFLS mechanism, system performance under this load shedding mechanism was evaluated.

- **<u>Loss of Generation</u>**

Table 2.2: Power stations tripped

Power station	MW At the time of failure	Tripped before load shedding	Tripped after load shedding
		MW	MW
WPS 2	25	25.00	
Kukule	2 x 38	76.00	
Asia power	42	42.00	
AES Kelanitissa	160		160.00
Barge power	60	60.00	
Sum of generation loss		**<u>203.00</u>**	**<u>160.00</u>**

Total generation loss = 363 MW

- **<u>Tripping of load</u>**

Table 2.3: Grid substations tripped

GSS		Tripped before load shedding/due to load shedding	Tripped after load shedding
		MW	MW
Kelaniya GSS		9.24	
Sapugaskanda GSS		30.99	
Maradana GSS			22.00
Havelock town GSS			24.88
Dehiwala GSS		17.82	
Matugama	Feeder 1	0.40	
	Feeder 5	0.83	
	Feeder 6	0.76	
	Feeder 8	3.56	
	Feeder 9	2.74	
	Feeder 10	2.67	
Habarana	Feeder 1	2.97	
	Feeder 3	5.45	
	Feeder 6	4.13	
	Feeder 7	4.13	
Kiribathkumbura	Feeder 6	4.29	
	Feeder 7	5.61	
	Feeder 14	2.64	
Thulhiriya	Feeder 5	5.05	
	Feeder 6	1.65	
	Feeder 4	6.83	
	Feeder 2	1.52	
	Feeder 1	3.27	

GSS		Tripped before load shedding/ due to load shedding	Tripped after load shedding
		MW	MW
Kosgama	Feeder 8	3.14	
	Feeder 5	3.47	
	Feeder 2	3.30	
Galle	Feeder 6	3.30	
	Feeder 2	2.48	
	Feeder 1	1.82	
Matara	Feeder 7	8.58	
	Feeder 6	4.29	
	Feeder 2	1.82	
Bolawatta	Feeder 3	4.46	
	Feeder 4	7.62	
	Feeder 5	2.77	
	Feeder 8	9.41	
	Feeder 2	4.62	
Katunayaka	Feeder 2	2.41	
	Feeder 8	2.71	
Biyagama	Feeder 4	5.61	
	Feeder 6	3.96	
	Feeder 3	5.61	
Badulla	Feeder 4	3.30	
	Feeder 3	2.81	
Pannipitiya	Feeder 8	1.75	
	Feeder 4	3.60	
	Feeder 3	3.53	
Horana	Feeder 3	6.93	
	Feeder 4	4.22	
	Feeder 2	2.57	
	Feeder 5	2.44	
Veyangoda	Feeder 6	0.50	
	Feeder 4	4.79	
	Feeder 3	3.80	
	Feeder 7	4.95	
Ratmalana	Feeder 7	0.17	
Aniyakanda	Feeder 3	3.99	
	Feeder 1	0.56	
Pannala	Feeder 2	4.42	
	Feeder 4	3.27	
	Feeder 6	1.19	
Ambalangoda	Feeder 3	3.27	
Kolonnawa	Feeder B1(13)	2.64	
	Feeder B2(14)	1.22	
	Feeder A1(15)	3.96	
	Feeder A2(16)	5.28	
Kotugoda	Feeder 13	5.08	
	Feeder 11	3.99	
	Feeder 9	6.70	
	Feeder 12	7.39	
		296.18	**46.88**

According to the above table,

Total load disconnected = 343.06 MW

- Total loss of generation after the failure occurrence and prior to the load shedding process activation is 203 MW.
- Total load disconnected after the failure occurrence and prior to the load shedding process activation or due to the load shedding process is 296.18 MW.
- If we consider separately total load shed under the load shedding mechanism, it is 238.13 MW.

  From the above observations, it is clear that under the existing load shedding mechanism excessive loads were disconnected. Load interrupted unnecessarily is about 93.18 MW.

2.2.2 Analysis of partial failure occurred on 29th October 2013 at 15:27 hours

Lakvijaya power plant was tripped at 15:27 hours giving the indication as ‘drum level low’. Load shedding process was activated up to stage IV.

Load tripped under each load shedding stage was analyzed in order to consider each load shed individually. Frequency plot drawn from the system frequency values extracted from Veyangoda 220 kV bus is mentioned below;

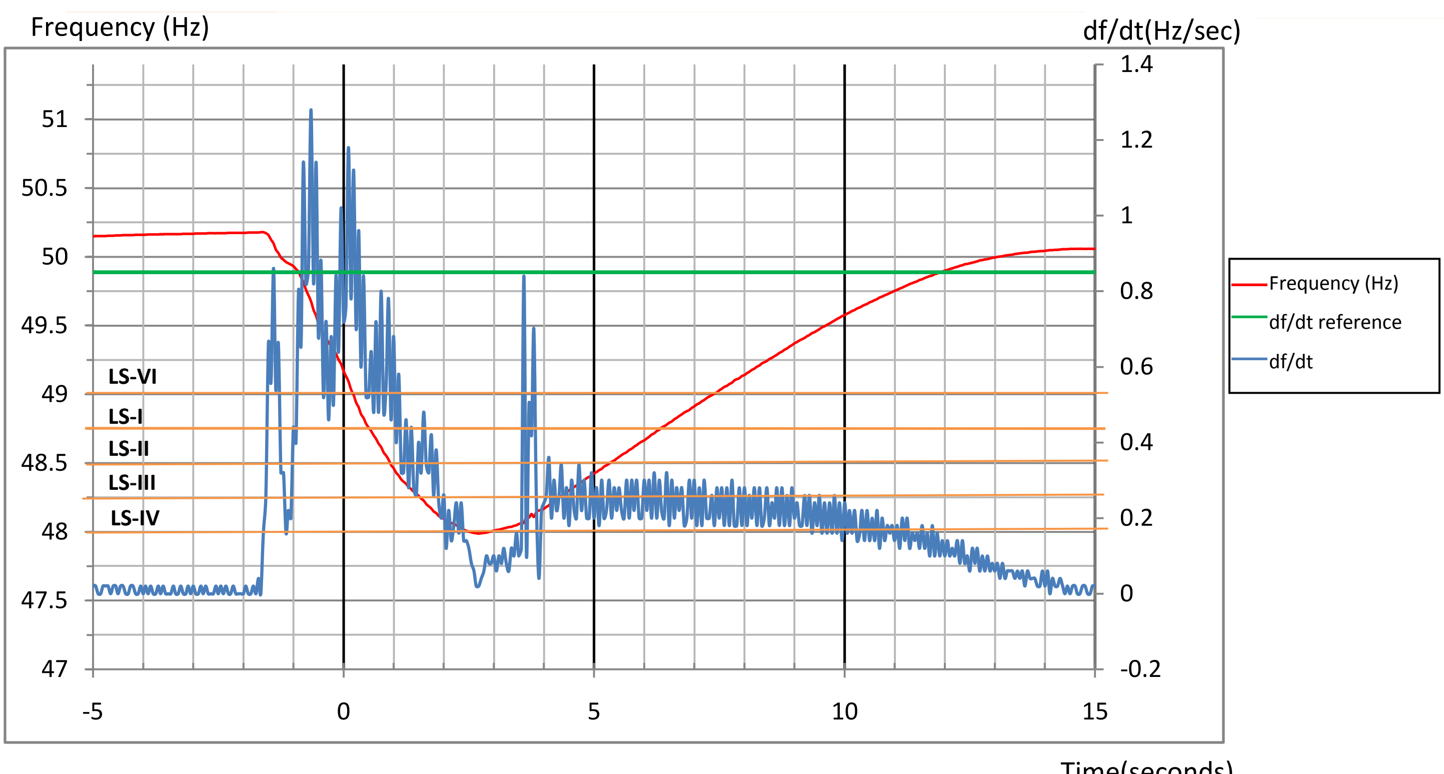


Figure 2.4 Frequency plot at 15:27 hours on 29th October 2013

Loads shed under each load shedding stage are graphically represented as below;

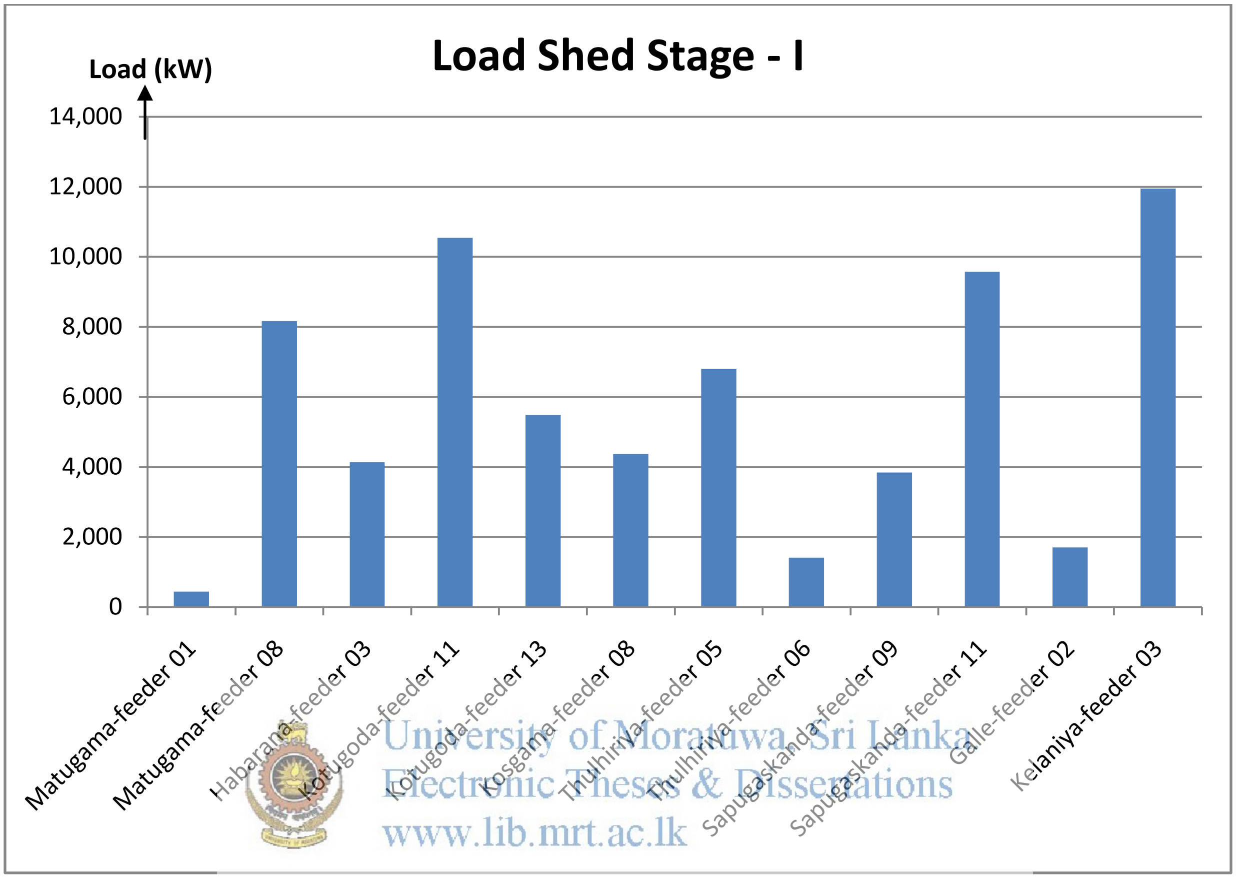


Figure 2.5 Load of the feeders shed under load shedding stage-I

Through analyzing above graph, loads which were unnecessarily interrupted can be clearly identified. Loads of Matugama GSS feeder 01, Thulhiriya feeder 06 and Galle feeder 02 were very less values and also not in the category which usually contribute greatly to reactive power value. Therefore these loads were unnecessarily interrupted through this existing load shedding mechanism due to pre-defined load shedding tables.

Load of the feeders shed under load shedding stage-II is illustrated below which also shows Matugama GSS feeder 05 was unnecessarily interrupted. Unawareness of the load of each feeder which can be shed at the time of the failure leads to this situation.

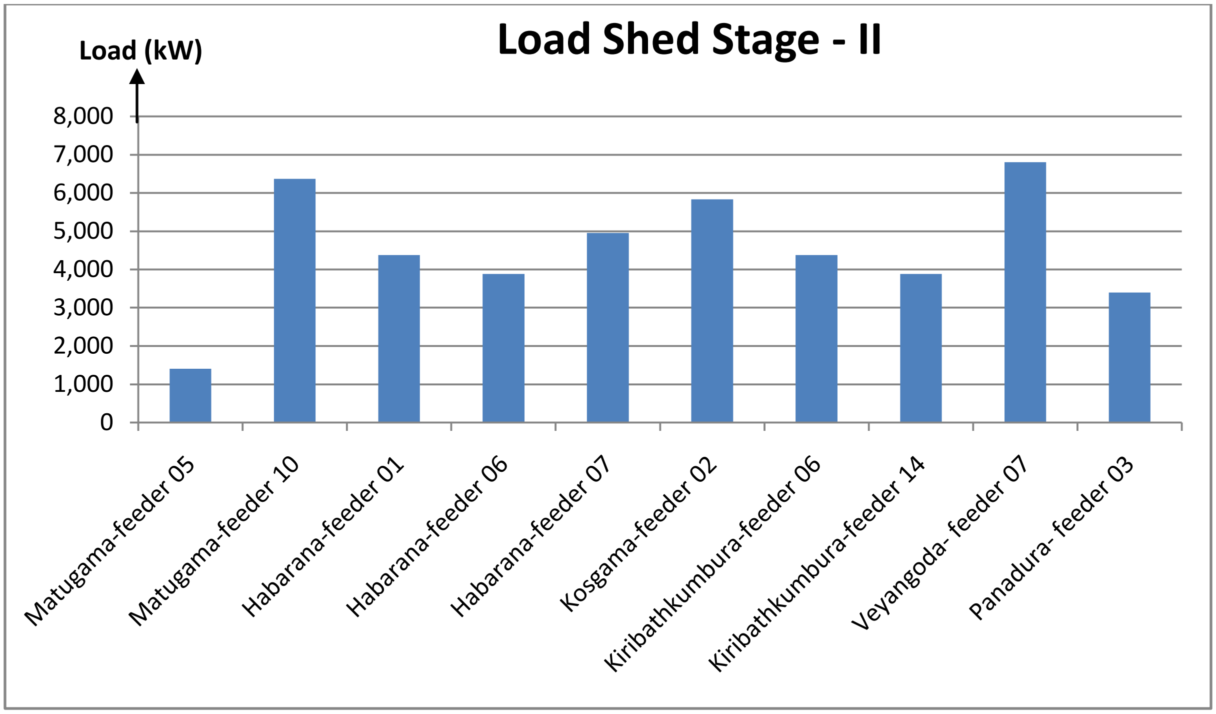


Figure 2.6 Load of the feeders shed under load shedding stage-II

Loads shed under load shedding stage III and IV are illustrated below;

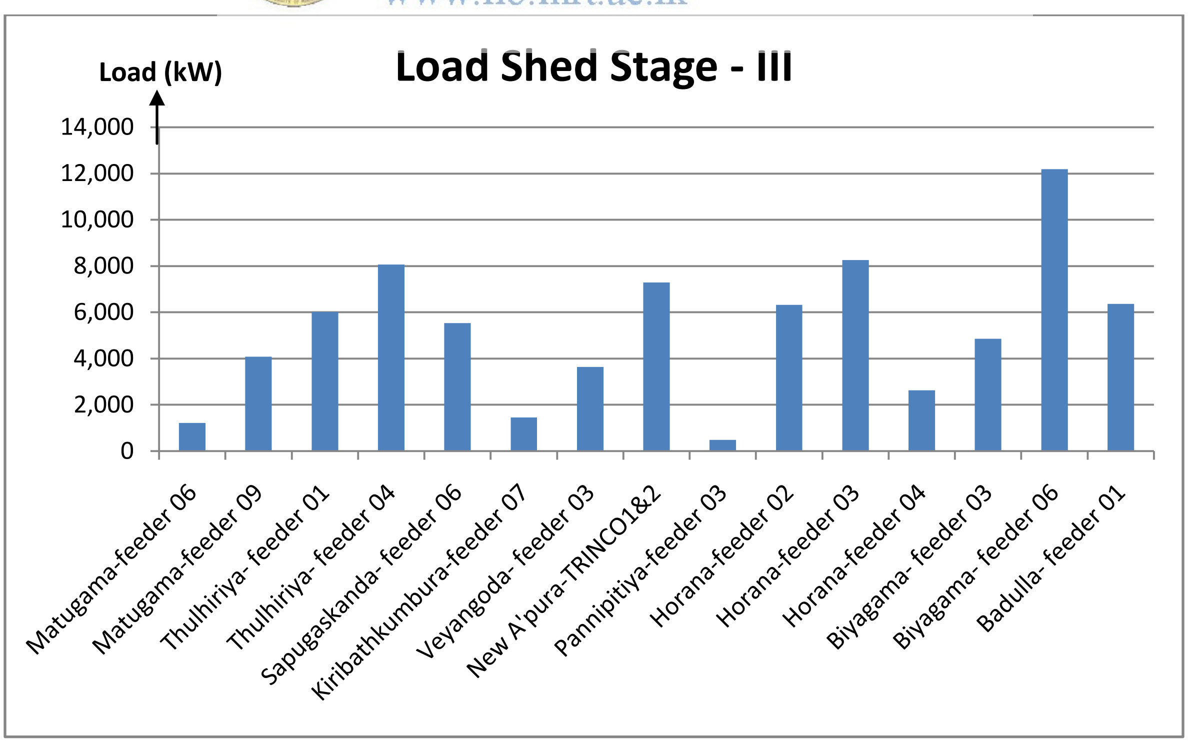


Figure 2.7 Load of the feeders shed under load shedding stage-III

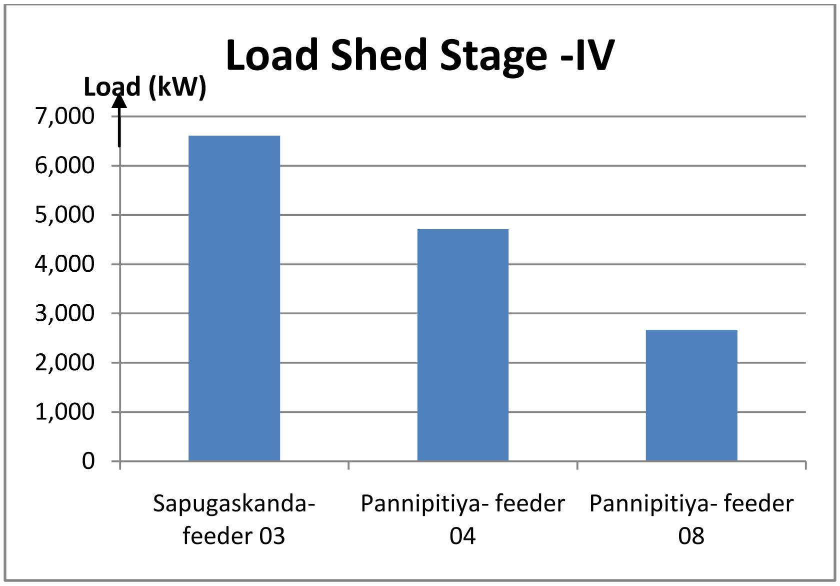


Figure 2.8 Load of the feeders shed under load shedding stage-IV

Loads of Matugama feeder 06, Kiribathkumbura feeder 07 and Pannipitiya feeder 03 were not contributing much for the total real power, but as per the predefined load shedding table these loads were shed.

Through the analysis of this failure and load shedding process it can be concluded that unnecessary load shedding was occurred due to predefined load shedding tables under existing under frequency load shedding mechanism.

2.2.3 Analysis of major failure occurred on 07th December 2007 at 04:48 hours

Kelanitissa Combined Cycle power plant (KCCP) was tripped at 04.48 hours rejecting 163 MW from the system due to a mechanical fault. Load shedding was operated up to stage-V. In the meantime ACE Embilipitiya was tripped after about 8 seconds. Associated frequency drop cascaded in to a total system collapse.

After data collection relevant to this failure following details were observed.

- Total generation available prior to the failure= 856.5 MW
- Generation loss after KCCP tripping = 163 MW (19%)
- Generation loss after Ace Embilipitiya tripping= (163+70)MW = 233 MW(27%)

Then I calculated the total load shed under existing under frequency load shedding mechanism.

Table 2.4: Load shed under existing load shedding mechanism on 07th December 2007 at 04:48 hrs

LOAD SHED. STAGE	FEEDER	TRIPPED AT	RESTORED AT	LOAD (MW)
I	Mathugama F1	-		
	Mathugama F3	-		
	Kotugoda F8	-		
	Thulhiriya F1	4:48	6:00	1.7
	Thulhiriya F5	4:48	6:09	4.3
	Sapugaskanda F9	4:48	5:10	0.8
	Sri J'Pura F3	Off		
	Sri J'Pura F8	4:48	5:52	0
II	Sapugaskanda F4	4:48	5:52	4.1
	Sapugaskanda F6	4:48	5:16	1.45
	Sapugaskanda F10	4:48	5:16	2.3
	Rathmalana F2	4:48	5:15	0.5
	Rathmalana F6	4:48	5:55	4.5
	Rathmalana F7	4:48	5:57	0.25
	Pannipitiya F2	-		
	Mathugama F5	-		
	Mathugama F6	-		
	Mathugama F8	-		
	Kotugoda F6	-		
	Dehiwala F7	4:48	6:04	4.4
	Habarana F8	4:48	6:20	1
	Habarana F6	4:48	6:20	3.25
III	Kotugoda F4	-		
	Kotugoda F7	-		
	Dehiwala F8	4:48	6:02	3.65
IV - 1	Sapugaskanda F3	4:48	5:16	8.65
	Mathugama F10	-		
	Thulhiriya F2	4:48	6:09	1.1
	Thulhiriya F6	4:48	6:10	1.65
	Kolonnawa A1	Off		
	Kolonnawa A2	4:48	5:29	2.2
	Kolonnawa B1	4:48	5:48	2.4
	Kolonnawa B2	4:48	5:28	2.2
	Pannipitiya F8	-		
	Pannipitiya F7	-		
	Pannipitiya F4	-		
	Dehiwala F6	-		
IV - 2	Sub E F 252	4:48	5:58	15.8
	Sub E F337	4:48	5:56	0
	Sub F F 08	4:48	5:54	8
	Sub F F 346	4:48	5:54	5
	Sub F F 351	4:48	5:54	4
V	Pannipitiya - Rath 1 and 2	-		
	Kotugoda - Veyan 1 and 2	-		
	Badulla - Ampara line	4:48	6:15	16
	New Anuradhapura - Trinco 1 and 2	4:48	6:33	21
TOTAL LOAD SHED (MW)				**120.2**

Before tripping of Ace Embilipitiya power plant, load shedding was operated. Even the generation loss due to tripping of KCCP was about 163 MW, total load shed was only 120.2 MW. Due to this insufficient load shedding, system frequency was not stabilized and this has caused a total system collapse.

From the above table it is observable that some feeders included in the load shedding table were not energized at that time due to some reason. But system was not aware about that. Online data monitoring is not possible within CEB system and load shedding tables are not updated.

Same pre-defined load shedding table is used without consideration of the time of the day (off-peak/day-peak/night-peak).

2.3 Weaknesses of the existing load shedding mechanism

Through the analysis of above partial and major failures occurred in recent past, following weaknesses were identified for the existing load shedding mechanism;

(I) Possibility of system collapse due to inadequate load shedding.

(II) Excessive load shedding due to pre-defined load shedding tables.

(III) Occurrence of more feeder interruptions than required.

(IV) Reactive power produced at each feeder is not under consideration.

(V) Same pre-defined load shedding table for off-peak, day-peak and night-peak.

To overcome these weaknesses, a properly managed updated load shedding mechanism is required to be implemented. Through the literature survey I learnt 'intelligent load shedding mechanism' is the best application to adapt in CEB network which can be practiced after completion of SCADA (Supervisory Control and Data Acquisition) which facilitates online data monitoring.

An intelligent load shedding system can provide faster and optimal load relief by utilizing actual operating conditions and knowledge of past system disturbances [1].

INTELLIGENT LOAD SHEDDING MECHANISM

An effective load shedding mechanism requires knowledge about power system dynamics, process constraints and system disturbances. This is possible within 'intelligent load shedding mechanism'.

An intelligent load shedding system can be illustrated as below;

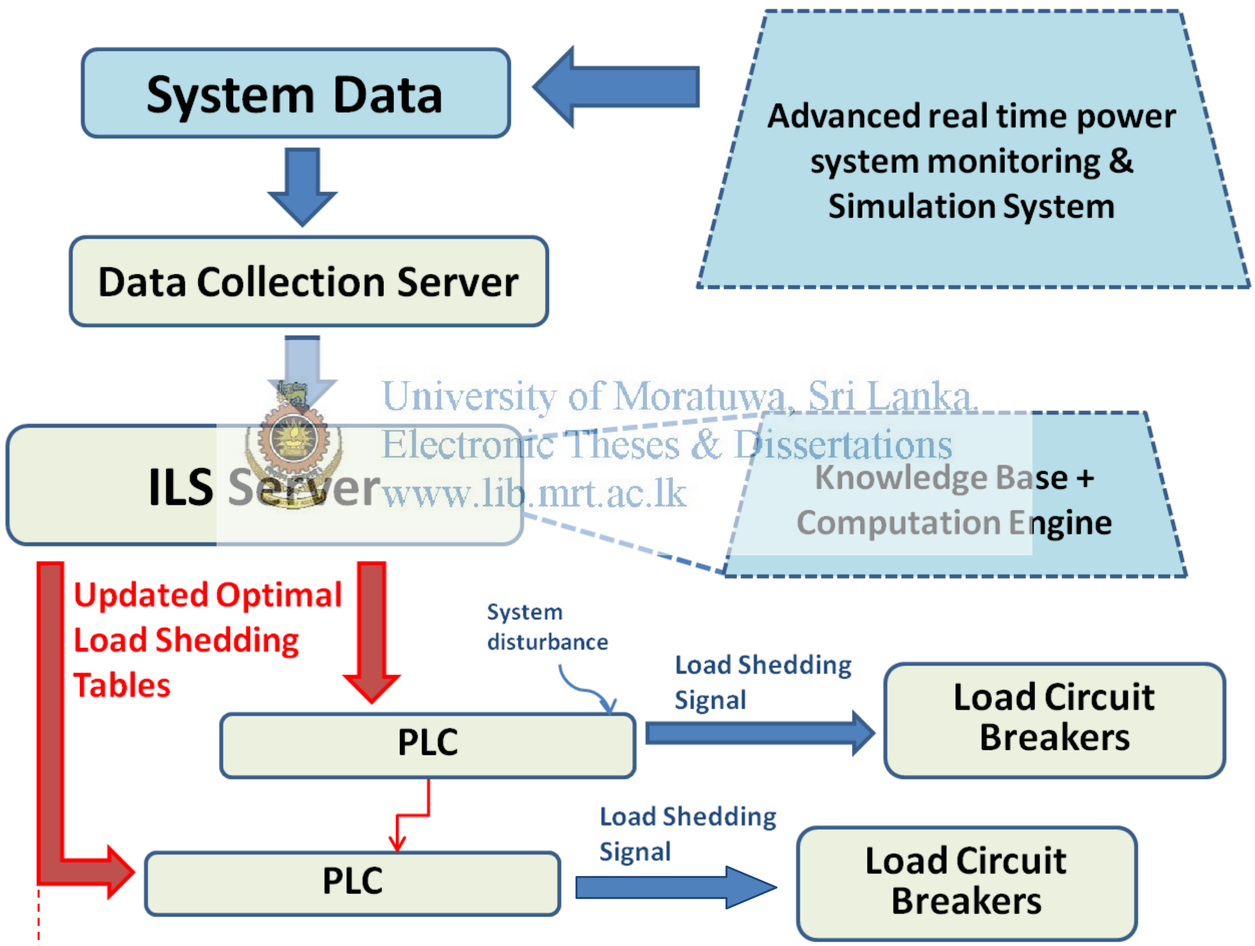


Figure 3.1 Basic representation of intelligent load shedding system

Here system data is continuously observed through advanced real time power system monitoring and simulation system. These system data can be generation of each on-site unit, total generation, total load demand, load demand of each feeder which is in the list of low priority feeders, spinning reserve.

These data is collected at data collection servers located at each substation. 'Intelligent Load Shedding server' (ILS server) which is a combination of 'knowledge base' and 'computation engine' is located at System Control Centre. This ILS server gets data from data collection servers continuously. Based on the input data and system updates, the knowledge base periodically sends requests to the ILS computation engine to update the load shedding tables, thus ensuring that the optimum load will be shed when a disturbance occurs [3].

These updated optimal load shedding tables are getting transferred to Programmable Logic Controllers (PLC) installed near feeders which can be shed. Whenever a system disturbance occurs, load shedding gets activated following updated optimal load shedding tables.

An intelligent load shedding scheme provides following main benefits;

1. Time-variant load shedding tables which reflect true status and loading conditions for the loads which can be shed.
2. Optimal combination of loads of feeders which can be shed to maximize load preservation.
3. Fast response to disturbance.
4. Environment to accelerate operator training with the ability to simulate and validate load shedding decisions [4].

3.1 Forming mathematical model in MATLAB software

As in CEB network online data accessing is not possible, MATLAB software was selected to build-up a model which facilitates ILS. Following steps were followed in this process;

i. Selecting a reduced network from CEB network to form a model in MATLAB software.
ii. Collecting data related to the network and modeling data for the uploading purpose in MATLAB software.
iii. Extracting load data of the feeders that can be shed.
iv. Importing modeled data into MATLAB software.
v. Designing Graphical User Interface (GUI) in MATLAB software.
vi. Developing the program algorithm and coding to update optimal load shedding tables and to activate load shedding through monitoring system frequency and frequency deviation rate.
vii. Application of case studies in MATLAB software.

3.1.1 Selection of reduced network

Following reduced network was selected in order to build-up a model in MATLAB software to apply ILS;

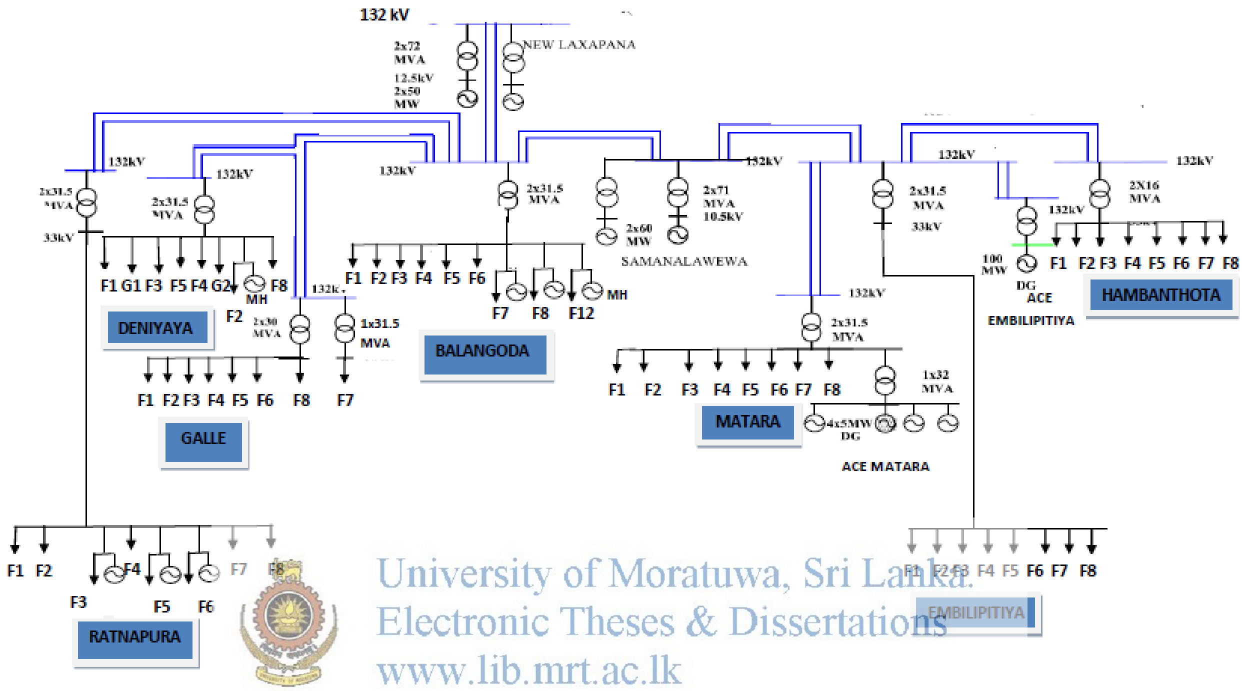


Figure 3.2 Selected network for MATLAB modeling

Two major hydro power plants, two thermal power plants and mini-hydro power plants are located in this network with below mentioned generation capacities;

- New Laxapana Power plant – 2 x 50 MW
- Samanalawewa Power plant – 2 x 60 MW
- Ace Power Matara – 4 x 5 MW
- Ace Power Embilipitiya – 100 MW
- Mini-hydro power plants in Ratnapura –22.05 MW
- Mini-hydro power plants in Deniyaya – 4 MW
- Mini-hydro power plants in Balangoda – 25.85 MW

Total generation produced at mini-hydro power plants were considered as constant values for this study.

There are seven grid substations located in this network as follows;

- Embilipitiya GSS
- Matara GSS
- Balangoda GSS
- Deniyaya GSS
- Galle GSS
- Hambanthota GSS
- Ratnapura GSS

3.1.2 Data collection and modeling

Initially MW readings of each GSS were modeled after deriving demand curve equation for each GSS. Average Watt readings extracted from energy meters located at GSS were obtained and demand curves were derived for day-peak, night-peak and off-peak as below;

Table 3.1: Derived Demand curve equations for each GSS based on time of the day

i. Embilipitiya GSS:

Day	Time of the day		
	Day-peak	Night-peak	Off-peak
Weekday	$y= 0.02 x^2 -0.35x+9.54$	$y= -x^2+39.3 x -368$	$y= 0.24 x^2 - 0.97 x +5.05$
Saturday	$y=-0.02x^2+0.66x+ 4.55$	$y = -0.93x^2 + 36.2x –337.5$	$y = 0.11x^2 -0.39x+ 5.4$
Sunday	$y=0.011x^2-0.175x+8.78$	$y = -1.02x^2 + 39.6x –369.04$	$y=0.15x^2-0.813x+6.5$

ii. Matara GSS:

Day	Time of the day		
	Day-peak	Night-peak	Off-peak
Weekday	$y= -0.014x^2 +0.53x+14.35$	$y= -1.17 x^2 +44.65x -400$	$y= 0.54 x^2 – 2.15x +11.9$
Saturday	$y= -0.07x^2+1.83 x+ 7.08$	$y= -1.12 x^2 + 43.12 x - 387$	$y= 0.28 x^2 -1.264x+12$
Sunday	$y= 0.004x^2 +0.008 x+15$	$y= -1.28 x^2 + 50 x - 454$	$y= 0.245 x^2 -1.33x+12.41$

iii. Balangoda GSS:

Day	Time of the day		
	Day-peak	Night-peak	Off-peak
Weekday	$y= 0.07x^2 +1.27x+34.3$	$y= -3.63 x^2 +141.43x -1326$	$y= 0.87 x^2 – 3.5x +18.2$
Saturday	$y= -0.098x^2+3.28 x+ 22.75$	$y= -4.65 x^2 + 180.95 x –1687.7$	$y= 0.539 x^2 -1.95x+27$
Sunday	$y= 0.034x^2 +0.525 x+26.35$	$y= -3.058 x^2 + 118.7 x - 1107$	$y= 0.5 x^2 -2.44x+19.5$

iv. Deniyaya GSS

Day	Time of the day		
	Day-peak	Night-peak	Off-peak
Weekday	$y= 0.02x^2 -0.34x+9.25$	$y= -0.98 x^2 +38x -357$	$y= 0.23 x^2 – 0.942x +5$
Saturday	$y= -0.09x^2+2.6 x+ 9.9$	$y= -1.57 x^2 + 60.37 x –541.9$	$y= 0.386 x^2 -1.77x+16.7$
Sunday	$y= 0.022x^2 -0.35 x+17.6$	$y= -2.04 x^2 + 79 x - 738$	$y= 0.3 x^2 -1.63x+13$

v. Galle GSS

Day	Time of the day		
	Day-peak	Night-peak	Off-peak
Weekday	$y= -0.02 x^2 +0.74x +20$	$y= -1.64 x^2 +62.5x -560$	$y= 0.76 x^2 – 3.01x +17$
Saturday	$y= -0.105x^2+2.93 x+ 11.326$	$y= -1.8 x^2 + 69 x –619$	$y= 0.44 x^2 -2.023x+19.05$
Sunday	$y= 0.006x^2 +0.011 x +19.5$	$y= -1.7 x^2 +64.5 x -590$	$y= 0.32 x^2 -1.33x+16.2$

vi. Hambanthota GSS

Day	Time of the day		
	Day-peak	Night-peak	Off-peak
Weekday	$y= -0.007 x^2 +0.26x +7.18$	$y= -0.584 x^2 +22.33x -200$	$y= 0.27 x^2 – 1.08x +6$
Saturday	$y= -0.034x^2+0.917x+ 3.54$	$y= -0.561 x^2 + 21.6 x –193.6$	$y= 0.137 x^2 -0.633x+5.95$
Sunday	$y= 0.002x^2 +0.0042 x+7.5$	$y= -0.64 x^2 +25 x -227$	$y= 0.123 x^2 -0.7x+6.2$

vii. Ratnapura GSS

Day	Time of the day		
	Day-peak	Night-peak	Off-peak
Weekday	$y= 0.06 x^2 -1.06x +28.6$	$y= -3.02 x^2 +118x -1105$	$y= 0.72 x^2 – 2.9x +15.15$
Saturday	$y= -0.08x^2+2.626x+ 18.2$	$y= -3.72 x^2 + 144.76 x –1350.16$	$y= 0.43 x^2 -1.56x+21.7$
Sunday	$y= 0.05x^2 -0.7 x+35$	$y= -2.5 x^2 +99 x -922$	$y= 0.6 x^2 -3.25x+26$

In these demand curve equations, x defines time of the day in hours while y represents the load at the particular time. Total load of each GSS was calculated based on this demand curve equation. After analyzing readings taken by System Control branch at off-peak, day-peak and night-peak feeder wise, relationship between demand of each feeder and total demand was observed. Total demand value at a particular time was distributed over feeders based on this relationship.

Demand database was formed as per the above criterion. Depending on the total demand at a particular time, generation database was formed. Main concern was on dispatching hydro generation units such as New Laxapana and Samanalawewa. Mini hydro generation was kept as constant.

3.1.3 Extracting load data of the feeders that can be shed

Electricity demand of the feeders which can be shed were filtered and entered in a separate sheet. Feeders which can be shed were selected depending on the demand of each feeder which is not categorized as 'high priority feeder'.

(i) Embilipitiya feeder 06
(ii) Matara feeder 01
(iii) Matara feeder 06
(iv) Matara feeder 07
(v) Balangoda feeder 05
(vi) Deniyaya feeder 01
(vii) Galle feeder 04
(viii) Galle feeder 07
(ix) Hambanthota feeder 05
(x) Ratnapura feeder 01
(xi) Ratnapura feeder 08

Here reactive power component of each feeder which can be shed was also calculated and entered. Power factor value was obtained for each GSS from readings taken by grid operators recently. Reactive power was calculated based on this power factor value.

Feeders which can be shed were arranged in descending orders of real power and reactive power as below;

Table 3.2: Descending order of real power and reactive power of feeders which can be shed

Descending order of real power	Descending order of reactive power
Ratnapura feeder 08	Ratnapura feeder 08
Balangoda feeder 05	Balangoda feeder 05
Galle feeder 04	Galle feeder 04
Galle feeder 07	Matara feeder 06
Matara feeder 06	Matara feeder 07
Ratnapura feeder 01	Ratnapura feeder 01
Matara feeder 07	Matara feeder 01
Matara feeder 01	Hambanthota feeder 05
Embilipitiya feeder 06	Galle feeder 07
Hambanthota feeder 05	Embilipitiya feeder 06
Deniyaya feeder 01	Deniyaya feeder 01

Based on above order, load shedding sequence was built up as below;

(i). Ratnapura feeder 08

(ii).Balangoda feeder 05

(iii).Galle feeder 04

(iv).Matara feeder 06

(v). Matara feeder 07

(vi).Galle feeder 07

(vii)Ratnapura feeder 01

(viii)Matara feeder 01

(ix) Hambanthota feeder 05

(x) Embilipitiya feeder 06

(xi) Deniyaya feeder 01

3.1.4 Importing modeled data into MATLAB software

Excel sheets consist of demand data, generation data and demand of feeders which can be shed were imported to MATLAB software.

Calculation of system frequency was done using following equation;

$$f_{new} = f_0 - \frac{df}{dt} \times (0.1)$$

Here 0.1 is Δt in seconds

$\frac{df}{dt}$ = rate of change of frequency (Hz/s)

The basic characteristic of the frequency change of a power system is derived from the following equation;

$$\frac{df}{dt} = \frac{(P_L - P_G)}{P_G} \times \frac{f_o}{2H} + D \times \Delta f$$

f_0 = frequency at the time of disturbance (Hz)

H = System inertia constant on system base (3.35)

P_L = Load prior to generation loss (MW)

P_G = Generation sum after loss (MW)

D = Power system load damping constant in pu/Hz

Δf = Change in frequency (Hz)

D depends on the load categories and varies between 1% and 2%. To simplify the model 'D' is assumed as 'zero'.

$$\frac{df}{dt} = \Delta P \times \frac{f_0}{2H}$$

Here, $\Delta P = \frac{(P_L - P_G)}{P_G}$

ΔP= Power change (per unit in system load base)

3.1.5 Designing Graphical User Interface (GUI) in MATLAB software

Coding was built-up in MATLAB software to form Graphical User Interface (GUI) where user can select required details as follows;

- Day of the week user wants to view data.
- Required plots such as ‘load vs. generation’ or ‘operation of power plants vs. time’, etc.
- Resolution in minutes and update speed in milliseconds.
- Manual option to trip a machine.

Here manual option was given for the user to input time for a machine tripping and time when relevant machine is coming back to the system. This facility was included in order to view the behavior of the system for each machine tripping.

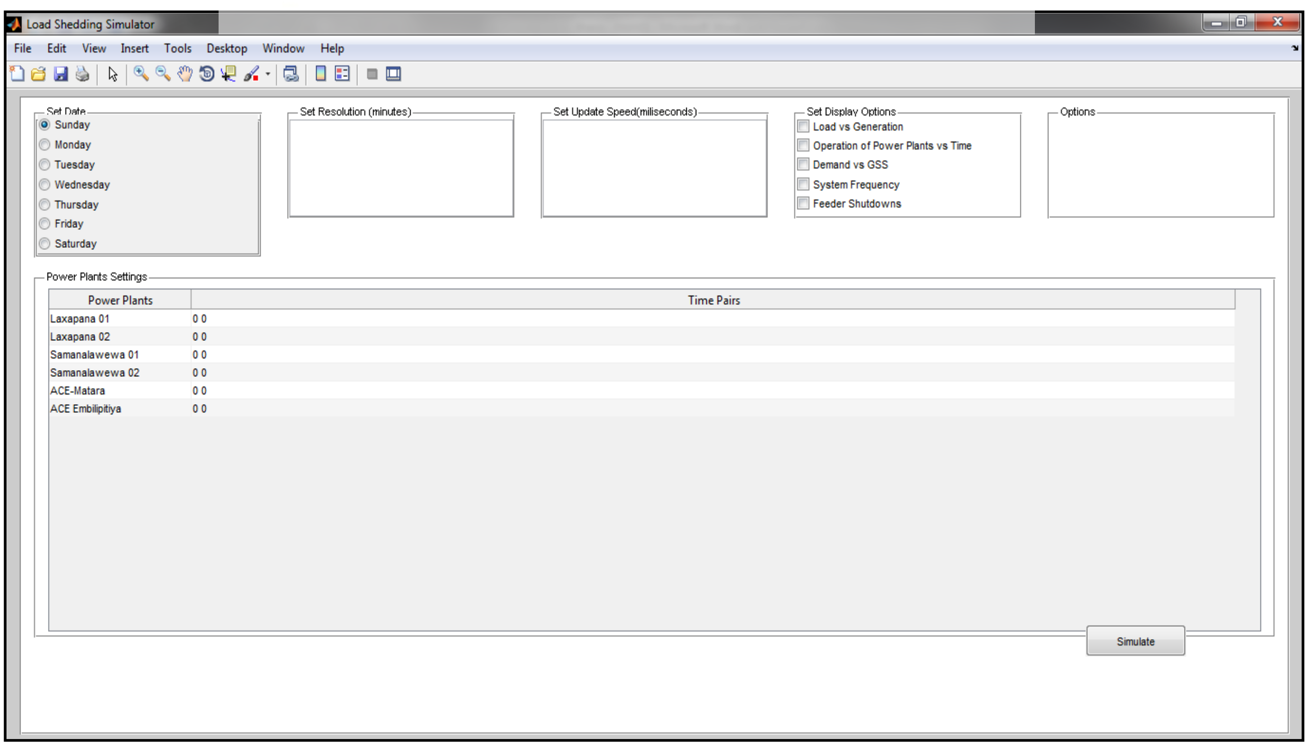


Figure 3.3 Graphical User Interface (GUI)

Imported data into MATLAB software can be accessed as below;

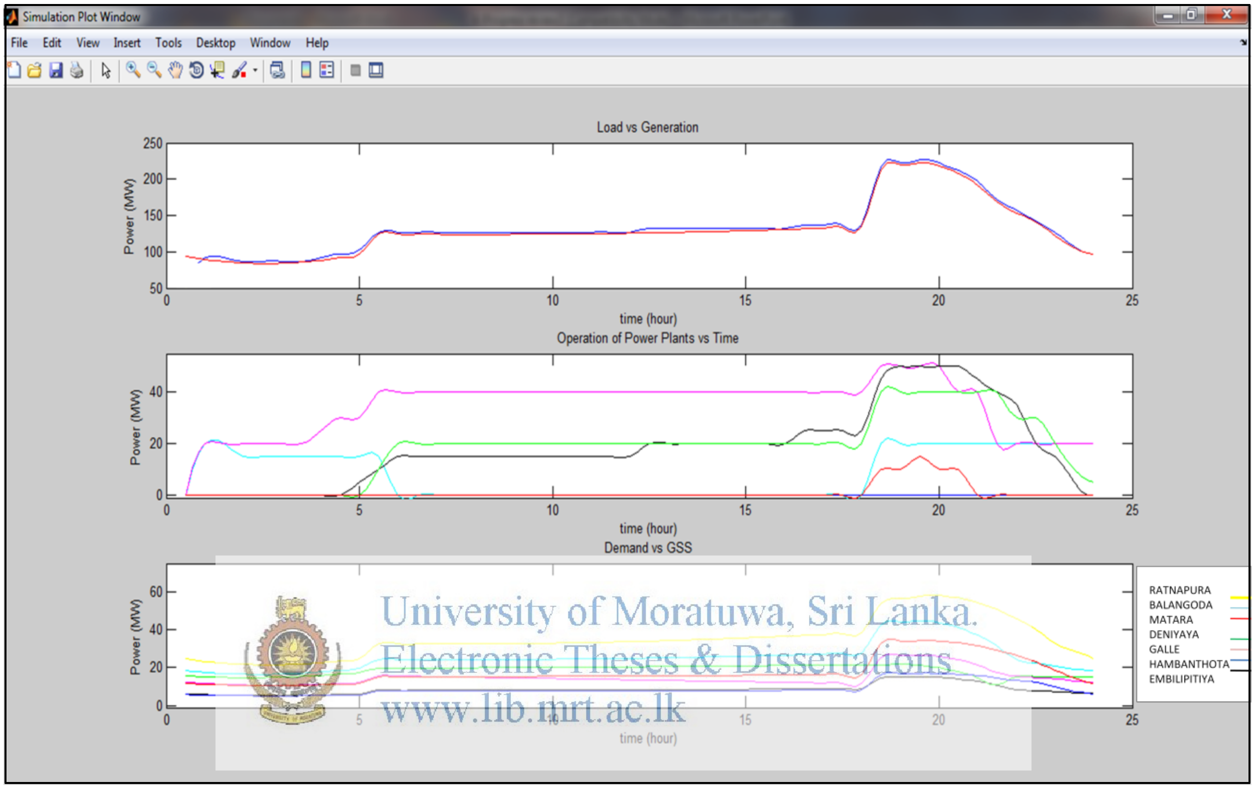


Figure 3.4 View of selected plots for a Sunday

3.1.6 Developing the program algorithm and coding to update optimal load shedding tables and to activate load shedding

Initially developing program algorithm for the operation of intelligent load shedding mechanism is done.

Flow chart representation is illustrated below;

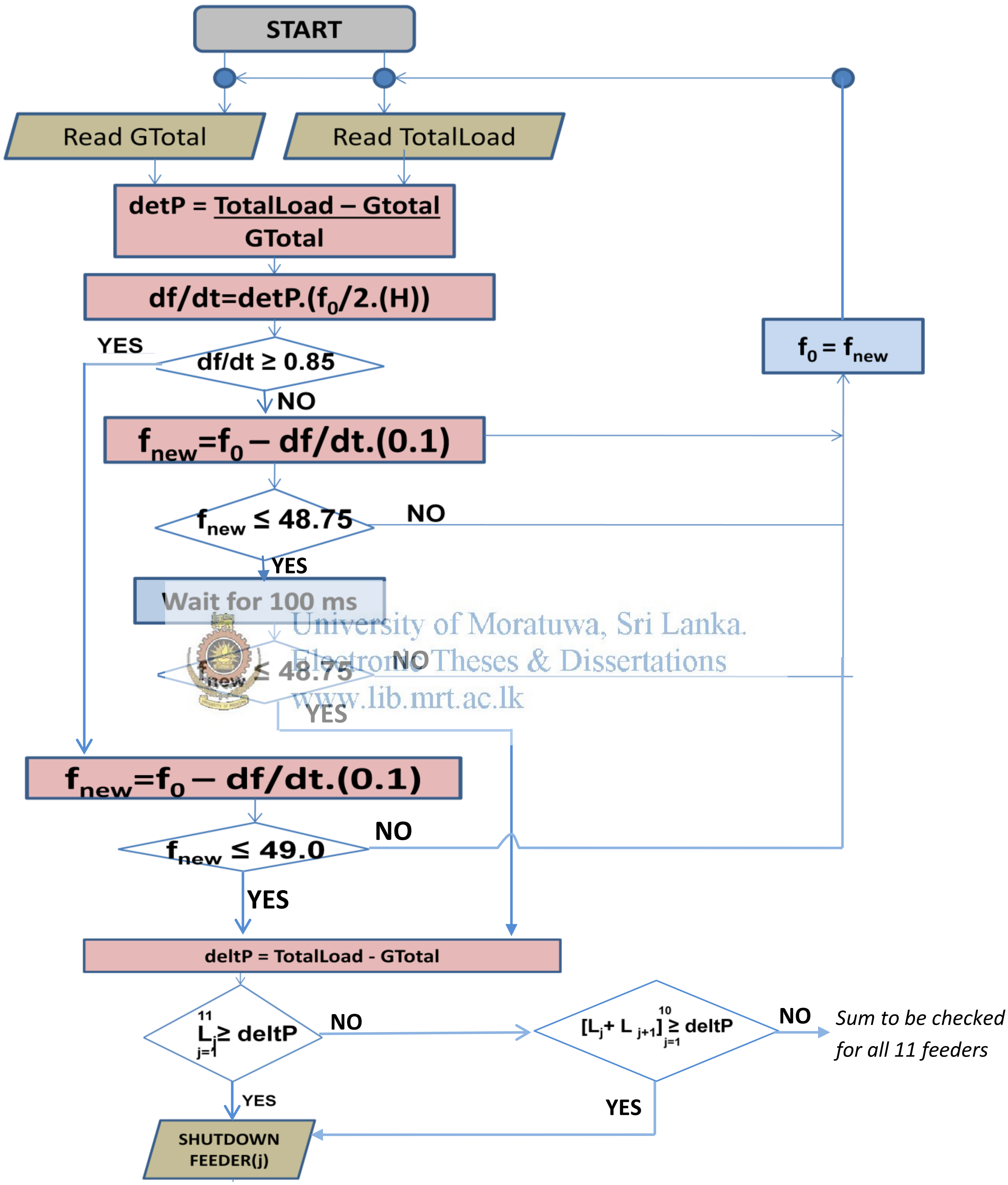
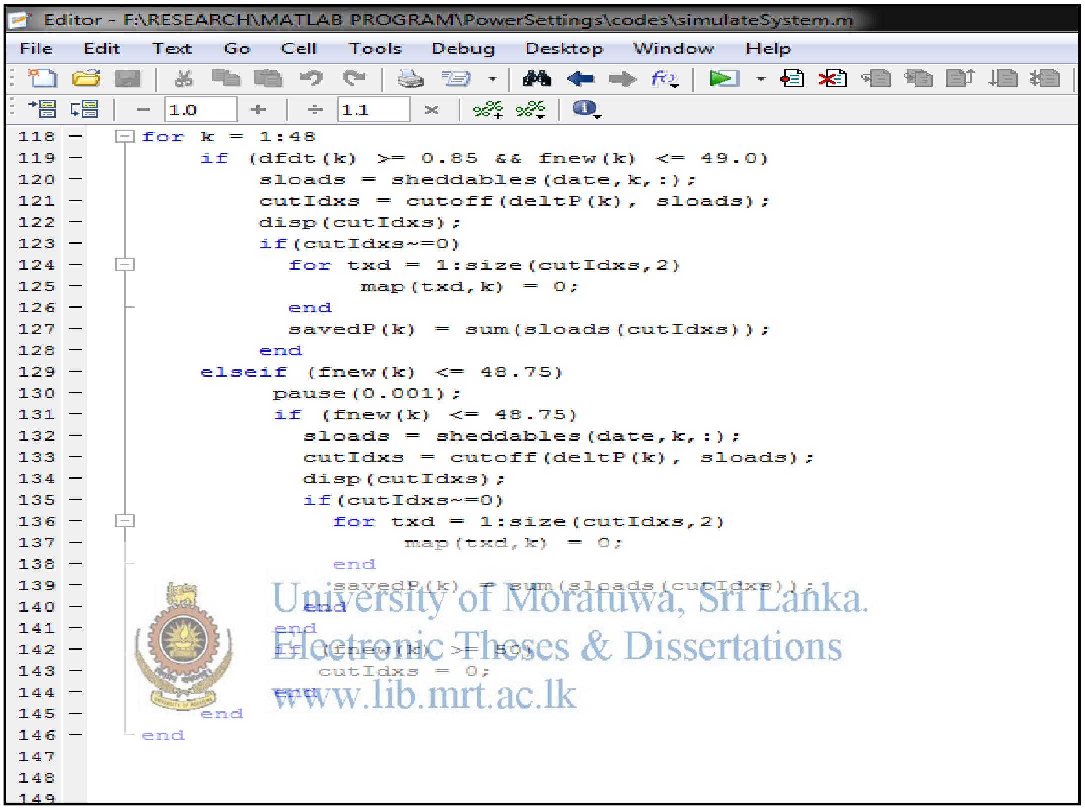


Figure 3.5 Flow Chart for the load shedding mechanism

Here L_j= Load of the feeder no.(j) which can be shed, at the time load shedding is required.

Each MATLAB file ('m' file) created is attached at the end of this report as appendix-B, appendix-C, appendix-D, appendix-E, appendix-F, appendix-G and appendix-H.

Coding written for the checking of system frequency and frequency deviation rate is shown below;



```
Editor - F:\RESEARCH\MATLAB PROGRAM\PowerSettings\codes\simulateSystem.m
for k = 1:48
    if (dfdt(k) >= 0.85 && fnew(k) <= 49.0)
        sloads = sheddables(date,k,:);
        cutIdxs = cutoff(deltP(k), sloads);
        disp(cutIdxs);
        if(cutIdxs~=0)
          for txd = 1:size(cutIdxs,2)
                map(txd,k) = 0;
          end
          savedP(k) = sum(sloads(cutIdxs));
        end
    elseif (fnew(k) <= 48.75)
         pause(0.001);
         if (fnew(k) <= 48.75)
           sloads = sheddables(date,k,:);
           cutIdxs = cutoff(deltP(k), sloads);
           disp(cutIdxs);
           if(cutIdxs~=0)
             for txd = 1:size(cutIdxs,2)
                   map(txd,k) = 0;
             end
             savedP(k) = sum(sloads(cutIdxs));
           end
         end
         if (fnew(k) >= 50)
           cutIdxs = 0;
         end
    end
end
```


Figure 3.6 MATLAB Coding for checking frequency and frequency deviation rate

Here, a time delay of 100 ms is introduced before activation of load shedding to check whether frequency is improved or not. This is the same time delay used by CEB to avoid unnecessary interruption of load.

3.1.7 Application of case studies in MATLAB software

Following case studies were implemented using the algorithm developed in MATLAB software;

(1). Shutting down of machine-02 in Laxapana power station at t=1000 minutes (16:40 hours) and bringing back to the system at t=1110 minutes (18:30 hours).

(2). Shutting down of machine-01 in Samanalawewa power station at t=1140 minutes (19:00 hours) and bringing back to the system at t=1170 minutes (19:30 hours).

(3). Shutting down of machine-01 in Laxapana at t=1200 minutes (20:00 hours) and bringing back to the system at t=1230 min (20:30 hrs) and shutting down machine-01 in Samanalawewa at t=1210 minutes (20:10 hours) and bringing back to the system at t=1240 minutes (20:40 hours).

3.1.7.1 Shutting down of machine-02 in Laxapana power station at t=1000 minutes (16:40 hours) and bringing back to the system at t=1110 minutes (18:30 hours)

The above time pairs when machine tripping occurs and coming back to the system were entered in GUI under 'power plants settings' column. Initially plots of 'load and generation vs. time' and 'operation of power plants vs. time' were obtained as below;

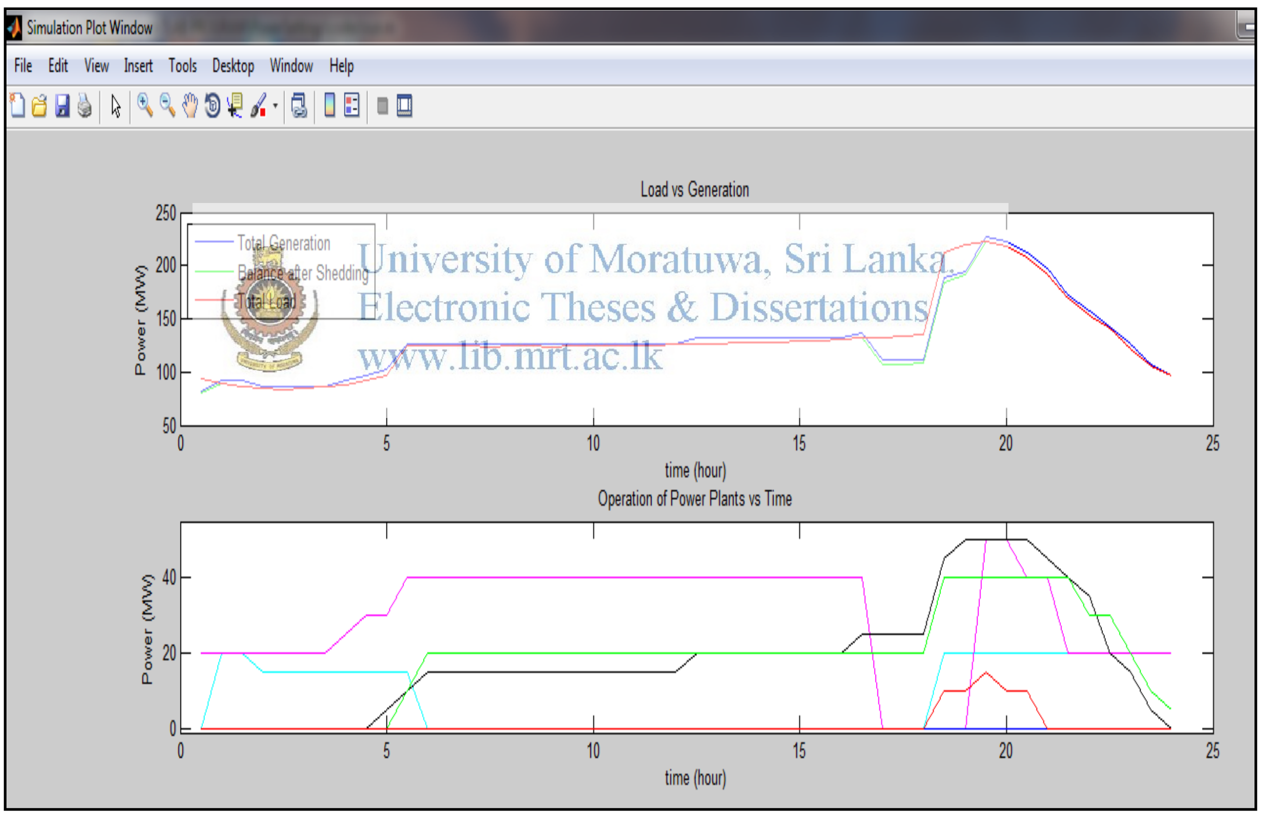


Figure 3.7 Plots of 'load and generation vs. time' and 'operation of power plants vs. time' for example-

Machine-02 in Laxapana power station was generating about 40 MW which was almost 29% of total generation available at that time. Plot line represented by 'pink colour' shows MW generated by machine-02 in Laxapana power station.

Plot of feeder shutdowns is shown below which represents shedding of feeder 08 in Ratnapura GSS, feeder 05 in Balangoda GSS, feeder 04 in Galle GSS, feeder 06 and 07 in Matara GSS. It can be said that it is the best combination of the loads to be shed by looking at system frequency behavior.

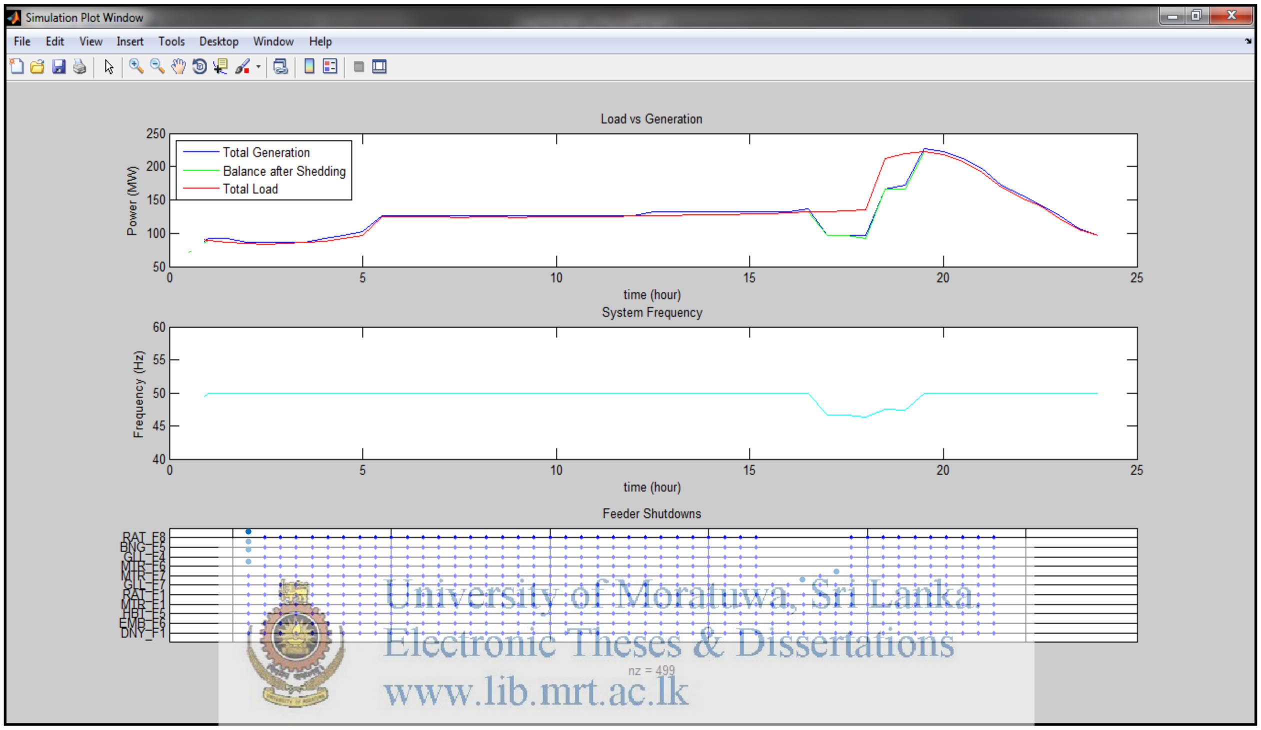


Figure 3.8 Plots of 'load and generation Vs. time', 'frequency Vs. time' and feeder shutdowns For example-01

3.7.1.2 Shutting down of machine-01 in Samanalawewa power station at t=1140 minutes (19:00 hours) and bringing back to the system at t=1171 minutes (19:31 hours)

The above time pairs when machine tripping occurs and coming back to the system were entered in GUI under 'power plants settings' column. Initially plots of 'load and generation vs. time' and 'operation of power plants vs. time' were obtained as below;

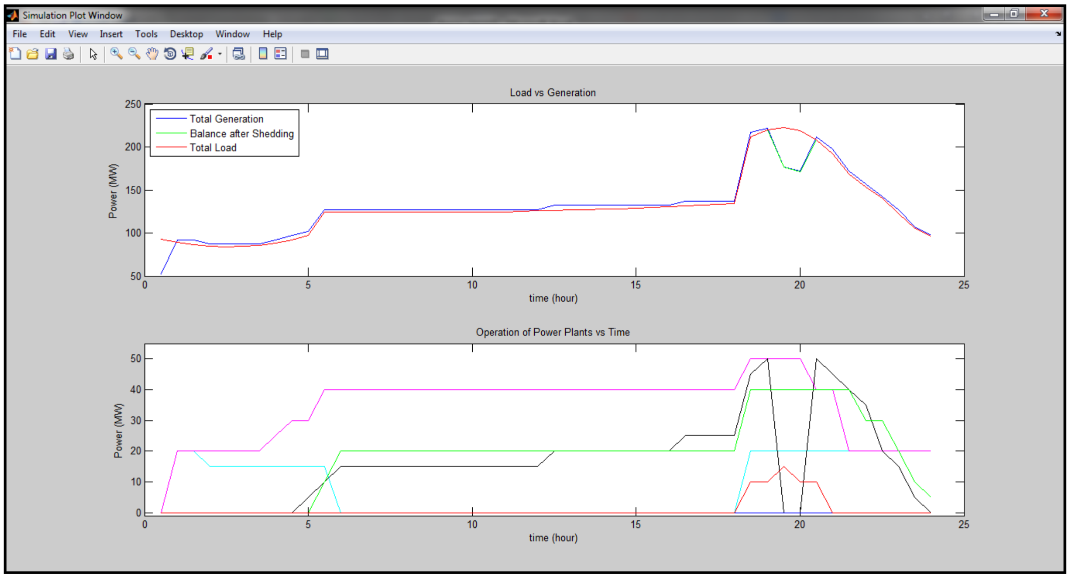


Figure 3.9 Plots of ‘load and generation vs. time’ and ‘operation of power plants’ for example-02

Machine-01 in Samanalawewa power station was generating about 50 MW which was almost 22% of total generation available at that time. Plot line represented by ‘black colour’ shows MW generated by machine-01 in Samanalawewa power station.

Plots of frequency with time and feeder shutdowns are shown below which represents shedding of feeder 08 in Ratnapura GSS, feeder 05 in Balangoda GSS, feeder 04 in Galle GSS, feeder 06 in Matara GSS;

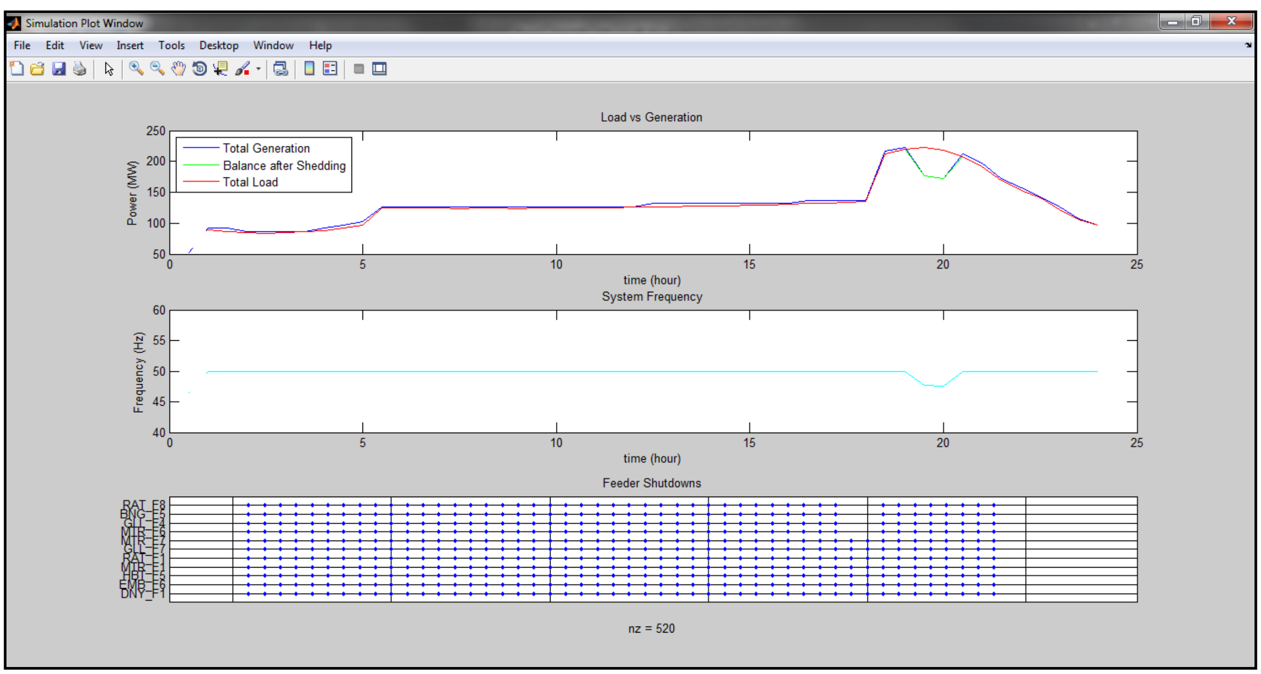


Figure 3.10 Plots of ‘load and generation vs. time’, ‘frequency vs. time’ and ‘feeder shutdowns’ for example-02

3.7.1.3 *Shutting down of machine-01 in Laxapana at t=1200 minutes (20:00 hours) and bringing back to the system at t=1230 min (20:30 hrs) and shutting down of machine-01 in Samanalawewa at t=1210minutes (20:10 hours) and bringing back to the system at t=1240 minutes (20:40 hours)*

The above time pairs when machines' tripping occurs and machines' coming back to the system occurs were entered in GUI under 'power plants settings' column. Initially plots of 'load and generation vs. time' and 'operation of power plants vs. time' were obtained as below;

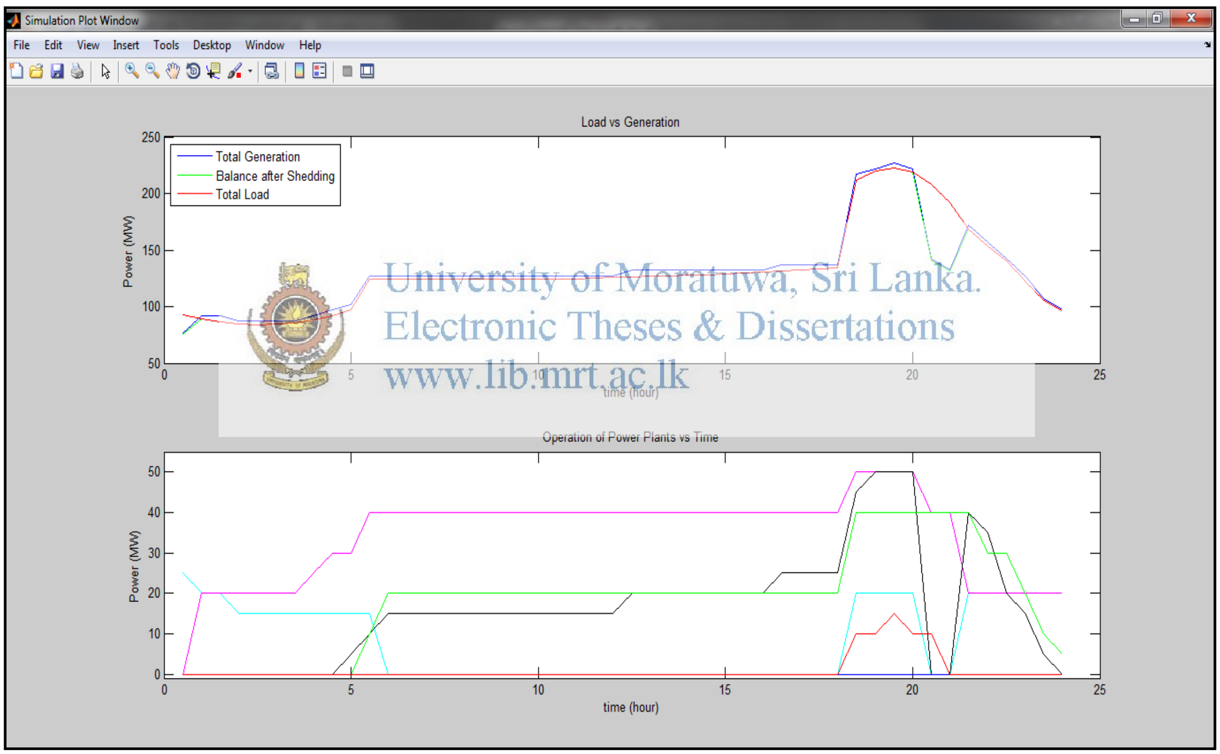


Figure 3.11 Plots of 'load and generation vs. time' and 'operation of power plants' for example-

Machine-01in Laxapana power station was generating about 20 MW which was about 9% of total generation available at that time. Plot line represented by 'cyan colour' shows MW generated by machine-01 in Laxapana power station.

Machine-01in Samanalawewa power station was generating about 50 MW which was almost 22% of total generation available at that time. Plot line represented by 'black colour' shows MW generated by machine-01 in Samanalawewa power station.

Plot of feeder shutdowns is shown below which represents shedding of feeder 01 and08 in Ratnapura GSS, feeder 05 in Balangoda GSS, feeder 04 and 07 in Galle GSS, feeder 06 and 07 in Matara GSS;

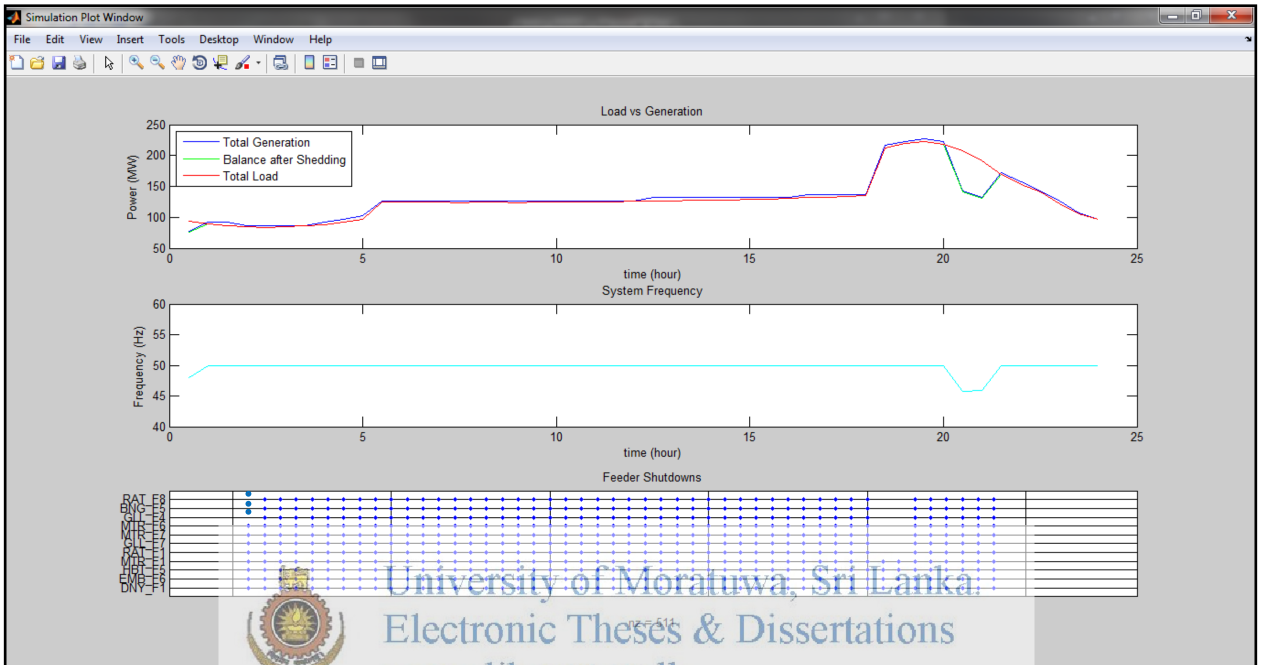


Figure 3.12 Plots of ‘load and generation vs. time’, ’frequency vs. time’ and ‘feeder shutdowns’ for example-03

Even though intelligent load shedding can be implemented in MATLAB software, result analysis cannot be done in a proper way as we have to apply ‘under frequency load shedding mechanism’ also in MATLAB software. It was decided to apply both load shedding mechanisms in ‘Power System Simulator for Engineering’ (PSS/E) software for further verification. This is described in the next chapter.

RESULT ANALYSIS IN PSS/E

4.1 Introduction to PSS/E software

Power System Simulator for Engineering (PSS/E) is an integrated program for simulating, analyzing and optimizing power system performance. This software is a tool for use in the design and operation of reliable networks. Transmission and Generation planning Engineers in CEB also make use of this software tool in order to improve system performance.

4.2 Planning Criteria

The planning criteria were established to ensure quality and reliable supply of electricity under normal operating conditions as well as under emergency situations. It was done in four important areas;

(i). Voltage criterion

(ii). Thermal criterion

(iii). Security criterion

(iv). Stability criterion

4.2.1 Voltage criterion

Permissible voltage variations from standard voltage at any live bus bar of the network under normal and single contingency operating conditions are defined.

Table 4.1 Permissible voltage variation in 220 kV, 132 kV and 33 kV systems

Bus bar voltage	Permissible voltage variation (%)	
	Normal operating condition	Single contingency condition
220 kV	±5%	-10% to +5%
132 kV	±10%	±10%
33 kV	±1%	±1%

4.2.2 Thermal criterion

This is a limitation for the loading of transmission network to avoid overheating under 'overloading'.

4.2.3 Security criterion

The system performance is assessed under emergency situations in this criterion. The adopted contingency level for the planning purposes is N-1 which implies outage of any one element of the transmission system at a time. When N-1 situation arises the system should be able to meet the distribution demand following voltage criterion and thermal criterion.

After system readjustment following a disturbance described above, the voltage and loading of elements should return to their corresponding normal limits [7].

4.2.4 Stability criterion

Under stability criterion system stability must be confirmed 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 [7]

4.3 Static versus Dynamic Analysis

Static and dynamic analysis studies are two most common methods used within CEB for analyzing power system stability.

4.3.1 Static Analysis

Static or steady-state analyses are the load-flow studies done when system is under equilibrium state. Here generation always equals to load demand and losses. Voltage stability studies are done through static analysis.

4.3.2 Dynamic Analysis

Dynamic analysis or time-domain analyses are the power system stability studies done when a disturbance occurs.

Here for the result analysis and for a better comparison, dynamic analysis was done for both load shedding mechanisms- under frequency load shedding(UFLS) and Intelligent Load Shedding(ILS) in PSS/E software.

4.4 Result Analysis

Simulation was done in PSS/E software for both load shedding mechanisms for three scenarios as mentioned below;

CASE STUDY 1: Tripping of both machines in New Laxapana power station and both machines in Samanalawewa power station.

CASE STUDY 2: Tripping of both machines in New Laxapana power station, both machines in Samanalawewa power station and machines in Old Laxapana power station.

CASE STUDY 3: Tripping of both machines in New Laxapana power station, both machines in Samanalawewa power station and machine 1 in Lakvijaya power station.

As in PSS/E load data are mentioned GSS-wise, initially I had to remodel load network in order to view 33 kV feeders in each GSS. Intelligent load shedding mechanism is considering each feeder separately not GSS-wise. Several other modifications were also done to the modeled PSS/E file for the implementation of ILS.

As these three scenarios were considered for a better comparison of the results I also considered another case study as mentioned below which has already been occurred in the system.

CASE STUDY 4: Tripping of machine-01 in Lakvijaya power station

Tripping of machine-01 in Lakvijaya power station was occurred on 07th April 2015 at 23:33 hours due to a failure in the cooling system. This scenario was considered as a practical case study.

4.4.1 Implementation of ILS in PSS/E software

Following procedure was followed in implementation of ILS in PSS/E.

(i). Load demand of each feeder in each GSS was collected for a particular date (14/12/2014).

(ii). Real power and reactive power were obtained for each feeder for the same date at 19:00 hours. Following equations were used in calculating real power (equation 1) and reactive power(equation 2) of GSS where relevant MW or MVAr meters are not available.

$$P = \sqrt{3} \times V \times I \times \cos Ø \longrightarrow (1)$$

$$Q = \sqrt{3} \times V \times I \times \sin Ø \longrightarrow (2)$$

Here, P=Active power or Real power in kW, V = Voltage in kV, I = Current in kA cosØ = power factor, Ø = The angle of difference between current and voltage in degrees

(iii). Generation data was collected for the same date (14/12/2014) at 19:00 hours where readings were taken in MW.

(iv). As feeders were not included in available PSS/E file for CEB network in System Control Centre, feeders were included for each GSS up-to-date with active power (P) and reactive power (Q).

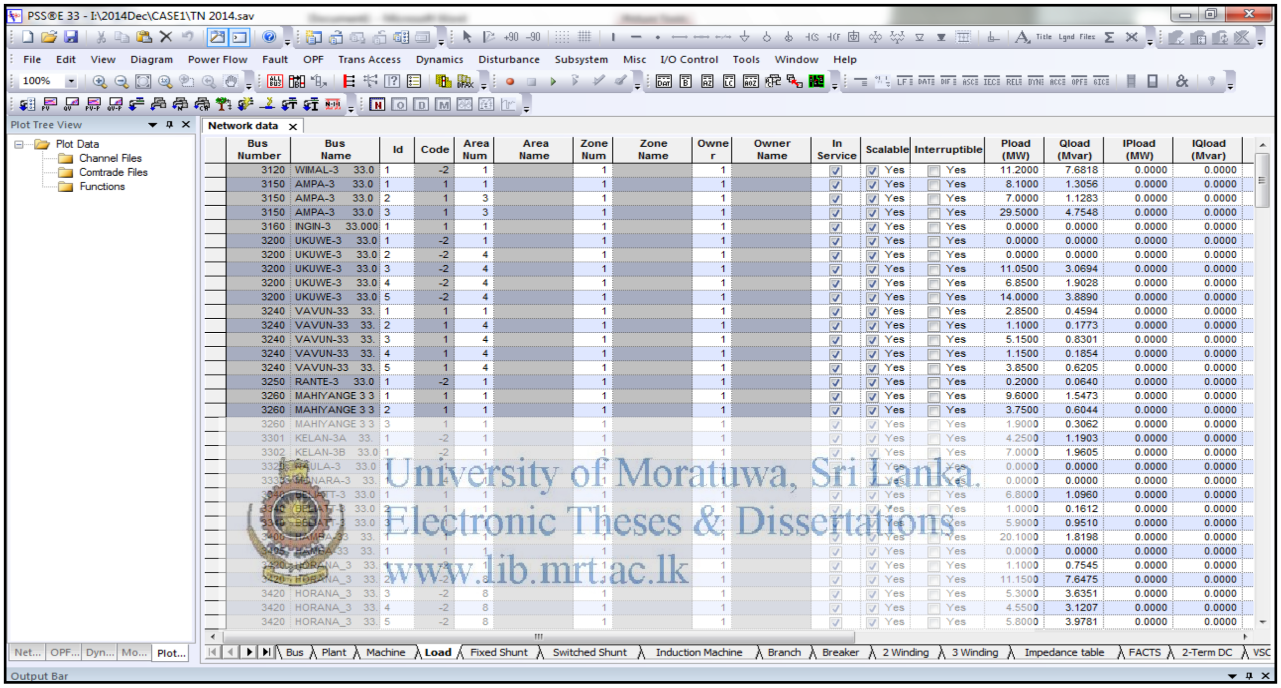


Figure 4.1 Load modeled feeder wise in PSS/E

(v). Collected generation data was entered to the same PSS/E file as shown in figure 4.2.

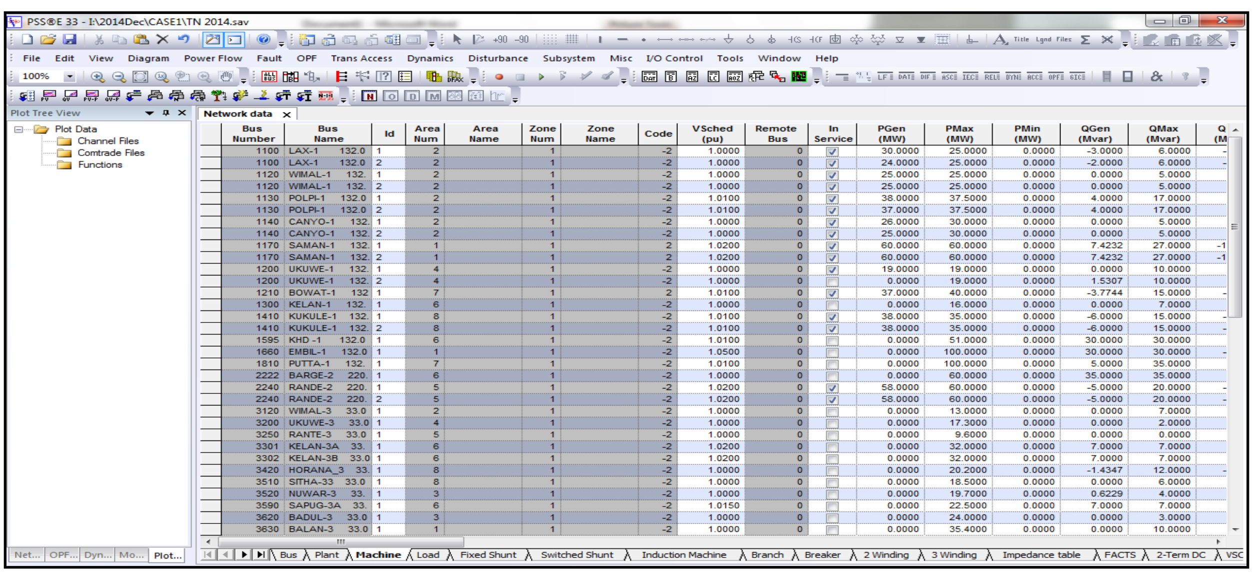


Figure4.2 Machine file updated with generation data in PSS/E

(vi). Depending on active power and reactive power descending order, best load shedding sequence was obtained as attached in appendix-I.

(vii). Diary file(.dyr file) was written for each 4 scenario as mentioned above (case study 1, case study 2, case study 3 and case study 4) with the use of best load shedding sequence.

Screenshot of each diary file is given below;

```
2014 DYRE CASE1 - Notepad
File  Edit  Format  View  Help
4300  'GENROU' 1  6.64   0.049  1.18  0.066  8    0.5  1.81  1.77  0.259  0.344  0.179  0.1  0.125  0.589  /
4300  'SEXS'      1      0.1    10    100    0.05 0    3.5   /
4300  'GAST'      1      0.05   0.4   0.1    3    1    2     0.95  0      0      /


3580  'LDSHBL' 2  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3650  'LDSHBL' 3  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3770  'LDSHBL' 1  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3600  'LDSHBL' 3  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3530  'LDSHBL' 3  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3600  'LDSHBL' 5  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3520  'LDSHBL' 2  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3890  'LDSHBL' 1  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3790  'LDSHBL' 5  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3820  'LDSHBL' 3  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3420  'LDSHBL' 2  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3200  'LDSHBL' 3  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
4920  'LDSHBL' 1  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3570  'LDSHBL' 7  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3580  'LDSHBL' 1  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3705  'LDSHBL' 1  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3260  'LDSHBL' 1  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3570  'LDSHBL' 5  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3680  'LDSHBL' 5  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3560  'LDSHBL' 6  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3590  'LDSHBL' 5  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
4435  'LDSHBL' 4  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
```


Figure 4.3 Diary file written for case study-01

```
2014 DYRE CASE2 - Notepad
File  Edit  Format  View  Help

3580  'LDSHBL' 2  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3650  'LDSHBL' 3  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3770  'LDSHBL' 1  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3600  'LDSHBL' 3  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3530  'LDSHBL' 3  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3600  'LDSHBL' 5  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3520  'LDSHBL' 2  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3890  'LDSHBL' 1  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3790  'LDSHBL' 5  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3820  'LDSHBL' 3  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3420  'LDSHBL' 2  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3200  'LDSHBL' 3  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
4920  'LDSHBL' 1  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3570  'LDSHBL' 7  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3580  'LDSHBL' 1  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3705  'LDSHBL' 1  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3260  'LDSHBL' 1  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3570  'LDSHBL' 5  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3680  'LDSHBL' 5  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3560  'LDSHBL' 6  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3590  'LDSHBL' 5  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
4435  'LDSHBL' 4  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3790  'LDSHBL' 1  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3860  'LDSHBL' 5  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3900  'LDSHBL' 3  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
4430  'LDSHBL' 1  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
4435  'LDSHBL' 3  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3770  'LDSHBL' 3  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
```

Figure 4.4 Diary file written for case study-02

2014 DYRE CASE3 with df by dt - Notepad

File Edit Format View Help

3580	'LDSHBL' 2	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3650	'LDSHBL' 3	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3770	'LDSHBL' 1	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3600	'DLSHBL' 3	0	0.0	0.0	0	0.0	0.0	49.0	0.0	1	0.06	-0.85	-0.85	-0.85	/
3530	'LDSHBL' 3	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3600	'DLSHBL' 5	0	0.0	0.0	0	0.0	0.0	49.0	0.0	1	0.06	-0.85	-0.85	-0.85	/
3520	'DLSHBL' 2	0	0.0	0.0	0	0.0	0.0	49.0	0.0	1	0.06	-0.85	-0.85	-0.85	/
3890	'DLSHBL' 1	0	0.0	0.0	0	0.0	0.0	49.0	0.0	1	0.06	-0.85	-0.85	-0.85	/
3790	'DLSHBL' 5	0	0.0	0.0	0	0.0	0.0	49.0	0.0	1	0.06	-0.85	-0.85	-0.85	/
3820	'DLSHBL' 3	0	0.0	0.0	0	0.0	0.0	49.0	0.0	1	0.06	-0.85	-0.85	-0.85	/
3420	'DLSHBL' 2	0	0.0	0.0	0	0.0	0.0	49.0	0.0	1	0.06	-0.85	-0.85	-0.85	/
3200	'LDSHBL' 3	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
4920	'DLSHBL' 1	0	0.0	0.0	0	0.0	0.0	49.0	0.0	1	0.06	-0.85	-0.85	-0.85	/
3570	'DLSHBL' 7	0	0.0	0.0	0	0.0	0.0	49.0	0.0	1	0.06	-0.85	-0.85	-0.85	/
3580	'LDSHBL' 1	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3705	'LDSHBL' 1	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3260	'LDSHBL' 1	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3570	'DLSHBL' 5	0	0.0	0.0	0	0.0	0.0	49.0	0.0	1	0.06	-0.85	-0.85	-0.85	/
3680	'LDSHBL' 5	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3560	'DLSHBL' 6	0	0.0	0.0	0	0.0	0.0	49.0	0.0	1	0.06	-0.85	-0.85	-0.85	/
3590	'DLSHBL' 5	0	0.0	0.0	0	0.0	0.0	49.0	0.0	1	0.06	-0.85	-0.85	-0.85	/
4435	'DLSHBL' 4	0	0.0	0.0	0	0.0	0.0	49.0	0.0	1	0.06	-0.85	-0.85	-0.85	/
3790	'DLSHBL' 1	0	0.0	0.0	0	0.0	0.0	49.0	0.0	1	0.06	-0.85	-0.85	-0.85	/
3860	'LDSHBL' 5	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3900	'LDSHBL' 3	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
4430	'DLSHBL' 1	0	0.0	0.0	0	0.0	0.0	49.0	0.0	1	0.06	-0.85	-0.85	-0.85	/
4435	'LDSHBL' 3	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3770	'LDSHBL' 3	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3850	'LDSHBL' 1	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3670	'LDSHBL' 2	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3860	'LDSHBL' 2	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3570	'LDSHBL' 4	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3150	'LDSHBL' 1	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3570	'LDSHBL' 8	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3770	'LDSHBL' 5	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3650	'LDSHBL' 4	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3620	'LDSHBL' 2	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3910	'LDSHBL' 3	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3560	'LDSHBL' 8	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3830	'LDSHBL' 2	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3600	'LDSHBL' 2	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3690	'LDSHBL' 5	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3620	'LDSHBL' 3	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3705	'LDSHBL' 2	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3800	'LDSHBL' 6	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3520	'LDSHBL' 1	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3600	'LDSHBL' 1	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3830	'LDSHBL' 1	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3150	'LDSHBL' 2	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3770	'LDSHBL' 4	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
4435	'LDSHBL' 2	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3200	'LDSHBL' 4	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3840	'LDSHBL' 6	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3551	'LDSHBL' 1	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3340	'LDSHBL' 1	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3590	'LDSHBL' 2	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			
3690	'LDSHBL' 3	48.75	0.1	1	0	0.0	0.0	0	0.0	0.0	0.06	/			

Figure 4.5 Diary file written for case study-03

As 29.6% of total generation was not available under case study-03, df/dt rate would be higher. Therefore separate set of loads were included for the shedding if df/dt rate exceeds -0.85.

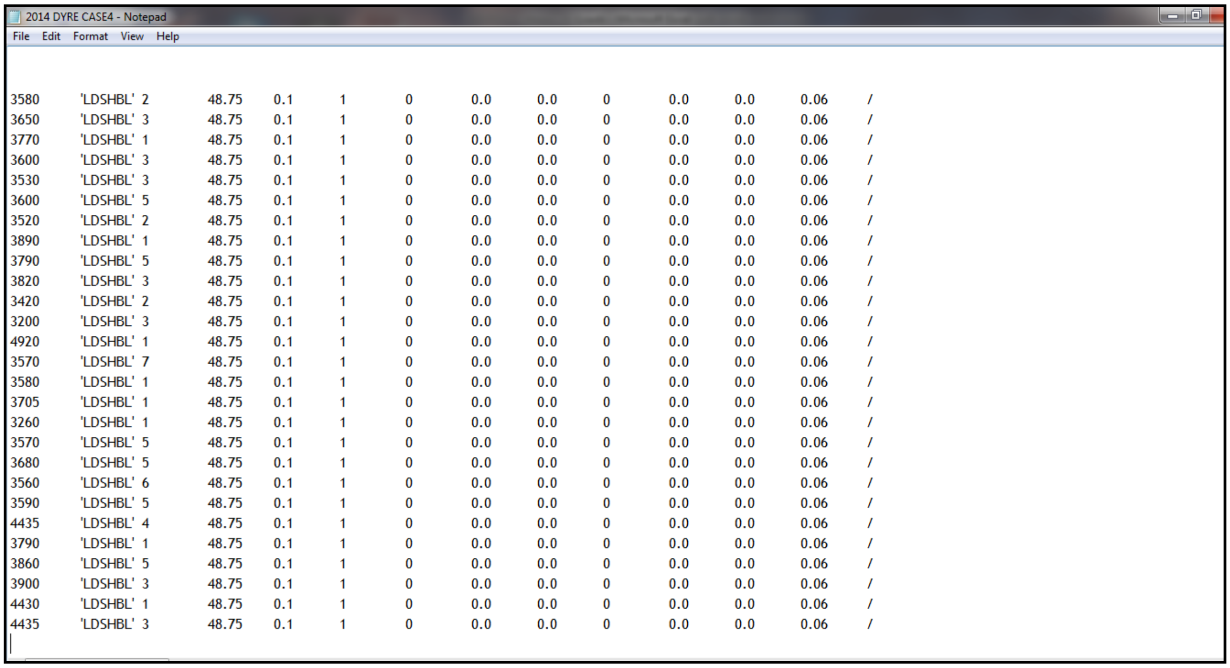

```
2014 DYRE CASE4 - Notepad
File  Edit  Format  View  Help

3580  'LDSHBL' 2  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3650  'LDSHBL' 3  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3770  'LDSHBL' 1  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3600  'LDSHBL' 3  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3530  'LDSHBL' 3  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3600  'LDSHBL' 5  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3520  'LDSHBL' 2  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3890  'LDSHBL' 1  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3790  'LDSHBL' 5  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3820  'LDSHBL' 3  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3420  'LDSHBL' 2  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3200  'LDSHBL' 3  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
4920  'LDSHBL' 1  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3570  'LDSHBL' 7  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3580  'LDSHBL' 1  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3705  'LDSHBL' 1  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3260  'LDSHBL' 1  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3570  'LDSHBL' 5  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3680  'LDSHBL' 5  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3560  'LDSHBL' 6  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3590  'LDSHBL' 5  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
4435  'LDSHBL' 4  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3790  'LDSHBL' 1  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3860  'LDSHBL' 5  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
3900  'LDSHBL' 3  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
4430  'LDSHBL' 1  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
4435  'LDSHBL' 3  48.75  0.1  1  0  0.0  0.0  0  0.0  0.0  0.06  /
```

Figure 4.6 Diary file written for case study-04

(viii). PSS/E simulation was done for each case study using diary files written above and modeled PSS/E file and frequency, voltage waveforms were obtained as below;

Voltage was monitored at several bus bars such as at Kolonnawa 33 kV bus bar, New Laxapana 132 kV bus bar, Galle 33 kV bus bar, Matara 33 kV bus bar and Kotugoda 33 kV bus bar.

<u>CASE STUDY-01</u>

i. <u>Frequency waveform:</u>

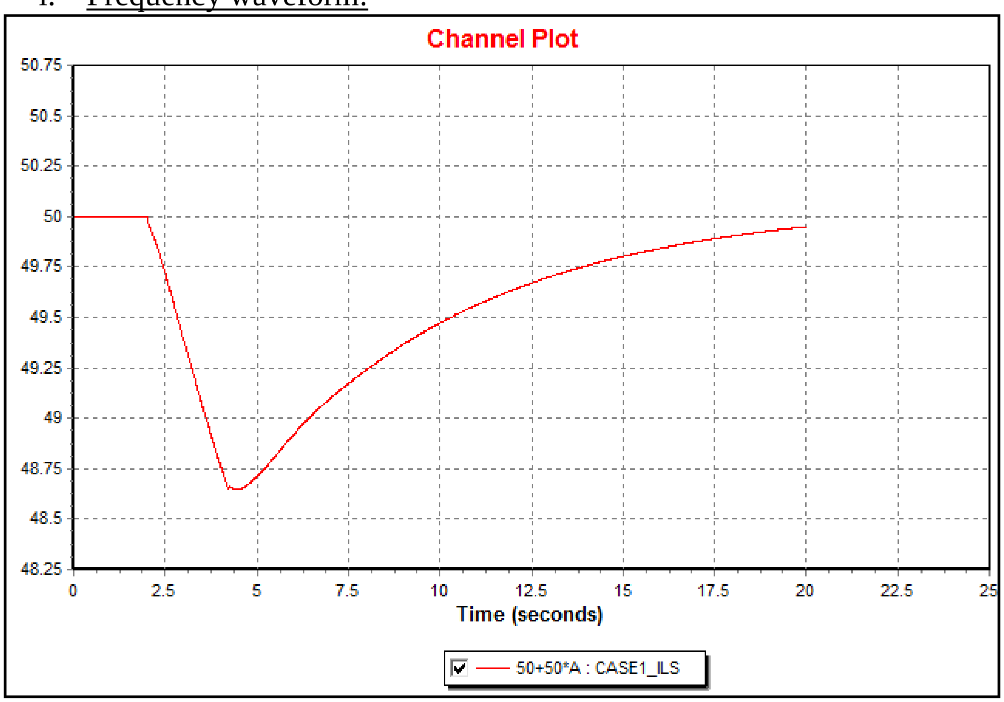


Figure 4.7 Frequency waveform obtained for case study-01

ii. Voltage waveform:

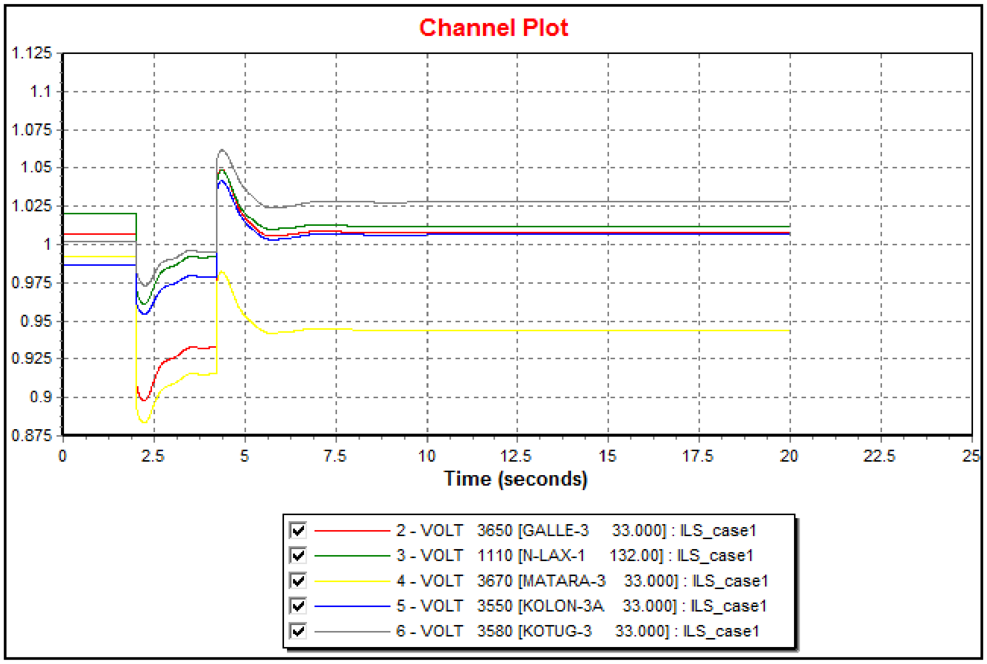


Figure 4.8 Voltage waveform obtained for case study-01

Highest decrease in voltage occurred at Matara 33 kV bus bar due to the disturbance. But voltage has improved in a better way after ILS application.

CASE STUDY-02

i. Frequency waveform:

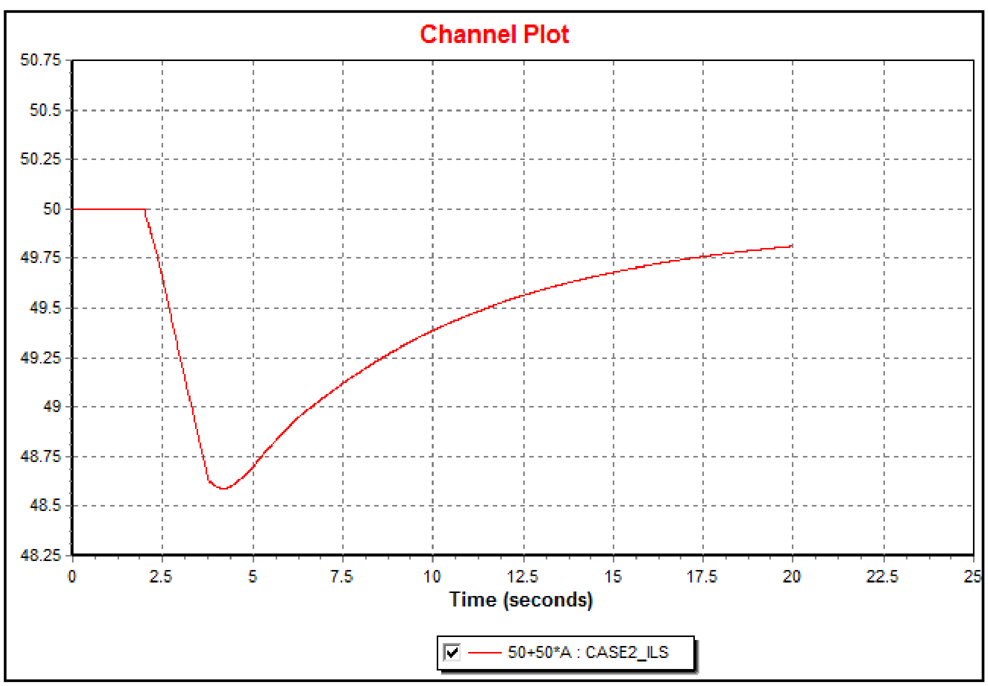


Figure 4.9 Frequency waveform obtained for case study-02

ii. Voltage waveform:

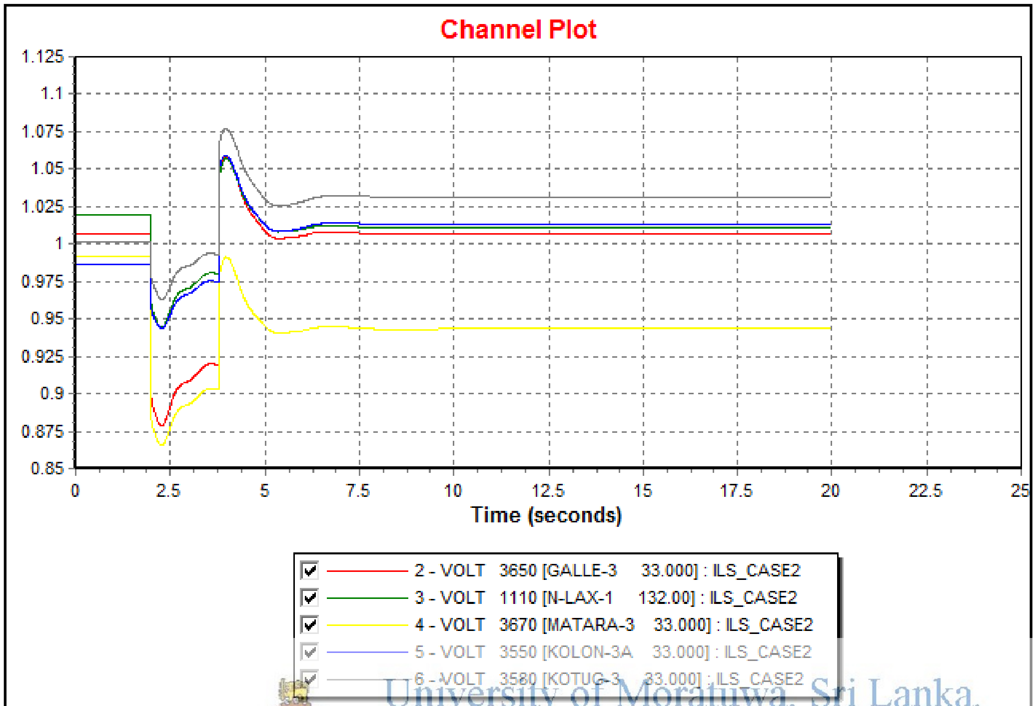


Figure 4.10 Voltage waveform obtained for case study-02

CASE STUDY-03

i. Frequency waveform:

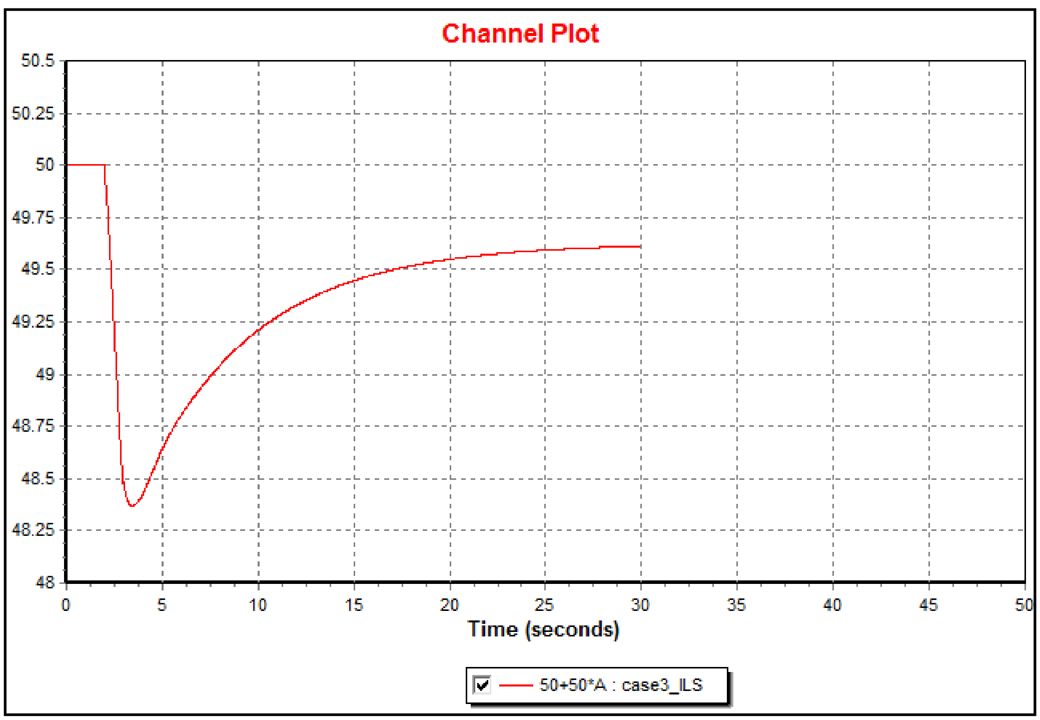


Figure 4.11 Frequency waveform obtained for case study-03

ii. Voltage waveform:

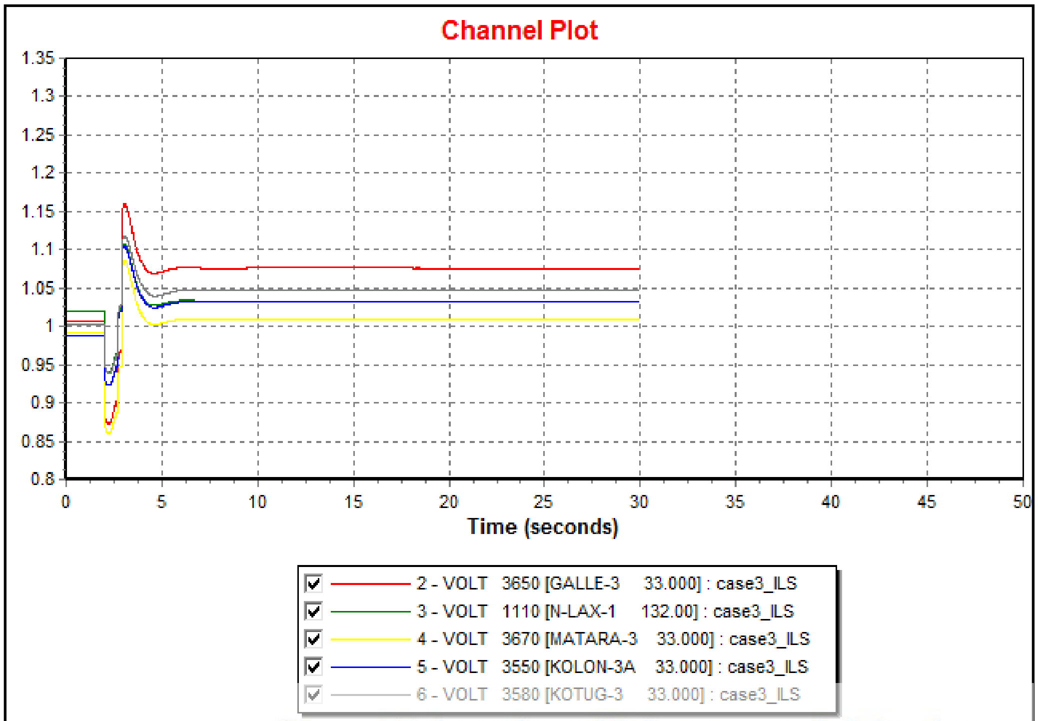


Figure 4.12 Voltage waveform obtained for case study-03

CASE STUDY-04

i. Frequency waveform:

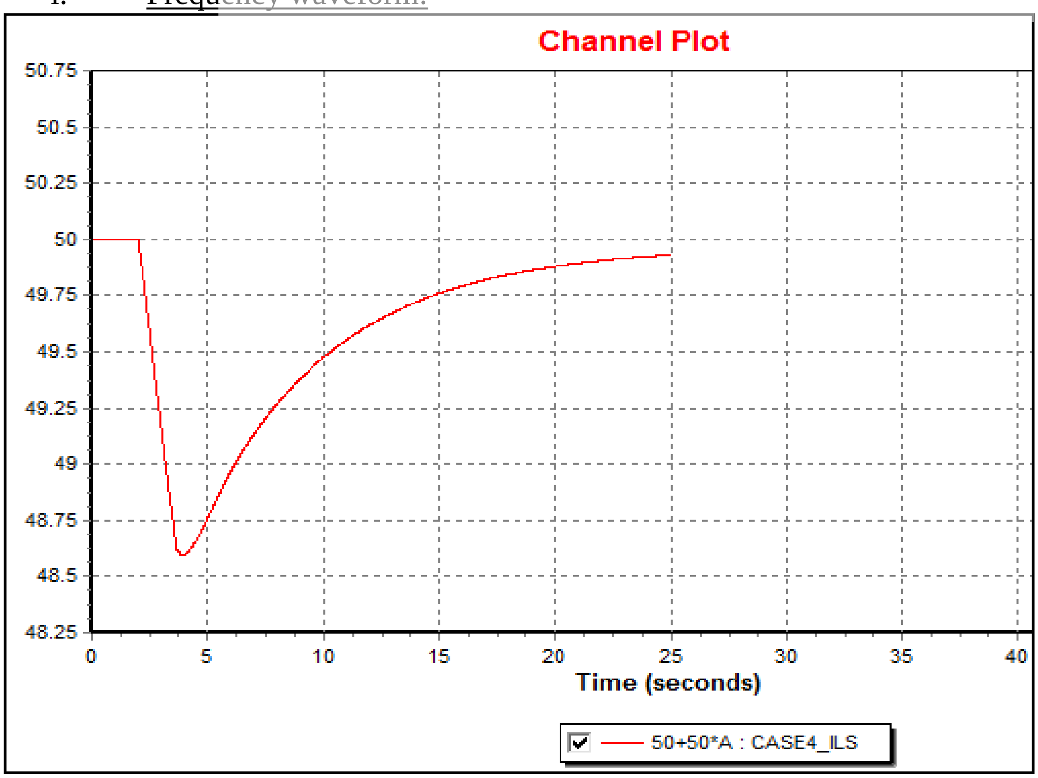


Figure 4.13 Frequency waveform obtained for case study-04

ii. Voltage waveform:

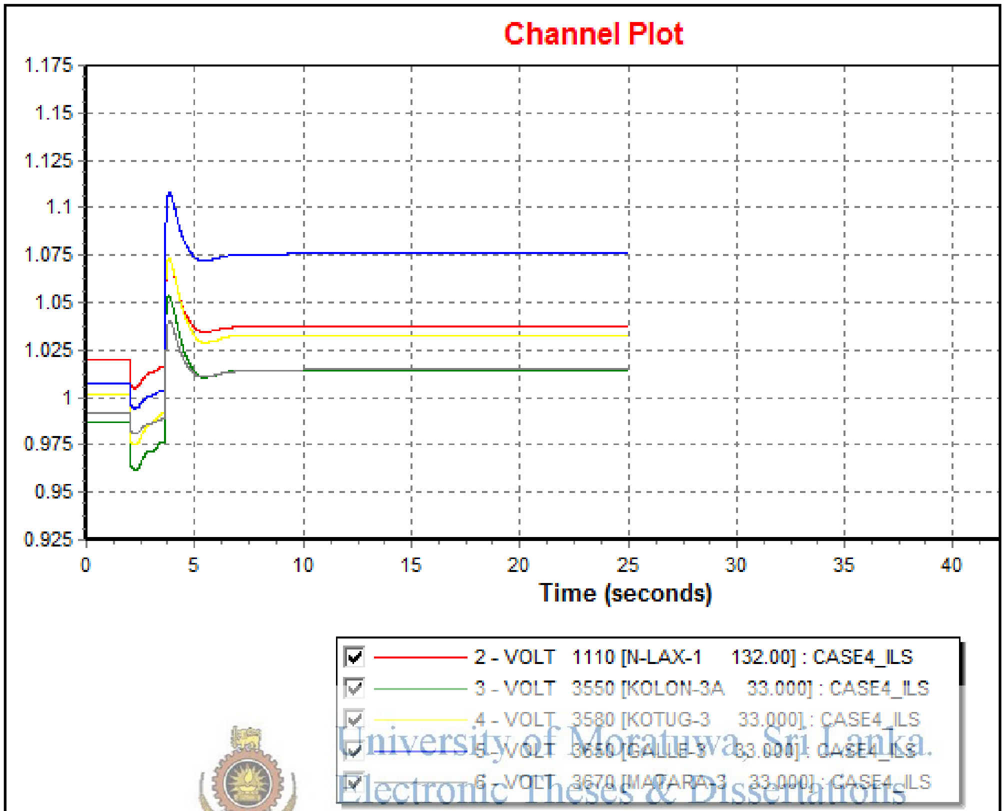


Figure 4.14 Voltage waveform obtained for case study-04

4.4.2 Implementation of UFLS in PSS/E software

For the same four case studies, existing load shedding mechanism- UFLS was applied using the PSS/E file and diary file already used by CEB. Both waveforms obtained under each case study were imported to a single plot area for a better comparison.

4.4.3 Comparison of UFLS and ILS through waveforms obtained in PSS/E software

Waveforms obtained through application of UFLS and ILS under each case study are displayed in the same plot for better comparison of the results.

4.4.3.1 CASE STUDY-01

(i). Frequency waveforms:

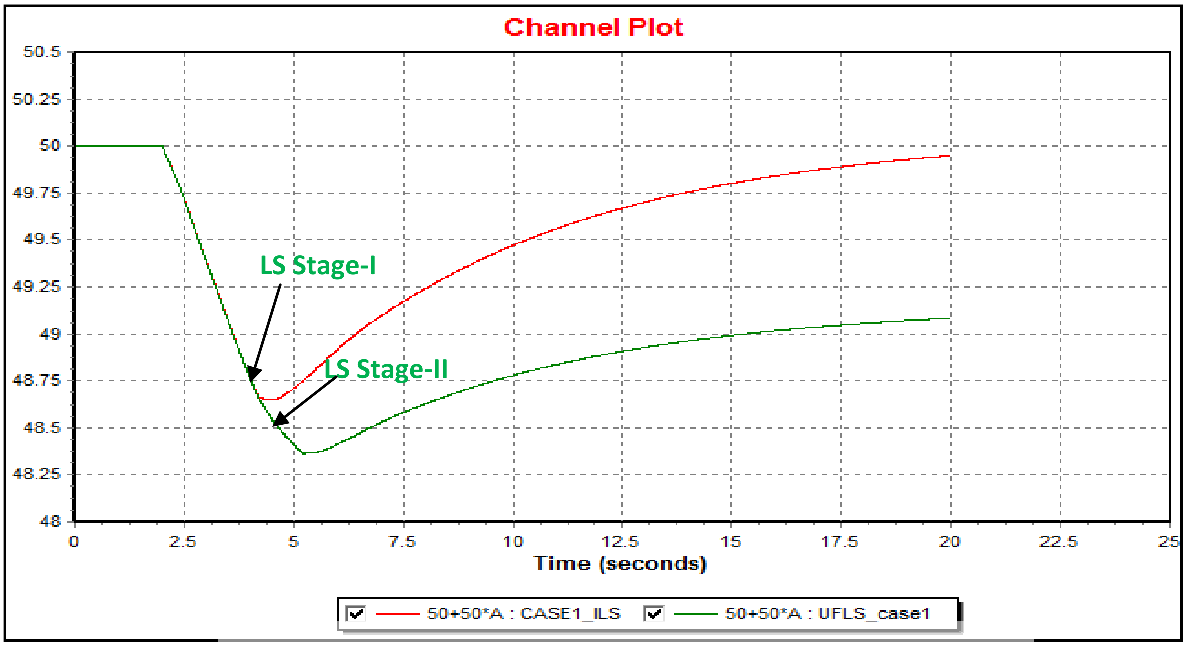


Figure 4.15 Frequency waveforms obtained through application of UFLS and ILS for case study-01

Under ILS, system frequency hasn't even dropped below 48.5 Hz and frequency has come back to 50 Hz within 20 seconds which is not the case under UFLS. However under UFLS as indicated above load shedding continued up to stage-II.

(ii). Voltage waveforms:

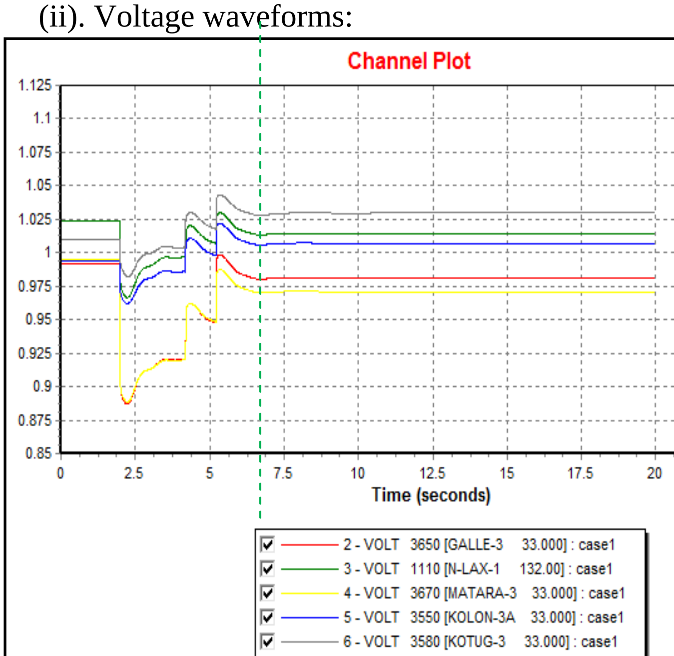


Figure 4.16 Voltage waveforms obtained under UFLS for CASE STUDY-01

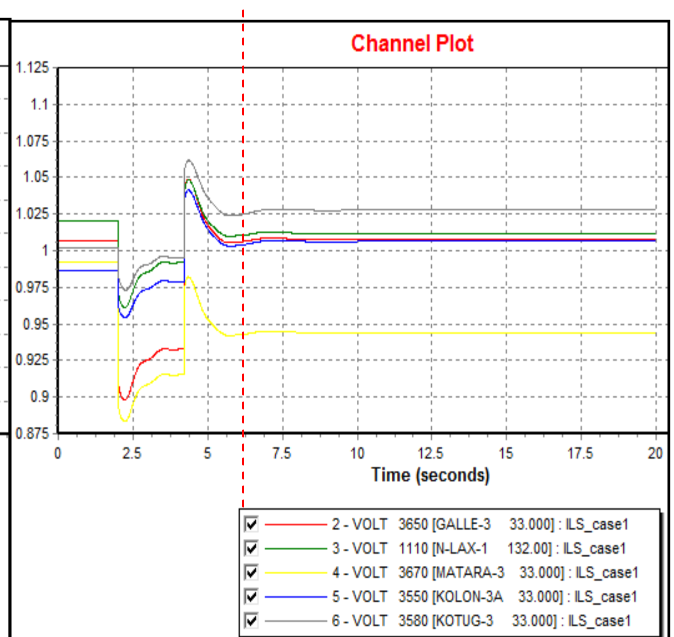


Figure 4.17 Voltage waveforms obtained under ILS for CASE STUDY-01

Various voltage ripples can be seen in the voltage waveforms obtained under UFLS. But under ILS, voltage has got stabilized within less than 7.5 seconds (within about 3 seconds after the disturbance) with less number of ripples.

4.4.3.2 CASE STUDY-02

(i). Frequency waveforms:

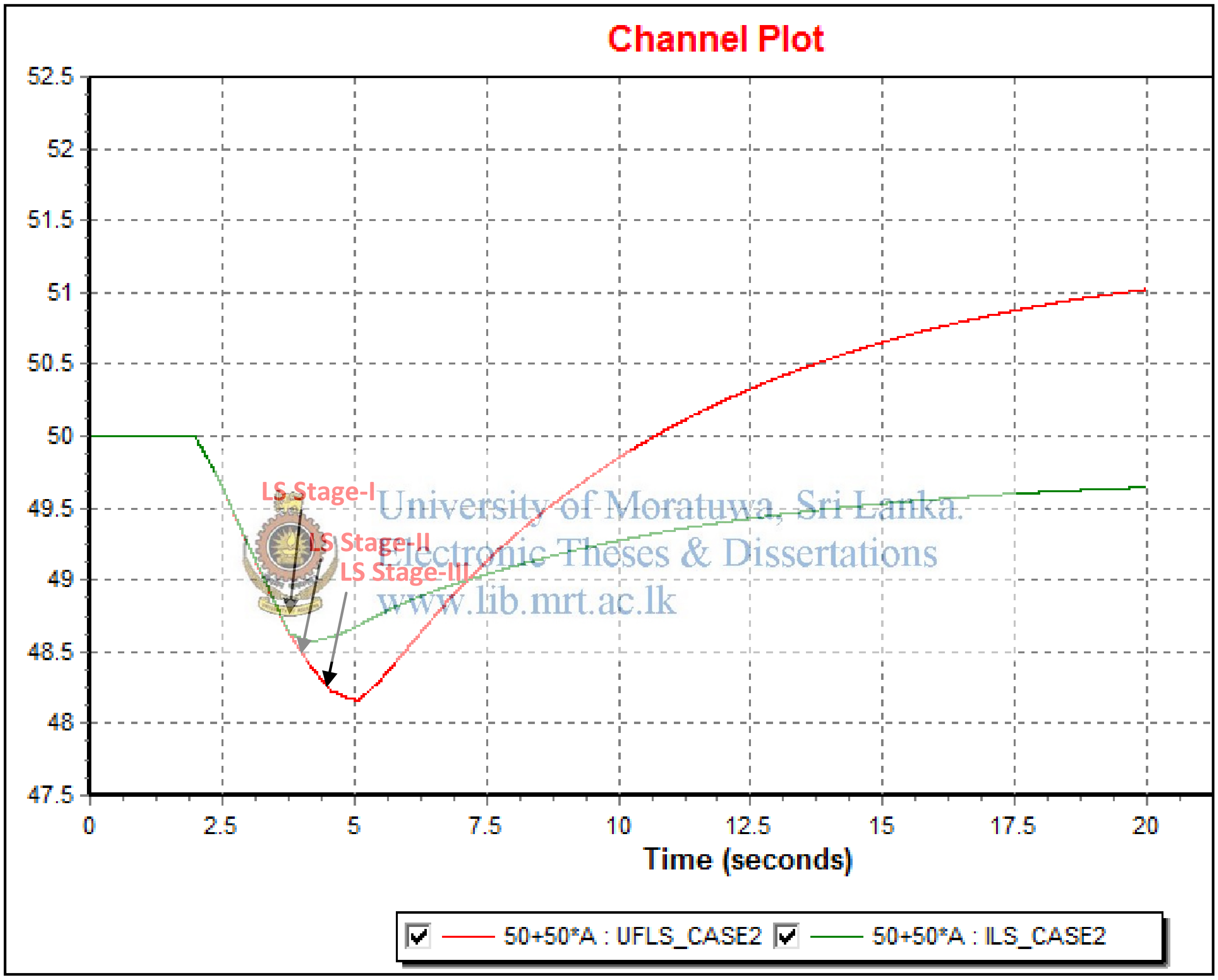
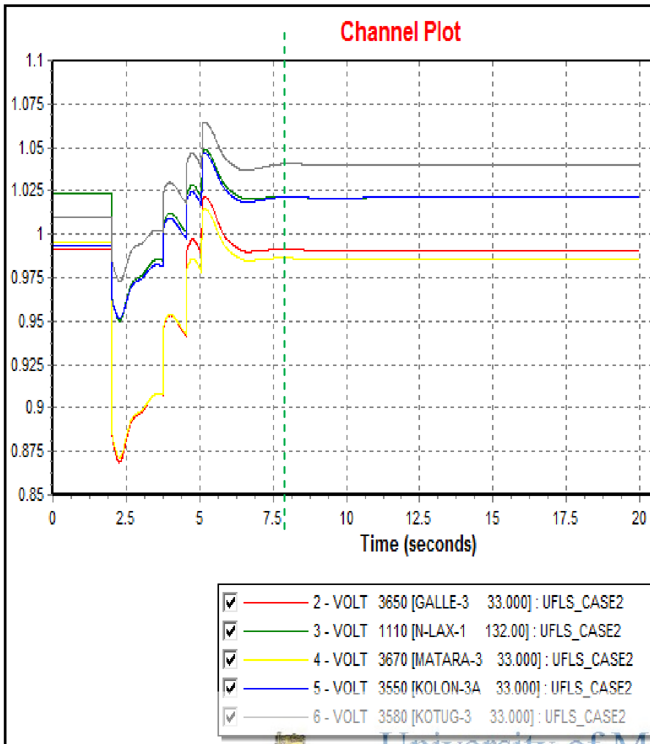


Figure 4.18 Frequency waveforms obtained through application of UFLS and ILS for case study-02

By comparing above frequency curves it can be said that under ILS, system frequency hasn't even dropped below 48.5 Hz and frequency has come close to 50 Hz within 20 seconds which is not the case under UFLS. However under UFLS as indicated above load shedding was occurred up to stage-III. Then only frequency has risen up even exceeding 50 Hz which may be due to shedding more load than required.

(ii). Voltage waveforms:



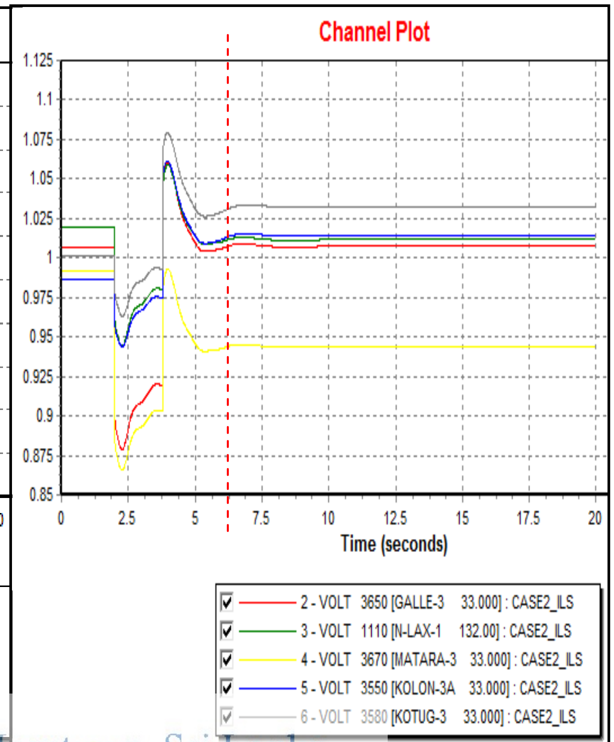


Figure 4.19 Voltage waveforms obtained under UFLS for CASE STUDY-02

Figure 4.20 Voltage waveforms obtained under ILS for CASE STUDY-02

Voltage overshoots can be seen in the voltage waveforms obtained under UFLS. But under ILS, voltage has got stabilized within less than 7.5 seconds (within about 3 seconds after the disturbance) with less number of ripples.

4.4.3.3 CASE STUDY-03

(i). Frequency waveforms:

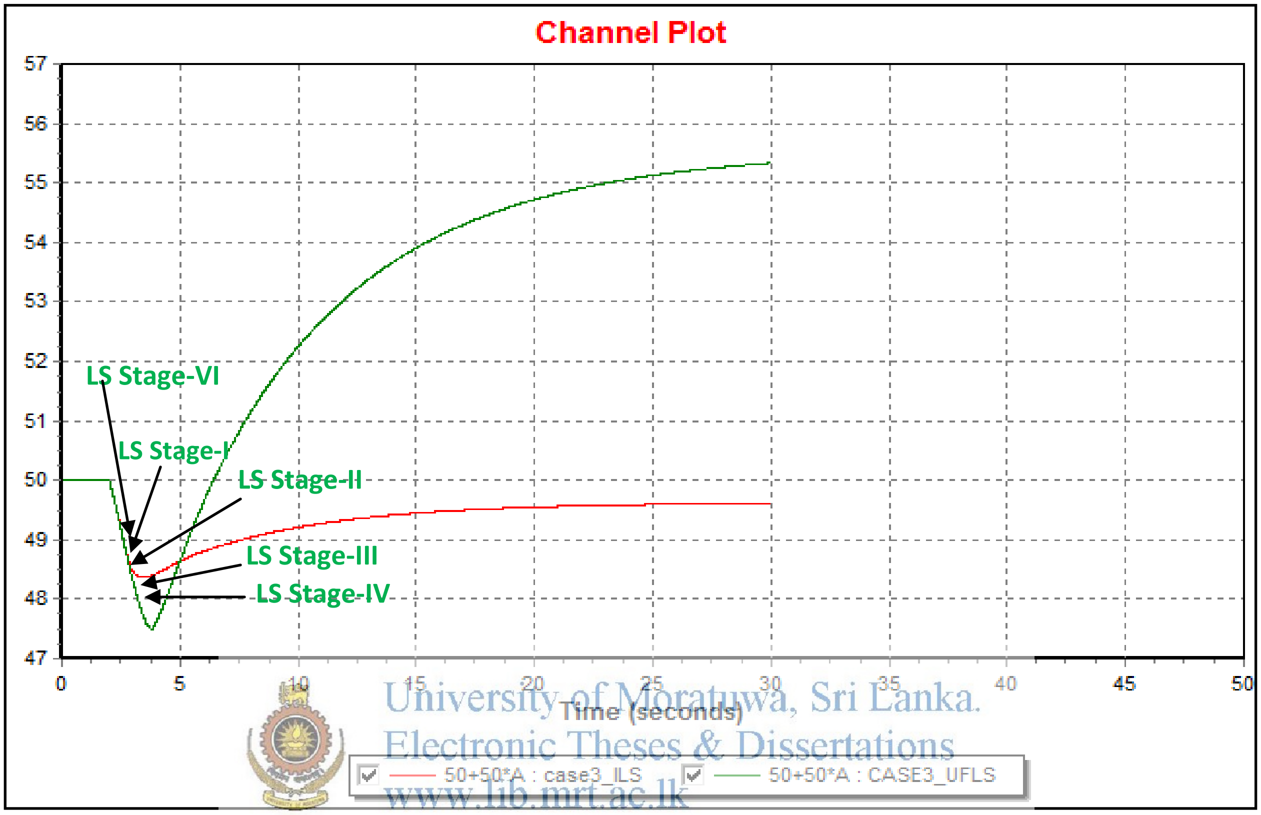
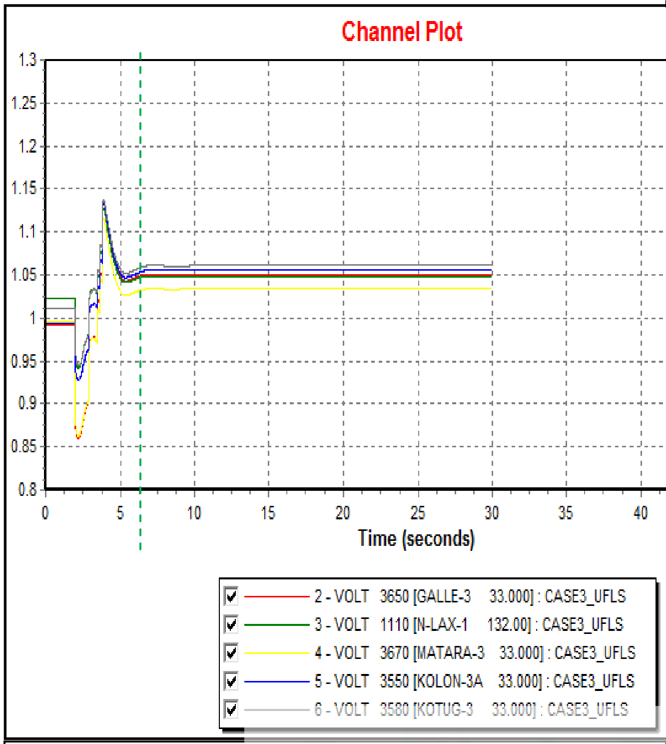


Figure 4.21 Frequency waveforms obtained through application of UFLS and ILS for case study-03

By comparing above frequency curves it can be said that under ILS, system frequency hasn't even dropped below 48 Hz and frequency has come close to 50 Hz within 30 seconds which is not the case under UFLS. However under UFLS as indicated above load shedding was occurred even up to stage-IV and VI. Then only frequency has risen up even exceeding 50 Hz which may be due to shedding more load than required.

(ii). Voltage waveforms:



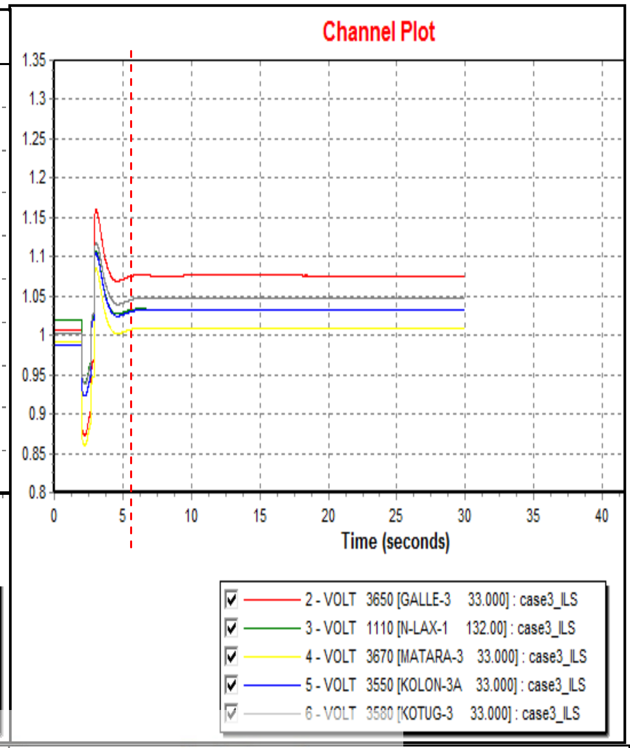


Figure 4.22 Voltage waveforms obtained under UFLS for CASE STUDY-03

Figure 4.23 Voltage waveforms obtained under ILS for CASE STUDY-03

Various voltage ripples can be seen in the voltage waveforms obtained under UFLS. But under ILS, voltage has got stabilized within lesser time period with less number of ripples.

Frequency waveforms and voltage waveforms obtained for case study-04 under application of UFLS & ILS are mentioned below;

4.4.3.3 CASE STUDY-04

(i). Frequency waveforms:

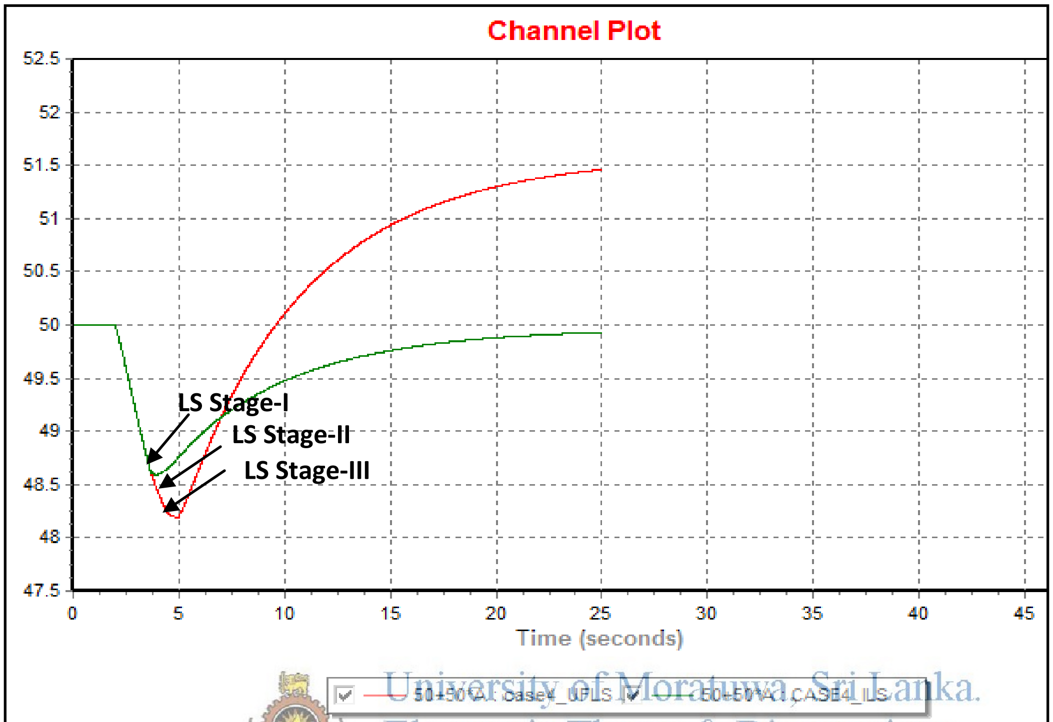


Figure 4.24 Frequency waveforms obtained through application of UFLS and ILS for case study-04

(ii). Voltage waveforms:

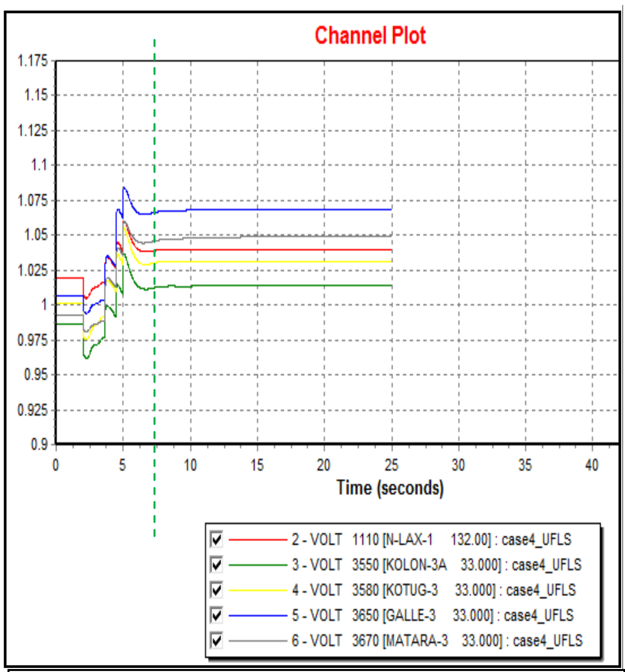


Figure 4.25 Voltage waveforms obtained under UFLS for CASE STUDY-04

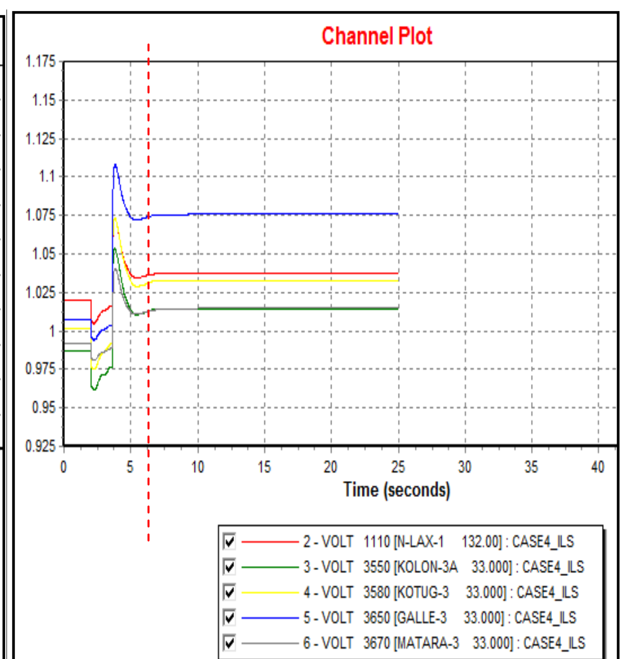


Figure 4.26 Voltage waveforms obtained under ILS for CASE STUDY-04

As per the above various voltage ripples can be seen in the voltage waveforms obtained under UFLS. But under ILS, voltage has got stabilized within lesser time period with less number of ripples.

4.4.4 Result Analysis on loads shed through ILS and UFLS

Result analysis was also done in following four areas;

(1) Difference between disconnected load and generation loss.
(2) Number of interrupted feeders.
(3) Uninterrupted load as a percentage (%) of total load connected at that time.
(4) Total MW of each disconnected load.

4.4.4.1 Difference between shed load and generation deficit

Initially total load shed under UFLS and ILS were calculated for three case studies as below;

CASE STUDY 1: Tripping of both machines in New Laxapana power station and both machines in Samanalawewa power station.

CASE STUDY 2: Tripping of both machines in New Laxapana power station, both machines in Samanalawewa power station and machines in Old Laxapana power station.

CASE STUDY 3: Tripping of both machines in New Laxapana power station, both machines in Samanalawewa power station and machine 1 in Lakvijaya power station.

Table 4.2 Total load shed under UFLS and ILS

CASE STUDY	GENERATION LOSS (MW)	TOTAL LOAD SHED (MW)	
		Under UFLS	Under ILS
01	236	206.22	248.45
02	290	370.73	302.15
03	511	689.16	518.13

Difference between shed load and generation loss are as tabulated below;

Table 4.3 Difference between shed load and generation loss under UFLS and ILS

CASE STUDY	DIFFERENCE BETWEEN DISCONNECTED LOAD AND GENERATION LOSS (MW)	
	Under UFLS	Under ILS
01	-29.78	+12.45
02	+80.73	+12.15
03	+178.16	+7.13

Through analyzing the above results, it is clear that insufficient load shedding has occurred under UFLS for case study-01. Further excessive load shedding has occurred for case study-02 and 03 under UFLS. However under ILS, excessive load amount shed is not varying much case by case as system is already aware of each load demand which can be shed.

4.4.4.2 Number of interrupted feeders

Number of interrupted feeders under each case study was counted for UFLS and ILS.

Table 4.4 Number of interrupted feeders under UFLS and ILS

CASE STUDY	NUMBER OF INTERRUPTED FEEDERS	
	Under UFLS	Under ILS
01	24	22
02	37	28
03	71	57

Even though insufficient load shedding was occurred under case study-01, number of feeders that were interrupted is higher under UFLS. As excessive load shedding was occurred under case study-02 and 03 under UFLS, number of feeders that were interrupted is higher. Under case study-03, fourteen feeders were shed additionally when compared to ILS. It is clear that some feeders were interrupted unnecessarily through UFLS.

4.4.4.3 Uninterrupted load as a percentage (%) of total load connected at that time

As a better measure I also considered uninterrupted load as a percentage of total load connected at that time under both mechanisms- UFLS and ILS.

Table 4.5 Uninterrupted load under UFLS and ILS as a percentage (%) of total load

CASE STUDY	UNINTERRUPTED LOAD AS A PERCENTAGE (%) OF TOTAL LOAD CONNECTED	
	Under UFLS	Under ILS
01	86.87%	84.19%
02	76.4%	80.77%
03	56.14%	67.02%

As insufficient load shedding has occurred under case study-01, uninterrupted load in percentagewise (with reference to total load connected) is slightly higher. Considering poor reaction by UFLS under case study-01 this cannot be considered as giving a good result.
However under other two cases, uninterrupted load in percentage wise is higher through ILS.

4.4.4.4 Total MW of each disconnected load

Total MW of each disconnected load is graphically represented below for each case study;

(i) <u>CASE STUDY-01</u>

(a). Application of UFLS:

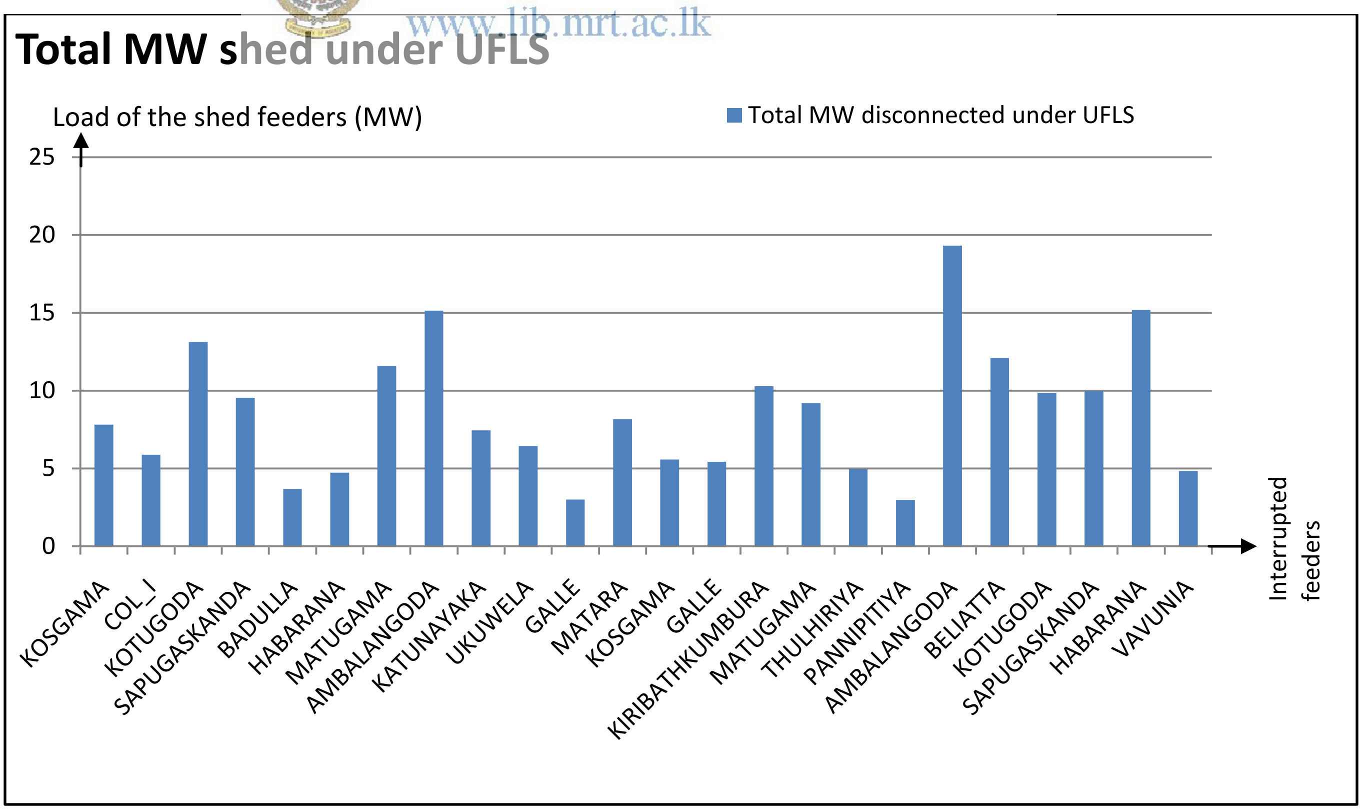


Figure 4.27 Total MW shed under UFLS for CASE STUDY-01

According to the above graph it can be observed that feeders in GSS such as Badulla, Galle and Pannipitiya were unnecessarily interrupted which were not contributing much for frequency improvement. Further MW values of loads in different feeders fall within a wide range.

(b). Application of ILS:

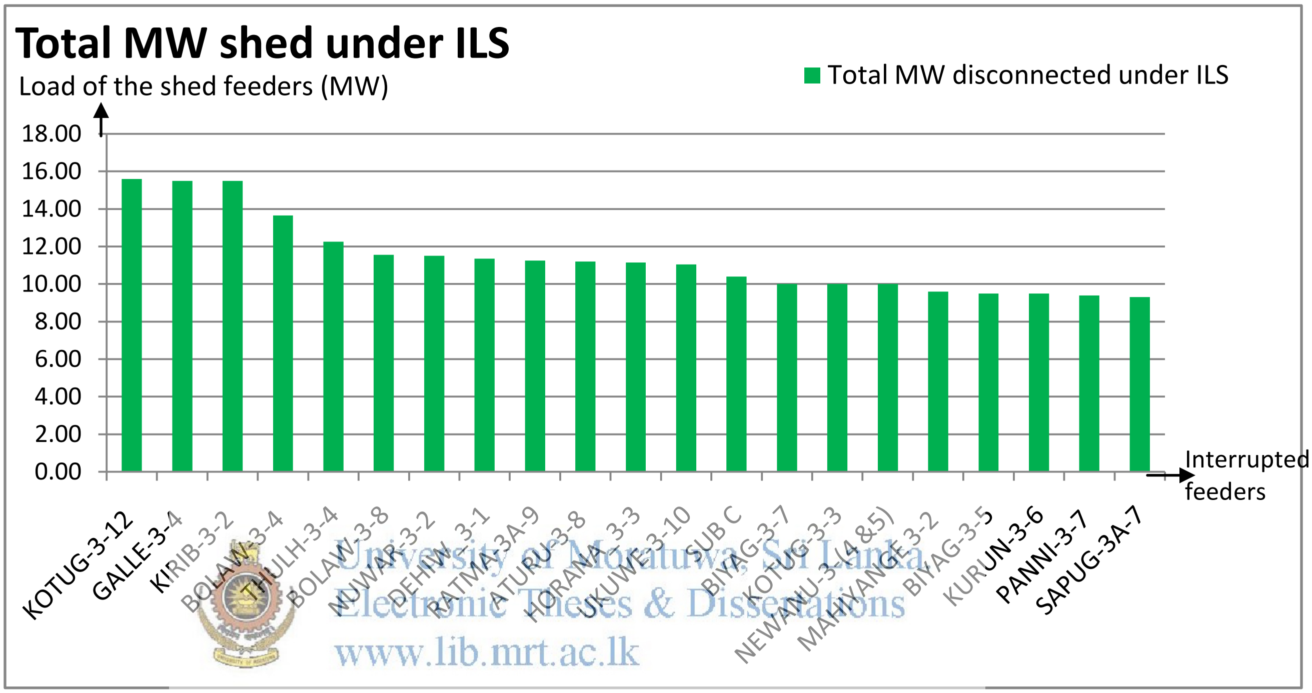


Figure 4.28 Total MW shed under ILS for CASE STUDY-01

According to the above graph, it is observable that MW values of loads shed under ILS are falling in the same region (8 MW~16 MW).

(ii) CASE STUDY-02

(a). Application of UFLS:

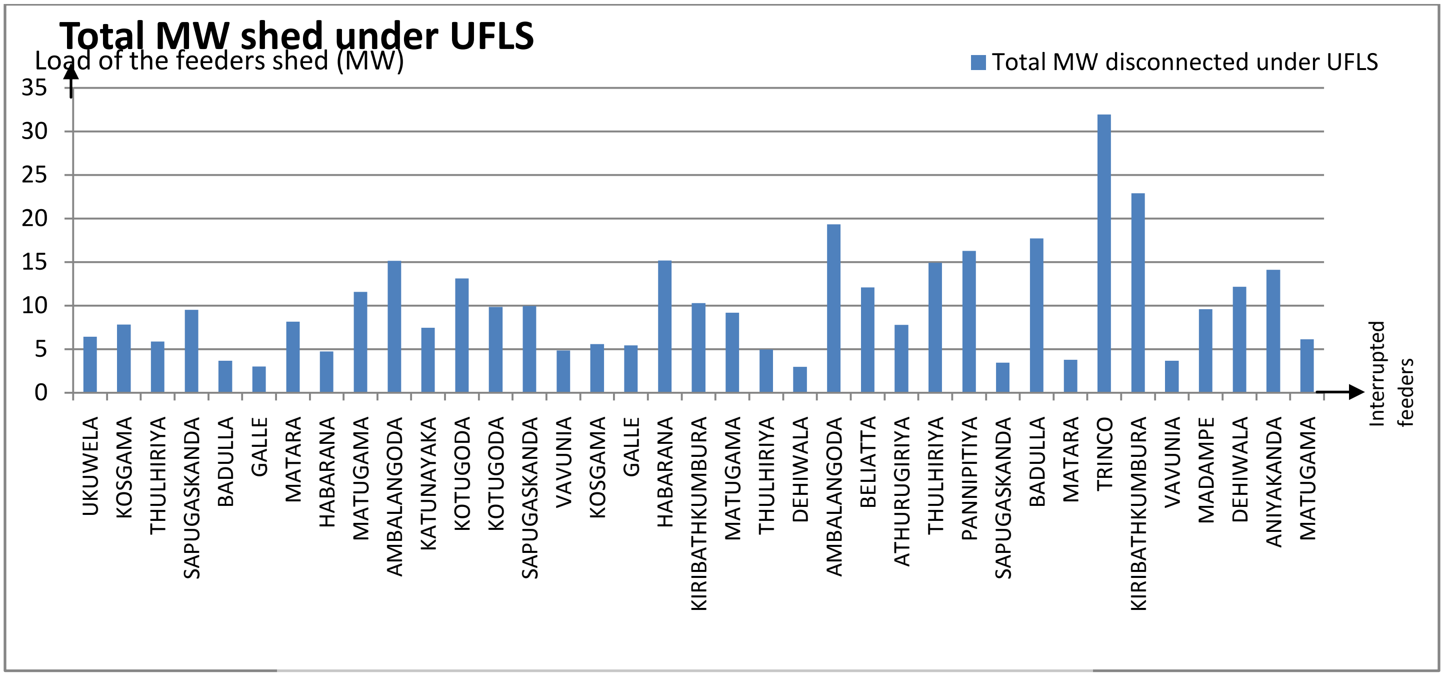


Figure 4.29 Total MW shed under UFLS for CASE STUDY-02

(b). Application of ILS:

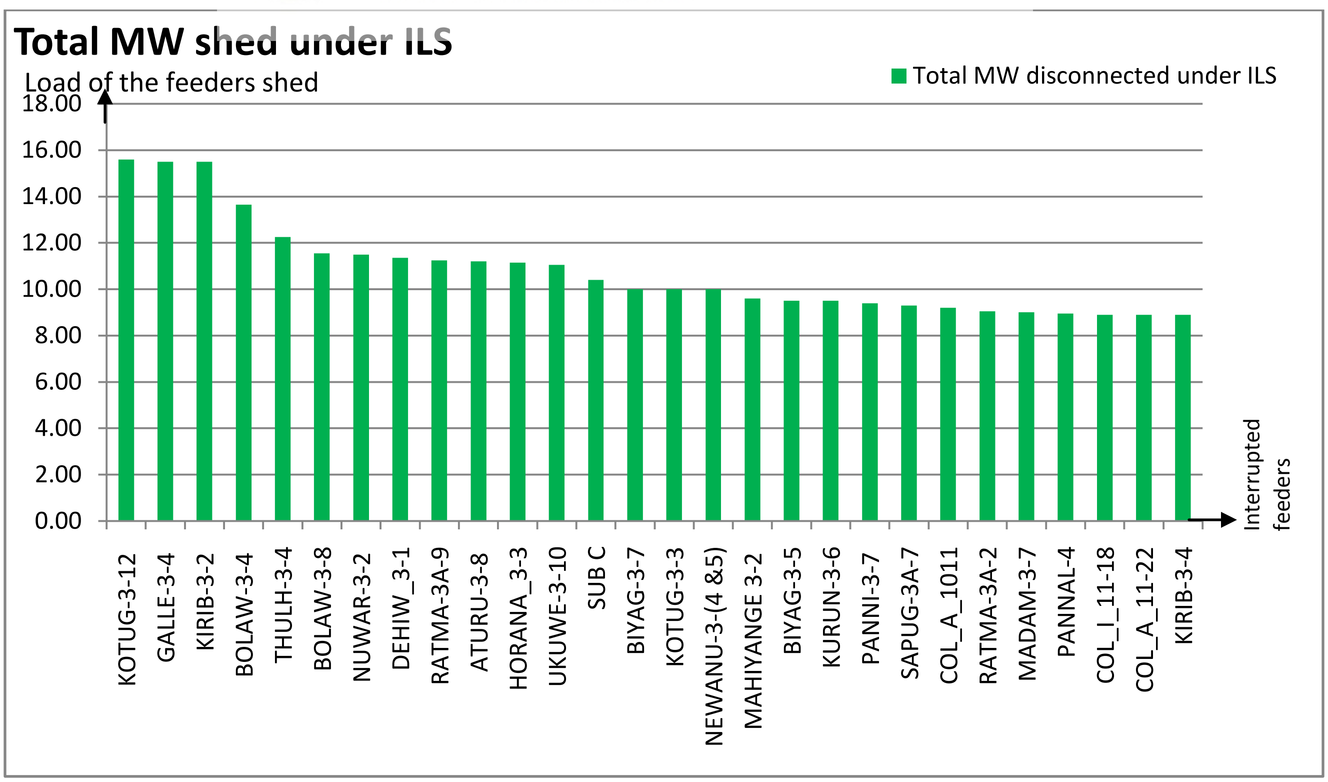


Figure 4.30 Total MW shed under ILS for CASE STUDY-02

According to the above graph, it is observable that MW values of loads disconnected under ILS are falling in the same region (8 MW~16 MW).

(iii) <u>CASE STUDY-03</u>

(a). Application of UFLS:

Graphical representation of total MW values of loads shed under UFLS is illustrated below;

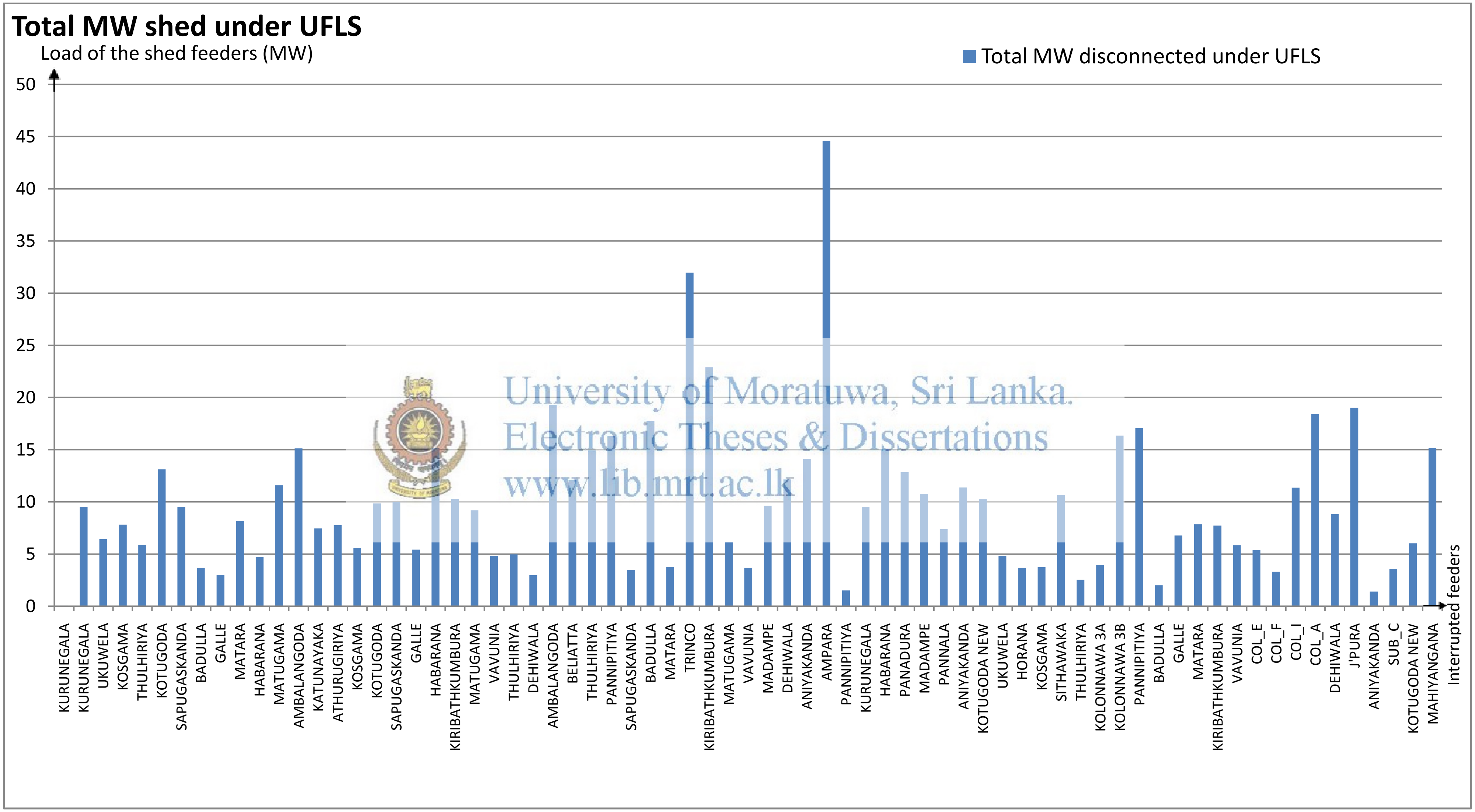


Figure 4.31 Total MW shed under UFLS for CASE STUDY-03

According to the above graph it can be observed that feeders in GSS like Badulla, Galle, Dehiwala, Sapugaskanda, Matara, Vavunia, Ukuwela, Horana, Kosgama, Thulhiriya, Kolonnawa, Badulla, Sub-F and Aniyakanda were unnecessarily interrupted which were not contributing much for frequency improvement. Further MW values of loads in different feeders fall within a wide range.

Reactive power components of interrupted feeders with less real power component were also considered;

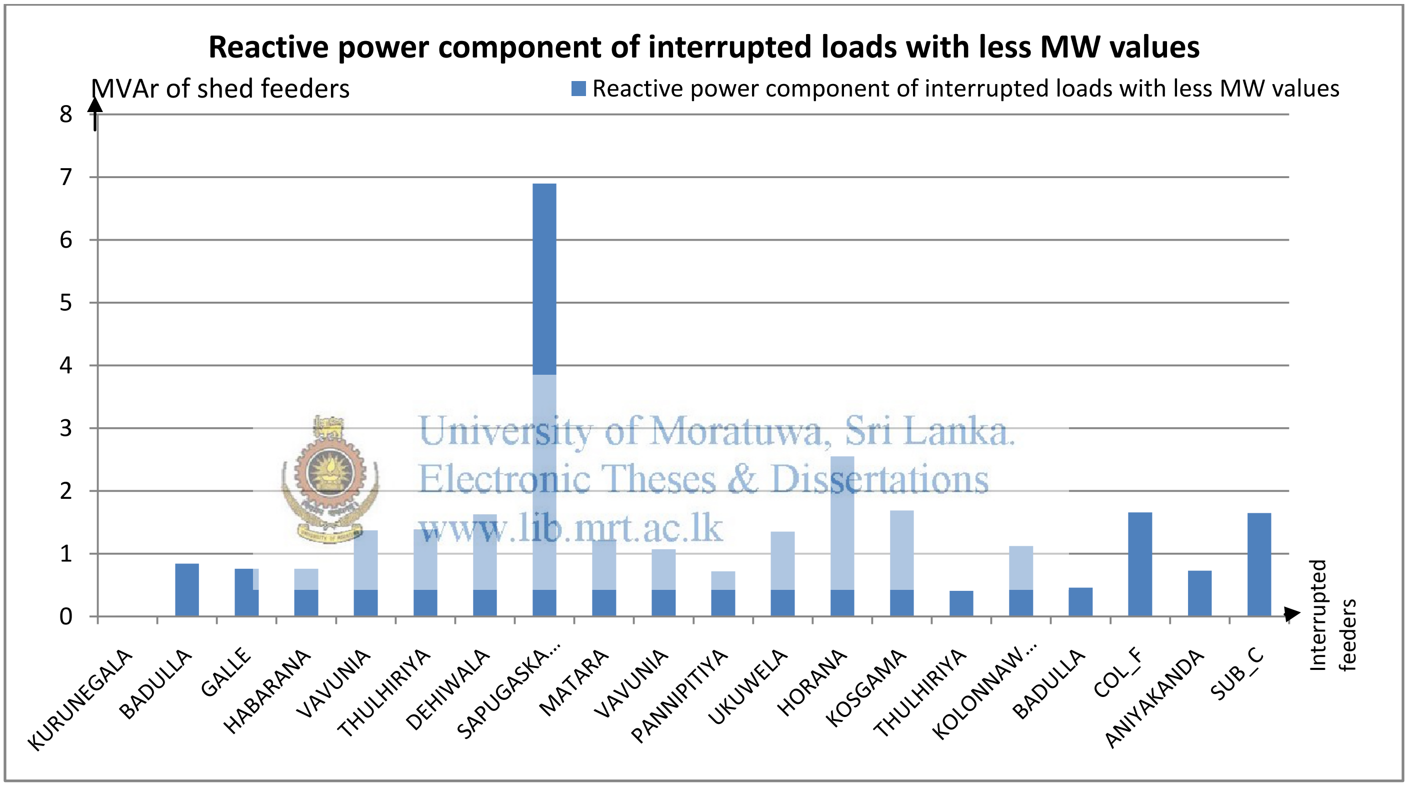


Figure 4.32 Reactive power components of interrupted feeders with less MW values under UFLS for CASE STUDY-03

As per the above graph it is clear that these loads were not contributing much for the total reactive power also. Most of the feeders were having reactive power component even less than 2MVAr. Only feeder in Sapugaskanda GSS was having larger reactive power component compared to the other feeders. These feeders have been unnecessarily interrupted due to unavailability of actual real power and reactive power consumption of each feeder.

(b). Application of ILS:

As in above two cases it is observable that for case study-03 also MW values of loads shed under ILS are falling in the same region (6 MW~16 MW).

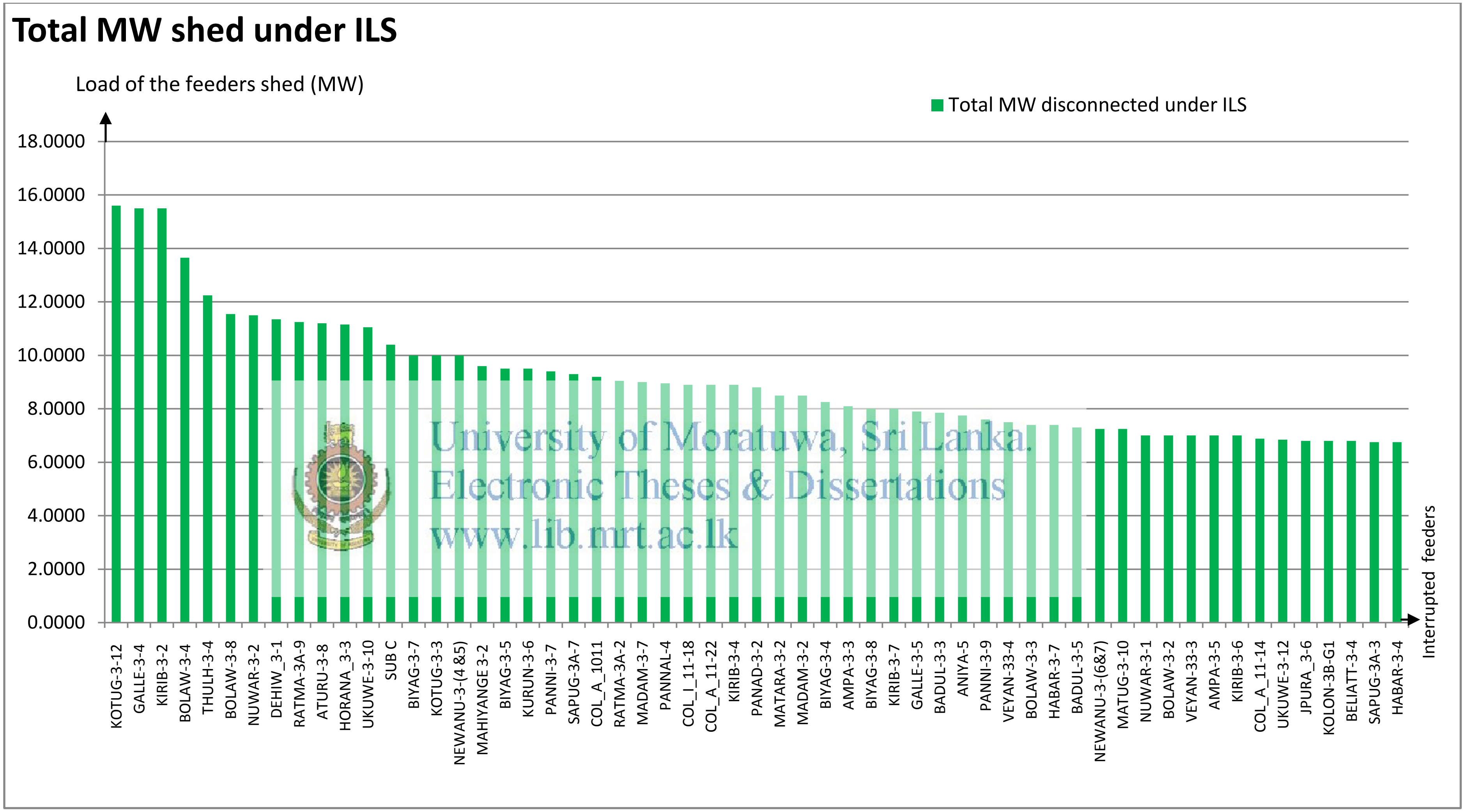


Figure 4.33 Total MW shed under ILS for CASE STUDY-03

➢ Reactive power components of interrupted feeders under ILS mechanism for case study-03 are graphically represented below;

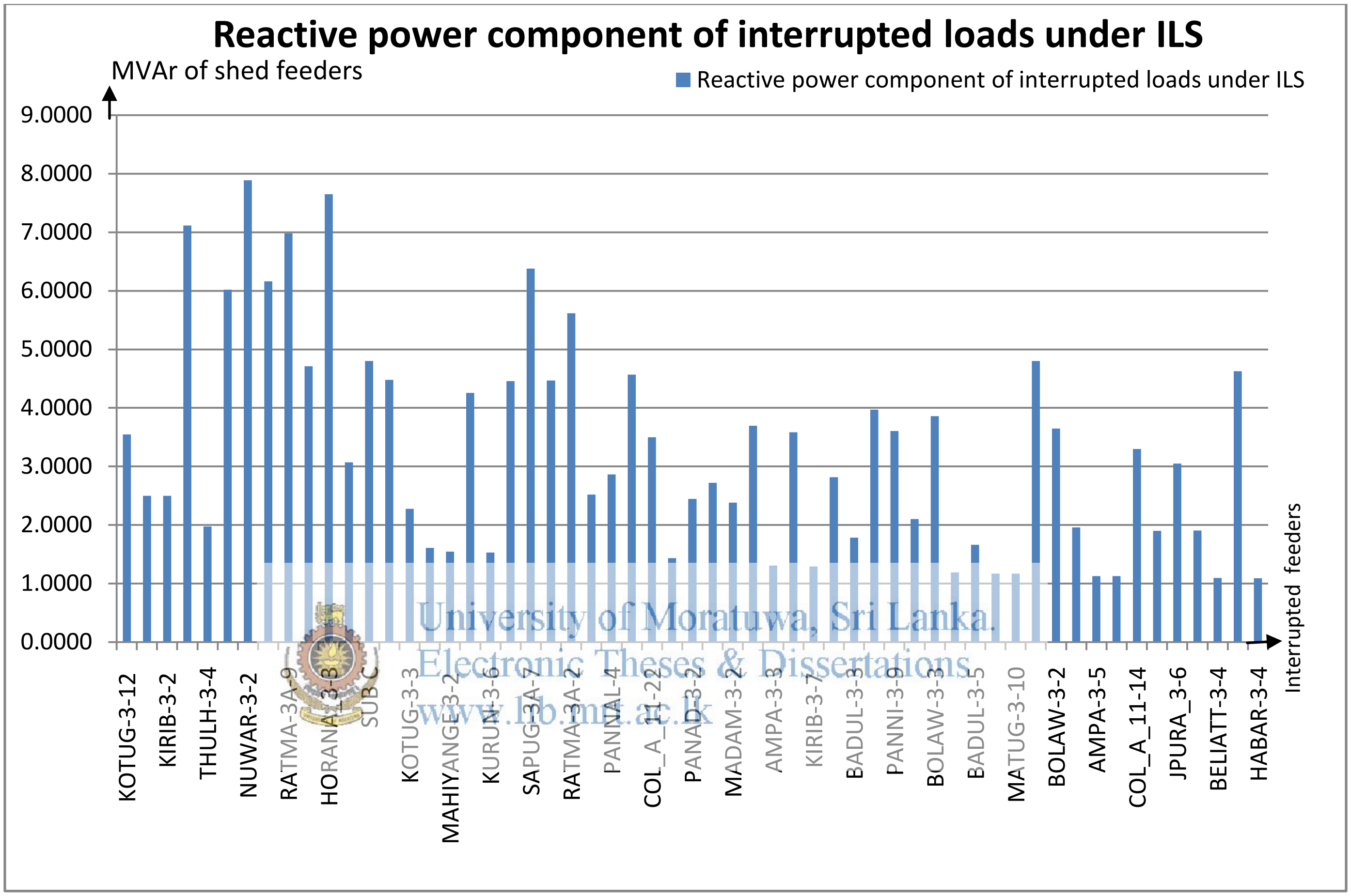


Figure 4.34 Reactive power components of interrupted feeders under ILS for CASE STUDY-03

According to the above graph it is noticeable that most of the interrupted feeders were having high reactive power component which might be affecting voltage stability.

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

Load shedding serves as the ultimate guard that protects the power system from a contingency [4]. It is a logical thought by some ways and means the load shedding has to be minimized [1].
Under Frequency Load Shedding (UFLS) mechanism used by CEB has common drawbacks such as lack of detailed system data before disturbance and after disturbance. Due to this unawareness, incorrect and mostly excessive load shedding occur.
In response to a dip or rate-of-change in frequency, frequency relays operate a set of fixed circuit breakers, independent of their actual operating load [4]. Some feeders might not be energized at the time load shedding is required. As UFLS scheme is totally independent of the system dynamics, total loss of the system is also a possibility.
This dissertation discussed about designing of Intelligent Load Shedding (ILS) mechanism which will shed optimal load after a disturbance considering demand at each feeder. After analyzing historical failures occurred in the system, weaknesses of the existing load shedding scheme-UFLS were identified. A model has been built in MATLAB software with GUI to analyze the operation of ILS at different failures.

In order to conduct a better comparison, both load shedding mechanisms UFLS and ILS were applied in PSS/E software which is the software tool used by CEB for power system studies. Result analysis was done comparing results obtained under three case studies through application of UFLS and ILS.
Through application of ILS to CEB network, following major benefits can be achieved;

(1). Probability for a total failure is reduced.

(2). Number of feeders getting interrupted is reduced.

(3). Quantity of real power curtailed is reduced.

(4). Voltage profile during contingency period is improved.

(5). Contribution to SAIDI and SAIFI reliability indicators is reduced.

From above mentioned benefits, benefits mentioned under (4) and (5) require further studies.

Apart from that each mentioned benefit is proved through results obtained in PSS/E simulation.

According to the following equations for the calculation of SAIDI and SAIFI reliability indicators, it can be proven that these indicators are getting improved through application of ILS. This is mainly due to number of feeders getting interrupted is reduced under ILS mechanism.

$$SAIDI = \frac{Sum\ of\ all\ customer\ interruption\ durations}{Total\ number\ of\ customers\ served}$$

$$SAIFI = \frac{Total\ number\ of\ customer\ interruptions}{Total\ number\ of\ customers\ served}$$

5.2 RECOMMENDATIONS

SCADA (Supervisory Control and Data Acquisition) is to be implemented in CEB system by the end of the year-2016. After completion of SCADA implementation, communication is possible within control centre, grid substations and power stations. Controlling of remote equipment, remote data monitoring and access, alarm handling, data examination and also taking actions depending on online status of the system are some possible activities in a SCADA facilitated-system.

It is recommended to apply 'intelligent load shedding' (ILS) mechanism after successful implementation of SCADA in CEB network. A separate server has to be maintained in Control Centre named 'ILS real-time server' which downloads the time-variant load shedding tables to each PLC located near grid sub stations where loads can be shed. A default priority load shedding table is also to be written to the PLC to use in the event of communication failure between the ILS server and PLC. Frequency relays are also required to be remained in the system.

Data collection servers are also required to be installed in the sub stations and power stations to update ILS server about demand and generation continuously. For accurate data acquisition Ethernet- equipped smart meters or intelligent electronic devices (IEDs) are required.

SCADA system which is to be implemented in CEB network follows STM-1 (Synchronous Transport Module level-1). The STM-1 is the SDH ITU-T fiber optic network transmission standard. It has a bit rate of 155.52 Mbit/sec [9].

With data transfer rate of 155 Mbit/sec, 19,375 kB of data can be transferred within 1 second. Within 100 milliseconds 1937.5 kB of data can be transferred which is almost more than 1 MB.

It is clear that optimal load shedding tables can be updated by ILS server within 100 milliseconds under operation of this data transmission module.

As all the calculations are done within the ILS server, if any modification is required to be done such as making feeder which is in low priority list as 'high priority' and removing from load shedding list, it can also be done in ILS server. ILS server should be properly maintained and a back-up server is also required to be installed to use in case of an emergency.

To overcome the weaknesses found in existing load shedding mechanism, it is recommended to apply 'intelligent load shedding' mechanism after proper implementation of SCADA and relevant servers in the CEB network.

REFERENCE LIST

[1] Rekha A., Rathina Kumar, M. Ashok Kumar N., Vanitha D., "An intelligent load shedding to improve power system congestion", International Journal of Current Research, Vol 5, Issue, 04, April, 2013, pp.973-977.

[2] Ghazanfar Shahgholian, Mahdi Ebrahimi Salary, "Effect of load shedding strategy on interconnected power systems stability when a blackout occurs", International Journal of Computer and Electrical Engineering, Vol.4, No. 2, April 2012.

[3] Farrokh Shokooh, J J Dai, Shervin Shokooh, Jacques Tastet, Hugo Castro, Tanuj Khandelwal, Gary Donner, "An intelligent load shedding (ILS) system application in a large industrial facility", Industry Applications Conference, Fortieth IAS Annual Meeting, Irvine, California, USA, 2005, pp. 417-425.

[4] Shervin Shokooh, Tanuj Khandelwal, Farrokh Shokooh, Jacques Tastet, JJ Dai, "Intelligent load shedding need for a fast and optimal solution", IEEE PCIC Europe 2005.

[5] Rasha M. El Azab and P. Lataire, E.H. Shehab Eldin, M. M. Sallam, "Simulation programs for load shedding studies: Experimental Results", *International Journal of Simulation, Systems, Science and Technology (IJSSST)*, Vol. 11, No. 6, December 2011.

[6] Urban Rudez, Rafael Mihalic, "Adaptive UFLS schemes in modern power systems – conceptual and simulation proved comparison", *International Journal of Energy Engineering*, May 2012, 2(3):100-107.

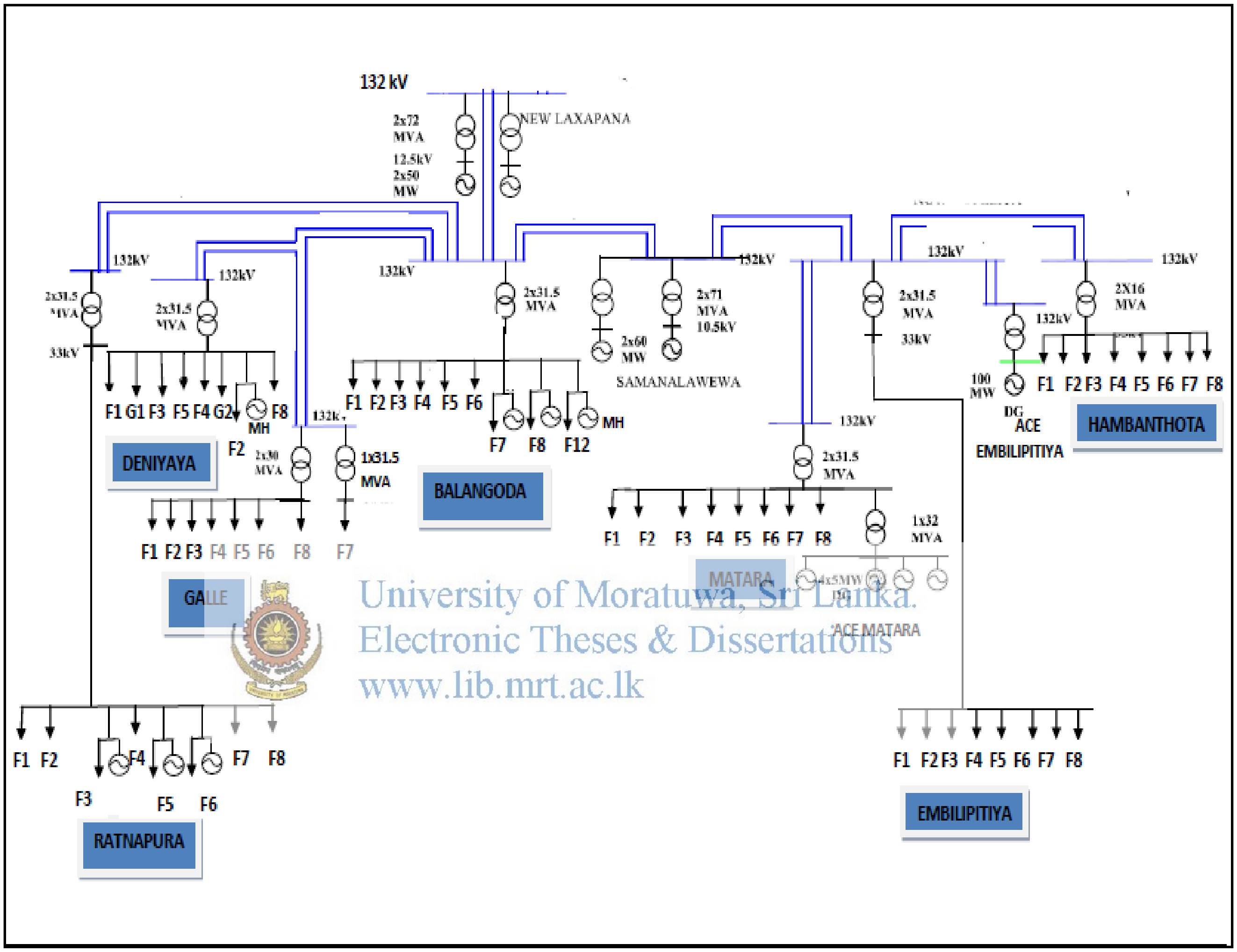
[7] Ceylon Electricity Board, "Coal fired thermal development project west coast – CEB transmission connection power system analysis studies", Rep., 2009.

[8] Global Energy Consulting Engineers and PA Government Services Inc., "India-Sri Lanka submarine cable interconnection project, interconnection reliability and stability study", PA Consulting Group, Haryana, India, Rep. Task order 1.3, October 12, 2009.

[9] Wikipedia the Free Encyclopedia, STM-1, 13th January 2015.

APPENDICES

Appendix-A: Selected reduced network from CEB system.



Appendix-B: 'loadData.m' file created in MATLAB software to read demand in each GSS from excel file.

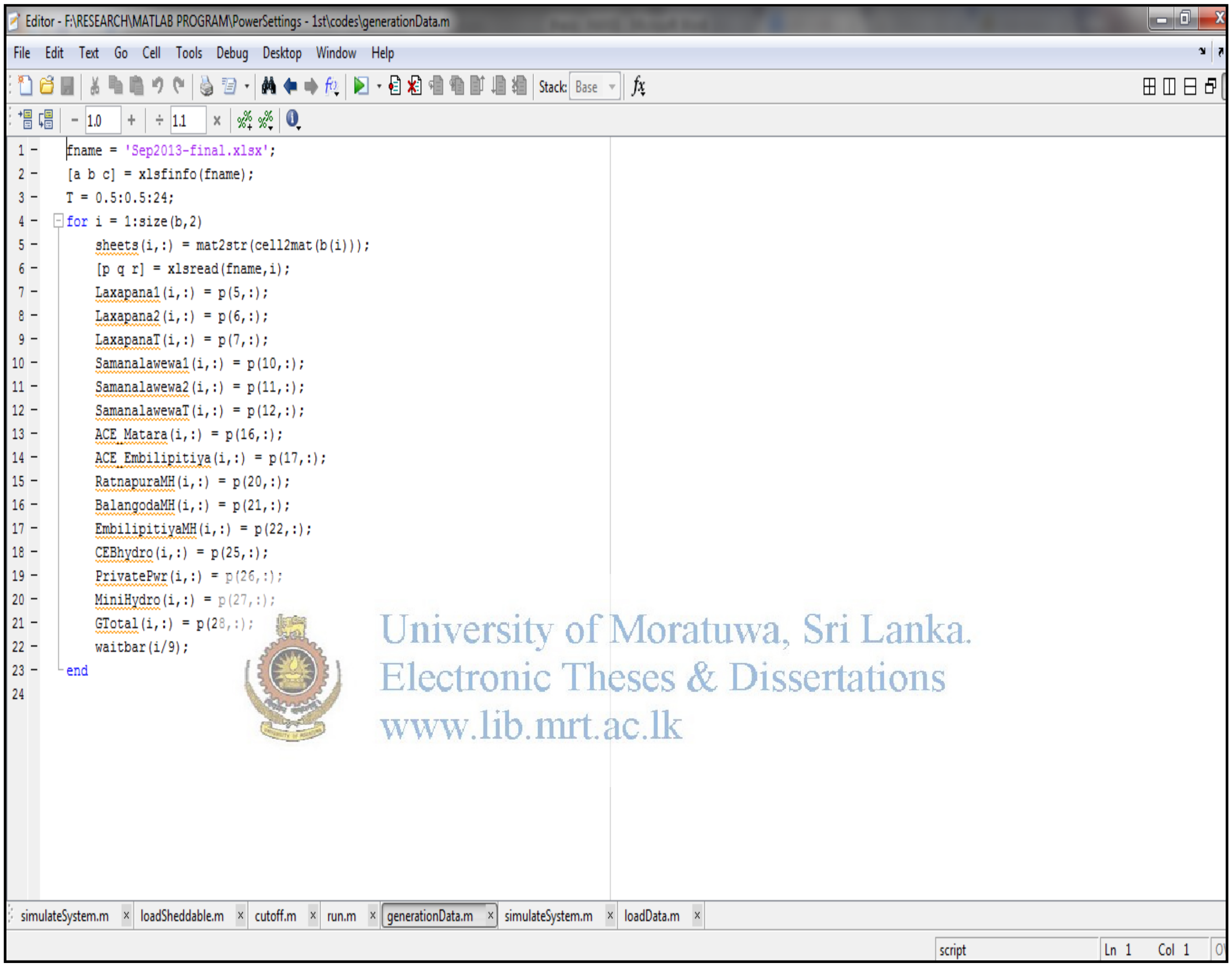
Editor - F:\RESEARCH\MATLAB PROGRAM\PowerSettings - 1st\codes\loadData.m

```
clc;
fname = 'loadData.xlsx';
[a b c] = xlsfinfo(fname);
T = 0.5:0.5:24;
for i = 1:size(b,2)
    sheets(i,:) = mat2str(cell2mat(b(i)));
    [p q r] = xlsread(fname,i);

    EMB(i,:) = p(5,:);
    EMB_F1(i,:) = p(6,:);
    EMB_F2(i,:) = p(7,:);
    EMB_F3(i,:) = p(8,:);
    EMB_F4(i,:) = p(9,:);
    EMB_F5(i,:) = p(10,:);
    EMB_F6(i,:) = p(11,:);
    EMB_F7(i,:) = p(12,:);
    EMB_F8(i,:) = p(13,:);

    MTR(i,:) = p(17,:);
    MTR_F1(i,:) = p(19,:);
    MTR_F2(i,:) = p(20,:);
    MTR_F3(i,:) = p(21,:);
    MTR_F4(i,:) = p(22,:);
    MTR_F5(i,:) = p(23,:);
    MTR_F6(i,:) = p(24,:);
    MTR_F7(i,:) = p(25,:);
    MTR_F8(i,:) = p(26,:);

    BNG(i,:) = p(31,:);
    BNG_F1(i,:) = p(33,:);
    BNG_F2(i,:) = p(34,:);
    BNG_F3(i,:) = p(35,:);
    BNG_F4(i,:) = p(36,:);
    BNG_F5(i,:) = p(37,:);
    BNG_F6(i,:) = p(38,:);
    BNG_F7(i,:) = p(39,:);
    BNG_F8(i,:) = p(40,:);
    BNG_F12(i,:) = p(41,:);

    DNY(i,:) = p(46,:);
    DNY_F1(i,:) = p(48,:);
    DNY_G1(i,:) = p(49,:);
    DNY_F2(i,:) = p(50,:);
    DNY_G2(i,:) = p(51,:);
    DNY_F3(i,:) = p(52,:);
    DNY_F4(i,:) = p(53,:);
    DNY_F5(i,:) = p(54,:);
    DNY_F8(i,:) = p(55,:);

    GLL(i,:) = p(59,:);
    GLL_F1(i,:) = p(61,:);
    GLL_F2(i,:) = p(62,:);
    GLL_F3(i,:) = p(63,:);
    GLL_F4(i,:) = p(64,:);
    GLL_F5(i,:) = p(65,:);
    GLL_F6(i,:) = p(66,:);
    GLL_F7(i,:) = p(67,:);
    GLL_F8(i,:) = p(68,:);

    HBT(i,:) = p(72,:);
    HBT_F1(i,:) = p(74,:);
    HBT_F2(i,:) = p(75,:);
    HBT_F3(i,:) = p(76,:);
    HBT_F4(i,:) = p(77,:);
    HBT_F5(i,:) = p(78,:);
    HBT_F6(i,:) = p(79,:);
    HBT_F7(i,:) = p(80,:);
    HBT_F8(i,:) = p(81,:);

    RAT(i,:) = p(85,:);
    RAT_F1(i,:) = p(87,:);
    RAT_F2(i,:) = p(88,:);
    RAT_F3(i,:) = p(89,:);
    RAT_F4(i,:) = p(90,:);
    RAT_F5(i,:) = p(91,:);
    RAT_F6(i,:) = p(92,:);
    RAT_F7(i,:) = p(93,:);
    RAT_F8(i,:) = p(94,:);

    TotalLoad(i,:) = p(96,:);
    waitbar((i+4)/9);
end
```

simulateSystem.m | loadSheddable.m | cutoff.m | run.m | generationData.m | simulateSystem.m | loadData.m

script | Ln 1 | Col 1

Appendix-C: 'generationData.m' file created in MATLAB software to read generation at each power station from excel file.



```matlab
fname = 'Sep2013-final.xlsx';
[a b c] = xlsfinfo(fname);
T = 0.5:0.5:24;
for i = 1:size(b,2)
    sheets(i,:) = mat2str(cell2mat(b(i)));
    [p q r] = xlsread(fname,i);
    Laxapana1(i,:) = p(5,:);
    Laxapana2(i,:) = p(6,:);
    LaxapanaT(i,:) = p(7,:);
    Samanalawewa1(i,:) = p(10,:);
    Samanalawewa2(i,:) = p(11,:);
    SamanalawewaT(i,:) = p(12,:);
    ACE_Matara(i,:) = p(16,:);
    ACE_Embilipitiya(i,:) = p(17,:);
    RatnapuraMH(i,:) = p(20,:);
    BalangodaMH(i,:) = p(21,:);
    EmbilipitiyaMH(i,:) = p(22,:);
    CEBhydro(i,:) = p(25,:);
    PrivatePwr(i,:) = p(26,:);
    MiniHydro(i,:) = p(27,:);
    GTotal(i,:) = p(28,:);
    waitbar(i/9);
end
```

Appendix-D: ‘gui.m’ file created in MATLAB software to view ‘GRAPHICAL USER INTERFACE’.

Editor - F:\RESEARCH\MATLAB PROGRAM\PowerSettings - 1st\codes\gui.m

```matlab

uimain = figure(...
    'Units', 'Normalized'...
    ,'Position',[0.01 0.12, 0.98, 0.7]...
    ,'Name','Load Shedding Simulator','NumberTitle','off');

mainPanel = uipanel(...
    'Units', 'Normalized',...
    'BackgroundColor','white',...
    'Position',[.01 .01 .98 .98]);

datePanel = uipanel(...
    'Parent',mainPanel,...
    'Title','Set Date',...
    'Units', 'Normalized',...
    'BackgroundColor','white',...
    'Position',[.01 .75 .18 .24]);


radDate = uibuttongroup(...
    'Parent',datePanel,...
    'Units', 'Normalized',...
    'visible','off','Position',[0 0 1 1]);
u0 = uicontrol('Style','Radio','String','Sunday',...
    'Units', 'Normalized',...
    'pos',[0 0.91 1 0.14],'parent',radDate,'HandleVisibility','off');
u1 = uicontrol('Style','Radio','String','Monday',...
    'Units', 'Normalized',...
    'pos',[0 0.76 1 0.14],'parent',radDate,'HandleVisibility','off');
u2 = uicontrol('Style','Radio','String','Tuesday',...
    'Units', 'Normalized',...
    'pos',[0 0.61 1 0.14],'parent',radDate,'HandleVisibility','off');
u3 = uicontrol('Style','Radio','String','Wednesday',...
    'Units', 'Normalized',...
    'pos',[0 0.46 1 0.14],'parent',radDate,'HandleVisibility','off');
u4 = uicontrol('Style','Radio','String','Thursday',...
    'Units', 'Normalized',...
    'pos',[0 0.31 1 0.14],'parent',radDate,'HandleVisibility','off');
u5 = uicontrol('Style','Radio','String','Friday',...
    'Units', 'Normalized',...
    'pos',[0 0.16 1 0.14],'parent',radDate,'HandleVisibility','off');
u6 = uicontrol('Style','Radio','String','Saturday',...
    'Units', 'Normalized',...
    'pos',[0 0.01 1 0.14],'parent',radDate,'HandleVisibility','off');
%set(radDate,'SelectionChangeFcn',@selcbk);
set(radDate,'SelectedObject',u0);  % No selection
set(radDate,'Visible','on');

resPanel = uipanel(...
    'Parent',mainPanel,...
    'Title','Set Resolution (minutes)',...
    'Units', 'Normalized',...
    'BackgroundColor','white',...
    'Position',[.21 .81 .18 .18]);
res = uicontrol(...
    'Parent',resPanel,...
    'Style','edit',...
    'Units', 'Normalized',...
    'BackgroundColor','white',...
    'Position',[0 0 1 1]);

spdPanel = uipanel(...
    'Parent',mainPanel,...
    'Title','Set Update Speed(miliseconds)',...
    'Units', 'Normalized',...
    'BackgroundColor','white',...
    'Position',[.41 .81 .18 .18]);
spd = uicontrol(...
    'Parent',spdPanel,...
    'Style','edit',...
    'Units', 'Normalized',...
    'BackgroundColor','white',...
    'Position',[0 0 1 1]);


dispOptPanel = uipanel(...
    'Parent',mainPanel,...
    'Title','Set Display Options',...
    'Units', 'Normalized',...
    'BackgroundColor','white',...
    'Position',[.61 .81 .18 .18]);
ldVgen = uicontrol(...
    'Parent',dispOptPanel, 'Style','checkbox',...
    'String','Load vs Generation',...
    'Units', 'Normalized', 'BackgroundColor','white',...
    'Position',[0 0.85 1 .18]);
genWgss = uicontrol(...
    'Parent',dispOptPanel, 'Style','checkbox',...
    'String','Operation of Power Plants vs Time',...
```

```
        'Units', 'Normalized', 'BackgroundColor','white',...
        'Position',[0 0.65 1 .18]);
    ldVfdr = uicontrol(...
        'Parent',dispOptPanel, 'Style','checkbox',...
        'String','Demand vs GSS',...
        'Units', 'Normalized', 'BackgroundColor','white',...
        'Position',[0 0.45 1 .18]);
    freqs = uicontrol(...
        'Parent',dispOptPanel, 'Style','checkbox',...
        'String','System Frequency',...
        'Units', 'Normalized', 'BackgroundColor','white',...
        'Position',[0 0.25 1 .18]);
    fdrSht = uicontrol(...
        'Parent',dispOptPanel, 'Style','checkbox',...
        'String','Feeder Shutdowns',...
        'Units', 'Normalized', 'BackgroundColor','white',...
        'Position',[0 0.05 1 .18]);

    uipanel(...
        'Parent',mainPanel,...
        'Title','Options',...
        'Units', 'Normalized',...
        'BackgroundColor','white',...
        'Position',[.81 .81 .18 .18]);

    onOffPanel = uipanel(...
        'Parent',mainPanel,...
        'Title','Power Plants Settings',...
        'Units', 'Normalized',...
        'BackgroundColor','white',...
        'Position',[.01 .15 .98 .58]);

    columnname =   {'Power Plants', 'Time Pairs'};
    columnformat = {'char', 'char'};
    columneditable =  [false true];
    tbl = uitable(...
        'Parent',onOffPanel,...
        'Units','normalized',...
        'Data',gssData,...
        'Position',[0.01 0.01 0.98 0.98],...
        'ColumnName', columnname,...
        'ColumnFormat', columnformat,...
        'ColumnEditable', columneditable,...
        'ColumnWidth',{150,1100},...
        'Interruptible', 'off',...
        'RowName','');


    simulator = uicontrol(...
        'Parent',mainPanel, 'Style','pushbutton',...
        'String','Simulate',...
        'Units', 'Normalized',...
        'Callback', 'simulateSystem',...
        'Position',[0.84 0.12 0.08 .05]);
```

simulateSystem.m × loadSheddable.m × cutoff.m × run.m × generationData.m × simulateSystem.m × loadData.m × gui.m ×

Appendix-E: 'loadSheddable.m' file created in MATLAB software to read demand of each GSS feeder which can be shed from excel file.

```
[a b c] = xlsfinfo('SHEDDABLE LOADS.xlsx');

[p q r] = xlsread('SHEDDABLE LOADS.xlsx',1);

sheds = ['RAT_F8'; 'BNG_F5'; 'GLL_F4'; 'MTR_F6'; 'MTR_F7'; 'GLL_F7'; 'RAT_F1'; 'MTR_F1'; 'HBT_F5';'EMB_F6'; 'DNY_F1';];

sheddables(:,:,1)  = RAT_F8;
sheddables(:,:,2)  = BNG_F5;
sheddables(:,:,3)  = GLL_F4;
sheddables(:,:,4)  = MTR_F6;
sheddables(:,:,5)  = MTR_F7;
sheddables(:,:,6) = GLL_F7;
sheddables(:,:,7) = RAT_F1;
sheddables(:,:,8) = MTR_F1;
sheddables(:,:,9) = HBT_F5;
sheddables(:,:,10) = EMB_F6;
sheddables(:,:,11) = DNY_F1;
```

Appendix-F: 'cutoff.m' file created in MATLAB software to define 'cutoff' function for load shedding.

Editor - F:\RESEARCH\MATLAB PROGRAM\PowerSettings - 1st\codes\cutoff.m

```
function loadIdx = cutoff(deltP, sloads)

    idxs = 1:11;
    loadIdx = 0;
    for i = 1:11
       idxRef = combntns(idxs,i);
       %disp(idxRef);
       cutPx = [];
       for ii = 1:size(idxRef,1)
           for iii = 1:size(idxRef,2)
               cutPx(ii,iii) = sloads(idxRef(ii,iii));
           end
       end
       %Sdisp(cutPx);

       cutPw = sum(cutPx',1)';

       x = find(cutPw>deltP,1,'first');
       %disp(x);
       if(x>0)
          loadIdx = idxRef(x,:);
          return;
       else
          if(deltP>0)
              loadIdx = idxs;
          end
          loadIdx = 0;
       end

    end

end
```

simulateSystem.m | loadSheddable.m | cutoff.m | run.m | generationData.m | simulateSystem.m | loadData.m | gui.m

cutoff | Ln 7 | Col 22

Appendix-G: 'simulateSystem.m' file created in MATLAB software for the simulation.

Editor - F:\RESEARCH\MATLAB PROGRAM\PowerSettings\codes\simulateSystem.m

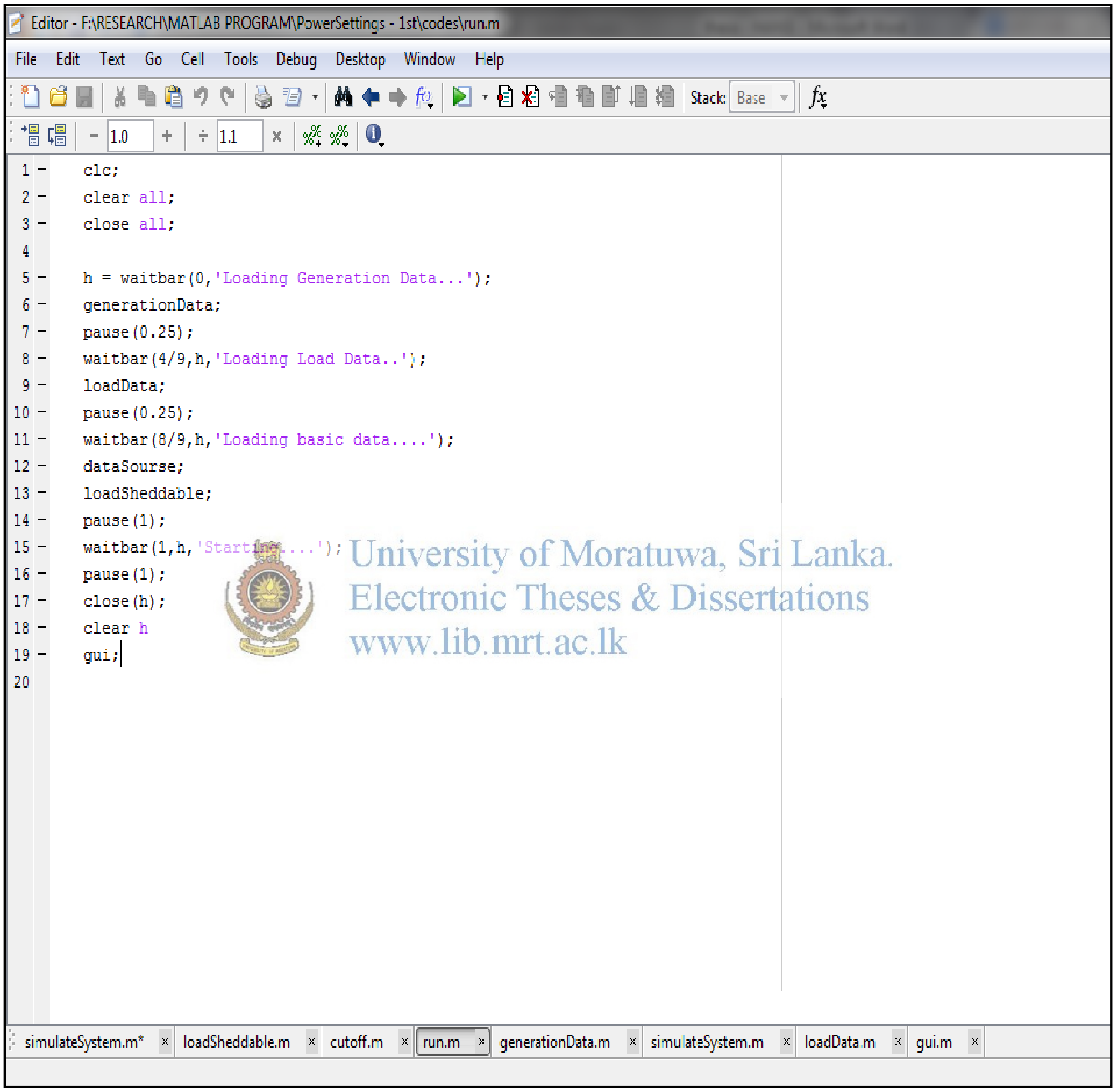
```matlab
vbl = get(radDate,'SelectedObject');
if(vbl == u0)
    date = 1;
elseif (vbl == u6)
    date = 3;
else
    date = 2;
end

resVal = get(res,'string');
disp(resVal);
try
    resVal = str2double(resVal);
catch Exception
    resVal = 30;
end
if isnan(resVal)
    resVal = 30;
end



updateRate = get(spd,'string');
disp(updateRate);
try
    updateRate = str2double(updateRate)/1000;
catch Exception
    updateRate = 0.1;
end
if isnan(updateRate)
    updateRate = 0.1;
end

tbldata = get(tbl,'data');
lx1 = 1+floor(str2num(tbldata{1,2})/30);
lx2 = 1+floor(str2num(tbldata{2,2})/30);
sw1 = 1+floor(str2num(tbldata{3,2})/30);
sw2 = 1+floor(str2num(tbldata{4,2})/30);
ac1 = 1+floor(str2num(tbldata{5,2})/30);
ac2 = 1+floor(str2num(tbldata{6,2})/30);



deflt = [0 0];
%if(lx1~= 0)
    for i = 1:2:size(lx1,2)
        GTotal(date,lx1(i):lx1(i+1)) = GTotal(date,lx1(i):lx1(i+1)) - Laxapana1(date,lx1(i):lx1(i+1));
        Laxapana1(date,lx1(i):lx1(i+1)) = 0;
    end
%end
%if(lx2~= 0)
    for i = 1:2:size(lx2,2)
        GTotal(date,lx2(i):lx2(i+1)) = GTotal(date,lx2(i):lx2(i+1)) - Laxapana2(date,lx2(i):lx2(i+1));
        Laxapana2(date,lx2(i):lx2(i+1)) = 0;
    end
%end
%if(sw1~= 0)
    for i = 1:2:size(sw1,2)
        GTotal(date,sw1(i):sw1(i+1)) = GTotal(date,sw1(i):sw1(i+1)) - Samanalawewa1(date,sw1(i):sw1(i+1));
        Samanalawewa1(date,sw1(i):sw1(i+1)) = 0;
    end
%end
%if(sw2~= 0)
    for i = 1:2:size(sw2,2)
        GTotal(date,sw2(i):sw2(i+1)) = GTotal(date,sw2(i):sw2(i+1)) - Samanalawewa2(date,sw2(i):sw2(i+1));
        Samanalawewa2(date,sw2(i):sw2(i+1)) = 0;
    end
%end
%if(ac1~= 0)
    for i = 1:2:size(ac1,2)
        GTotal(date,ac1(i:i+1)) = GTotal(date,ac1(i):ac1(i+1)) - ACE_Matara(date,ac1(i):ac1(i+1));
        ACE_Matara(date,ac1(i):ac2(i+1)) = 0;
    end
%end
%if(ac2~= 0)
    for i = 1:2:size(ac2,2)
        GTotal(date,ac2(i):ac2(i+1)) = GTotal(date,ac2(i):ac2(i+1)) - ACE_Embilipitiya(date,ac2(i):ac2(i+1));
        ACE_Embilipitiya(date,ac2(i):ac2(i+1)) = 0;
    end
%end

resVal = resVal/60;
p = size(T,2);
x = 0.5:resVal:0.5*p;
GTotalyy = spline(T,GTotal(:,1:48),x);
TotalLoadyy = spline(T,TotalLoad(:,1:48),x);
deltP = (TotalLoadyy(date,:) - GTotalyy(date,:));

ff1 = cast(deltP>0,'double');
ff2 = cast(deltP<=0,'double');

deltP = (TotalLoadyy(date,:) - GTotalyy(date,:));
```

```
 t0 = size(x,2);
 map = ones(11,t0);
 savedP = zeros(1,t0);
 detP = (TotalLoadyy(date,:) + savedP - GTotalyy(date,:))./GTotalyy(date,:);
 fnew = 50*ones(size(detP));

     dfdt = detP*50/(2*2.92);
     fnew = fnew - dfdt*(resVal);
     ff1 = cast(fnew<50,'double');
     ff2 = cast(fnew>=50,'double');
     fnew = (50*ones(size(detP))).*ff2) + fnew.*ff1;
 for k = 1:48
     if (dfdt(k) >= 0.85 && fnew(k) <= 49.0)
         sloads = sheddables(date,k,:);
         cutIdxs = cutoff(deltP(k), sloads);
         disp(cutIdxs);
         if(cutIdxs~=0)
           for txd = 1:size(cutIdxs,2)
                map(txd,k) = 0;
           end
           savedP(k) = sum(sloads(cutIdxs));
         end
     elseif (fnew(k) <= 48.75)
          pause(0.001);
          if (fnew(k) <= 48.75)
            sloads = sheddables(date,k,:);
            cutIdxs = cutoff(deltP(k), sloads);
            disp(cutIdxs);
            if(cutIdxs~=0)
              for txd = 1:size(cutIdxs,2)
                  map(txd,k) = 0;
              end
              savedP(k) = sum(sloads(cutIdxs));
            end
          end
          if (fnew(k) >= 50)
             cutIdxs = 0;
          end
     end
 end



 detP = (TotalLoadyy(date,:) + savedP - GTotalyy(date,:))./GTotalyy(date,:);

 fnew = 50*ones(size(detP));
 dfdt = detP*50/(2*2.92);
 fnew = fnew - dfdt*(resVal);
 ff1 = cast(fnew<50,'double');
 ff2 = cast(fnew>=50,'double');
 fnew = (50*ones(size(detP))).*ff2) + fnew.*ff1;
 Laxapana1yy = spline(T,Laxapana1(:,1:48),x);
 Laxapana2yy = spline(T,Laxapana2(:,1:48),x);
 Samanalawewa1yy = spline(T,Samanalawewa1(:,1:48),x);
 Samanalawewa2yy = spline(T,Samanalawewa2(:,1:48),x);
 ACE_Matarayy = spline(T,ACE_Matara(:,1:48),x);
 ACE_Embilipitiyayy = spline(T,ACE_Embilipitiya(:,1:48),x);

 BNGyy = spline(T,BNG(:,1:48),x);
 DNYyy = spline(T,DNY(:,1:48),x);
 EMByy = spline(T,EMB(:,1:48),x);
 GLLyy = spline(T,GLL(:,1:48),x);
 HBTyy = spline(T,HBT(:,1:48),x);
 MTRyy = spline(T,MTR(:,1:48),x);
 RATyy = spline(T,RAT(:,1:48),x);

 figure(...
     'Units', 'Normalized'...
     ,'Position',[0.01 0.12, 0.98, 0.76]...
     ,'Name','Simulation Plot Window','NumberTitle','off');

 noPlots = 0;

     if(get(ldVgen,'Value'))
         noPlots = noPlots + 1;
     end

     if(get(genWgss,'Value'))
         noPlots = noPlots + 1;
     end

     if(get(ldVfdr,'Value'))
         noPlots = noPlots + 1;
     end

     if(get(freqs,'Value'))
         noPlots = noPlots + 1;
     end
```

```
        if(get(fdrSht,'Value'))
            noPlots = noPlots + 1;
        end
        |
    for k = 0:t0

        plotid = 0;
        if(get(ldVgen,'Value'))
           plotid = plotid + 1;
           subplot(noPlots,1,plotid);
           plot(x(i:k),GTotalyy(date,1:k));
           hold on
           plot(x(i:k),TotalLoadyy(date,1:k) - savedP(1:k),'-g');
           plot(x(i:k),TotalLoadyy(date,1:k),'-r');
           legend('Total Generation','Balance after Shedding', 'Total Load',2);
           hold off
           title('Load vs Generation');
           xlabel('time (hour)');
           ylabel('Power (MW)');
           xlim([0 25]);
        end

        if(get(genWgss,'Value'))
           plotid = plotid + 1;
           subplot(noPlots,1,plotid);
           plot(x(i:k),Laxapana1yy(date,1:k),'-c');
           hold on
           plot(x(i:k),Laxapana2yy(date,1:k),'-m');
           plot(x(i:k),Samanalawewa1yy(date,1:k),'-k');
           plot(x(i:k),Samanalawewa2yy(date,1:k),'-g');
           plot(x(i:k),ACE_Matarayy(date,1:k),'-b');
           plot(x(i:k),ACE_Embilipitiyayy(date,1:k),'-r');
           hold off
           xlabel('time (hour)');
           ylabel('Power (MW)');
           xlim([0 25]);
           ylim([-1 55]);
           title('Operation of Power Plants vs Time');
        end

        if(get(ldVfdr,'Value'))
           plotid = plotid + 1;
           subplot(noPlots,1,plotid);
           plot(x(i:k),BNGyy(date,1:k),'-c');
           hold on
           plot(x(i:k),DNWyy(date,1:k),'-m');
           plot(x(i:k),EMByy(date,1:k),'-k');
           plot(x(i:k),GLLyy(date,1:k),'-g');
           plot(x(i:k),SSTyy(date,1:k),'-b');
           plot(x(i:k),MTRyy(date,1:k),'-r');
           plot(x(i:k),RATyy(date,1:k),'-y');
           hold off
           xlabel('time (hour)');
           ylabel('Power (MW)');
           xlim([0 25]);
           ylim([-1 75]);
           title('Demand vs GSS');
        end
        if(get(freqs,'Value'))
           plotid = plotid + 1;
           subplot(noPlots,1,plotid);
           plot(x(i:k),fnew(1:k),'-c');
           xlabel('time (hour)');
           ylabel('Frequency (Hz)');
           xlim([0 25]);
           ylim([40 60]);
           title('System Frequency');
        end
        if(get(fdrSht,'Value'))
           plotid = plotid + 1;
            subplot(noPlots,1,plotid);
            mpr = map(:,1:k);
            if(size(mpr,2) > 1)
                spy(mpr);
                axis fill
                set(gca,'XTickLabel', ' ', 'YTick', 1:11,'YTickLabel',sheds,...
                    'GridLineStyle','-','XGrid','on','YGrid','on');
                xlim([-4 t0+9]);
            end
           title('Feeder Shutdowns');
        end
        pause(updateRate);
    end
```

simulateSystem.m* × loadSheddable.m × cutoff.m × run.m × generationData.m × simulateSystem.m × loadData.m × gui.m ×

Appendix-H: ‘run.m’ file created in MATLAB software to run the simulation.



Appendix-I: Load Shedding Sequence used in ILS mechanism for PSS/E simulation.

Bus no.	FEEDER	ID	P(MW)	Q(MVAr)	**Subtotal of P (MW)**	
3580	KOTUG-3-12 33.000	2	15.6000	3.5487	**15.6000**	
3650	GALLE-3-4 33.000	3	15.5000	2.4983	**31.1000**	
3770	KIRIB-3-2 33.000	1	15.5000	2.4983	**46.6000**	
3600	BOLAW-3-4 33.000	3	13.6500	7.1152	**60.2500**	
3530	THULH-3-4 33.000	3	12.2500	1.9745	**72.5000**	
3600	BOLAW-3-8 33.000	5	11.5500	6.0206	**84.0500**	
3520	NUWAR-3-2 33.000	2	11.5000	7.8875	**95.5500**	
3890	DEHIW_3-1 33.000	1	11.3500	6.1628	**106.9000**	
3790	RATMA-3A-9 33.000	5	11.2500	6.9830	**118.1500**	
3820	ATURU-3-8 33.000	3	11.2000	4.7115	**129.3500**	
3420	HORANA_3-3 33.000	2	11.1500	7.6475	**140.5000**	
3200	UKUWE-3-10 33.000	3	11.0500	3.0694	**151.5500**	
4920	SUB C-11 11.000	1	10.4000	4.8000	**161.9500**	
3570	BIYAG-3-7 33.000	7	10.0000	4.4810	**171.9500**	
3580	KOTUG-3-3 33.000	1	10.0000	2.2748	**181.9500**	
3705	NEWANU-3-(4 and5) 33.000	1	10.0000	1.6118	**191.9500**	
3260	MAHIYANGE-3-2 33.000	1	9.6000	1.5473	**201.5500**	
3570	BIYAG-3-5 33.000	5	9.5000	4.2570	**211.0500**	
3680	KURUN-3-6 33.000	5	9.5000	1.5312	**220.5500**	
3560	PANNI-3-7 33.000	6	9.4000	4.4593	**229.9500**	
3590	SAPUG-3A-7 33.000	5	9.3000	6.3786	**239.2500**	
4435	COL_A_11-1011 11.000	4	9.2000	4.4700	**248.4500**	CASE STUDY-1
3790	RATMA-3A-2 33.000	1	9.0500	5.6175	**257.5000**	
3860	MADAM-3-7 33.000	5	9.0000	2.5206	**266.5000**	
3900	PANNAL-4 33.000	3	8.9500	2.8647	**275.4500**	
4430	COL_I_11-18 11.000	1	8.9000	4.5670	**284.3500**	
4435	COL_A_11-22 11.000	3	8.9000	3.5000	**293.2500**	CASE STUDY-4
3770	KIRIB-3-4 33.000	3	8.9000	1.4345	**302.1500**	CASE STUDY-2
3850	PANAD-3-2 33.000	1	8.8000	2.4444	**310.9500**	
3670	MATARA-3-2 33.000	2	8.5000	2.7206	**319.4500**	
3860	MADAM-3-2 33.000	2	8.5000	2.3805	**327.9500**	
3570	BIYAG-3-4 33.000	4	8.2500	3.6969	**336.2000**	
3150	AMPA-3-3 33.00	1	8.1000	1.3056	**344.3000**	
3570	BIYAG-3-8 33.000	8	8.0000	3.5848	**352.3000**	
3770	KIRIB-3-7 33.000	5	8.0000	1.2894	**360.3000**	
3650	GALLE-3-5 33.000	4	7.9000	2.8176	**368.2000**	
3620	BADUL-3-3 33.000	2	7.8500	1.7857	**376.0500**	
3910	ANIYA-5 33.000	3	7.7500	3.9689	**383.8000**	
3560	PANNI-3-9 33.000	8	7.6000	3.6054	**391.4000**	

Bus no.	FEEDER	ID	P(MW)	Q(MVAr)	Subtotal of P(MW)	
3830	VEYAN-33-4 33.000	2	7.5000	2.1005	**398.9000**	
3600	BOLAW-3-3 33.000	2	7.4000	3.8573	**406.3000**	
3690	HABAR-3-7 33.000	5	7.4000	1.1927	**413.7000**	
3620	BADUL-3-5 33.000	3	7.3000	1.6606	**421.0000**	
3705	NEWANU-3-(6and7) 33.000	2	7.2500	1.1686	**428.2500**	
3800	MATUG-3-10 33.000	6	7.2500	1.1686	**435.5000**	
3520	NUWAR-3-1 33.000	1	7.0000	4.8011	**442.5000**	
3600	BOLAW-3-2 33.000	1	7.0000	3.6488	**449.5000**	
3830	VEYAN-33-3 33.000	1	7.0000	1.9605	**456.5000**	
3150	AMPA-3-5 33.00	2	7.0000	1.1283	**463.5000**	
3770	KIRIB-3-6 33.000	4	7.0000	1.1283	**470.5000**	
4435	COL_A_11-14 11.000	2	6.8800	3.3000	**477.3800**	
3200	UKUWE-3-12 33.000	4	6.8500	1.9028	**484.2300**	
3840	JPURA_3-6 33.000	6	6.8000	3.0471	**491.0300**	
3551	KOLON-3B-G1 33.000	1	6.8000	1.9044	**497.8300**	
3340	BELIATT-3-4 33.000	1	6.8000	1.0960	**504.6300**	
3590	SAPUG-3A-3 33.000	2	6.7500	4.6296	**511.3800**	
3690	HABAR-3-4 33.000	3	6.7500	1.0880	**518.1300**	CASE STUDY-3
3670	MATARA-3-7 33.000	5	6.7000	2.1445	**524.8300**	
3551	KOLON-3B-G2 33.000	2	6.6000	1.8484	**531.4300**	
3690	HABAR-3-3 33.000	2	6.6000	1.0638	**538.0300**	
3670	MATARA-3-4 33.000	3	6.5000	2.0805	**544.5300**	
3580	KOTUG-3-13 33.000	3	6.5000	1.4786	**551.0300**	
3581	KOTU_NEW-3-9 33.000	1	6.5000	1.4786	**557.5300**	
3890	DEHIW_3-8 33.000	5	6.4000	3.4751	**563.9300**	
3910	ANIYA-7 33.000	4	6.4000	3.2776	**570.3300**	
4430	COL_I_11-1240 11.000	3	6.2000	3.3000	**576.5300**	
3880	AMBALA-6 33.000	4	6.2000	2.7782	**582.7300**	
4750	COL_E-11-10 11.000	2	6.2000	1.9000	**588.9300**	
3910	ANIYA-3 33.000	2	6.1000	3.1239	**595.0300**	
3581	KOTU_NEW-3-11 33.000	2	6.1000	1.3876	**601.1300**	
3680	KURUN-3-3 33.000	2	6.0500	0.9751	**607.1800**	
3440	KATUNA-3-1 33.000	1	6.0000	2.6886	**613.1800**	
3500	KOSGA-3-1 33.000	1	6.0000	2.6886	**619.1800**	
3500	KOSGA-3-2 33.000	2	6.0000	2.6886	**625.1800**	
3770	KIRIB-3-14 33.000	6	6.0000	0.9671	**631.1800**	
3790	RATMA-3A-7 33.000	4	5.9500	3.6932	**637.1300**	
3340	BELIATT-3-6 33.000	3	5.9000	0.9510	**643.0300**	
3870	K-NIYA-3-2 33.000	2	5.8500	4.0124	**648.8800**	
3900	PANNAL-2 33.000	1	5.8500	1.8724	**654.7300**	

Bus no.	FEEDER	ID	P(MW)	Q(MVAr)	**Subtotal of P(MW)**
4435	COL_A_11-1137 11.000	1	5.6700	2.1110	**660.4000**
3880	AMBALA-3 33.000	2	5.6500	2.5318	**666.0500**
3590	SAPUG-3A-11 33.000	8	5.5500	3.8066	**671.6000**
3510	SITHA-33-6 33.000	4	5.5000	3.0556	**677.1000**
4430	COL_I_11-45 11.000	2	5.4000	1.2000	**682.5000**
3560	PANNI-3-2 33.000	1	5.3500	2.5380	**687.8500**
3420	HORANA_3-4 33.000	3	5.3000	3.6351	**693.1500**
3800	MATUG-3-9 33.000	5	5.2500	0.8462	**698.4000**
3240	VAVUN-33-4 33.000	3	5.1500	0.8301	**703.5500**
3870	K-NIYA-3-1 33.000	1	5.1000	3.4979	**708.6500**
3790	RATMA-3A-3 33.000	2	5.1000	3.1656	**713.7500**
3680	KURUN-3-2 33.000	1	5.1000	0.8220	**718.8500**
3570	BIYAG-3-1 33.000	1	5.0000	2.2405	**723.8500**
3860	MADAM-3-3 33.000	3	5.0000	1.4003	**728.8500**
3650	GALLE-3-1 33.000	1	5.0000	0.8059	**733.8500**
3690	HABAR-3-1 33.000	1	5.0000	0.8059	**738.8500**
3890	DEHIW_3-7 33.000	4	4.9500	2.6878	**743.8000**
4430	COL_I_11-602 11.000	5	4.9171	1.3330	**748.7171**
3890	DEHIW_3-6 33.000	3	4.8500	2.6335	**753.5671**
4760	COL_F-11-624 11.000	3	4.7800	1.9800	**758.3471**
3620	BADUL-3-6 33.000	4	4.7000	1.0692	**763.0471**
3740	RATNAP-3-1 33.000	1	4.6000	2.0613	**767.6471**
3420	HORANA_3-5 33.000	4	4.5500	3.1207	**772.1971**
3670	MATARA-3-8 33.000	6	4.5500	1.4563	**776.7471**
4750	COL_E-11-609 11.000	3	4.5500	1.1000	**781.2971**
3510	SITHA-33-1 33.000	1	4.5000	2.5000	**785.7971**
4430	COL_I_11-1130 11.000	4	4.5000	1.3846	**790.2971**
3680	KURUN-3-4 33.000	3	4.5000	0.7253	**794.7971**
4435	COL_A_11-571 11.000	5	4.4776	1.0591	**799.2747**
3600	BOLAW-3-5 33.000	4	4.4000	2.2936	**803.6747**
3560	PANNI-3-4 33.000	3	4.3500	2.0636	**808.0247**
3880	AMBALA-4 33.000	3	4.3000	1.9268	**812.3247**
3500	KOSGA-3-8 33.000	4	4.2500	1.9044	**816.5747**
3530	THULH-3-5 33.000	4	4.2500	0.6850	**820.8247**
3440	KATUNA-3-7 33.000	3	4.2000	1.8820	**825.0247**
3840	JPURA_3-5 33.000	5	4.1500	1.8596	**829.1747**
3530	THULH-3-1 33.000	1	4.1000	0.6608	**833.2747**
3510	SITHA-33-2 33.000	2	4.0000	2.2222	**837.2747**
3820	ATURU-3-6 33.000	2	4.0000	1.6827	**841.2747**
3860	MADAM-3-4 33.000	4	4.0000	1.1203	**845.2747**

Bus no.	FEEDER	ID	P(MW)	Q(MVAr)	**Subtotal of P(MW)**
3850	PANAD-3-3 33.000	2	4.0000	1.1111	**849.2747**
4750	COL_E-11-335 11.000	4	4.0000	1.0000	**853.2747**
3800	MATUG-3-8 33.000	4	3.8500	0.6205	**857.1247**
3670	MATARA-3-6 33.000	4	3.7500	1.2003	**860.8747**
3260	MAHIYANGE 3-5 33.000	2	3.7500	0.6044	**864.6247**
3900	PANNAL-7 33.000	6	3.7000	1.1843	**868.3247**
3720	KILINOCH-3-2 33.000	1	3.6500	1.9819	**871.9747**
3560	PANNI-3-6 33.000	5	3.6500	1.7315	**875.6247**
3640	DENIY-3-1 33.000	1	3.6000	0.5802	**879.2247**
3590	SAPUG-3A-8 33.000	6	3.5500	2.4348	**882.7747**
4760	COL_F-11-54 11.000	2	3.4800	2.5600	**886.2547**
3590	SAPUG-3A-6 33.000	4	3.4500	2.3663	**889.7047**
3440	KATUNA-3-8 33.000	4	3.3500	1.5011	**893.0547**
3690	HABAR-3-8 33.000	6	3.3000	0.5319	**896.3547**
3560	PANNI-3-8 33.000	7	3.2000	1.5181	**899.5547**
4750	COL_E-11-981 11.000	1	3.2000	0.5000	**902.7547**
3530	THULH-3-2 33.000	2	3.1000	0.4997	**905.8547**
3820	ATURU-3-3 33.000	1	3.0000	1.2620	**908.8547**
3650	GALLE-3-6 33.000	5	3.0000	1.0700	**911.8547**
3590	SAPUG-3A-9 33.000	7	2.9000	1.9890	**914.7547**
3880	AMBALA-2 33.000	1	2.9000	1.2995	**917.6547**
3240	VAVUN-33-1 33.000	1	2.8500	0.4594	**920.5047**
3900	PANNAL-5 33.000	4	2.7500	0.8802	**923.2547**
3650	GALLE-3-2 33.000	2	2.7500	0.4432	**926.0047**
3690	HABAR-3-6 33.000	4	2.7500	0.4432	**928.7547**
3620	BADUL-3-1 33.000	1	2.7000	0.6142	**931.4547**
3551	KOLON-3B-B1 33.000	3	2.6500	0.7422	**934.1047**
3720	KILINOCH-3-4 33.000	2	2.5000	1.3575	**936.6047**
4760	COL_F-11-116 11.000	1	2.5000	0.8000	**939.1047**
3530	THULH-3-6 33.000	5	2.5000	0.4029	**941.6047**
3720	KILINOCH-3-5 33.000	3	2.4500	1.3303	**944.0547**
3900	PANNAL-6 33.000	5	2.4500	0.7842	**946.5047**
4760	COL_F-11-43 11.000	4	2.4000	0.6000	**948.9047**
3830	VEYAN-33-6 33.000	3	2.2500	0.6301	**951.1547**
3800	MATUG-3-5 33.000	2	2.1500	0.3465	**953.3047**
3551	KOLON-3B-B2 33.000	4	2.1000	0.5881	**955.4047**
3830	VEYAN-33-8 33.000	5	2.0000	0.5601	**957.4047**
3840	JPURA_3-2 33.000	2	1.8500	0.8290	**959.2547**
4760	COL_F-11-9 11.000	5	1.8400	0.5600	**961.0947**
3590	SAPUG-3A-4 33.000	3	1.6000	1.0974	**962.6947**

Bus no.	FEEDER	ID	P(MW)	Q(MVAr)	**Subtotal of P(MW)**
3570	BIYAG-3-6 33.000	6	1.5000	0.6722	**964.1947**
3840	JPURA_3-4 33.000	4	1.3500	0.6049	**965.5447**
3590	SAPUG-3A-2 33.000	1	1.3000	0.8916	**966.8447**
3800	MATUG-3-6 33.000	3	1.3000	0.2095	**968.1447**
3790	RATMA-3A-6 33.000	3	1.2500	0.7759	**969.3947**
3850	PANAD-3-5 33.000	4	1.2500	0.3472	**970.6447**
3240	VAVUN-33-6 33.000	4	1.1500	0.1854	**971.7947**
3420	HORANA_3-2 33.000	1	1.1000	0.7545	**972.8947**
3240	VAVUN-33-2 33.000	2	1.1000	0.1773	**973.9947**
3640	DENIY-3-2 33.000	2	1.1000	0.1773	**975.0947**
3800	MATUG-3-1 33.000	1	1.1000	0.1773	**976.1947**
3520	NUWAR-3-6 33.000	5	1.0000	0.6859	**977.1947**
3570	BIYAG-3-3 33.000	3	1.0000	0.4481	**978.1947**
3830	VEYAN-33-7 33.000	4	1.0000	0.2801	**979.1947**
3860	MADAM-3-1 33.000	1	1.0000	0.2801	**980.1947**
3340	BELIATT-3-5 33.000	2	1.0000	0.1612	**981.1947**
3840	JPURA_3-8 33.000	7	0.9500	0.4257	**982.1447**
3440	KATUNA-3-2 33.000	2	0.9000	0.4033	**983.0447**
3560	PANNI-3-3 33.000	2	0.5500	0.2609	**983.5947**
3510	SITHA-33-5 33.000	3	0.5000	0.2778	**984.0947**
3560	PANNI-3-5 33.000	4	0.3000	0.1423	**984.3947**
3770	KIRIB-3-3 33.000	2	0.2500	0.0403	**984.6447**
3670	MATARA-3-1 33.000	1	0.1000	0.0320	**984.7447**
3200	UKUWE-3-1 33.000	1	0.0000	0.0000	**984.7447**
3200	UKUWE-3-3 33.000	2	0.0000	0.0000	**984.7447**
3500	KOSGA-3-5 33.000	3	0.0000	0.0000	**984.7447**
3560	PANNI-3-10 33.000	9	0.0000	0.0000	**984.7447**
3680	KURUN-3-5 33.000	4	0.0000	0.0000	**984.7447**
3840	JPURA_3-1 33.000	1	0.0000	0.0000	**984.7447**
3850	PANAD-3-4 33.000	3	0.0000	0.0000	**984.7447**
3870	K-NIYA-3-3 33.000	3	0.0000	0.0000	**984.7447**
3890	DEHIW_3-3 33.000	2	0.0000	0.0000	**984.7447**
3900	PANNAL-3 33.000	2	0.0000	0.0000	**984.7447**
3910	ANIYA-1 33.000	1	0.0000	0.0000	**984.7447**
3520	NUWAR-3-4 33.000	3	-1.0000	-0.6859	**983.7447**