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An Endeavor of Frequency Regulation by Free Governor Mode of Operation in Bangladesh Power System

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Abstract : *For satisfactory, secured and economic operation of a power system, the frequency should remain nearly constant. The only way to maintain system frequency within an acceptable range is to make balance between generation and load in real time. Power system frequency in Bangladesh varies routinely on a normal days between 48.9-51.2 Hz and can go as low as 48.7 Hz and as high as 51.5 Hz under contingency. This is a major impediment to system reliability and also causes a severe economic loss including our-of-merit dispatch. This paper summarizes the findings of an investigation into the genesis of such variation and potential remedy with the simplest primary governor control scheme. A set of trials with Free Governor Mode of Operation (FGMO) with limited number of generating units was conducted to stabilize the system frequency with encouraging results. Simple but effective and useful measures like these can provide enormous relief to the Bangladesh system and paves the way for it to grow rapidly over the coming decades. These experiments are also highly relevant for a number of other developing countries experiencing similar issues to systematically explore frequency control measures.*

Keywords: *Droop, FGMO, governor, primary response*

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I. Introduction

System frequency is one of the most important parameters of power system. System frequency curve can be compared with ECG report of human body to understand its condition, stability and identify potential threats. In order to secure a safe, reliable, quality & economic power system frequency variation should remain within a specified range e.g. 50±0.2 Hz or below. The variation in system frequency is caused by the inequality of load and generation. As the system load changes all time, there must have some mechanism to make balance between system load and generation. Frequency control in a power system is an age old subject. The semantics around AGC were being debated some 25 years ago [1, 2] and the modern literature is discussing fully embedding it in an economic dispatch [3]. While most advanced power systems involve three levels of controls - primary, secondary and tertiary - from the generation side to manage system frequency, the problem is tackled largely from the load end in most developing countries. A developing country like Bangladesh deploys this technique mostly due to sustained power shortage problem. There is no practice in Bangladesh to hold regulating reserve and there is in fact no frequency control participation from any of the generators in the system with the governors largely remaining inactive even during major demand-supply imbalances. As a result, system frequency of Bangladesh power system is very unstable (50±1.2 Hz) which makes it insecure and unreliable. There have been grid failures including a major countrywide blackout event on 1st November 2014. The latter event triggered sharp reactions that led to initiating measures to arrest system frequency variation within 50±0.5 Hz range by activating governors of number of generating units immediately for primary response (FGMO). The ultimate goal of these measures is to stabilize system frequency in a tighter range by implementing all levels of control (i.e. AGC) in future. Keeping frequency higher than 50 Hz – often close to 51 Hz – using expensive oil-based generation has also been part of the poor practice. Oil generation is kept on in anticipation of load picking up has been costing the system several hundred million dollars per year [4]. Frequency control absent a formal ancillary services allocation mechanism is a problem in most developing countries. This was noted by Power grid India [5] which continues to rely on relatively ad-hoc mechanism for frequency control ancillary services. A set of trials for frequency regulation by FGMO with seven to ten power plants has been conducted in Bangladesh power system with incremental time period (02 hours, 08 hours and 01 months) to understand the effectiveness of these measures. The tests were conducted and supervised from National Load Dispatch Center in Dhaka with help of Bangladesh power development board (BPDB). Different types of generating units i.e. gas turbine, hydro unit, combined cycle power plant running on different types of fuel i.e. natural gas, liquid fuel and hydro etc. were participated in trials. A number of interesting findings were noted and lessons were learned that are of interest to several other developing countries that face a similar set of issues.

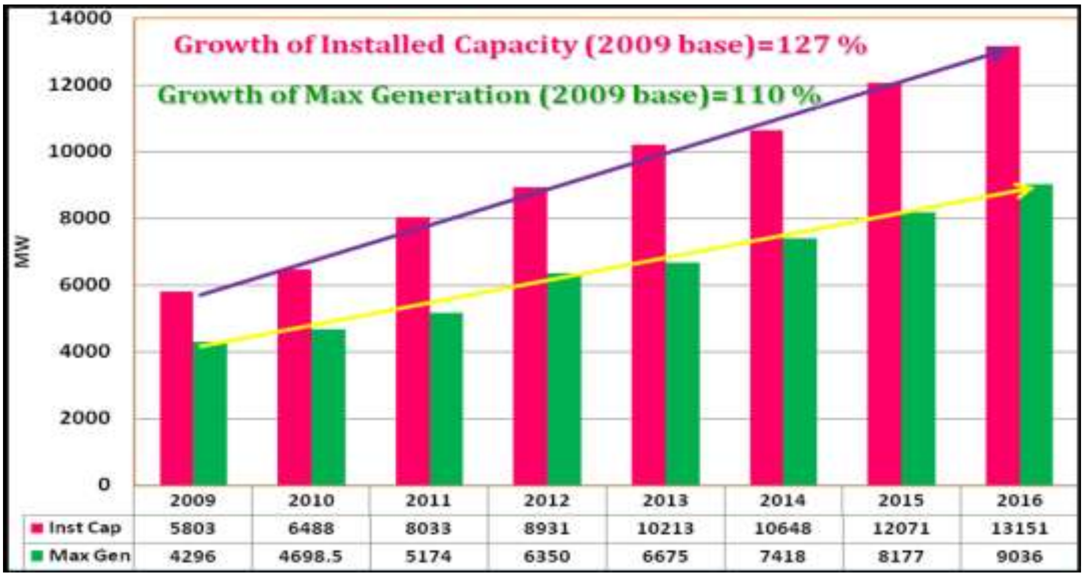
II. The Bangladesh Power System

The power system of Bangladesh is expanding rapidly with the target to reach electricity to all by 2021. It is a 50 Hz system with a present installed capacity of 13 GW. There are 106 numbers of power stations are under running conditions. Although present capacity is 12.2 GW but maximum generation was recorded as 9036 MW on 30th June 2016. Fuel mix (installed capacity) of current generation capacity is given in following Table 1.

Table 1. Fuel Wise Installed Capacity

Fuel Type	Gas	HFO	HSD	Coal	Hydro	Import	Total
MW	8351	2692	1028	250	230	600	13,151
In %	63.50 %	20.47 %	7.82 %	1.90 %	1.75 %	4.56 %	100 %

Last seven years installed capacity & actual generation has been doubled. As per PSMP 2010, the system will be more than 24 GW by 2021 & 40 GW by 2030. At present approximately 64% of power is coming from natural gas based power plants. In order to ensure energy security, system reliability & economy government has taken a massive initiative in fuel diversification. The growth of Bangladesh power system is shown in following Fig. 1. It shows that installed capacity has increased by 127% and actual generation has increased by 110% in last seven years.



	2009	2010	2011	2012	2013	2014	2015	2016
■ Inst Cap	5803	6488	8033	8931	10213	10648	12071	13151
■ Max Gen	4296	4698.5	5174	6350	6675	7418	8177	9036

Figure 1: Growth of Bangladesh power system in last eight years

In general 8500 MW to 9000 MW generation capacity remains available during evening peak hours of the summer to meet 9000 MW to 9500 MW demand. The main reasons of unavailable 3000 MW to 3500 MW are outages (scheduled/emergency) of generating units for maintenance & shortage of primary fuels (natural gas, coal or liquid fuel). Therefore, load shed is often deployed to match demand with available generation. In winter maximum demand is approximately 7500 MW while off-peak demand comes down to 3500 MW. Although during evening peak hours of the summer it is difficult to keep spinning reserve for frequency regulation deploying significant load shedding, but during off-peak hours and winter season it is possible to keep spinning reserve easily. One of the limitations of Bangladesh power system is lack of hydro power generation which is very much suitable for ancillary services. At present approximately 33% power plants is engine (internal combustion) driven which is not suitable for frequency control. Type of prime over present in Bangladesh system is shown in following Table 2. Again, types of plants and its ownership is shown in Fig. 2.

Table 2. Type of Power Plant (Installed & De-rated Capacity)

Type of Generation	Hydro	GT	ST	CCPP	Engines	Engine +ST	Import	Total
Installed (MW)	230	1501	2514	3753	4358	195	600	13151
De-rated (MW)	230	1421	2071	3714	4316	195	600	12547

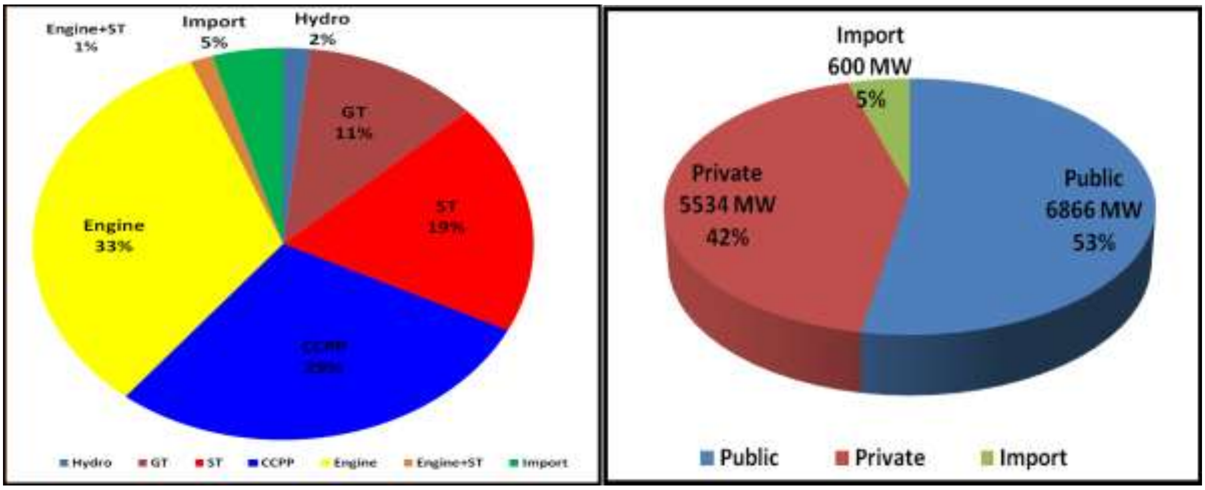


Figure 2: Types of power plants and their ownership of generation in Bangladesh power system

As per Grid Code of Bangladesh, allowable range for frequency variation is 49.0 to 51.0 Hz. The system frequency often exceeds this range resulting under frequency relay operations and over frequency plant tripping. This makes Bangladesh power system very much unsecured and inefficient. Following Fig. 3 shows system frequency trend of Bangladesh power system.

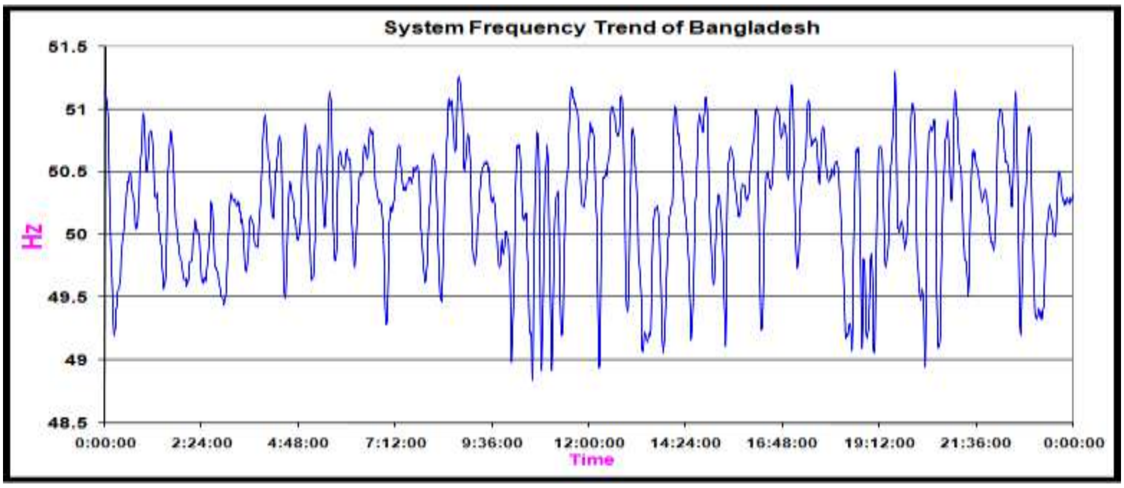


Figure 3: System frequency trend of Bangladesh power system

Frequency distribution & pie chart of Bangladesh power system for 2016 in shown in Fig. 4. It has been observed that approximately 45% of total time system frequency of Bangladesh remains very high (above 50.5 Hz) and approximately 4% time system operate below frequency nadir (49.5 Hz)

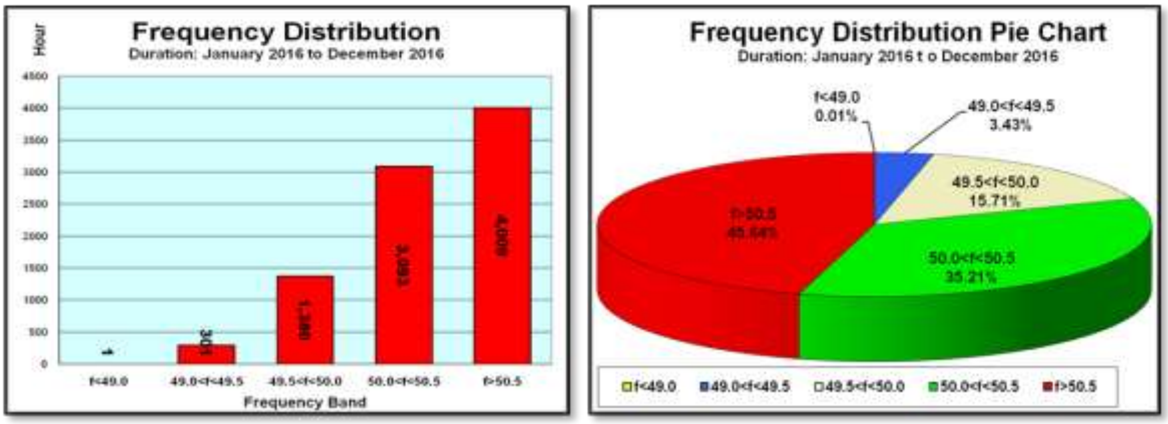


Figure 4: Frequency distribution & pie chart of Bangladesh power system (year: 2016)

Load frequency response or system frequency bias of any power system depends on system volume and types of generation operating in the system. In general during off-peak hours of winter when Bangladesh power system runs with low system inertia (capacity of 3300 to 3500 MW) load frequency response or frequency bias remains in between 8.5 and 9.0 MW/0.1 Hz. When the system volume remains 6000 to 6200 MW frequency bias remains in between 19 and 10 MW/0.1 Hz and during summer peak hours when system runs 8900 to 9000 MW frequency bias remains in between 38.0 and 40.0 MW/0.1 Hz. A typical calculated load frequency bias curve is shown in Fig. 5.

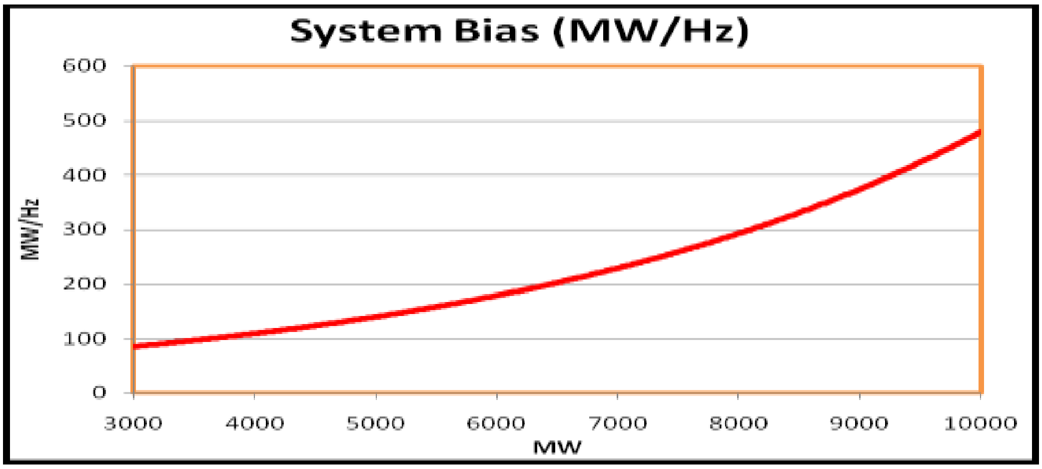


Figure 5: Typical load frequency bias curve of Bangladesh power system

III. Causes And Effects Of Unstable Frequency Of Bangladesh Power System

3.1. Reasons of unstable system frequency of Bangladesh

The main reasons for unstable system frequency of Bangladesh power system are given below:

- There is no power plant running on primary frequency response mode (FGMO).
- There is no secondary response (LFC/AGC) or tertiary response for frequency regulation. NLDC can only monitor analog data (MW, MVAR etc.) and digital status (circuit breaker or CB status etc.). NLDC instructs plants over telephone to adjust output as per requirements.
- Currently frequency is being managed manually by demand side management (in case of declining frequency condition). In case of an emergency, NLDC uses SCADA to open 33 kV CB of different feeders to control demand. If frequency goes below 49.00 Hz under-frequency relays kick in to avoid blackout.
- A number of old generating units' exhibit load fluctuation due to problems in their governor systems.
- A numbers of bulk consumers with oscillating loads (arc furnaces) are connected with national grid without any mechanism of active power compensation. Load fluctuation often exceeds 200 MW within few seconds which is shown in Fig. 6.

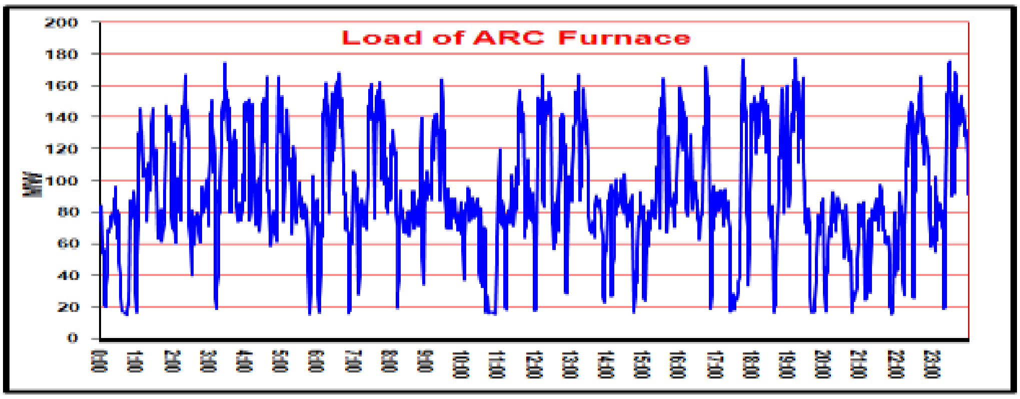


Figure 6: Load fluctuation at arc furnace of a steel mil

- Expected frequency response is a negative value i.e., the generator output should increase as frequency drops [2]. In Bangladesh many power plants (most combined cycle power plant, CCPP) are running on the turbine exhaust temperature control (TETC) mode where generator output increases as frequency increases and vice versa, which makes system frequency more unstable. Fig. 7 shows output of few power plants with system frequency.

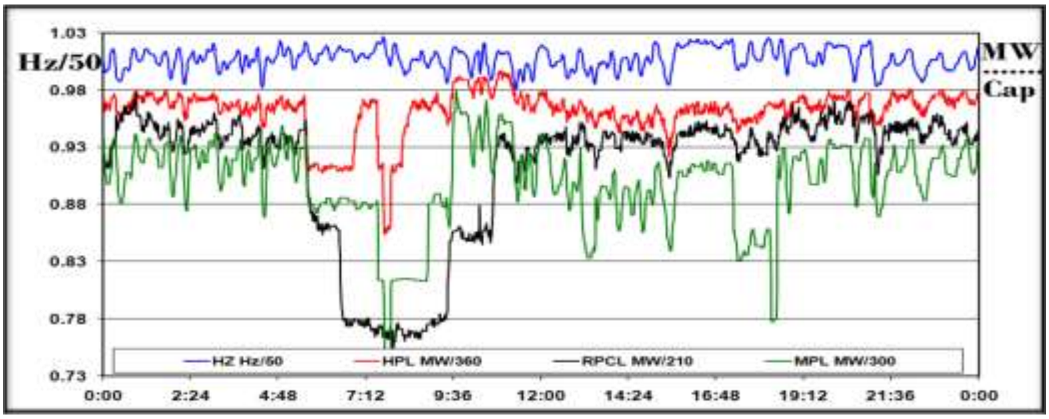


Figure 7: Output of few selected plants with frequency variation

- There is no distribution SCADA system for precise load management. Distribution network operator (DNO) control & manage their load manually as per NLDC's instruction which is time consuming & not a precise technique.

3.2. Impact of unstable system frequency of Bangladesh

Unstable system frequency has severe negative impacts on whole power system (from generator to consumer level). Few important negative impacts are:

- It hampers system security and stability. In Bangladesh as system frequency is quite unstable, under frequency (UF) relays for first stages is set as low as at 49.0 Hz. Tripping of large plants or interconnection can lead to a system blackout as had in fact happened in November 2014.
- For power plants, off frequency increases vibration, causes overheating and damages turbine blades & shaft. Therefore, lifetime of power plants gets reduced.
- Every generator is designed for a synchronized speed (3000 rpm for 2 poles generator at 50 Hz). High frequency implies higher rotation and more energy loss. In Bangladesh, most of the time system frequency actually remains higher than the desired value which causes a huge energy loss. It has been approximated that for one day 2,300 to 3,200 MWh energy is lost due to higher system frequency which costs approximately 10 to 15 million BDT (~$128-192K/d). An estimated energy loss in a day due to high system frequency is shown in Fig. 8.

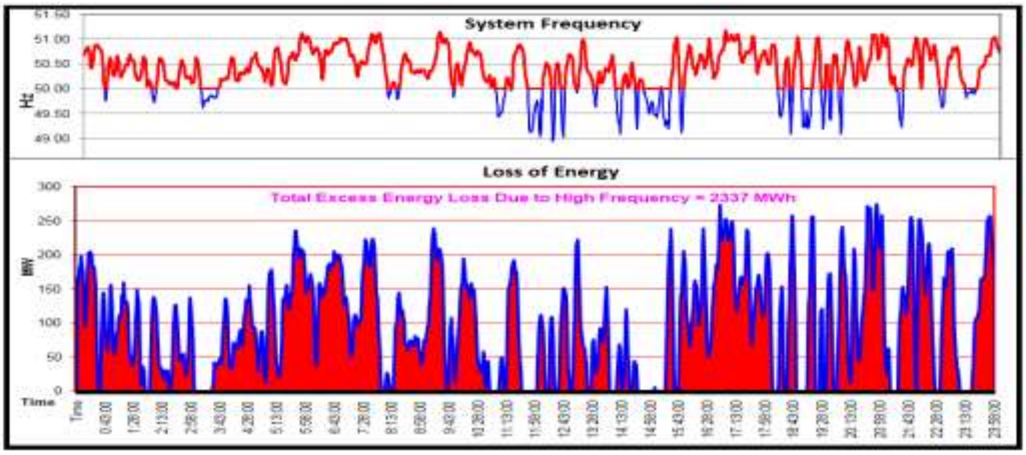


Figure 8: Typical daily energy loss due to high system frequency

- Under frequency reduces efficiency of motors and damages other equipments of consumers.
- With such frequency variation it is almost impossible to add large generating units (500 MW or more) and nuclear power plants to the grid. Integration of renewable energy to power network is also difficult. Both of these issues are vitally important for the Bangladesh power system as it embarks on building a nuclear power station and connect large scale solar and wind.
- Private power generators (IPPs) are not interested for investment with such system instability.

- Due to unstable system frequency number of SCADA operations are executed from NLDC to avoid under frequency relay operation. These causes number of interruptions in consumer end. Therefore, consumer satisfaction reduces & productivity of the consumer becomes hampered.
- Due to poor quality power, investor for hi-tech industries will not be attracted to invest in Bangladesh.

IV. Frequency Regulation

Frequency regulation is one of the most vital system reliability services that must be from generation side. The inequality between load and generation due to contingencies or large difference of load causes variation in frequency and it is required to maintain the frequency within the normal operating band (NOB) as arranged by the reliability requirement of different countries or regions. To maintain or bring back the frequency within the NOB, different approaches have been adopted by different countries or regions by their system operators. Frequency regulation is mainly achieved by balancing mechanisms by some regulatory approach.

In a power system comprising of number of turbines and generators, a mismatch between total power generated and total electrical load causes the frequency change as dictated by the combined system inertia. Small mismatches are generally consumed with combined system inertia (i.e. with stored kinetic energy). For a mismatch that results a change in system frequency, the governors of all the machines sense the frequency and the mechanical power outputs will be changed automatically and locally to match to total system generation with new combined load. This is known as primary regulation or free governor mode of operation (FGMO). However, primary regulation will not bring frequency back to pre-fault value and just settle in an acceptable quasi-steady state. After reaching this quasi-steady state value, the secondary regulation comes in action to return frequency to its nominal value. This function is commonly referred to as load-frequency control (LFC). The combined package of load-frequency control (LFC), economic dispatch (ED) and interchange scheduling is commonly known as automatic generation control (AGC) which originates at central control center or NLDC. Few power systems use semi-automatic regulation known as direct plant control (DPC) in addition to primary & secondary regulation to control plants output from NLDC in case of emergency.

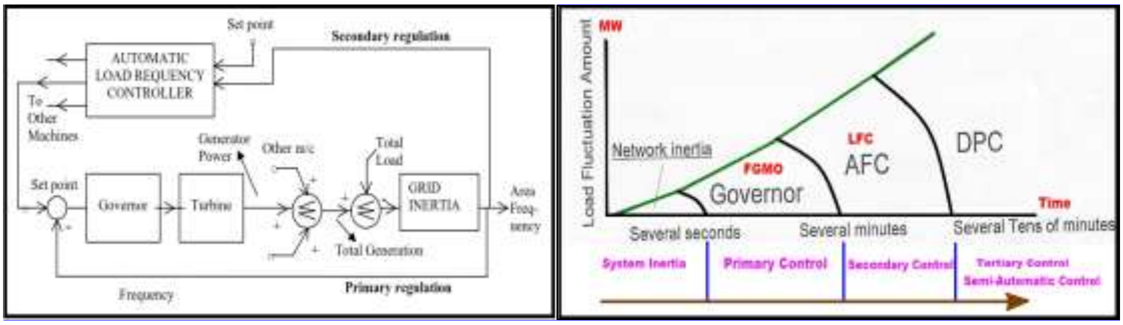


Figure 9: Frequency response of power system (primary, secondary and tertiary control)

In primary regulation the plant shall be used as a load following / variable loads power station. The governor system of the plants running on FGMO shall be fitted with adjustable droop and shall have capability to operate with droop of 4% to 6% for the thermal units & 2% to 3% for the hydro units. The response to a change of system frequency shall be fully available within 10 seconds of the frequency change and be sustainable for a further 30 seconds. Secondary response shall fully available by 30 seconds from the time of frequency change to take over from primary response, and shall be sustainable for a period of at least 30 minutes. If the secondary control is insufficient, tertiary control operates to return frequency to target value and restore the secondary control reserve. Tertiary frequency response is normally in the form of security constrained economic dispatch. Engagement of three levels of frequency control is shown in Figure 8. There are specific differences between each frequency control level. The characteristics of these frequency control levels are compared in Table 3.

Table 3. Comparison between Frequency Control Levels [7]

Control mode	Primary control	Secondary control	Tertiary control
Used means	Governor	AGC Manual set-point	Spinning, non-spinning reserve
Control method	Automatically	Automatically and manually	Manually
Control place	Locally	Centrally	
Control signal	Local sensor	Local sensor or system operator	
Activation time	Immediately	Depends on power system	

V. FREE GOVERNOR MODE OF OPERATION (FGMO) And Important Parameters

FGMO entails that the governor of a power plant is free to govern its regulation/droop characteristics. This primary regulation is autonomous and an inherent property of turbine governing system. The governing system senses the change in speed and adjusts the control valve of working fluid so that mechanical power matches with the changed load [6]. The steady state and dynamic response behavior of the turbine is mainly influenced by its droop characteristics.

Droop can be defined as the percentage change in the frequency required for 100% change in load.

$$\text{Percent} \quad R = \frac{\text{percent speed or frequency change}}{\text{percent power output change}} \text{ x } 100 \quad .... \quad .... \quad (1)$$

$$R = \left(\frac{\omega_{NL} - \omega_{FL}}{\omega_0} \right) x \ 100$$

Where,

ω_{NL} = steady-state speed at no load

ω_{FL} = steady-state speed at full load

ω_0 = nominal or rated speed

Indeed, droop is an important parameter in the frequency regulation that in thermal power plants is usually 4 % to 6 % and in hydro plants this value is around 2 to 3%. A 5% droop or regulation means that a 5% frequency deviation causes 100% change in valve position or power output [2]. Again, the change in output of a plant with respect to time is specified with ramp rate (MW/Min) for loading and unloading. Other two important parameters for plant’s governor response are dead band and limiter which are shown in Fig. 10.

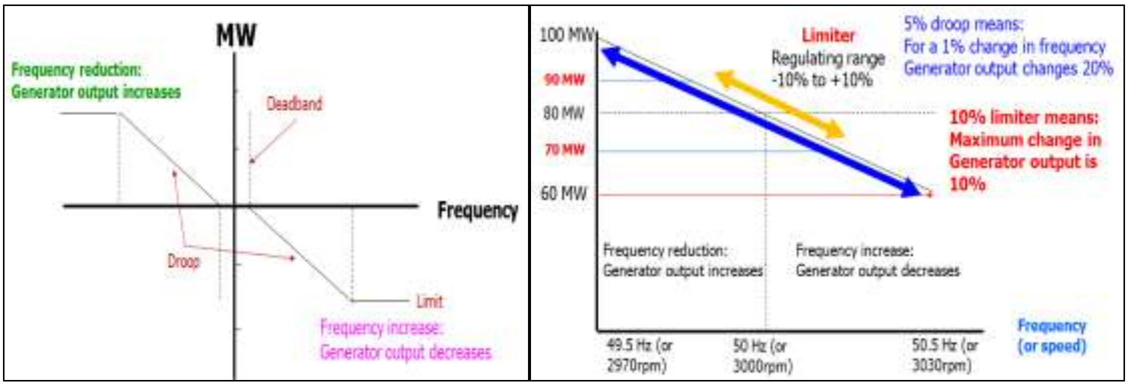


Figure 10: Droop, dead band and limiter for governor response

Dead band is a region (frequency range) in which changes in frequency cause no governor response. Dead band reduces the governor activities if frequency is close to nominal. Many governors, especially on steam plant, may have limiters to prevent them trying to respond to changes in frequency that are too large. By using limiter maximum allowable variation in power output of generator can be limited. A setting of 10% limiter means maximum change in generator output is 10%. Country like Bangladesh where frequency variation is too large, use to proper limiters and dead band settings is very important for both the plant and system.

VI. Trials Of Fgmo In Bangladesh System

In order to stabilize system frequency by activating governor (FGMO) in number of generating units, three trails were conducted by NLDC & BPDB with increasing time duration. The first trial was performed on 08 April 2016 for 02 hours. The second trial was performed on 06 August 2016 for 08 hours. The third & final trail was started on 29 October 2016 and continued for 01 month. To conduct a trial of FGMO and to observe its impact on system frequency, initially 250-320 MW of spinning reserve was targeted for the primary response from ten generating units with a combined generation capacity of 1,600-1,800 MW (~14% of capacity). The test was performed with four to eight numbers of power plants in three trials and different parameters were recorded in the SCADA archive. In first trial, only four generating units were running on FGMO keeping 150 MW to 170 MW of spinning reserve from 560 MW of total capacity for two hours. In second test, eight to ten power plants were participated and the system was running in between 6500 to 7100 MW with a system bias of 22-25 MW/0.1 Hz. During second FGMO test total capacity of selected plants was kept at approximately 1400 MW from 1867 MW and spinning reserve varied from 250-500 MW to stabilize frequency deviation which is shown in Fig. 11.

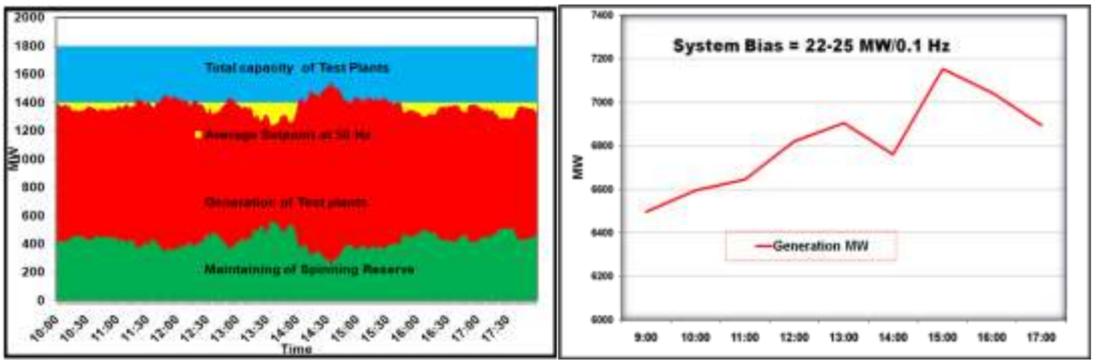


Figure 11: Maintaining of spinning reserve & system generation curve during test-2

After two successful trials for two and eight hours, final trial was performed for one month that started on 29 October 2016 and continued up to 30th November 2016. For this longer trial approximately 300 to 400 MW of spinning reserve were targeted from 10-12 numbers of plants with total 1800-1900 MW of generation capacity. Not all plants were running on FGMO throughout the time. List of the plants participated for three FGMO tests is shown in Table 4.

Table 4. List of Power Plants Participated in FGMO Test

Name of Plant	Capacity	Type	Fuel Type	Set Point at 50 Hz	Spinning Reserve
	MW				MW
Sikalbaha	150	GT	Natural Gas	100	50
Khulna	150	GT	Liquid fuel, HSD	110	40
Sirajganj	210	CCPP	Natural Gas	175	35
RPCL	210	CCPP	Natural Gas	150	60
Kaptai (U:1-4)	180	Hydro	Hydro power	140	40
Summit Meghnaghat	305	CCPP	Liquid fuel, HSD	280	25
Summit Bibiyana	341	CCPP	Natural Gas	275	65
Baghabari 71	71	GT	Natural Gas	40	31
Baghabari 100	100	GT	Natural Gas	85	15
Sylhet	150	GT	Natural Gas	100	50
Total capacity	1867			1455	412

Most of the power plants engaged in the test were switched on to FGMO when system frequency was kept at near 50 Hz at the beginning of all trials. Response of different types of plants engaged in FGMO tests are discussed below.

6.1. Response of natural gas driven gas turbine (Sikalbaha Plant)

Sikalbaha GT has a capacity of 150 MW which runs on natural gas. It has 5% droop with a ramp rate of 11 MW/Min. Sikalnaha does not exhibit frequency response normally because it bypasses the governor, but during the test its output varied from 73 to 123 MW with the variation of system frequency. Fig. 12 shows plant’s output in normal (left) & test (right) day.

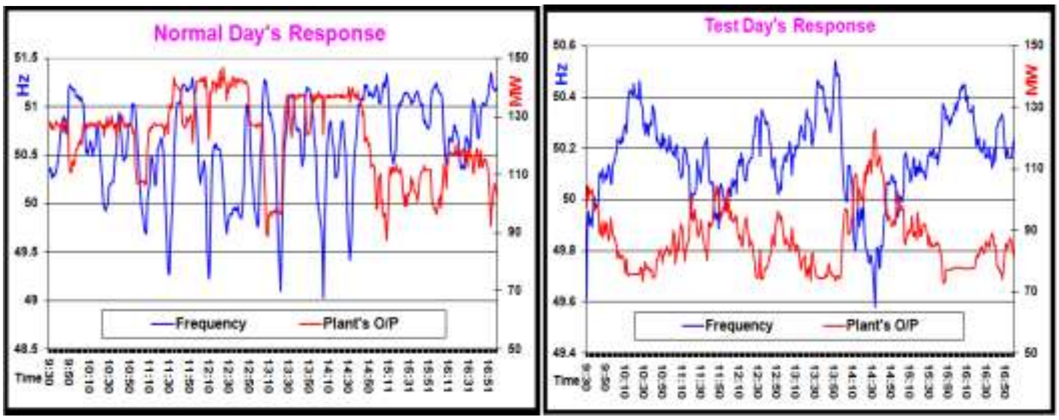


Figure 12: Frequency response of gas turbine power plant in normal (left) & test (right) day

The set point of this plant at 50Hz was at 100 MW when switched on to FGMO. The regulating range (limiter) of this plant was set as -33.3% to +33.3%. Therefore, the plant output was varied with a wide range with frequency. When system frequency rose to 50.46 Hz, output of the plant reduced to 75 MW. Again when system frequency came down to 49.58 Hz, plant output increased to 123 MW. The response of this plant as per droop characteristic is shown in Fig. 13.

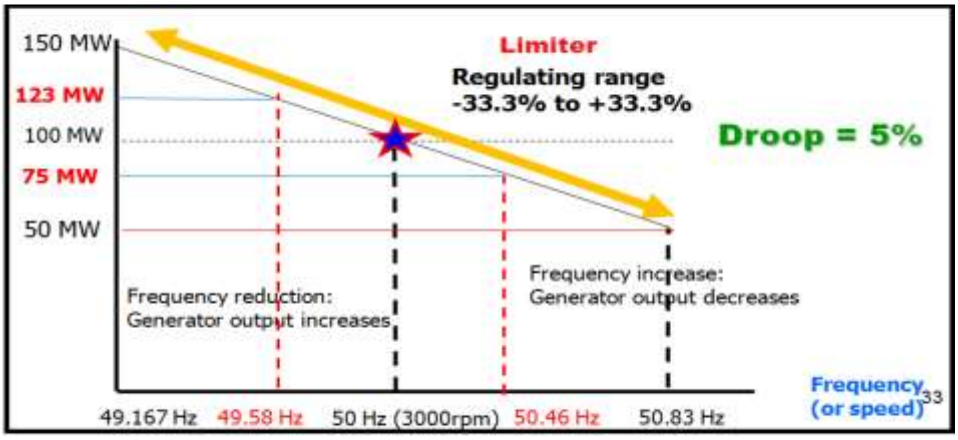


Figure 13: Droop characteristic of a gas turbine (Sikalbaha plant)

6.2. Response of a liquid fuel (HSD) driven gas turbine (Khulna Plant)

Khulna GT has a capacity of 150 MW which runs on high speed diesel (HSD). It has 5% droop with a ramp rate of 12 MW/Min. This plant has a frequency dead band of 50±0.4Hz. The set point at 50 Hz for this plant was kept 110 MW. The regulating range (limiter) of this plant was set as -26.67% to +26.67%. At first, the plant didn't respond in between 49.6 Hz and 50.4 Hz of frequency range. After bypassing dead band, plant responded well in FGMO. The output of the plant varied from 78 to 139 MW with frequency variation. The response of this plant as per droop characteristic is shown in Fig. 14.

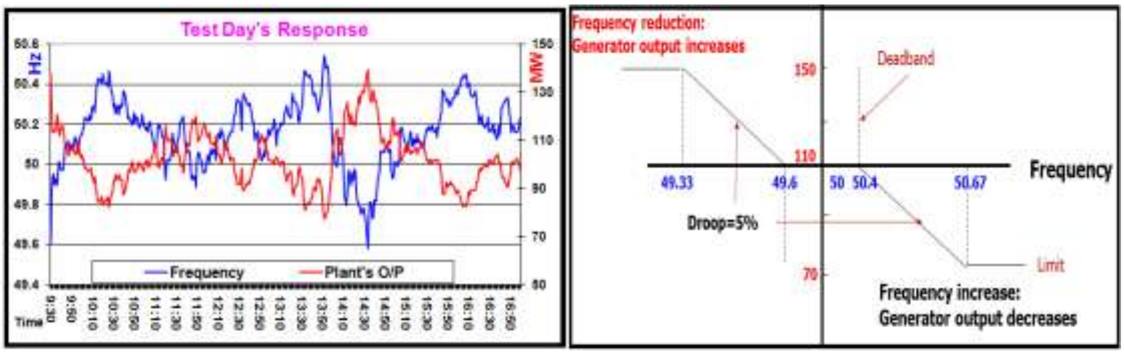


Figure 14: Response of a liquid fuel (HSD) driven gas turbine (Khulna Plant)

6.3. Response of a natural gas driven combined cycle power plant (RPCL plant)

It is a natural gas driven CCPP (210 MW) with 4x35 MW GT and 1x70 MW ST. The droop for GT-1/2 unit is 4.2% and GT-3/4 unit is 3.5%. During the tests, plant set point was 150 MW at 50 Hz. The regulating range (limiter) of this plant was set as -28.5% to +28.5%. Therefore, output of the plant varied from 112 to 156 MW during FGMO test with the variation of the system frequency which is shown in Fig. 15.

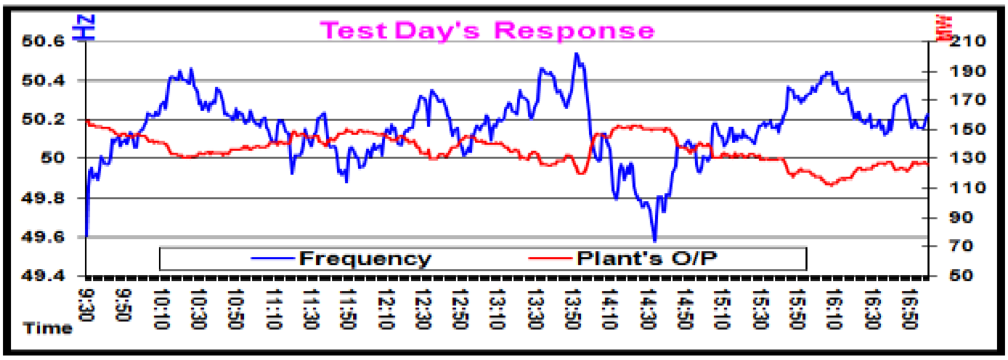


Figure 15: Response of a natural gas driven combined cycle power plant (RPCL plant)

6.4. Response of a liquid fuel (HSD) driven combined cycle power plant (Summit Meghnaghat plant)

This independent power producer (IPP) is a liquid fuel (high speed diesel) driven CCPP. It has a total present capacity of 305 MW with 2x110 MW GT and 1x85 MW ST. The droop for GT-1/2 unit is 10% and ST unit is 4.5%. During the tests, plant set point was 280 MW at 50 Hz with 25 MW of spinning reserve. The regulating range (limiter) of this plant was set as -8.2% to +8.2%. Therefore, output of the plant varied from 260 to 295 MW during FGMO test with the variation of the system frequency shown in Fig. 16.

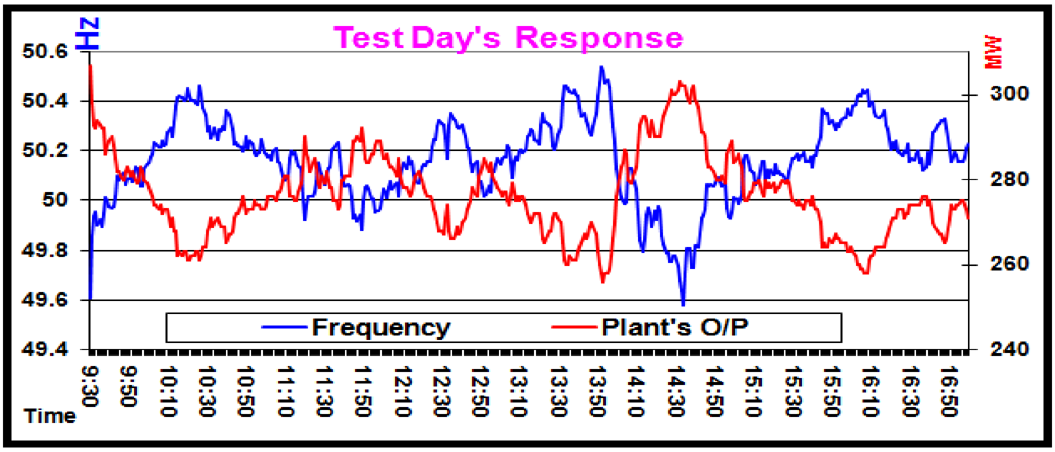


Figure 16: Response of a liquid fuel (HSD) driven combined cycle power plant (Summit Meghnaghat plant)

6.5. Response of a hydro power plant (Kaptai hydro plant)

It is the only hydro plant (230 MW) in Bangladesh with three 50 MW and two 40 MW Kaplan reaction turbines. The droop setting for this hydro power plant is kept 3% to 4%. The control system for the governor of unit 1, 2 and 3 is currently manual and therefore, they can only respond manually with system frequency. Unit 4 & 5 are capable of running on governor control mode (FGMO). During the test period unit 5 was under shut down for maintenance and unit 4 (capacity of 50 MW) was the only unit running on FGMO. During the tests, set point for unit 4 was 30 MW at 50 Hz with 20 MW of spinning reserve. The regulating range (limiter) of this plant was set as -40% to +40%. Unit 4 of this hydro plant responded well and output varied from 15 to 42 MW during the test which is shown in Fig. 17.

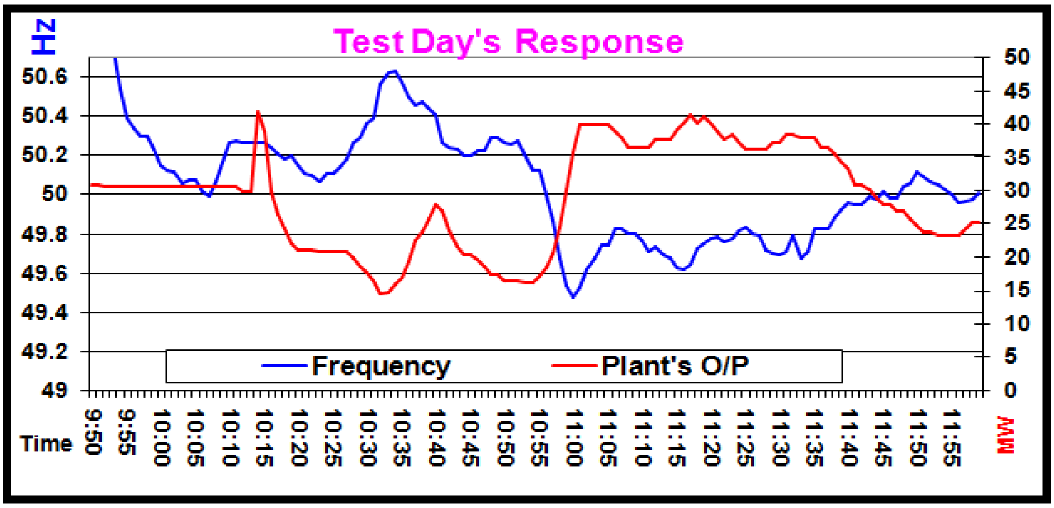


Figure 17: Response of a hydro power plant's unit (Kaptai hydro plant, unit: 4)

6.6. Comparison of the response of different types of plant.

The response of different types of prime mover with system frequency under governor control mode (FGMO) is summarized in Table 5.

Table 5. Response of Different Types of Prime Mover (Generating Unit)

Type of prime mover	General droop setting (%) for governor	Overall plant's response for frequency control
Hydro	2-3%	Poor initial (3-5 sec) response due to water inertia and time taken to open the guide vanes. It has average response while the water column accelerates in between 10 to 20 seconds but excellent after overcoming water inertia (after 30 seconds).
GT	4-6%	Good initial and overall response. Gas turbines can start up and ramp up/down quickly to meet active power dispatch instructions.
ST	6-10%	Good initial (3-5 sec) response and poor intermediate (10-20 sec) response because of reduction of steam pressure. After 30 seconds response is good because of increasing fuel input. This is very much suitable for initial support.
CCPP	As per GT & ST	Good overall response
IC engine		In general IC engine doesn't take part in automatic frequency control. Few plants were kept ready for manual response (tertiary control) & peak load shaving.

VII. Key Results Of The Fgmo Tests

After successful completion of three tests on free governor mode of operation with limited number of generating units, data recorded in SCADA archive system and power plants was analyzed to observe the impact on system stability. Key results of these tests are summarized below.

7.1. Stable system frequency

The system frequency was stable during FGMO tests (three tests in total) with seven to ten power plants on FGMO mode compare to normal days. System frequency on a normal day in August varied from 48.90 to 51.4 Hz. During the eight hours of test period (09:00 to 17:00 hours) on 06 August 2016, system frequency remains within 49.58 to 50.54 Hz even number of contingencies. Again before start of the final trail on October 2016 system frequency of seven days (22 October to 28 October 2016) was analyzed. Maximum and minimum system frequency during this period was 51.39 Hz & 49.005 Hz considerably. Therefore total fluctuation band for this period was approximately2.385 Hz. Average system frequency was 50.633 Hz which indicates the tendency of operating system at higher frequency range. The final test started at approximately at 09:30 hr on 29 October 2016. The selected plants were started to shift their operational mode on FGMO at 09:30 hr to 10:30 hr. The system frequency variation came down 0.9 Hz (Maximum 50.61 Hz to Minimum 49.61 Hz) immediately for the rest of the time of the day. Average system frequency came down to 50.11 hz from 50.61 Hz which indicates more discipline and saving of energy. The system frequency curve of test days (06 August and 29 October 2016) are shown in Fig. 18 and 19 indicate a remarkable improvement in frequency stability with primary frequency response.

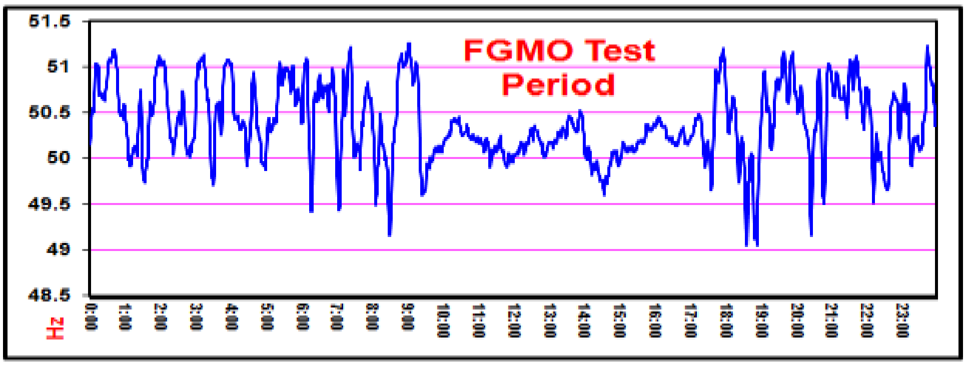


Figure 18: System frequency of the test day (06 August 2016)

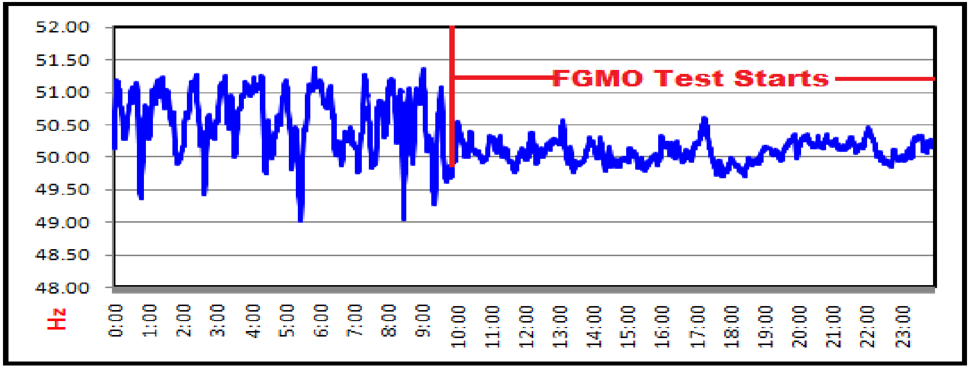


Figure 19: System frequency of the test day (29 October 2016)

7.2. Reduction of energy loss for high system frequency

The second trial lasted for only 08 hours on 06 August 2016. It was estimated that in a general day (13 August 2016) approximately 3151 MWh energy is lost due to high system frequency whereas approximately 2303 MWh energy was lost due to high system frequency on 06 August 2016. Therefore, approximately 800 MWh energy was saved during FGMO test in 08 hours which is shown in Fig. 20. Again, when the final trial started on 29 October 2016, energy loss due to high frequency with and without number of plants on FGMO was estimated for a whole day. It is estimated that approximately 2200 MWh energy can be saved on a whole day with only seven to ten number of generating station running on primary frequency control mode (FGMO) which is shown in Fig. 21. As per the cost of energy in Bangladesh 125,000 to 150,000 USD/ day can be easily saved only from reducing energy loss with less than 10% generating plants running with governor control mode (FGMO).

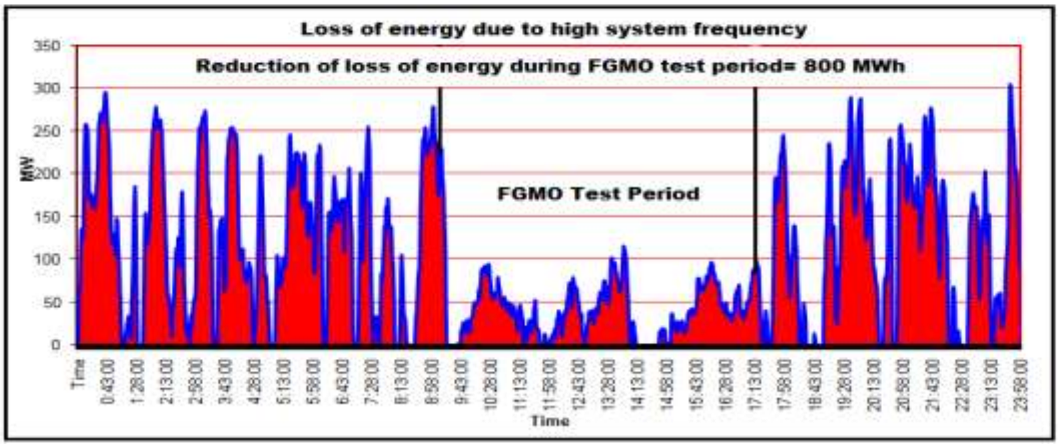


Figure 20: Energy saved during 08 hours of FGMO test (06 August 2016)

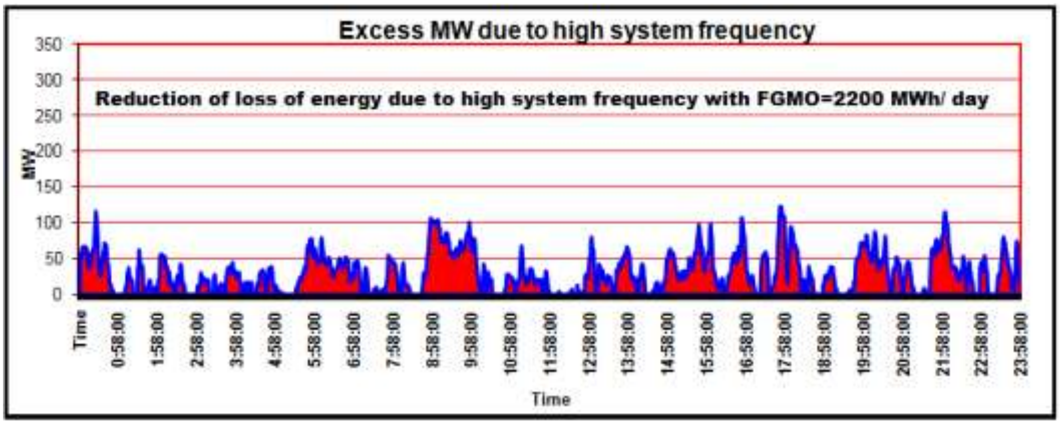


Figure 21: Energy saved during whole day of FGMO test (30 October 2016)

7.3. Quality power due to reduction of power interruption for under frequency and SCADA operations

When system is running with number of power plants on FGMO, system frequency remains stable and improves power quality by reducing power interruption for under frequency and SCADA operations on 33 kV feeders for load shedding. The final trial of FGMO continued for one month. During this one month trial under frequency operation has reduced by 81% and SCADA operation on 33 kV feeders for load shedding has reduced by 90%. Few under frequency & SCADA operations were observed for contingencies (tripping of large plants, generation loss etc.). Interruptions in consumer side were remarkably reduced which ensured consumer satisfaction.

7.4. Increased system reliability under contingency conditions

Under normal operating days (without FGMO) any contingency (loss of generation or load) has more severe impact on system than system with few plants running on FGMO. During FGMO test hours number of contingencies occurred but system frequency remained within 1.0 Hz. These included tripping of 50 MW generating unit, forced shutdown of a hydro unit (50 MW), 128 MW load rejection for transformer tripping etc. Again, impact of fluctuating load (arc furnaces) was remarkably dampened while the system was running on FGMO.

VIII. Concluding Remarks

The FGMO trial conclusively demonstrated for the first time and revealed that Bangladesh power system frequency can be maintained within the 50±0.5 Hz band with approximately 350 to 400 MW of spinning reserve for a contingency size less than 300 MW. For a contingency more than 300 MW, there has to be a special protection system (i.e. contingency based load shed, under frequency relays etc.) to run the system economically as well as to save the system from ‘blackout’. It will also ensure power quality for the consumers. Adopting these measures would also improve the utilization of gas and reduce that of oil, lowering the carbon and local pollutant emissions for the sector. There are some contractual and technical limitations for running all generating units on FGMO today but these can be (and are being) addressed with minimal investments. By activating governors of 15-20 units out of 108 power plants, it is possible to save a huge amount of energy which may cost approximately 500 million of USD per year. If some of the other transmission and distribution constraints and dispatch inefficiencies (lack of proper EMS applications) are removed, the total savings to the system can exceed USD 1 billion per year [4], making these measures some of the most economical ones in the sector. Solving the frequency problem also helps Bangladesh to pave the way for much bigger investments for interconnection, larger coal/gas/nuclear units and large-scale variable renewable energy.

There are several other systems in South Asia itself that could benefit from a similar exploration and trial. As AGC and more modern controls are yet to be implemented in parts of South East Asia and a significant part of Africa – the findings from a simple trial such as this is highly relevant. It is useful to explore these simple options that require minimal investments, but can transform the system making it ready for modern controls and cleaner technologies.

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