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MPPT Algorithms: Extracting Maximum Power from Wind Turbines

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Abstract: This paper proposes a new Maximum Power Point Tracking (MPPT) algorithm employed in Wind Energy Conversion Systems (WECS). One of the major issues concerning HCS is its inefficiency in detecting the peak power when there is a change in wind ·speed. In addition, the HCS produces oscillations in delivered power once this peak is detected. A modified HCS algorithm is proposed in this paper to overcome these limitations. This algorithm employs a variable duty cycle to reduce the oscillations in delivered power once the peak power is detected.

Keywords: HCS, MPPT, PMSG, TSR, WECS.

I. INTRODUCTION

Even though renewable energy is a good substitute for conventional sources, there is some scepticism associated with their performance and cost. Engineers have been working to address these concerns. 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. This has led to control algorithms referred to as MPPT algorithms. These aids wind and solar energy conversion systems in extracting the maximum available power for a given wind and solar resource. This paper analyses conventional methods of MPPT in wind conversion systems, including the popular Hill Climb Search (HCS) method. A new adaptive control algorithm for MPPT has been proposed.

II. WIND POWER SYSTEM

A. Physics of Energy Extraction from Wind

The power carried by a flowing mass of air that is called wind is the product of the cross-sectional area of the mass and the wind, the density of the wind, ρ, and the wind speed, v. Wind Power:

$$P_0 = \frac{1}{2}\rho A V^3 (Watts) \quad (1)$$

Where, ρ is the air density *(kg/m^3)* and v is the wind speed *(m/s).* The air density is proportional to the air temperature and the air pressure, both of which vary with height above sea level. The power in the wind cannot be completely converted to mechanical energy of a wind turbine. The theoretical maximum of energy extraction from wind was discovered by Betz in 1926, and is written as:

$$P_0 = \frac{1}{2}\rho A V^3 C_P = \frac{1}{2}\rho A V^3 0.59 \quad (2)$$

According to Betz, even if no losses occurred a wind turbine could utilize only 59% of the wind power. In addition when unavoidable swirl losses are included, this figure reduces to about 0.42. This happens to be observed as the current limit of well-designed turbines today.

B. Variable Speed Wind Turbine

Original models of wind turbines were fixed speed turbines; that is, the rotor speed was a constant for all wind speeds. The tip-speed ratio for a wind turbine is given by the following formula:

$$TSR = \frac{Linear\ speed\ of\ blade\ outermost\ tip}{Free\ upstream\ wind\ velocity}$$

$$TSR = \frac{\omega . R}{V} \quad (3)$$

Where, ω is the rotor speed (in radians per second), R is the length of a blade, and v is the wind speed. For a fixed-speed wind turbine, the value of the tip-speed ratio is only changed by wind speed variations. In reference to a C_p-λ graph, which illustrates the relationship between Tip-speed ratio and efficiency, it is evident that only one value of λ yields the highest efficiency. That is, the fixed speed wind turbine does not operate at peak efficiency across a range of wind speeds. This was why variable speed wind turbines were developed. Since tip-speed ratio is given by the aforementioned expression, variable speed wind turbines can operate at maximum efficiency over all wind speeds (ideally). Below is an illustration of the C_p- λ curve for a typical wind turbine.

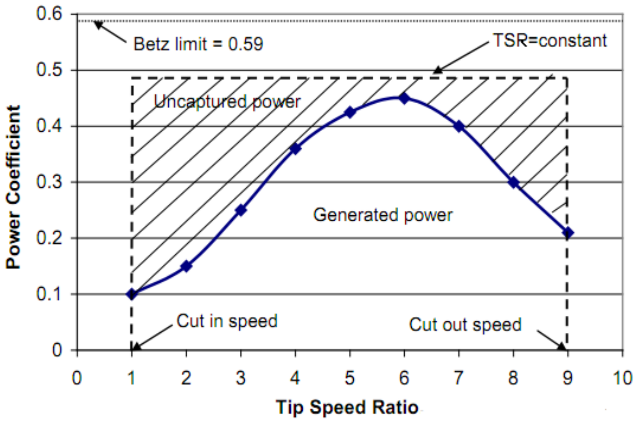

Fig. 1: Power coefficient as a function of tip speed ratio.

Variable speed configurations provide the ability to control the rotor speed as they often have a power electronic converter stage between the turbine and grid, as shown in Fig. 2. This allows the wind turbine system to operate constantly near to its optimum tip-speed ratio.

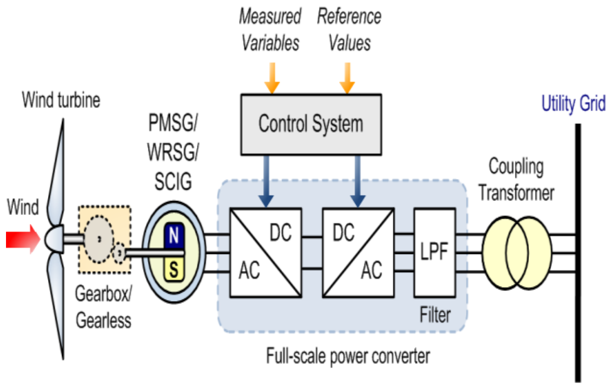

Fig. 2: Basic block diagram of WTG connected to converter.

The following advantages of variable-speed over constant-speed can be highlighted:

- The Annual Energy Production (AEP) increases because the turbine speed can be adjusted as a function of wind speed to maximize output power. Depending on the turbine aerodynamics and wind regime, the turbine will on average collect up to 10% more annual energy.

- The mechanical stresses are reduced due to the compliance to the power train. The turbulence and wind shear can be absorbed, i.e., the energy is stored in the mechanical inertia of the turbine, creating a compliance that reduces the torque pulsations.

- The output power variation is somewhat decoupled from the instantaneous condition present in the wind and mechanical systems. When a gust of the wind arrives at the turbine, the electrical system can continue delivering constant power to the network while the inertia of mechanical system absorbs the surplus energy by increasing rotor speed.

Although the main disadvantage of the variable-speed configuration are the additional cost and the complexity of power converters required to interface the generator and the grid, its use has been increased due the above mentioned advantages.

III. MAXIMUM POWER PONT TRACKING ALGORTIHMS

The following section describes the various conventional methods of MPPT in WECS.

A. Hill Climb Search (HCS) method

HCS method of MPPT makes use of the inverted U shaped graph between power and rotor speed. As there is a definite peak power corresponding to a particular rotor speed, the algorithm compares the present power at an instant to the power obtained at the previous step. If the power is found to be increasing, then the duty cycle of the gating pulse applied to the converter switches are increased to drive the operating point more towards the peak power. If the power is found to be decreasing, then the duty cycle is reduced. The primary advantage of this method is its simplicity and independence from wind turbine characteristics. A severe limitation of the HCS method is its inability to track the maximum power point in cases of abruptly varying wind conditions. In normal HCS methods the increments/decrements given to the duty cycle are fixed.

B. Tip Speed Ratio (TSR) ratio

TSR method tries to modify the rotational speed of generator so as to maintain an optimum TSR. The limitation of this method is that wind speed needs to be known along with the turbine rotational speed measurements. This adds to the system cost, especially when considered for use with small-scale wind turbines.

C. Power Signal Feedback (PSF)

PSF method uses a reference power, which is the maximum power at that particular wind speed. This in itself presents an issue, as the prior knowledge of the wind turbine characteristics and wind speed measurements is required. Once this reference power is obtained from the power curve for a particular wind speed, a comparison with the present power yield is done. The error produced then drives a PI control algorithm. PI control refers to Proportional (P), Integral (I) control. It has a P and I part that are manipulated to reduce the error between a known set point and the instantaneous values of the measured values (here power).

IV. PROPOSED ALGORITHM

Due to the nature of wind energy systems, the power available from the wind turbine is a function of both the wind speed and the rotor angular speed. The wind speed being uncontrollable, the only way to alter the operating point is to control the rotor speed. Rotor speed control can be achieved by using power electronics to control the loading of the generator. Without any given knowledge of the aerodynamics of any wind turbine, the HCS principle searches for the maximum power point by adjusting the operating point and observing the corresponding change in the output. The HCS concept is essentially an "observe and perturb" concept used to traverse the natural power curve of the turbine. With respect to wind energy systems, it monitors the changes in the output power of the turbine and rotor speed. The maximum power point is defined by the power curve in Fig. 3 where $\Delta P/\Delta\omega = 0$.

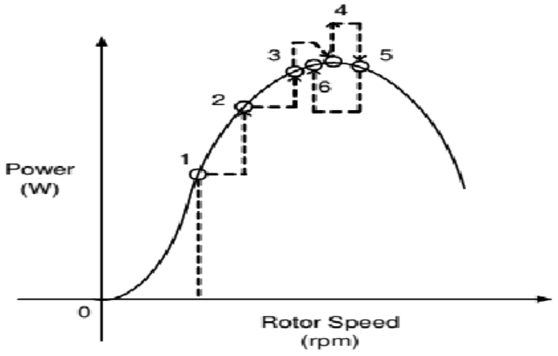

Fig. 3: Wind power curve for an arbitrary wind speed.

Thus, the objective of HCS is to 'climb' the curve by changing the rotor angular speed and measuring the output power until the condition of $\Delta P/\Delta\omega = 0$ is met. There are several different ways of implementing the HCS idea. In this paper, the algorithm generates the reference speed by measuring the output power of the wind energy conversion system and adjusts the system's operating point accordingly. The $\Delta P/\Delta\omega = 0$ condition is achieved when $\Delta P \approx 0$ because the amount of adjustment in the rotor speed is chosen to be proportional to the change in power; thus when ΔP, $\Delta\omega \approx 0$. The flowchart of proposed algorithm is as shown in Fig. 4.

The system begins at point 1 and chooses to increase the rotor speed to point 2. Observing that there has been an increase in power due to an increase in speed, the algorithm signals to further increase the rotor speed to point 3. Since $\Delta P/\Delta\omega$ is positive, the system is 'climbing' up the power curve. With $\Delta P/\Delta\omega$ still positive, the system continues to increase the rotor speed to point 5. The algorithm notices that the change in power from point 4 and point 5 is negative, and it was due to an increase in speed. With $\Delta P/\Delta\omega$ now negative, the optimum point has been passed. As a result, the rotor speed is decreased to point 6. The slope of the power curve diminishes as the system approaches the peak power point (level of extracted power is less sensitive to the change in rotor speed). Therefore, it follows that as the operating point moves closer to the maximum power point (point (4)), the magnitude of the speed adjustment should be smaller. The algorithm will oscillate and eventually settle at the maximum power point (which is defined to be where $\Delta P/\Delta\omega = 0$).

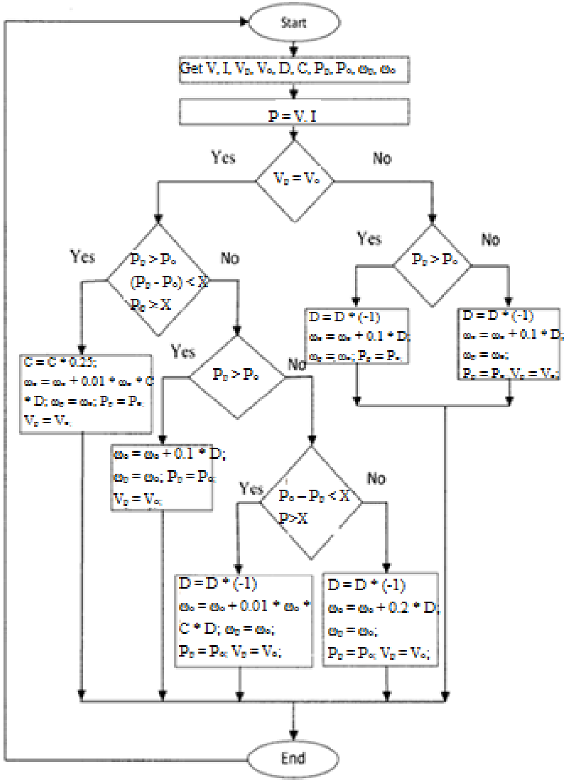

Fig. 4: Flowchart of proposed algorithm.

V. CONCLUSION

With rising concerns over rising energy prices, depletion of natural resources and pollution, environmentally friendly energy resources like wind energy are becoming more prominent. Wind energy is inexhaustible, safe, has no harmful by products and is capable of supplying substantial amounts of power. The unpredictable availability of wind however, only allows it to become a secondary source of power. In order to harness as much power from the wind as possible while it is available, intelligent control strategies must be implemented. With technological advancements in wind turbine aerodynamics and power electronic interfaces, wind energy can be considered to be an excellent renewable supplementary energy source. Power electronic interfaces and intelligent control strategies make wind energy viable and attractive despite its intermittent availability. In this paper, an algorithm has been designed and developed to enable maximum power transfer under fluctuating wind conditions. Various algorithms and control schemes that attempt to extract the maximum power from the wind were studied and presented. The study identified the main problems in existing maximum power point extraction algorithms, and then used them as guidelines for the algorithm design. The main problems are customization, speed, and wasted power. A wind turbine does not naturally operate at its most efficient operating point, and due to the shape of wind turbine power curves, a significant amount of wind power can be left unharnessed. As a solution to these problems, the proposed algorithm uses a modified version of an established concept known as the hill climb search (HCS) algorithm.

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BIOGRAPHY

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