Simple Direct Sensorless Control of Permanent Magnet Synchronous Generator Wind Turbine

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Abstract - This paper proposes a new and simple wind speed estimator for wind energy conversion system (WECS). The wind speed is estimated based on the common estimated rotor speed of permanent magnet synchronous generator (PMSG). The method achieves maximum power point tracking in a variable speed wind turbine PMSG. Moreover, a PI controller is employed to control the injected power into the grid at almost unity power factor. The employed control can control both the active and reactive power independently. The proposed wind speed estimator uses only two measurements to estimate rotor speed and thus wind speed can be estimated. The optimum tip speed ratio and optimum power coefficient can be achieved from the relation governed the rotor speed and wind speed. Thus maximum power point tracking can be attained. Accuracy of estimated rotor speed and estimated wind speed is verified by simulation results.

Index Terms - Sensorless control, Wind Energy Conversion System, Permanent Magnet Synchronous Generator, and Maximum Power Point Tracking (MPPT).

I. INTRODUCTION

Wind energy has become a popular renewable energy source in the search for cleaner energy source. As this technology becomes more widely adopted, improvement in the aspect of efficiency and prolonging the system lifespan is required. PMSG has been used more frequently as variable speed systems in Wind Energy Conversion Systems. PMSG connected to a power converter can operate at low speed, so that a gear was usually omitted. Since a gearbox causes higher weight, losses, costs and demands maintenance [1]. A gearless construction represents an efficient and robust solution, which was believed to be beneficial especially for offshore applications. Also variable speed systems have several advantages such as yielding maximum power output while developing low amount of mechanical stress compared to constant speed systems. ac - dc converter such as rectifier is used to convert variable voltage and variable frequency from the PMSG to dc voltage, thereby producing dc power. The dc link is converted back to ac at a fixed frequency that is appropriate for electrical utilizations in the grid [2-4]. Wind power varies continually with changing the wind speed throughout the day. Wind turbine can deliver Maximum Power when the rotor speed varying with changing the wind speeds to get maximum power coefficient and consequently the maximum power point tracking. So extracting maximum possible power from the available wind power is very important. Therefore, MPPT control is an active research area [5-8].

There are two common types of these interferences, the first configuration is made by a diode-bridge rectifier, a boost converter and an inverter connected to the grid [9-12]. The second configuration is a back-to-back converter connected to the grid [13-15]. The former is less expensive, robust and rigid (used in this paper), but the later has a lot of switches which cause more losses and voltage stress in addition to presence of Electromagnetic Interference (EMI).

In this paper, we can get maximum power point tracking from wind turbine by estimating rotor speed of PMSG from dc voltage, dc current and some known parameters. From estimated wind speed and rotor speed the maximum power point tracking can be achieved easily by adjusting the speed of PMSG through dc-dc boost converter. At the grid side unity power factor can be simply achieved by using PI controller on hybrid inverter.

II. WIND ENERGY CONVERSION SYSTEM

Figure 1 shows the power circuit topology and control system of a variable speed wind turbine which considered in this paper. The system consists of wind turbine connected to PMSG 20KW rated power, uncontrolled rectifier which is used to convert the ac PMSG output waveforms to dc voltage. The dc-dc boost converter is used to catch the maximum wind power, where a MPPT control algorithm is employed. Additionally, a single phase H-bridge inverter is used for grid connection at unity power factor. The proposed system has been modeled and simulated using MATLAB SIMULINK.

A- Mathematical Equation of Wind Energy Conversion System

The amount of mechanical power that can be extracted from wind turbine and fed to the PMSG is governed by the following well know equation:

\[ P_m = 0.5 \rho AC_p \nu^3 \]  

(1)
Where $P_m$ is the mechanical output power of the wind turbine (W), $\rho$ is the air density (Kg/m$^3$), $A$ is swept area (m$^2$), $C_p$ is Power coefficient of wind turbine and $u$ is Wind speed (m/sec.). Consequently, the output energy is determined by the power coefficient ($C_p$) of wind turbine if the swept area, air density, and wind speed are constant. $C_p$ is function of pitch angle (β) in degree and tip speed ratio (TSR), if β is equal zero degree, in this case the power coefficient is only function in TSR as shown in equation (2), and TSR is function of rotor mechanical speed, rotor radius of blade and wind speed as shown in equation (3).

\[ C_p(TSR, \beta) = 0.5176 \left\{ \frac{1}{(16/T - 0.4 \beta - 5)} \right\} + 0.0068 * TSR \]
\[ TSR = \omega_r / \omega \]  

(2)

(3)

Where $\omega_r$ is the rotor mechanical speed (rad/sec.) and ‘R’ is radius of blade. Fig. 2 indicates the relation between $C_p$ and TSR when pitch angle (β) equals zero. It can be noticed that the optimum value of $C_p$ is about 0.48 for TSR of 8.1. So by attaining TSR to be 8.1, the maximum power can be obtained from the wind. This can be done by adjusting the rotor speed according to the value of the wind speed. Since the value of radius of blade is constant, so this can be achieved by controlling of the dc-dc boost converter. To do this by using sensor-less mechanical control, the value of rotor mechanical speed and wind speed should be estimated by using electrical sensors as shown in later sections.

### B- Generator side converter control:

Maximum power from the wind can be captured by estimating rotor and wind speed. Control of the duty cycle of the dc-dc boost converter is achieved through MMPT to adjust the generator speed as shown in the flowchart given in Fig. 3.

- **Estimating Rotor Speed**

  The parameters of the PMSG used in this paper are given in Table 1. The equation used to estimate the value of rotor speed by measuring only the average output voltage $V_d$ and current $I_d$ of the diode rectifier is governed by equation (4) [16].

\[ \omega_m = \frac{V_d + 2R_s I_d}{3N_s^3 K_m - \frac{p}{20} L_s I_d} \]

(4)

Where $\omega_m$ is the mechanical rotor speed in (rpm) and $K_m$ as given in Table 1. Figure 4 gives the MATLAB / SIMULINK configuration of equation (4).

- **Estimate Wind Speed**

  From equations (1) to (4), wind speed can be estimated if the value of mechanical power and power coefficient which is a function in rotor speed and wind speed are known. (5) governs the estimated wind speed. Fig.5 shows the representation of (5) in MATLAB / SIMULINK.

\[ V_{wind} = \frac{V_r^2 I_p / \eta}{0.5 \rho A C_p} \]

(5)

To estimate the wind speed from (5), the efficiency (\( \eta \)) of the PMSG is assumed to be equal to 90% and losses of uncontrolled rectifier are neglected.
Direct MPPT Control Strategy for Wind Turbine Conversion System:

MPPT can be executed by maintaining the TSR to be at 8.1. From the estimated rotor speed and the estimated wind speed, it can be easily compared the value of the multiplied estimated rotor speed by radius of blade and divide this value on estimated rotor speed and compare the result with 8.1. By controlling the dc-dc boost switch converter, the speed of rotor speed can be controlled to get maximum power from the wind as shown in flowchart.

C- Grid Side Converter Control

With respect to the grid side, VSI is used to interface between the dc converter side and the grid. A simple PI controller is employed to achieve unity power factor at the grid side.

III- SIMULATION RESULTS

Figure 6 (a) shows the actual and estimated wind speed. The wind speed steps up at time 1.5 second from 8 m/sec to 12 m/sec during 0.5 second time span and at 3.25 second it steps down from 12 m/sec to 10 m/sec also during 0.5 second time span. The percentage error between the actual and estimated wind speeds is found less than 3.5% as shown in Fig. 6 (b). Figure 6 (c) shows that the estimated and measured rotor speeds where it changes with changing the wind speed to obtain optimum TSR and consequently maximum power point. The percentage error between the actual and estimated rotor speeds is found less than 3% as shown in Fig. 6 (d). Figure 6 (e) shows the value of power coefficient. It is clear that the simple control technique works well where the value of power coefficient kept its optimum value which equal 0.48 with changes the wind speed to obtain MPPT. Figure 6 (f) and (g) indicate the output ac voltage and current when the wind speed is 12 m/sec. and 10 m/sec., respectively. Which clear the the unity power factor at the grid is achieved. The average output power according to the wind speed is shown in Fig. 6 (h), whereas this value of the power is the maximum extracted power from available wind power because the value of power coefficient is at optimum value.

TABLE 1: MACHINE NOTATION AND PARAMETER

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<td>$P_r$</td>
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<tr>
<td>$K_m$</td>
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Fig. 6 Simulation results performances of the considered system for achieving Maximum power point tracking from wind turbine and get unity power factor at the grid.
IV. CONCLUSION
In this paper, a sensor-less wind energy conversion system uses PMSG is presented. The system is analyzed and simulated in MATLAB SIMULINK. MPPT control algorithm is employed based on estimated both of wind and rotor speeds to harvest the maximum power from the available wind power. The MPPT algorithm can maintain the TSR to be almost constant at its optimum value to get MPPT. Additionally, a simple PI controller is employed on the grid side to connect the system with grid at unity power factor. Some selected simulation results have been provided to validate the presented technique.

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REFERENCES