**Proceedings of the**
**International Conference on Mechanical Engineering 2011**
**(ICME2011) 18-20 December 2011, Dhaka, Bangladesh**

**ICME 11-RT-039**

# SMOOTHING CONTROL OF WIND TURBINE GENERATOR FLUCTUATIONS BY USING PITCH CONTROLLER

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## ABSTRACT

Since wind turbine output is proportional to the cube of the 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. Energy storage devices must be the good tool for smoothing the wind generator output fluctuations without the loss of any energy; however, these methods have a cost problem. Therefore, this paper proposes a new pitch control system for smoothing the wind generator output fluctuations, which can mitigate the grid frequency fluctuation to the desired level. Real wind speed data have been used for the simulation analyses that validate the effectiveness of the proposed control system. The simulation analyses have been performed using PSCAD/EMTDC.

**Keywords:** Wind Farm Output Fluctuations, Pitch Controller, Smoothing Control, And Power System Frequency.

## 1. INTRODUCTION

Recently, renewable energy sources, like wind power generation, are widely being used in the world. One of the simplest methods of operating a wind generation system is to use an induction generator connected directly to the power grid, because an induction generator is the most cost-effective and robust machine for wind energy conversion. However, during startup, the induction generators need reactive power. As the reactive power drained by the induction generators is coupled to the active power generated by them, the variation of wind speed causes the variations of IGs real and reactive powers. These active and reactive power variations interact with the network and thus initiate voltage and frequency fluctuations. 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. 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. Hence, if the power capacity of wind generators becomes large, the wind generator output can have an influence on the power system frequency. Energy storage devices, have been proposed in literature for smoothing the wind generator output fluctuations, however, these methods have a cost problem. Therefore, this paper proposes a new pitch control system for smoothing the wind generator output fluctuations. Considering these viewpoints, this paper proposes the novel control strategy for mitigating grid frequency fluctuations with high wind power penetration.

The organization of this paper is as follows, section 2 presents the model system, which will be analyzed here, and section 3 contains the synchronous generator model. Description of wind turbine model and proposed pitch control model are given in section 4 and 5, respectively. Simulation results and conclusions are presented in section 6 and 7 respectively.

## 2. MODEL SYSTEM

The model system used in the simulation analyses is shown in Fig. 1. The model system consists of a wind farm (WF), a hydro power generator HG (a salient pole synchronous generator, SG1), two thermal power generators (cylindrical type synchronous generators, SG2 and SG3), a nuclear power generator NG (a cylindrical type synchronous generators, SG4), and a load. The wind farm consists of five wind power generators (squirrel cage induction machines, IGn, n=1,2,,,5). SG1 and SG3 are operated under Load Frequency Control (LFC), SG2 is under Governor Free (GF) control and SG4 is under Load Limit (LL) operation. 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. LL is used to output constant power. $Q_{WF}$ and $Q_{Load}$ are capacitor banks. $Q_{WF}$ is used at the terminal of WF to compensate the reactive power demand of WF at steady state. The value of the capacitor is chosen so that power factor of the wind power station during the rated operation becomes unity [1]. $Q_{Load}$ 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. The initial power flow and initial conditions are shown in Table I. Parameters of IGs and SGs are shown in Table II.

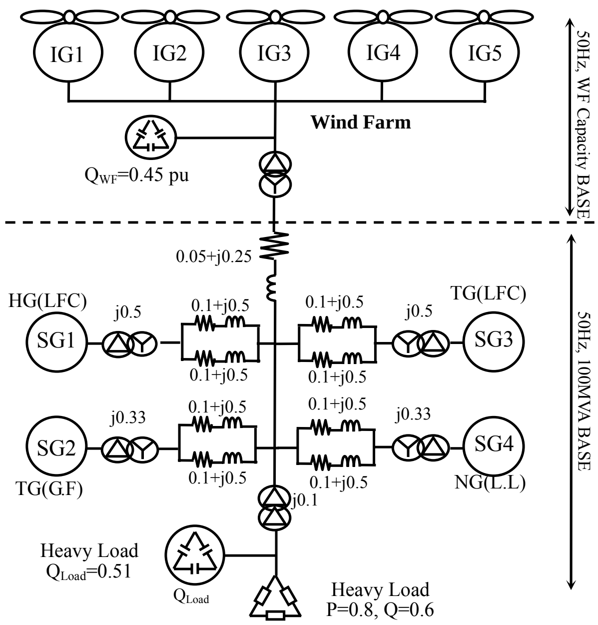


Fig 1.. Power system model

TABLE 1: INITIAL CONDITIONS

| | IG | SG1 | SG2,SG3,SG4 |
|---|---|---|---|
| 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% | | |

TABLE 2: PARAMETERS OF GENERATOR

| Induction Generator | | | |
|---|---|---|---|
| | Squirrel cage type (IGn,n=1,2,,,5) | | |
| MVA | 3 | 5 | 10 |
| $R_1$ [pu] | 0.01 | | |
| $X_1$ [pu] | 0.18 | | |
| $X_m$ [pu] | 10 | | |
| $R_2$ [pu] | 0.015 | | |
| $X_2$ [pu] | 0.12 | | |
| 2H [sec] | 1.5 | | |

| Synchronous Generator | | | | |
|---|---|---|---|---|
| | Salient pole type (SG1) | Cylindrical type | | |
| | | SG2 | SG3 | SG4 |
| MVA | 20 | 30 | 20 | 30 |
| Xd [pu] | 1.2 | 2.11 | | |
| Xq [pu] | 0.7 | 2.02 | | |
| 2H [sec] | 2.5 | 2.32 | | |

## 3. SYNCHRONOUS GENERATOR MODEL

### 3.1 Governor for Hydro, Thermal and Nuclear Generators

The governor models [7] used in the simulation analyses are shown in Fig. 2 and Fig. 3, in which the values of 65M and 77M are shown in Table III, 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]. PLM for SG2 is set 5[%], and for SG4 PLM is set -20[%] because the nuclear generator output (SG4) is controlled constant (LL operation).

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]

Table 3: Values of 65M and 77M

| SG1(Hydro) | | | SG3(Thermal) | | |
|---|---|---|---|---|---|
| Frequency control | 65M | 77M | Frequency control | 65M | 77M |
| LFC | LFC signal | 1 | LFC | LFC signal | 1 |
| SG2(Thermal) | | | SG4(Nuclear) | | |
| Frequency control | 65M | 77M | Frequency control | 65M | 77M |
| GF | 0.8 | 0.84 | LL | 0.96 | 0.8 |

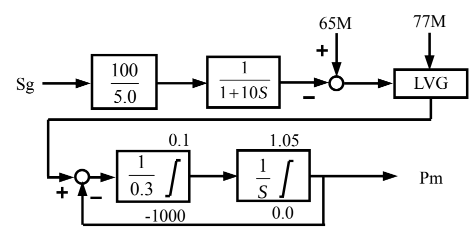


**Fig 2.** Hydro Governor

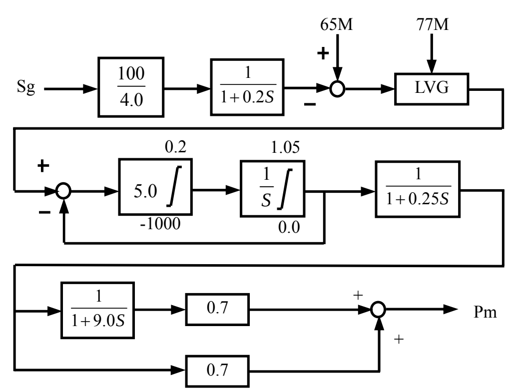


Fig 3. Thermal Governor

Sg is set zero for SG1 and SG3, because these generators are operated under LFC to control frequency fluctuations with a relatively long period.

### 3.2. 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 system. AVR model is shown in Fig. 4. Parameters of AVR are shown in Table IV.

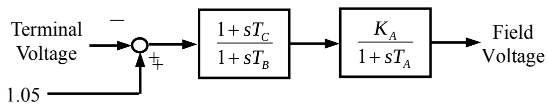


Fig. 4. AVR model

Table 4: Parameters of AVR

| | |
|---|---|
| Gain $K_A$ [pu] | 400 |
| Time Constant $T_A$ [sec] | 0.02 |
| Time Constant $T_B$=$T_C$ [sec] | 0.00 |

### 3.3 Load Frequency Control Model

In the Load Frequency Control (LFC), [1] the output power signal is sent to each power plant when the frequency deviation is detected in the power system. Then, governor output value 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 with short period, because the LFC is used to control frequency fluctuations with a long period. The LFC model [2] is shown in Fig. 5, where, Tc: the LFC period = 200[s]; ωc: the LFC frequency = 1 / Tc = 0.005[Hz], and ζ: the damping ratio = 1.

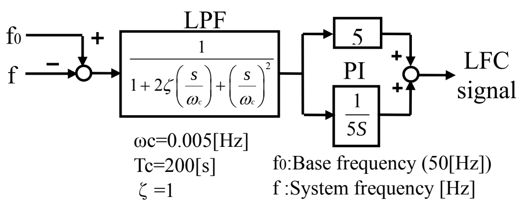


Fig 5. LFC model

### 4. WIND TURBINE MODEL

In this paper, the MOD-2 characteristic [3] is used for the wind turbine model. Modeling expression of MOD-2 is given as follows. The captured power from the wind can be obtained from (1). Tip speed ratio, $\lambda$, and power coefficient, $C_P$, can be expressed as (2) and (3). Since $C_P$ is expressed in feet and mile, $\Gamma$ is corrected as (4).

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

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

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

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

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], $\omega_{wtb}$ is the wind turbine angular speed [rad/s], $\beta$ is the blade pitch angle [deg], $V_w$ is the wind speed [m/s], $\rho$ is the air density [kg/m$^3$], and $\tau_M$ is the wind turbine output torque [Nm].

### 5. PROPOSED PITCH CONTROL MODEL

As the conventional pitch controller [6] works only when the wind speed is larger than the rated speed, thus the wind generator output fluctuate due to wind speed variations between cut in and rated speed and also the power system frequency may fluctuate.

So this paper proposes a new pitch control system for smoothing the wind generator output fluctuations when the wind speed is between the cut in and the rated speed. Since the wind turbine output can be expressed as (7), the reference power for the proposed pitch control system is determined by using the discrete low pass filter as shown in Fig.6.

In the proposed method, the reference value, $P_{ref}$, for wind generator output, which corresponds to the pitch controller command signal, is determined by using discrete LPF [7] as shown in Fig. 6, of wind speed. Therefore, the oscillating components in the wind turbine output can be decreased, and the power system frequency can be controlled. The pitch control system is modeled as shown in Fig. 7. Using the discrete mode character of the LPF, better signal can be obtained for a reference

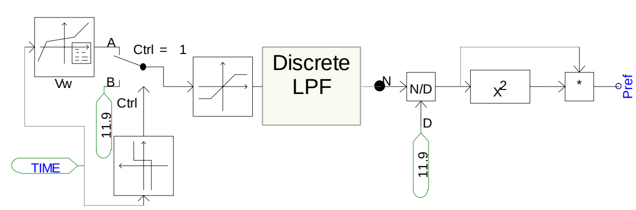


Fig. 6. Reference power generator system

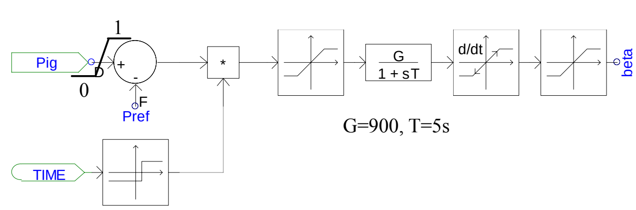


Fig. 7. Proposed pitch angle controller

value of wind turbine output by proper tuning the parameters of LPF. Therefore, the energy loss can be expected to become small.

## 6. SIMULATION RESULTS

The Simulation analyses have been carried out to investigate the performance of the proposed pitch controller with using real wind speed data. The simulation analyses have been performed using PSCAD/EMTDC [8].The wind speed data applied to each wind generator is shown in Fig. 8. Simulation results have been carried out for six patterns as shown in Table V in order to investigate the influence of the ratio of the wind farm capacity to the power system capacity, on the power system frequency.

The simulation results are shown from Fig. 9 through Fig. 14. Fig. 9 shows the wind farm output for different cases, which fluctuates due to the wind speed variations. The operation of the proposed pitch angle controller is shown in Fig. 10 for case-6. Fig. 11 & 12 show the output of thermal power generator SG2. This output is fluctuating so much, because this generator is operated under GF to control the electric power fluctuations with short period. Fig. 13 shows the power system frequency in the case when conventional pitch controller is used. In Case-3, the frequency deviation is in the range of +0.28 ~ -0.29[Hz]. It is seen that, when the power capacity of the wind farm is relatively large compared with that of the power system, the power system frequency cannot be maintained well by the frequency control of synchronous generators. Fig. 14 also shows the power system frequency when the proposed pitch controller is used. The frequency deviation is small compared with that shown in Fig. 13 and the maximum frequency deviation is within about ±0.125[Hz].

Table 5: Simulation Patterns & Evaluation of Results

| Cases | Rated capacity of WF [MVA] | Pitch Control System | Frequency Fluctuations |
|---|---|---|---|
| Case-1 | 3 | Conventional | ○ |
| Case-2 | 5 | | ○ |
| Case-3 | 10 | | × |
| Case-4 | 3 | Proposed | ○ |
| Case-5 | 5 | | ○ |
| Case-6 | 10 | | ○ |

(‘○’ means within ± 0.2[Hz], and ‘×’ means beyond ± 0.2[Hz])

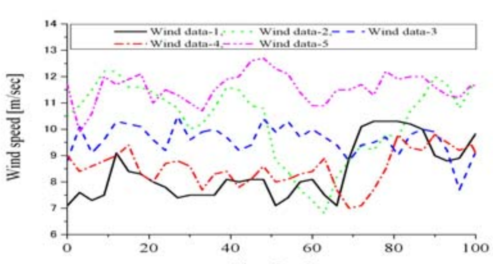


Fig 8. Response of wind speed data

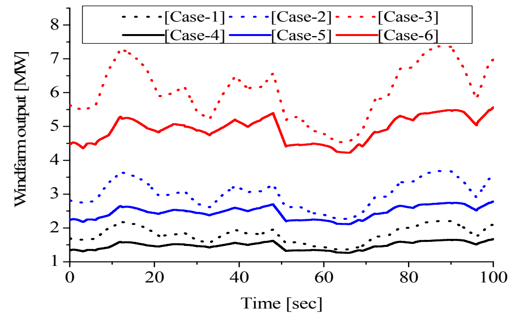


Fig 9. Responses of wind farm output power

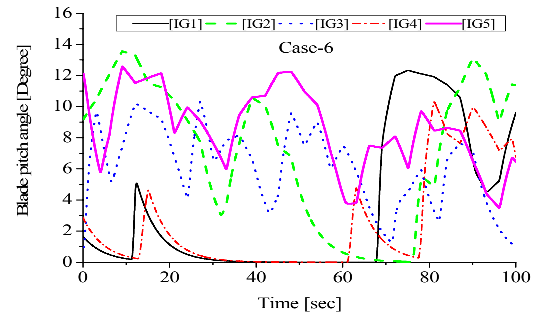


Fig 10. Responses of turbine blade pitch angles [Case-6]

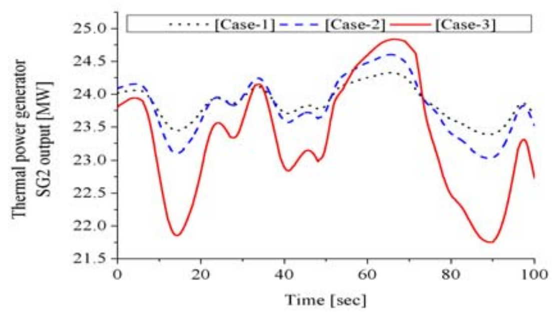


Fig 11. Responses of thermal generator (SG2) outputs

The permissible range of the power system frequency provided by the general electric utility industry law in Japan is within 50 ± 0.2[Hz]. In the case with the wind farm of 10[MVA], the frequency can not be controlled within 50 ± 0.2[Hz] by the conventional pitch controller, but proposed pitch controller can maintain the frequency within the permissible range.

## 7. CONCLUSIONS

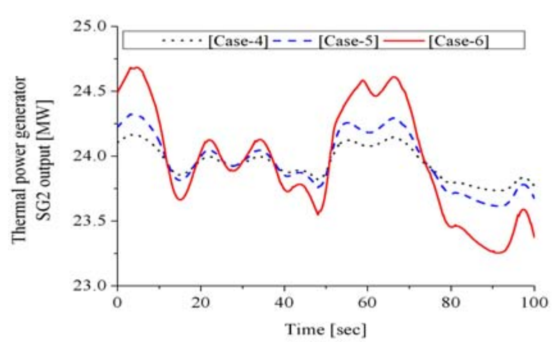


Fig 12. Responses of thermal generator (SG2) outputs

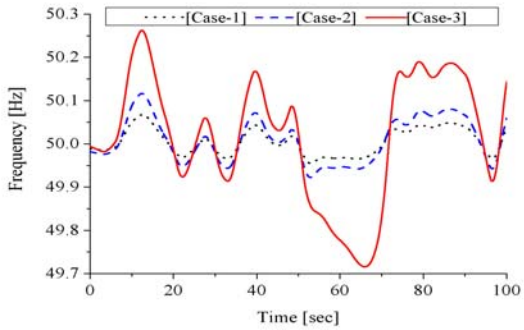


Fig 13. Responses of power system frequency

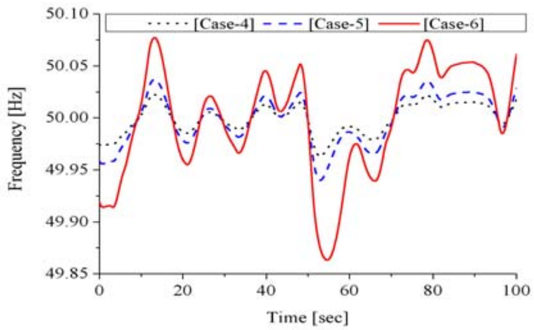


Fig 14. Responses of power system frequency

In this paper, a new pitch control system for smoothing the wind generator output fluctuations is proposed. The wind farm output fluctuations due to the wind speed variations can be smoothed more effectively by the proposed pitch controller than the conventional pitch controller. It is confirmed that the wind farm output gives rise to fluctuations of system frequency more as the power capacity of wind farm becomes large. By using the proposed pitch control system, the wind farm output fluctuations and thus the power system frequency deviation can be decreased.

## 8. REFERENCES


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## 9. NOMENCLATURE

| Symbol | Meaning | Unit |
|---|---|---|
| R1 | Stator resistance | Ω |
| X1 | Stator reactance | Ω |
| Xmu | Magnetizing reactance | Ω |
| R21 | Rotor 1st cage resistance | Ω |
| X21 | Rotor 1st cage reactance | Ω |
| R22 | Rotor 2nd cage resistance | Ω |
| X22 | Rotor 2nd cage reactance | Ω |
| Xd | Direct-axis synchronous reactance | Ω |
| Xq | Quadrature-axis synchronous reactance | Ω |
| H | Inertia constant | Second |
| QWF | Wind farm terminal capacitor bank | Var |
| $Q_{LOAD}$ | Load capacitor bank | Var |
| Pref | Reference value of transmission line power | Watt |
| $T_{m.max}$ | Turbine maximum output torque | N-m |
| Lsm | Inductance of the coil | Henry |
| Ism | DC current flowing through the coil | Ampere |
| Vsm | voltage across the coil | Volt |
| $V_w$ | Wind velocity | m/sec |
| D | Duty cycle | |
| $C_p$ | Power coefficient | |