International Journal of Electrical and Computer Engineering (IJECE)
Vol. 2, No. 1, February 2012, pp. 46~56
ISSN: 2088-8708

Performance of Governor System on Minimizing Frequency Fluctuations with Wind Power Generation

M.R.I. Sheikh[1], Md. Mejbaul Haque[2], and M.A. Hossain[3]
[1]EEE Department, Rajshahi University of Engineering & Technology
Rajshahi – 6204, Bangladesh
Email: ris_ruet@yahoo.com[1], mhmukul.eee05@gmail.com[2], amzad_nam@yahoo.com[3]

Article Info

Article history:

Received Nov 10th, 2011
Revised Jan 26th, 2012
Accepted Feb 5th, 2012

Keyword:

Governor control system model
Power system frequency
SGs operating mode
Wind power generation

ABSTRACT

As wind turbine output is proportional to the cube of wind speed, the wind turbine generator output fluctuates due to wind speed variations. Hence, if the power capacity of wind power generators becomes large, wind power generator output can have an influence on the power system frequency. Therefore, this study investigates the influence of governor control systems of synchronous generators (SGs) for minimizing frequency fluctuations with high wind power penetration level, when a total capacity of SGs is considered as 100 MVA. It is seen that when both SGs operate as governor free (GF) operation, system perform better frequency control. But it can not be maintained to the acceptable level when SGs operate at GF-LFC or LFC-GF operation with wind power capacity about 5% of total capacity. Finally, it is seen that when several interconnected SGs are operated with different control modes, system frequency become more severe for 10% capacity of wind power.

Corresponding Author:

M.R.I. Sheikh,
EEE Department, Rajshahi University of Engineering & Technology
Rajshahi – 6204, Bangladesh.
Email: ris_ruet@yahoo.com

1. INTRODUCTION

Recently, exhaustion of the fossil fuel and environmental problem such as global warming has become serious problems. Therefore, it is necessary to introduce clean energy more in place of the fossil fuel. Wind power is one of the prospective clean energy resources and thus a large number of wind farms are being in service in the world. However, wind generator output power fluctuates greatly due to the wind speed variations. Hence, if the power capacity of wind generators becomes large, the wind generator output can have an influence on the power system frequency [1-4].

In the conventional operation of wind power generators, when the wind speed is between the rated speed and the cut out speed, the wind power generator output is controlled at the rated value by a pitch control system. On the other hand, when the wind speed is between the cut in speed and the rated speed, the blade pitch angle is maintained constant (= 0 deg), in general, for the wind turbine to capture the maximum power from the wind turbine. Therefore, the wind power generator output fluctuates due to wind speed variations in the latter condition, because the wind power is proportional to the cube of wind speed. Therefore, it is necessary to investigate the influence of the ratio of the wind generator capacity to the power system capacity, on power system frequency.

The governor control system models have a great influence to maintain frequency to the desired level with the increased wind power penetration. So impacts of different governor control system models have been investigated in this study. Also performances of governor control system model for maintaining frequency fluctuations are investigated with considering combination of several SGs operating in different control mode. In the previous study [5] it is seen that thermal governor perform better frequency control than hydro governor. Therefore, this study performed on thermal governor only. Simulation results show that when both generators operate on governor free (GF) control mode, system frequency becomes comparatively better than that of GF-LFC (governor free-load frequency control mode) or LFC-GF control modes. Finally, it is seen that when single SG or several SGs with different capacities are connected to the network, only governor control system model and pitch controller can not maintain power system frequency to the desired level and severe situation occur when wind power penetration become 10% of the total capacity. For this, as the wind power penetration increases day by day, this study will be helpful for taking preventive measures for the power grid companies to improve the stability and quality of electric power. Considering these view points, the study plays a vital role for power system application.

2. MODEL SYSTEM FOR SIMULATION ANALYSES

2.1. Model System

The model system used in the simulation analyses is shown in Fig. 1. Two synchronous generators (SG1[30 MVA] & SG2[70 MVA]) with a total capacity of 100 MVA are used with the network. The model system consists of a wind generator, IG [6], two thermal power generators, TG (cylindrical type synchronous generators, SG1and SG2) and two loads. SG1 and SG2 are operated under different control modes [Governor Free (GF) control and load frequency control (LFC) modes][6].

In general, LFC is used to control frequency fluctuations with a long period more than a few minutes, and GF is used to control fluctuations with a short period less than a minute. Q_{WF} and Q_{Load} are capacitor banks. Q_{WF} is used at the terminal of IG to compensate the reactive power demand of wind generator at steady state. The value of the capacitor is chosen so that the p.f. becomes unity, when the wind generator operated in the rated condition [7]. Q_{Load} is used at the terminal of load to compensate the voltage drop by the impedance of transmission lines. Core saturations of induction generator and synchronous generators are not considered for simplicity. Parameters of IGs and SGs are shown in Table I. The initial power flow and initial conditions are shown in Table II.

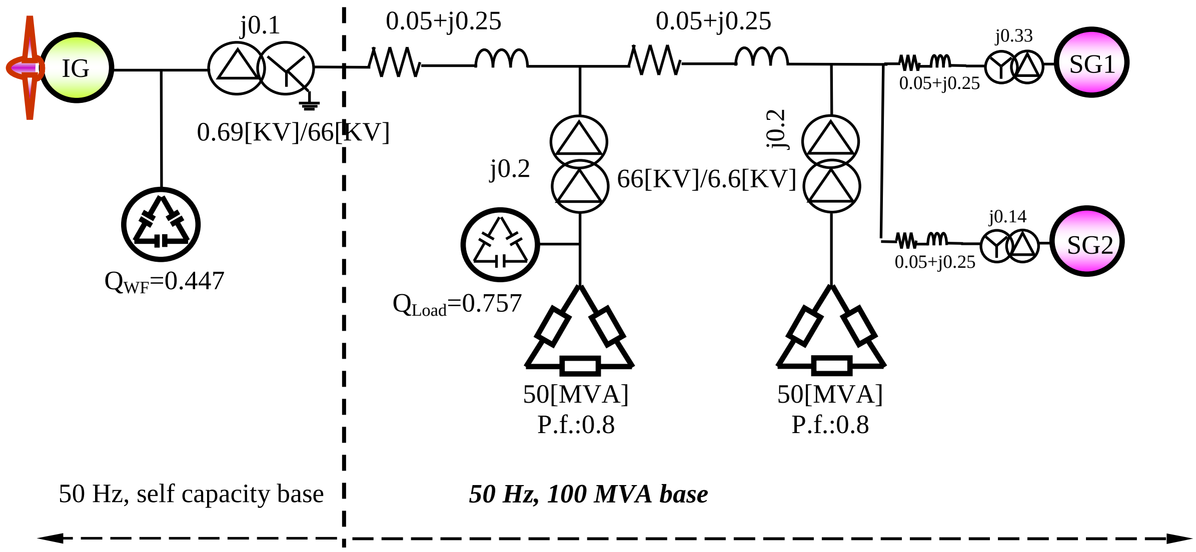

Fig. 1. Model System

3. SYNCHRONOUS GENERATOR MODEL

3.1. Governor

The governor is a device that automatically adjusts the rotational speed of the turbine and the generator output. When the generator load is constant, the turbine is operated at a constant rotational speed. However, when the load changes, balance between the generator output and the load is not maintained, and the rotational speed changes. When the load is removed, the governor detects the increase of the rotational speed, and then, the valve is closed rapidly so that an abnormal speed increase of the generator is prevented.

TABLE I. PARAMETERS OF GENERATOR

Induction Generator				Synchronous Generator		
	MVA				Salient pole type (HG)	Cylindrical type (TG)
				MVA	100	100
MVA	3	5	10	Xd[pu]	1.2	2.11
R_1 [pu]	0.01			Xq[pu]	0.7	2.02
X_1 [pu]	0.18			Xd'[pu]	0.3	0.28
X_m [pu]	10			Xd"[pu]	0.22	0.215
R_2 [pu]	0.015			Xq"[pu]	0.25	0.25
X_2 [pu]	0.12			Tdo'[sec]	5.0	4.2
2H [sec]	1.5			Tdo"[sec]	0.05	0.032
				Tqo"[sec]	0.14	0.062
				H[sec]	2.5	2.32

TABLE II. INITIAL CONDITIONS

	IG	SG1	SG2
P	0.03/0.05/0.1	1.00	1.00
V	1.00	1.05	1.05
Q	0.00		
s(Slip)	-1.733%		

3.2. Governor for hydro and thermal generators [6]

The governor models used in the simulation analyses are shown in Fig. 2 and Fig. 3, in which the values of 65M and 77M for hydro generator and thermal generator are shown in Table III and Table IV respectively. The values of 65M and 77M for thermal generators are shown in Table V, when operating in different control modes. Where, Sg: the revolution speed deviation [pu]; 65M: the initial output [pu]; 77M: the load limit (65M + rated MW output × PLM[%]); PLM: the spare governor operation [%]; Pm: the turbine output [pu].

For Governor Free (GF) operation, when PLM > 0:

65M = the initial output [pu]

77M = 65M + rated MWoutput × PLM [%]

For Load Limit (LL) operation, when PLM < 0:

65M = 77M+ rated MWoutput× | PLM[%] |

77M = the initial output [pu]

Sg is set zero for LFC to control frequency fluctuations with a relatively long period.

Table III. Values of 65M and 77M for hydro generator

	IG: 3[MVA]	IG: 5[MVA]	IG: 10[MVA]
65M [pu]	0.72	0.703	0.653
77M [pu]	0.756	0.7733	0.751
PLM [%]	5	10	15

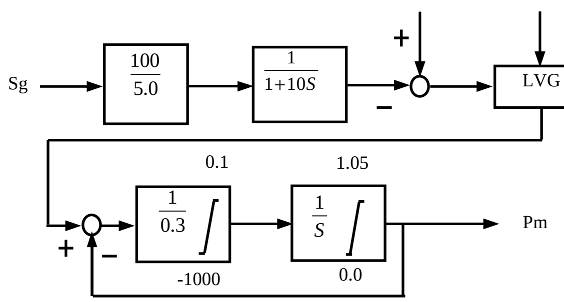

Fig. 2. Hydro Governor

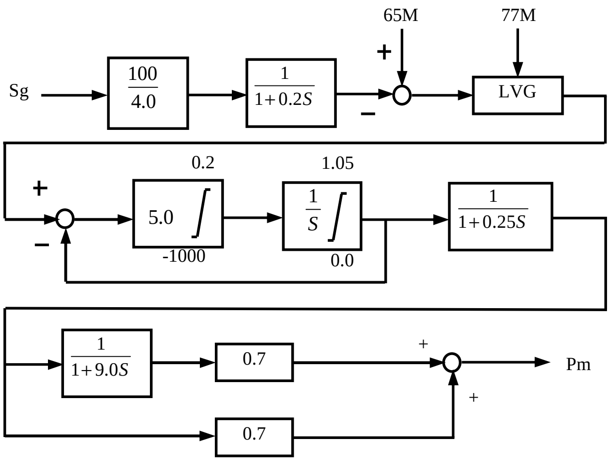

Fig. 3. Thermal Governor

Table IV. Values of 65M and 77M for thermal generator

	IG: 3[MVA]	IG: 5[MVA]	IG: 10[MVA]
65M [pu]	0.72	0.7	0.65
77M [pu]	0.828	0.805	0.767
PLM [%]	15	15	18

Table V. Governor control parameters for SGs

SG1			**SG2**		
Frequency control	65M	77M	Frequency control	65M	77M
LFC	LFC signal	1	GF	0.8	0.84

3.3. Automatic voltage regulator (AVR)

To keep the voltage of the synchronous generators constant, AVR is needed. In the simulation analyses, the AVR is expressed by a first order time delay. AVR model is shown in Fig.4. Parameters of AVR are shown in Table VI.

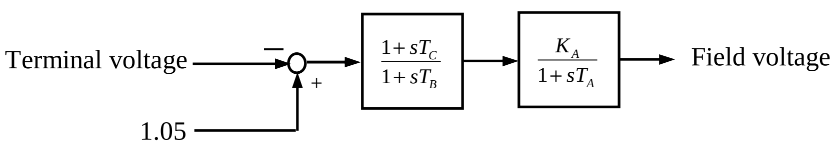

Fig. 4. AVR model

Table VI. Parameters of AVR

Gain, K_A [pu]	400
Time Constant, T_A [sec]	0.02
Time Constant T_B=T_C [sec]	0.00

3.4. Load Frequency Control Model

In the Load Frequency Control (LFC) model, the output power signal is sent to each power plant when the frequency deviation is detected in the power system. Then, governor output value (65M) of each power plant is changed by LFC signals, and then the power plant output is changed. The frequency deviation is input into Low Pass Filter (LPF) to remove fluctuations within short period, because the LFC is used to control frequency fluctuations with a long period. The LFC model is shown in Fig. 5, where, Tc : the LFC period = 200[s]; ωc : the LFC frequency = 1 / Tc = 0.005[Hz]; ζ : the damping ratio = 1.

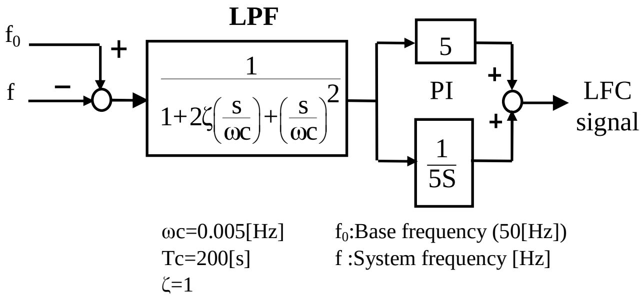

Fig. 5. Load frequency control model

4. WIND TURBINE MODELING

In this paper, the MOD-2 model [8] is considered for the Cp-λ characteristics, which is represented by the following equations and shown in Fig. 6 for different values of β. The captured power from the wind can be obtained from eq.(1). Tip speed ratio, λ, and power coefficient, C_P, can be expressed as eq.(2) and eq.(3). Since C_P is expressed in feet and mile, Γ is corrected as eq.(4).

$$P_{wtb} = \frac{1}{2}\rho C_P(\lambda)\pi R^2 V_w^{\ 3} \quad (1)$$

$$\lambda = \frac{\omega_{wtb} R}{V_w} \quad (2)$$

$$C_P(\lambda) = 0.5(\Gamma - 0.022\beta^2 - 5.6)e^{-0.17\Gamma} \quad (3)$$

$$\Gamma = \frac{R}{\lambda}\cdot\frac{3600}{1609} \quad (4)$$

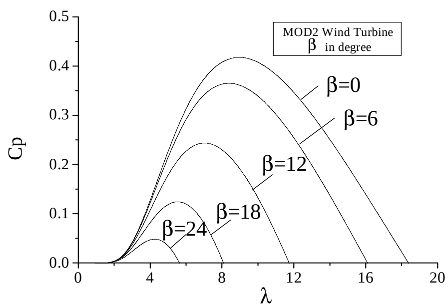

Fig. 6. C_P- λ curves for different values of pitch angle

The torque coefficient and the wind turbine torque are shown as follows.

$$C_t(\lambda) = \frac{C_P(\lambda)}{\lambda} \quad (5)$$

$$\tau_M = \frac{1}{2}\rho C_t(\lambda)\pi R^3 V_w^{\ 2} \quad (6)$$

Where, P_{wtb} is the wind turbine output [W], R is the radius of the blade [m], ω_{wtb} is the wind turbine angular speed [rad/s], β is the blade pitch angle [deg], V_w is the wind speed [m/s], ρ is the air density [kg/m^3], and τ_M is the wind turbine output torque [Nm].

5. PITCH CONTROLLER

In the simulation analysis, conventional pitch controller as shown in Fig. 7 is used. The purpose of using the pitch controller is to maintain the output power of the wind generator at rated level by controlling the blade pitch angle of turbine blade when the wind speed is over the rated speed. Generally, the blade pitch operation system is complicated, but this paper simulates the pitch operation system by using a first order time delay system with time constant T_w=5 seconds. In addition, the pitch angle cannot be changed instantly due to the rotational inertia of blade and mechanical limitations. Therefore, the rate of change of pitch angle is limited to 10 degrees per second in the simulations.

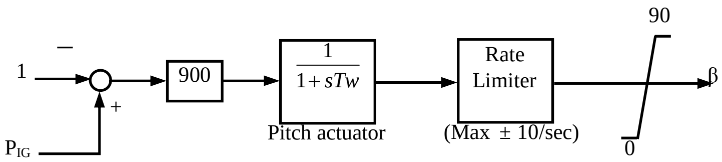

Fig. 7. Conventional pitch control system

6. SIMULATION RESULTS

Simulation analyses have been carried out to investigate the performance of the power system frequency with the increased wind power penetration using real wind speed data. The wind speed data used in the analysis is the real data, which is measured in Hokkaido Island, Japan. The wind speed data applied to the wind generator is shown in Fig. 8. The conventional pitch controller as shown in Fig. 7 is used to maintain the output power as describe in section 5.

Simulation analyses have been carried out for nine patterns shown in Table VII in order to investigate the influence of the governor system to control power system frequency. The simulation analyses have been performed by using PSCAD/EMTDC [9].

Figure 9 shows the wind generator output for different capacities. Figures 10 through 12 show the performances of SGs output and power system frequency for the cases 1, 2 & 3 respectively. Figures 13 to 15 show the performances of SGs output and power system frequency for cases 4, 5 and 6 respectively. Similarly, results for cases 7, 8 & 9 are studied. Finally, the evaluation of the results have been presented in Table VIII. From the table it is seen that system frequency becomes better when both SGs operate in GF condition. It is also seen that power system frequency become severe when wind generator capacity become more than 10% of the total capacity.

TABLE VII. CONDITIONS FOR GOVERNOR CONTROL OPERATION OF SGS

Cases	IG	SG1 [MVA]	Frequency Control	SG2 [MVA]	Frequency Control
Case-1	3[MVA]				
Case-2	5[MVA]		GF		GF
Case-3	10[MVA]				
Case-4	3[MVA]				
Case-5	5[MVA]	30	GF	70	LFC
Case-6	10[MVA]				
Case-7	3[MVA]				
Case-8	5[MVA]		LFC		GF
Case-9	10[MVA]				

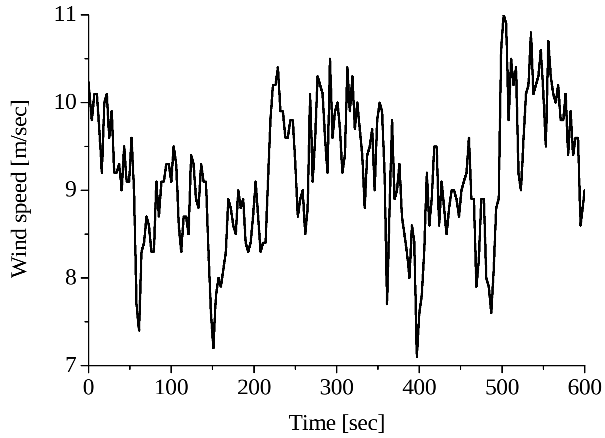

Fig. 8. Wind speed data

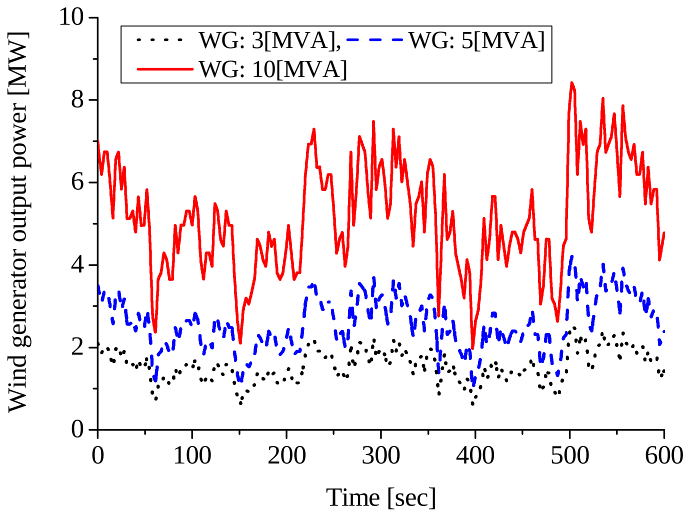

Fig. 9. Wind generator output power

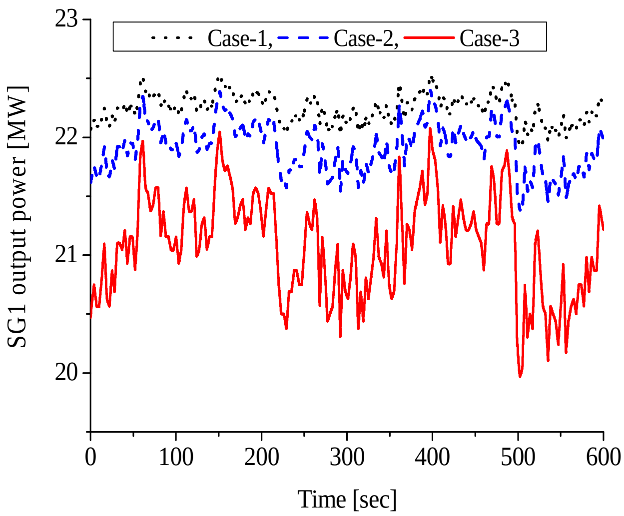

Fig. 10. SG1 output power for GF operation [Cases 1,2,3]

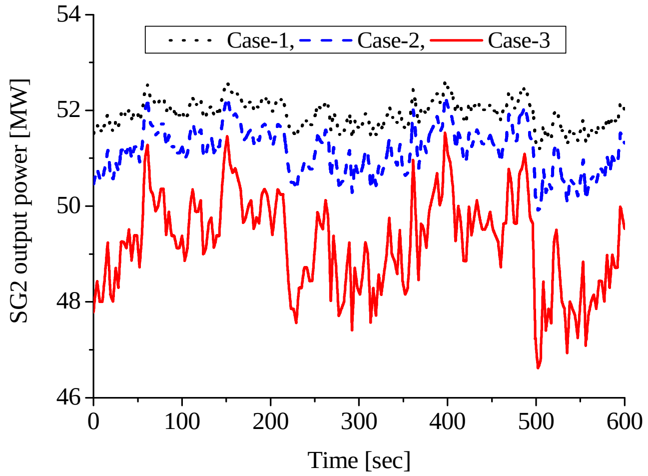

Fig. 11. SG2 output power for GF operation [Cases 1,2 & 3]

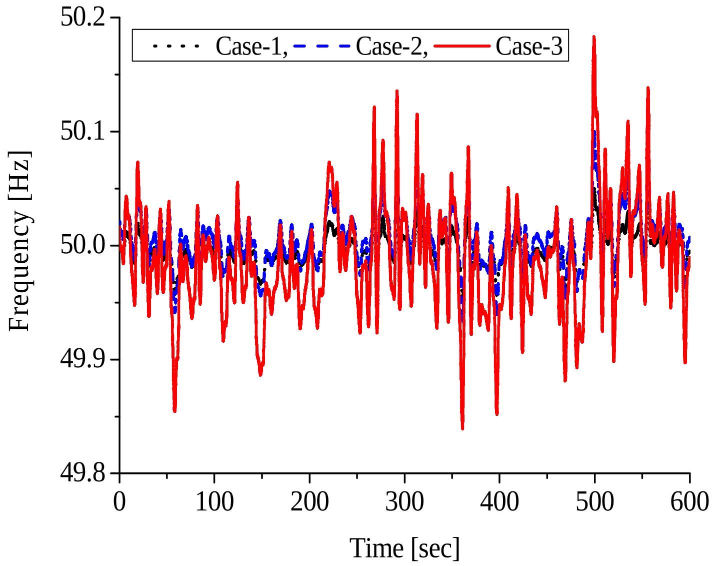

Fig. 12. Frequency fluctuations for cases 1, 2 & 3

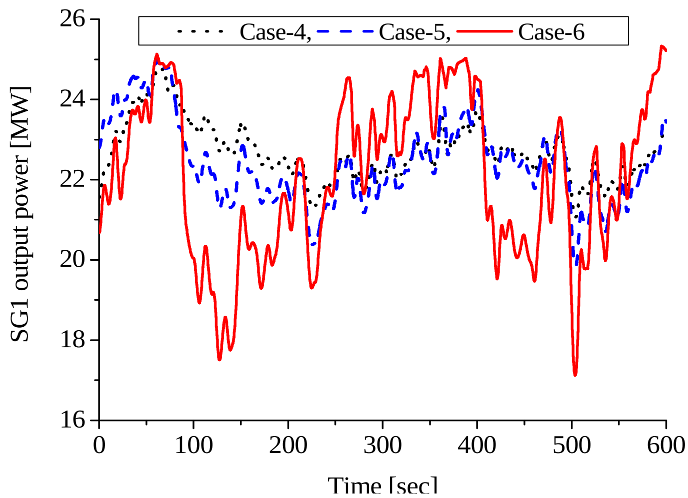

Fig. 13. SG1 output power for GF operation [Cases 4, 5&6]

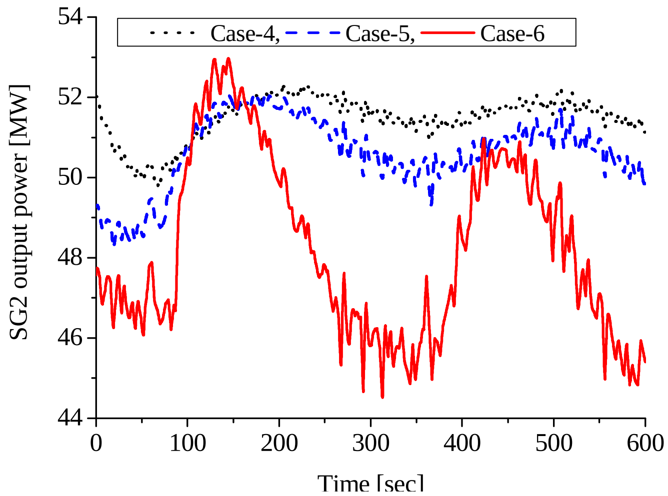

Fig. 14. SG2 output power for LFC operation [Cases 4,5&6]

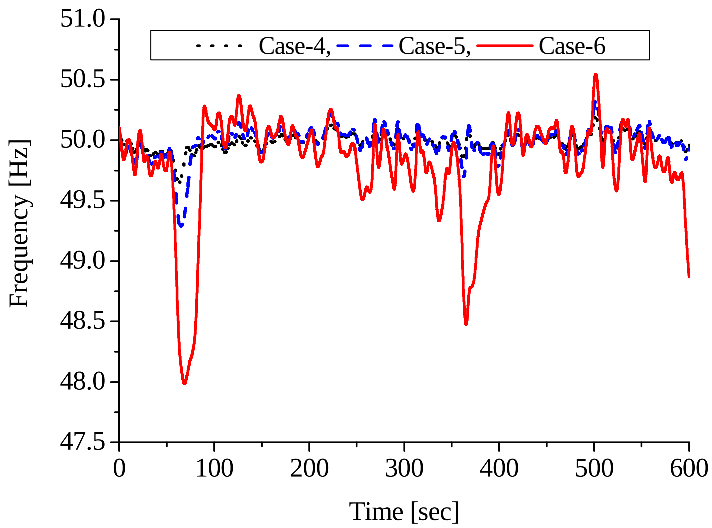

Fig. 15. Frequency fluctuations for cases 4, 5 & 6

Table VIII. Evaluation of Simulation Results

[Cases]	'o' and '×' of frequency fluctuations
Case-1	o
Case-2	o
Case-3	o
Case-4	o
Case-5	×
Case-6	×
Case-7	o
Case-8	×
Case-9	×

'o' means within ± 0.2 [Hz] and '×' means beyond ± 0.2 [Hz]

7. CONCLUSION

As the wind power penetration influences on power system frequency, some countermeasures must need to be considered in near future by the power grid companies, to improve the reliability and quality of electric power. In these cases (i) performance of the governor control system should be improved, (ii) new pitch control system can be used to improve the performance, upto a certain percentage of wind power, but the problem is that some energy need to be lossed to maintain frequency, (iii) energy storage devices like battery energy storage system (BESS) [10], electric capacitor system (ECS) consisting of electric double layer capacitor (EDLC) [11] or superconducting magnetic energy storage (SMES) [12] system can reduce the fluctuation of output power without any loss of energy, but these devices are expensive. So, governor control with a combination of energy storage device and new pitch control system may be the good tool for reducing frequency fluctuations with large wind power penetration.

References:

[1] Yamazaki, T., Takahashi, R., Murata, T., Tamura, J., Fukushima, T., Sasano, E., Shinya, K., and Matstumoto, T. 2009. Smoothing Control of Wind Generator Output Fluctuations by New Pitch Controller. *IEEJ Trans. on Power and Energy*, 129(7) : 880-888.

[2] Luo, C., and Ooi, B.-T. 2006. Frequency Deviation of Thermal Power Plants Due to Wind Farms", *IEEE Trans. Energy Convers*., 21(3) : 708-716.

[3] Carrillo, C., Feijoo, A.E., Cidras, J. and Gonzalez, J. 2004. Power Fluctuations in an Isolated Wind Plant. *IEEE Trans. Energy Convers*., 19(1) : 217-221.

[4] Inoue, T. 2004. MW Response of Thermal Power Plant from Viewpoint of Power System Frequency Control, *Trans. IEE of Japan*, 124-B(3) : 343-346.

[5] M.R.I. Sheikh, R. Takahashi, and J. Tamura, "Study on Frequency Fluctuations in Power System with a Large Penetration of Wind Power Generation", accepted for publication in *International Energy Journal*, Paper ID IEJ_10-03-005.

[6] IEE of Japan, Technical Reports Vol.754: Standard Models of Electrical Power System, pp. 40-43

[7] Sheikh, M.R.I., Muyeen, S.M. Takahashi, R., Murata, T., Tamura, J. 2009. Minimization of Fluctuations of Output Power and Terminal Voltage of Wind Generator by Using STATCOM/SMES. *2009 IEEE Bucharest PowerTech Conference*, CD Records, Bucharest, Romania.

[8] Anderson, P.M., and Bose, A., 1983. Stability Simulation of Wind Turbine Systems. *IEEE Transaction on Power Apparatus* System, PAS-102(12) : 3791-3795.

[9] PSCAD/EMTDC Manual. 1994, *Manitoba HVDC Research Center*.

[10] Murakami, A., Yokuyama, A., Tada, Y., 2006. Basic Study on Battery Capacity Evaluation for Frequency Control in Power System with a Large Penetration of Wind Power Generation. *IEE Trans. of Japan*, 126-B(2) : 236-242.

[11] Muyeen, S.M., Shishido, S., Ali, M.H., Takahashi, R., Murata, T., Tamura, J. 2008. Application of Energy Capacitor System (ECS) to Wind Power Generation. *Wind Energy*, 11(4) : 335-350.

[12] Sheikh M.R.I., Muyeen S.M., Takahashi R., and Tamura J. 2010, "Smoothing Control of Wind Generator Output Fluctuations by PWM Voltage Source Converter and Chopper Controlled SMES", *European Transactions on Electrical Power*, pp.1-18, available online in www.interscience.wiley.com DOI: 10.1002/etep.469.

BIBLIOGRAPHY OF AUTHORS:

Dr. M.R.I. Sheikh was born in Sirajgonj, Bangladesh on October 31, 1967. He received his B.Sc. Engineering and M.Sc. Engineering Degrees from Rajshahi University of Engineering & Technology (RUET), Bangladesh, in 1992 and 2003 respectively, all in Electrical and Electronic Engineering. He carryout his Ph.D degree from Kitami Institute of Technology, Hokkaido, Kitami, Japan in 2010 in the field of Renewable Wind Energy. He published more than seventy papers including Transactions, Journal and International Conferences. He was the Editor of the book Energy Storage. He also published two book chapters. He is recently working to publish a book based on his research in Wind Energy. He is currently Professor and working as the Head of Electrical and Electronic Engineering Department, RUET. His research interests are, Power system stability enhancement including wind generator by using SMES, FACTs devices and Load Frequency Control of multi-area power system.

Mr. Sheikh is the member of the IEB and the BCS of Bangladesh.

Md. Mejbaul Haque was born in Kushtia, Bangladesh on September 27, 1988. He received his B.Sc. Engineering Degree from Rajshahi University of Engineering & Technology (RUET), Bangladesh, in April 19, 2010 in Electrical and Electronic Engineering. He published three conference papers. He is currently working as a Lecturer in Electrical and Electronic Engineering Department, KUET. His research interests are Power system stability, Power quality improvement and Renewable Energy. Md. Mejbaul Haque is the associate member of the IEB of Bangladesh.

Md. Amzad Hossain was born in Chuadanga, Bangladesh on 23th November, 1986. He received his B.Sc. Engineering Degree from Rajshahi University of Engineering & Technology (RUET), Bangladesh, in April 19, 2010 in Electrical and Electronic Engineering. He is currently working as a Part time Lecturer in Electrical and Electronic Engineering Department, RUET, Bangladesh. He has been actively involved in the study, research, teaching and consulting project works to undergraduate students. Mr. Hossain is experienced in doing research on Renewable energy, sustainable resources, and industrial energy analysis. His research interests are Renewable Energy, Power system stability, and Nanotechnology.