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TRANSIENT ANALYSIS OF WIND FARM INTERCONNECTED POWER SYSTEM BY USING PITCH CONTROLLER

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Abstract*- In this paper, the stability enhancement of a wind farm interconnected power system associated with pitch controller is investigated. A control system model for the pitch controller is used in this study. The pitch controller is specially used for transient stability augmentation. It is seen that, the wind farm terminal voltage during the fault in the grid cannot be maintained without pitch controller. However, pitch controller can improve the system performances under fault conditions. From the simulation results, it is also seen that the pitch controller can enhance the transient stability of the power system during unsuccessful reclosing of circuit breaker. Therefore, pitch controller has better effect on wind farm interconnected power system for stabilizing the system with unsuccessful reclosing of circuit breakers (CB) and thus enhance the stability of power system. Detail procedure with simulation results i.e., block diagram, description of the system, simulation wave shapes and performance analysis are presented in this paper. The steps are presented in a sequential manner that would be advantageous for the beginners as well as for the advanced readers who are interested to research with such systems.*

Keywords: Wind farm stabilization, pitch controller, real power, terminal voltage and fault.

1. INTRODUCTION

This paper aims at investigating the effect of pitch controller on the transient stability in a multi machine power system during unsuccessful re-closing of circuit breakers (CB). The conventional pitch controller is used for this purpose. When the wind speed exceeds the rated speed, the pitch angle needs to be controlled. The purpose of pitch controller is normally used to maintain the output power of the wind generator at rated level by controlling the blade pitch angle of turbine blade when wind speed is over the rated speed. However this study shows that the pitch controller can enhances the transient stability of power system. Simulation results of balanced fault at different points in a multi machine power system show that the pitch controller is able to stabilize the system in case of an unsuccessful re-closing of circuit breakers (CB). So, the use of pitch controller has better effect on wind farm interconnected power system to enhance the transient stability of power system. Here governor model for synchronous generators (hydro, thermal and nuclear) are used. Also the automatic voltage regulator (AVR) model and load frequency control (LFC) model are used.

The organization of this paper is as follows, section 2 presents the model system, which will be analyzed here, and section 3 contains the wind turbine chracteristics. Description of Pitch control and pitch controller is given in section 4 and 5. Also, simulation results, discussion and conclusion are presented in section 6, 7, and 8 respectively.

2. THE MODEL SYSTEM ANALYSIS

The model system shown in Figure 1 has been used for the simulation analyses of wind generator stabilization, in this work. The model system consists of one synchronous generator (100MVA), SG, and one wind turbine generator (50MVA induction generator, IG), which are delivering power to an infinite bus through a transmission line with two circuits. Though a wind power station is composed of many generators, it is considered to be composed of a single generator with the total power capacity, in this study. There is a local transmission line with one circuit between the main transmission line and the transformer followed by the wind power station. A double squirrel-cage induction machine model, which is represented by the steady state equivalent circuit shown in Figure 2, where s denotes a rotational slip, is used for the wind generator. To establish the rotating magnetic field of the stator, reactive power is needed to be supplied from the network to the stator winding of the induction generator. Therefore, to compensate the reactive power demand at steady state, a capacitor bank is inserted at the terminal of IG. The value of the capacitor (0.2393pu) is chosen in such a way that the power factor of the wind power station becomes unity during the rated condition (V=1.0, P=0.5)**.** The AVR (Automatic Voltage Regulator) and GOV (Governor) control system models shown in Figure 3 and 4 respectively are used in the synchronous generator model. Moreover, the SG parameters as well as IG parameters and initial conditions are shown in Table 1 and 2 respectively [1]. The system base power is 100 MVA. The pitch controller is specially used for transient analysis in this study.

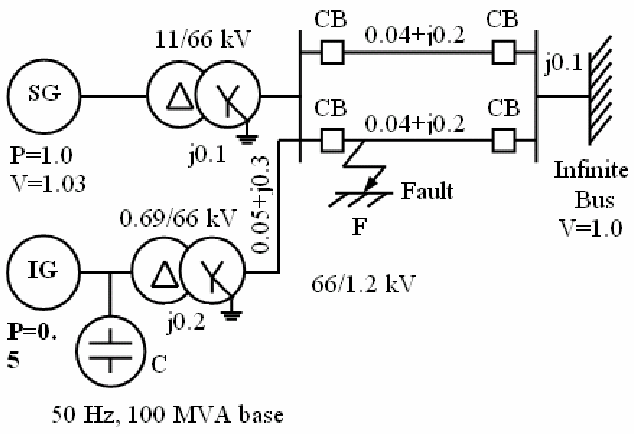


Fig. 1: Model System

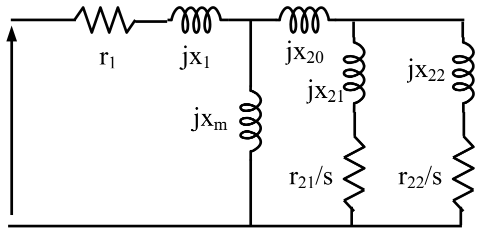


Fig. 2: Steady state equivalent circuit of double squirrel-cage induction generator

TABLE 1

GENERATOR PARAMETERS

SG		IG	
MVA	100	MVA	50
Ra(pu)	0.003	r1(pu)	0.01
Xa(pu)	0.13	x1(pu)	0.10
Xd(pu)	1.2	Xmu(pu)	3.50
Xq(pu)	0.7	r21(pu)	0.035
Xd′(pu)	0.3	x21(pu)	0.030
Xd″(pu)	0.22	r22(pu)	0.014
Xq″(pu)	0.25	x22(pu)	0.098
Td0′(sec)	5.0	2H(sec)	3.0
Td0″(sec)	0.04		
Tq0″(sec)	0.05		
H(sec)	2.5		

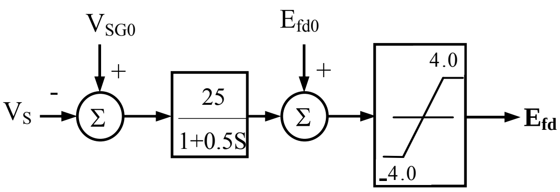


Fig. 3: AVR Model

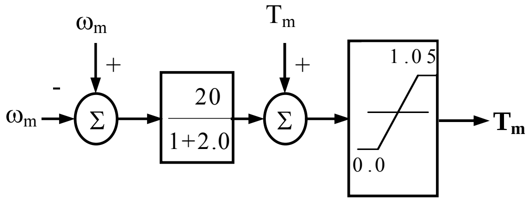


Fig. 4: Governor Model

TABLE 2

INITIAL CONDITIONS

	SG	IG
P(pu)	1.0	0.50
V(pu)	1.03	0.999
Q(pu)	0.334	0.00 (.239*)
E_{fd}(pu)	1.803	-
Tm(pu)	1.003	-
δ(deg)	50.71	-
slip	0.0	-1.09%
V_w(m/s)	-	11.797
β(deg)	-	0

*Reactive power drawn by induction generator

3. WIND TURBINE CHARACTERISTICS

The wind turbine can be characterized by its CP -TSR (curve as shown in Figure 5), where the TSR is the tip-speed ratio; that is, the ratio between the linear speed of the tip of the blade with respect to the wind speed. It is shown that the power coefficient CP varies with the tip-speed ratio. It is assumed that the wind turbine is operated at high CP values most of the time. In a fixed-frequency application, the rotor speed of the induction generator varies by a few percent (based on the slip) above the synchronous speed while the speed of the wind may vary across a wide range. In Figure 5, the change of the CP-TSR curve as the pitch angle is adjusted is also shown. In low to medium wind speeds, the pitch angle is controlled to allow the wind turbine to operate at its optimum condition. In the high wind speed region, the pitch angle is increased to shed some of the aerodynamic power. From equation 1, the tip-speed ratio for a fixed speed wind turbine varies across a wide range depending on the wind speed. The power captured by the wind turbine may be written as equation 2. From equation 2, it is apparent that the power production from the wind turbine can be maximized if the system is operated at maximum CP. As the wind speed changes, the rotor speed should be adjusted to follow the change. This is possible with a variable-speed wind turbine. Unfortunately, it appears that the wind speed cannot be reliably measured. To avoid using the wind speed, the equation to compute the target power can be rewritten by substituting the wind speed V and the CP.

The target power P_{TARGET} can be written

$$TSR = \frac{\omega_m R}{V} \qquad (1)$$

Where
ω_m= Rotor speed mechanical rad/sec
R= Radius of the blade meter
V= Linear speed of the wind m/sec

$$P_{mech} = 0.5\ \rho A C_P V_3 \qquad (2)$$

Where
ρ= Air density kg/m^3
A= swept area m^2
C_P= Coefficient of wind turbine
V= Wind velocity m/sec

$$P_{TARGET} = 0.5\,\rho\, A\, C_{P_{TARGET}} \left[\frac{R}{TSR_{TARGET}}\right]^3 \omega_m^3 \qquad (3)$$

$$P_{TARGET} = Kp\ (RPM)^3 \qquad (4)$$

Where
P_{TARGET}= Target power (max C_P)
Cp_{TARGET}= Cp at TSR_{TARGET}
Kp= Computed wind turbine data
RPM= Rotor speed

as in equation 3, or in it can be written in its simple form shown in Equation 4. It can be seen that the P_{TARGET} is proportional to the cube of the rotor speed.

For simulations used in this study, the wind input data is a time series of wind data of different turbulence conditions. To reduce the computing time, the input data (the wind speed) of a 10-second time series is used. The work performed in this project was based on a generic wind turbine. The physical dimension and the CP-TSR characteristic of the wind turbine are the inputs for this program. The inertia of the blade and the inertia of the generator are given. The stiffness of the shaft and the damping are given. The induction generator modeled is a wound-rotor induction generation with the stator connected to the utility and the rotor winding connected to the power converter. The generator can be controlled to respond to the torque command almost instantaneously.

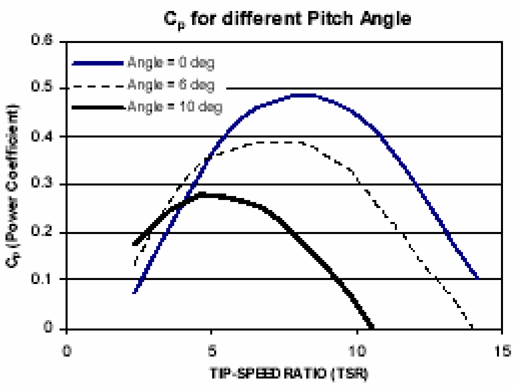


Fig.5: Power coefficient C_p versus Tip speed ratio

4. PITCH CONTROL

In the simulation analysis, conventional pitch controller as shown in Figure 6 is used. The purpose of using the pitch controller [6] 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.

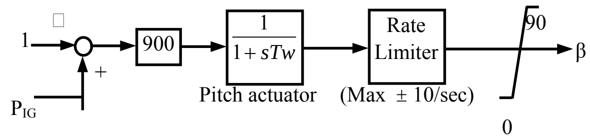
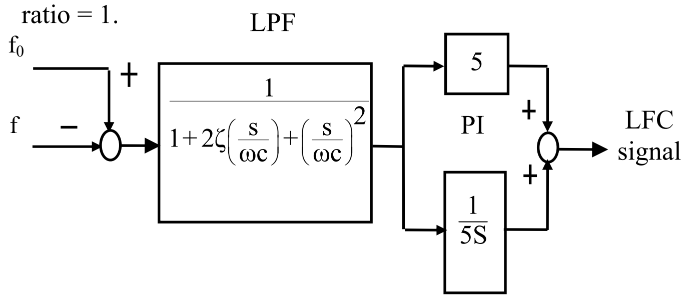


Fig. 6: Conventional pitch control system

Generally, the blade pitch operation system is complicated, but this paper simulates the pitch operation system [5] 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. This study uses the pitch controller for transient stability augmentation also.

5. Load Frequency Control Model

In the Load Frequency Control (LFC) [2], the control output signal is sent to LFC power plant when the frequency deviation is detected in the power system. 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 7, where, Tc: the LFC period = 200[s]; ωc: the LFC frequency = 1 / Tc = 0.005[Hz]; and ζ: the damping ratio = 1.



ωc= 0.005[Hz]
Tc= 200[s]
ζ= 1

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

Fig. 7: Load frequency control model

6. SIMULATION RESULTS

Simulations have been carried out to investigate the performance of the power system stability with the increased wind power penetration using real wind speed data. The wind speed data is the real data, which was obtained in Hokkaido Island, Japan. The wind speed data applied to the wind generators. The simulation analyses have been performed using PSCAD/EMTDC [3]. When the wind speed of each wind generator varies randomly, the power system real power and voltage of the grid system also vary. These fluctuations caused by the wind farm can be adjusted significantly by using the proposed pitch controller. Thus pitch controller system enhances the system reliability and stability effectively.

The 3LG fault is considered at the wind generator terminal. During fault the wind speed is considered at rated speed (11.8 m/s) for the short duration. The fault is considered at 0 sec and fault is cleared at 1 sec, but due to unsuccessful reclosing the CB is opened at 1.1 sec. Figure 8 shows the responses of wind farm real power. It is seen that real power can be maintained to the rated value by using the proposed pitch controller. The black line shows the performance of pitch controller and the dotted line also shows the performance without pitch controller. It is known that when the wind speed of each wind generator varies randomly, the power system terminal voltage of the grid system also varies. These fluctuations also can be decreased significantly by using the proposed pitch controller. In Figure 9 the solid line shows the terminal voltage response with pitch controller and the dotted line also shows the terminal voltage response without pitch controller. It is seen that the terminal voltage can be enhanced effectively by the proposed pitch controller. Figure 10 shows that IG speed can also be maintained stable by the proposed pitch controller. Figure 11 shows the Turbine blade pitch angle versus time curve.

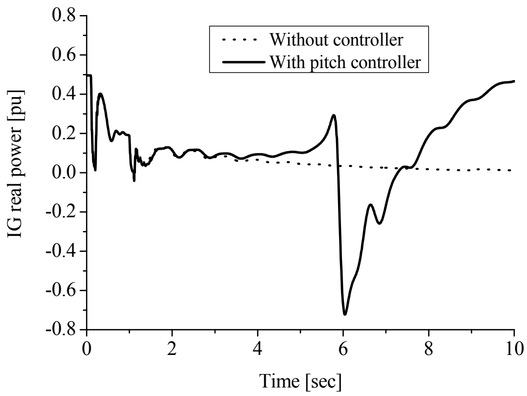


Fig.8: Response of wind farm real power

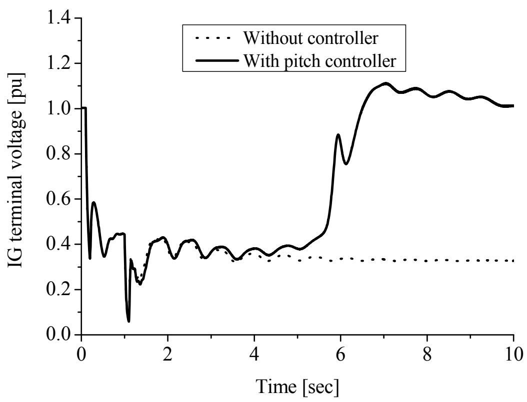


Fig.9: Response of wind farm terminal voltage

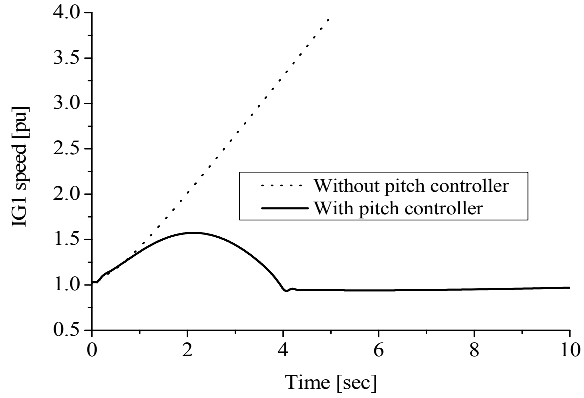


Fig.10: IG output versus time

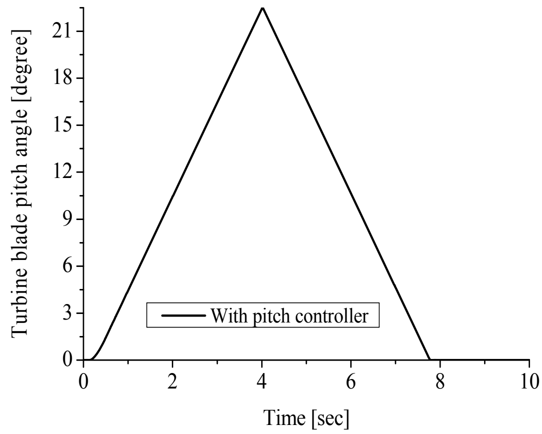


Fig.11: Turbine blade pitch angle versus time

7. DISCUSSION

The simulation analyses using PSCAD/EMTDC shows that, when the wind speed of each wind generator varies randomly, the power system real power and voltage of the grid system also varies. These fluctuations caused by the wind farm can be decreased significantly by using the proposed pitch controller. The pitch controller system can also enhance the system stability during the fault condition.

8. CONCLUSIONS

This paper proposes pitch controller to enhance the stability of wind farms in order to maintain the grid stability to within an acceptable range. The effect of the smoothing control is evaluated using a power system model installed with the pitch controller unit. The simulation analyses show that, using the proposed pitch controller system, the wind farm output fluctuations can be decreased, and hence the transient stability during unsuccessful re-closing of CB can be enhanced efficiently. Therefore, the integration of the proposed pitch controller system into a wind farm can be an effective means of improving the LVRT capability of wind firm.

9. REFERENCES

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10. 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	Wind velocity	m/sec
D	Duty cycle	
C_p	Power coefficient	