International Journal of Research in Advent Technology (IJRAT) (E-ISSN: 2321-9637)
Special Issue
National Conference "CONVERGENCE 2016", 06th-07th April 2016

Maximum Power Point Tracking Techniques for Wind Energy System

Suresh R.Alase[1], Sunil S. Jawale[2], Prashant R.Borale[3], Tushar Nemade[4], Samadhan R. Sarode[5]
[1,2,3,4,5]*Department of Mechanical Engineering*
[1,2,3,4,5]*Pankaj Laddhad Institute of Technology and Management Studies, Buldana*
Email: sureshalase9@gmail.com [1], *suniljawale2013@rediffmail.com*[2]

Abstract-

Wind energy systems are being closely studied because of its benefits as an environmentally friendly and renewable source of energy. Due to the instantaneous changing nature of wind it is desirable to determine the optimal generator speed that ensures maximum energy yield. So, it is essential to include a controller that can track the maximum power point regardless of wind speed. Techniques have been developed to extract maximum power from the wind available, thus ensuring that for any given wind speed, the wind turbine is able to produce power at its peak. An examination of various approaches utilized and an analysis of the strengths and weaknesses of each is presented in this report. Based on simulation results available in the literature, the optimal torque control (OTC) has been found to be the best MPPT method for wind energy systems due to its simplicity. On the other hand, the perturbation and observation (P&O) method is flexible and simple in implementation, but is less efficient and has difficulties determining the optimum step-size.

Index Terms- WECS, Types of wind mill, MPPT techniques.

1. INTRODUCTION

Due to the increasing concern about the environment and the depletion of natural resources such as fossil fuels, much research is now focused on obtaining new environmentally friendly sources of power. To preserve our planet for the future generations, natural renewable sources are being closely studied and harvested for our energy needs. Wind energy is environmentally friendly, inexhaustible, safe, and capable of supplying substantial amounts of power. Wind turbines are controlled to operate only in a specified range of wind speeds bounded by cut-in (Vcut-in) and cut-out (Vcut-out) speeds. Beyond these limits, the turbine should be stopped to protect both the generator and turbine. Figure.1 shows the typical power curve of a wind turbine. From the figure, it can be observed that there are three different operational regions.

The first is the low-speed region, where the turbine should be stopped and disconnected from the grid to prevent it from being driven by the generator. The second is the moderate-speed region that is bounded by the cut-in speed at which the turbine starts working, and the rated speed (Vrated), at which the turbine produces its rated power. The turbine produces maximum power in this region, as it is controlled to extract the available power from the wind. In the high speed region (i.e. between Vrated and Vcut-oSut), the turbine power is limited so that the turbine and generator are not over-loaded and dynamic loads do not result in mechanical failure. It is noteworthy that to protect the turbine from structural over-load, it should be shut down above the cut-out speed. This paper focuses on the moderate-speed region, where the maximum power point tracking (MPPT) algorithm is needed.

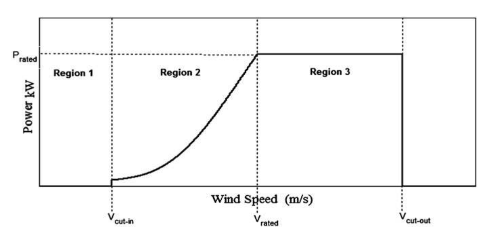

Figure 1 Ideal power curve of a wind turbine

2. LITERATURE REVIEW

In order to determine the optimal operating point of the wind turbine, including a MPPT algorithm in the system is essential. Much has been written on the topic of MPPT algorithms, especially for wind energy systems. Raza Kazmi reviewed many published wind MPPT algorithms and concluded that the two methods described in Hui and Bakhshi and Kazmi are the best solution due to their adaptive-tracking and self-tuning capabilities. Studies have compared some of the wind MPPT algorithms particularly for PMSG driven wind turbines. Musunuri and Ginn Iii categorized the available MPPT algorithms into nine groups based on the specified performance and measurement requirements. The authors also reported that there is an increasing trend of MPPT algorithm use among researchers over the past decade. Therefore, recent trends in the proposed wind MPPT technology should be reviewed and compiled. To the best of the current authors' knowledge, there is limited peer-reviewed literature on the MPPT algorithms for wind energy systems. This review complied and analyzed recently developed MPPT algorithms especially for wind energy systems, particularly the PMSG integrated with boost converter. The fundamentals of the available MPPT techniques for wind energy systems are also reviewed and revised.

3. WIND ENERGY MARKET

Wind energy has been harnessed by many generations for thousands of years to mill grain, pump water and sailing. It wasn't until the late nineteen century when the development of a 12 kW windmill generator was used to generate electricity, however, it was only in the 1980s that the technology has become mature enough to efficiently and reliably produce electricity. Since then, many wind energy systems have been developed and the technological advances have been phenomenal. Just in last decade, the wind global value of new wind energy plants installed in 2006 alone has reached US $24 billion, and over energy industry has experienced a growth of almost 30 percent each year]. The 70 countries have wind turbine installations. From 1996 to 2014, the total cumulative capacity of global wind power has increased from 6.1 GW to 369.6 GW (See Figure 3.1) In particular, the last two years (2008 and 2009) have been record breaking years for the wind industry. Before 2007, 2006 had the highest ever amount of installations of wind energy systems in a single year, reaching 15 GW (See Figure 3.2). Afterwards, the year 2014 became another historical year as the total cumulative capacity of global wind power increased by 51 GW (27% growth) to reach a final total of 369.6 GW of installed wind power.

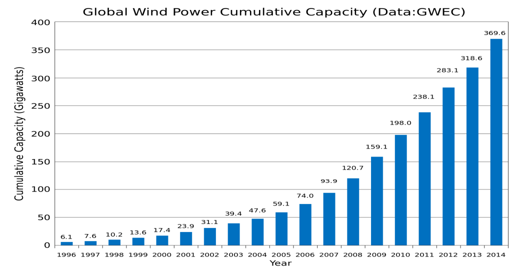

Figure 3.1: the total amount of globally installed wind energy systems per year

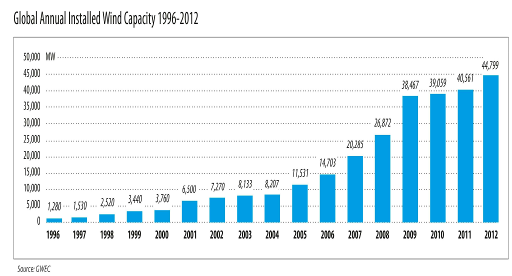

Figure 3.2: the total amount of the newly installed wind energy systems around the world per year

4. WIND ENERGY CONVERSION SYSTEM

4.1 Wind Turbine Technology

The wind turbine is the first and foremost element of wind power systems. There are two main types of wind turbines, the horizontal-axis and vertical-axis turbines.

4.1.1 Horizontal-axis Turbines

Horizontal-axis turbines are primarily composed of a tower and a nacelle mounted on top of tower. The generator and gearbox are normally located in the nacelle. It has a high wind energy conversion efficiency, self-starting capability, and access to stronger winds due to its elevation from the tower. Its disadvantages, on the other hand, include high installation cost, the need of a strong tower to support the nacelle and rotor blade, and longer cables to connect the top of the tower to the ground.

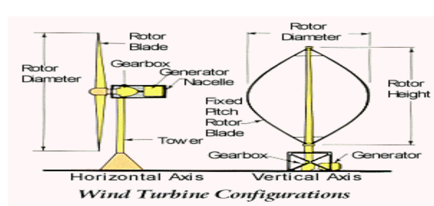

Figure 4.1: illustration of a horizontal axis and a vertical axis wind turbine

4.1.2 Vertical-axis Turbines

A vertical axis turbines' spin axis is perpendicular to the ground (See Figure 4.1). The wind turbine is vertically mounted, and its generator and gearbox is located at its base.

Compared to horizontal-axis turbines, it has reduced installation cost, and maintenance is easier, because of the ground level gear box and generator installation. Another advantage of the vertical axis turbine is that its operation is independent of wind direction. The blades and its attachments in vertical axis turbines are also lower in cost and more rugged during operation. However, one major drawback of the vertical wind turbine is that it has low wind energy conversion efficiency and there are limited options for speed regulation in high winds. Its efficiency is around half of the efficiency of horizontal axis wind turbines. Vertical axis turbines also have high torque fluctuations with each revolution, and are not self-starting. Mainly due to efficiency issue, horizontal wind turbines are primarily used. Consequently, the wind turbine considered in this thesis is a horizontal axis turbine.

4.2 Types of Horizontal-Axis Wind Turbines

4.2.1 Pitched Controlled Wind Turbines

Pitch controlled wind turbines change the orientation of the rotor blades along its longitudinal axis to control the output power. These turbines have controllers to check the output power several times per second, and when the output power reaches a maximum threshold, an order is sent to the blade hydraulic pitch mechanism of the turbine to pitch (or to turn) the rotor slightly out of wind to slow down the turbine.

4.2.2 Stalled Controlled Wind Turbines

The rotor blades of a stall controlled wind turbine are bolted onto the hub at a fixed angle. The blades are aerodynamically designed to slow down the blades when winds are too strong. The stall phenomenon caused by turbulence on rotor blade prevents the lifting force to act on the rotor. The rotor blades are twisted slightly along the longitudinal axis so that the rotor blade stalls gradually rather than suddenly when the wind reaches the turbines' critical value.

4.2.3 Active Stall Controlled Wind Turbines

Active stall turbines are very similar to the pitch controlled turbine because they operate the same way at low wind speeds. However, once the machine has reached its rated power, active stall turbines will turn its blades in the opposite direction from what a pitch controlled machine would. By doing this, the blades induces stall on its rotor blades and consequently waste the excess energy in the wind to prevent the generator from being overloaded. This mechanism is usually either realized by hydraulic systems or electric stepper motors.

5. MPPT TECHNIQUES

Due to the constant variability of wind speed, design of controllers capable of extracting maximum power from the wind is a constant challenge, and various techniques have been developed to obtain higher efficiency from wind turbines. This should, in the long run, make wind power an economically viable alternative to non-renewable energy sources. Although the speed of the wind turbine could be fixed or variable, maximization of the extracted energy is achievable with variable speed wind turbines only. Since these turbines can change their rotational speed to follow instantaneous changes in wind speed, they are able to maintain a constant rotational speed to wind speed ratio. It can be noted that there is a specific ratio called the optimum tip speed ratio (TSR) for each wind turbine for which the extracted power is maximized. As the wind speed is instantaneously changing, it is necessary for the rotational speed to be variable to maintain the optimal TSR at all times. To operate in variable-speed conditions, a wind energy system needs a power electronic converter to convert the variable-voltage–variable frequency of the generator into a fixed-voltage–fixed-frequency that is suitable for the grid. In addition to increasing the energy capture, variable-speed turbines can be controlled to reduce the load on the drive-train and tower structure, leading to potentially longer installation life. Researchers have discussed the different possible configurations of power converters and electrical generators for variable-speed wind turbine systems. MPPT techniques are divided into two broad categories:

- Techniques that use known turbine characteristics
- Techniques without knowledge of turbine characteristics that allow optimization.

5.1. Tip speed ratio (TSR) control

The optimal TSR for a given wind turbine is constant regardless of wind speed. If TSR remains constantly at the optimal value, it is guaranteed that the extracted energy will be maximized. There-fore, this method seeks to force the energy conversion system to remain at this point by comparing it with the actual value and feeding this difference to the controller. That, in turn, changes the speed of the generator to reduce this error. The optimal point of **t**he TSR can be determined experimentally or theoretically and stored as a reference. Although this method seems simple as wind speed is directly and continuously measured, a precise measurement for wind speed is impossible in reality and increases the cost of the system. The block diagram of the tip speed ratio control method is shown in Figure.5.1.3

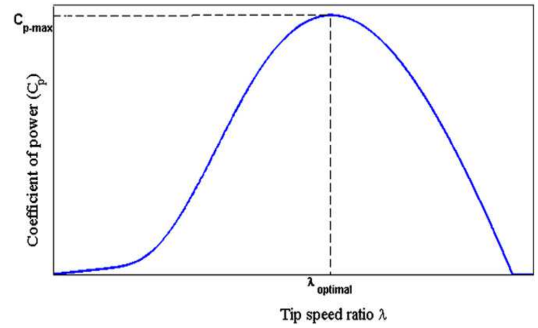

Figure 5.1.1 The characteristic of the power coefficient as a function of tip speed ratio

The amount of power produced by a wind turbine is expressed as

$$P_T = 0.5 c_p \rho A V^3$$

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

$$\lambda = \frac{\text{Tip speed of blade}}{\text{Wind speed}}$$

The tip speed of the blade can be calculated as ωtimes R, where $\omega$is the rotor rotational speed in radians/second, and R is the rotor radius in meters. Therefore, we can also write:

$$\lambda = \frac{\omega R}{v}$$

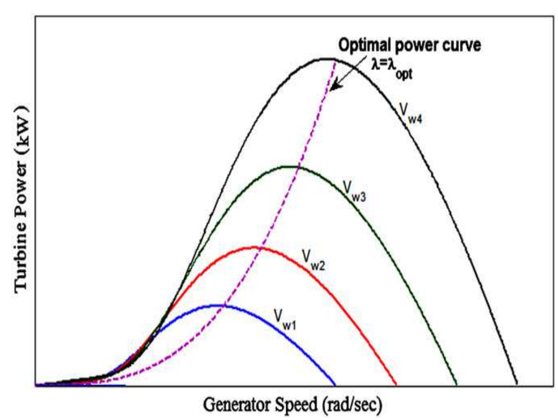

Figure 5.1.2. Characteristics of turbine power as a function of the rotor speed for a series of wind speeds.

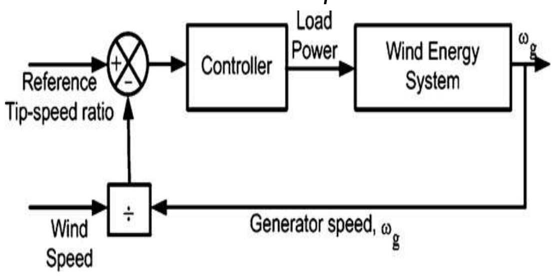

Figure 5.1.3. The block diagram of the tip speed ratio control

5.2 Optimal torque (OT) control

As mentioned previously, maintaining the operation of the system at _opt ensures the conversion of available wind energy into mechanical form. It can be observed from the block diagram, rep-resented in Figure 5.2.1, that the principle of this method is to adjust the PMSG torque according to a maximum power reference torque of the wind turbine at a given wind speed. For the turbine power to be determined as a function of λ and ωm.

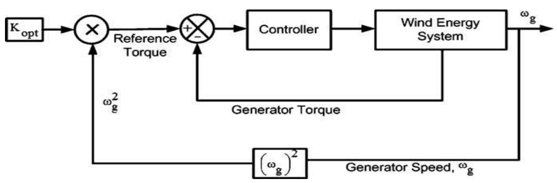

Figure. 5.2.1. The block diagram of optimal torque control MPPT metho

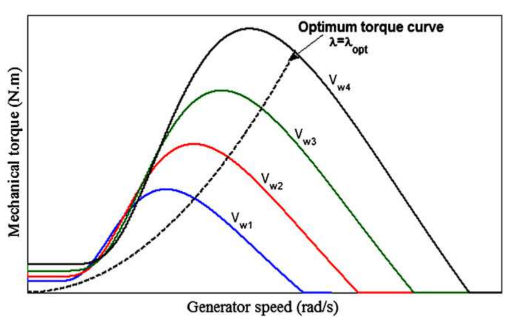

Figure 5.2.2. The torque–speed characteristic curve for a series of wind speeds

5.3 Power signal feedback (PSF) control

The block diagram of a wind energy system with power signal feedback (PSF) control is shown in Fig. 8. Unlike the OT control, in this method the reference optimum power curve of the wind turbine (Figure 5.3.1) should be obtained first from the experimental results.

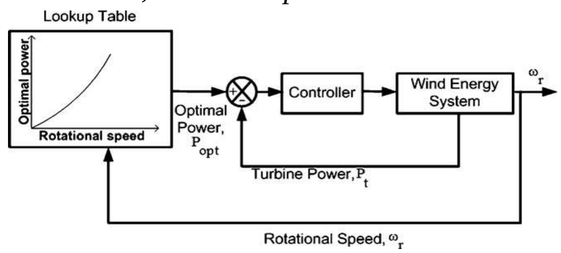

Fig. 5.3.1. The block diagram of a wind energy system with the power signal feedback control technique

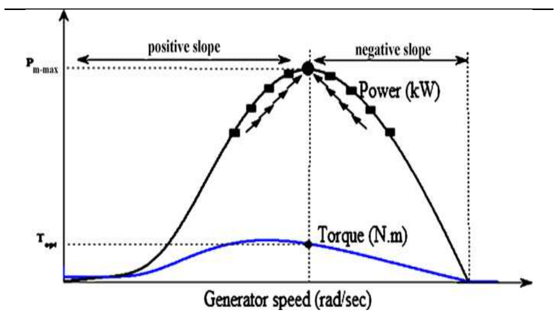

Fig. 5.3.2. Wind turbine output power and torque characteristics with MPP tracking process

6. CONCLUSION

Maximum Power Point Tracking is an important technique for efficiently harnessing the wind power. Selection of the right control strategy is significant to ensure that the system performs optimally. Techniques based upon the knowledge of wind turbine characteristics, that is, Torque, Speed and Power Signal Feedback based methods provide a simple way of obtaining maximum wind power where the manufacturer or by experimentation, the turbine characteristics have been provided. This discussed the available MPPT algorithms for wind energy systems.

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