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.

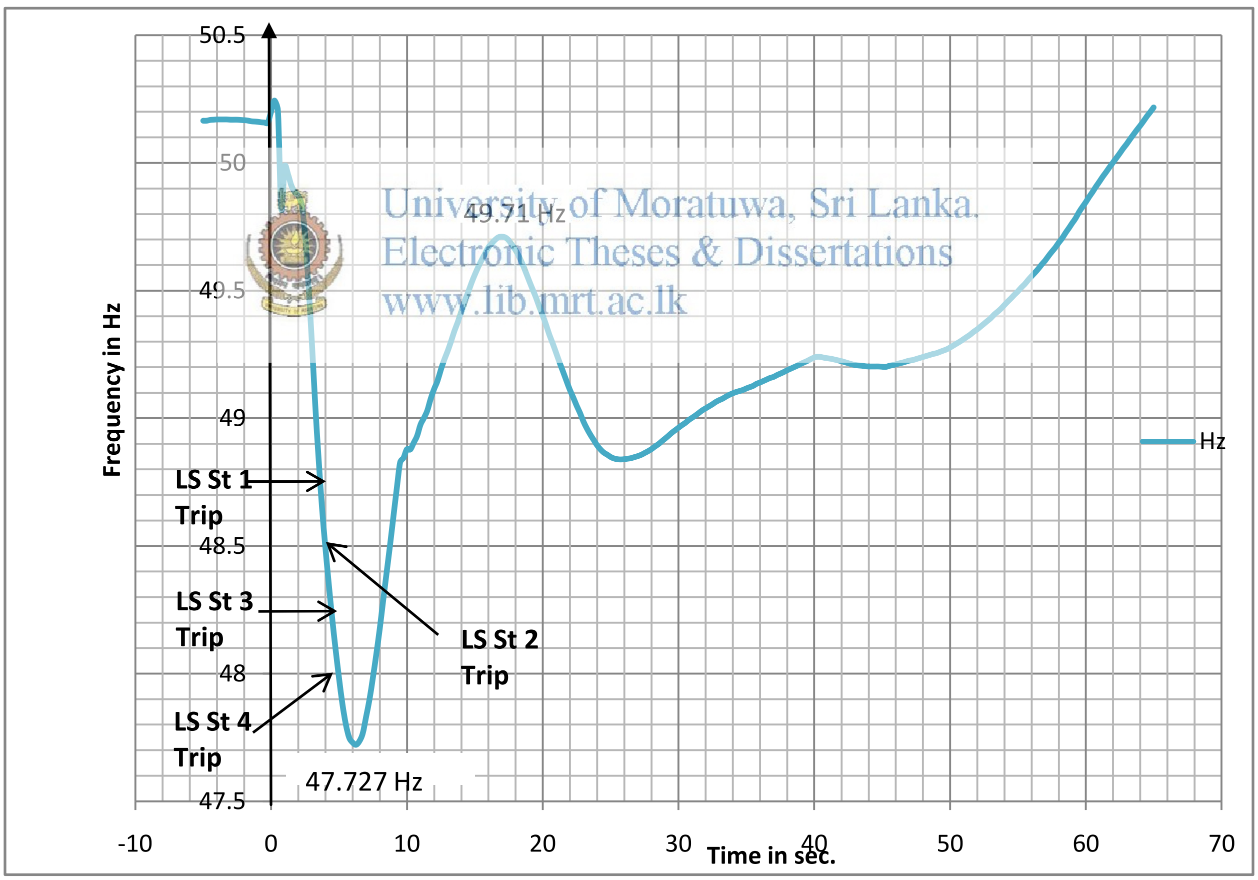

Figure 2.1 Frequency plot of 132kV Sub C feeder at Kolonnawa GIS on 06th May 2013 at 20:41:39 hrs

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

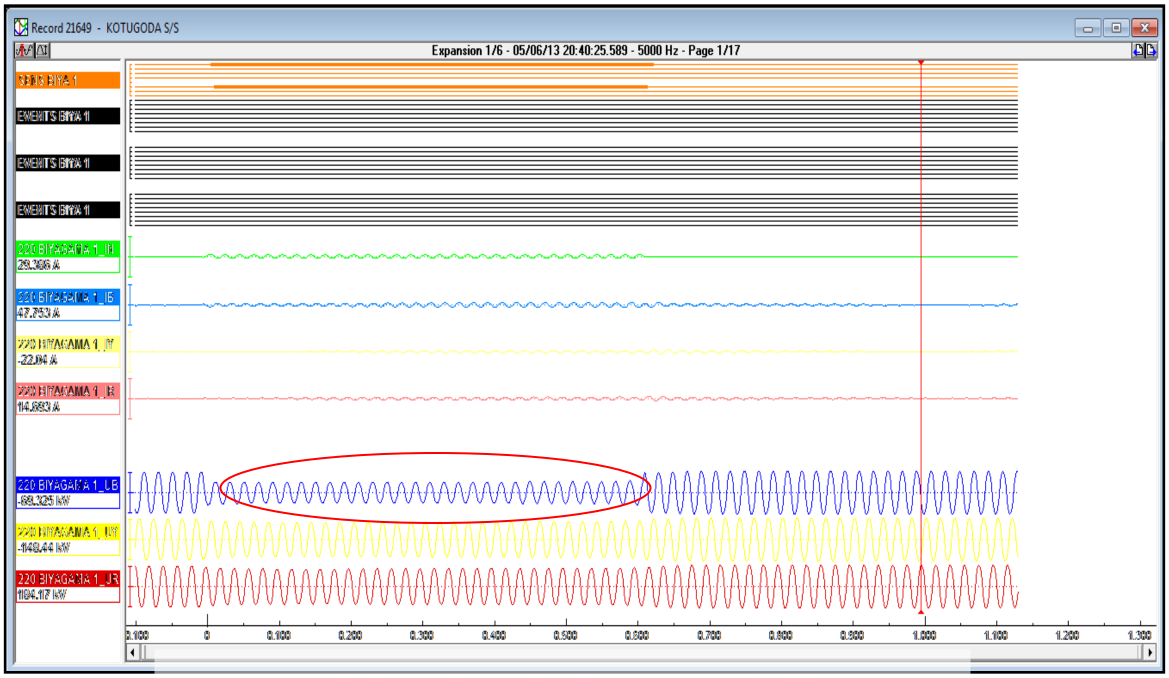

Figure 2.2 DFR record at Kotugoda GSS at 20:41 hrs

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

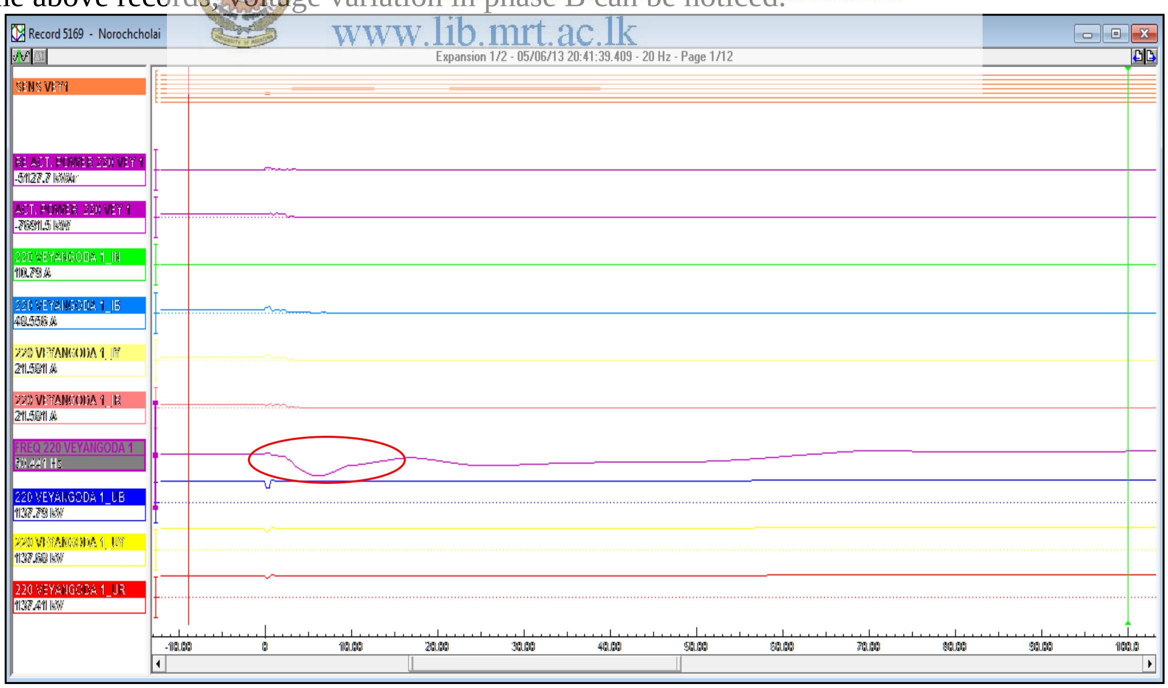

Figure 2.3 DFR record at Lakvijaya power station at 20:41 hrs

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.

- **Loss of Generation**

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		**203.00**	**160.00**

Total generation loss = 363 MW

- **Tripping of load**

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;

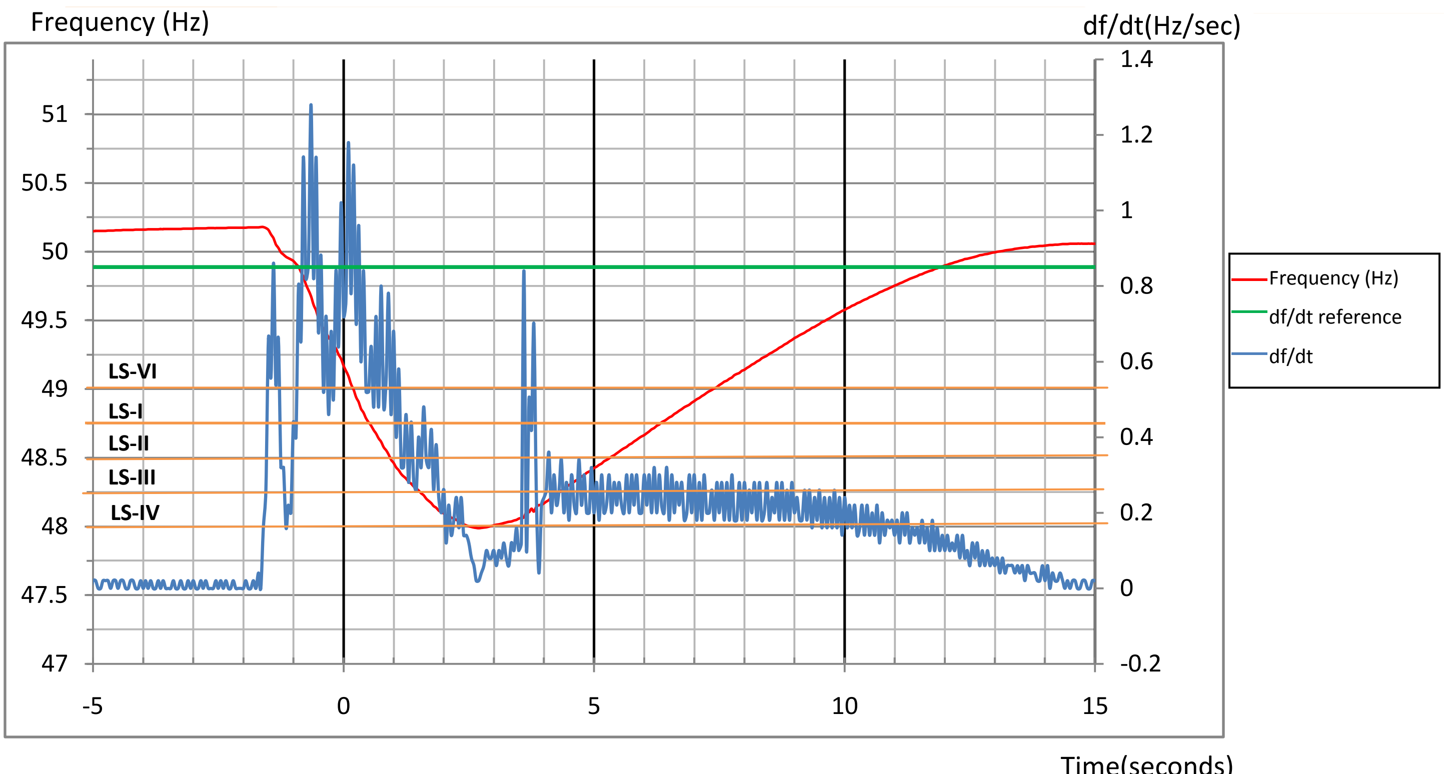

Figure 2.4 Frequency plot at 15:27 hours on 29th October 2013

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

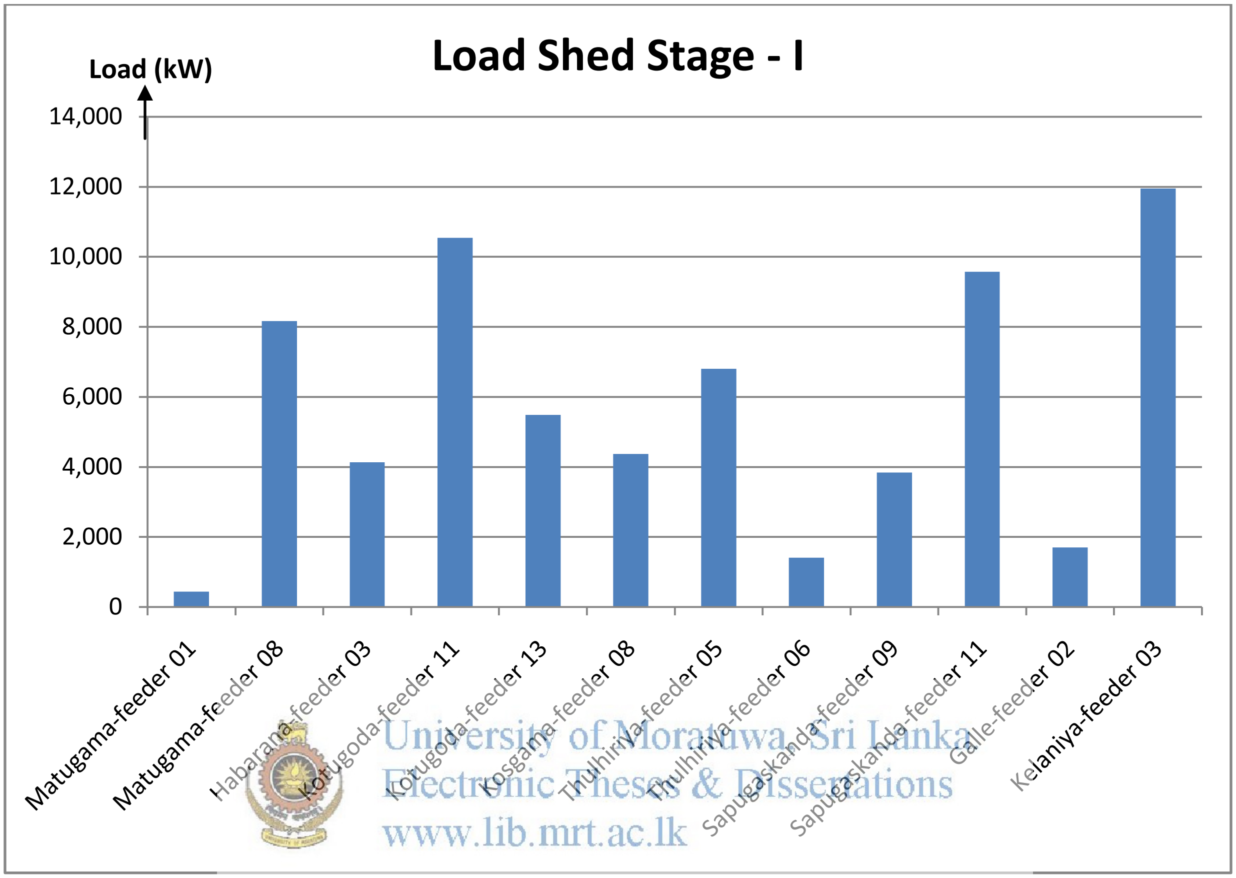

Figure 2.5 Load of the feeders shed under load shedding stage-I

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.

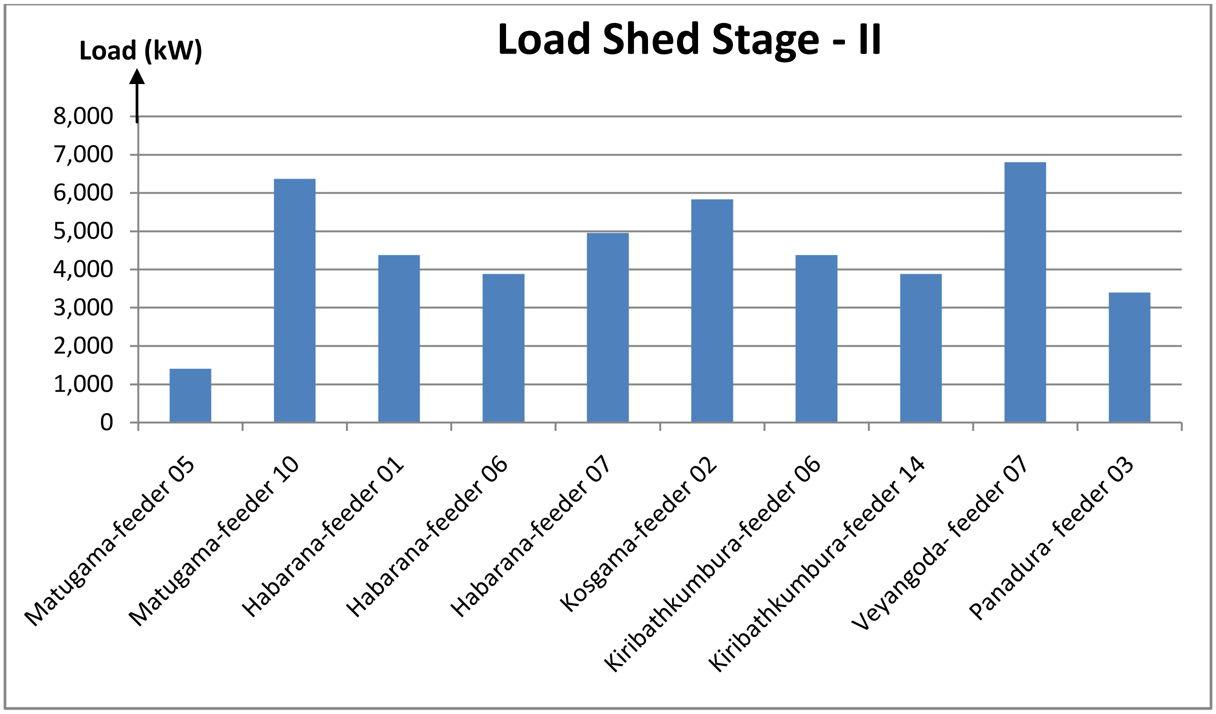

Figure 2.6 Load of the feeders shed under load shedding stage-II

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

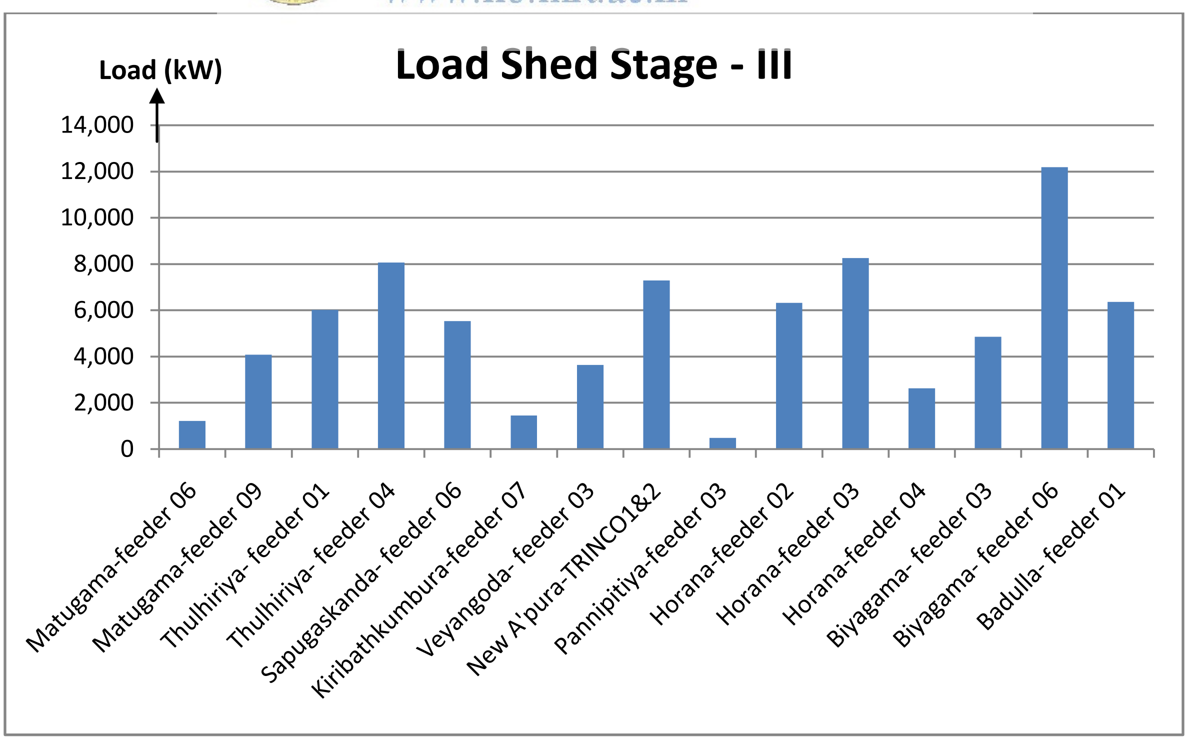

Figure 2.7 Load of the feeders shed under load shedding stage-III

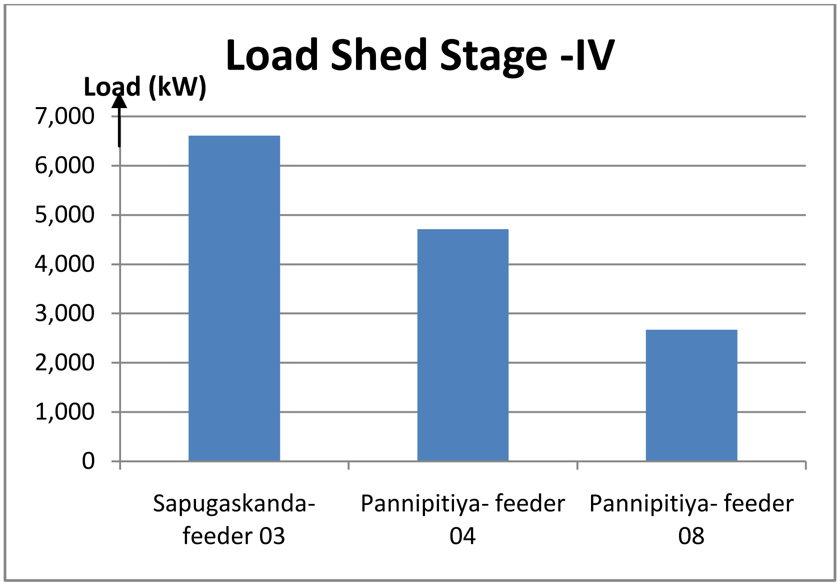

Figure 2.8 Load of the feeders shed under load shedding stage-IV

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].