IMPROVED GENERATION BY AN INTELLIGENT MPPT SYSTEM BASED ON PMSG-WECS SYSTEM

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***Abstract-* Wind energy is one of the most prominent sources of energy with the prospect of large scale future power generation. A simple wind energy conversion system consists of blade arrangement, generator and converter system.**
Many methods have been designed to track the maximum power point of wind energy system, but it's a problem during continuously variable wind speeds as selecting a proper step size becomes a challenge. In this paper, we have reviewed a few methods designed to work perfectly in variable speed conditions in a PMSG and converter based system.
***Keywords-* Controller, Fuzzy logic, PMSG, PWM converter, HCS, Sensors**

I. INTRODUCTION

Renewable energy is a good replacement option for presently used sources like coal and natural gas, but even after much development in the technology, there is still some confusion in the minds with respect to their performance and cost.
Wind turbines are available in two major configurations: Vertical Axis Wind Turbines and Horizontal Axis Wind Turbines (HAWT). The more common HAWT may operate either with fixed rotor speed or variable speed. Many researchers are working to make the functioning of wind system more reliable and efficient.
Wind turbines capture the power from the wind by means of aerodynamically designed blades and convert it to rotating mechanical power. The generator converts the mechanical power into electrical energy, which is fed into a grid through power electronic converter. The connection of wind turbines to the grid is possible even at the extra high voltage system since the transmittable power of an electricity system usually increases with increasing the voltage level.
It is desirable to operate wind energy system at its Maximum PowerPoint (MPP) in operating region for economic reasons. The amount of mechanical energy that can be extracted from wind is not only depending on wind speed, but also depending on the wind turbine rotational speed. The wind turbine rotational speed can be adjusted as the wind speed changes to tracking the maximum power point in the operating region. A unique limitation of energy conversion systems such as wind and solar is their inability to track peak power production efficiently at varying wind speeds and solar insulation respectively. Many algorithms have been developed that have aided wind/solar energy systems in extracting the maximum available power for a given wind and solar resource.

II. WIND ENERGY CONVERSION SYSTEM

In the WECS, wind turbine can operate with either variable speed or fixed speed. For fixed speed wind generation system, because of the generator is directly connected to the grid, the turbulence of the wind will result in power variations, and so affect the power quality in the grid, whereas for variable speed generation system, the generator is controlled by power electronic converter.

So, variable speed wind energy conversion systems have many advantages over fixed speed generation, such as maximum power point tracking control method, increased power capture, power quality, improved efficiency and they can be controlled in order to reduce aerodynamic noise and mechanical stress. In addition, with the development of power electronics technology, it's possible to control the rotor speed, to increase wind energy production and to reduce drive train loads. Thus the variable speed wind turbine generator system is becoming the most important and fastest growing application of wind generation system. [1]
As per Betz Limit, a wind turbine at the maximum efficiency can capture around 59.3% of incoming wind energy. A wind turbine can't fully capture wind energy. So, the components of

wind turbine have been modelled by the following equations. The output power of the wind-turbine is expressed as:

$$P_T = 0.5C_p\rho AV^3$$

Where ρ is the air density, A is the cross sectional area of the turbine V is the wind velocity. The coefficient of power (Cp) is a value dependent on the ratio between the turbine rotor's angular velocity, (ωT) and the wind speed (V). This ratio is known as the Tip speed ratio (TSR), and is represented by γ. TSR is given by:

$$\gamma = \omega_T R / V$$

here, R is the radius of the turbine. So, using the above two equations, we can derive the equation of power dependent on ω_T and γ:

$$P_T = 0.5C_p\rho A (\omega_T R/ \gamma)^3$$

A wind turbine is generally characterised by its Cp versus γ curves obtained for different wind speeds, and usually takes the shape shown below.

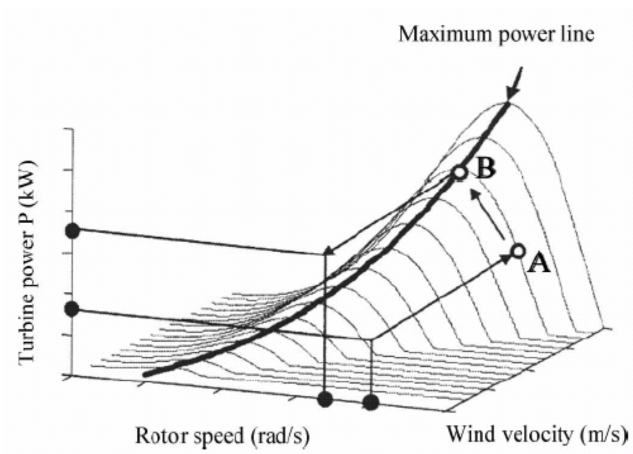


Figure 1- Wind Turbine Power Curves [3]

III. GENERATORS IN WECS

In terms of the generators for WECS, several types of electric generators are used such as Squired- Cage Induction Generator (SCIG), Synchronous Generator with external field excitation, Doubly Fed Induction Generator (DFIG) and Permanent Magnet Synchronous Generator (PMSG) with power electronic converter system [1]. In recent times, the use of DFIG and PMSG has taken a big leap in the field of wind power generation.

Wind power generation based on the doubly-fed induction generator (DFIG) has gained increasing popularity due to several advantages. But the use of PMSG is becoming more and more common for reasons such as very high torque can be achieved at low speeds because PMSG is connected directly to the turbine without gearbox; lower operational noise is achieved; no significant losses are generated in the rotor and external excitation current is not needed.

So, the efficiency of a PMSG based WECS has been assessed higher than other generators and PMSG is an attractive choice for variable-speed generation system.

In this paper we will consider the case of PMSG based WECS. To adjust the rotational speed for maximizing the wind turbine output power from the fluctuating wind, variable speed operation of the system is necessary and, for various wind speeds, the wind turbine can be operate as close as possible to its optimal speed to realize maximum power point tracking (MPPT).

IV. CONVERTER TOPOLOGIES FOR WECS

The WECS adopts an AC-DC-AC converter system. The PMSG is connected to the grid through two PWMVSCs: a generator-side converter and a grid-side inverter.

Each of the four quadrant power converters is a standard 3-phase two-level unit, composed of six insulated gate bipolar transistors (IGBTs) and controlled by triangular wave PWM law. The generator-side converter achieves variable speed operation by controlling the generator torque. On the other hand, the grid-side inverter supplies the electrical power which is synchronized with the grid frequency. The DC-link includes a chopper circuit to avoid DC-link over-voltages at the time of system fault. Therefore, stable operation for the WECS can be achieved under a system fault.[5] Another possible option is the boost converter, which converts an input voltage to a higher output voltage. The boost is a popular non-isolated power stage topology.

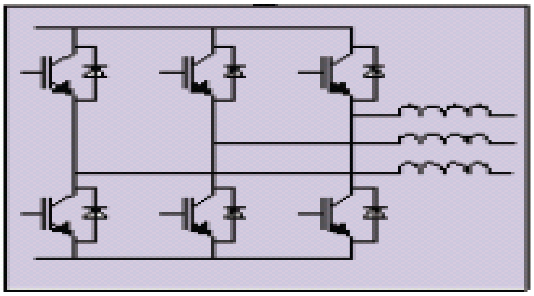


Figure 2- 2 Level conductors

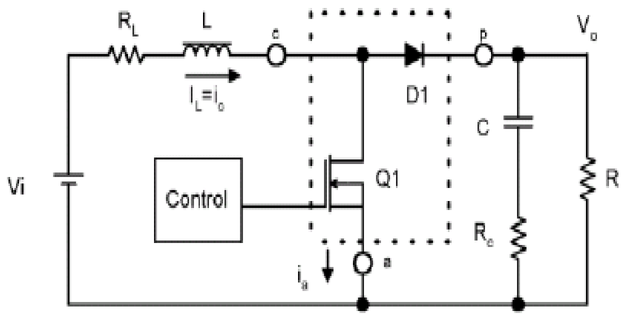


Figure 3- Boost Converter

Power supply designers choose the boost power stage because the required output is always higher than the input voltage. The input current for a boost power stage is continuous, or non-pulsating, because the output diode conducts only during a portion of the switching cycle. The output capacitor supplies the entire load current for the rest of the switching cycle.[2]

Inductor L and capacitor C make up the effective output filter. Resistor R represents the load seen by the power supply output. A power stage can operate in continuous or discontinuous inductor current mode. In continuous inductor current mode, current flows continuously in the inductor during the entire switching cycle in steady-state operation. In discontinuous inductor current mode, inductor current is zero for a portion of the switching cycle. It starts at zero, reaches peak value, and return to zero during each switching cycle. It is desirable for a power stage to stay in only one mode over its expected operating conditions because the power stage frequency response changes significantly between the two modes of operation.

V. WECS CONTROL FOR MPPT

From the relationship between TSR and cp, it is possible to devise a control strategy that ensures that the wind turbine operates around or at the peak point of the curve. Such strategies are commonly referred to as Maximum Power Point Tracking (MPPT) techniques.

MPPT techniques fall into two broad categories:

1.Techniques using known turbine characteristics

From the wind turbine power equation, the size of the turbine may be used to calculate the power. Maximum power point tracking is achieved either by Speed control or torque control

2. Techniques without turbine characteristics

Where wind turbine characteristics are unknown, the controller algorithm brings the operating point towards maximum value of Cp by stepwise increases or decreases in the rotational speed of the wind turbine. This is known as *perturbation and observation method*.[6]

Generally, MPPT in this case is achieved using intelligent control methods. The most commonly used techniques are based on Adaptive Fuzzy Logic controllers and Neural Network based controllers.

A. MPPT Based On Speed/TSR Control

Methods based on speed control are applied if a PWM converter is used along with PMSG attached to the wind turbine. The converter is vector controlled with a speed loop. From the definition of tip speed ratio shown before, we have:

$$V = \omega R/\gamma$$

To optimally capture the power, we need to determine the optimum value of γ at which we will get the maximum value of Cp.

$$Cp(\gamma) = Cp(\gamma o) = \text{max. } Cp$$

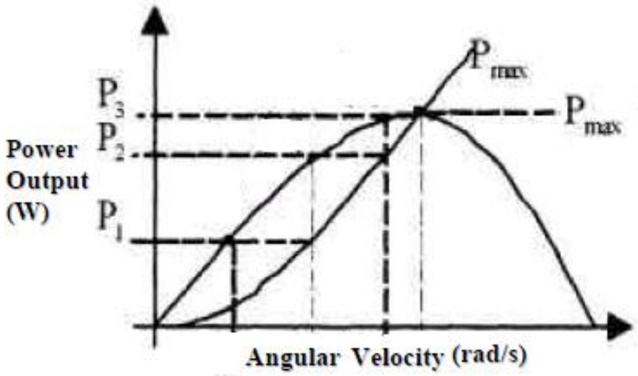


Figure 4- C_p vs Power output curve

So at maximum C_p, we can have the power equation as:

$$^{max}P_T = \frac{0.5\ ^{max}C_p \rho A R^3 \omega^3}{\gamma_o^3}$$

Using the above equation we can derive a coefficient that can be optimised for achieving maximum power output from the wind turbine. Also, it is very clear that, the reference angular speed can be derived from the reference power and it can be used to track the maximum power using controllers.

$$\omega = \sqrt[3]{\frac{Pref}{Ko}}$$

B.MPPT Based On TSR Control-Hysteresis Control

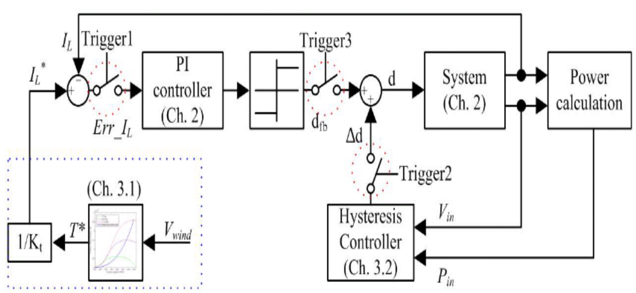


Figure 5-MPPT with TSR Hysteresis Control

MPPT method based on TSR cannot guarantee the operation of the controller at the MPP when the errors occurring in the *Cp*-curve are caused by a variance in the blade characteristics. In an article, the Hysteresis controller is combined with TSR control to solve this problem.[7] The controller monitors the power output in order to have a band of maximum power when the wind turbine operates at the MPP of the *Cp-curve* using TSR control.

C. MPPT Using Switched Mode Rectifier

In the method as given in [9], the wind speed is not required to be monitored, and, therefore, it is a simple output-maximization control method without wind-speed sensor. The measurement of the power generated is simpler and more accurate than the measurement of the wind velocity, so in an article [8] the structure of control strategy of the switch-mode rectifier is explained. The control objective is to control the duty cycle of the switch ***S*** to extract maximum power from the variable-speed wind turbine and transfer the power to the load.

The control algorithm includes the following steps:

1) Measure generator speed ωg.
2) Determine the reference torque
3) This torque reference is then used to calculate the DC current reference by measuring the rectifier output voltage V_d
4) The error between the reference dc current and measured dc current is used to vary the duty cycle of the switch to regulate the output of the switch-mode rectifier and the generator torque through a Proportional–Integral (PI) controller.

The generator torque is controlled in the optimum torque curve according to the generator speed. The acceleration or deceleration of the generator is determined by the difference of the turbine torque and generator torque.

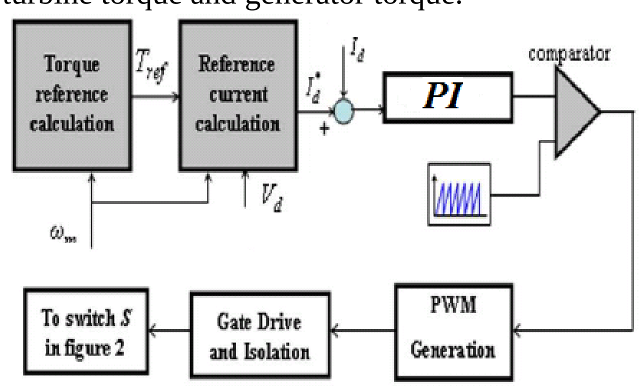


Figure 6: - Control strategy of the switch-mode rectifier [9]

If the generator speed is less than the optimal speed, the turbine torque is larger than the generator torque, and the generator will be accelerated. The generator will be decelerated if the generator speed is higher than the optimal speed. Therefore, the turbine and generator torques settle down to the optimum torque point opt at any wind speed, and the wind turbine is operated at the maximum power point.

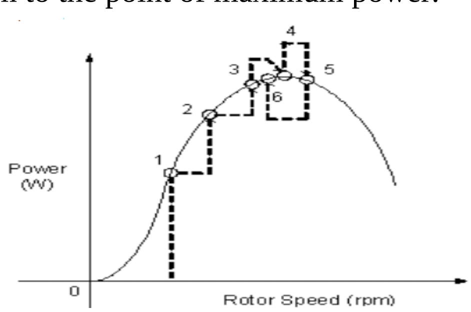
D. MPPT Using Fuzzy Based On Output Power Control

This method involves basing the adjustment in rotor speed adjustment on the difference in wind power output.

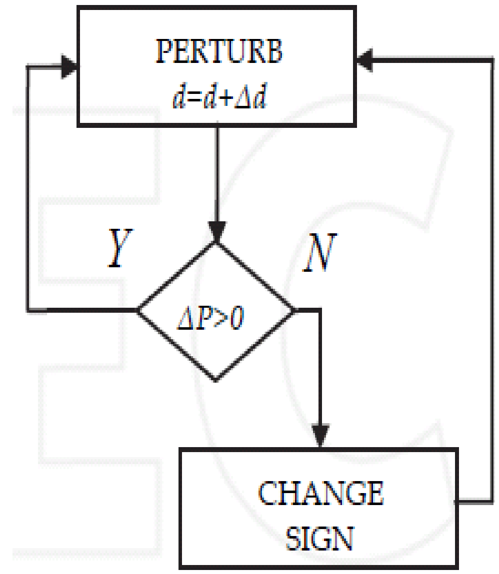
The controller operates blind with regard to wind speed and adjusts the speed of the wind turbine rotor based solely on the change observed in wind power output. This is made possible by the nature of the wind power output characteristic curve, which levels out when the generated power reaches its maximum.

Thus the controller adjusts the rotor speed until the change in wind power produced is zero, indicating that a maximum has been reached. A negative or positive change in the wind power output would indicate that the turbine is yet to reach the maximum power point.

The HCS control algorithm can be implied using Fuzzy based controller. It continuously searches for the peak power of the wind turbine. The tracking algorithm, depending upon the location of the operating point and relation between the changes in power and speed, computes the desired optimum signal in order to drive the system to the point of maximum power.



(a)



(b)

Figure 7- HSC Algorithm

VI. COMPARISON OF DIFFERENT METHODS

A) Speed-Based Control

This method is capable of efficiently tracking the maximum power point with a simple design and is easily implemented where turbine characteristics are known. Problem is faced while tuning the speed controller as it's very sensitive due to high values of inertia, and is instable during start-up, and it relies heavily on sensor accuracy and efficiency.

B) Torque-Based Control

In this method the power and torque ripples are reduced, efficiency is higher, simpler and more robust compared to speed control techniques. The time required to track MPPT is small when working below rated wind speed. The major disadvantage is more dependence on sensor.

C) Fuzzy logic based methods

The fuzzy based control is universal, so can be used with minimal adjustments in any system. The system shows low power fluctuation, low rotational speed fluctuation, fast tracking time when working at above rated wind speed. The controller relies on the actual performance of the wind turbine with few sensors are requirement, and is relatively unaffected by variations in turbine inertia and wind speed.

The major problem faced in this method is of tuning of algorithm in high turbulence condition and a strong dependence on the algorithm with a single error destroying the whole operation.

D. Neural-Fuzzy Control

This method is Capable of tracking maximum mechanical power of the wind turbine at both dynamic and steady states. Sensors requirements are few and simple. The system can be easily implemented replacing human error.

The point of concern is that the final algorithm cannot be generalised since it is adaptively tuned to a specific turbine, which can take a long time to achieve optimal performance, depending on the learning algorithm selected.

VII. CONCLUSION

So in this study we have seen that a variety of methods have been designed to track the MPPT of a wind turbine.

Some methods are based on known characteristic of turbine and some are designed based on Unknown parameters using intelligent controllers. The systems can be either Sensor dependent or sensor independent. It's very easy to understand that a method based on intelligent control i.e. based on fuzzy control or neural algorithm is not only fast but also efficient in terms of error. If we can reduce the use of sensors in an intelligent system, the method will become more powerful and useful.

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