

Simulation of Excitation Synchronous Wind Power Generator

D. Anusha¹, G. Satyanarayana²

¹PG Scholar, Anurag Engineering College

²Associate Professor, Anurag Engineering College

Abstract: This paper presents a novel excitation synchronous wind power generator (ESWPG) with a maximum power tracking scheme. The excitation synchronous generator and servo motor rotor speed tracks the grid frequency and phase using the proposed coaxial configuration and phase tracking technologies. The generator output can thus be directly connected to the grid network without an additional power converter. The proposed maximum power tracking scheme governs the exciter current to achieve stable voltage, maximum power tracking, and diminishing servo motor power consumption. Simulation model is developed and observed the results.

Keywords:

1. Introduction

THE GLOBAL market demand for electrical power produced by renewable energy has steadily increased, explaining the increasing competitiveness of wind power technology. Wind power generators can be divided into induction and synchronous types [1]–[8]. The excitation synchronous generator driven by hydraulic, steam turbine, or diesel engines has been extensively adopted in large-scale utility power generation owing to desired features such as high efficiency, reliability, and controllable output power. A wind power generator in grid connection applications, except for doubly fed induction generators, achieves these features using variable speed constant frequency technology.

However, most excitation synchronous wind generators cannot be connected directly to the grid, owing to instabilities in wind power dynamics and unpredictable properties that influence the generator synchronous speed. The direct-drive permanent magnet synchronous wind generator (PMSWG) uses variable speed and power converter technologies to fulfill the grid connection requirements, which has advantages of being

This paper presents a novel converterless wind power generator with a control framework that consists of an excitation synchronous generator, permanent magnet (PM) synchronous servo motor, signal sensors, and servo control system. The wind and servo motor powers are integrated with each other and transmitted to the excitation synchronous generator via a coaxial configuration. When the wind speed varies, the servo motor provides a compensatory energy to maintain constant generator speed. The additional servo motor power is also transformed into electricity, and output into the load. This means that the motor power is not wasted. Using a precise phase tracking function design, the proposed robust integral servo motor control scheme reduces the output voltage phase shift in the excitation synchronous generator from wind disturbances. According to the servo motor power magnitude and the generator power, the proposed maximum power tracking scheme controls the excitation field current to ensure that the excitation synchronous generator fully absorbs the wind power, and converts it into electricity for the loads. Based on physical

theorems, a mathematical model for the proposed system is established to evaluate how the control function performs in the designed framework.

2. Power Flow and Speed

For simplicity, assume that all energy transmission elements behave ideally, allowing us to ignore the mechanical power losses of the wind turbine, the servo motor, and the excitation synchronous generator. Fig. 1 shows the power flows of the proposed system, where T , T , and T denote the torques and ω , ω , and ω are the wind turbine, servo motor, and excitation synchronous generator speeds, respectively. The total excitation synchronous generator input power is the product of T and ω . The power flow equation can thus be defined as

$$T_g \cdot \omega_g = T_w \cdot \omega_w + T_m \cdot \omega_m.$$

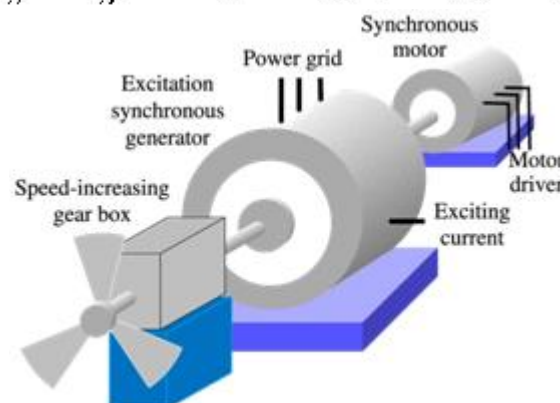


Figure 1: Proposed coaxial construction configuration

Fig. 1 shows the corresponding coaxial configuration. The wind generator rotor shaft input-end receives rotating torques from the speed increasing gear box. The tail-end of the generator rotor shaft is coupled with a servo motor. The input energy of the excitation synchronous generator is the sum of the wind power and servo motor powers. The speed and rotating direction for the wind turbine output, servo motor, and excitation synchronous generator is the same, i.e., the system speeds satisfy $\omega_w = \omega_m = \omega_g$. This

arrangement can reduce the power transmission losses.

3. Proposed System Configuration

Fig. 4 schematically depicts the servo motor and maximum power tracking control (MPTC) loops which are designed to stabilize the speed, frequency, and output power of the excitation synchronous generator under wind disturbances. The wind turbine provides mechanical torque to rotate the generator shaft via the speed-increasing gear box. As the generator shaft speeds reach the rated speed, the generator magnetic field is excited. The MPTC then controls the output voltage reaching grid voltage. Moreover, the generator output waveform is designed in phase with the grid using the servo motor control track grid sine waveform. Owing to the difficulty in precisely estimating the wind speed, the proposed MPTC scheme measures the motor output power as the reference signals to determine the generator output power. The excitation synchronous generator output frequency, voltage-phase, and output power are fed back into the control scheme. The phase/frequency synchronization strategy in Fig. 4 compares the grid voltage-phase and frequency with the generator's feedback signals, and produces the position command θ_{cmd} with pulse-type signals to the servo motor driver. The MPTC also adjusts the excitation field current I_f based on the wind power and motor power inputs, where θ denotes the servo motor rotor mechanical rotor angular displacement detected by an encoder. Due to the coaxial configuration, detecting the relative position of the rotor allows us to determine the generator voltage phase during the wind power generator system

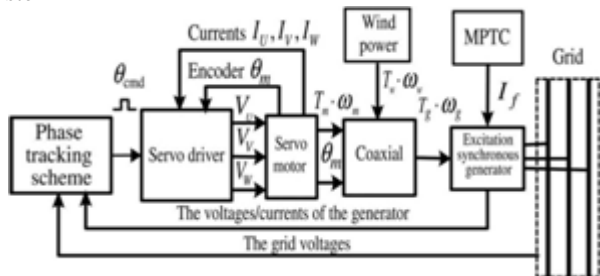


Figure 2: Proposed system configuration



parameters of the PM synchronous motor. According to (1), wind power, generator power, and servo motor power can be transformed into three torque functions and incorporated in the three-phase PM synchronous motor model.

The electromagnetic torque T of the servo motor can be expressed as [17]

$$T_m = \frac{P}{2} \lambda_{pm} \cdot \left[I_U \cdot \sin \theta_r + I_V \cdot \sin \left(\theta_r - \frac{2}{3} \pi \right) + I_W \cdot \sin \left(\theta_r - \frac{4}{3} \pi \right) \right] \quad (2)$$

where P denotes the number of motor poles, and I_U , I_V , and I_W are the applied stator currents. The mechanical torque T can be expressed as

$$T_m + (T_w - T_g) = J_s \left(\frac{2}{P} \right) \frac{d\omega_r}{dt} + B \left(\frac{2}{P} \right) \omega_r$$

$$\theta_r = \int \omega_r dt$$

$$\theta_{in} = \frac{2}{P} \theta_r. \quad (3)$$

5. Modeling of System

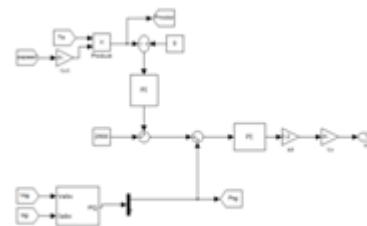


Figure 3: MPPT modeling using MATLAB/SIMULINK

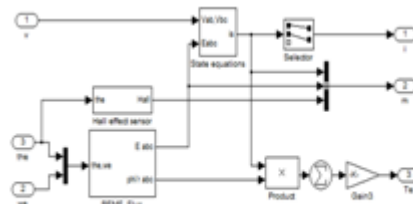


Figure 4: Wind turbine modeling in SIMULINK

4. Servo Motor Controller Design

The transient and dynamic responses of the servo motor controller must satisfy robustness requirements to reduce the influence of wind fluctuations to the generator. Thus, the robust integral structure control (RISC) method is chosen to ensure the voltage phase and the frequency in phase with the grid. Among general electrical motors, the three-phase PM synchronous motor has the advantages of high-efficiency and low-maintenance requirements, the reason controllable power for the servo control structure was chosen in the research [17]–[20]. This study designs an analysis model based on the electrical circuit, motor torque, and mechanical theorems. Fig. 5 shows the block diagram of the three-phase PM synchronous motor, and Table I lists the

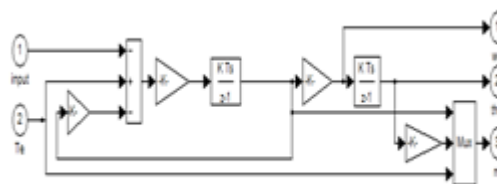


Figure 5: modeling of servo motor

6. Simulation Results

The generator design functionality is confirmed using a wind power generator framework simulation model with an excitation synchronous generator and its corresponding sub-systems, using MATLAB/Simulink and MATLAB/Simpower software. Sub-systems include the wind power input, servo motor phase tracking control, maximum power tracking control, excitation synchronous generator, and grid connection. respectively. To output the three-phase voltage signals at 60 Hz, the excitation synchronous generator must operate at 1800 rpm with 4-pole windings.

The voltage phase tracking performance of the system at generator output 2 kW is investigated. Fig. 10(a) shows the phase voltage and current waveforms of the excitation synchronous generator. Fig. 10(b) shows the grid and generator voltage phase tracking waveforms. The simulation voltage and current waveforms in Fig. confirm that the proposed system has high-quality power and sufficient control stability during grid connection. The generator output phase voltage is in phase with the grid in Fig. Owing to the excitation synchronous generator rotation speed control and excitation control, the output power, voltage, and frequency are constant. The wind power generator system can thus connect directly to the grid

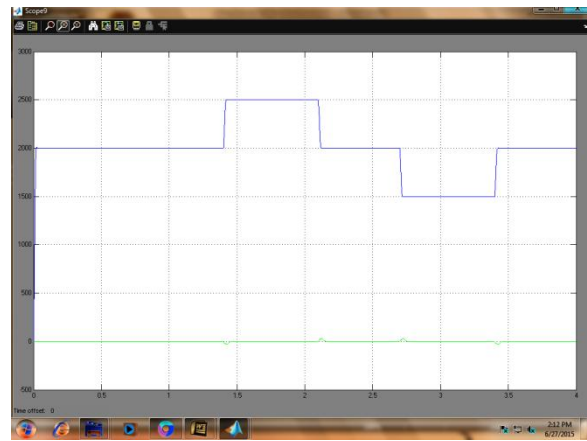


Figure : wind Power and torque of generator

7. Conclusion

This paper presented an excitation synchronous wind power generator with MPTC scheme. In the proposed framework, the servo motor provides controllable power to regulate the rotor speed and voltage phase under wind disturbance. Using a phase tracking control strategy, the proposed system can achieve smaller voltage phase deviations in the excitation synchronous generator. In addition, the maximum output power tracking scheme governs the input and output powers to achieve high performance. The excitation synchronous generator and control function models were designed from the physical perspective to examine the presented functions in the proposed framework. Experimental results demonstrate that the proposed wind power generator system achieves high performance power generation with salient power quality.

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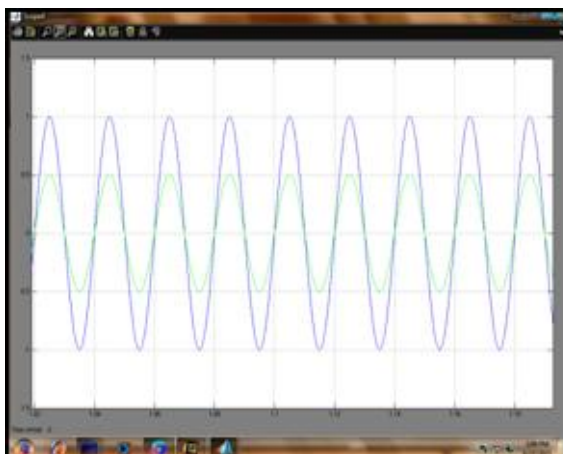


Figure : Vsg And Isg Of Phase A

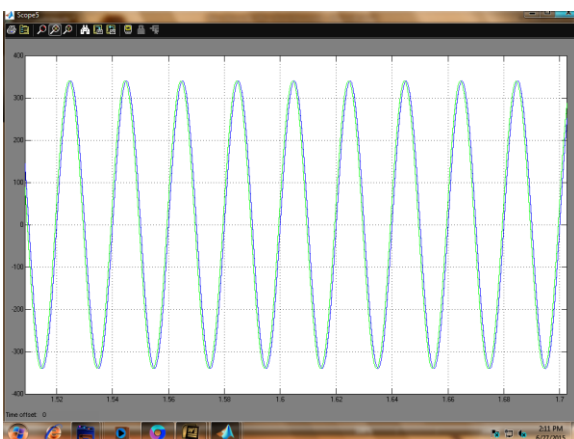


Figure : Grid Voltage And Inverter Voltage

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