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MODIFIED HILL CLIMB SEARCHING METHOD FOR TRACKING MAXIMUM POWER POINT IN WIND ENERGY CONVERSION SYSTEMS

Farzia Karim [1], Md. Faruk Hossain[2] and Md. Shah Alam[2]

[1]Asian Institute of Technology (AIT), Thailand.
[2]Department of EEE, RUET, Bangladesh

ABSTRACT
This work presents a solution to the problems that exist in the conventional hill climb searching (HCS) maximum power point tracking (MPPT) method in wind energy conversion systems (WECS). The proposed solution not only solves the tracking speed versus control efficiency trade-off problem of HCS but also makes sure that the changing wind conditions do not lead HCS in the wrong direction. This method does not require the knowledge of intangible turbine mechanical characteristics such as its power coefficient curve, power characteristic or torque characteristic. For this an adaptive control algorithm has been used which performs self-tuning to cope with the non-constant efficiencies of the generator–converter subsystems and can work robustly under changing wind conditions. In addition, a smart speed-sensorless scheme has been developed to avoid the use of mechanical sensors for cost and reliability consideration.

Keywords: Hill Climb Searching (HCS) Method, Maximum Power Point Tracking, WECS.

1. INTRODUCTION
As briefly reviewed in [1], several maximum power point (MPP) tracking (MPPT) algorithms for the wind energy conversion system (WECS) can be found in the literature. Among these algorithms, the hill climb searching (HCS) control happens to be the one that does not require any prior knowledge of the system and is absolutely independent of the turbine, generator, and wind characteristics. Also, it can work independently in conjunction with variable-pitch control, whereas the rest of the methods have to be reprogrammed for every change in pitch angle. Therefore, the HCS control bears the potential to be the most appropriate choice for MPPT, but there are two serious problems with HCS which significantly deteriorate its performance under rapidly changing wind conditions. These two problems are the speed–efficiency tradeoff and the wrong directionality under rapid wind change, as explained in Section 2.

2. PROBLEMS IN THE CONVENTIONAL HCS CONTROL

2.1 Perturbation Step Size and Speed Efficiency Tradeoff
As shown in Fig 1., a larger perturbation step size increases the speed of convergence but deteriorates the efficiency of the MPPT [2] by amplifying the oscillations, ΔPmpp around the MPP. This is due to the fact that the HCS control does not halt at MPP because it does not possess a peak detection capability, and hence, the oscillations are an unavoidable attribute of the HCS control. A smaller step size boosts the efficiency, but then, the convergence speed becomes slower; therefore, the controller may become incapable of tracking MPP under rapidly varying wind conditions. Hence, in the conventional HCS control, a tradeoff always exists between the tracking speed and the control efficiency.

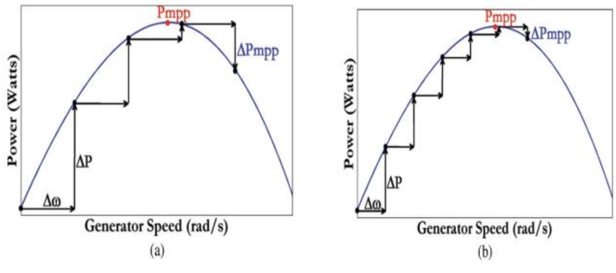

Fig 1.Size of Δω perturbation in (a) is larger than that in (b). Hence, the tracking speed in (a) is faster than that in (b) but oscillations around MPP is larger in (a) than (b)

2.2 Perturbation Direction under Wind Change
In the normal HCS control method, the direction, i.e.,

the sign of the next perturbation, is decided by the increase or decrease in power due to the previous perturbation. Since the HCS control is blind to the atmospheric changes, this rule can be misleading, as the sign might be dictated by the change in wind rather than the applied perturbation. This wrong decision leads to the failure in keeping track of MPP, and the HCS control moves downhill, as shown in Fig. 2. Of the two problems discussed previously, the latter one is of major concern because it significantly deteriorates the energy extraction from the renewable source and hence greatly affects the overall input–output efficiency of the system.

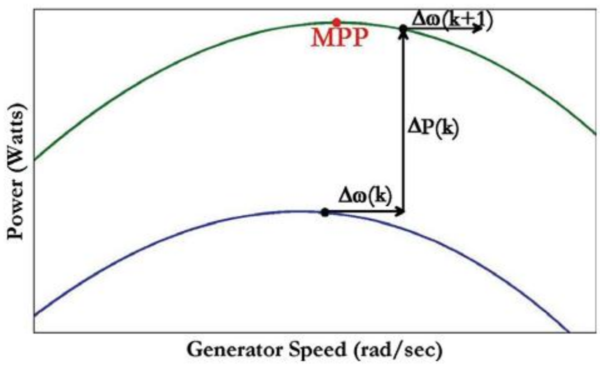

Fig 2 HCS control losing its tractability under changing wind conditions and traveling downhill instead of climbing uphill

3. MATHEMATICAL MODELLING OF A WIND ENERGY TURBINE

There are three main equations that describe the wind turbine system. The turbine mechanical power, the turbine mechanical torque and the turbine's tip-speed ratio is described by (1.1), (1.2), and (1.3) respectively [3].

$$P_m = 0.5\rho AC_p(\lambda,\beta)V_w^3 \qquad (1)$$

$$t_m = p_m \frac{R}{G\lambda V_w} \qquad (2)$$

$$\lambda = \frac{R\omega_b}{V_w} \qquad (3)$$

Where, ρ = air density, A = rotor swept area, $C_p(\lambda,\beta)$ = power coefficient function (which is dependent on λ, the tip speed ratio and pitch angle, β), V_w = wind speed, and G = gear ratio between the turbine shaft and the generator rotor shaft.

4. PROPOSED MPPT ALGORITHM

4.1 Principle

The adaptive control MPPT algorithm proposed in this paper exploits the fact that a constant-pitch variable-speed wind turbines mechanical power P_m has a unique optimal power curve P_{opt} which exhibits a cubic function of the generator speed ω [4]. Therefore, the optimal curve of a wind turbines mechanical power is characterized by a unique constant k_{opt}, as given below

$$P_{opt} = k_{opt}\omega^3 \qquad (4)$$

During the normal hill climbing, if we happen to reach the maximum and detect it successfully, then we can extract k_{opt} simply by measuring the corresponding power and rotational speed. A point to be noted here is that the MPPT techniques found so far in literature do not have the peak detection capability under varying wind conditions. A set of checks are given here to formulate a robust yet very simple peak detection under varying wind conditions. Once the peak is detected and k_{opt} is extracted, the latter can then serve as an accurate reference for the size and the direction of the next perturbation. Fig. 3 shows an illustration of this idea—with a known optimal curve, if the operating point lies on its right, like A, the next perturbation would be in the direction of decreasing ω in order to move the operating point closer to the optimal curve. Also, the size of the step can be determined through the measure of how far the operating point lies from the optimal curve.

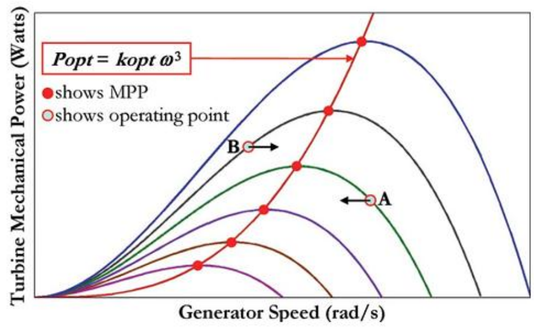

Fig.3. P_m–ω curves for various wind speeds and the optimal curve that passes through the MPPs. The arrowheads on the operating points A and B show the desired direction of perturbation.

It gives a very effective solution to both the problems stated in Section 2 because now, regardless of the wind change, the operating point lying anywhere, like A or B in Fig. 3, will always move toward the optimal curve. This eradicates the loss of tractability under changing wind conditions. Also, it should be mentioned that the farther the operating point from the optimal curve is, the larger the perturbation size for faster tracking will be. However, as it converges into the optimal curve, the perturbation size will automatically approach zero, thus eliminating the speed–efficiency compromise of HCS.

4.2 Optimal P_o versus Optimal P_m

The principle presented previously is actually not straight forward to implement. The existence of a unique k_{opt}, on which the proposed method fully depends, is associated with the captured mechanical power Pm, whereas the power being actually measured and subjected to maximization is the output electrical power P_o supplied to the load. In order to extend the proposed MPPT principle to P_o, it is necessary that P_o should also have a unique optimal curve for all wind speeds. This can be investigated by considering the relationship of the optimal curve constants ($(k_{opt})_m$ and $(k_{opt})_o$ of P_m and P_o, respectively, via generator efficiency η_g and converter efficiency η_c, given in steady state as

$$P_o = \eta_g \eta_c . P_m \Rightarrow (k_{opt})_o = \eta_g \eta_c .(k_{opt})_m \qquad (5)$$

Equation (5) implies that the key to the existence of a unique optimal P_o–ω curve for various wind speeds lies in a very important question whether the generator–converter efficiencies are constant or they vary with wind velocity, rotor speed, and load variations. But, the overall efficiency of a WECS is not constant under wind and load variations [5]. With the non-constant efficiency of WECS, we can infer two very important conclusions:

1) There does not exist a unique optimal curve constant kopt for P_o

2) The maximum of the P_o–ω curve does not coincide with the peak of the P_m–ω curve.

4.3 Methodology

An adaptive control algorithm has been used which performs self-tuning to cope with the non-constant efficiencies of the generator–converter subsystems. It operates in three different modes [5]. Mode 0 searches for a k_{opt} with HCS via a novel peak detection capability. Mode 1 retains the system at the detected maximum, unless there is a change observed in wind velocity V_w.

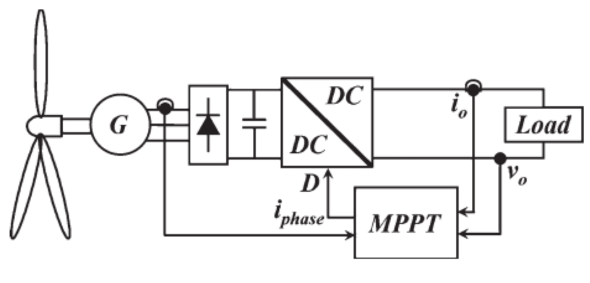

Fig.4 Schematic diagram of WECS

Mode 2 gets into action under changing wind conditions and implements the adaptive hill climbing via the earlier found k_{opt}. This may not yield the true MPP, but still, it drives the operating point in the close vicinity of the true peak power. Therefore, this strategy is quite useful for fast tracking [5]. Here, the control input is the duty ratio D of the converter which is driven by the MPPT controller, as also shown in Fig. 4.

4.4 Detecting Wind Change

Here, ΔV_w is not measured through an anemometer; instead, a novel sensorless scheme is used. Its working principle is based on the three fundamental properties of WECS which can be formulated as

$$|\omega(k) - \omega(k-1)| \le \varepsilon \qquad (6)$$

$$\text{sgn}(\Delta d) = \text{sgn}(\Delta \omega) \qquad (7)$$

$$\Delta P(k) < 0 \quad \Delta P(k-1) < 0 \qquad (8)$$

Therefore, a wind change will be signaled either if (6) is not true or if any one of (7) and (8) is true.

5. GENERATOR SPEED SENSORLESS SCHEME

The measurement of the generator speed is essential not only to implement the adaptive hill climbing proposed method but also to detect the wind changes. Using a mechanical sensor for this purpose will not only increase the cost of the system but also always have maintenance issues and cannot be used for a long run. Therefore, a very smart sensorless scheme has been used as shown in Fig. 5 that simply takes into account the cyclic nature of the generator phase current whose frequency is directly proportional to the speed of the generator.

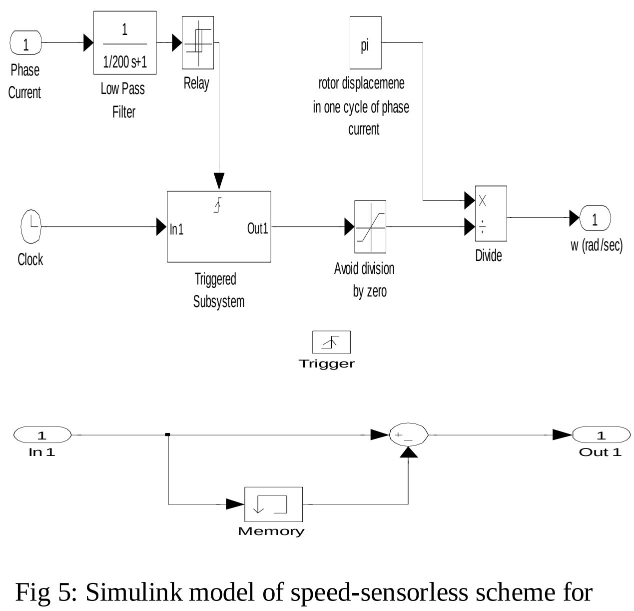

Fig 5: Simulink model of speed-sensorless scheme for estimating generator speed.

The generator speed can be estimated simply by knowing the number of rotor poles p and measuring the time lapse Δt between two rising zero crossings (one complete cycle) of the generator phase current. The rotor displacement between these two zero crossings would be 2π/p. Hence, the speed can be estimated as

$$\omega = \frac{2\pi / p}{\Delta t} \qquad (9)$$

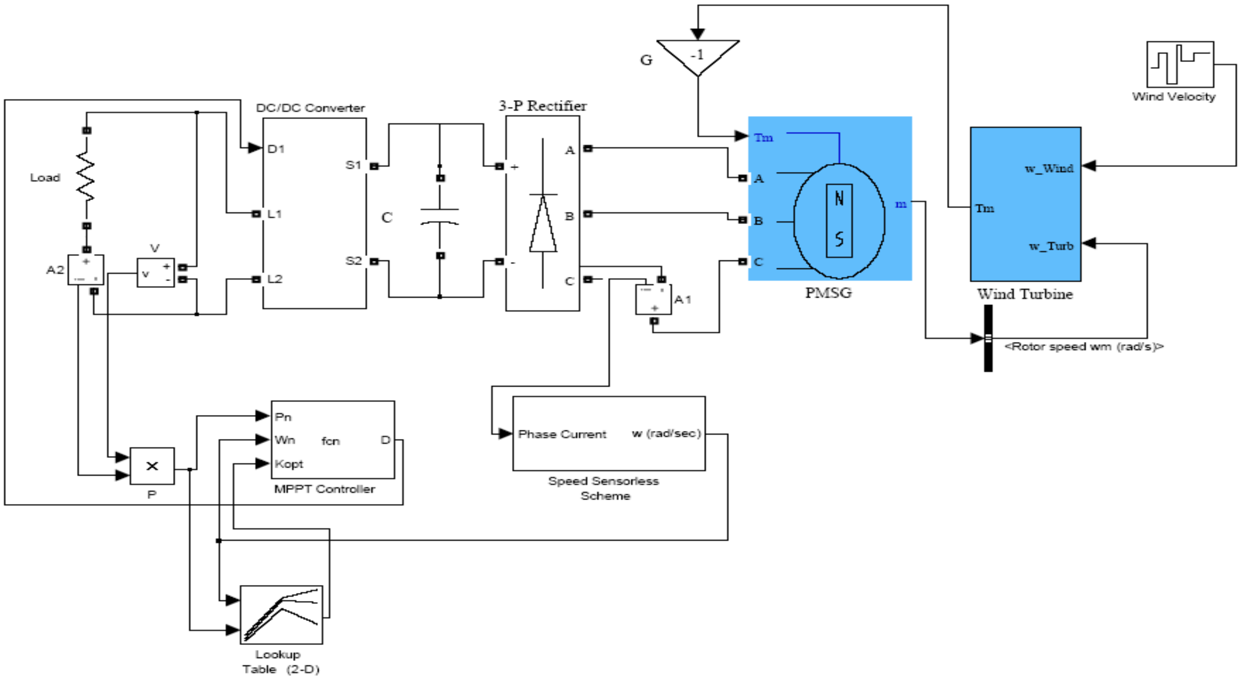

Fig 6 Simulink Model of Designed WECS Based on Control Algorithm

6. DESIGN OF WECS FOR MPPT BASED ON CONTROL ALGORITHM

The Simulink model is the complete designed WECS based on the adaptive control algorithm is shown in Fig 6. Here, the permanent magnet synchronous generator (PMSG) is used for the variation of wide range of wind speed. PMSG is coupled with wind turbine. Wind speed is given in the wind turbine as input which is the simulated wind profile. The output ac voltage of PMSG is converted to dc by a rectifier and a capacitor is used to reduce the ripple. A DC-DC convertor is used to step up or step down this output voltage in the desired level. This DC-DC converter is nothing but a buck-boost converter. The output power of the converter is given as an input of the maximum power point tracking (MPPT) controller. The output of the speed sensorless scheme i.e. generator speed is another input of the MPPT controller. Another input of the MPPT controller is Kopt which is given to the controller from a 2-D look-up table calculated from the wind turbine modeling equation. The output of the MPPT controller is the converter duty ratio, D. Based on the adaptive control algorithm a MATLAB code is given in the MPPT controller. According to the given controlled program, the MPPT controller controls its input values in the desired level and thereby provide output i.e. the converter duty ratio, D in such a way that it can track maximum power point in wind energy conversion system (WECS) accurately.

7. SIMULATION RESULTS

The simulated wind profile i.e. the wind speed is given to the wind turbine of the designed WECS according to Figure 6 is shown in Figure 7. Fig 8 shows mechanical power, P_m has a unique optimal power curve

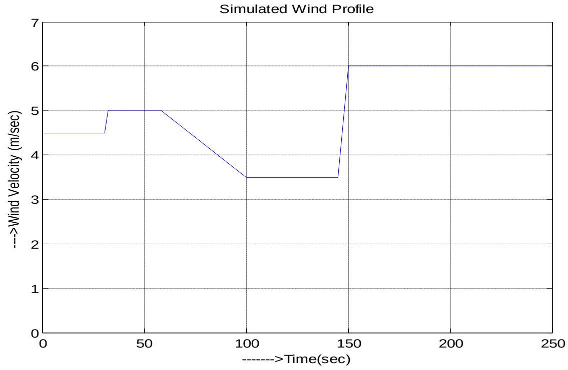

Fig 7. Simulated Wind Profile

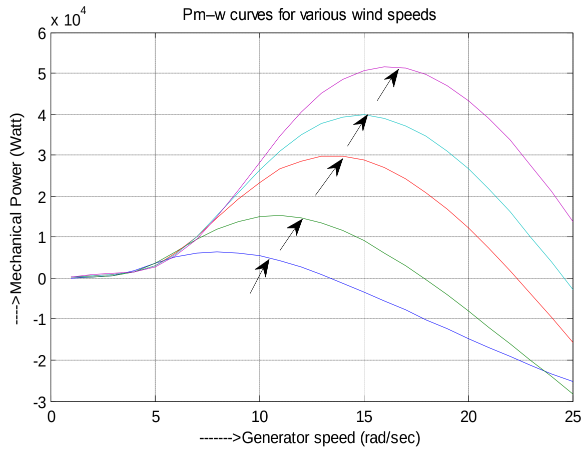

Fig 8. Unique Optimal P_m–ω curves at different wind speed

for different wind speeds. Fig. 9 shows the output electrical power curves at different wind speed which clearly imply the non-uniqueness of *k*opt. Furthermore, Fig 10 shows the P_o–ω curve in comparison with P_m–ω curve, and shows that their maxima do not coincide.

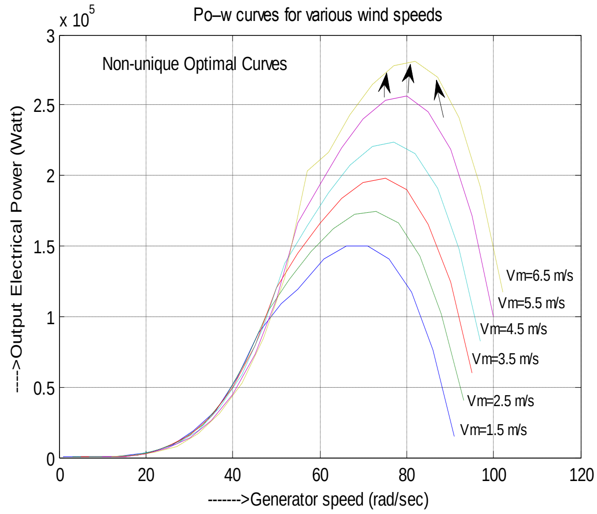

Fig 9. Non-unique Optimal P_o–ω curves at different wind speeds

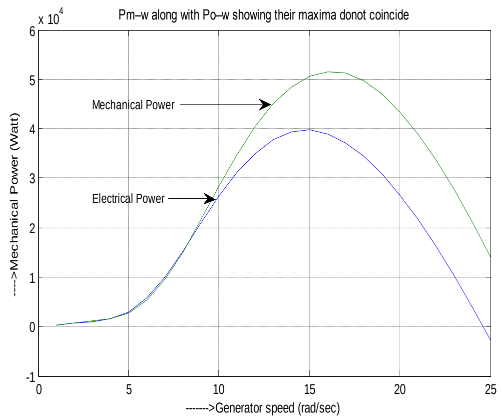

Fig 10. P_o–ω drawn along with P_m–ω, showing that their maxima do not coincide

Fig 11. Estimated Speed by designed Sensor-less Scheme

Now, the sensor-based system is carried out on the simulated wind profile shown in Fig 7. The new adaptive HCS algorithm has been compared with the conventional HCS operating at the same step size as that in Mode 0. Fig. 12 shows the tracking results of the two algorithms subjected to the simulated wind profile of Fig. 7. Fig.11 confirms the excellent performance of the speed estimator. Fig. 12 clearly shows the remarkable boost in MPPT with the new adaptive control algorithm as compared with conventional one.

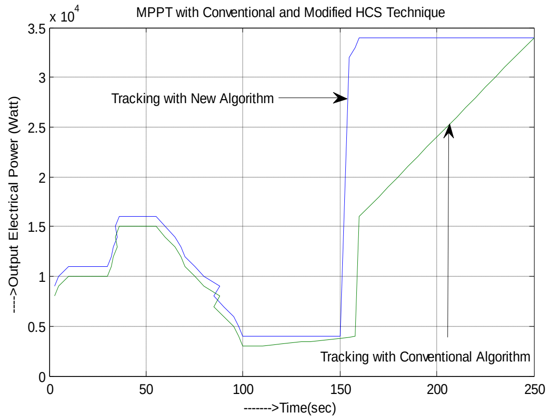

Fig 12. MPP tracked by Conventional and Modified HCS Technique

8. CONCLUSION

A complete simulink model of WECS has been designed in this paper which eradicates the problems that exist in the conventional hill-climbing MPPT technique. For this an adaptive control algorithm [5] and a simulink model of speed sensorless scheme has been used. The simulation results confirm that the proposed modified HCS method is very fast and efficient as compared with the conventional HCS MPPT technique.

9. REFERENCES

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10. NOMENCLATURE

Symbol	Meaning	Unit
P_m	Mechanical Power	(KW)
P_o	Electrical Power	(KW)
A	Rotor Swept Area	(m^2)
λ	Tip Speed Ratio	No unit
ρ	Air Density	(kg/m^3)
$C_p(\lambda, \beta)$	Power Coefficient	No unit
V_w	Wind Speed	(m/sec)
R	Radious of the Turbine	(m)
G	Gear Ratio Between the Turbine Shaft and the Generator Rotor Shaft.	No unit
t_m	Mechanical Torque	(N/m)
ω_b	Rotor Angular Speed	(rad/sec)
η_g	Generator Efficiency	No unit
η_c	Converter Efficiency	No unit

11.MAILING ADDRESS

Farzia Karim
Master's Student
Asian Institute of Technology (AIT)
Thailand