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***Abstract*—This paper proposed novel Hill Climbing Search (HCS) algorithm to reach maximum power point tracking (MPPT). The proposed algorithm used two main techniques; the first one is power prediction mode and the second one is the two-mode HCS algorithm. The latter is used to achieve the maximum possible power from Wind Energy Conversion System (WECS) with better efficiency, faster convergence speed and using only two-mode (more simple) to avoid the iteration and delay. Moreover, novel algorithm not requires any prior knowledge of WECS and it's considered absolutely independent of Wind Turbine (WT) generator. The simulation results confirm that the proposed algorithm is remarkably faster by 30 % of the total time required comparing to the mode HCS and more efficient due to simplicity.**

Keywords—maximum power point tracking (MPPT), hill climbing search (HCS), wind turbine (WT), wind energy conversion system (WECS)

I. INTRODUCTION

Hill Climbing Search (HCS) algorithm or perturbing and observing (P&O) is considered the simplest Maximum Power Point Tracking (MPPT) technique [1-4]. In addition, HCS algorithm does not require any prior knowledge of regime or any additional sensor except the measurement of power which is subjected to maximization. Thus, HCS can be applied to any Wind Energy Conversion System (WECS) that exhibits a unique power maximization. HCS algorithm brings operating point in the curve to ward power coefficient Cp by decreasing or increasing the perturbing to reach the maximum peak point in the power curve. . In this research, a Permanent Magnet Synchronous Generator (PMSG) has been chosen due to its better reliability as a WECS [5-17].

HCS algorithm MPPT monitors the difference of the rotor Wind Turbine (WT) generator speed and output power reacts on them by adding small decrements or increments to the rotor speed reference. This technique eliminates the utilize of an anemometer for wind speed and the employ of any experimental wind speed data or theoretical data about the WT. The main problem of the HCS traditional algorithm is to reach the maximum power point on the curve or peak point location [18-20]. It will keep searching by constantly changing always the rotor speed reference. Therefore, this will make hysteresis around the peak point a rotor speed fluctuation [8, 10, 12, 14, 21-25].

In this paper, a new algorithm based on wind speed data is proposed. The new algorithm depend on power prediction mode and used two-mode for detect maximum peak point. Power generation process depends on wind speed due to the cubic proportional between power and wind speed. Average wind speed reflects to the rotor speed due to this relation. Therefore, the total output power is proportional with rotor speed[26-30].

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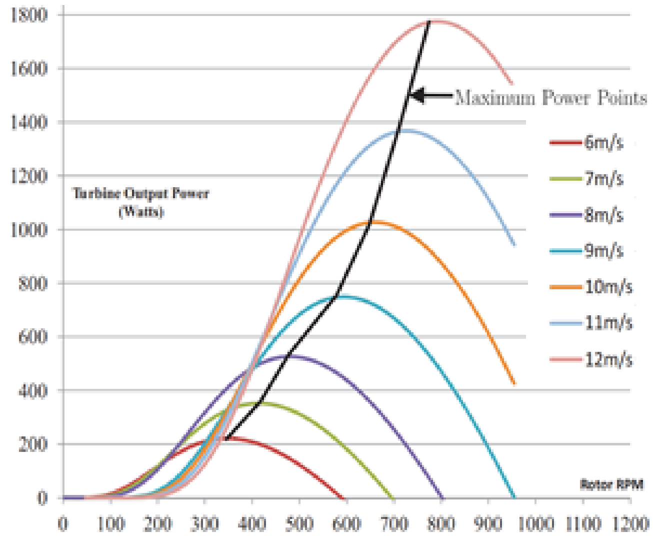

Fig. 1. Turbine output power versus rotor at varying wind speed[27].

Figure 1 presents the rotor speed versus output power for each wind speed; there is a maximum output amount of power that the WT could extract if WT operated at the rated rotor speed (optimum speed) ω_{opt}. The optimum rotor speed value ω_{opt} can reached at the optimum tip speed ration TSR λ_{opt}. In order to collect maximum possible power from the WT, WT must be turned on at optimal TSR λ_{opt}. This case of operation is possible by controlling the rotational speed of the WT that it always turns on at the optimum or rated speed[31, 32].

Utilizing equation 1 and 2, the maximum power out or the target output power of the WT can be expressed as in the following equation.

$$P_{\max} = K_{opt}\omega_{rop}^{3} \tag{1}$$

Where, K_{opt} is an optimum wind written by equation 2.

$$K_{opt} = \frac{0.5\pi\rho C_{p\max} R^{5}}{\lambda_{opt}^{3}} \tag{2}$$

Where, C_{pmax} is the power coefficient of the WT, this value is the maximum value at maximum point of power curve. Where ω_{opt} is given by the following equation.

$$\omega_{opt} = \frac{\lambda_{opt}\upsilon_{\omega}}{R} \tag{3}$$

Consequently, the controller for the MPPT tries to turn on the WT at the rated or optimum speed $\omega_{opt}$for each wind speed, v_w mean wind speed. Therefore, to reach the maximum peak point depends upon the parameters value and controller algorithm type[33].

II. PROPOSED NOVEL ALGORITHMS TO REACH MPPT

In this research the HCS algorithm had been developed to avoid the time delay of the iteration to reach the maximum peak point on the curve. Therefore, increased the power efficiency for the WECS. There are two main part of the proposed novel algorithm the first part is power prediction mode and the second is two-mode HCS algorithm.

A. *Power Prediction Mode*

In this part wind distribution had been divided into several areas to avoid the iteration in calculations to reach the decision in the algorithm based on wind speed. Therefore it can reach to maximum power point in short period of time.

B. *Two-Mode HCS Algorithm*

Three-mode algorithm is very complicated due to the large number iteration process for same equation of ω^* as shown in mode number 0 and mode number 1. The three-mode HCS algorithm had been combined to simplified the iteration process . Thus it can reach the decision for the MPPT without any delay time because wind speed changes very fast. very complicated due to iteration for same equation of ω^* .

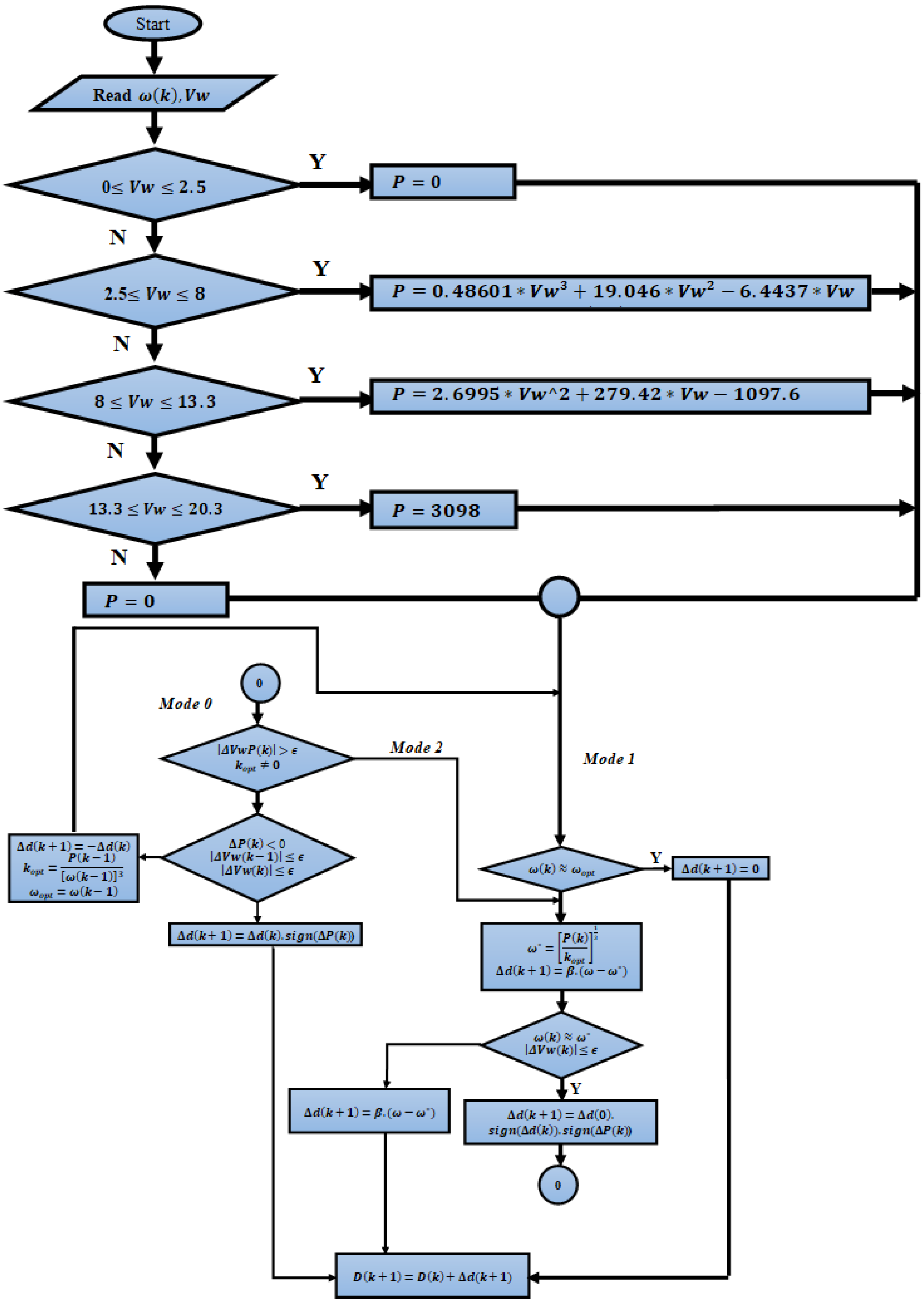

Fig. 2. Flowchart of the proposed novel HCS algorithm

The author illustrates the two-mode algorithm as shown in figure 2 .The main aim of the novel algorithm is to increase power efficiency, avoid the trade-off between the speed detection and accuracy of tracking process. The new algorithm has been enhanced to avoid the large number of iterations for calculation to reach maximum peak point and the time delay. Wind speed is divided in reference ranges in order to extract maximum wind energy, in this case whatever the wind speed can easily determine the output power based on wind speed records range. This is a new approach uses an identification method to determine a mathematical function generating the optimal speed reference MPPT. In order to optimize the equations that used in the proposed algorithm, it is essential to divide the wind distribution into several areas. The proposed zones division takes into consideration the distribution trend of the cloud points and the studied system limits. Following these criteria, five areas have been identified[27, 34].

Area1: very low wind speed less than 2.5m/s,

Area2: Wind speed between 2.5m/s and 8m/s,

Area3: Wind speed between 8m/s and 13.3 m/s,

Area4: Wind speed between 13.3m/s and 20.3m/s and

Area5: Wind speed more than 20.3m/s.

III. SIMULATION FOR WECS MODEL WITH NOVEL HCS ALGORITHM

A WT model had been implemented using Simulink Matlab. The WT converts the power of the wind to mechanical power this is the main function of the rotor shaft for the WT. The next stage is converted to electricity utilizing a PMSG. PMSG feeding the three-phase diode bridge rectifier whose output voltage in DC , the output DC voltage is controlled via a DC/DC boost converter. The boost DC/DC converter was controlled at the DC link to obtain maximum power from the WECS into the DC grid

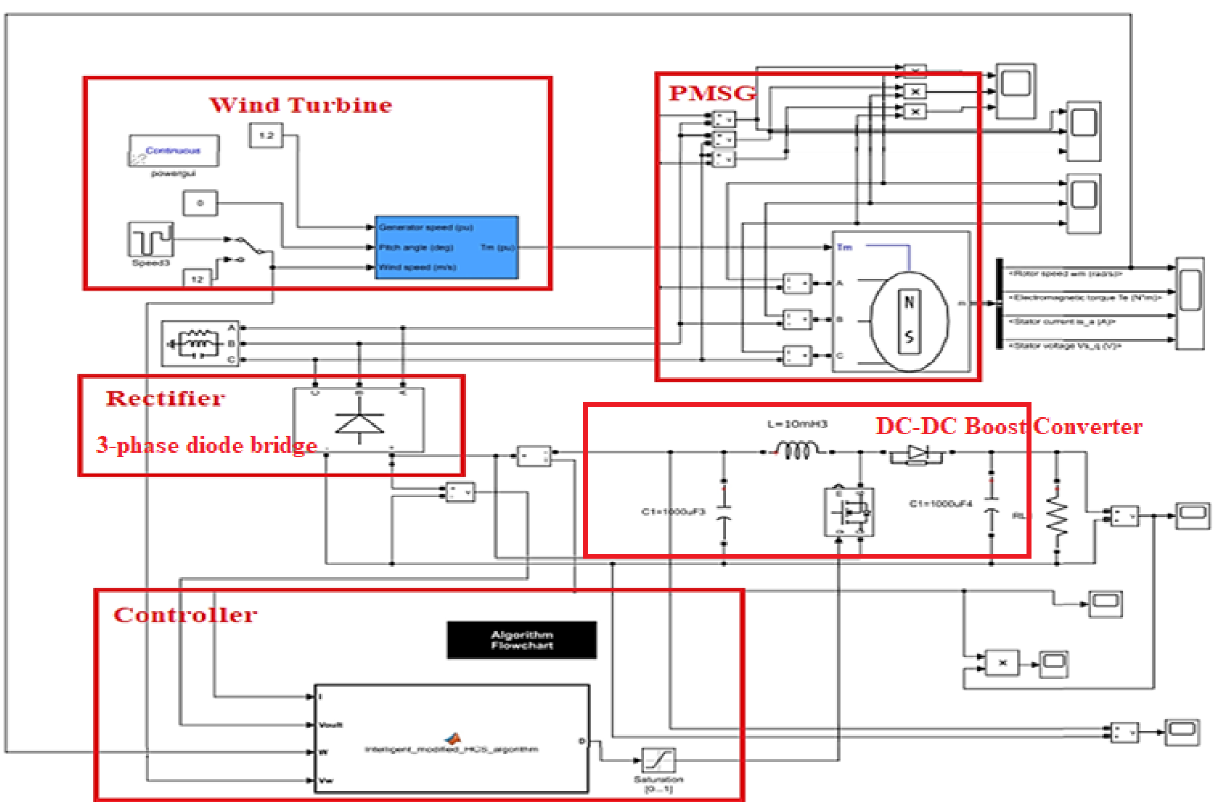

Fig. 3. Wind turbine with PMSG and boost DC/DC converter simulink model

WECS model had been developed using Matlab Simulink which as shown in Figure 3.There are five main blocks in WECS model which as PMSG, three phase diode bridge rectifier DC-DC boost converter and controller. Where, rotor speed unit is (rad/s), Generator speed (pu) per unit based on the nominal speed of the generator, wind speed (in m/s), blade pitch angle (in degrees), nominally β kept at 0 as pitch angle control. The implementation model consisting of a PMSG driven by WT was interfaced to the DC link through a three phase diode bridge rectifier and DC/DC boost converter.

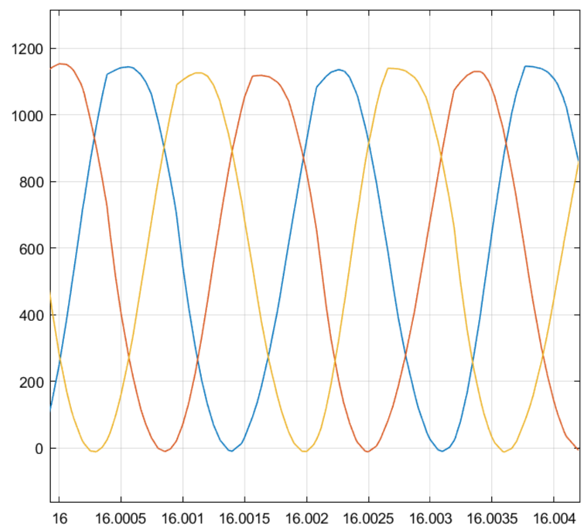

Fig. 4. Zoom of generator power output at t= 16 s

Figure 4 presents the output power for PMSG, it can be seen wind generator reaches to its maximum peak point at a wind speed after 15 m/s. The electric power and rotor speed are sampled every 3 seconds after a new rotor speed reference is set. The frequency of the PMSG generator is equal to 50 Hz. The simulation results of the WECS with HCS novel algorithm zoomed for three phase AC stator current and voltage and AC output power. The three-phase stator voltage is changing heavily because of the action of controller. Therefore, If the turbine has to speed up, the generator torque will be set to zero so the electric power will become zero to avoid damage the wind turbine component. If the wind turbine needs to slow down, the torque of the wind generator will be limited to reach its rated value, which clarifies the flattening of the tops in the curve especially when wind speed change.

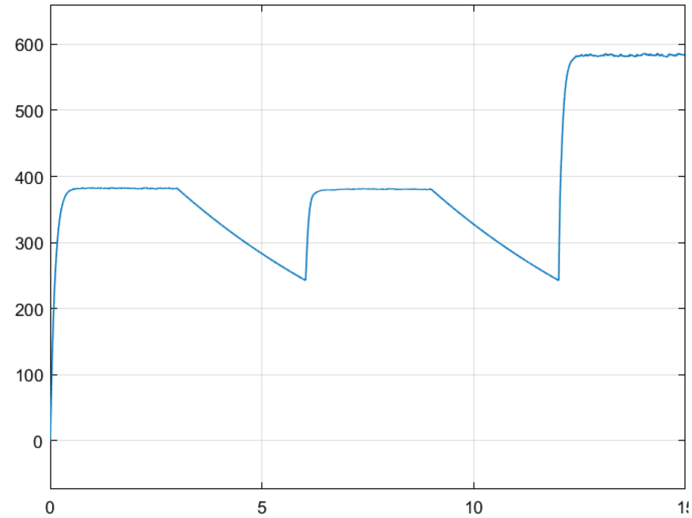

Fig. 5. DC voltage before applying HCS improved algorithm for WECS-PMSG

In Figure 5 it can be seen the DC voltage from the three phase diode rectifier without controller. The voltage decreased based on wind speed change.

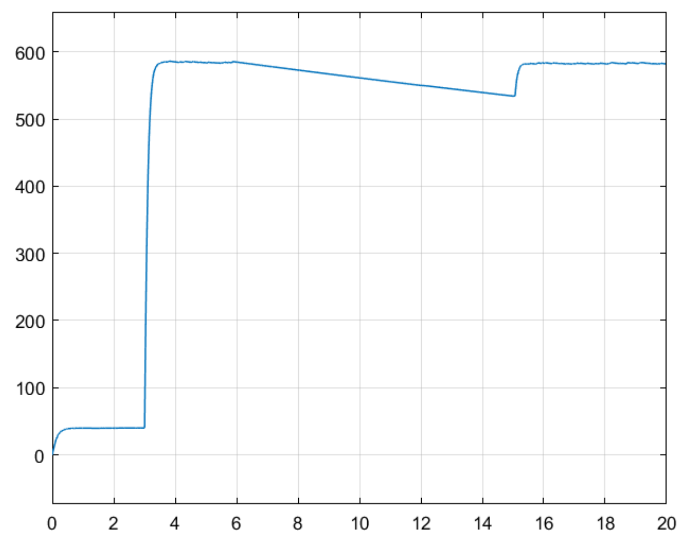

Fig. 6. DC voltage after applying HCS improved algorithm for WECS-PMSG

Figure 6 shows the performance of the proposed MPPT algorithm under mixed wind profile with six variation point. The new algorithm is controlled in D duty cycle to control the voltage to reach maximum peak point. Bitch angle is considered constant (β=0, where β is the angle between the chord line and the relative wind vector for the wind turbine) irrespective of wind speed. It's clear from the Figure 5 and

Figure 6 after the rating wind speed the proposed algorithm reached the curve to the maximum point value through the duty cycle.

The performance of the developed algorithm presents fast tracking capabilities. The new improved algorithm can reached to the maximum peak point with minimum calculation which making it simple implementation algorithm and competitive due to combined three-mode to two-mode. The proposed improved algorithm prevents the PMSG from stalling under fast wind speed change by utilizing the wind speed change detection capability through the dc-link voltage information.

IV. CONCLUSION

In this paper power prediction mode technique used to increase the power efficiency of the WECS model. Moreover, the three mode algorithm combined to two main mode to avoid the calculation iteration. The simulation results have illustrated that the novel HCS algorithm has reached the power peak point for all wind speeds without the knowledge of the wind turbine aerodynamic characteristics. The proposed algorithm is remarkably faster by 30% of the total time required comparing to the three-mode algorithm due to simplicity and used power prediction mode based on wind speed to avoid the time delay to reach the maximum power point in the power curve. The novel algorithm shows fast tracking capability and enhanced stability under both low and high rate of change wind speed conditions and is verified using Simulink.

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