Excitation Synchronous Wind Power Generators with Maximum Power Tracking process

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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 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: Excitation Synchronous Wind Power Generator (ESWPG), Permanent Magnet Synchronous Wind Generator (PMSWG).

I. 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. 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 means that the motor power is not wasted. Using a precise 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 gearless. Various power transfer technologies are applied for ac/dc transformation to obtain a constant frequency ac power [9]–[16]. However, extensive use of power electronic devices in those systems will cause unavoidable power losses from the rectifier’s conducting resistance and high-frequency power switches, which will increase power consumption. Therefore, a converter less method for a high-efficiency excitation synchronous wind generator is an important issue, especially for middle and high output voltage wind power generators. This paper presents a novel converter less 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 with fuzzy logic controller. The wind and servomotor 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. 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.

II. 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 $T_\omega, T_m$ and $T_g$ denote the torques and $\omega_W, \omega_m, \omega_g$ are the wind turbine, servo motor, and excitation synchronous generator speeds, respectively. The total excitation synchronous generator input power is the product of and the power flow equation can thus be defined as

$$T_g \omega_g = T_\omega \omega_W + T_m \omega_m \quad \text{(1)}$$

Fig. 1. Power flow block diagram

Fig. 2. Proposed coaxial construction configuration.

Fig. 2 shows the corresponding coaxial configuration. The Fig. 4 schematically depicts the servo motor and maximum 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 $\omega_W, \omega_m$, and $\omega_g$. This arrangement can reduce the power transmission losses.

III. CONTROL OF PROPOSED PRINCIPLES WIND POWER GENERATOR SYSTEMS

Fig. 3 depicts the control framework of the proposed system. The control system design concepts maintain power flow balance between the input and the output and, simultaneously, force the generator frequency to synchronize with the utility grid. When the system complies with these conditions, the generator output can be connected to the utility grid network, subsequently reaching the high efficiency and maximum power tracking objectives. The control signals, including the generator voltage, current, grid phase, motor encoder, and output power, are sensed and transferred to the microprocessor control unit (MCU). The servo motor controller plays an important role in output power and grid voltage phase tracking. A situation in which the controller detects a power increase from the servo motor implies decreasing wind speeds. At this moment, the
system regulates the exciter current to reduce the excitation generator output power.

A chain reaction subsequently occurs in which the servo motor power returns to a balanced level. During the energy balance periods, the servo motor consumes only a slight amount of energy to stabilize the shaft speed. Once (1) is satisfied, both the maximum power and the constant speed can be obtained by the designed control scheme. The transient and dynamic responses of the servo motor the mechanical time constant as $T_\theta << T_m$. The three-phase 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 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 of the servo motor can be expressed as

$$T_m = \frac{P}{2} \lambda_m$$

$$[I_u \sin \theta_r + I_v \sin (\theta_r - \frac{2}{3} \pi) + I_v \sin (\theta_r - \frac{4}{3} \pi)]$$

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

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

$$\theta_m = \frac{2}{P} \theta_r$$  \hspace{1cm} (3)

Additionally, \( \omega_r \) denotes the electrical rotor angular velocity; \( \theta_r \) represents the electrical rotor angular displacement; \( \theta_m \) is the mechanical rotor angular displacement; \( J \) is the rotor inertia; and \( B \) is the damping coefficient. In Fig. 5, \( L \) denotes the inductance of the stator windings; \( \lambda_m \) represents the amplitude of the flux linkage established by the permanent magnet as viewed from the stator windings; \( U_u, U_v, \) and \( U_w \) are the applied stator voltage of the motor; and \( R_a \) denotes the resistance of each stator winding. Moreover, \( T_0 = L/R_a \) is the electrical time constant, and \( T_m = J/B \) is the mechanical time constant. It is clear from the physical characteristics stated above that the motor electrical time constant is overwhelmingly lower than PM synchronous motor model can thus be simplified as a first-order mathematical model, as shown in the Fig. 6.

According to Fig. 6, the position control structure includes the RISC and servo motor transfer function. The conventional motor current feedback controller can avoid instantaneous current stress to the servo driver. This technology has been applied to the servo motor control to improve the control performance. The RISC outer loop is designed to achieve a fast and accurate servo tracking response under load disturbances and plant parameter variations. In Fig. 6, \( \theta_{cmd} \) denotes the position command.

Parameters \( K_1 \) and \( K_3 \) are proportional gains and \( K_2 \) is the integral gain. The PM synchronous motor state equations are described as

$$x_1(t) = x_2(t)$$

$$x_2(t) = -\alpha_1 x_1(t) - \alpha_2 x_2(t) + b u(t) - T_L$$

Where \( x_1 \) is \( \theta_r \) and \( x_2 \) is \( \omega_r \).

### IV. MAXIMUM POWER TRACKING CONTROL

In a natural environment, the wind power varies with time. To stabilize the generator output voltage, current, and output power, the excitation synchronous generator output power has to track the input power variation and react immediately by adjusting the excitation field current. In this paper, a maximum power tracking control scheme is proposed. The proposed MPTC scheme includes two control loops as shown in Fig. 8, which is motor power control loop, and the generator power control loop. By MPTC scheme, it can make the motor consumption power minimize and most of wind power can be transferred to the grid by the generator.

![MPTC control loops](Fig. 8)
Fig. 7 depicts the proposed phase tracking control scheme. Before the excitation synchronous generator system connects to the grid (SW=0), $\theta^*$ equals to the grid voltage angle. With the coaxial configuration described in Section II, the servo motor and generator electrical angle can be obtained using the motor encoder and the grid voltage sensor, respectively.

The MCU compares the phase difference between the two signals, and gradually adjusts the excitation synchronous generator rotor position to reduce the phase deviation. The MCU generates pulse trains of frequency command for the servo motor to drive the servomotor, explaining why the generator can lock the generator frequency and phase in the phase command. When the generator is connected to the grid (SW=1), $\theta^*$ equals the generator current angle. MCU calculates the generator electrical angle and current phase angle difference to adjust the generator rotor position to reduce the phase deviation. Consequently, the generator power factor can be controlled and improved.

**VI. THREE-PHASE EXCITATION**

In a natural environment, the wind power varies with time. To stabilize the generator output voltage, current, and output power, the excitation synchronous generator output power has to track the input power variation and react immediately by adjusting the excitation field current. In this paper, a maximum excitation synchronous generator power outputs are fed back for comparison with the generator power command. This power deviation passing the PI controller and the excitation gain generates a corresponding excitation field current control signal.

Thus the excitation synchronous generator output power can track the generator power command.

**VII. SIMULATION AND RESULTS**

The generator design functionality is confirmed using a wind power generator framework simulation model with an excitation synchronous generator and its corresponding subsystems, using MATLAB/Simulink and MATLAB/Simulink 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 60Hz, the excitation synchronous generator must operate at 1800 rpm with 4-pole windings.
VIII. CONCLUSION

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. Simulation results demonstrate that the proposed wind power generator system achieves high performance power generation with salient power quality.

REFERENCES


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