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 07^{th} 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).

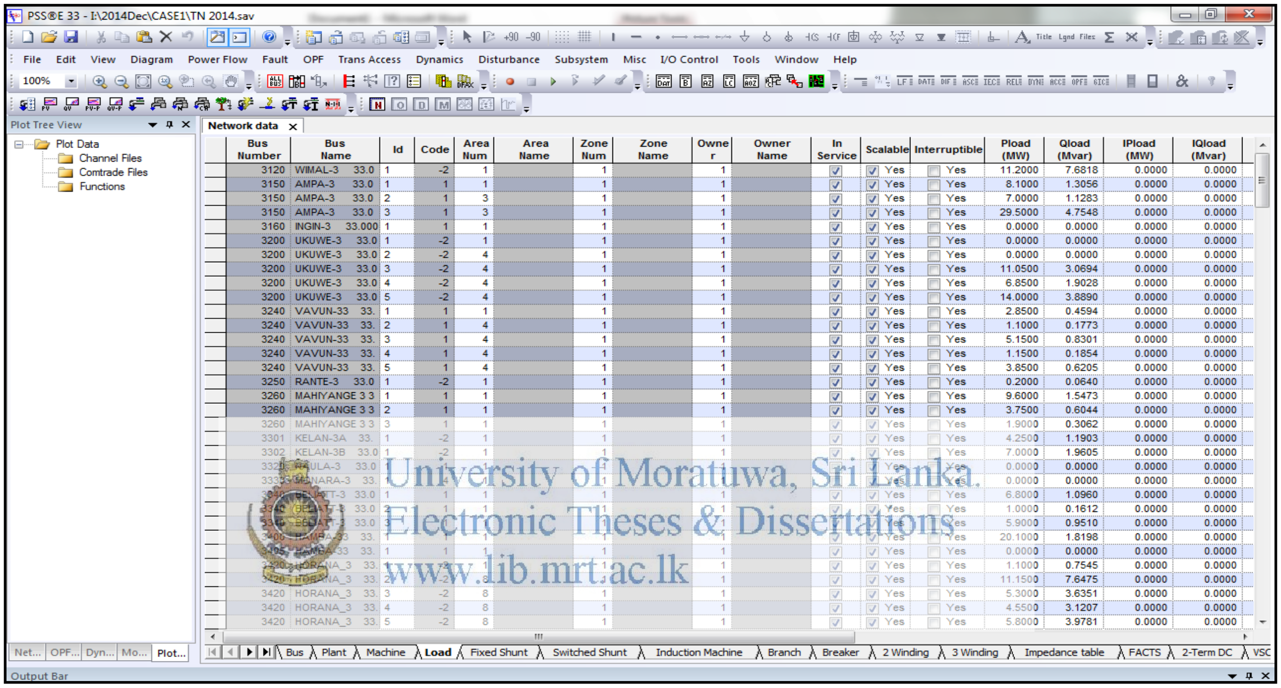


Figure 4.1 Load modeled feeder wise in PSS/E

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

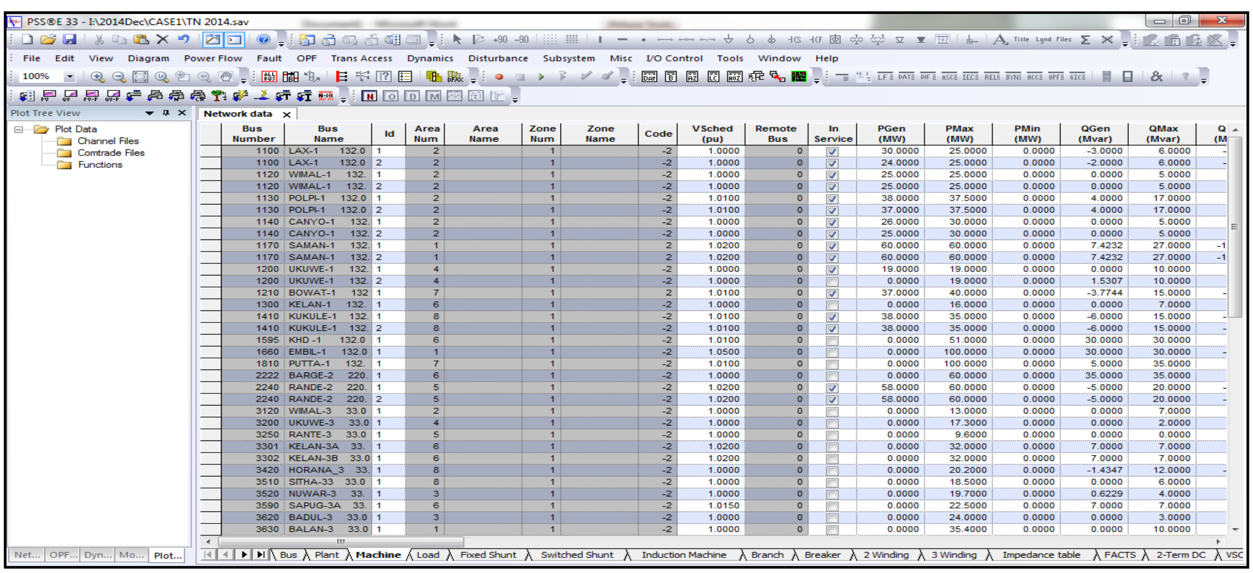


Figure4.2 Machine file updated with generation data in PSS/E

(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.

CASE STUDY-01

i. Frequency waveform:

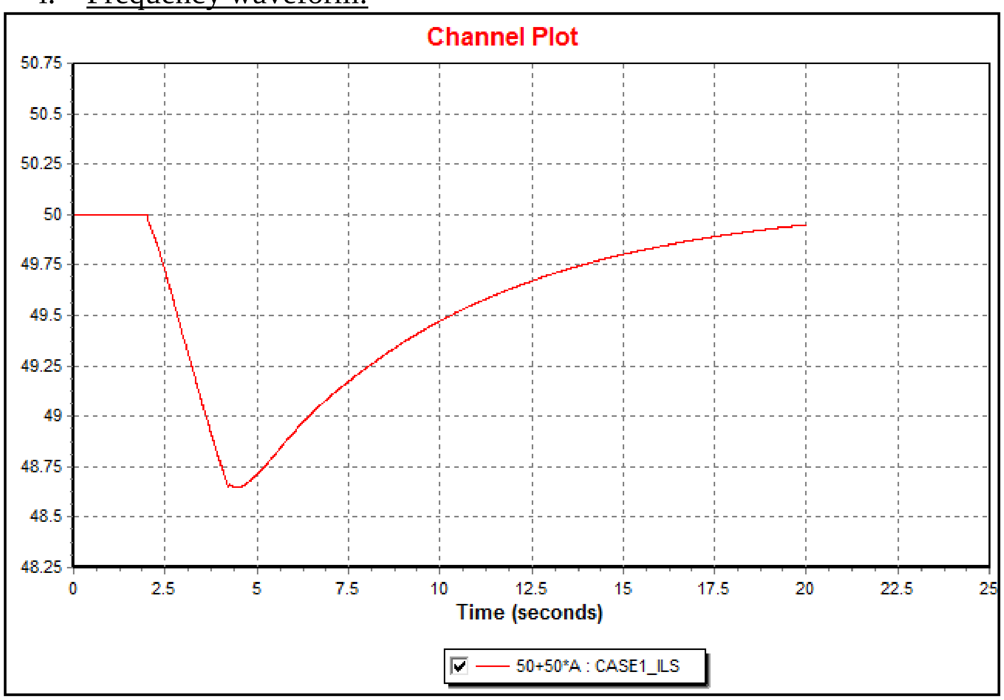


Figure 4.7 Frequency waveform obtained for case study-01

ii. Voltage waveform:

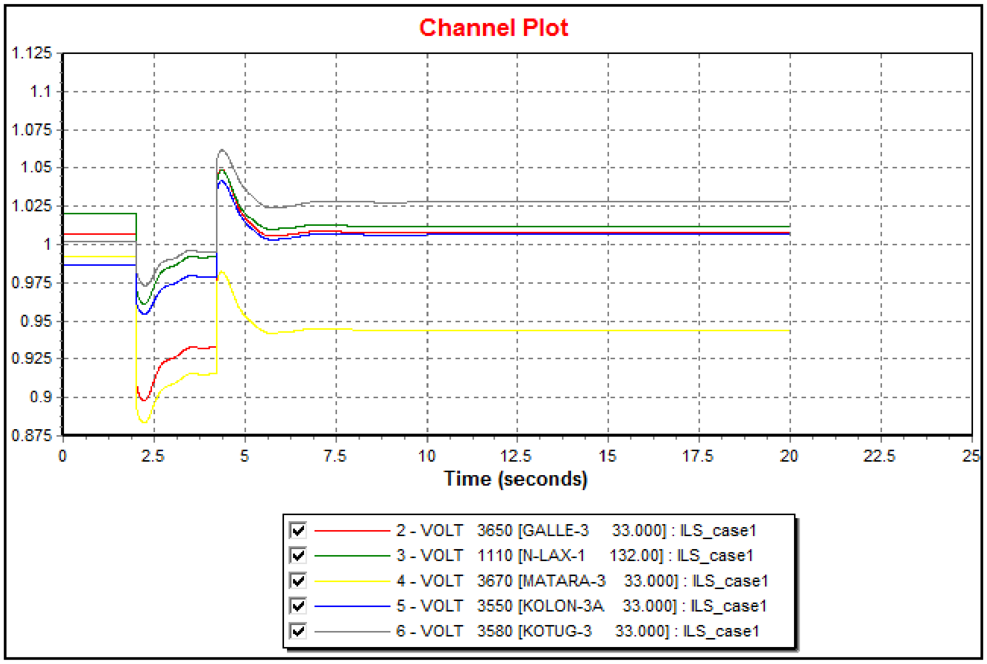


Figure 4.8 Voltage waveform obtained for case study-01

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:

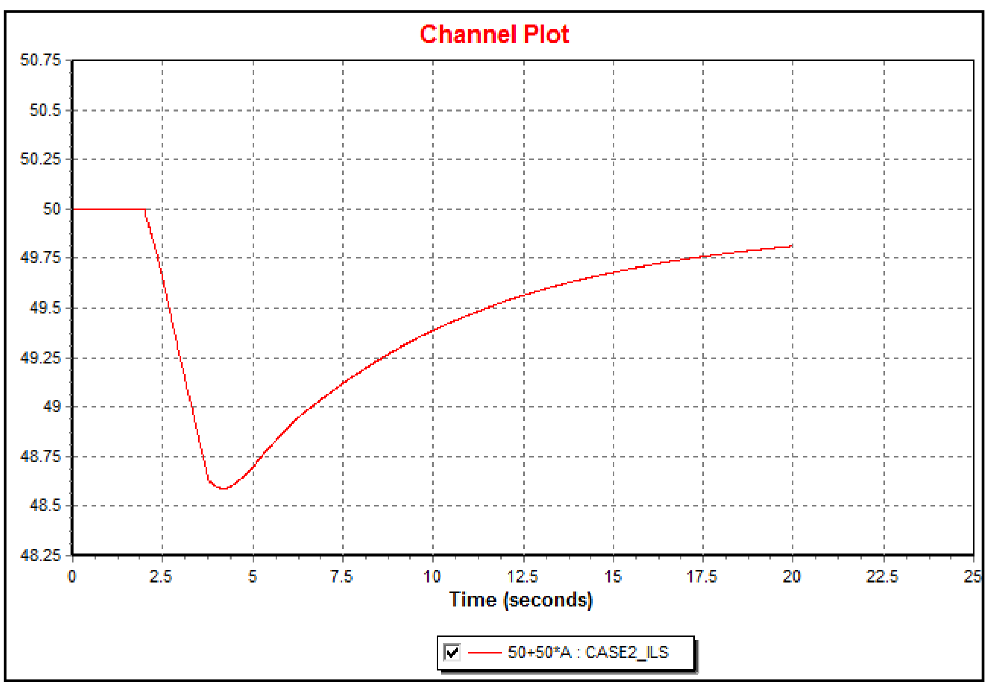


Figure 4.9 Frequency waveform obtained for case study-02

ii. Voltage waveform:

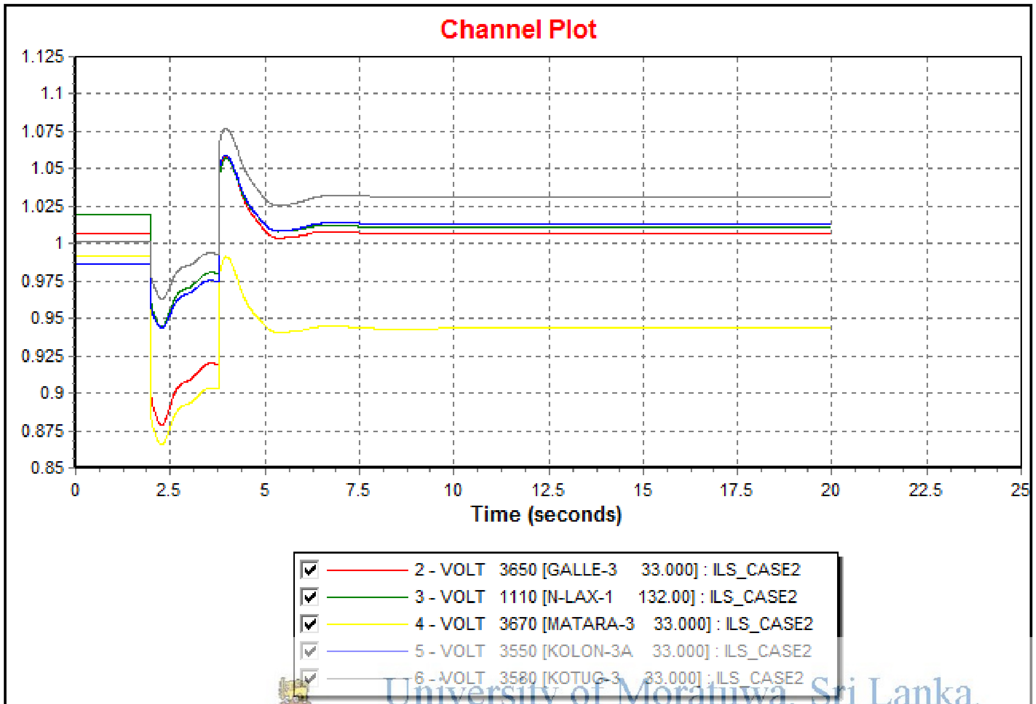


Figure 4.10 Voltage waveform obtained for case study-02

CASE STUDY-03

i. Frequency waveform:

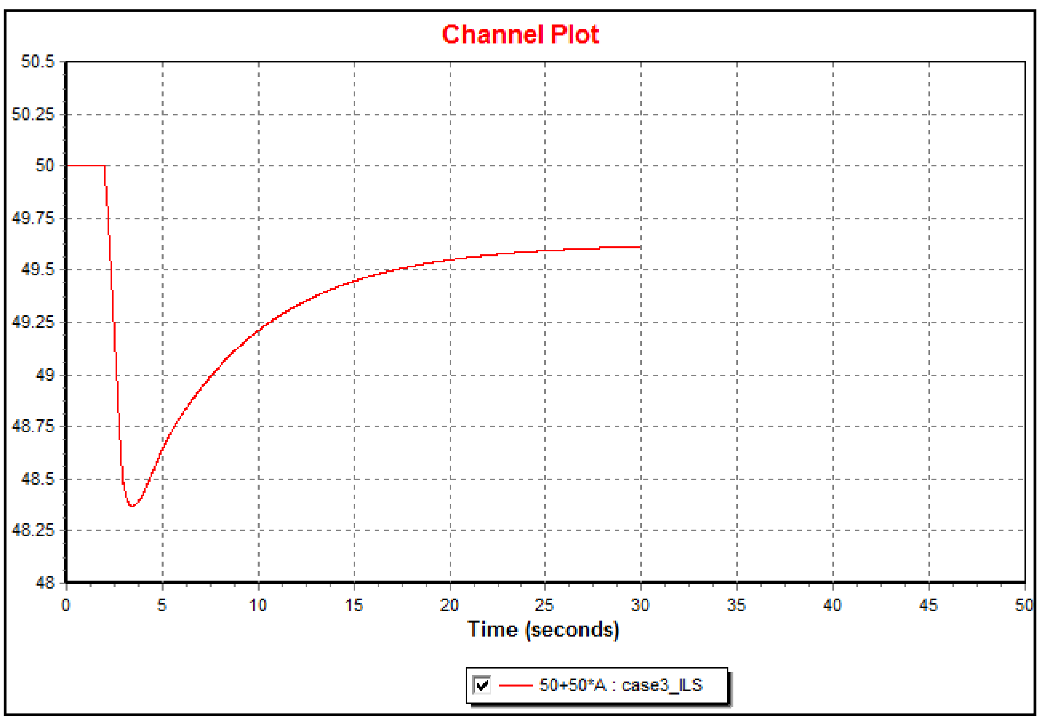


Figure 4.11 Frequency waveform obtained for case study-03

ii. Voltage waveform:

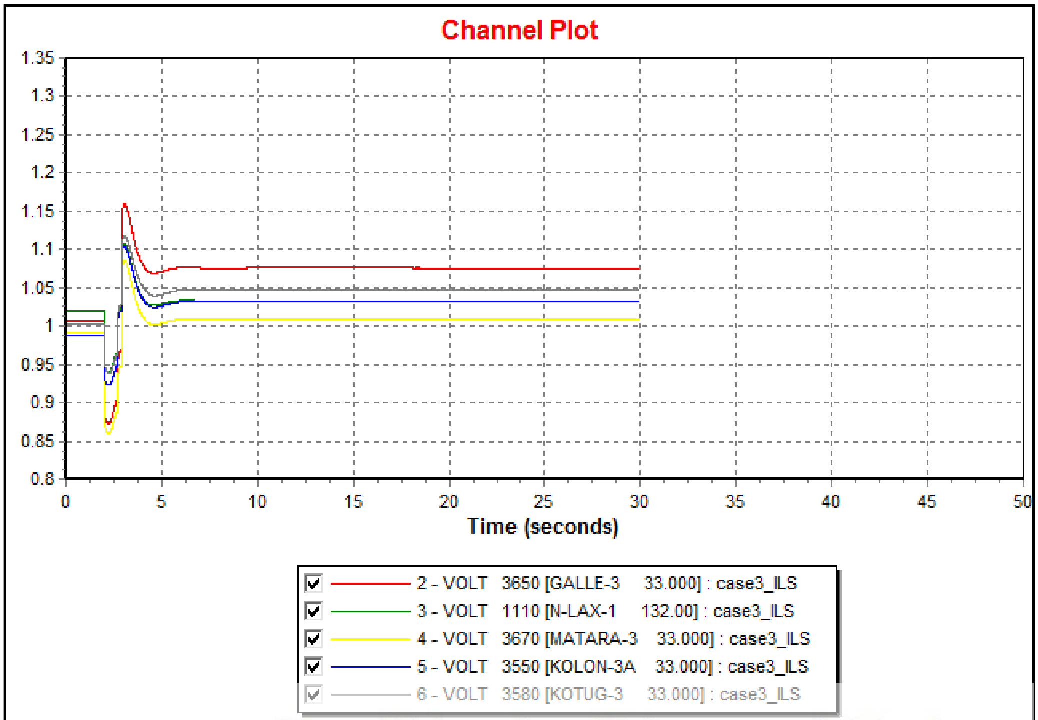


Figure 4.12 Voltage waveform obtained for case study-03

CASE STUDY-04

i. Frequency waveform:

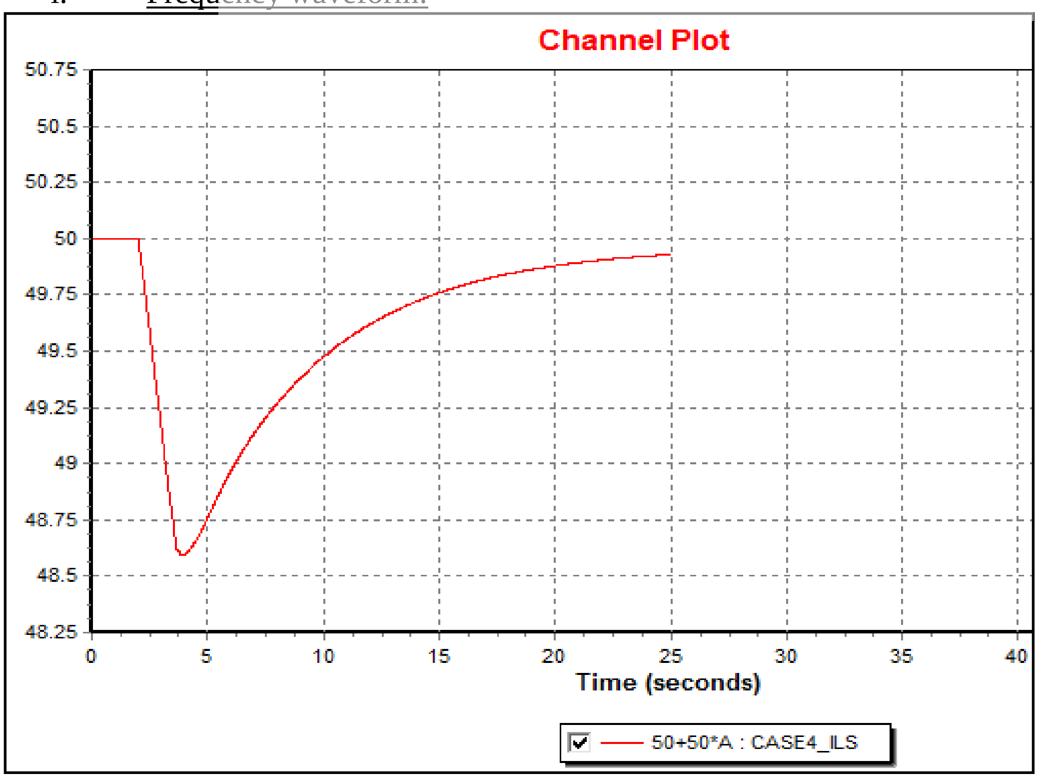


Figure 4.13 Frequency waveform obtained for case study-04

ii. Voltage waveform:

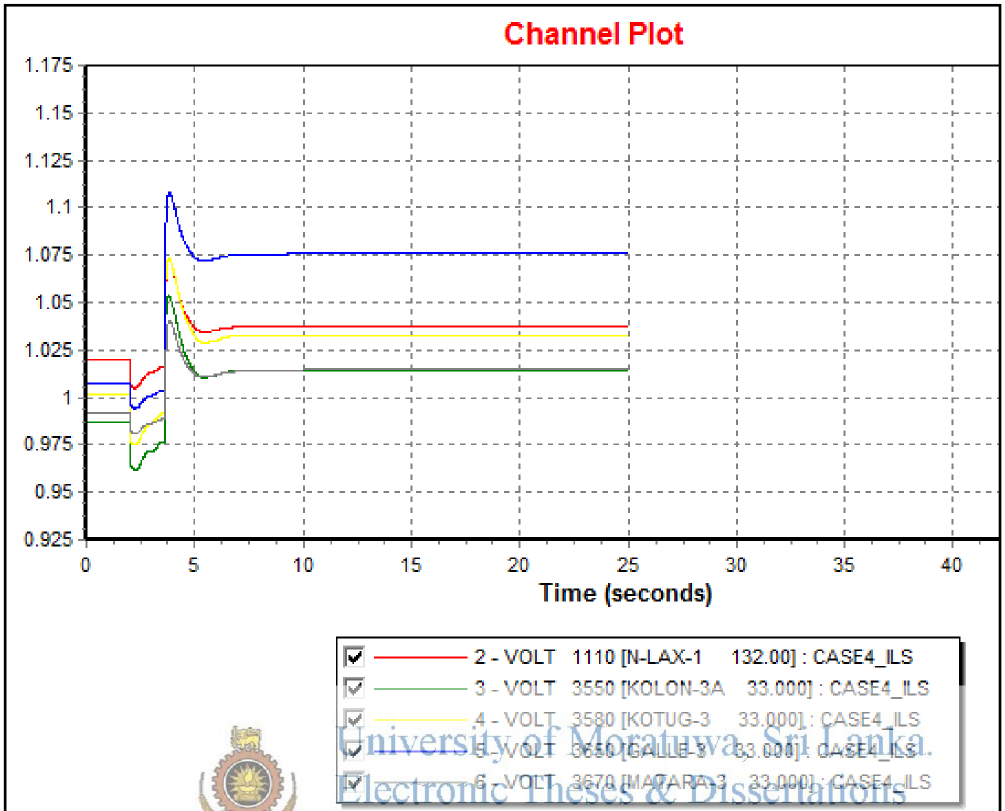


Figure 4.14 Voltage waveform obtained for case study-04

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:

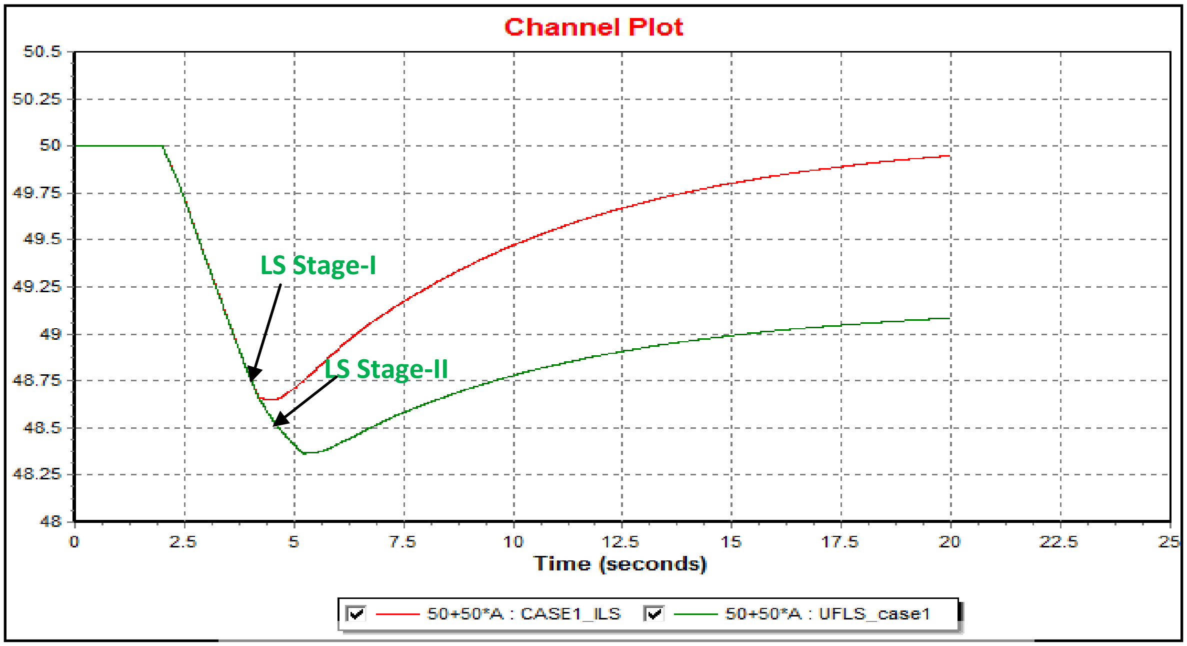


Figure 4.15 Frequency waveforms obtained through application of UFLS and ILS for case study-01

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:

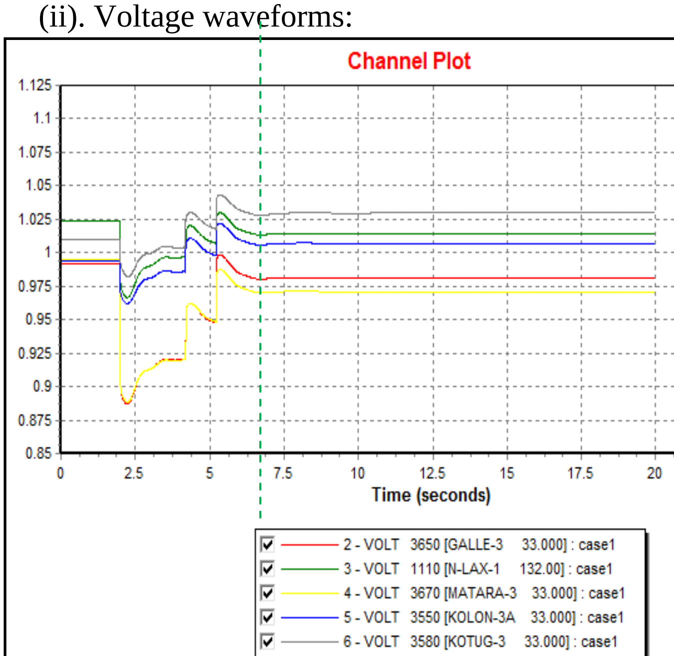


Figure 4.16 Voltage waveforms obtained under UFLS for CASE STUDY-01

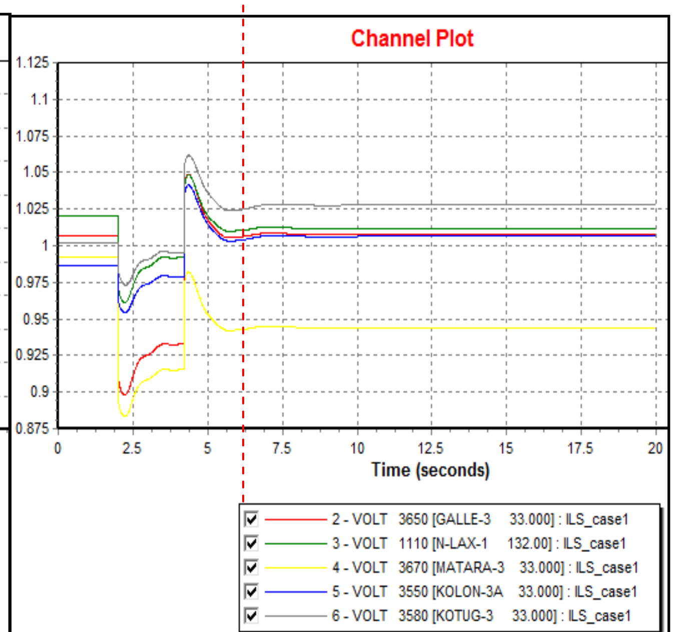


Figure 4.17 Voltage waveforms obtained under ILS for CASE STUDY-01

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:

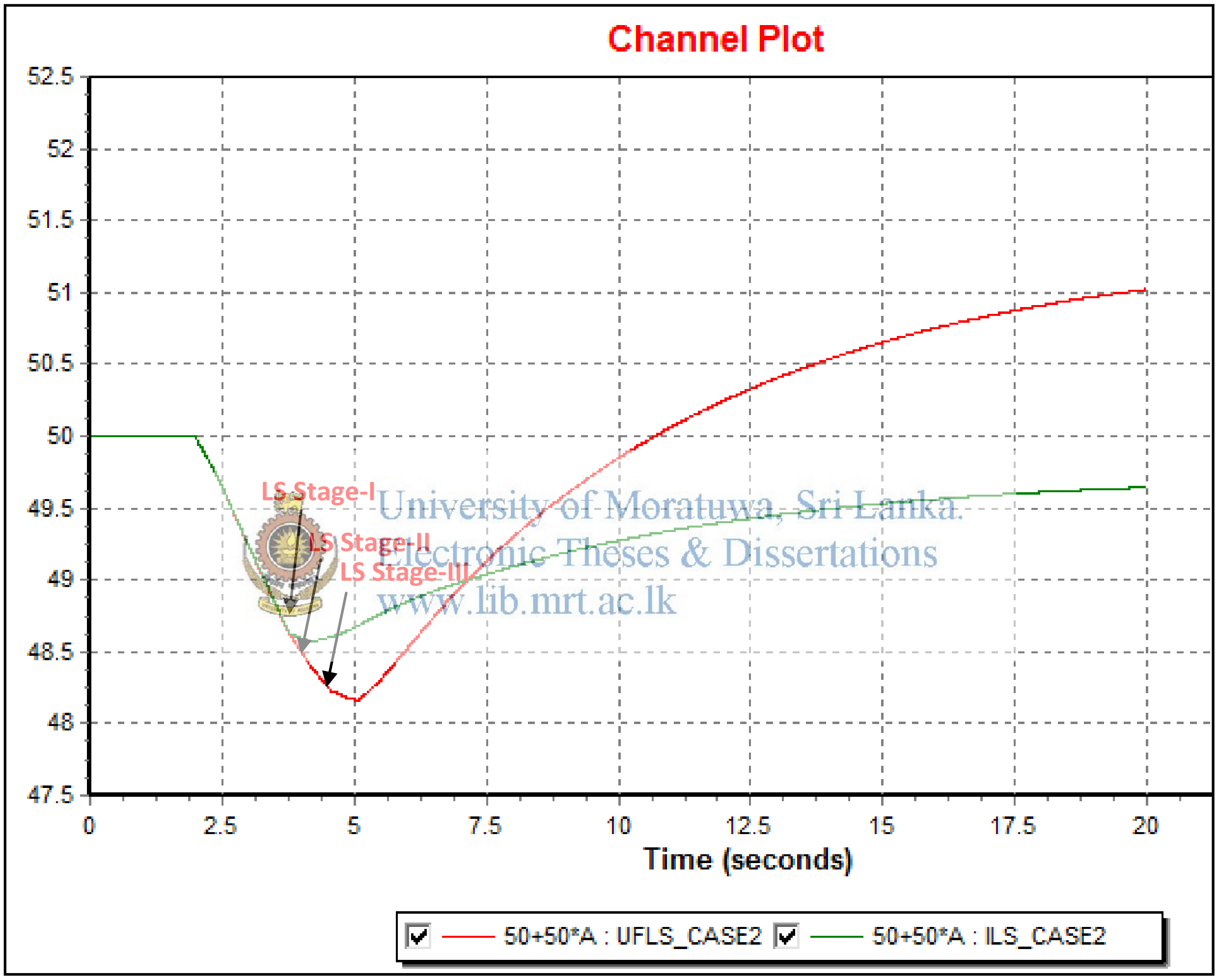
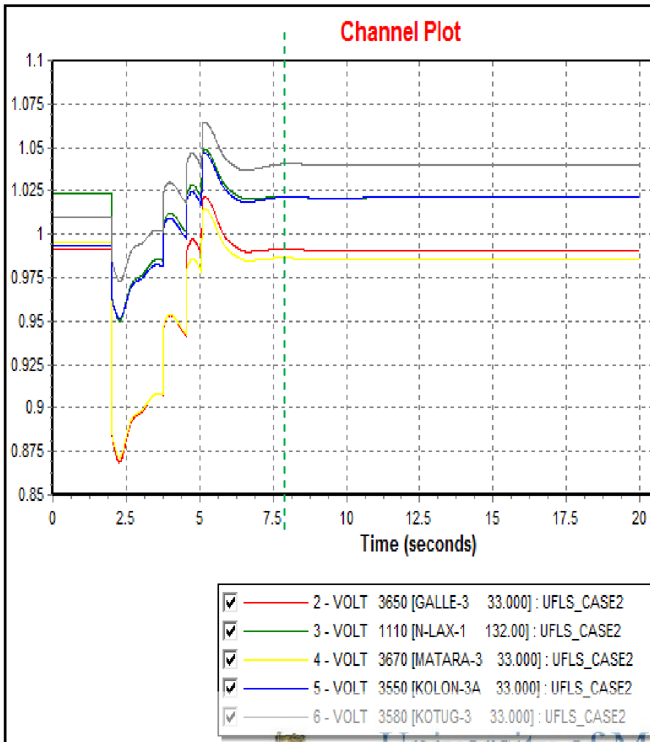


Figure 4.18 Frequency waveforms obtained through application of UFLS and ILS for case study-02

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:



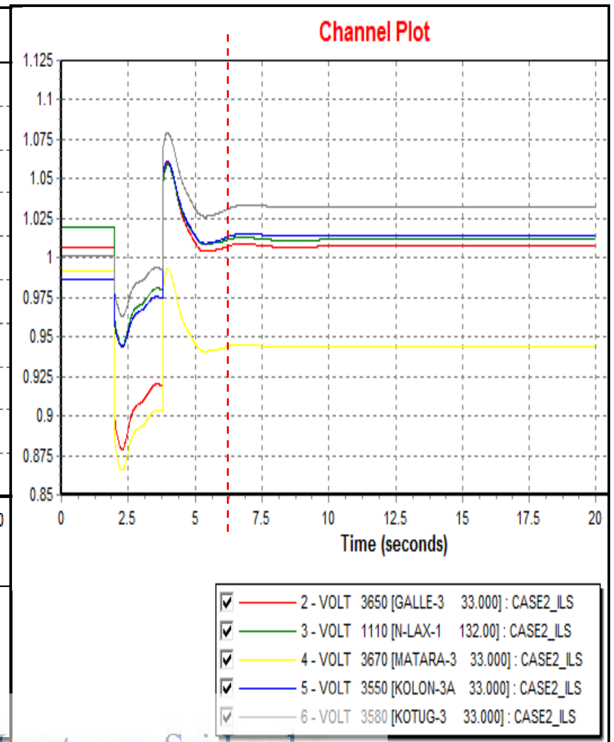


Figure 4.19 Voltage waveforms obtained under UFLS for CASE STUDY-02

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:

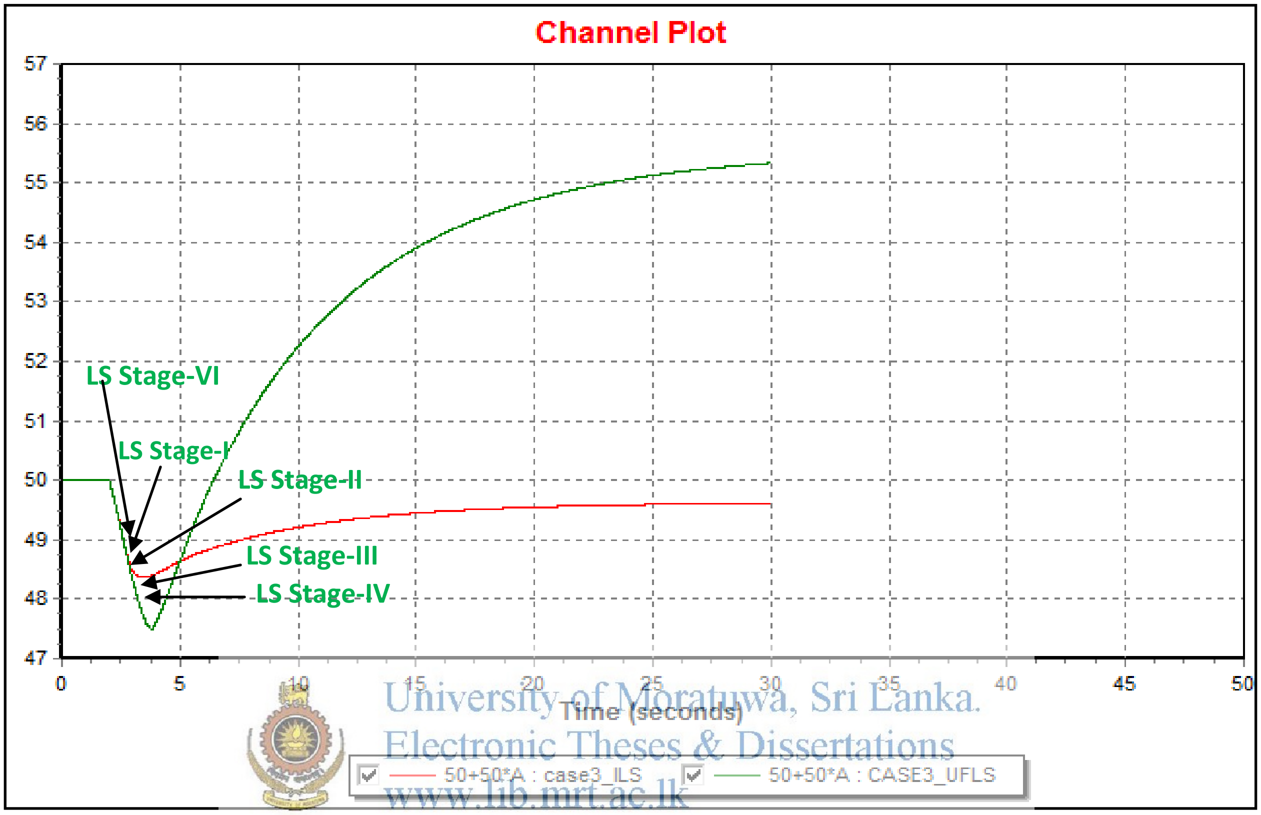


Figure 4.21 Frequency waveforms obtained through application of UFLS and ILS for case study-03

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:

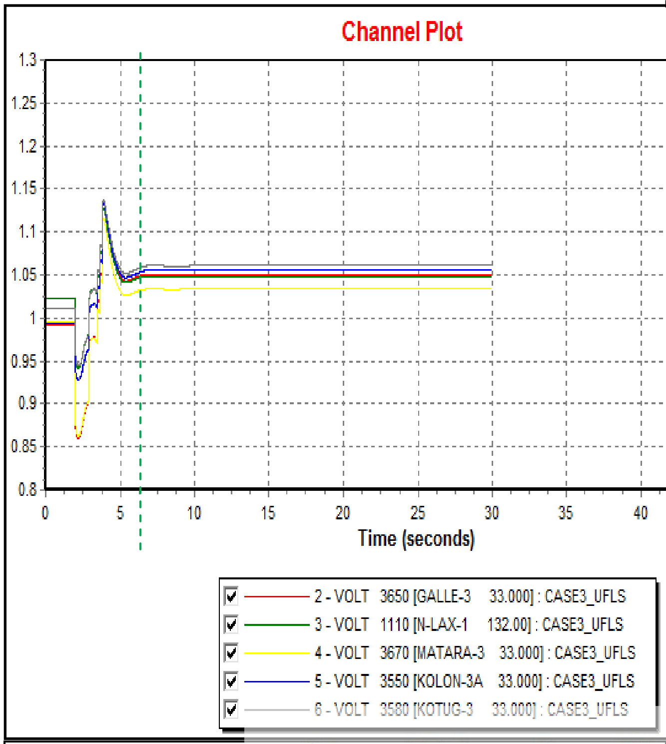


Figure 4.22 Voltage waveforms obtained under UFLS for CASE STUDY-03

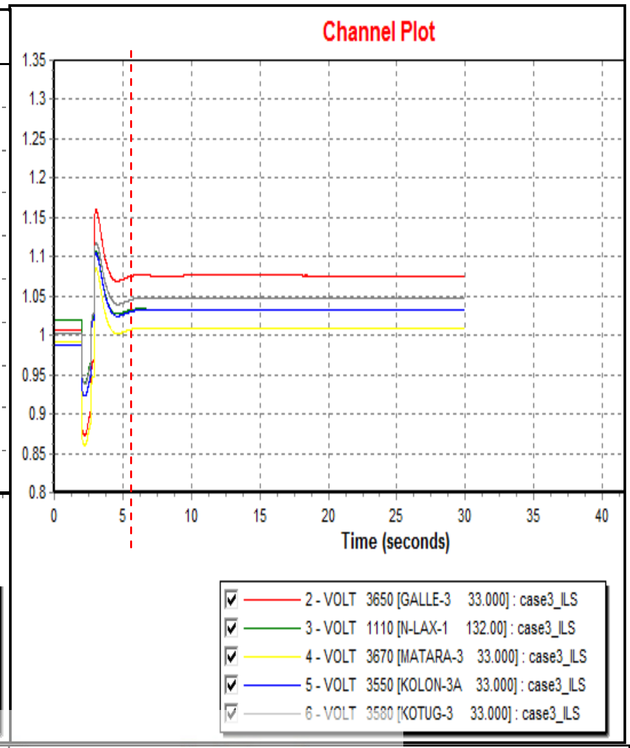


Figure 4.23 Voltage waveforms obtained under ILS for CASE STUDY-03

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:

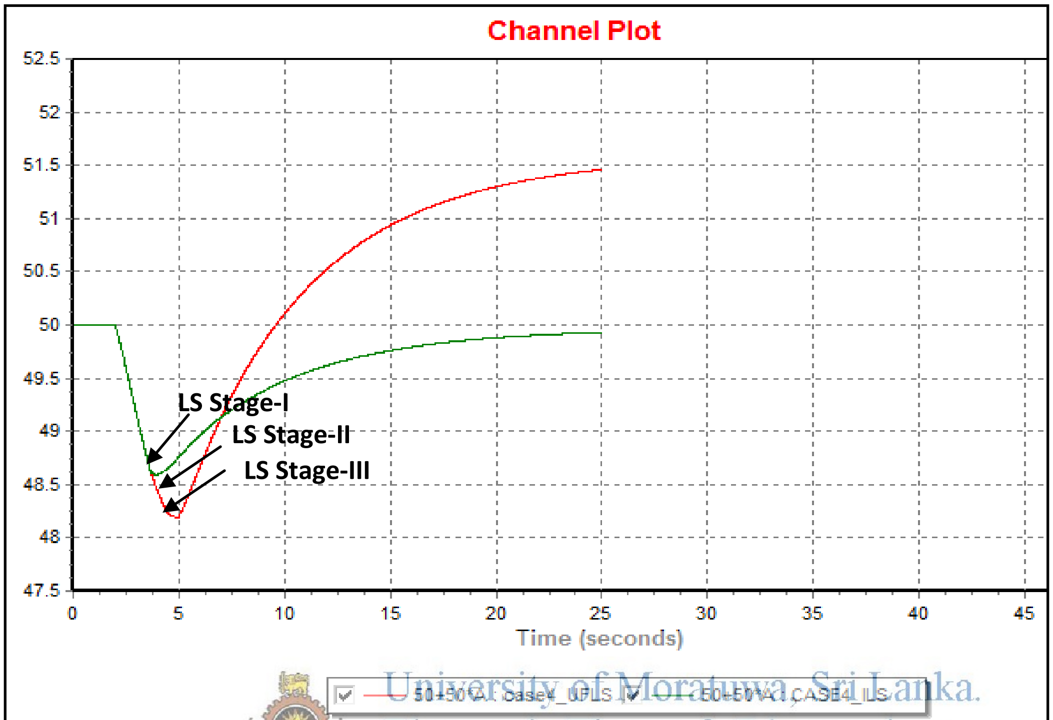
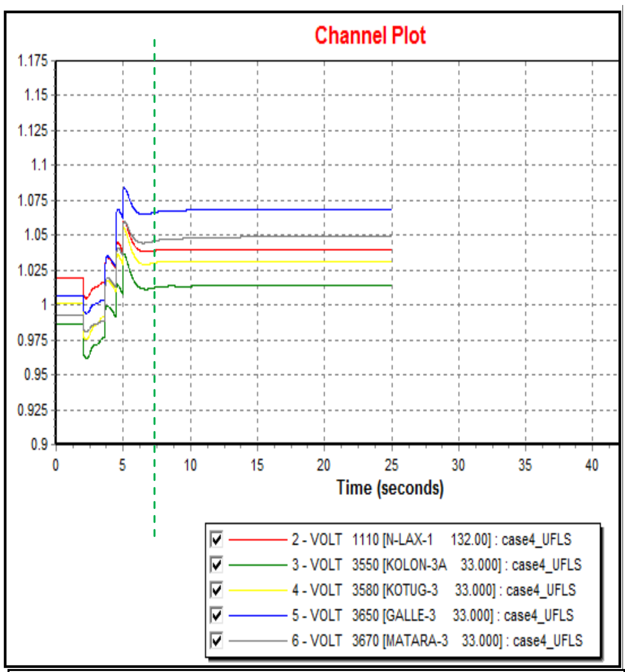


Figure 4.24 Frequency waveforms obtained through application of UFLS and ILS for case study-04

(ii). Voltage waveforms:



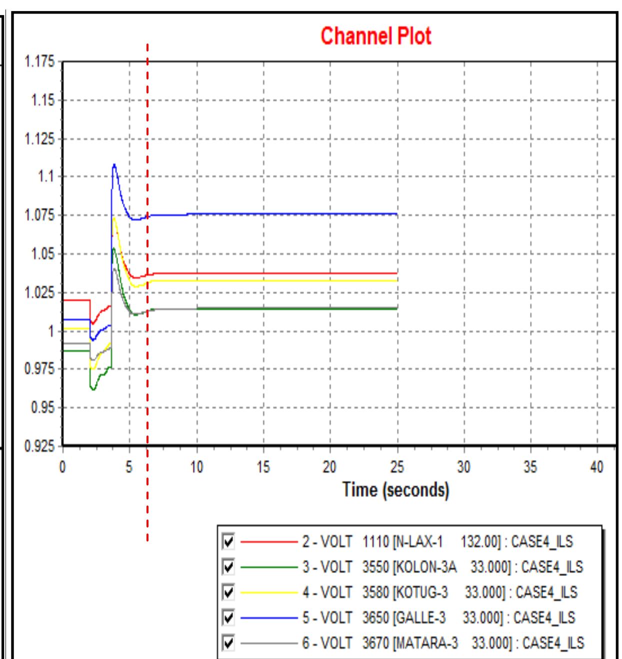


Figure 4.25 Voltage waveforms obtained under UFLS for CASE STUDY-04

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) CASE STUDY-01

(a). Application of UFLS:

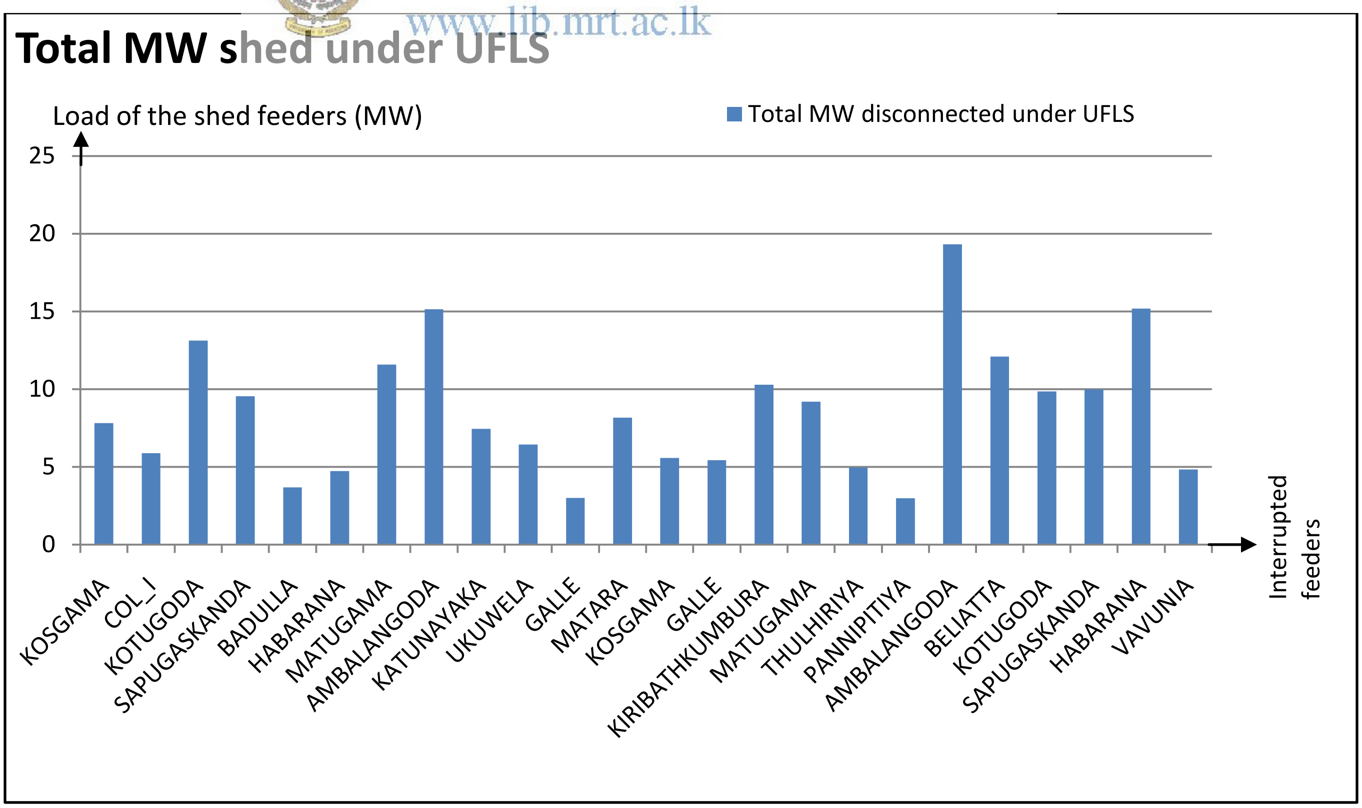


Figure 4.27 Total MW shed under UFLS for CASE STUDY-01

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:

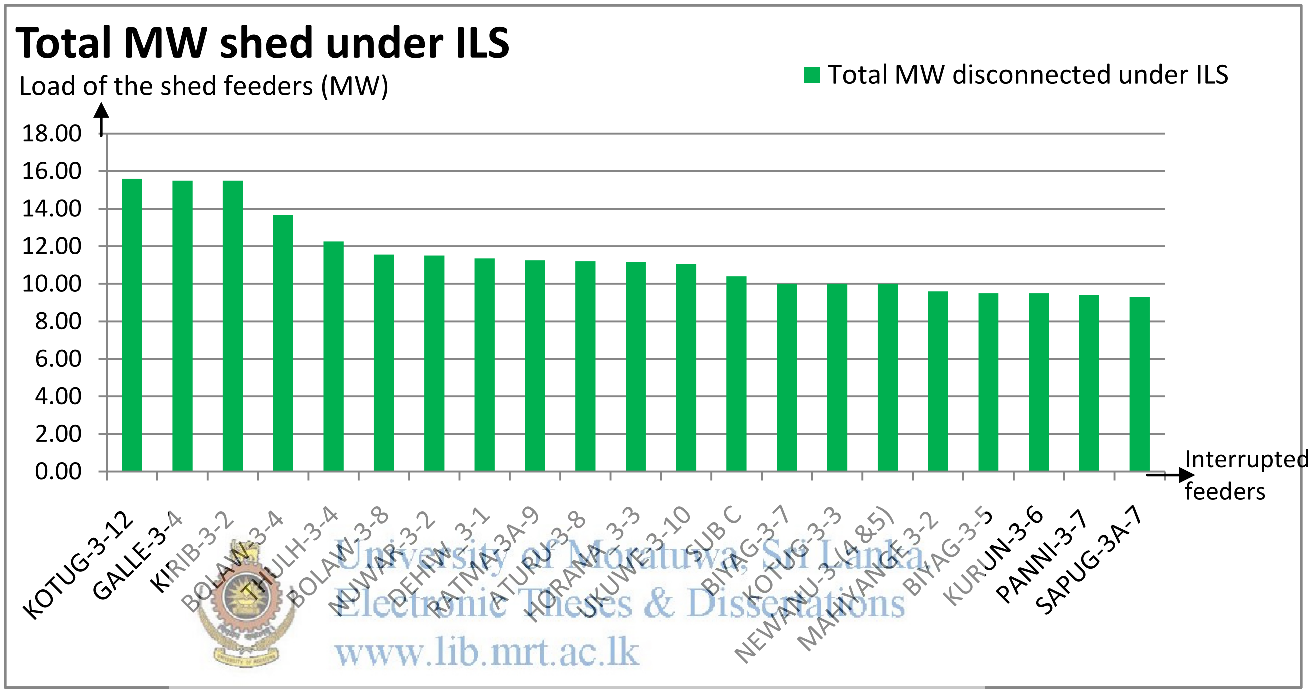


Figure 4.28 Total MW shed under ILS for CASE STUDY-01

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:

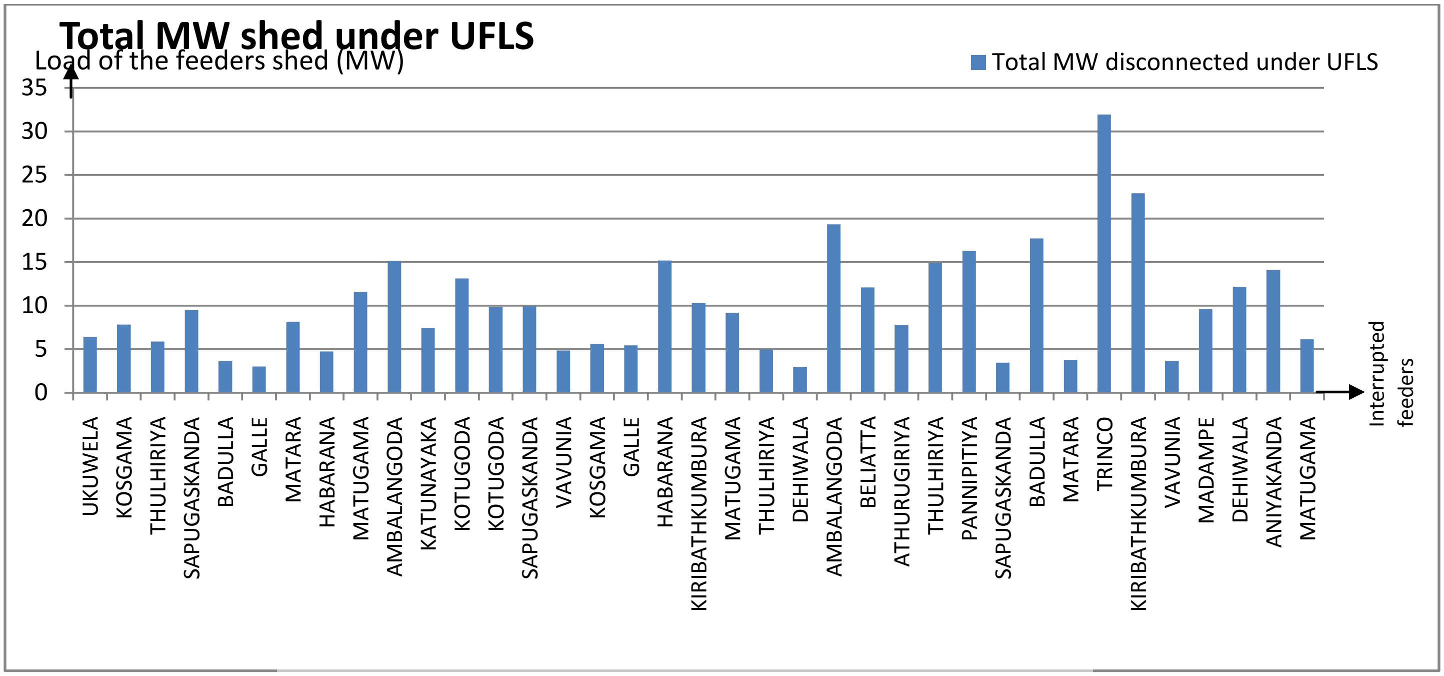


Figure 4.29 Total MW shed under UFLS for CASE STUDY-02

(b). Application of ILS:

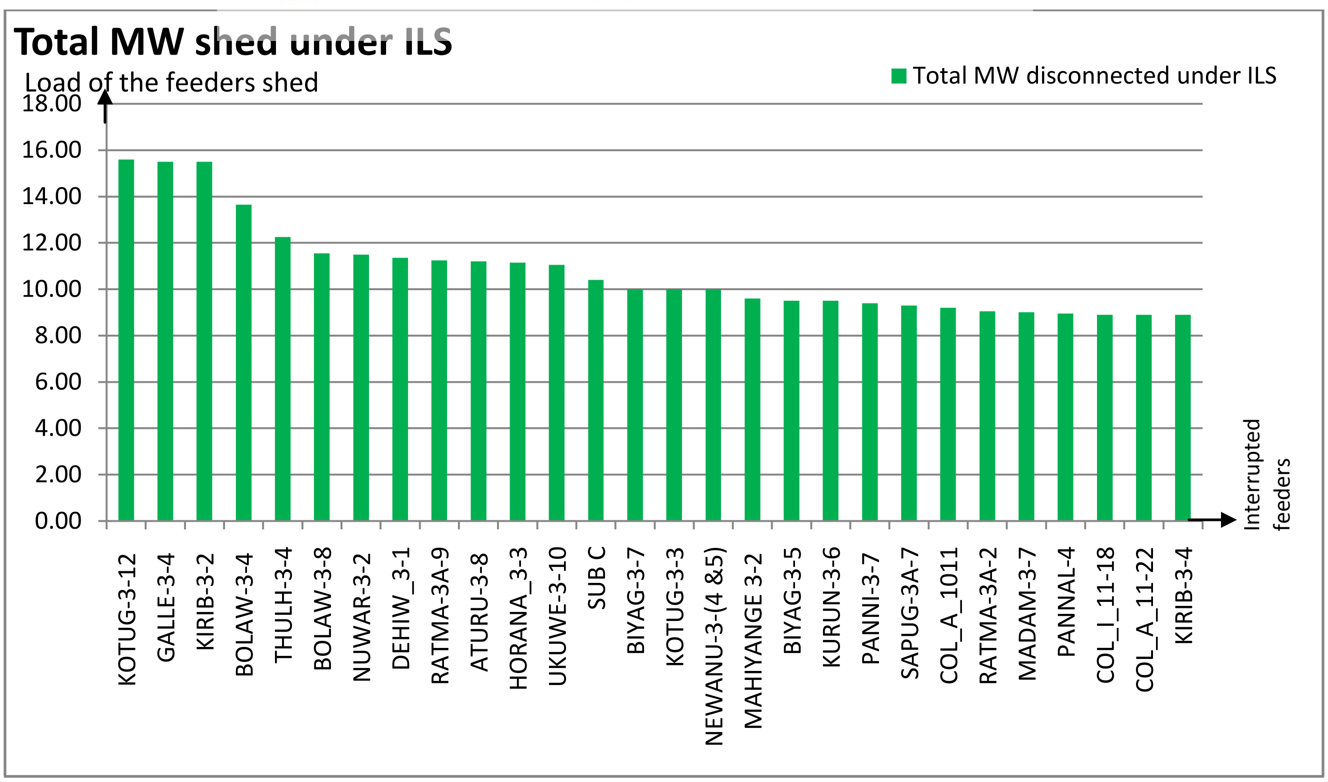


Figure 4.30 Total MW shed under ILS for CASE STUDY-02

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) CASE STUDY-03

(a). Application of UFLS:

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

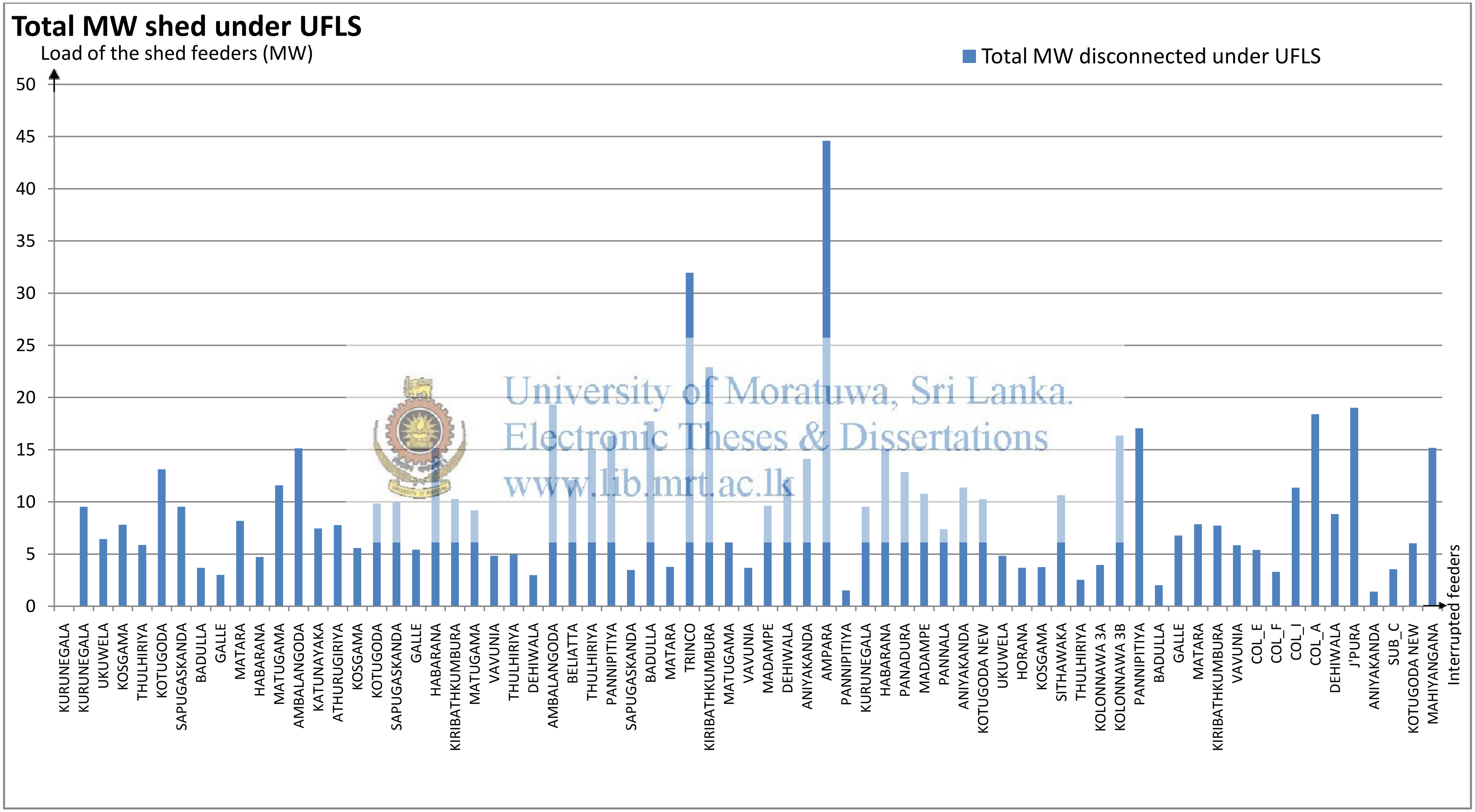


Figure 4.31 Total MW shed under UFLS for CASE STUDY-03

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;

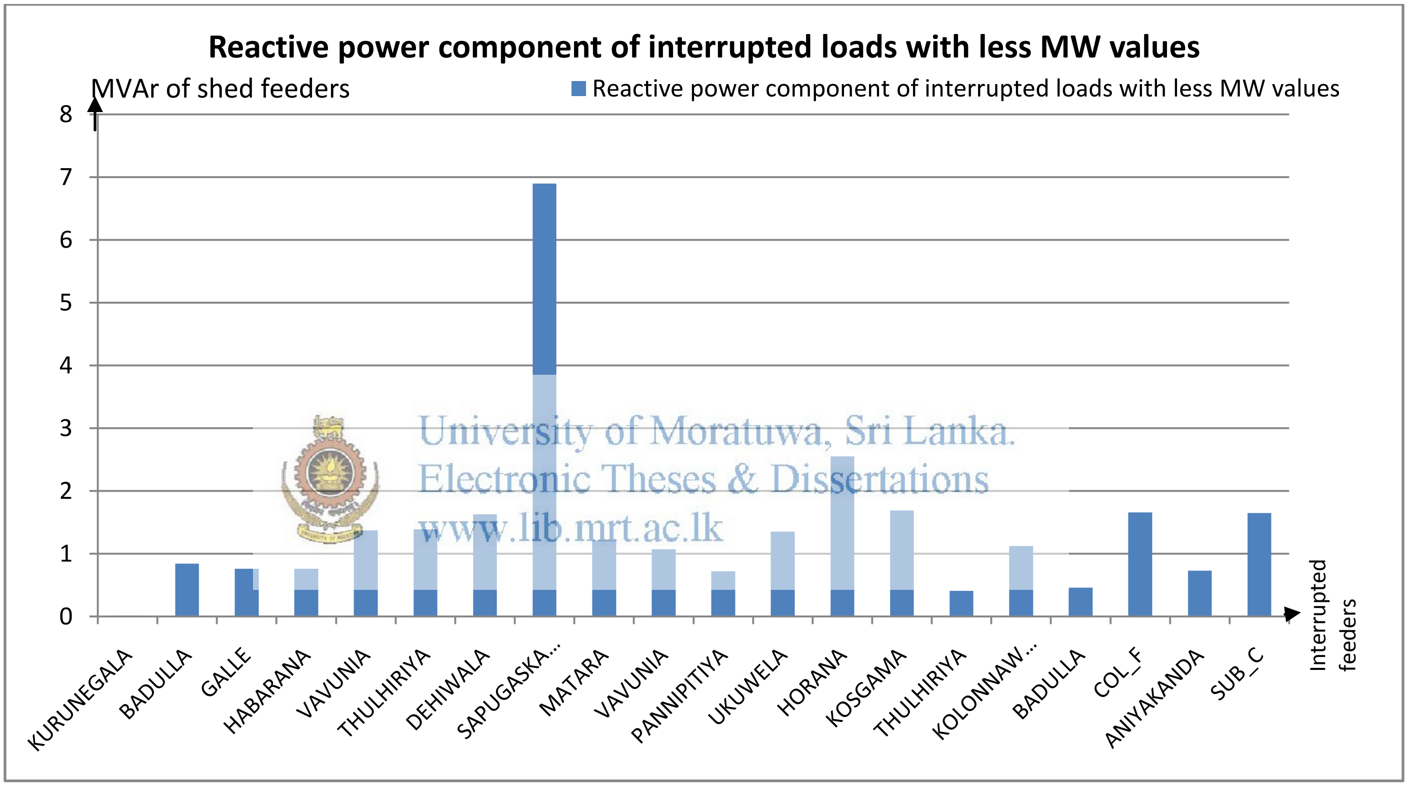


Figure 4.32 Reactive power components of interrupted feeders with less MW values under UFLS for CASE STUDY-03

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).

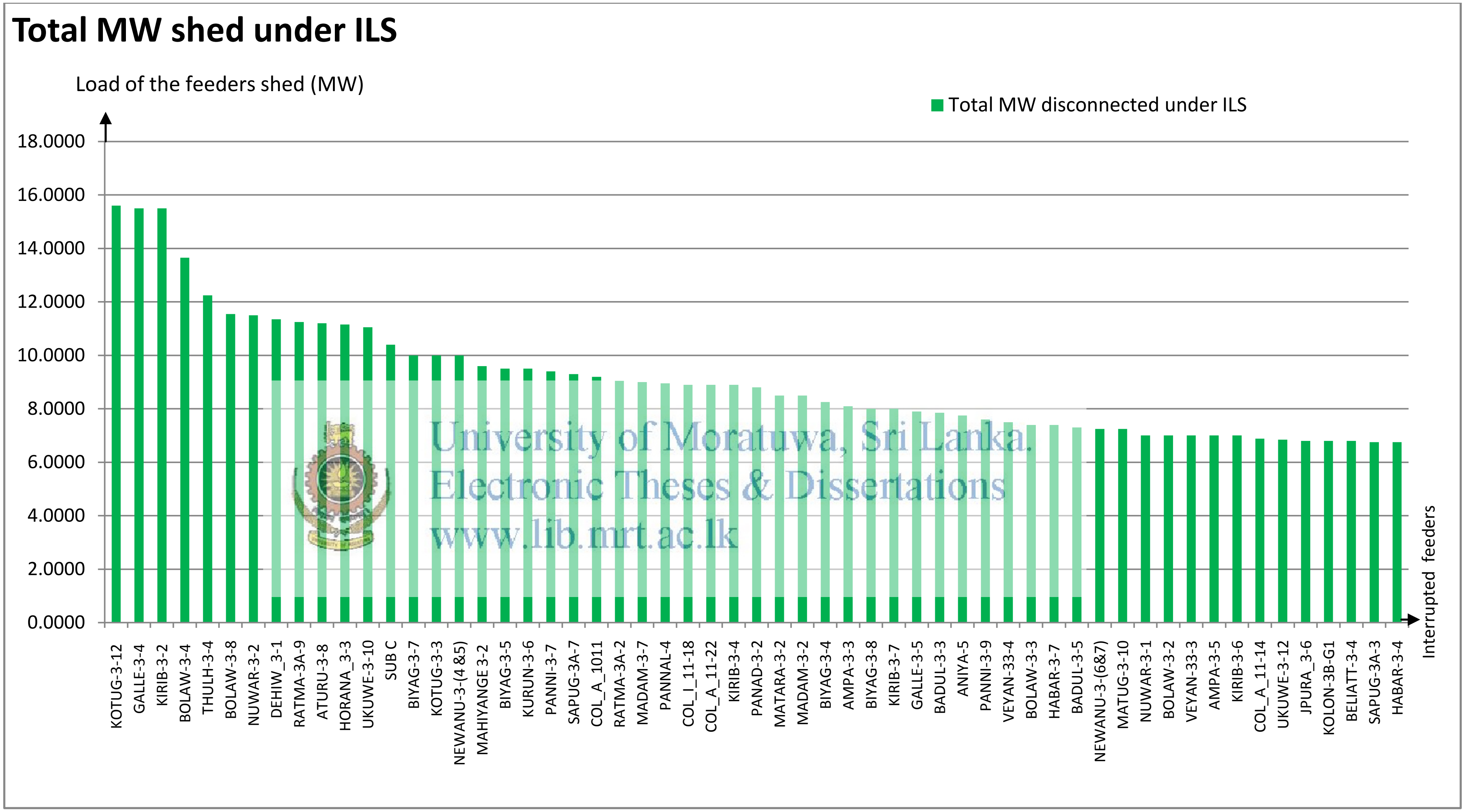


Figure 4.33 Total MW shed under ILS for CASE STUDY-03

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

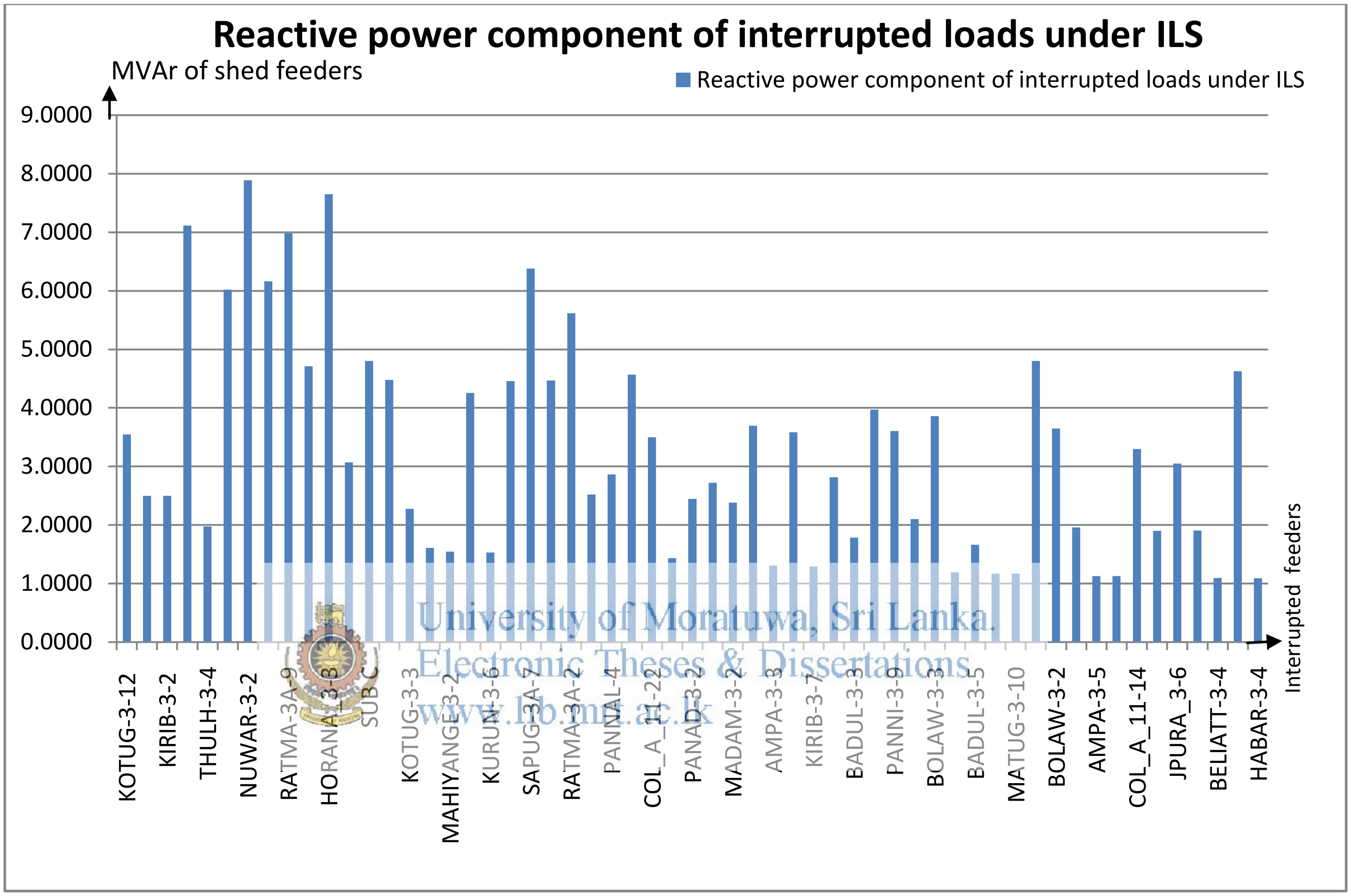


Figure 4.34 Reactive power components of interrupted feeders under ILS for CASE STUDY-03

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.