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Excitation Synchronous Wind Power Generators with Maximum Power Tracking process

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Abstract: This paper presents a novel excitation synchronouswind power generator (ESWPG) with a maximum powertracking scheme. The excitation synchronous generator andservo motor rotor speed tracks the grid frequency and phaseusing the proposed coaxial configuration and phase trackingtechnologies.The excitation synchronous generator and servo motor rotor speed tracks the grid frequency and phase using the proposedcoaxial configuration and phase tracking technologies. The genera-tor output can thus be directly connected to the grid network withoutan 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 powerproduced by renewable energy has steadily increased,explaining the increasing competitiveness of wind powertechnology. Wind power generators can be divided intoinduction and synchronous types. The excitationsynchronous generator driven by hydraulic, steam turbine, ordiesel engines has been extensively adopted in large-scaleutility power generation owing to desired features such asmeans that the motor power is not wasted. Using a precisehigh efficiency, reliability, and controllable output power. Awind power generator in grid connection applications,except for doubly fed induction generators, achieves thesefeatures using variable speed constant frequency technology.

However, most excitation synchronous wind generatorscannot be connected directly to the grid, owing toinstabilities in wind power dynamics and unpredictableproperties that influence the generator synchronous speed.The direct drive permanent magnet synchronous windgenerator (PMSWG) uses variable speed and powerconverter technologies to fulfill the grid connectionrequirements, which has advantages of being gearless.Various power transfer technologies are applied for ac/dctransformation to obtain a constant frequency ac power [9]–[16]. However, extensive use of power electronic devices inthose systems that will cause unavoidable power losses fromthe rectifier’s conducting resistance and high-frequencypower switches, which will increase power consumption.Therefore, a converter less method for a high-efficiencyexcitation synchronous wind generator is an important issue,especially for middle and high output voltage wind powergenerators. This paper presents a novel converter less windpower generator with a control framework that consists of anexcitation synchronous generator, permanent magnet (PM)synchronous servo motor, signal sensors, and servo controlsystem with fuzzy logic controller. The wind and servomotor powers are integrated with each other and transmittedto the excitation synchronous generator via a coaxialconfiguration. When the wind speed varies, the servo motorprovides a compensatory energy to maintain constantgenerator speed. The additional servo motor power is alsotransformed into electricity, and output into the load.phase tracking function design, the proposed robust integralservo

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motor control scheme reduces the output voltagephase shift in the excitation synchronous generator fromwind disturbances. According to the servo motor powermagnitude and the generator power, the proposed maximumpower tracking scheme controls the excitation field currentto ensure that the excitation synchronous generator fullyabsorbs the wind power, and converts it into electricity forthe loads. Based on physical theorems, a mathematicalmodel for the proposed system is established to evaluatehow the control function performs in the designedframework.

II. POWER FLOW AND SPEED

For simplicity, assume that all energy transmissionelements behave ideally,allowing us to ignore themechanical power losses of the wind turbine,theservomotor,and the excitation synchronous generator. Fig.1 shows the power flows of theproposed system, where T_{ω},T_m and T_g denote the torquesand ω_W ,ω_m , and ω_g are the wind turbine, servo motor, andexcitation synchronous generator speeds, respectively. Thetotal excitation synchronous generator input power is theproduct of and the power flow equation can thus be definedas

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

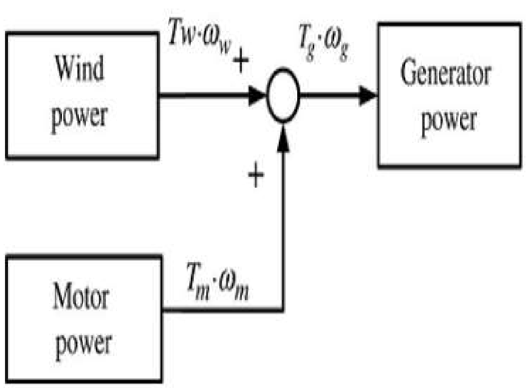

Fig. 1. Power flow block diagram

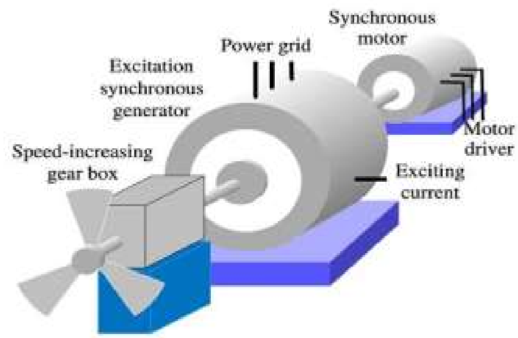

Fig. 2. Proposed coaxial construction configuration.

Fig. 2 shows the corresponding coaxial configuration. TheFig. 4 schematically depicts the servo motor and maximumwind generator rotor shaft input-end receives rotatingtorques from the speed increasing gear box. The tail-end ofthe generator rotor shaft is coupled with a servo motor. Theinput energy of the excitation synchronous generator is thesum of the wind power and servo motor powers. The speedand rotating direction for the wind turbine output , servomotor, and excitation synchronous generator is the same ,i.e., the system speeds satisfy the ω_W ,ω_m, and ω_g. Thisarrangement 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 flowbalance between the input and the output and,simultaneously, force the generator frequency tosynchronize with the utility grid. When the system complieswith these conditions, the generator output can be connectedto the utility grid network, subsequently reaching the highefficiency and maximum power tracking objectives. Thecontrol signals, including the generator voltage, current, grid phase, motor encoder, and output power, are sensed andtransferred to the microprocessor control unit (MCU). Theservo motor controller plays an important role in outputpower and grid voltage phase tracking. A situation in whichthe controller detects a power increase from the servo motorimplies decreasing wind speeds. At this moment, the

systemregulates the exciter current to reduce the excitation
generator output power.

A chain reaction subsequentlyoccurs in which the servo motor power returns to a balancedlevel. During the energy balance periods, the servo motorconsumes only a slight amount of energy to stabilize theshaft speed. Once (1) is satisfied, both the maximum powerand the constant speed can be obtained by the designedcontrol scheme.The transient and dynamic responses of the servo motorthe mechanical time constant as Tθ<<Tm . The three-phasecontroller must satisfy robustness requirements to reduce theinfluence of wind fluctuations to the generator. Thus, therobust integral structure control (RISC) method is chosen toensure the voltage phase and the frequency in phase with thegrid. Among general electrical motors, the three-phase PMsynchronous motor has the advantages of high-efficiencyand low-maintenance requirements, the reason controllablepower for the servo control structure was chosen in theresearch [17]–[20].

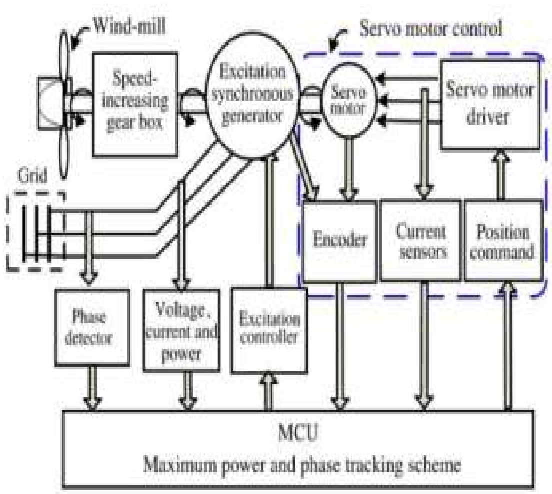

Fig. 3. Proposed wind power system framework.

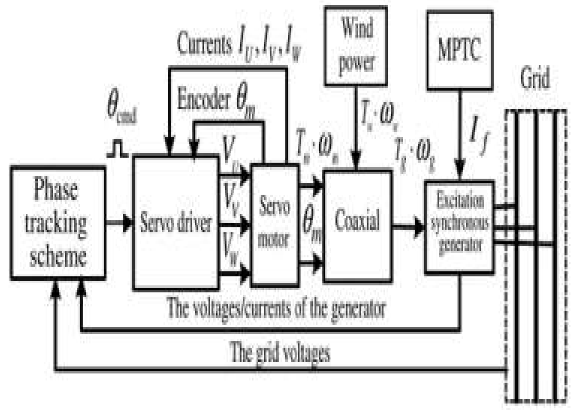

Fig. 4. Proposed wind power generator system

This study designs an analysis modelbased on the electrical circuit, motor torque, and mechanicaltheorems. Fig. 5 shows the block diagram of the three-phasePM synchronous motor, and Table I lists the parameters ofthe PM synchronous motor. According to (1), wind power,generator power, and servo motor power can be transformedinto three torque functions and incorporated in the threephase PM synchronous motor model.

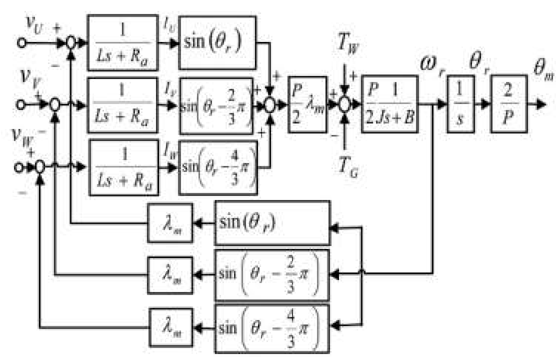

Fig. 5. Servo motor block diagram.

The electromagnetictorque of the servo motor can be expressed as

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

$$[I_u sin\theta_r + I_v.\sin\left(\theta_r - \frac{2}{3}\pi\right) + I_v.\sin(\theta_r - \frac{4}{3}\pi)] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

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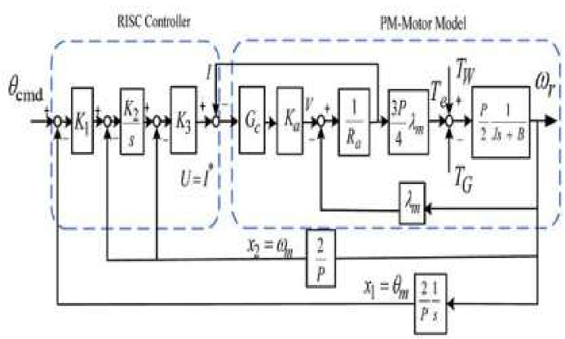

Fig. 6. Servo motor position control loops.

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

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

$$\theta_m = \frac{2}{P}\theta_r \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Additionally ωr, denotes the electrical rotor angularvelocity;θr represents the electrical rotor angulardisplacement θm; is the mechanical rotor angulardisplacement; J is the rotor inertia; and B is the dampingcoefficient. In Fig. 5, L denotes the inductance of the statorwindings; λm represents the amplitude of the flux linkageestablished by the permanent magnet as viewed from thestator windings; Uu,Uv, and Uw are the applied statorvoltage of the motor; and Ra denotes the resistance of eachstator winding. Moreover, Tθ=L/Ra is the electrical timeconstant, and Tm=J/B is the mechanical time constant. It isclear from the physical characteristics stated above that themotor electrical time constant is overwhelmingly lower thanPM synchronous motor model can thus be simplified as afirst-order mathematical model, as shown in the Fig. 6.

According to Fig.6, the position control structure includesthe RISC and servo motor transfer function. Theconventional motor current feedback controller can avoidinstantaneous current stress to the servo driver. Thistechnology has been applied to the servo motor control toimprove the control performance. The RISC outer loop isdesigned to achieve a fast and accurate servo trackingresponse under load disturbances and plant parametervariations. In Fig. 6, θcmd denotes the position command .Parameters K1 and K3 are proportional gains and K2 is theintegral gain. The PM synchronous motor state equations aredescribed as

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

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

Where x1 is θr and x2 is ωr

IV. MAXIMUM POWER TRACKING CONTROL

In a natural environment, the wind power varies with time. Tostabilize the generator output voltage, current, and output power,the excitation synchronous generator output power has to trackthe input power variation and react immediately by adjusting theexcitation field current. In this paper, a maximum power trackingcontrol scheme is proposed. The proposed MPTC scheme includes two control loops as shown in Fig. 8, which is motorpower control loop, and the generator power control loop. ByMPTC scheme, it can make the motor consumption powerminimize and most of wind power can be transferred to the gridby the generator.

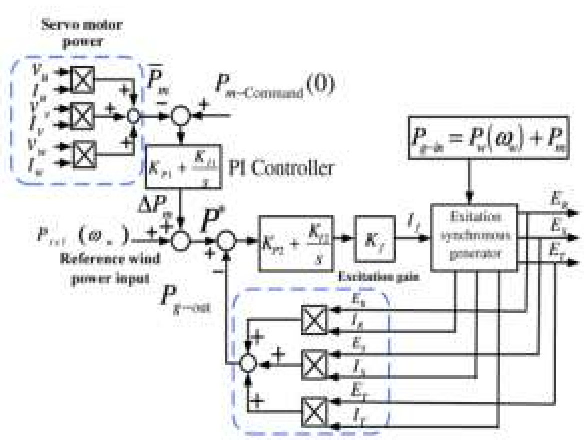

Fig. 8. MPTC control loops.

V. PHASE TRACKING CONTROL SCHEME

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Fig. 7 depicts the proposed phase tracking control scheme.Before the excitation synchronous generator systemconnects to the grid (SW=0),θ* equals to the grid voltageangle. With the coaxial configuration described in SectionII, the servo motor and generator electrical angle can beobtained using the motor encoder and the grid voltagesensor,respectively.

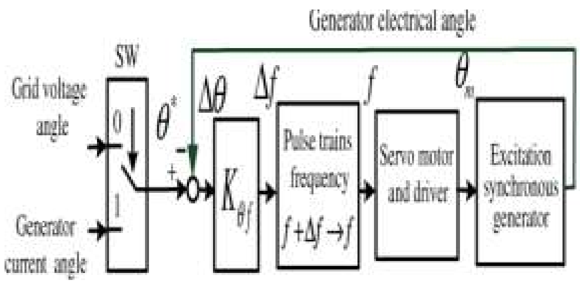

Fig. 9. Phase tracking control scheme.

The MCU compares the phase difference between the twosignals, and gradually adjusts the excitation synchronousgenerator rotor position to reduce the phase deviation.The MCU generates pulse trains of frequency command for the servo motor to drive the servomotor, explaining whythe generator can lock the generator frequency and phase inthe phasecommand. When the generator is connected to the grid(SW=1) θ* equals the generator current angle. MCUcalculates the generator electrical angle and current phaseangle difference to adjust the generator rotor position toreduce the phase deviation. Consequently, the generatorpower 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 outputpower, the excitation synchronous generator output powerhas to track the input power variation and react immediatelyby adjusting the excitation field current. In this paper, amaximum excitation synchronous generator power outputs are fed back for comparison with the generator powercommand. This power deviation passing the PI controllerand the excitation gain generates a corresponding excitationfield current control signal. Thus the excitation synchronousgenerator output power can track the generator powercommand.

VII.SIMULATION AND RESULTS

The generator design functionality is confirmed using a windpower generator framework simulation model with anexcitation synchronous generator and its corresponding subsystems,using MATLAB/Simulink andMATLAB/Simpowersoftware. Sub-systems include thewind power input,servo motor phase tracking control,maximum power tracking control, excitation synchronousgenerator, and grid connection. respectively. To output thethree-phase voltage signals at 60Hz, the excitationsynchronous generator must operate at 1800 rpm with 4-polewindings.

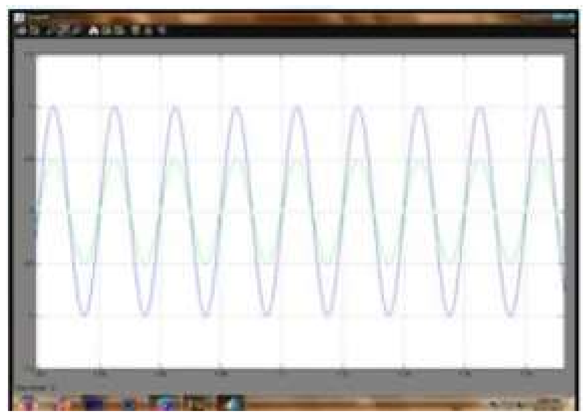

Fig.10 V_{sg}And$I_{sg}$of Phase A

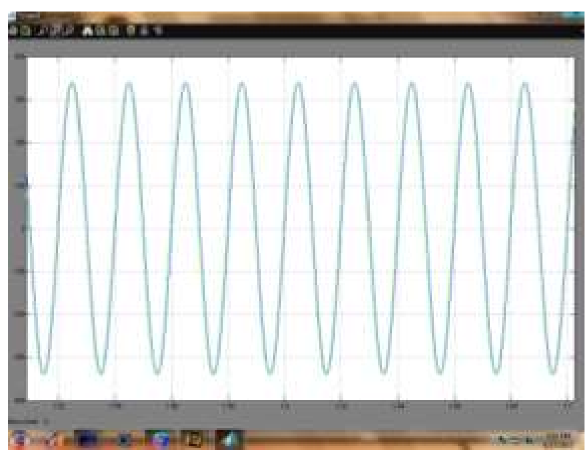

Fig.11 Grid Voltage and Inverter Voltage

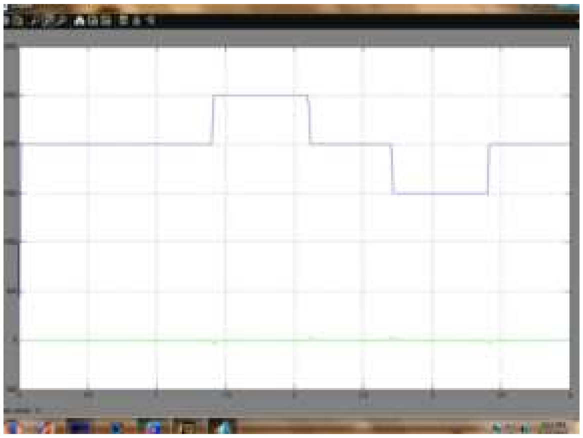

Fig.12 Wind Power and torque of generator

VIII. CONCLUSION

In the proposed framework,the servo motor provides controllable power to regulate therotor speed and voltage phase under wind disturbance. Usinga phase tracking control strategy, the proposed system canachieve smaller voltage phase deviations in the excitationsynchronous generator. In addition, the maximum outputpower tracking scheme governs the input and output powersto achieve high performance. The excitation synchronousgenerator and control function models were designed fromthe physical perspective to examine the presented functionsin the proposed framework. Simulation resultsdemonstrate that the proposed wind power generator systemachieves high performance power generation with salientpower quality.

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