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;
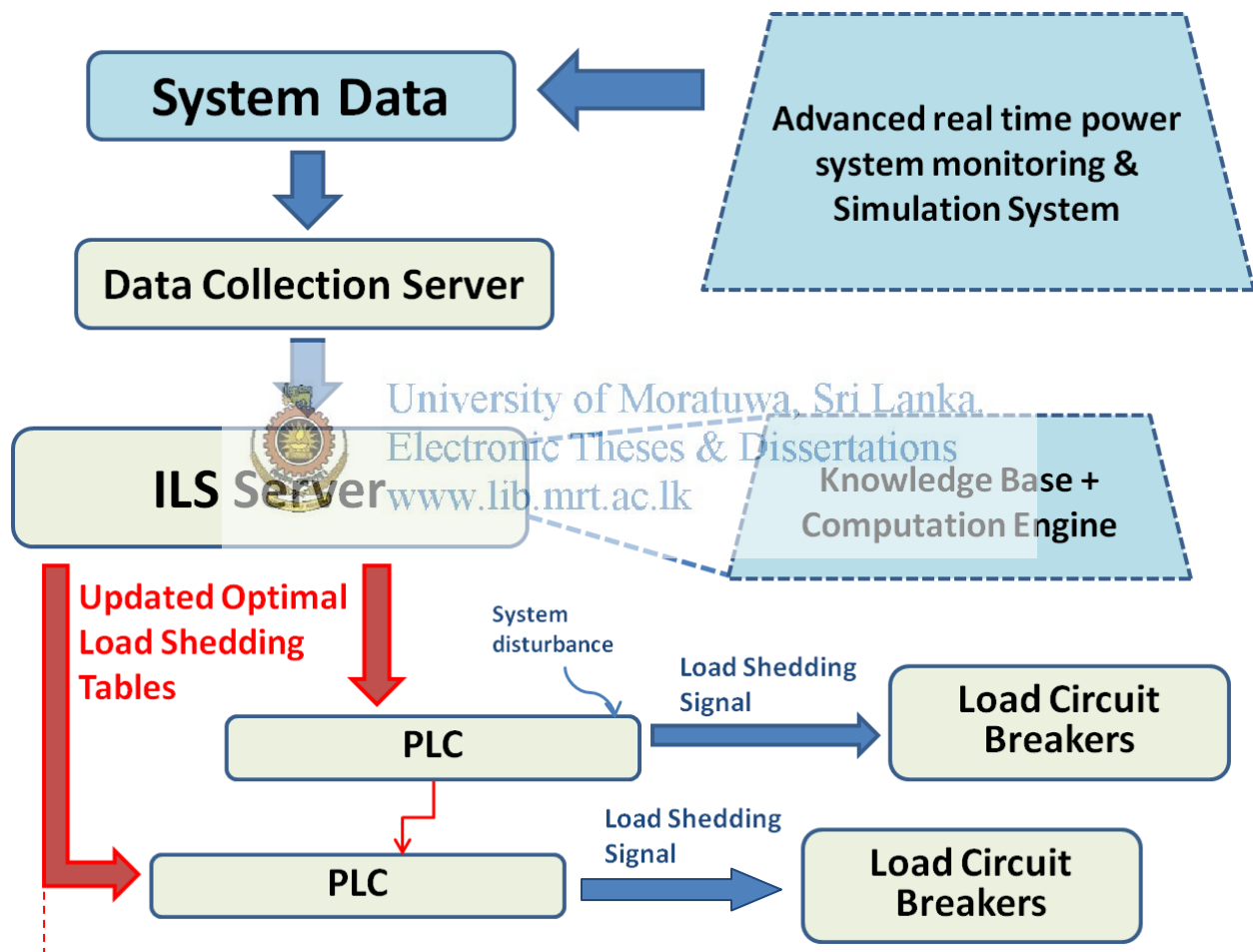

Figure 3.1   Basic representation of intelligent load shedding system

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;
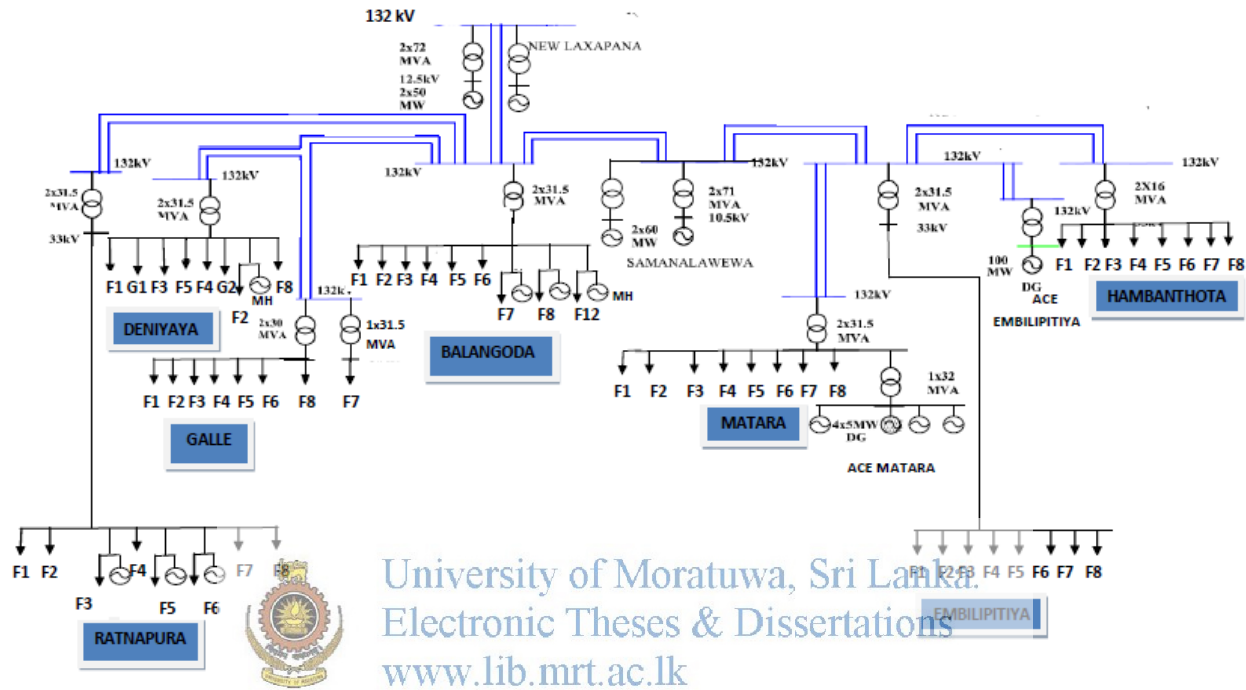
Figure 3.2   Selected network for MATLAB modeling

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	$y= 0.002x^2 +0.0042 x+7.5$	$y= -0.64 x^2 +35 x -227$	$y= 0.123 x^2 -0.7x+6.2$

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;

$$\cdot f_{new} = f_0 - \frac{df}{dt} \times (0.1)$$ 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.
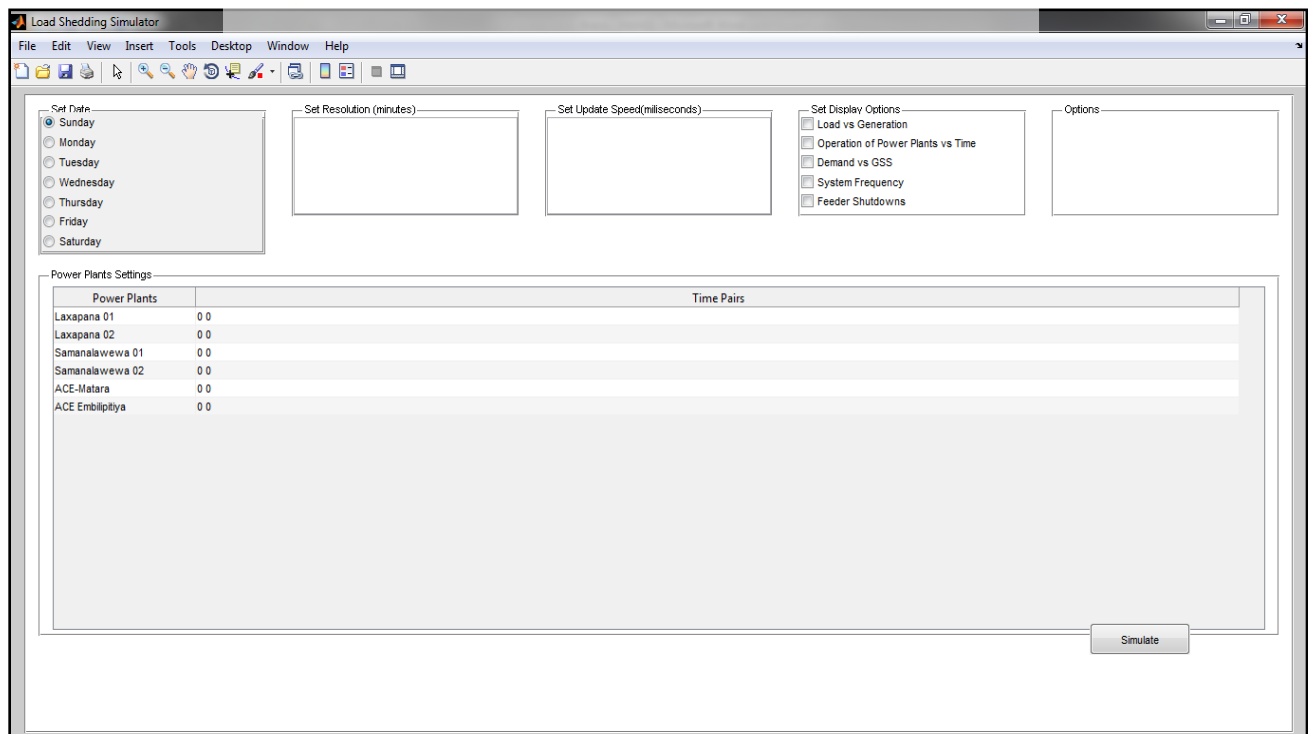
Figure 3.3   Graphical User Interface (GUI)

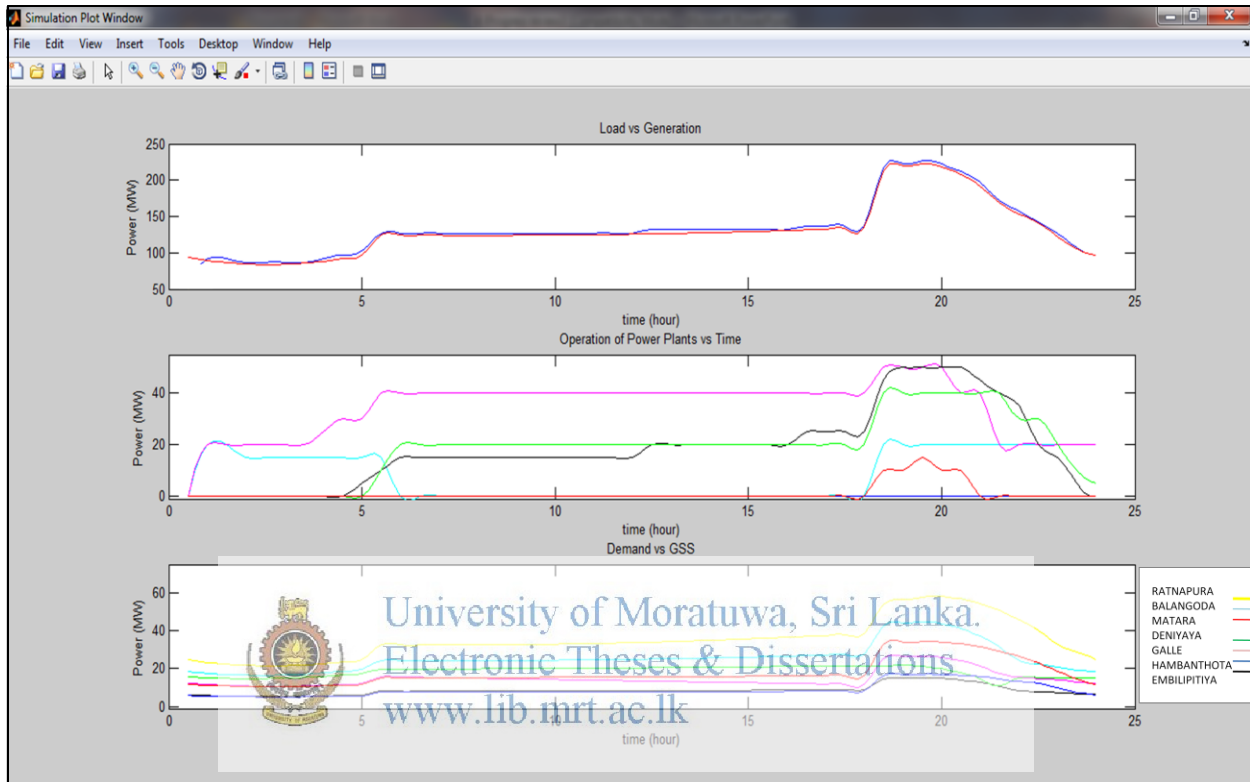Imported data into MATLAB software can be accessed as below;

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.

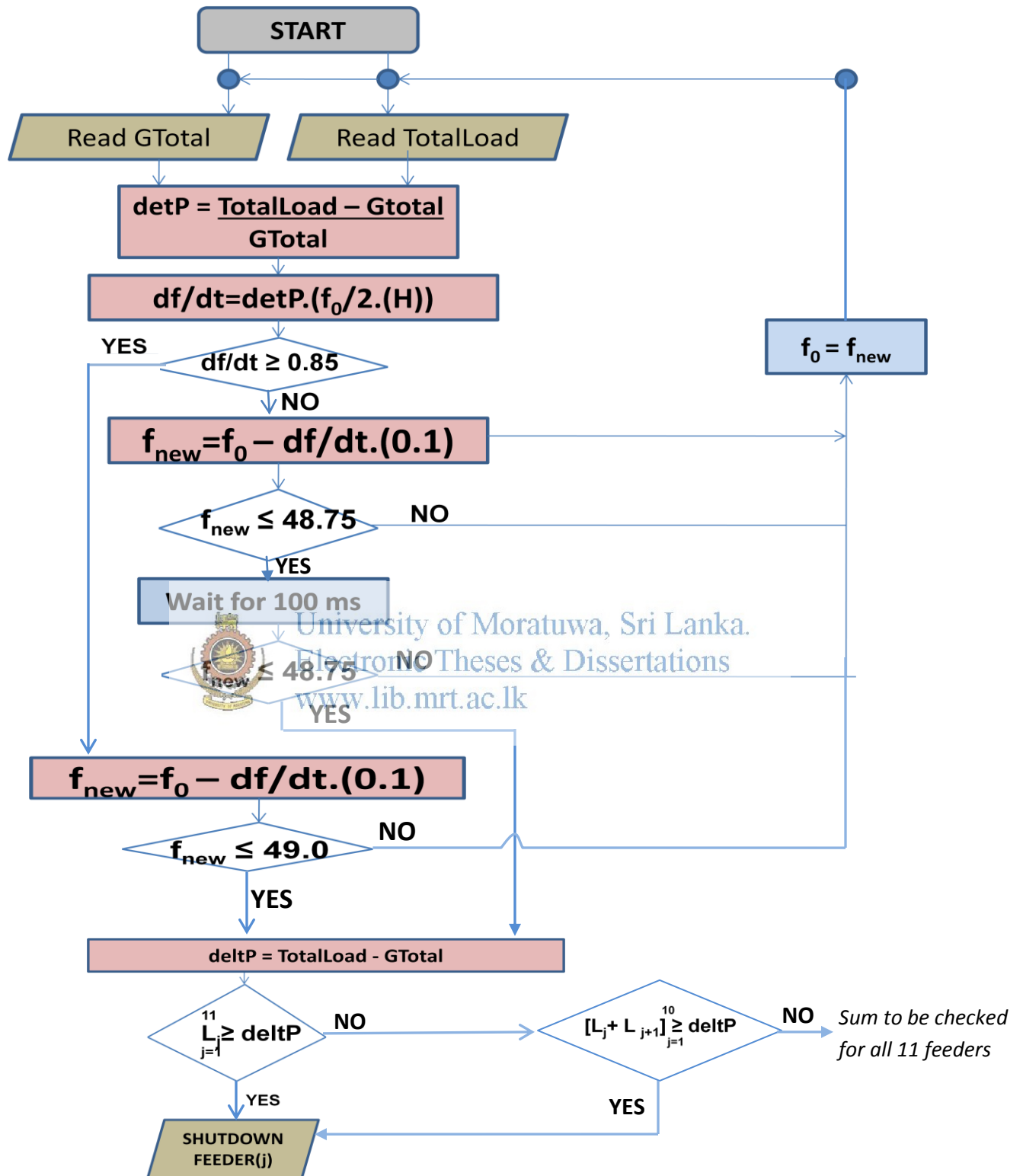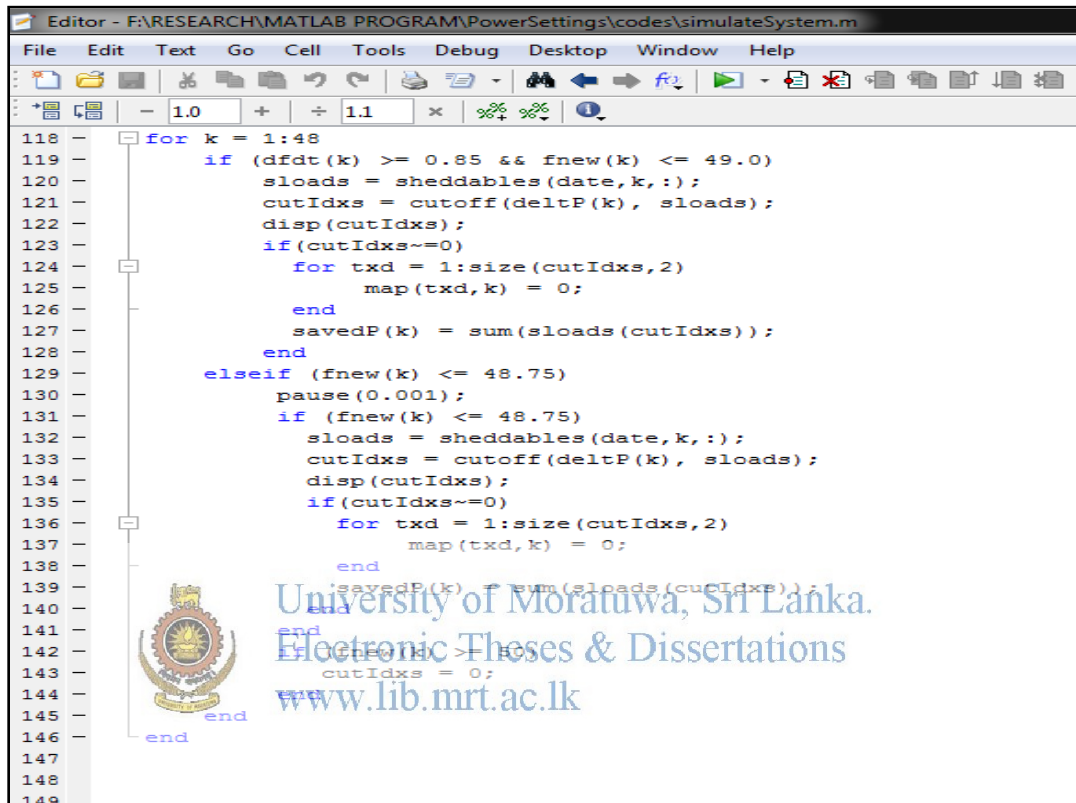Flow chart representation is illustrated below;

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;


```
118 -    □ for k = 1:48
119 -          if (dfdt(k) >= 0.85 && fnew(k) <= 49.0)
120 -              sloads = sheddables(date,k,:);
121 -              cutIdxs = cutoff(deltP(k), sloads);
122 -              disp(cutIdxs);
123 -              if(cutIdxs~=0)
124 -    □             for txd = 1:size(cutIdxs,2)
125 -                      map(txd,k) = 0;
126 -                  end
127 -                  savedP(k) = sum(sloads(cutIdxs));
128 -              end
129 -          elseif (fnew(k) <= 48.75)
130 -              pause(0.001);
131 -              if (fnew(k) <= 48.75)
132 -                  sloads = sheddables(date,k,:);
133 -                  cutIdxs = cutoff(deltP(k), sloads);
134 -                  disp(cutIdxs);
135 -                  if(cutIdxs~=0)
136 -    □                 for txd = 1:size(cutIdxs,2)
137 -                          map(txd,k) = 0;
138 -                      end
139 -                      savedP(k) = sum(sloads(cutIdxs));
140 -                  end
141 -              end
142 -          else
143 -              cutIdxs = 0;
144 -          end
145 -      end
146 -    └ end
147
148
149
```

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;
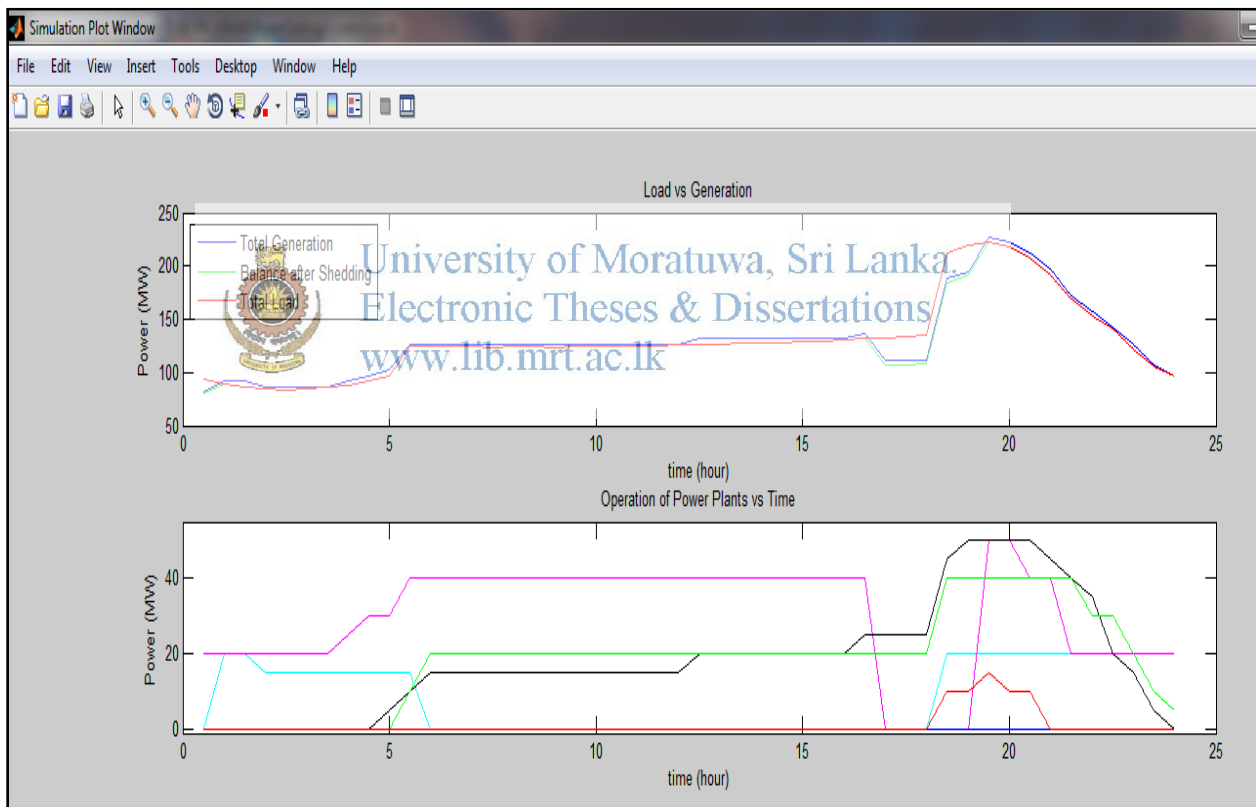

Figure 3.7   Plots of 'load and generation vs. time' and 'operation of power plants vs. time' for example-

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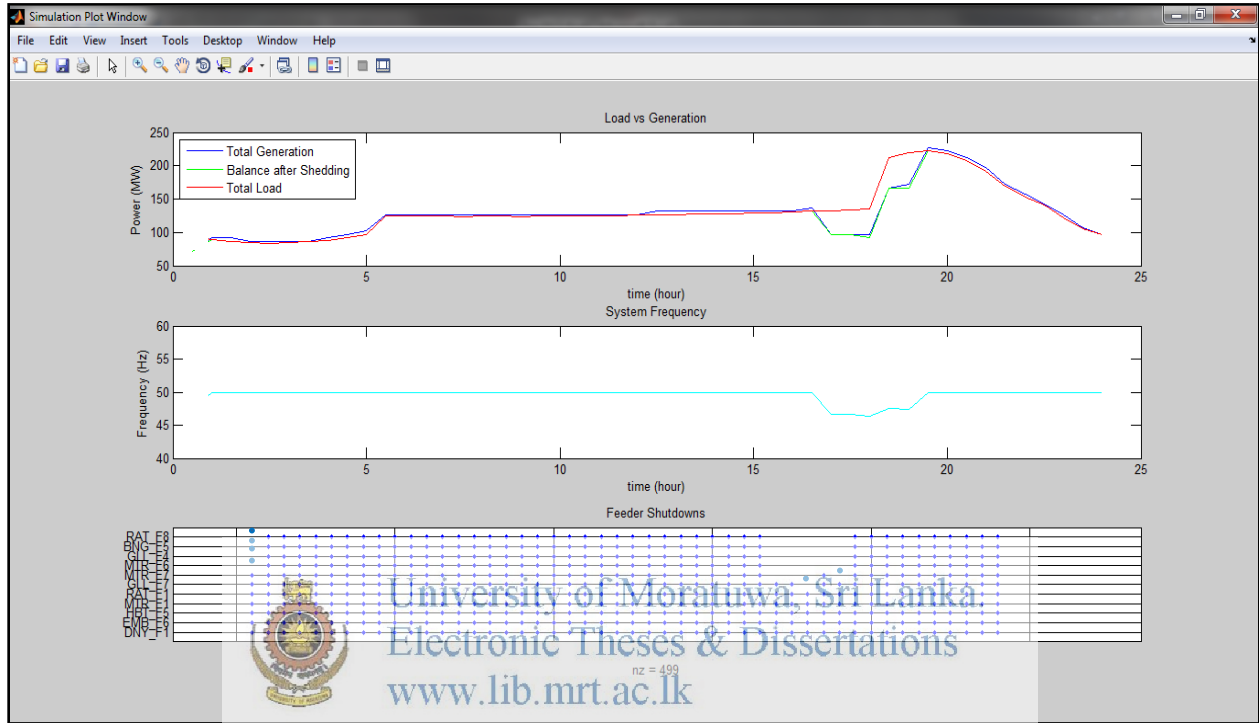
Figure 3.8   Plots of 'load and generation Vs. time', 'frequency Vs. time' and feeder shutdowns
For example-01

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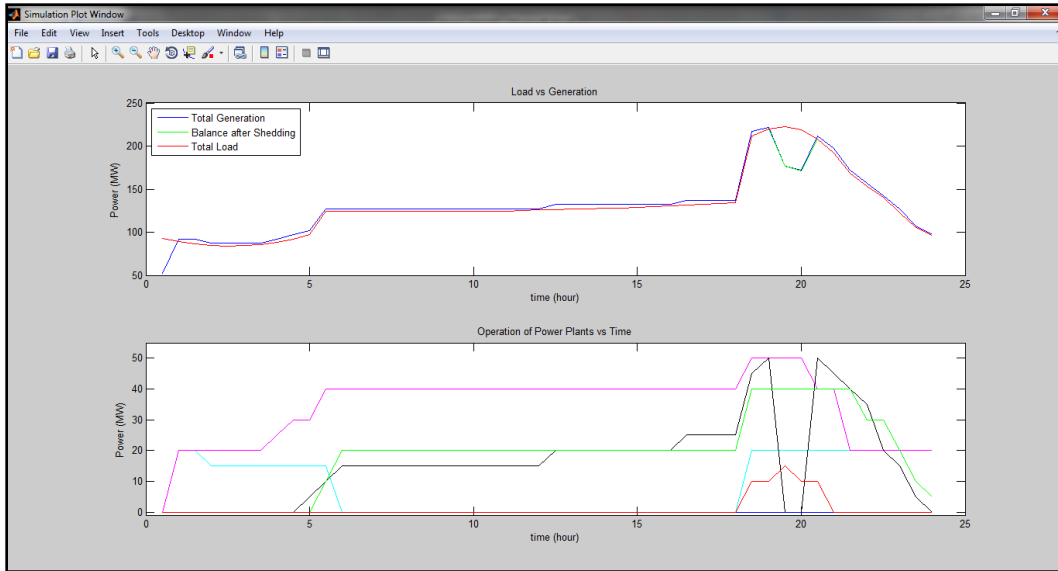
Figure 3.9   Plots of 'load and generation vs. time' and 'operation of power plants' for example-02

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;
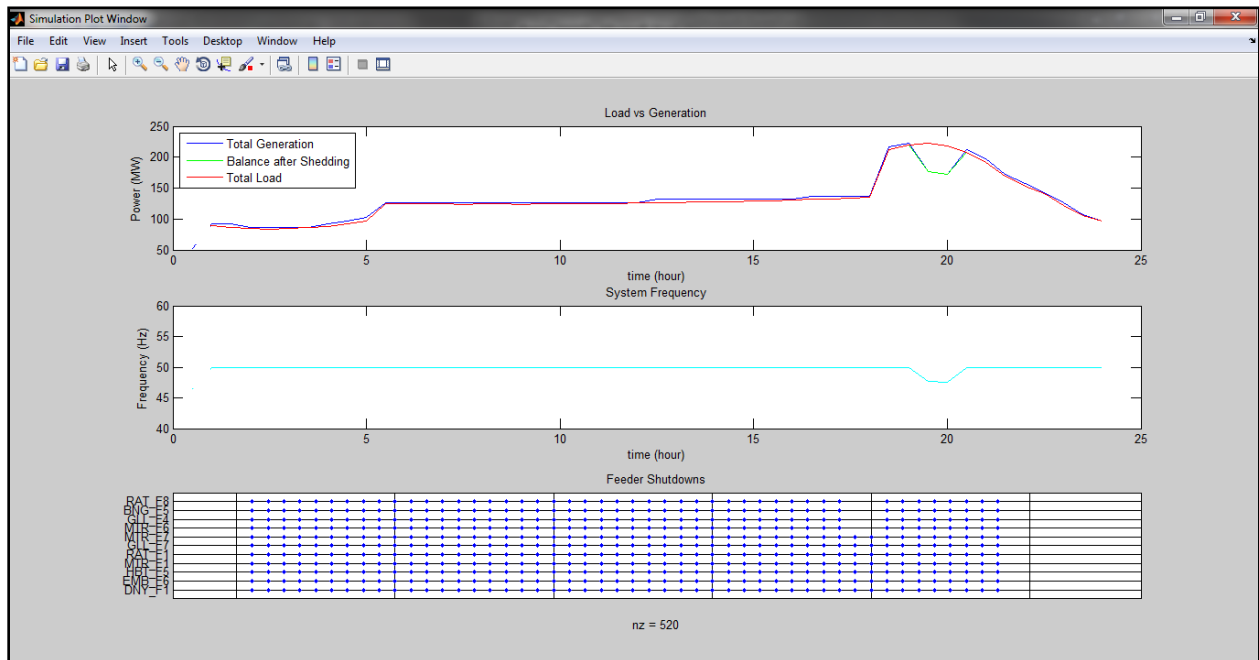

Figure 3.10   Plots of 'load and generation vs. time', 'frequency vs. time' and 'feeder shutdowns' for example-02

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;
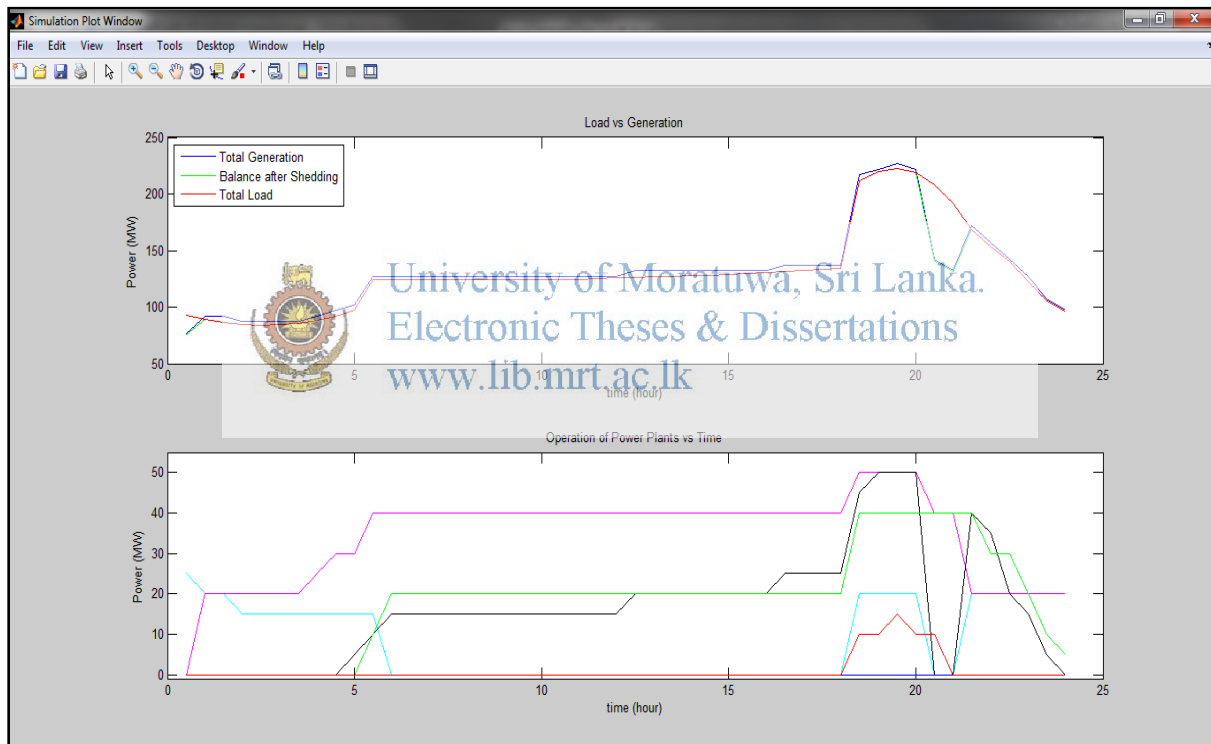

Figure 3.11   Plots of 'load and generation vs. time' and 'operation of power plants' for example-

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;
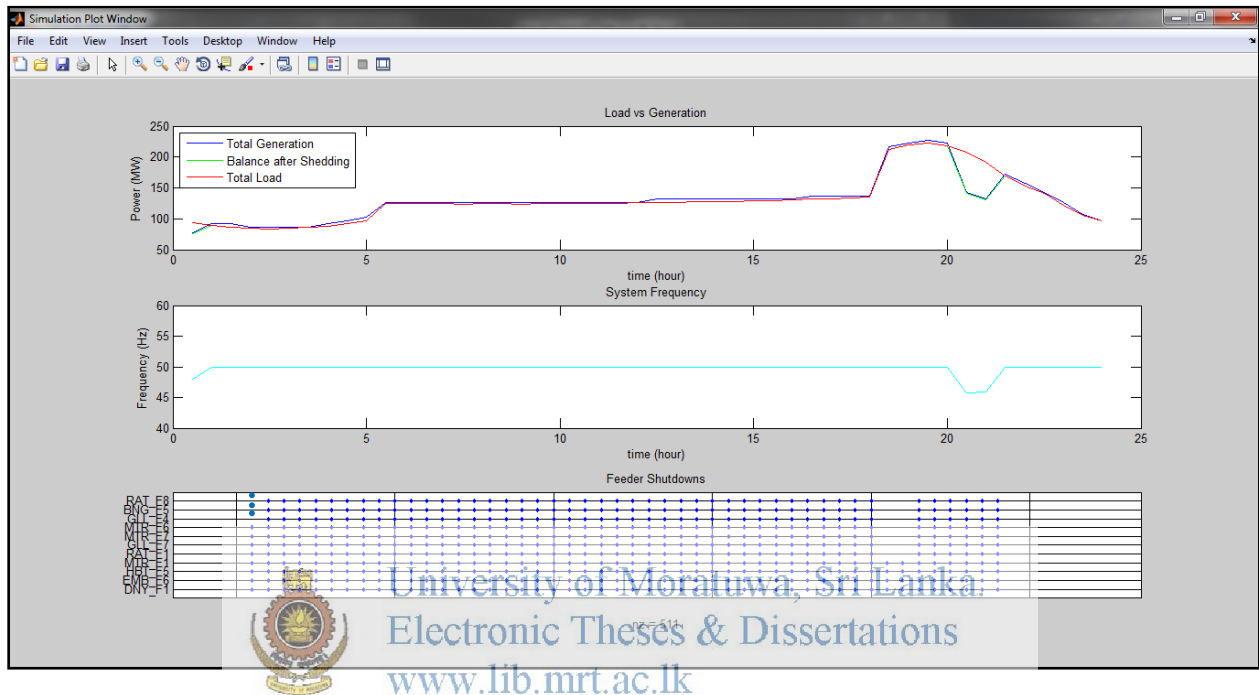

Figure 3.12   Plots of 'load and generation vs. time', 'frequency vs. time' and 'feeder shutdowns' for example-03

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.