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Performance evolution of a PMSG based WECS using maximum power point tracking method

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ABSTRACT

This paper presents a control system for a direct-drive permanent magnet synchronous generator wind turbine system with the objectives to capture the optimal power from the wind and ensure a maximum efficiency for this system. Moreover, in order to eliminate the electrical speed sensor mounted on the rotor shaft of the PMSG to reduce the system hardware complexity and improve the reliability of the system, a sliding mode observer based PM rotor position and speed sensor less control algorithm is presented here. The mathematical models for the wind turbine and the permanent magnet synchronous machine are first given in this thesis, and then optimal power control algorithms for this system are presented. The optimal tip speed ratio based maximum power point tracking control is utilized to ensure the maximum power capture for the system. The field oriented control algorithm is applied to control the speed of the PMSG with the reference of the wind speed. In the grid-side converter control, voltage oriented control algorithm is applied to regulate the active and reactive power injected into the power grid. What is more, sliding mode observer based sensor less control algorithm is also presented here. The simulation study is carried out based on MATLAB/Simulink to validate the proposed system control algorithms.

Index Terms— *direct drive; permanent magnet synchronous generator (PMSG); wind energy conversion system (WECS); maximum power point tracking (MPPT),hyteresis current controller*

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I. INTRODUCTION

In wind energy conversion systems (WECSs), the technologies include the wind turbine system, power electronics technology, and system control technology. The wind turbines, based on the orientation of the rotation axis of the wind turbine, there are HAWT and VAWT. In HAWT, the rotation axis of the wind turbine is parallel, while in the VAWT, the rotation axis is perpendicular to the ground. Compared to the VAWT, HAWT have higher energy conversion efficiency, which makes it widely used in the wind energy industry. The wind turbines can also be classified as fixed-speed wind turbines and variable-speed wind turbine. The fixed-speed wind turbines are simple, robust, and requires low maintenance cost. However, their operating speed is fixed and cannot be controlled with the variation of the wind speed, which results in poorer energy conversion efficiency compared to the variable-speed wind turbines. Nowadays, most of the wind turbines used in industry is variable-speed wind turbines. Among various types of variable-speed WECSs, three kinds are most widely used in industry: doubly-fed induction generator (DFIG) WECSs with reduced-capacity power converters, geared/gearless squirrel-cage induction generator (SCIG) WECSs with full-capacity power converters, and geared/gearless wound-rotor (WRSG)/permanent magnet synchronous generator (PMSG) WECSs with full-capacity power converters . In the DFIG WECSs, only 30% of the rated power is treated by the power converters, which significantly reduces the cost of the converters while conserving the ability to control the speed of the generator in the range of about of its rated speed [6]. In SCIG, WRSG and PMSG WECSs, full-capacity power converters are needed to process the power generated by the generators up to the evaluated power of the systems. With the application of the full-capacity power converters, the generators are fully decoupled from the grid, and are *able to work in the full speed range. As the turbines up to 10 MW attract more attention nowadays, the direct-drive PMSG based WECSs which are very suitable for large wind plants.. The direct-drive wind turbine PMSGs do not have gearbox between the wind turbine and the PMSG rotor shaft, which reduced the mechanical power losses caused by the gearbox. Moreover, the elimination of the gearbox also helps in reducing the budget of the system. This system is consists of a wind turbine PMSG, a rectifier, and an inverter. The wind turbine PMSG converts the mechanical power from the wind into the electrical power, while the rectifier changes the AC power into DC power and controls the speed of the PMSG. The controllable inverter supports in converting the DC power to variable frequency and magnitude AC power. With the voltage oriented control algorithm, the inverter also has the ability to control the active and reactive powers injected into the grid. For the control of PMSG systems,* *the information of the rotor position and speed is required to implement the advanced control algorithms such as the field oriented control (FOC) and direct torque control (DTC). To maximize the use of wind energy when the wind speed is below the rated speed, the maximumpower point tracking (MPPT) of the system is indispensable. The MPPT is realized by controlling the inverter which is linked to the generator.*

II. SYSTEM DISCRIPTION

The system under consideration employs PMSG-based variable speed WECS consisting of three phase full AC-DC-AC converter and load with a common dc-link. The block diagram of variable speed WECS is shown in Fig. 2.1 and the main components of system with their important characteristics are discussed below:

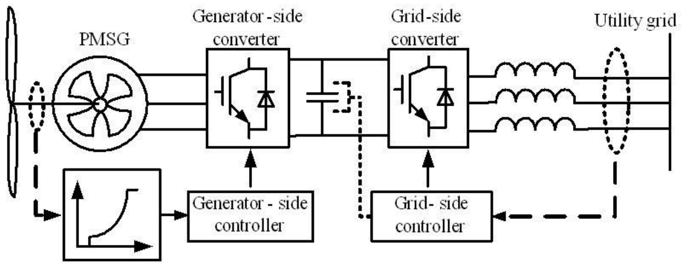


Figure 2.1 simple wind turbine system

2.1 WIND TURBINE MODEL

The wind turbine power curves as seen in fig. 2.2, illustrate how the mechanical power that can be extract from the wind depends on the rotor speed. For each wind speed there is an ideal turbine speed at which the extract wind power at the shaft reaches its supreme value. Such a family of wind turbine power curves can be signified by a single dimensionless characteristic curve, namely, the $C_p - \lambda$ curve, as shown in fig. 2.3, where the power coefficient is plotted against the TSR.

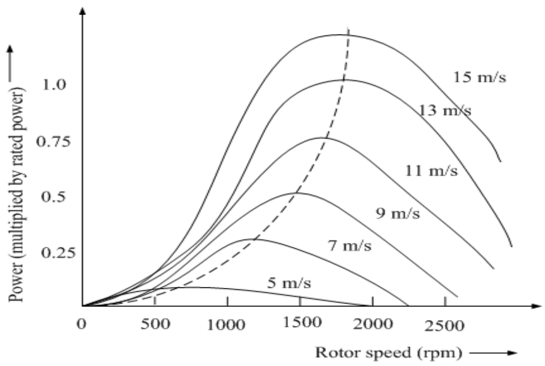


Figure-2.2 A typical power versus speed characteristics of a wind turbine.

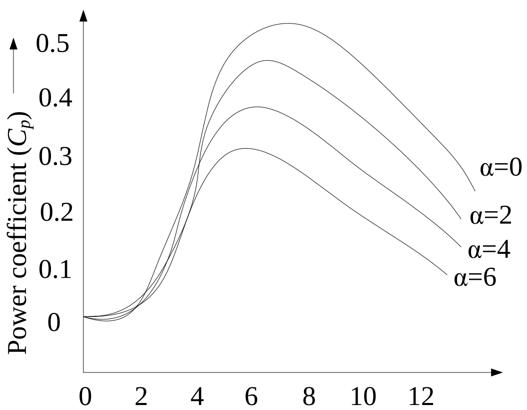


Figure-2.3 Typical curves of power coefficient versus tip speed ratio for various values of the pitch angle α.

For a turbine, the power coefficient depends not only on the TSR but also on the blade pitch angle. The figure 2.3 shows the typical variation of the power coefficient with respect to the TSR λ with blade pitch control.From the following equations,

$$P_o = \frac{1}{2}\rho A V_\infty^3$$

The mechanical power transmitted to the shaft is

$$P_m = \frac{1}{2}\rho C_p A V_\infty^3$$

Where C_p is a function of the TSR λ and the pitch angle α.

For a wind turbine with radius *R*, the above equation can be stated as

$$P_m = \frac{1}{2}\rho C_p \pi R^2 V_\infty^3$$

For a given wind speed, the power extracted from the wind is maximized if C_p is maximized. The optimum value of C_p, say $C_{p,opt}$, always occurs at a definite value of λ say λ_{opt}. This means that for variable wind speed, the rotor speed must be adjusted proportionally to adhere always to this value of $\lambda(=\lambda_{op})$ for supreme mechanical power output from turbine. Using the relation $\lambda = \omega R / V_\infty$ in above equation, the maximum value of the shaft mechanical power for wind speed can be expressed as

$$P_{\max} = \frac{1}{2}\rho C_{p,opt}\, \pi \left(\frac{R^5}{\lambda_{opt}^3} \right) \omega^3$$

Thus the maximum mechanical power that can be get from wind is proportional to the cube of the rotor speed, i.e.

$$P_{\max} \propto \omega^3$$

Studying the torque versus speed characteristics of any prime mover is very important for properly matching the load and ensuring stable operation of the electrical generator. The torque and power are associated as

$$T_m = \frac{P_m}{\omega}$$

from equation , at the optimum operating point ($C_{p,opt}$, λ_{opt}), the relation between aerodynamic torque and rotational speed is

$$T_m = \frac{1}{2}\rho C_{p,opt}\, \pi \left(\frac{R^5}{\lambda_{opt}^3} \right) \omega^2$$

It is seen that at the optimum operating point on the $C_p - \lambda$ curve, the torque is quadratic ally related to the rotational speed.

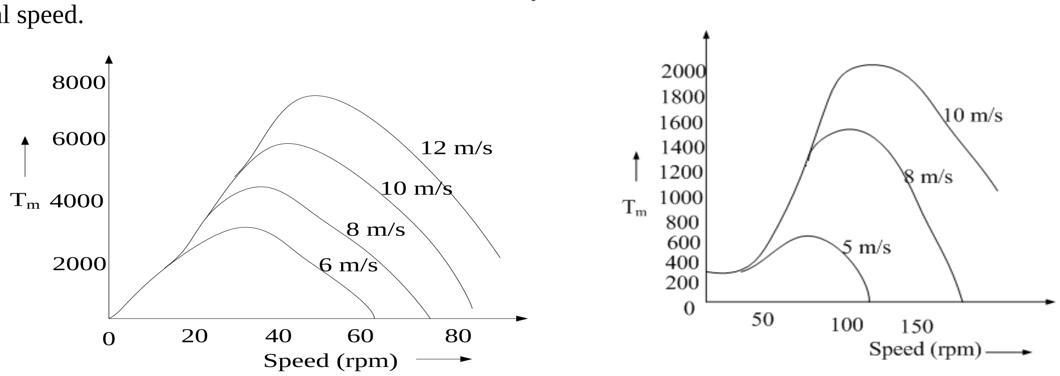


Figure-2.4 Torque-speed characteristics of Darrieus type and Propeller type wind turbines**.**

The curves in Figure 2.4 shows that the propeller turbine and the Darrieus turbine, for several wind speed, the torque reaches a extreme value at a precise rotational speed, and this maximum shaft torque varies approximately as the square of the rotational speed. In case of electricity production, the load torque depends on the electrical loading, and by properly choosing the load, the torque can be made to vary as the square of the rotational speed. The choice of constant of proportionality of load is very important. At the optimal value, the load curve follows the maximum shaft power. But at a higher value, the load torque may exceed the turbine torque for most speeds. Consequently, the machine would fail to speed up above a very low value. If the constant *K* is lower than the optimum value, the machine may over speed at the rated wind speed, activating the speed-limiting mechanism. Thus the proportionality constant of the load needs to be selected from a rather narrow range, about 10-20% of the optimum power curve. Note that the point of maximum torque is not the same as that for maximum power. As the power output is a product of torque and speed, it also has maxima that vary as the cube of the rotational speed, The matching characteristics of the load can make the load curve pass through the maximum power points at all wind speeds. For generators that feed power to the grid, the torque-speed characteristics are changed using power electronics panels.In terms of power coefficient $C_p(\lambda,\alpha)$, the aerodynamic torque becomes

$$T_m = \frac{1}{2}\rho C_T \pi R^3 V_\infty^3$$

Where $C_T = C_p / \lambda$ is called the *torque coefficient*.

III. PROPOSED METHODOLOGY

By measuring the DC voltage and current of the uncontrolled rectifier the maximum power point track from the wind turbine. By these given values, the power can easily be calculated. Comparison between the current and previous values of DC voltage by using appropriate delay time. To control the value of duty cycle for the DC-DC boost converter, the MPPT algorithm needs to sense the power and the sign of the change in DC voltage.

3.1 MPPT Control in DC-DC Boost converter

The control system makes use of the fact that the generated voltage and VDC depend upon the speedof the turbine. Therefore, instead of detecting the turbine speed, it senses the VDC and tries to control the same. The fixed point for this voltage is not constant.This is due to the wind speed which is varying every instant and then which causes the optimum turbine speed to vary frequently. The set point is floating and has to be decided by a trial and error method.The method is called Peak seeking. Figure 3.1 shows the step and search control strategy to track maximum power.

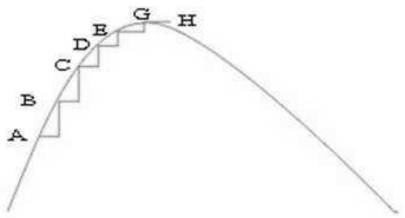


Figure 3.1 step and search control strategy to track maximum power

The strategy is to start with any arbitrary setpoint (A). Then give a small increment to theset point. Again check the output at point B. If the output has amplified, give an additional increment and check the output once again. Incrementing the set point through small steps should be continued till the stage (H) when the increment does not yield a favourable result. At this stage, a small decrementto the set point should be given. The set point will be moving back and forth around the finest value. Thus, the power output might be maximized.

In this method, after giving increment to the setpoint, both the power output as well as the voltagelevel has to be checked. Four possibilities arise:

- Power increased – voltage increased
- Power increased – voltage decreased
- Power decreased – voltage increased
- Power decreased – voltage decreased

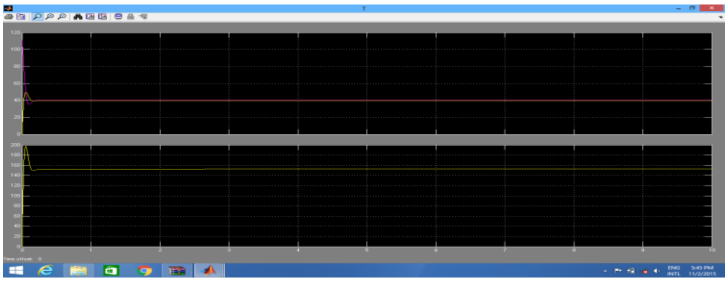
When output power and the voltage are increased (case 1), the set point has to be incremented. If the wind speed changes from one point to another, the turbine is not being operated at the maximum power point at the new value. The MPPT controller has to search for the new extreme power point for the new wind speed. Thus, depending upon the MPPT controller output, the dc-dc boost converter switch runs and maintains a constant VDC link across the capacitor. The adaptive hysteresis band current controller adjusts the hysteresis band width, according to the measured line current of the grid connected inverter.

IV. SIMULATION RESULT

To simulate the PMSG based WECS system using MPPT and hyteresis current controller has been carried out using MATLAB/SIMULINK.

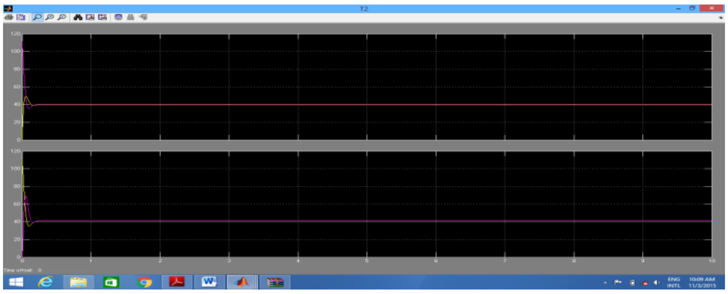
4.1 WIND SYSTEM WITHOUT USING MPPT

The figure 4.1 shows the result of Te and Tm of a wind generation system without using MPPT method.



4.2 WIND SYSTEM USING MPPT

The figure 4.2 shows the result of Te and Tm by using MPPT. As compared to the figure 4.1 the system using MPPT improves the overall performance of a system.



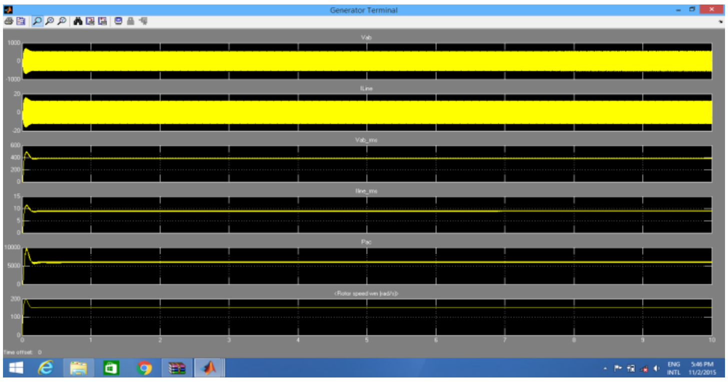


Figure 4.3 results of generator terminal of a system

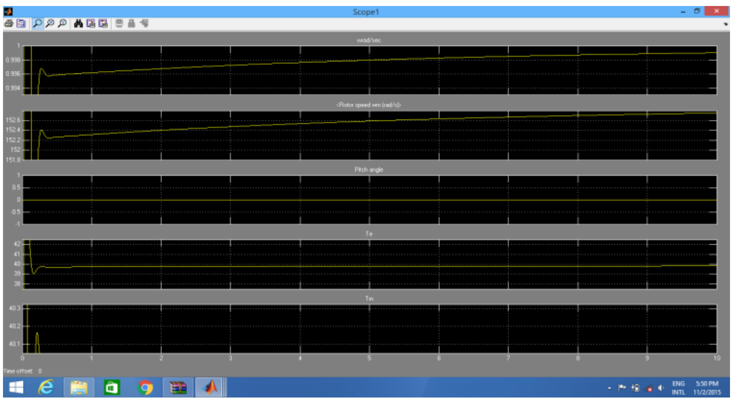


Figure 4.3 Shows the results of different parameters of a wind generation system

V. CONCLUSION

In this paper, hysteresis controlled MPPT is integrated into power systems and its effect on voltage stability is analysed. It is found that with the proposed control, DC link voltage is sustained constant under changing wind speeds and different load conditions. The steady-state power transfer capacity of the transmission line is also increased. So overall PMSG based WECS with MPPT is a efficient method for the varying speeds of wind and overall improves the performance of a WECS.

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