Chapter 4

4. Frequency Stability Analysis

4.1. Introduction

Section 1.2.4 described the impact of wind integration on the power system. In this chapter the impact of wind power on system frequency will be discussed in greater detail.

Frequency stability of the power system will be investigated under sudden wind farm outages during this chapter. Further, the system frequency behaviour will be presented following wind resource input variations.

4.2. Evaluate frequency stability limit

Since the prime mover of the wind power cannot be controlled, it impacts on the frequency control and the dispatch of the remaining conventional units in the power system. Therefore it is necessary to quantify the wind integration level where the adverse system wide frequency affects starts to occur.

4.2.1. Factors affecting the frequency stability

The frequency stability of the system primarily depends on the available spinning reserve, governor availability and their parameters, mechanical limit switch positions and power system strength at that operating point.

Note that, in this dissertation, the spinning reserve is defined as the percentage of excess amount of generation available from all synchronized units responsive on droop and ready to serve the additional demand, to the total load and losses being supplied.

Spinning reserve must be allocated to obey certain rules, usually set by the regulators.

Governor droop setting defines the active power participation factor of the machine for frequency changes. Lower droop setting results higher active power participation.

Power system strength for frequency variations was evaluated by using system frequency characteristic constant, K.

$$K = \frac{dp/p}{df}$$

Where;

dp : Outage capacity

p : Demand at outage in MW

df : Maximum frequency drop at outage.

4.2.2. Existing practice in frequency controlling

The allowable frequency deviation in Sri Lanka is stated as ±1% in the Electricity Act and strictly adhered during the system operations.

The current practice is to use a single frequency controlling machine under free governor mode with a lower droop setting to control the system frequency. However all other candidate units are keep at free governor mode with higher droop settings.

In addition, a load shedding scheme is used in system operations in order to protect the system from cascade collapses after large generator outages. Normally, the first load shedding frequency is considered as 48.75Hz and several load shedding stages are used according to the severity of the failure. The allowable outage capacity before initiating the load shedding scheme is determined by the system frequency characteristic constant, K.

4.2.3. Frequency stability limit for wind integration

This study concentrated into a small geographical area located in the same wind line. Therefore, following frequency limits are considered in order to assure a quality and reliable electricity supply to consumers and to minimize the power system operational issues

- The system frequency should be recovered without initiating load shedding schemes following total wind farm outages.
- Frequency fluctuations resulted due to anticipated wind speed variations should be within allowable ±1% limit.
- The maximum allowable wind ramp rate is limited to 10MW/min, as mentioned in the grid code [12].

4.3. Data and assumptions

This study is based on the transmission networks proposed in the "Long Term Transmission Development Plan 2008-2016" and assumes that all development proposals presented in the above plan would be implemented as per schedules.

The power system constants of the transmission lines and transformers and the constants for individual generation facilities were extracted from " Master Plan Study on the Development of Power Generation and Transmission System in Sri Lanka"[13]. The substation equipment data were taken from CEB data base.

Governor droop setting for all generators except the frequency controlling unit was set to 5% and the droop setting for frequency controlling unit was taken as 1.6% throughout this study.

System spinning reserve (reserve available in the units with governors) was maintained approximately at 5% for year 2010 and 2012, and about 10% spinning reserve was maintained for year 2014 and 2016.

The system frequency impact is severe at low loading conditions. Therefore the frequency stability analysis was carried out for off peak loading scenario. Off peak demand considered for each year is depicted in the table below:

Year	Off peak demand(MW)
2010	916
2012	1076
2014	1267
2016	1491

Table 4-1: System demand- off peak

4.4. Methodology and results

The frequency stability is considered as a system-wide impact. Therefore this section of the study does not present the local network arrangement. This section focuses on investigating an allowable generator outage capacity for each year, which does not initiate the first load shedding scheme.

Further, this part investigates the system frequency response that occurs due to anticipated wind input variations. However, it is not reasonable to apply the same wind input variation to all WTGs at the same time. Hence, to reduce the complexity of the study and to increase the validity of the result, this study uses only 70% of the full wind power range to simulate wind variations.

4.4.1. System analysis – Year 2010

A system frequency characteristic constant, K (refer section 4.2.1) for year 2010 off peak loading scenario was found as 5.2%MW/Hz after simulating number of generator outage simulations. Therefore, the capacity outage limit was calculated as 59MW for year 2010 off-peak scenario just before the activation of automatic load shedding scheme (scheduled to activate at 48.75 Hz).

4.4.2. System analysis – Year 2012

Several generator tripping simulations were carried out for year 2012 off peak loading scenario while keeping approximately 5% spinning reserve. System simulation results depicted that the capacity outage limit for year 2012 system is only 90 MW just before initiating the load shedding scheme. The system frequency response and mechanical power variation of the frequency controlling machine after 90MW generation outage is shown in figure 4.1.

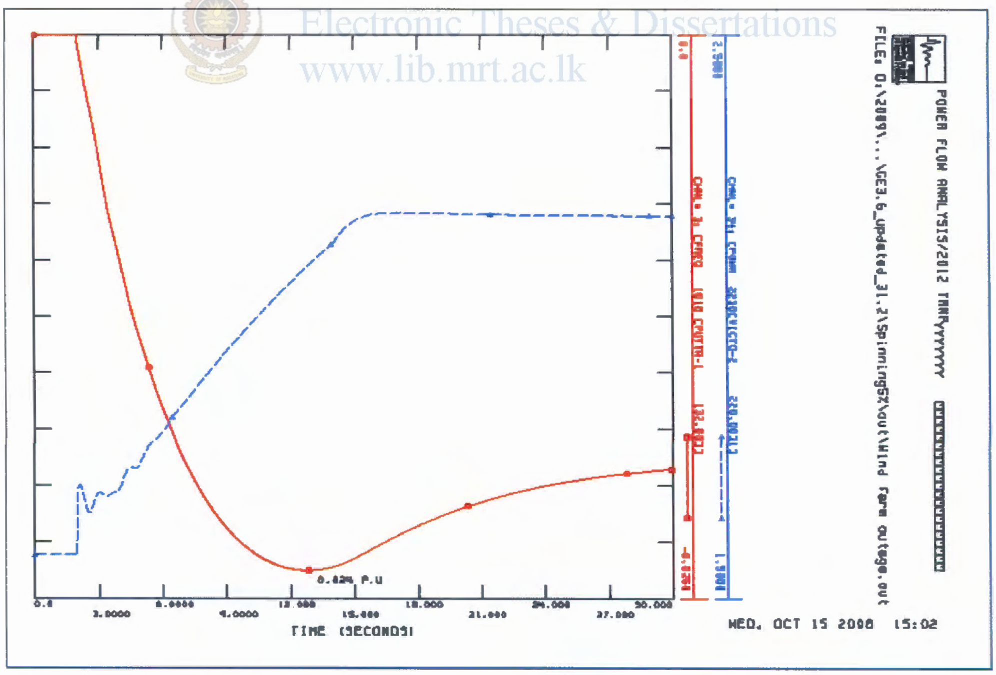

Figure 4.1: System response at 5% spinning reserve- off peak loading scenario-90MW generation outage

Year 2012 network under off peak loading condition with 90MW wind integration was tested against wind speed variations. The applied wind speed input variation, the observed mechanical power output variation of the largest wind farm and the observed system frequency variation are shown in figure 4.2. The rate of change of mechanical power output of the largest wind farm is shown on the same graph.

Results depict that the observed frequency variation is within the allowable ±1% limit.

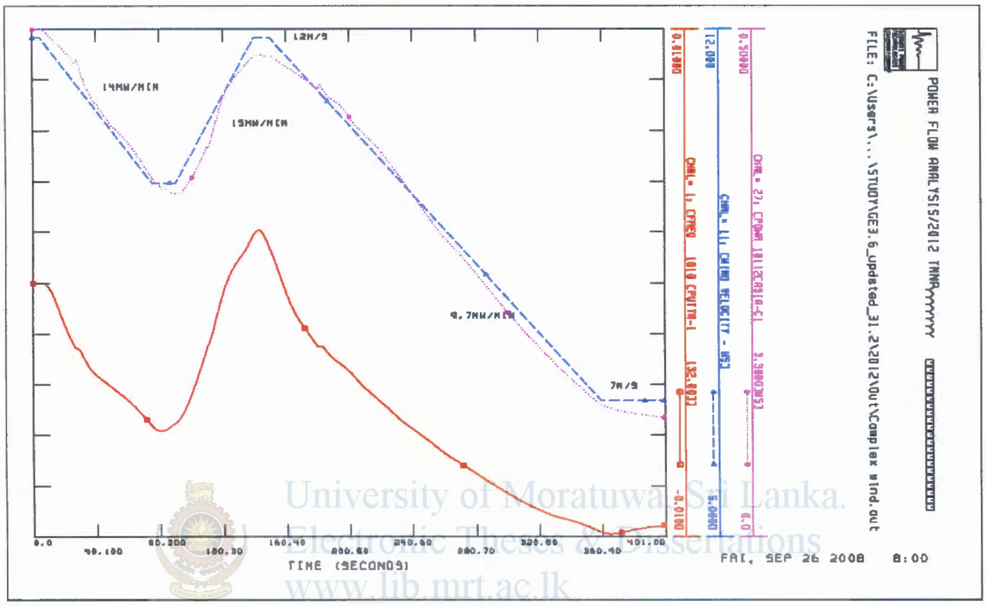

Figure 4.2: System frequency response for wind input variations – Year 2012 at 90MW wind integration level

4.4.3. System analysis – Year 2014

It has been found that the voltage fluctuation becomes the limiting factor for wind integration during year 2014. The capacity limit for voltage stability was obtained as 185MW. The voltage stability will be discussed in detail during the next chapter. Therefore this section discusses the frequency stability of the power system with 185MW wind integration.

The maximum frequency drop observed during the off peak scenario, following a sudden 185MW generation outage was only 1.6%. Year 2014 network under off peak loading condition with 185MW wind integration was tested against wind speed variations and it was found that the system frequency deviation remains within allowable ±1% limit (refer figure 4.3).

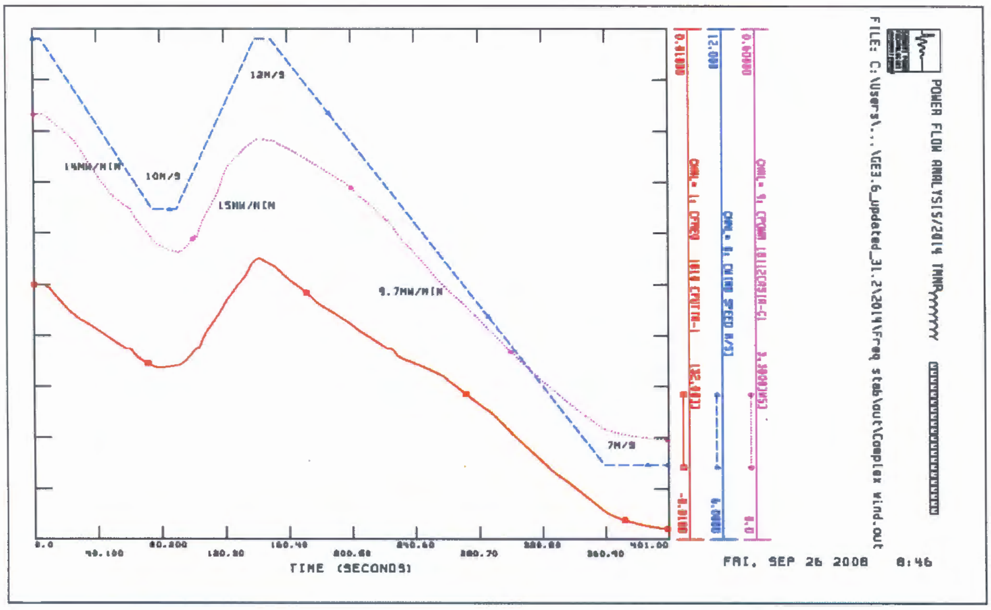

Figure 4.3: System frequency response for wind input variations – Year 2014 at 185MW wind integration level

4.4.4. System analysis – Year 2016

Frequency stability studies were carried out for year 2016 network against 220MW outage capacity. The limit 220MW was obtained from the voltage stability studies, which will be discussed in the next chapter.

The off peak frequency drop observed was only 2%, where the first load shedding is designed to be activated at 2.5% drop. Year 2016 network under off peak loading condition with 220MW wind integration was tested against wind speed variations and it was found that the system frequency deviation remains within allowable ±1% limit (refer figure 4.4).

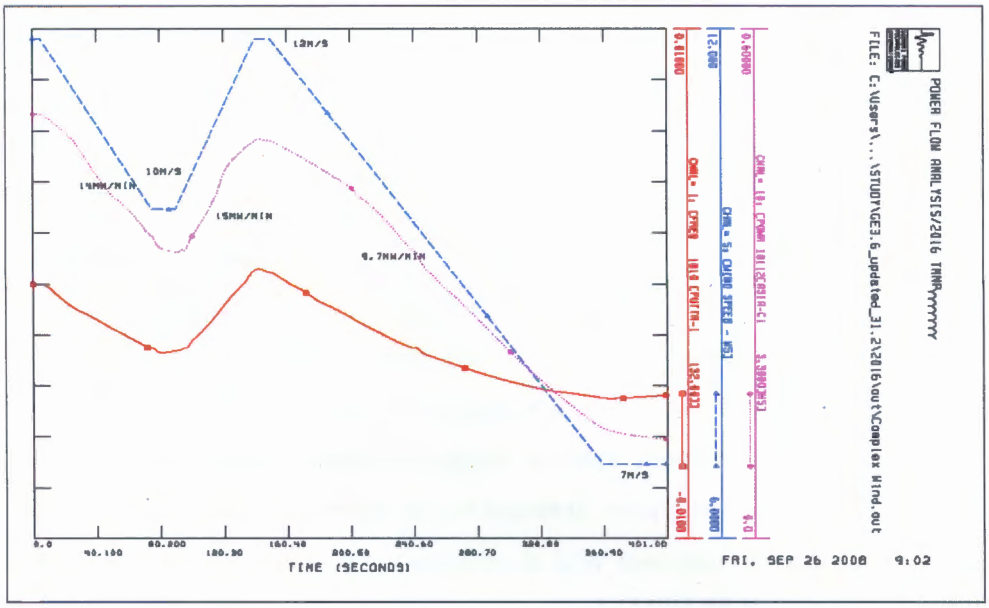

Figure 4.4: System frequency response for wind input variations – Year 2016 at 220MW wind integration level