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Simulation of Power Tracking Scheme Through Excitation Synchronous Wind Power Generator

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ABSTRACT: This paper Proposes Maximum Power Extraction from Wind Turbine with permanent magnet synchronous generator, using MPPT (Maximum Power Point Tracking) control scheme with the help of regulating the dc link Voltage through Boost converter. This MPPT control scheme is applied by using directly the voltage and current of the generator which is much accurate then getting the parameters from the mechanical and other relative transducers will reduce the accuracy and cost. Feasibility of this control become possible from the relation of the power to the rotor speed and the speed is then related to the DC voltage on the rectifier's side. The simulation is done with help of MATLAB/SIMULINK and the result is shown which prove that the maximum power point tracking algorithm is suitable for wind turbine. These 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.

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 tech-nology. 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 gener-ation 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 prop-erties 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 gener- ator 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 synchro-nous generator from wind disturbances. According to the servo motor power magnitude and the generator power, the proposed maximum power tracking scheme

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Wind is abundant almost in any part of the world. Its existence in nature caused by uneven heating on the surface of the earth as well as the earth's rotation means that the wind resources will always be available. The conventional ways of generating electricity using non renewable resources such as coal, natural gas, oil and so on, have great impacts on the environment as it contributes vast quantities of carbon dioxide to the earth's atmosphere which in turn will cause the temperature of the earth's surface to increase, known as the green house effect. Hence, with the advances in science and technology, ways of generating electricity using renewable energy resources such as the wind are developed. Nowadays, the cost of wind power that is connected to the grid is as cheap as the cost of generating electricity using coal and oil. Thus, the increasing popularity of green electricity means the demand of electricity produced by using non renewable energy is also increased accordingly.

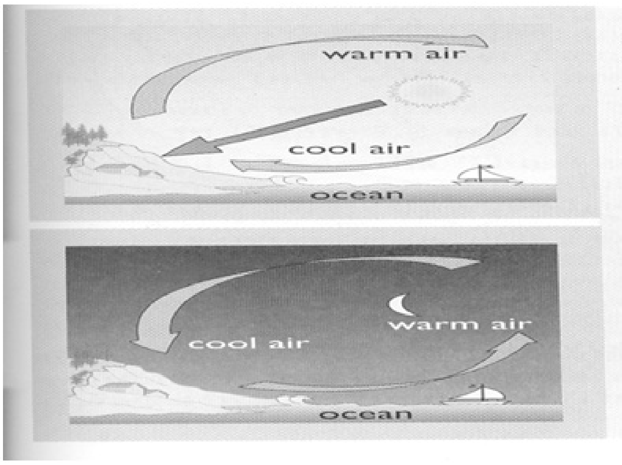

Fig 1: Formation of wind due to differential heating of land and sea

There are some distinctive energy end use features of wind power systems

i. Most wind power sites are in remote rural, island or marine areas. Energy requirements in such places are distinctive and do not require the high electrical power.
ii. A power system with mixed quality supplies can be a good match with total energy end use i.e. the supply of cheap variable voltage power for heating and expensive fixed voltage electricity for lights and motors.
iii. Rural grid systems are likely to be weak (low voltage 33 KV). Interfacing a Wind Energy Conversion System (WECS) in weak grids is difficult and detrimental to the workers' safety.
iv. There are always periods without wind. Thus, WECS must be linked energy storage or parallel generating system if supplies are to be maintained.

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II. LITERATURE SURVEY

T. Shanthi and A.S. Vanmukhil [8] have proposed the fuzzy logic controller to extract maximum power from the hybrid renewable energy system model. The proposed system includes both the photovoltaic (PV) and wind energy conversion system (WECS). Fuzzy logic controller was used to adjust the duty cycle of the switch converter to extract the maximum power from the PV array. The Voltage Source Inverter (VSI) was employed to control the voltage from the dc link and the output voltage of VSI was regulated by PI controller. Huynh Quang Minh et.al [10] has proposed the control scheme of a wind energy conversion system using fuzzy logic. They have proposed two fuzzy controllers in the wind energy conversion system. The first fuzzy controller was used to track the maximum power from the wind turbine. The output of the fuzzy controller was given to the dc-dc converter to adjust the duty cycle. When adjusting the duty cycle, the rotor speed of PMSG was controlled to get the maximum power. The second one was used to maintain both the production and the storage of energy in respecting load demand for better performance of the system. Wei Qiao et.al [11] have proposed the sensor less maximum wind power tracking controller based on the wind speed estimation. A Control algorithm was presented to control the wind turbine equipped with doubly fed induction generator (DFIG). The wind speed was estimated from the measured generator output power and the dynamics of the wind generator based on nonlinear mapping which was provided by a Gaussian radial basis function network (GRBFN). The estimated wind speed was used to find the optimal DFIG rotor speed for extraction of maximum wind power. The speed controller of DFIG was designed to damp low-frequency torsion oscillations. M. Sarvi, Sh. and Abdi, S. Ahmadi [12] have proposed the maximum power point tracking control scheme based on particle swarm optimization _ fuzzy logic for wind turbine PMSG system. The maximum wind power was captured by adjusting the rotor speed of the PMSG. The rotor speed varies according to the wind speed and the wind turbine generator was operated by adjusting the duty cycle of the boost converter and increases the efficiency of wind energy conversion system. Jogendra Singh Thongam and Mohand Ouhrouche [13] have proposed MPPT controllers to extract maximum power from the wind using various types of generators such as Permanent Magnet Synchronous Generator (PMSG), Squirrel Cage Induction Generator (SCIG) and Doubly Fed Induction Generator (DFIG). They have used three main control methods to track the maximum power namely tip speed ratio (TSR) control, Power signal feedback (PSF) control and hill-climb search control (HCS). E. Koutroulis and K. Kalaitzakis [14] have proposed the Maximum power tracking system for wind energy conversion applications. The output voltage and current of the wind generator was determined to monitor the output power of wind generator. Based on the result of comparison between successive wind power values, the dc-dc boost converter was adjusted directly. Y. Izumi et.al [15] has proposed a control method for tracking maximum power in a wind energy conversion system using online parameter identification. The wind turbine was connected with PMSG and transmits the power into AC grid through the converter. The generator side converter controls the torque of PMSG and the grid side inverter controls the voltage in the dc link and the grid for steady operation. The online parameter identification was used to determine the optimum torque of the PMSG and it varies due to wind turbulence, parameter error and other unexpected conditions. The parameter identification was achieved by the use of weighted least square method and it was appropriate for practical systems

III. RELATED WORK

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 Tw ,Tm , and Tg denote the torques and Ww, Wm , and Wg 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

$$T_g \cdot \omega_g = T_w \cdot \omega_w + T_m \cdot \omega_m \cdot \quad - (1)$$

Fig.2. Power flow block diagram.

Control Principles of Proposed Wind Power Generator 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

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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. 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

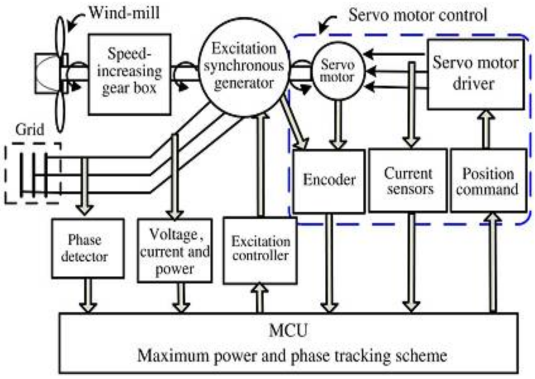

Fig. 4. Proposed wind power system framework.

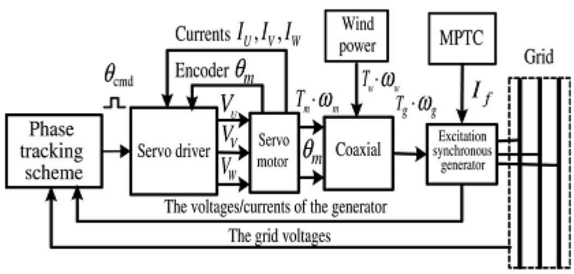

Fig. 5. Proposed wind power generator system

Fig. 5 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 magneticfield 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.

IV. PROPOSED WORK

Wind power technology dates back many centuries. There are historical claims that wind machines which harness the power of the wind date back beyond the time of the ancient Egyptians. Hero of Alexandria used a simple windmill to power an organ whilst the Babylonian emperor, Hammurabi, used windmills for an ambitious irrigation project as early as the 17th century BC. The Persians built windmills in the 7th century AD for milling and irrigation and rustic mills similar to these early vertical axis designs can still be found in the region today. In Europe the first windmills were seen much later, probably having been introduced by the English on their return from the crusades in the middle east or possibly transferred to Southern Europe by the Muslims after their conquest of the Iberian Peninsula. It was in Europe that much of the subsequent technical development took place. By the late part of the 13th century the typical ‗European windmill' had been developed and this became the norm until further developments were introduced during the 18th century. At the end of the 19th century there were more than 30,000 windmills in Europe, used primarily for the milling of grain and water pumping.

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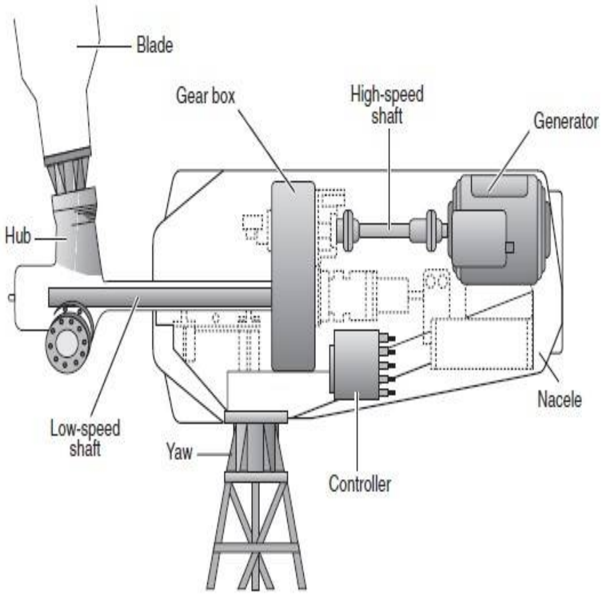

Fig.6. Wind generation system.

V. METHODOLOGY

The blades on a wind turbine are similar to the propeller blades on an airplane. The rotor blades generate lift from the passing wind, causing them to rotate the hub of the turbine. The rotating action of the hub then turns a generator, which creates electricity. A gearbox is generally necessary to optimize the power output from the machine. That power is then either fed into the electric grid or stored in batteries for use on-site. While wind speed is important, so is the size of the rotor. On a turbine, the power available to the blades is proportional to the square of the diameter of the rotor. In other words, simply by making the turbine blades twice as long and beefing up the generator, you increase the power producing capability of the turbine by a factor of four. Modern wind turbines come in two varieties: horizontal axis and vertical axis. Horizontal axis turbines have blades that spin on an axis that is parallel to the ground. These systems often look like the propeller on an airplane. Vertical axis systems have blades that spin on a vertical axis giving them an appearance somewhat like giant egg beaters. Although large utilities are getting the most attention for their move into wind power, rural residents in all 50 states and dozens of foreign countries have quietly been installing small-scale wind generation systems. These systems can be obtained for as little as $1,000 and are perfect compliments to photovoltaic systems. Several vendors sell readymade towers and turbines that are easily installed.

The wind systems that exist over the earth‘s surface are a result of variations in air pressure. These are in turn due to the variations in solar heating. Warm air rises and cooler air rushes in to take its place. Wind is merely the movement of air from one place to another as shown in Fig.9. There are global wind patterns related to large scale solar heating of different regions of the earth‘s surface and seasonal variations in solar incidence. There are also localized wind patterns due the effects of temperature differences between land and seas, or mountains and valleys. Wind speed generally increases with height above ground. This is because the roughness of ground features such as vegetation and houses cause the wind to be slowed. Wind speed data can be obtained from wind maps or from the meteorology office. Unfortunately the general availability and reliability of wind speed data is extremely poor in many regions of the world. However, significant areas of the world have meant annual wind speeds of above 4-5 m/s (meters per second) which makes small-scale wind powered electricity generation an attractive option. It is important to obtain accurate wind speed data for the site in mind before any decision can be made as to its suitability. Methods for assessing the mean wind speed are found in the relevant texts (see the ‗References and resources‘ section at the end of this fact sheet).

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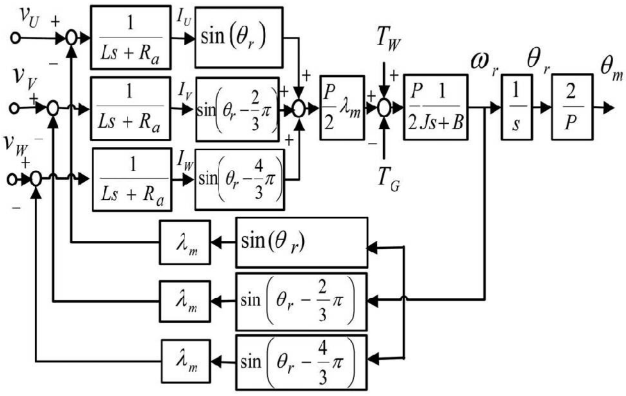

Fig. 7. PM synchronous motor block diagram.

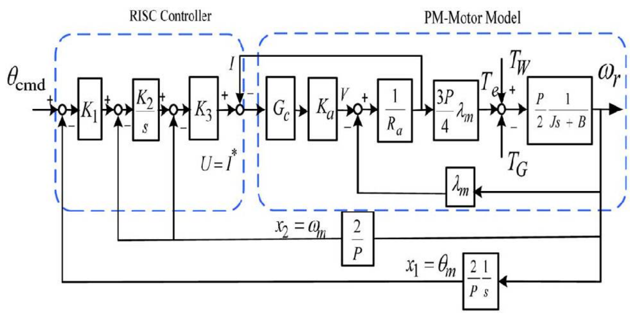

Fig. 8. Servo motor position control loops.

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_m can be expressed as

$$T_m + (T_w - T_g) = Js\left(\frac{2}{P}\right)\frac{d\omega_r}{dt} + B\left(\frac{2}{P}\right)\omega_r$$
$$\theta_r = \int \omega_r dt$$
$$\theta_m = \frac{2}{P}\theta_r. \quad (3)$$

According to Fig. 8, 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.

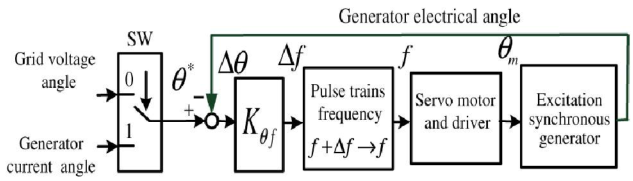

Fig. 9. Phase tracking control scheme.

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where x_1 is θ_r and x_2 is ω_r

$$\begin{cases} a_1 = 0 \\ a_2 = \frac{B}{J} + \frac{\frac{3P}{4}\lambda_m^2}{JR_a + JG_cK_a} \\ b = \frac{\frac{3P}{4}GcK_a\lambda_m}{JR_a + JG_cK_a} \\ T_L = \frac{1}{J}\left(T_w - T_g\right). \end{cases} \tag{5}$$

RISC is a typical state feedback control scheme that combines an integral controller and the plant series state feedback information. The RISC function is expressed as (6) and (7), where $a_i, i = 1, 2$ and b are the plant state variables and G_c is the current compensator for the current feedback loops. The pulsewidth modulation (PWM) circuit mode can be simplified as a constant gain $K_a = V_{DC}/2E_d$, where V_{DC} denotes the supply voltage; E_d is the triangular waveform peak value; T_L refers to the total disturbance which is defined in (5), and U is the system control function. For a third RISC system, the control function U can be expressed as follows:

$$U(s) = K_1K_2K_3\frac{\theta_{\text{cmd}}(s) - x_1(s)}{s} - K_2K_3x_1 - K_3x_2. \tag{6}$$

Transfer function of the system is

$$\frac{x_1(s)}{\theta_{\text{cmd}}(s)} = \frac{K_1K_2K_3b}{s^3 + (a_2 + K_3b)s^2 + (a_1 + K_2K_3b)s + K_1K_2K_3b}. \tag{7}$$

By designing the system characteristic function to lie on the stable plane, one can obtain

$$(s + \lambda_1)(s + \lambda_2)(s + \lambda_3) = 0 \tag{8}$$

where λ_1, λ_2, and λ_3 are the system selected close-loop poles. The characteristic function of (7) can then be rewritten as

$$s^3 + (\lambda_1 + \lambda_2 + \lambda_3)s^2 + (\lambda_1\lambda_2 + \lambda_1\lambda_3 + \lambda_2\lambda_3)s + \lambda_1\lambda_2\lambda_3 = 0. \tag{9}$$

The system control gain K_1, K_2, and K_3 can be determined by (9) and the pole-zero placement method

$$\begin{cases} K_3 = \frac{(\lambda_1+\lambda_2+\lambda_3) - a_2}{b} \\ K_2 = \frac{(\lambda_1\lambda_2+\lambda_2\lambda_3+\lambda_2\lambda_3) - a_1}{K_3b} \\ K_1 = \frac{\lambda_1\lambda_2\lambda_3}{K_2K_3b}. \end{cases} \tag{10}$$

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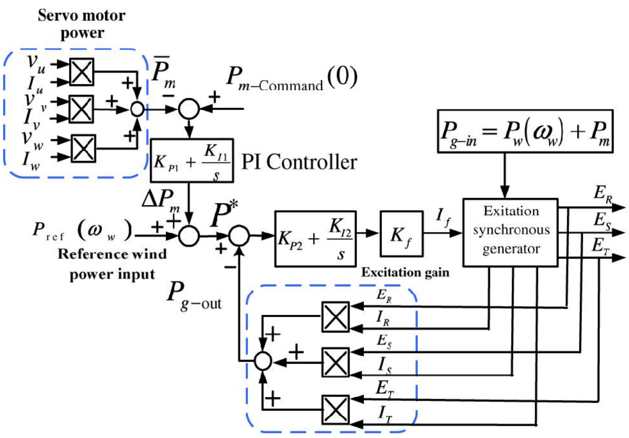

Fig. 10. MPTC control loops

VI. RESULTS

This paper also demonstrates the feasibility of the proposed control system, using an experiment involving a 3-kW synchronous excitation wind power generator (ESWPG). A photograph of the prototype system with utility grid connection is shown in Fig. 12. The proposed system is implemented on a platform consisting of an MCU Texas Instruments TM320F28M35 Experimenter Kit and Code Composer Studio (CCS). There are two motors in the experimental system. Motor 1 employs torque control to simulate natural wind power and motor 2 is the servo motor used to complete the phase-locked function. Current transducers LEM-CKSR measure the generator and motor currents, and low-frequency transformers sense the generator and grid voltages. A motor encoder is installed for calculating the generator electrical angle and the shaft speed. A firmware program was written to complete the maximum power tracking control and motor phase-locking. Notably, the grid voltage is three phases of phase to phase. Before the system is connected to the grid, a set of three-phase fixed resistance with wye connection is applied as the resistance loading for the generator. Fig. 13 shows the transition responses of the experimental system connected to the grid. Ensuring the phase tracking is essential before connecting to the grid. Before grid connection, a preset wind torque accelerates the generator shaft speed up to approximate 1800 rpm, and the phase tracking control ( ) is then started to regulate the generator output voltage waveform inphase with the grid voltage. In this case, three resistances with wye connection as the isolated load were connected to the generator. The calculated generator power factor is nearly 0.97. After grid connection, to improve the generator power factor, the phase tracking control is started to regulate the generator phase voltage waveform in phase with generator phase current ( ). The measured generator power factor is approximately 0.94 under grid-connection condition. The measured output power is 2000 W. The proposed MPTC control system is characterized by the controller change generator output power to follow the wind power fluctuation, simultaneously, maintaining output voltage waveform in phase with the grid. Consequently, the generator fully absorb s the wind power and grid connect ion requirement can be ensured. To observe the system feasibility, the transient responses for wind power, generator power, motor power, and generator shaft speed were measured as shown in Fig. 14(a) and (b). The system is assumed to have a stable point at a wind power of 2500 W in the time period beginning in Fig. 14(a) and (b). However , the measured generator power output is only 2000 W. The generator output power is 500 W less than the wind power, which is mainly due to the power consumptions of mechanical friction and moment of inert ia at running speed of 1800 rpm, and the partial power loss comes from energy conversion efficiency of the generator. According to Fig. 14(a) and (b), regard less of whether the wind is step or sine wave change cases, the proposed MPTC scheme converts the wind energy into electricity. A slight amount of power in the servo motor can maintain the generator shaft speed constantly and achieve excellent power quality

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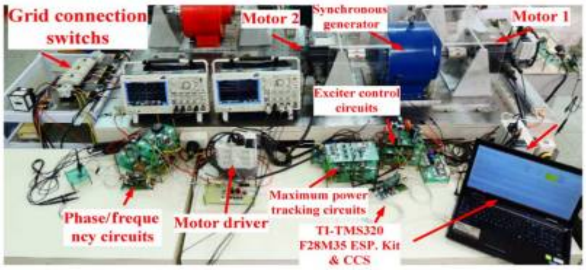

Fig. 11. Photograph of experimental setup

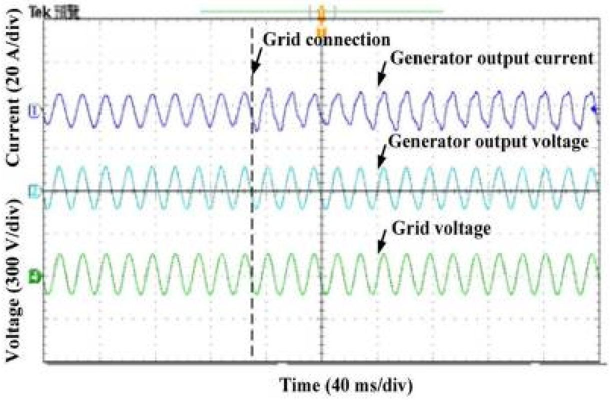

Fig. 12. Generator output current and voltage versus grid phase voltage

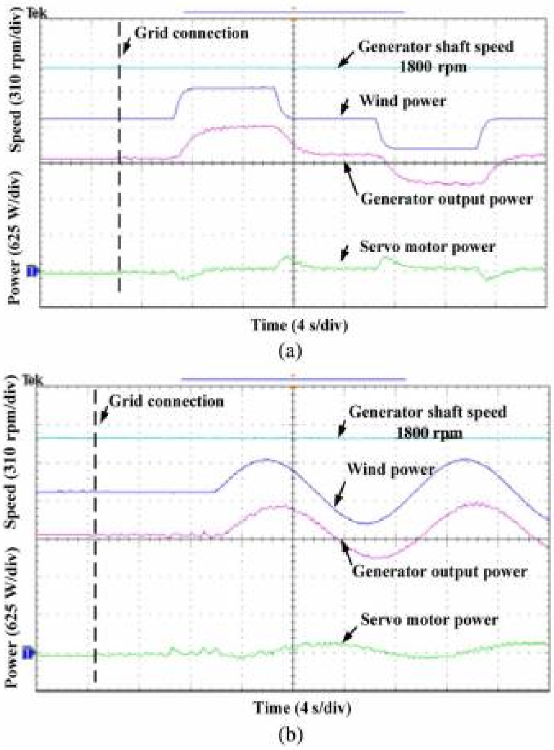

Fig. 13. Maximum power tracking experimental results. (a) Wind power step changes. (b) Wind power sine wave changes.

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VII. 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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