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# Grid frequency fluctuations with the issue of high wind power penetration

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**Abstract:** *Now a day's worldwide energy problem is one of the great problems. Wind energy, a renewable and environmental friendly, is an important source of electrical power in recent years. As wind turbine output is proportional to the cube of wind speed, the wind turbine generator output fluctuates due to wind speed variations and highly variable at several different timescales from hour to hour, daily, and seasonally, can have an influence on the power system frequency. This paper investigates the influence of the ratio of the wind generator capacity to the power system capacity, on the power system frequency. To do this, impacts of thermal and hydro governor control system models are presented to show the performance of single synchronous generator. This study will be helpful for taking preventive measures for the power grid companies to improve the stability and quality of electric power. 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 simulation analyses have been performed by using PSCAD/EMTDC.*
***Keywords:*** *Renewable energy, Wind data, Fluctuations, PSCAD.*

## I. INTRODUCTION

Now a day's worldwide energy crisis is one of the great problem. The interest in renewable energy has been revived over last few years, especially after global awareness regarding the ill effects of fossil fuel burning. Winds are caused by the uneven heating of the atmosphere by the sun, the irregularities of the earth's surface, and rotation of the earth. Wind is a renewable resource because it is inexhaustible. Wind power is the world's fastest growing electricity generation technology. The use of renewable energy technology to meet the energy demands has been steadily increasing for the past few years, however, the important drawbacks associated with renewable energy systems are their inability to guarantee reliability and their lean nature [1]. If the power capacity of a wind generator becomes large, output power fluctuation caused by the randomly variable wind speed can have an influence on the power system frequency [1]. Though new pitch control system can smooth the wind generator output fluctuation up to a certain limit, it also maintains frequency to the desired level when wind power penetration becomes large (about 10% of total capacity).

## II. MODEL FOR SIMULATION ANALYSIS

The model system used in the simulation analyses is shown in Figure 2.1. 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, two thermal power generators, TG (cylindrical type synchronous generators, SG1hydro and SG2) and two loads. SG1 and SG2 are operated under different control modes [Governor Free (GF) control and load frequency control modes [2, 3]. 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. QWF and QLoad are capacitor banks. QWF 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. QLoad 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 3.1. The initial power flow and initial conditions are shown in Table 3.2.

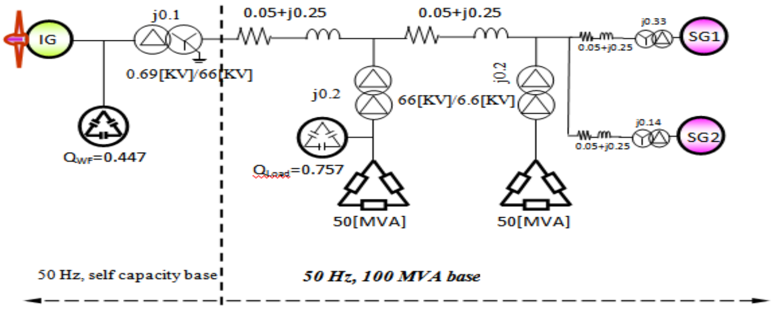



Fig.2. 1. Model System

Table 3.1 Parameters of Generator

| Induction Generator | | | | Synchronous Generator | | |
|---|---|---|---|---|---|---|
| | Squirrel cage type (IGn,n=1,2,3) | | | | Salient pole type (HG) | Cylindrical type (TG) |
| MVA | 3 | 5 | 10 | MVA | 100 | 100 |
| $R_1$ [pu] | 0.01 | | | Xd[pu] | 1.2 | 2.11 |
| $X_1$ [pu] | 0.18 | | | Xq[pu] | 0.7 | 2.02 |
| $X_m$ [pu] | 10 | | | Xd'[pu] | 0.3 | 0.28 |
| $R_2$ [pu] | 0.015 | | | Xd"[pu] | 0.22 | 0.215 |
| $X_2$ [pu] | 0.12 | | | Xq"[pu] | 0.25 | 0.25 |
| 2H [sec] | 1.5 | | | Tdo'[sec] | 5.0 | 4.2 |
| | | | | Tdo"[sec] | 0.05 | 0.032 |
| | | | | Tqo"[sec] | 0.14 | 0.062 |
| | | | | H[sec] | 2.5 | 2.32 |

Table 3.2: 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% | | |

# III. 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 [6]. 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 [3].

## 3.2. Governor for Hydro and Thermal Generators

The governor models used in the simulation analyses are shown in Figure 3.1 and figure 3.2, in which the values of 65M and 77M for hydro and thermal generators are shown in Table 3.3 and Table 3.4 respectively. When several SGs are connected together their values of 65M and 77M are shown in Table 3.5. 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, load limit operation).

For Governor Free (GF) operation:

When PLM > 0

65M = the initial output [pu]

77M = 65M + rated MWoutput × PLM [%]

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

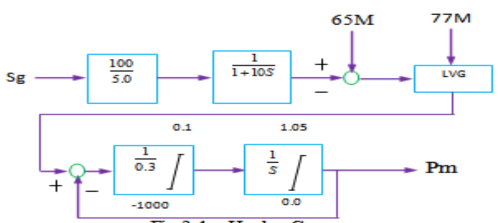


Fig.3.1: Hydro Governor

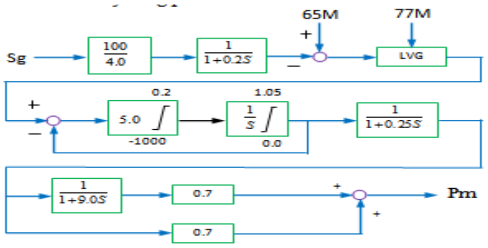


Fig.3.2: Thermal Governor

Table 3.3: 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 |

Table 3.4: Values of 65M and 77M 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 3.5: Parameter of SG1 (Hydro)

| | | |
|---|---|---|
| Frequency control | 65M | 77M |
| LFC | LFC signal | 1 |
| SG2(Thermal) | | |
| Frequency control | 65M | 77M |
| 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 Figure.3.3. Parameters of AVR are shown in Table 3.6 [5].

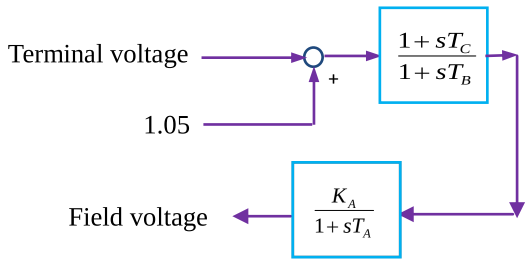


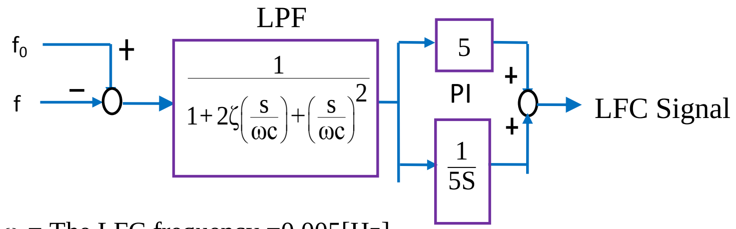
Fig.3.3: AVR model

Table 3.6: Table 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), the control output signal is sent to LFC power plant when the frequency deviation is detected in the power system [5]. Then, governor command signal and thus the output of LFC power plant is changed according to LFC signal. 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 used in this study is shown in Figure 3.4, where, Tc: the LFC period = 200[s]; ωc: the LFC frequency = 1 / Tc = 0.005[Hz]; ζ: the damping ratio = 1.



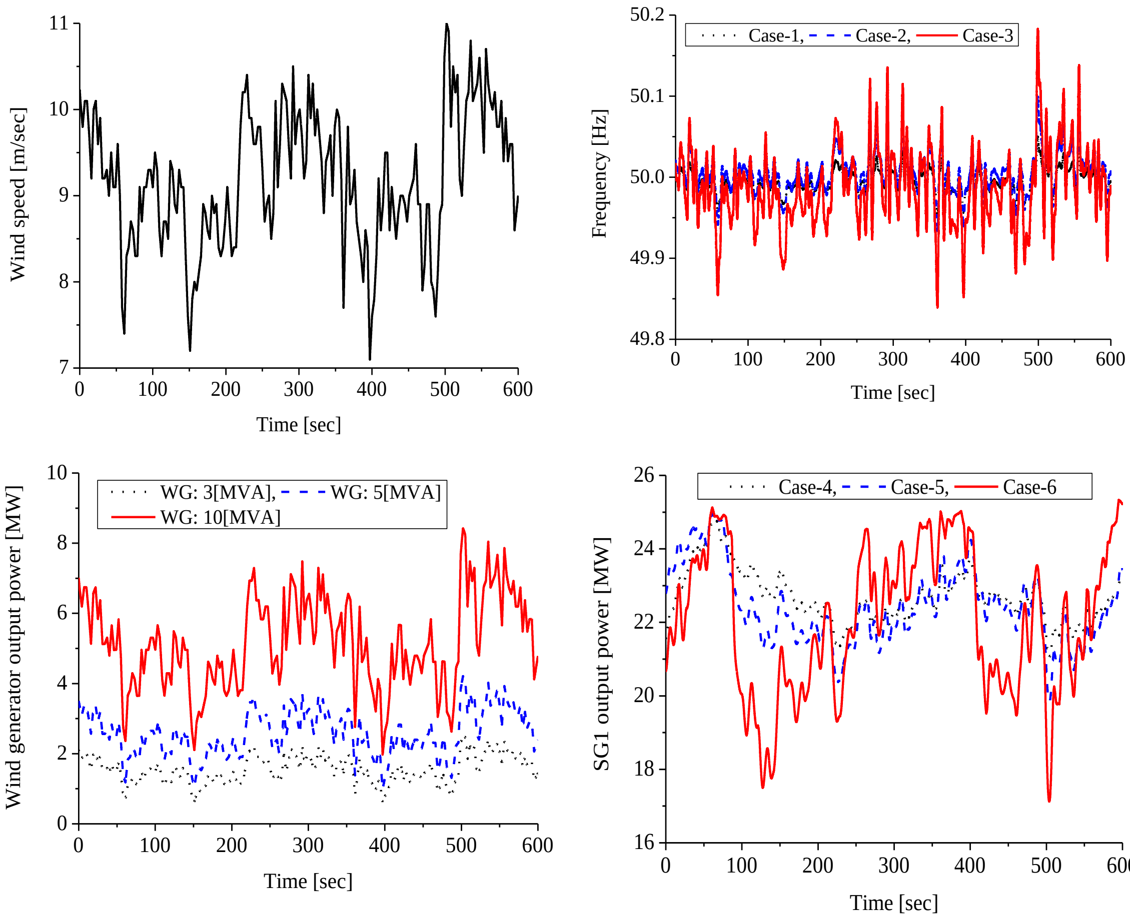

$\omega_c$= The LFC frequency =0.005[Hz]
Tc= The LFC period=200[s]
ζ= The damping ratio=1

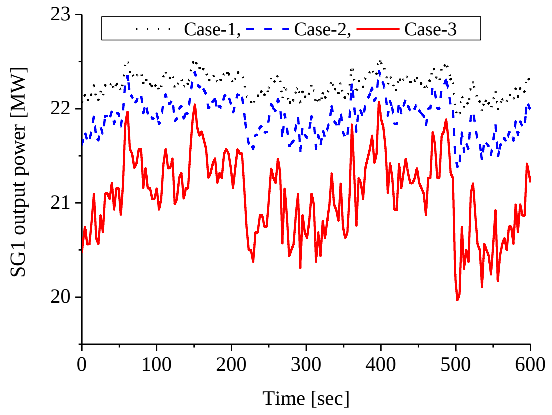
$f_0$: Base frequency (50[Hz])
f: System frequency [Hz]

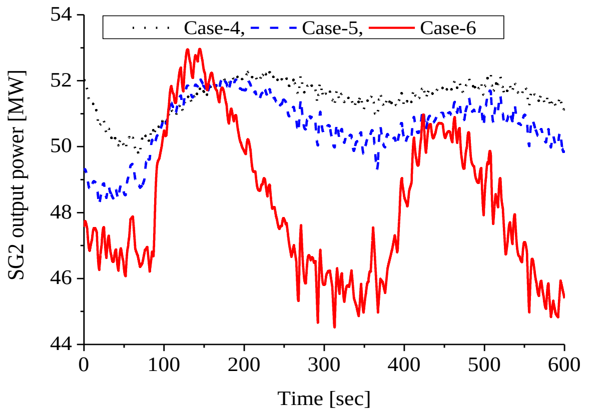
Fig.3.4: Load frequency control model

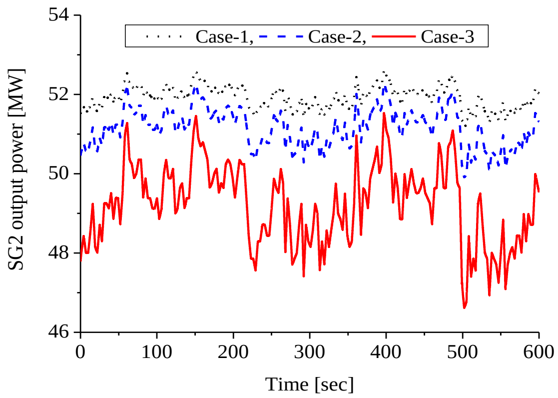
## IV. SIMULATION RESULTS

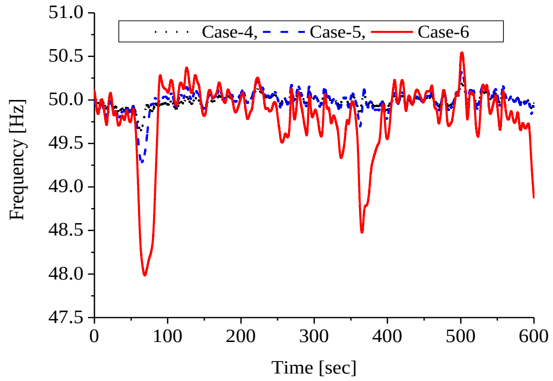
Simulation analyses have been carried out to investigate the performance of the power system frequency with the increased wind power penetration using real wind speed data [3]. The wind speed data used in the analysis is the real data, which is measured in Hokkaido Island, Japan. The wind speed data applied to the wind generator is shown in Figure 4.1. Simulation analyses have been carried out for seven patterns shown in Table 4.1 in order to investigate the influence of the ratio of the wind generator capacity to the power system capacity, on the power system frequency. The simulation analyses have been performed by using PSCAD/EMTDC. All generators are rated in MVA [3].

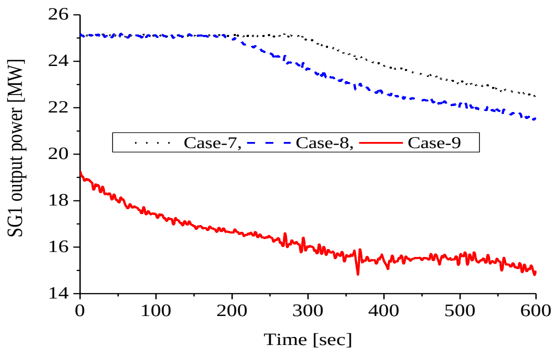


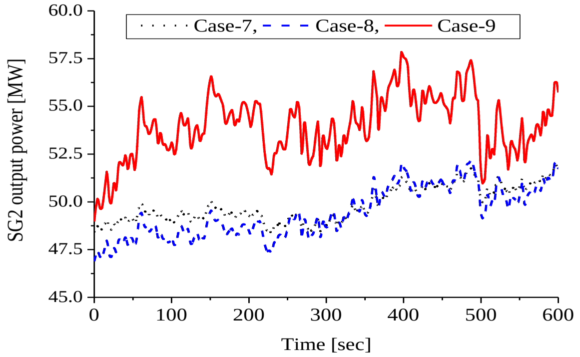


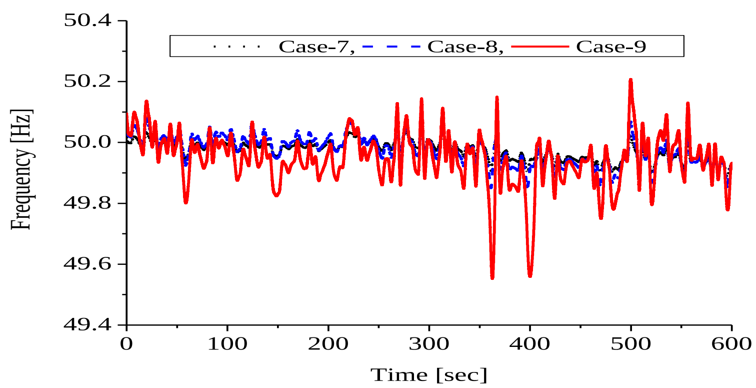




Fig.4.11: Frequency vs. Time for case 7-8-9

Table 4.1: Different cases for analysis

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

## V. SUMMARY OF THE RESULTS

Evaluation of the simulation results are summarized in the Table 5.1below. From the evaluation of simulation results, it may be predicted that, which case is adopted or not. There is a notification that, ’o’ means within ± 0.2 [Hz] and ’×’ means beyond ± 0.2 [Hz]. It is clear that case 1, case 2 and case 4 maintain grid frequency fluctuation in a permissible limit, where others exceed tolerable limit.

Table 5.1: Evaluation of simulation results

| [Cases] | ’o’ and ’×’ of frequency fluctuations |
|---|---|
| Case-1 | o |
| Case-2 | o |
| Case-3 | × |
| Case-4 | o |
| Case-5 | × |
| Case-6 | × |
| Case-7 | × |
| Case-8 | × |
| Case-9 | × |
| ’o’ means within ± 0.2 [Hz] and ’×’ means beyond ± 0.2 [Hz] | |

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