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A NEW EFFICIENT MPPT FOR WECS IN TROPICAL COUNTRIES

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ABSTRACT

This paper proposes a novel solution to the problems exist in the conventional HCS MPPT algorithm for the WECS. The proposed finding not only solves the tracking speed Vs Control efficiency problems but also makes sure variable wind conditions do not lead HCS in wrong direction. It intelligently adapts variable step size to keep up with rapid change in wind and seizes the perturbation at the maximum at a yield of 100% of control efficiency. The proposed MPPT performs a self-tuning to cope with non-constant efficiencies of Generator-Converter subsystems. In addition, a smart speed-sensor less scheme has been developed to eliminate the use of mechanical sensors. This proposed solution is very efficient the use of mechanical sensors. This proposed solution is very efficient for tropical countries like India under wind changing conditions.

The experimental results confirm that the proposed algorithm is remarkably faster and more efficient than conventional HCS.

KEYWORDS: MPPT, HCS, Speed-sensor less scheme, WECS.

INTRODUCTION

As brief description and reviews [1], several MPPT algorithms for WECS can be found in literature. Although, many algorithms are proposed, the hill climbing search control(HCS) has been that one doesn't require any prior knowledge of the system. HCS is absolutely independent of turbine and Generator, and wind characteristics irrespective of high-speed wind direction nature. Even, it can work without any specific limitations with variable-pitch control, whereas the other methods have to be remodelled for every pitch angle. Therefore, the HCS control must overcome two serious problems under rapidly changing wind Conditions. They are speed-efficiency transaction and wrong directionality under prompt conditions as explained in section II. Only very few research citations address this problem in accordance to Perturb and observe algorithm in photovoltaic (PV) system [3],[6],[8]. However, none of these citations provides a complete and easily implementable solution to aforementioned problems. For example, G.Petrone et al [3], focus on solving the issue of wrong directionality and a formula proposal for the ideal perturbation step size. Conversely, the solution is very complicated and requires the various system parameters. Regarding the speed-efficiency trade-off, the papers[4]-[6] proposing a variable such as duty ratio $D(dP/dD)$ of MPPT controller. Since, these variable step-size schemes provide a false sense of distance from maximum limit under fluctuating environmental conditions.

The Agarwal et al.[7] also uses the slope of power 'P' and Generator speed ' ω ' with respect of variable ' β ', Whose calculation requires turbine's mechanical power knowledge, which is impractical in most system. According to ref[7], the signs of $dP/d\omega$ and $dP/d\beta$ cannot indicate the true operating sector. In addition to Agarwal et al.[8] also suggests additional measurement in the middle of sampling period through which the change in power can be calculated by the MPPT. Unlike the PV system, the output current is a linear function of irradiance, the torque output in WECS is a square of wind velocity. Therefore, a linear change in wind velocity over a sampling period doesn't result in a linear change in power, hence the Lenoll et al. could not be extended to WECS. The sampling period is usually set equal to settling time, hence an intermediate measurement will not be true value.

In the reference [2], the techniques are illustrated in solving the intrinsic problems of HCS, WECS designers tend to use other MPPT techniques which employ the optimal curve characteristics. Such technical proposals are very quick and productive, system-specific and non-variable pitch control aided. Even if the pitch angle is unchanged, still the variable efficiency of Generator-Converter sub system can result deviation in optimum ones. The result provided in [9]-[11], phenomenon resembles quite lookup-table like tables, a unique optimal curve is assumed. The experimental results shows up the output powers are unique less at different wind velocities.

This paper presents a very simple yet very efficient solution to the two problems of HCS by making use of the general optimal curve characteristics. The non-uniqueness can be tailored by integrating a self-tuning capability into the system. This research paper extends the work of Raze et al. [1],[2]. With an indigenous scheme to make the proposed system completely mechanical sensor less analysis, which in [2], based on simulated wind profile, has been carried out here under a real wind profile measured on normal and windy day in India.

PROBLEMS IN CONVENTIONAL HCS CONTROL

Perturbation step size and Speed efficiency Trade-off:

In accordance to ref[3], the figure 1 illustrates larger the perturbation step size increases, the convergence speed. The efficiency gets deteriorates the oscillation ΔP_{mpp} around the maximum power point P_{mpp} . Because of this fact, that the HCS control does not halt at MPP, Peak detection capability is not obtained, the oscillations are an inevitable attribute. A small step-size increases the efficiency but then convergence speed become slower; Therefore the controller may become not sufficient of tracking MPP under rapidly varying wind conditions. Hence, in the existing HCS control, a trade-off always exists between speed and control efficiency.

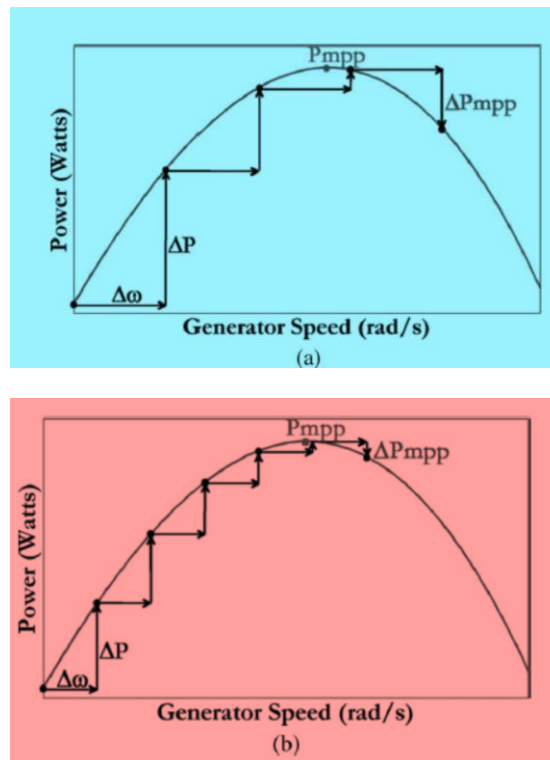


Fig 1: size of $\Delta\omega$ perturbation in (a) is larger than that in (b), so the tracking speed in (a) is larger than (b).

Perturbation Direction and track ability under wind change :

In the normal HCS control method, the direction is declined by the power range setting due to previous Perturbation. Since it depends on the sign given to the Perturbation. This wrong decision leads to the failure in tracking MPP and the HCS control moves downhill, as shown in figure 2.

Of the problems discussed early, the second one is of major concern because it reduces the energy extraction from renewable energy source and hence greatly effects the overall efficiency of the system.

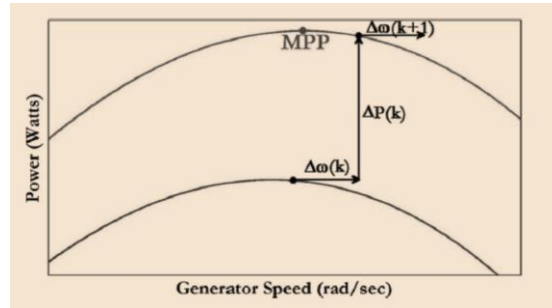


Fig 2: HCS control is losing its tractability under variable wind conditions and travelling downhill.

PROPOSED MPPT ALGORITHM

Principle:

The novel MPPT algorithm proposed in the paper explains the fact that a constant-pitch variable- speed wind turbine’s mechanical power P_m has unique optimal power curve P_{opt} which occurs a cubic function of generator speed ω [9]. Therefore, the optimal mechanical power is characterised by unique constant K_{opt} is expressed as;

$$P_{opt} = k_{opt} \omega^3 \quad (1)$$

In normal hill climbing, if we happen to reach maximum, then we can extract the constant(K_{opt}). This research paper proposes a formula later(3), to formulate a robust yet very simple detection under wind varying conditions.

Once the peak detection is achieved and K_{opt} is extracted the (1) can then serve as an actuator reference for the size and direction of next Perturbation. Figure 3 , illustrates direction of next Perturbation would be in the decreasing order of ‘ ω ’ in way to move the operating point closer to optimal curve.

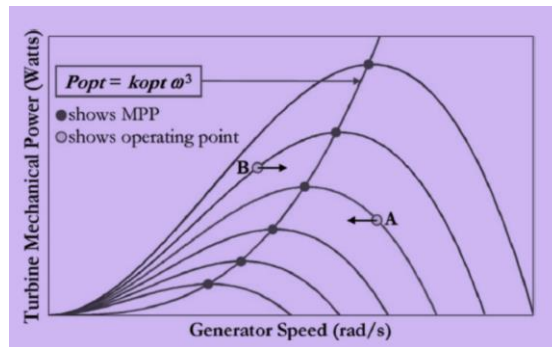


Fig 3: $P_m - \omega$ curves for variable wind speeds and operating points of MPP for various perturbations

This idea includes the core of algorithm presented in the paper. It gives the appropriate way out to both the problems stated in section II, regardless of wind direction change the operating point lies anywhere at A or B. This eliminates the loss of tractability under changing wind conditions. Also it is mentioned that the farther operating point from the optimal curve, the larger the Perturbation size for faster tracking will be. Thus , by eliminating the speed-efficiency compromises, the optimal curve diverges and the Perturbation size will automatically approaches Zero.

Optimal P_o Vs Optimal P_m :

The existence of K_{opt} on which the proposed method fully associated with the captured mechanical power P_m , whereas power is being subjected to maximisation of the supplied power to the load. For the proposed method P_o is necessary and should also have unique optimal curve for all wind speeds. This can be considered by the relationship of optimal curve constant (K_{opt})_m and (K_{opt})_o of P_m and P_o respectively viz generator efficiency (η_g) and (η_c) converter efficiency

$$P_o = \eta_g \eta_c \cdot P_m \quad \longrightarrow \quad (k_{opt})_o = \eta_g \eta_c \cdot (k_{opt})_m \quad (2)$$

There is no significant research work formulating these efficiencies, Usually they are regarded as constants[9]-[11] , which can be most likely be mistaken because the efficiency of generator get worse on increase in phase current.

Therefore the overall efficiency of WECS is not constant under wind and load variations.

Methodology:

A self-tuning strategy is developed in the new intelligent MPPT algorithm.

The flowchart shows three modes of operation: Mode 0, Mode 1, Mode 2

Mode 0:

- i) This mode searches for a K_{opt} with Hill climb search(HCS) via a novel peak detection capability,
- ii) The contrasting feature of this HCS is the checks (3) which ensure that the peak detection should not be misled by the change in wind. MPP is detected when all the following checks are true;
- iii) The first check detects the Zero crossing of ΔP that happens when the HCS crosses over the MPP,
- iv) $\Delta V_{\omega}(k)$ check proposal ensures this check is only provision for peak detection , when the decrease in power is due to wind change instead of MPP crossing,
- v) The important check $\Delta V_{m}(k-1)$, which is necessary even if the current ΔV_{ω} says no wind change. The augmenting check on $\Delta V_{\omega}(k-1)$ will help to retrace the correct MPP.

Once $\Delta V_{m}(k-1)$ becomes true , K_{opt} is calculated through (1) by measuring the power and rotational speed and then the algorithm switches to Mode 1.

$$\begin{aligned} \Delta P(k) < 0 \\ \Delta V_{\omega}(k) = 0 \\ \Delta V_{\omega}(k-1) = 0 \end{aligned} \quad (3)$$

Mode 1:

- i) This mode retains the system at detected maximum, unless there is a change observed in wind velocity V_{ω} ,
- ii) This mode sets the perturbation to zero to retain maxima,
- iii) Once K_{opt} is reached in the close proximity of pseudo-optimal curve ,if there is no significant wind change, then the algorithm switches back again to Mode0 to search for the current wind level,
- iv) The strategy mentioned in (ii) is quite useful for fast tacking,
- v) The system is shifted to mode 2 when the wind change is detected through the change in rotor speed or the drift in output power.

Mode 2:

- i) This mode implements the central theme of the research paper, the adaptive HCS according to stored K_{opt} ,
- ii) This mode gets into action under changing wind conditions and implements the novel adaptive hill climbing via earlier K_{opt} ,
- iii) Mathematically the control law of Mode2 can be formulated as;
 $\Delta d(k+1) = \beta \cdot (\omega - \omega^*)$
Where ω^* is the abscissa of the optimal curve corresponding to power P and β is the positive definite gain,
- iv) Mode 2 is kept in operation until the operating point reaches sufficiently closer to the curve characterised by K_{opt}
- vi) Once, K_{opt} reaches the close proximity of pseudo-optimal curve ,if there is no significant wind change, then the algorithm switches back again to Mode0 to search for the current wind level,
- v) As per fig (4),first check block of Mode 0 , its utility during the self tuning ,when the system switches to Mode 0 from Mode 2 in search of new K_{opt} ... During this search, if a wind change happens , through this check the system immediately resumes the adaptive tracking of Mode2 .Hence the tractability of algorithm is now compromised.

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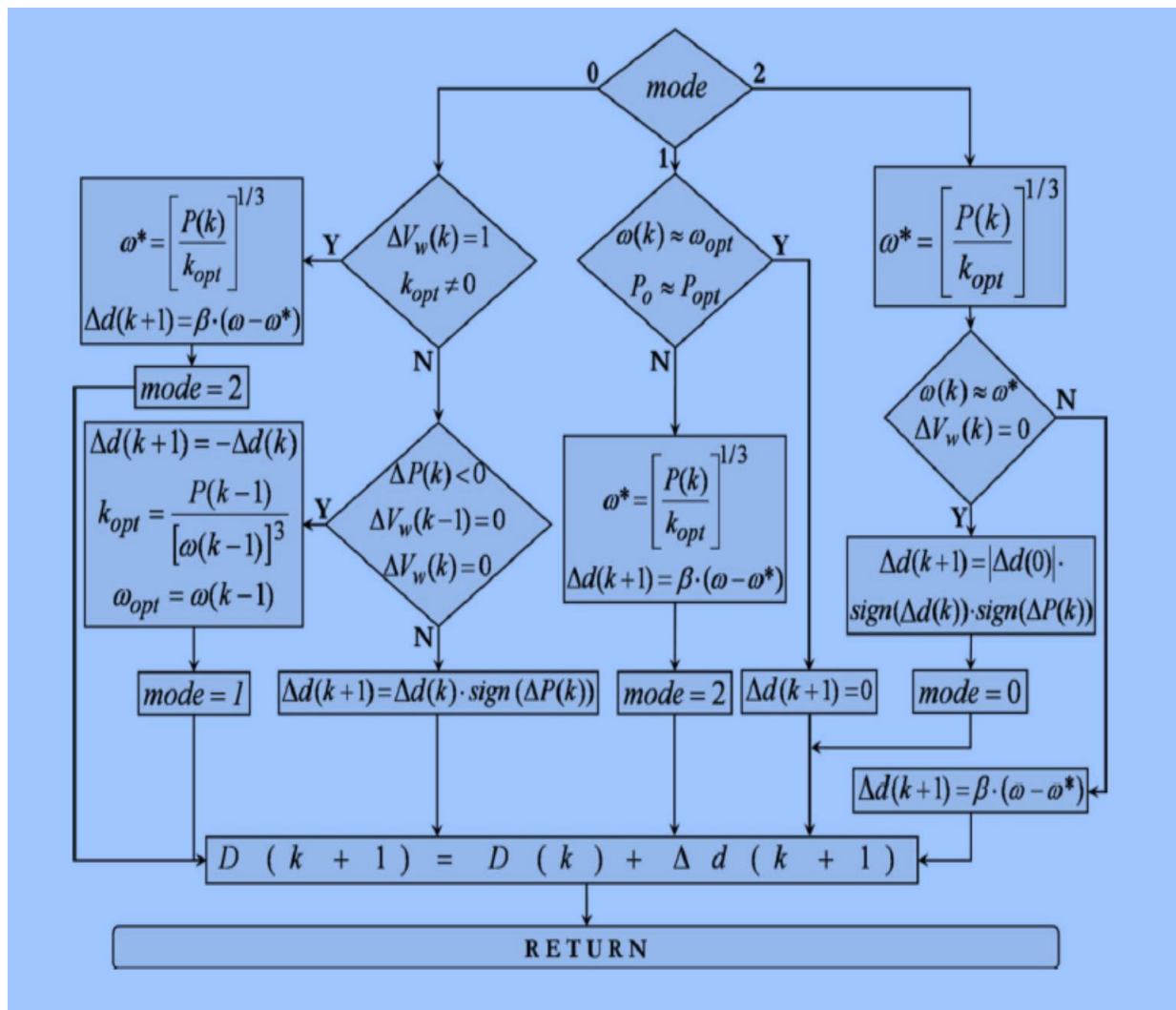


Fig 4: Flowchart for proposed MPPT Algorithm

Detecting wind change

Anemometer is not admitted detected $\Delta V\omega$ measurement. Instead of Anemometer and other schemes, novel sensor less scheme is employed.

The following conditions should be satisfied along with fundamental properties of WECS,

- i) The change in rotor speed should be bounded by a limit if the perturbation is of constant magnitude ,
- ii) The change in rotor speed will bear the opposite sign to the change in duty ratio,

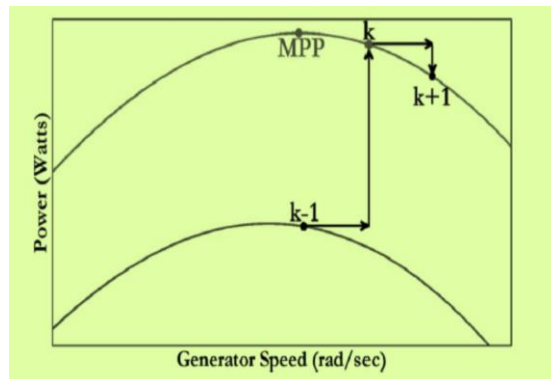


Fig 5: Detection of correct maxima using ΔV_{ω} and $\Delta V_{\omega}(k-1)$

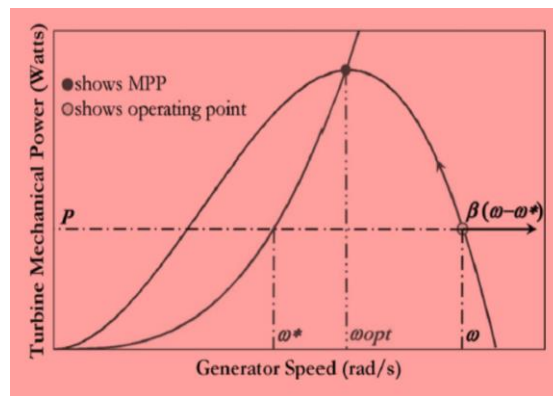


Fig 6: Mode 2 adaptive tracking with variable step size

Generator Speed-Sensor less scheme:

According to (4), measurement of generator speed is essential to detect wind changes and also to implement the adaptive hill climbing search. Implementation of rotary encoder make disable to sensor noise. when compared to mechanical sensor ,this scheme makes the turbine to run for long time.

This smart sensor-less scheme taken into account that generator’s phase current whose frequency is directly proportional to speed of the generator. This can be converted into speed estimation by simply knowing the number of rotor poles P and measuring the time lapse of one cycle(Δt) for the generator phase current. The rotor displacement between these one complete cycle would be $2\pi/P$. Hence, the speed can be estimated as;

$$\hat{\omega} = \frac{2\pi/p}{\Delta t} \quad (5)$$

The speed estimator scheme is implemented in Matlab- dspace for a four-pole generator. In order to avoid false zero-crossing due to sensor noise the first order low pass filter with hysteresis band has been put into service.

This proposed speed sensor-less scheme is entirely simple and its ease implementation makes it outstanding when compared to other salient pole machine techniques. As it is evident from the literature review [14]-[20], the proposed require various parameters, look up tables, model equations. In contrast, this method needs only single current sensor. Even the number of rotor poles is not a necessary and true measure of generator speed is also not required as per the fig4. Therefore, any positive integer can be assigned to ‘P’(i.e)

number of rotor poles. Hence , this proposed scheme is very suitable for salient pole generators.

EXPERIMENTAL RESULTS

Experimental setup:

The designed sketch of WECS in fig 8,and respective Hardware loop is shown in fig 9. An emulator is develop via servo-driver model based DC Motor for the prototyping of the system. In Matlab- dspace this emulator gives a torque command, this computer Hardware is driven by FPGA(20).

Configuring control system Parameters:

- i) For Mode0 , the initial step size $\Delta d(0)$ is set as 0.01,
- ii) To detect any change in wind profile, the bound of ϵ should be low enough and it must be higher than $\Delta\omega$ of constant wind. In a test run, it have found that duty step $\Delta d=0.01$, that $\epsilon=1$ is good for detecting the wind change(5),
- iii) The gain β for mode 2 is set as 5/1000.Adaptive step control is like proportional control , the result may yield high β in oscillation(4),
- iv) The perturbation frequency is noticed by the settling time of the system to a step-Input,

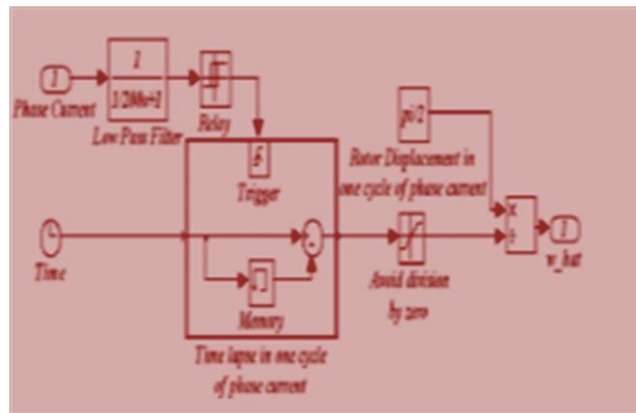


Fig 7: Speed estimator for speed sensorless scheme

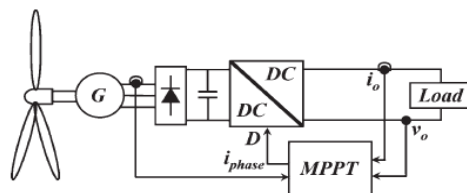


Fig 8: Schematic design of WECS

Inference:

The following two inference can be concluded with non-constant efficiency of WECS;

- i) For P_o , there does not exist a unique optimal curve constant K_{opt} ,
- ii)The maximum of $P_o - \omega$ curve does not coincide with peak of $P_m - \omega$ curve.

Results and Discussion:

In (1), for a sensor-based system experimental evaluation was carried out on a simulated wind profile. This new HCS algorithm has been compared with conventional HCS algorithm operating at same step size as that in perturbing frequency at Mode0.

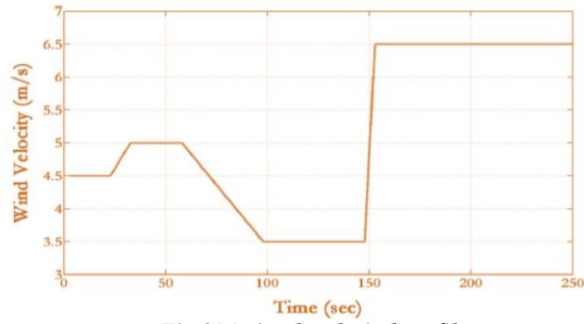


Fig 9(a) simulated wind profile

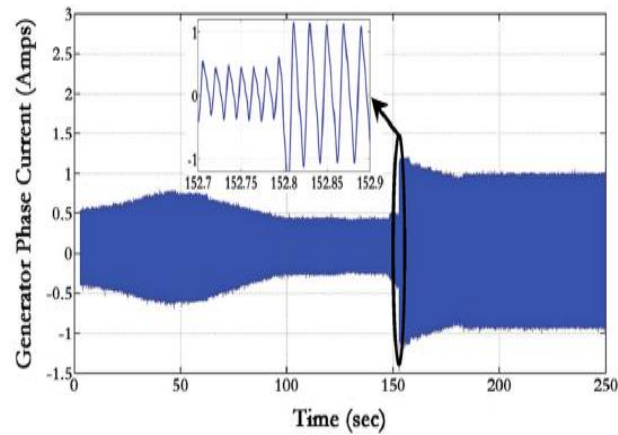


Fig 9(b) simulated wind profile and generator phase current

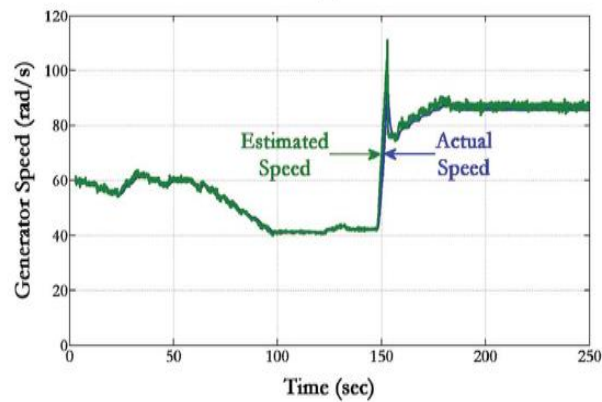


Fig 9(c) Generator speed comparison

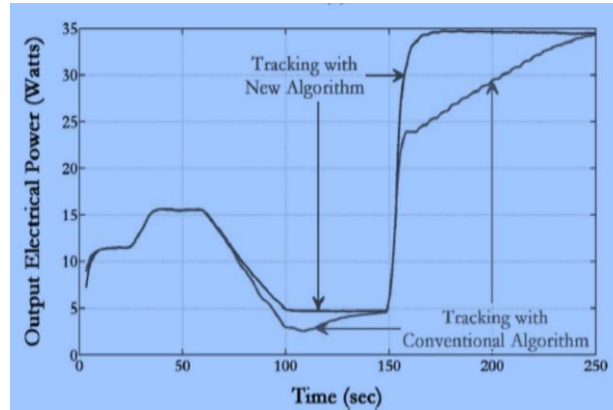


Fig 9(d) output power on conventional and proposed scheme

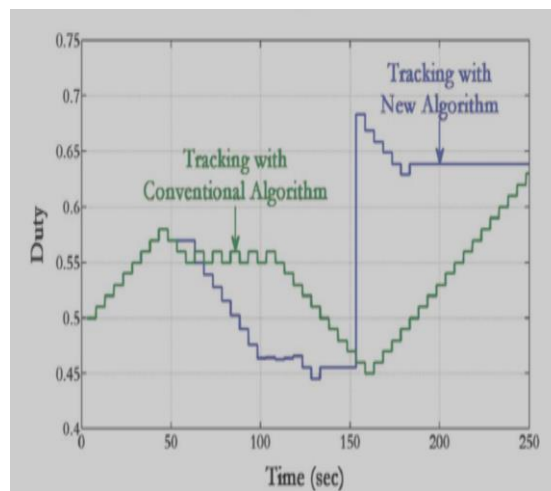


Fig9(e) Duty ratio driven by conventional and proposed MPPT

Fig 9 shows the tracking results of two algorithms subjected to simulated wind profile of varied slopes in fig 9(a). Fig 9(b) shows the cyclic nature of generator. Fig 9(c) confirms the cyclic nature of generator phase current. Fig 9(c) confirms the excellent performance of speed estimator performance.

Fig 9(d) clearly remarks the rise in MPPT with the proposed algorithm. Note that , during the drop in wind speed such as from 5 to 3.5 m/s , the new algorithm exhibits a very steep slope as from 5 to 3.5 m/s, the new algorithm tends to slow down the resulting decrease in power and therefore it exhibits a slower gradient of output power curve as compared to with conventional tracking of MPPT. As it is evident in 9(d), when the wind speed suddenly changes from 3.5 to 6.5 m/s. in addition , during such sharp wind bursts , the normal MPPT consumes too much time to reach maximum value and hence become very ineffective.

A similar conclusion can be drawn from 9(e), which proves that the new algorithm is fast in reaching the optimal duty ratio, whereas the conventional one gets control gets confused during the wind change.

From the figure 9(e), an important feature is noticeable, the conventional HCS resembles go on happens when the energy decreases continuously during the continuous drop in wind speed from 5 to 3.5m/s. the controller remains in a confused state because the next perturbation is overruled by the change in control variable. This novel algorithm eliminates this effect and gives clear to the controller no matter how fast the wind changes. And also it is approved that 100% of control efficiency is achieved by while the perturbation is reactivated.

It is also be noted that proposed algorithm provides a control with performance for the user. The parameter β may further improve the tracking speed, but a larger value may result in oscillations.

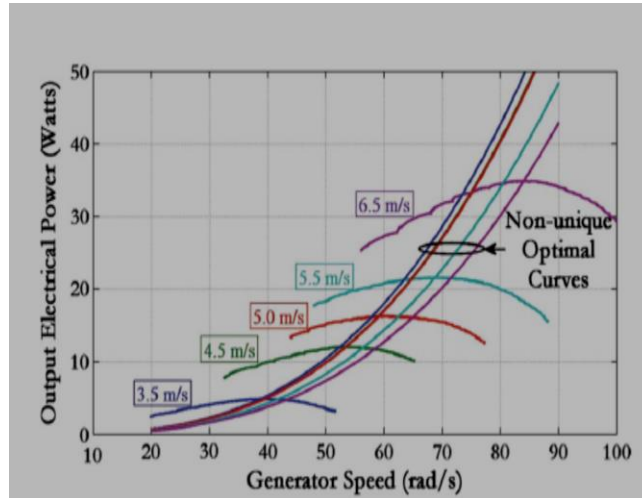


Fig 11 (a) Experimental results with real wind profile

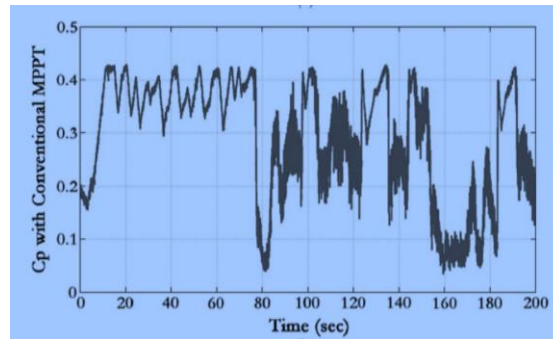


Fig 11(b) conventional MPPT's power coefficient track

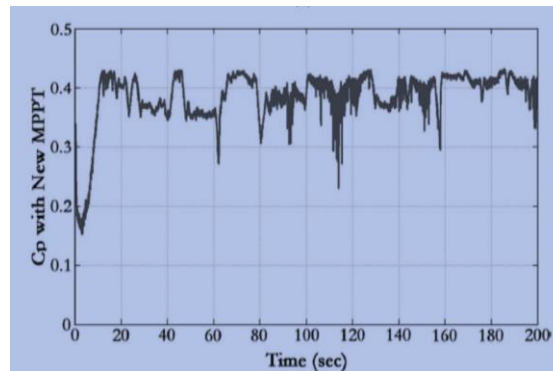


Fig 11(c) Proposed MPPT algorithm's power coefficient track

Fig 11, shows the performance comparison of conventional method versus MPPT under real wind profile. The comparison has been established by observing the power coefficient C_p curves tracked by both algorithms. As it is evident from fig 11(b), 11(c), the conventional method fails to maintain the optimum C_p and results in large fluctuations under rapidly varying wind conditions, whereas the novel method is very fast with quite less fluctuation considerably for lesser amount of time.

Hence, there results also confirm the proposed method is very fast and productive with the conventional one.

CONCLUSION

In this paper, a new method MPPT algorithm eradicates the problems that exist in the conventional HCS algorithm. The strategy is on the basis of detecting the cubic optimal power curve and by employing this curve as a future

reference for the future perturbation size and direction. with such reference , the algorithm adapts a larger perturbation step during the wind change which gradually approaches to zero as the peak gets nearer. This drives the system towards MPP, inspite the wind change and keeps the control efficiency to maximum . Due to the variable efficiencies of Generator- Converter subsystem, the algorithm performs self tuning to update the optimal curves for different wind speeds. Another new technique is smart and simple speed-sensor less scheme that is devised for salient-pole generator. Hence , the proposed MPPT is sensor less intelligent adaptive algorithm promising higher control efficiency and faster tracking under rapid wind change without requiring any prior knowledge of the system characteristics.

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