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Modeling And Simulation Of Hill Climb Search Method For Maximum Power Point Tracking As Applied To Wind Energy Conversion System

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Abstract— Wind energy systems are taken into consideration because of its advantages as pollution free, reliable and renewable source of energy. Because of its unpredictable availability, difficult in power management concepts and complex circuitry, it becomes essential to extract as much power as possible from the wind when it becomes available. The Hill climb search algorithm allows the generator to track the maximum power point of the wind turbine system under fluctuating and varying wind conditions and the tracking process speeds up over time. The algorithm uses its memory to find optimum rotor speed for given wind turbine and to infer maximum power. The algorithm uses a modified version of Hill Climb Search (HCS) and memory to implement this very important power management scheme as applied to wind energy conversion system. This algorithm is suitable for smaller grid or battery connected wind energy conversion systems.

Keywords: HCS; MPPT; WECS; Converters;

I. INTRODUCTION

Renewable energy is energy generated from natural resources—such as sunlight, wind, rain, tides, and geothermal heat—which are renewable (naturally replenished). Renewable energy sources have a great potential to generate electricity as they are abundant in nature, cost-effective and also cause a little harm to the nature. Wind energy has been developed rapidly as one of the best sources for electricity generation over the last few decades. Large wind turbines are complex in operation, deploy multitude of control methods and operate mainly in grid-connected mode. On the other hand, small wind turbines can be used for standalone as well as grid-connected applications. Due to the increasing concern about the environment and the depletion of natural resources such as fossil fuels, researchers are now started focusing on obtaining new environ-mentally friendly sources of power i.e wind energy. To preserve our planet and sources of energy for the future generations, natural renewable sources are being closely studied and analyzed as per our energy needs.
Wind energy is environmentally friendly, inexhaustible, safe, and capable of supplying substantial amounts of power. However, due to wind's erratic nature, unpredictable behavior, intelligent control strategies are needed to extract maximum power from wind energy as possible while it is available. Because of its advantages, erratic nature, and recent technological advancements in wind turbine aerodynamics and advancement in power electronic converters, now wind energy is considered to be an excellent supplementary energy source. Research to extract the maximum power out of wind energy is an essential part of making wind energy much more viable and attractive.

Problems with Non-Renewable Energy Sources

Non-renewable energy sources are being depleted at a rapid rate these days. If this continues, the earth will be completely exhausted of all its natural energy reserves within a few years.
Renewable energy is energy generated from natural resources—such as sun light, wind, rain, tides, and geothermal heat—which are renewable.

II. WIND ENERGY CONVERSION PRINCIPLES

The classical equations of kinetic energy and power describe the potential energy that can be harnessed from the wind. The kinetic energy available from wind is described by E_k. By classical physics theory, to translate kinetic energy into the power, energy is divided by time; thus the power from the kinetic energy is given by

$$E_k = 0.5mv_w^2 = 0.5\rho A d v_w^2 \text{ ....(1.1)}$$

$$P_w = \frac{0.5\rho A d v_w^2}{t} = 0.5\rho A v_w^3 \ldots\ldots\ldots\ldots\ldots\ldots(1.2)$$

Where ρ= air density, A= rotor swept area, d= distance, m= mass of air=air density* volume= $\rho * A * d$and $v_w = \frac{distance}{time}$

With the theoretical power available in wind established by above equations, the power extracted by wind turbines must be taken care of first since it is the first and foremost element of any wind energy conversion system (WECS). The aerodynamic efficiency of the turbine while converting wind into usable electrical power is described by its power coefficient, Cp, curve. The physical meaning of the Cp curve is the ratio of the actual power delivered by the turbine and the theoretical power available in the wind. A turbine's efficiency, and thus power coefficient curve, is what differentiates one turbine from another. By taking the efficiency of the turbine into account, (1.3) represents the mechanical power captured by the wind by any turbine. [1] [2]

$$p_m = 0.5\rho A C_p(\lambda, \beta) v_w^3 \qquad (1.3)$$

Where Cp(λ, β) = power coefficient function, _ λ = the tip speed ratio, and β = Pitch angle

It can be observed that the power available in the wind is proportional to the cube of the wind speed. This means that there is much more energy in high speed winds than in slow winds. Also, since the power is proportional to the rotor swept area, and thus to the square of the diameter, doubling the rotor diameter will quadruple the available power. Air density also plays a role in the amount of available mechanical power of the turbine; lower air densities (e.g. warm air) results in less available power in wind. The power coefficient function, Cp (λ, β), is dependent on two factors: i) the tip speed ratio (λ), and ii) the pitch angle (β). This function is normally provided (in the form of a curve) by the wind turbine manufacturer since it characterizes the efficiency of its wind turbines. If this curve is not provided, then it can be obtained by performing field tests. The power coefficient can be evaluated by

$$C_p(\lambda, \beta) = \frac{\text{actual turbine power}}{\text{theoretical Power}} = \frac{P_m}{P_w} = \frac{P_m}{0.5\rho A v_w^3}$$

The power characteristic of a typical wind turbine (this curve illustrates (1.3). The trajectory labeled Pmax represents the maximum points on the power curves

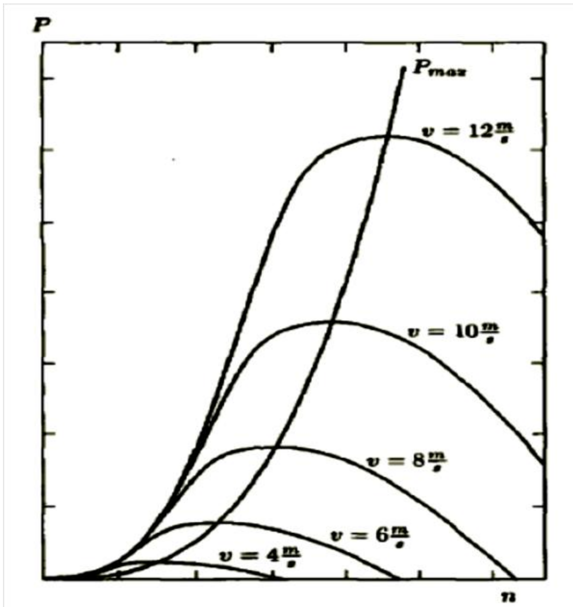


Fig. 2.1 Maximum power point Curve

The trajectory labeled Pmax gives the maximum power points on the power curves. These power curves also characterize the shape of the torque curve which is characterized by the power coefficient (Cp). As a result, the peak torque will also correspond to a particular rotor speed. Because the torque is the mechanical power divided by a constant gear ratio and the angular speed of the turbine, the shape of the curve is very similar to the power curve. Their peaks however, do not correspond to the same rotor speed. Therefore, the rotor speed that gives maximum torque does not correspond to the rotor speed that gives maximum power.

III. Concept of Maximum Power Extraction

Normal wind energy conversion is relatively straight forward process, but in order to capture the maximum power from the wind, the process is much more involved. It can be observed from Figure 2.1 that the maximum of the power curve, for a particular wind speed, occurs at a particular rotor speed. Due to the aerodynamic characteristics of a wind turbine, a small variation from the optimum rotor speed will cause a significant decrease in the power extracted from the wind. Turbines do not naturally operate at the optimum wind speed for any given wind velocity because its rotor speed is dependent on the generator loading as well as the wind speed fluctuations. Because of this, non-optimized conversion strategies lead to a large percentage of wasted wind power. The more energy extracted from the wind, the more cost effective the wind energy becomes. Due to the aerodynamics of a wind turbine (dictated by the Cp function), the same turbine angular speed for different wind speeds will result in different levels of extracted power. Cp,max for a fixed pitched wind turbine corresponds to one particular TSR value Because the TSR is a ratio of the wind speed and the turbine angular rotational speed, the optimum speed for maximum power extraction is different for each wind speed [6], but the optimum TSR value remains the same. The power and torque characteristics illustrated by Figure 4.1(a) and (b) are similar to the characteristics of typical fixed pitch wind turbines. [3]

Fixed-speed wind turbine systems will only operate at its optimum point for one wind speed. So to maximize the amount of power captured by the turbine, variable-speed wind turbine systems are used because they allow turbine speed variation [6][7]. MPPT algorithm assesses the wind conditions and then forces the system to adjust the turbine's rotational speed through power electronic control and will manage the speed of of rotor of wind energy conversion system to extract the maximum out of it. The primary challenge of wind energy systems is to be able to capture as much energy as possible from the wind is to reduce the time by which algorithm converge to find out the optimum speed at which the system extract the maximum power out of wind energy. From the electronics side, this purpose can be solved by either choosing different converter topologies or by choosing different maximum power point tracking (MPPT) algorithms.[9]

Algorithm Concept and Features

Algorithm used is hill climb search method along with intelligent memory and power management to track the maximum power points of wind energy systems under varying wind conditions. The main problems in existing power extraction methods are:

(i) customization, (ii) speed, (iii) wasted power.

The algorithm implemented in matlab provides a solution to these problems. In order to avoid the customization problems in some of the existing algorithms, the proposed technique does not require the basic characteristics of the turbine to implement the algorithm rather , the algorithm uses a general way to obtain the maximum power point. As it does not involve the basic wind turbine characteristics for its operation, the algorithm can be easily used for a wide range of wind turbines. The algorithm gives the fairly good estimation through feedback concept to obtain the rotor speed at which the rotor of WECS should rotate to extract the maximum power. The observations and estimations allow the system to immediately operate near to the maximum power point, where the change in speed corresponds to small changes in power. Due to this small waste in power speeds up the estimation processes which is much needed for efficient algorithm. When the operating point is closer very less number of iterations are used for determination of maximum power point. The power available from the wind turbine is a function of both the wind speed and the rotor angular speed. When the wind speed changes in an uncontrollable way then the only way to shift the operating point to the maximum power point position is to change the wind speed by using some reliable algorithm. The change is rotor speed is achieved using power electronics converter hysteresis controller etc. [4][5]

The Hill climb search algorithm does not need any aerodynamics or design parameter of the wind turbine used it only searches for the maximum power point by adjusting the operating point and observing the corresponding change in the output. The power curve of wind energy conversion system is shown in fig 2.1for different wind speed. It shows the power extraction will be different at different speed and for each curve we have a maximum power point which is going to come at certain speed and by using the algorithm we are going to estimate that speed and change the rotor speed by controller.. The maximum power point is defined by the power curve in Fig. 3.1 where $dP/dw = 0$. 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 $dP/dw = 0$ is met.

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 $dP/dw = 0$ condition is achieved when $dP \approx 0$ because the amount of adjustment in the rotor speed is chosen to be proportional to the change in power; thus when $dP/dw \approx 0$. The system begins at point 1 and chooses to increase the rotor speed to point 2. Observing that 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 dP/dw is positive, the system is 'climbing' up the power curve. With dP/dw 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 dP/dw 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, dP/dw → 0). 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.

IV. MODELLING AND SIMULATION

Static Model

Equations that represent the static behavior of the WT are :

$$\lambda = \frac{w_r r_r}{v_w}$$

$$C_p(\lambda, \beta) = C_1\left(\frac{C_2}{\lambda} - C_3\beta - C_4\right)e^{-\frac{C_5}{\lambda_1}} + C_6\lambda$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1}$$

$$P = 0.5rAC_P v^3$$

THE POWER COEFFICIENT FUNCTION, $C_P(\lambda)$, IS DEPENDENT ON TWO FACTORS: THE TIP SPEED RATIO (λ) AND THE PITCH ANGLE (Β).

The power coefficient can be evaluated by,

$$C_p(\lambda, \beta) = \frac{P_m}{P_w} = \frac{P_m}{0.5PAv_w^3}$$

For a variable-speed turbine, the objective is to operate near maximum efficiency, where the resulting target power can be expressed as shown in Equation

$$TSR = \frac{wR}{V}$$

$$P_{target} = 0.5rAC_{ptarget}\left(\frac{R}{TSR_{Target}}\right)^3 w^3$$

$$\tau_m = \frac{1}{2}\rho A r_r v_w^2 C_m$$

Rotor Power characteristics in MATLAB
The mechanical power on the rotor

$$P_R = C_p \frac{1}{2}\rho A V_w^3$$

$$c_p(\lambda, \beta) = C_1\left(C_2\frac{1}{\lambda_i} - C_3\beta^x - C_5\right)e^{-C_6\frac{1}{\lambda_i}} + 0.0068\lambda$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{1 + \beta^3}$$

$$c_1 = 0.5176, c_2 = 116, c_3 = 0.4, c_4 = 5, c_5 = 21 and\ c_6 = 0.0068.$$
$$If: \beta = 0$$

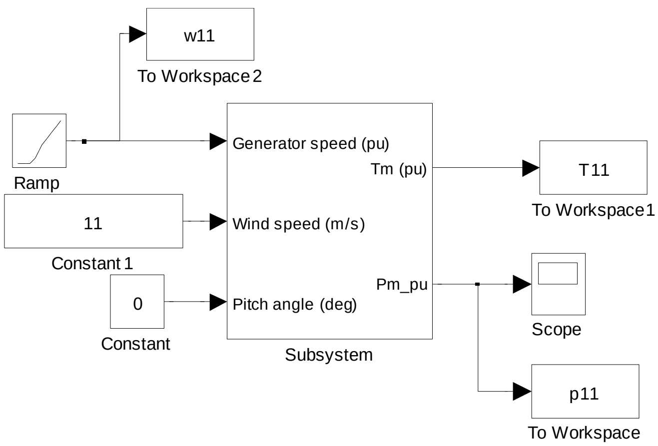
$$C_P(\lambda, \beta) = 0.5176\left(\frac{116}{\lambda_i} - 5\right)e^{-\frac{21}{\lambda_i}} + 0.068\lambda$$

$$C_p(\lambda, \beta) = \left(\frac{60.0416}{\lambda_i} - 4.7026\right)e^{-\frac{21}{\lambda} + 0.7350} + 0.0068\lambda$$

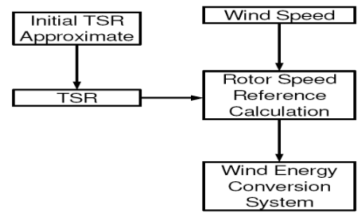
$$e^{0.7350} = 2.0855$$

$$C_P(\lambda,\beta) = \left(\frac{125.2156}{\lambda_i} - 9.80\right) e^{-\frac{21}{\lambda}} + 0.0068\,\lambda$$

Wind Turbine Simulation
Data Used: blade pitch angle ß = 0 degree, base wind speed = 12 m/s, maximum power at base wind speed = 0.73 pu (kp = 0.73) and base rotational speed = 1.2 pu).



Hill Climb Search
Algorithm Implemented in MATLAB



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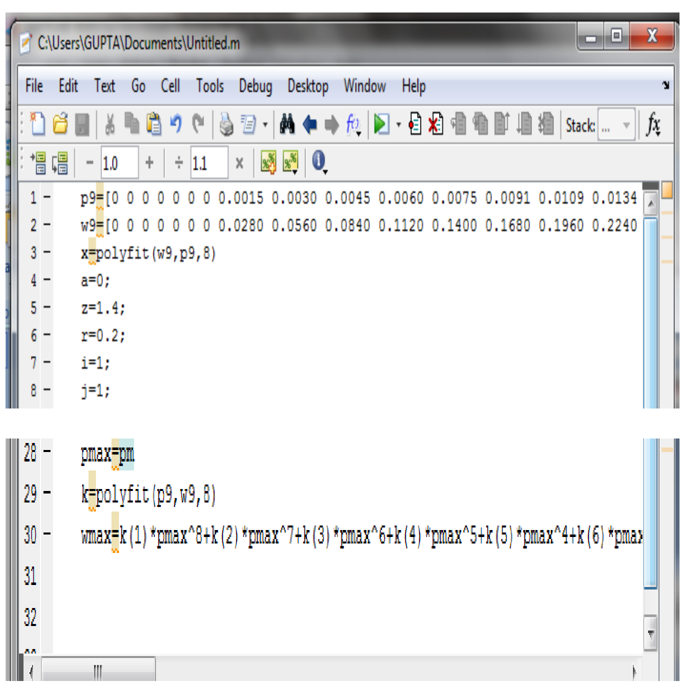

Fig 4.2 Hill climb search algorithm implemented in MATLAB

Output:
pmax = 0.4222, wmax = 0.8798

V. CONCLUSION

This paper provides knowledge on the wind energy market, turbine technology, and energy conversion. The main purpose of this paper is to design and develop an algorithm to enable maximum power extraction under fluctuating wind conditions. The main problems of wind energy conversion systems 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 unutilized. As a solution to these problems, the hill climb search algorithm (HCS) algorithm is implemented in matlab and being tested for maximum power point extraction in set of data points and after doing the simulation the algorithm written is able to find the rotor speed as per the set of data which gives maximum power from the wind speed given..

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