IMPLEMENTATION OF SENSOR-LESS MAXIMUM POWER EXTRACTION SCHEME FOR PMSG SMALL WIND TURBINE SYSTEMS

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ABSTRACT

In this paper, the implementation and testing of a prototype of sensor-less maximum power extraction scheme is developed to extract approximately the maximum available power from a generator driven by the wind turbine without wind speed or rotor speed measuring. The actual efficiency is calculated and compared to the reference efficiency. The resulting error is used to adjust the modulation index of the inverter. The reference efficiency is average of uncontrolled system efficiencies at different wind speeds. The scheme is based on the generator's output voltages and currents information to calculate the actual efficiency. The scheme is so simple that it needs only online values of generator voltages and currents which can be obtained easily by using just current and voltage sensors.

INTRODUCTION

Wind turbine is considered today as energy source which allows electrical energy production with minimum environment perturbations. This energy source is especially suitable for remote areas, which are not connected to the conventional electrical grid. Large wind turbines are complex in operation, deploy multitude of control methods and operate in grid-connected mode. On the other hand, small wind turbines can be used for a stand-alone as well as grid-connected system. To achieve optimum utilization of wind turbine system, the maximum power extraction schemes have been used. These schemes employ a rotor speed and wind velocity sensors. However, from aspects of reliability and cost, rotor speed and wind speed sensors are not usually preferred. There are several schemes to extract the maximum power from the wind turbine system such as power control scheme and constant tip speed ratio scheme. Power control scheme [1-5] is based on the wind turbine system optimal power versus the wind speed characteristics, which is usually stored in a microcontroller memory. The wind speed is measured; the optimal output power is calculated and compared to the actual output power. The resulting error is used to control a power interface. This scheme has the disadvantage that knowledge of the power-speed characteristic is required, this maximum power curve needs to be obtained via simulations or tests for individual wind turbines, which makes power control scheme difficult and expensive to implement in small wind turbine systems. Another scheme is the constant tip speed ratio scheme [6-11]. This scheme is based on wind speed and rotor speed measurements. The wind speed is measured, and the required rotor speed for maximum power generation is computed. The rotor speed is also measured and compared to the calculated optimal rotor speed, while the resulting error is used to control a power interface. The first barrier to implement this scheme is the wind and rotor speed measurements, which add extra cost and increase the control system complexity.

In this paper, an alternative approach for maximum power extraction is described. The scheme is based on sensing the generator's output voltages and currents.

THE PROPOSED SCHEME

When the wind speed increases, the input mechanical power increases. The different between the input power and output power will be converted to an increase in the kinetic energy stored in the rotor. To benefit from this energy, more power should be delivered to the load to reduce this accelerating effect. To achieve this objective, the sensor-less maximum power extraction scheme is developed to extract approximately the maximum available power from a generator driven by the wind turbine without wind speed or rotor speed measuring devices. Fig. 1 shows a schematic configuration of a small wind turbine system with the proposed maximum power extraction scheme. The system consists of small wind turbine, permanent magnet synchronous generator (PMSG), and a local load that is supplied from the generator through uncontrolled three-phase rectifier and pulse width modulation (PWM) inverter. The system is controlled by PC with interface card PCI 1711[12]. The scheme is based on the generator's output voltages and currents instantaneous values and stator resistance value. The stator voltages and currents of the generator are sensed. The three-phase stationary reference frame voltages and currents are transformed into two-phase (quadrature, direct) stationary reference frame. By using the two components values, the actual power and efficiency are calculated. The actual efficiency is compared to the reference efficiency to determine the error. According to the error values, the PI controller adjusts the modulation index of the inverter in order to extract the maximum power from the wind turbine system. By investigating the uncontrolled system efficiencies, the reference efficiency is obtained as average of uncontrolled system efficiencies at different wind speeds. Thus, neither knowledge of the wind turbine power versus the rotor speed of rotation or wind-speed characteristic nor measurements of the wind speed are required. The scheme is so simple that it needs only the knowledge of online values of the generator voltages and currents which can be obtained easily by using just current and voltage sensors.

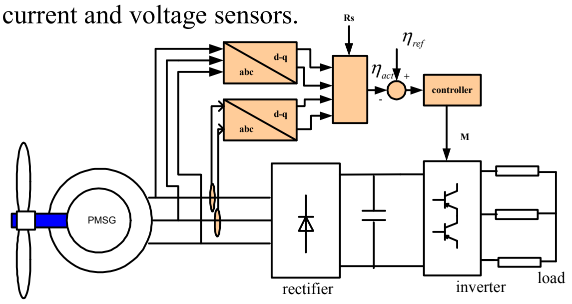

Fig. 1 The proposed maximum power extraction scheme

IMPLEMENTATION OF THE PROPOSED SYSTEM

The wind turbine used in this paper is considered as a direct drive system. The generator is connected to the load through uncontrolled three phase rectifier and an inverter. The torque produced by the wind turbine is used as the input torque to the PMSG and the voltage produced by the PMSG is rectified and passed through an inverter to the load. The system is controlled by PC computer with interface card PCI 1711. The experimental setup of the proposed scheme is shown in Fig.2.

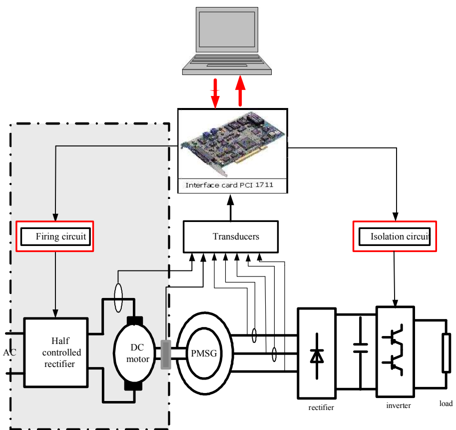

Fig.2 The block diagram of experimental setup

DC Motor Emulation of Wind Turbine

It is difficult to use a real wind turbine in the laboratory. So a separately excited DC motor is used to simulate the characteristics of the wind turbine. The armature current of the motor is controlled so that it can have the same power versus rotor speed characteristics of the wind turbine. Fig. 3 shows the block diagram of the laboratory simulator of the wind turbine using a DC motor with a current control technique. The PI controller is used to control the armature current of the motor. The instants of the firing pulses of the half-controller rectifier bridge are controlled by the controlling voltage that comes out from analog output port of PCI 1711card.

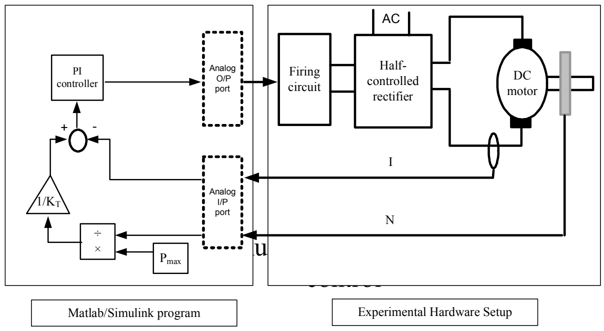

Fig. 3 The block diagram of armature current control

The Matlab/Simulink file that describes the armature current controller algorithm including input/output blocks of PCI 1711 card is shown in Fig. 4.

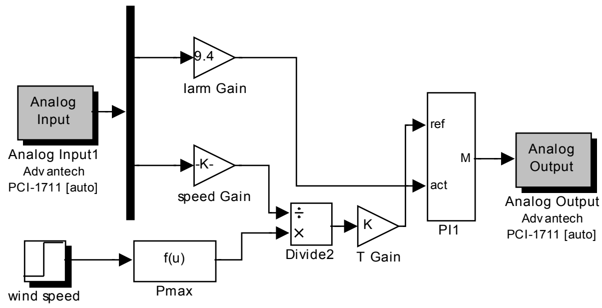

Fig. 4 The Simulink model of armature current control

Maximum Power Extraction Algorithm

The maximum power extraction algorithm has been implemented experimentally as shown in Fig. 5

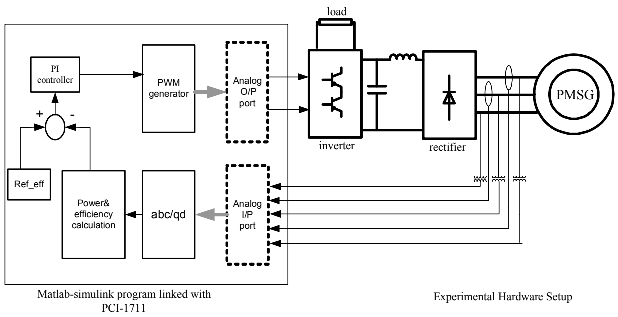

Fig. 5 The block diagram of maximum power extraction algorithm

The algorithm is built in Matlab/Simulink program; the stator voltages and currents of the generator are sensed and send to analog input of the interface card. The three-phase stationary reference frame voltages and currents are transformed into two-phase (quadrature, direct) stationary reference frame by using Equation 1

$$\begin{bmatrix} vq \\ vd \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{-\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} va \\ vb \\ vc \end{bmatrix} \qquad (1)$$

The actual efficiency and power are calculated as shown in Fig.6. The actual efficiency is compared to the reference efficiency to determine the error. According to the error values, the PI controller determines the modulation index value. The output data of Matlab/Simulink file is the switching instants that should be sent to the digital output of the interface card.

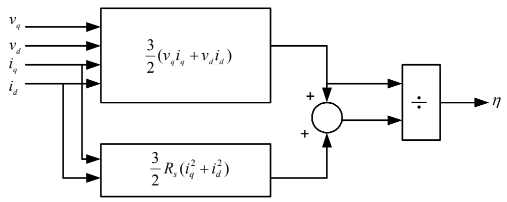

Fig. 6 The efficiency calculation

Fig.7 shows the Matlab/Simulink model including digital output and analog input blocks of PCI 1711 card. The input voltages and currents are adjusted through a set of gains to have their real values.

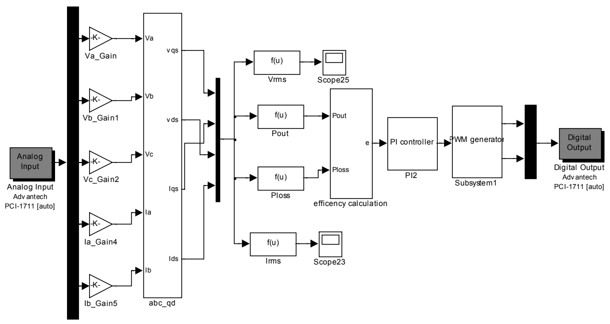

Fig. 7 The Simulink model of maximum power extraction algorithm

EXPERIMENTAL RESULTS

To evaluate the effectiveness of the proposed algorithm, the closed loop system is tested at several disturbances such as sudden change in wind speed, sudden change in the load. The closed loop system results are compared to those of uncontrolled system results.

Wind Speed Step Change

The performance of the controlled system will study under step change in wind speed. Fig. 8 shows the experimental closed loop results of wind energy conversion for an increasing step in wind speed. The initial value of wind speed is 7.5 m/sec and the final value is 9m/sec. The figure shows the wind speed, rotor speed, generator output power and efficiency.

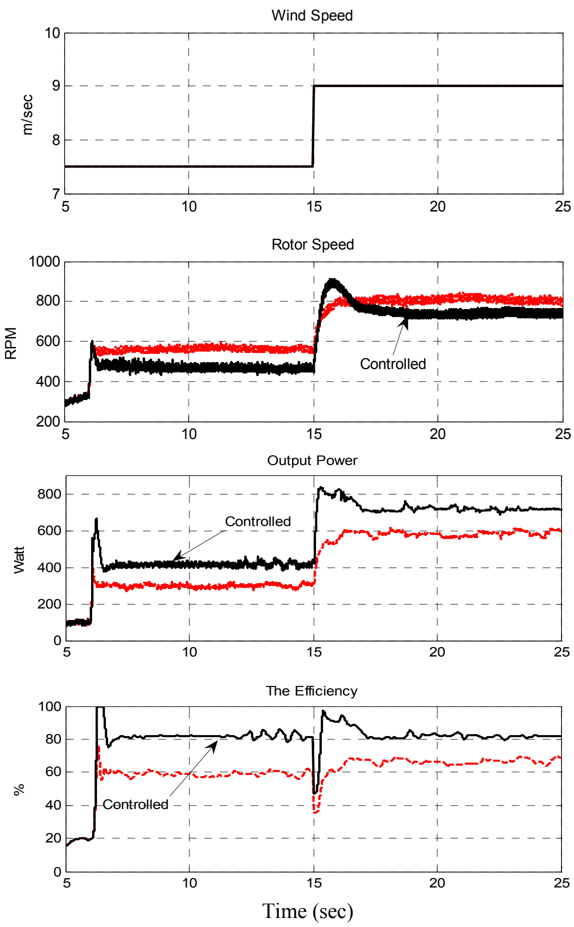

Fig. 8 Closed loop experimental results for increasing step change in wind speed

It is obvious that when wind speed increases, the controller allows the load to extract more power. The controller does that by adjusting the modulation index to increases the actual efficiency as reference efficiency as shown in the figure

Load Step Change

The system was subjected to step change in load to evaluate the performance of the algorithm. Fig.9 shows the experimental closed loop results of wind energy conversion for increasing step in load. The wind speed is 9 m/sec. The figure shows rotor speed, generator output power and efficiency respectively.

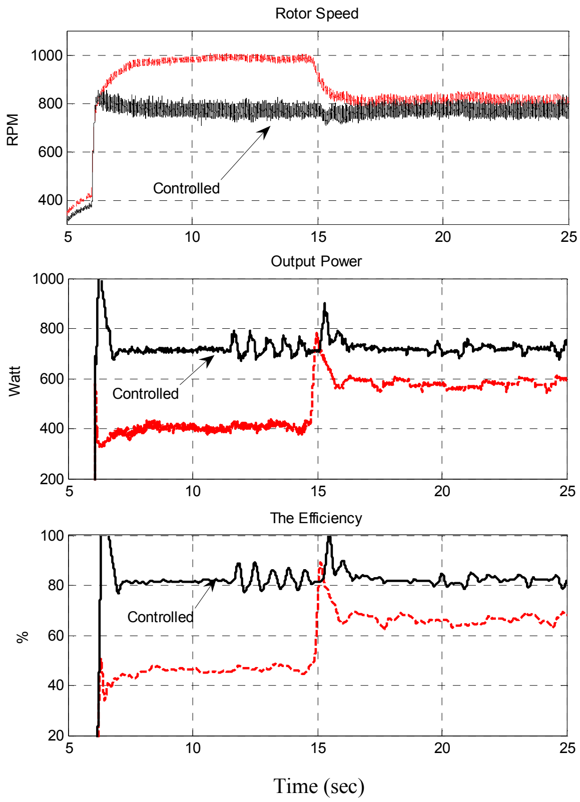

Fig. 9 Closed loop experimental results for load step change

CONCLUSION

In this paper, a simple maximum power extraction scheme for small wind turbine system employing the output voltages and currents of the generator has been proposed. The advantages of the proposed scheme are no knowledge of the wind turbine characteristics or measurements of the wind speed or rotor speed is required. Experimental implementation has been carried out to show the effectiveness of the proposed scheme. The experimental results of the proposed scheme indicate that the scheme can extract more power from the system as compared to the case of open loop system results.

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