A Control MPPT Algorithm for Wind Energy Conversion System

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Abstract- **This paper proposes a maximum power point tracking (MPPT) algorithm for wind energy conversion systems. The proposed algorithm utilizes the dc current as the disturbing variable. The algorithm detects sudden wind speed changes indirectly through the dc-link voltage slope. The voltage slope is additionally used to enhance the tracking speed of the algorithm and to avert the generator from stalling under rapid wind speed slowdown conditions. The proposed method uses two modes of operation: A perturb and observe (P&O) mode with adaptive step size under slow wind speed fluctuation conditions, and a prediction mode employed under expeditious wind speed change conditions. The dc-link capacitor voltage slope reflects the expedition information of the generator, which is then used to prognosticate the next step size and direction of the current command. The proposed algorithm shows enhanced stability and expeditious tracking capability under both high and low rate of change wind speed conditions.**

Keywords-Maximum power point tracking(MPPT),Perturb & observe algorithm(P&O),wind energy conversion system(WECS).

I .INTRODUCTION

The authoritative ordinance for renewable energy has been boosted by the incrimination of the price of conventional fuels and inhibited reserve capacity availability for the prognostic able future. Of all available renewable resources, solar and wind energy are magnetizing the most attention. Wind energy conversion systems (WECSs) are acclimated to convert wind energy into different forms of electrical energy utilizing a wind turbine and a potency conversion system as shown in fig.1. Permanent-magnet synchronous generators (PMSGs) are increasingly popular due to their advantages of minuscule size, high energy density, low maintenance cost, and facilitate of control [1], [2]. Up to now, most of the wind energy generation systems have been implemented in sizably large-scale projects in the megawatt level. However, small-scale WECS can provide a good alternative in urban areas and residential applications in remote places where connection to grid is virtually infeasible.

To operate the WECS at an optimum power extraction point, a maximum power point tracking (MPPT) algorithm should be implemented. Several MPPT algorithms have been proposed in literature [3]–[12]. Generally, the MPPT algorithms can be related into three major types: tip speed ratio (TSR) control, perturb and observe (P&O) control, and optimum-relation-predicated (ORB) control.

II.WECS CONFIGURATION

The wind turbine is directly coupled to the PMSG. Compared to other generators, the PMSG has the advantage of being directly coupled to a wind turbine with no need for a gear box; there is no need for excitation current as in the doubly Fed induction

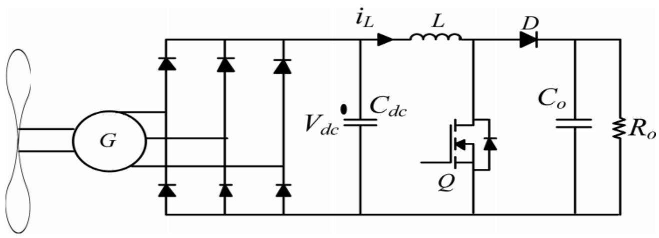

Fig 1.WECS Configuration

generator (DFIG) case, and there is no direct connection between the generator and the grid for grid tie applications. The load Ro can be superseded by a unity power factor inverter that supplies a standalone ac load or is connected to the utility grid. In this paper, a resistor is utilized as the load, and the MPP will be reflected into maximum voltage across it [8], [15]. The diode bridge rectifier is used rather than a three-phase controlled PWM rectifier because of its lower cost and higher reliability. The boost converter consisting of the inductor *L*, the diode *D*, and the switch *Q* will be current controlled to track the MPP and boost the voltage across the load resistor.

A .Wind Aerodynamic Model

The mechanical power of the wind P_{wind} can be expressed as

$$P_{Wind} = \frac{1}{2}\rho\pi R^2 V_\omega^3 \quad (1)$$

Where ρ is the air density, R is the turbine radius and V_ω is the wind speed

The power captured by the blades of the turbine is P_{blade} is

$$P_{blade} = \frac{1}{2}\rho\pi R^2 V_\omega^3 C_P(\lambda) \quad (2)$$

Where C_P is the turbine power coefficient and

$$\lambda = R\omega_r/V_\omega \quad (3)$$

The available turbine mechanical torque (T_m) can be expressed as

$$T_m = \frac{1}{2}\rho\pi R^2 V_\omega^3 C_P(\lambda)/\omega_r \quad (4)$$

Where ω_r is the rotational speed of the wind turbine.

For a concrete wind speed, there is a maximum shaft speed (at zero torque loads) beyond which the generation theoretically ceases and the potency curve goes into the negative region. In speed-controlled WECS, the generation system will be stable as long as the commanded speed is less than that maximum speed. Generally, a speed loop will generator a torque command that will be translated into current commands to the machine control system [11]. The outer speed loop will ascertain that the generator torque will not exceed the maximum available torque from the wind, thus ascertaining perpetual generation and maintaining system stability. In direct torque controlled WECS, special attention must be paid to the commanded generator torque, because if the generator torque is, for some reason, more than the maximum available turbine torque, the system will decelerate and the generation will. Thus, the generator torque should be maintained below the maximum wind turbine torque at all wind speeds. In the proposed MPPT algorithm in this paper, the MPP is tracked by directly adjusting the inductor current, which directly corresponds to the generator torque as will be shown in later sections. Thus, it will have the same inhibition as direct torque controlled systems, that is, the commanded current should not exceed a certain maximum value for a concrete wind speed to forefend the generation system from deceleration and ceasing. The proposed algorithm utilizes the dc-link voltage slope information to keep the generator torque at its optimum value and below the maximum torque point at all times, which ascertains perpetual generation and system stability.

B. Problems in the Conventional P&O Algorithm

The conventional P&O control algorithms are the simplest form of sensor less MPPT algorithms presented in previously. The step direction of the perturbation depends on the observed power change with the perturbation variable. However, for the conventional implementation of the fine-tuned step size P&O algorithms, there are two quandaries that deteriorates its performance: A astronomically immense perturbation step size increases the speed of convergence but deteriorates the efficiency of the MPPT as the oscillations around the MPP will be more astronomically immense. A small step size enhances the efficiency but slows the convergence speed; this is unsuitable under rapid wind speed fluctuations.

To solve this quandary and eschew the trade-off between the efficiency and the convergence speed in conventional P&O algorithms, an adaptive step size control is suggested to enhance the tracking capabilities of the MPPT algorithms, where, the step size is scaled by the slope of the power with veneration to the perturbation variable. The step size is expected to be more immensely colossal when the operating point is away from the MPP due to the astronomically immense slope of the power curve in that region, and small step size is enforced when getting proximate to the MPP as the power curve inclines to flatten near the MPP betokening lower slope. However, in this kind of control implementation, there are two major quandaries: When the operating point jumps from one power curve to another for different wind speeds, the desired step size depends on the operating point location along the curve, resulting in dispensable small or large step. Moreover, the power distinguishment between successive MPPs is not uniform, that is, $\Delta\omega/\Delta P$ is not uniform; it is more for low wind speeds and less for high wind speeds, thus, the tuning of the scaling factor will be inhibited to the lowest $\Delta\omega/\Delta P$ to overshooting the operating point at high wind speeds. The other quandary, which is of more concern, is that the next perturbation direction can be owing to the fact that the P&O algorithm is optically incapacitated to the wind speed change.

Unlike the conventional adaptive P&O algorithms, the proposed method utilizes the dc-link voltage slope information to scale the step size during sudden wind speed change conditions. It will be shown later in this paper that the dc-link voltage slope variation with the wind speed changes is relatively independent of the operating point location along the power curve and is constant for the same magnitude of wind speed increase or decrease. Thus, scaling factor in this case is more facile to tune and is optimized for the whole operating range and for different wind speed regions. The direction bamboozling quandary is additionally
abstracted in the proposed method as the devotement of the voltage slope always follows the transmutation in the wind speed, positive slope with incrementing wind speed and negative slope with decrementing one.

III.PROPOSED MPPT SCHEME

A. Electrical Characteristics of the WECS

The inductor current i_L is as follows

$$i_L = \frac{V_{dc}}{Z_{dc}} \quad (5)$$

Where Z_{dc} is the input impedance of the boost converter and it as follows

$$Z_{dc} = (1-d)^2 R_L \quad (6)$$

Where d is the duty cycle

The mechanical system can be described by the following equation

$$T_m - T_e = J\frac{d\omega}{dt} \quad (7)$$

where J is the system inertia. If T_e is less than T_m, the generator will expedite. While the speed is incrementing during expedition, the turbine torque will decrement, until it matches the generator torque and then the system will be in a stable operating point that will be the MPP if T_e equals an optimum torque point. If T_e is more preponderant than T_m, the generator will decelerate and the speed will decrement; thus, the turbine torque will increment until it matches the generator torque and stabilizes the system. If T_e is more preponderant than the maximum turbine torque the system will never stop decelerating and the generation will eventually stop. Thus, the generator torque should be kept below the maximum turbine torque for a categorical wind speed to obviate the generation from ceasing.

For P&O algorithms, and under sudden wind speed change, categorically wind speed slowdown scenarios, it is likely that the system will go into this operating condition. In this case, an expeditious adjustment of the engenderer torque should be done to match the turbine torque. A conventional P&O algorithm may fail under this operational condition due to its slow replication to expeditious wind speed change conditions. In the proposed algorithm, the sudden wind speed change is projected into dc-link voltage slope change that will be detected by the algorithm. When a sudden dc-link voltage slope exceeds a certain threshold, the wind speed is verbally expressed to be transmuting rapidly. Hence, a corresponding adjustment of the inductor current is commanded to avert the machine from ceasing and to perpetuate generation with MPPT control. This is an advantage of the proposed algorithm over conventional P&O algorithms.

B. Indirect detection of wind speed change

As pointed out in the antecedent section, the generator will expedite or decelerate predicated on the torque difference applied to its input and output. The power electronic interface is current controlled, which translated to torque on the machine side. The MPP algorithm will perpetually transmute the current command to reach the MPP. Transmuting the current, and hence the torque applied to the generator, will transmute the expedition properties of the machine. Another cause that can transmute the expedition properties of the machine is the vicissitude in the wind speed itself. It is consequential to distinguish between the two cases, where the distinguishment between them will be utilized to enhance the MPPT algorithm tracking speed and stability. The expedition information will be projected into the dc-link voltage slope. The higher the expedition/deceleration is, the steeper the rate of change of the dc-link voltage. Cognizance of the slope of the dc-link voltage then, in addition to that of the dc current, can be habituated to determine roughly how much electrical torque should be applied to the generator to match the turbine torque and stabilize the system.

$$V_{dc} \propto \omega_e \quad (8)$$

Then

$$\frac{dV_{dc}}{dt} = \frac{d\omega_e}{dt} \quad (9)$$

We have

$$\frac{dV_{dc}}{dt} \propto \frac{T_m - T_e}{J} \quad (10)$$

From above equation we can conclude the following

$$\frac{dV_{dc}}{dt} \propto V_\omega^3 \quad (11)$$

$$\frac{dV_{dc}}{dt} \propto -i_L \quad (12)$$

The dc-link voltage slope shows much higher sensitivity to the wind speed change than to the inductor current change since the slope is proportional to the cubic wind speed and linear proportionality is shown to the inductor current change. If the MPPT algorithm steps the current command up or down, the corresponding slope of the dc-link voltage will be diminutive since the step size of the current will be small for fine tracking. On the other hand; when the wind speed changes; even by a small scale value, the dc link voltage slope will be astronomically immense. Through the dc link voltage slope information, we can detect any possible wind speed change during the operation of the conversion system. If the wind speed fluctuation is small in magnitude and slow, the slope will be small and less than certain threshold, while in the case of large magnitude expeditious fluctuations, the slope will be steeper and will give the algorithm the capability of extracting the wind speed change information.

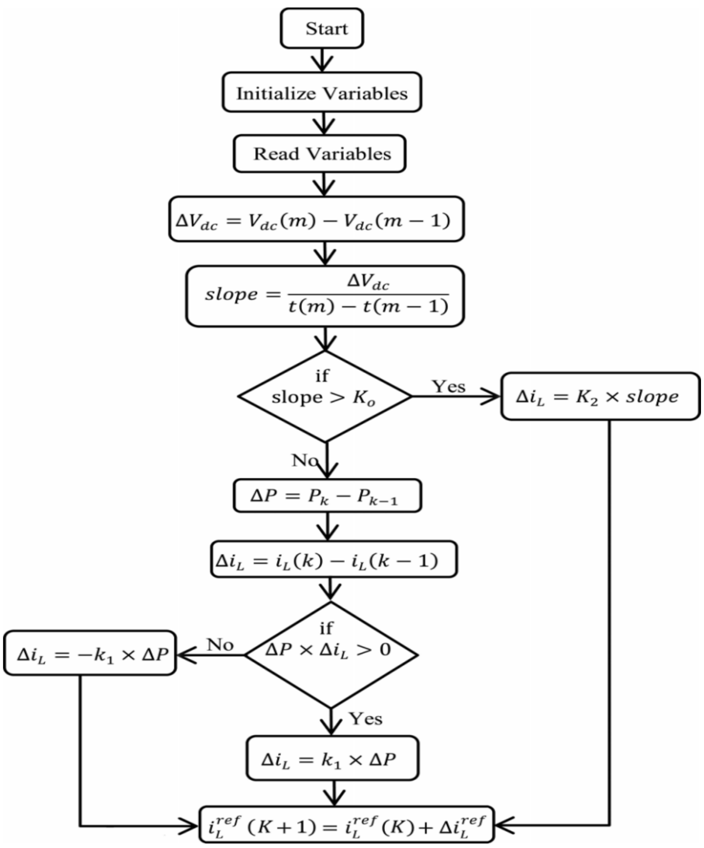

Fig 2: Flowchart for the proposed MPPT

C. MPPT Algorithm

The MPPT algorithm proposed in this paper to track the MPP by perpetually adjusting the inductor current to reach the MPP. The dc-link voltage is not controlled; thus, it will be monitored and the natural comportment of the dc voltage during wind speed change will be acclimated to enhance the tracking speed of the algorithm. The algorithm works in two distinct modes: The normal P&O mode under slow wind fluctuation conditions in which an adaptive step size is employed with the power increment utilized as a scaling variable. The second mode is the predictive mode under sudden wind speed change conditions; this mode is responsible for bringing the operating point to the vicinity of the MPP during expeditious wind speed change, and it will avail obviate the generator from stalling by rapidly adjusting the generator torque in replication to sudden drops in wind speed. In this mode, the dc-link voltage slope is utilized as a scaling variable and is utilized to determine the next perturbation direction. First, the system variables are initialized and samples from the dc-link voltage and the dc current are taken. The samples of the voltage and current are taken at a rate that depends on the system replication time. When the MPPT algorithm decides to increment the current command, which denotes more load torque, the system decelerates and reaches an incipient operating point. The rectified dc-link voltage will transmute according to the transmutation of the speed. An incipient dc-link voltage level with the incipient inductor current will give an incipient dc power operating point that will be used inside the algorithm calculations. However, the generator speed cannot be transmuted instantly as it is constrained by the system inertia; thus, when the current is step transmuted, the dc-link voltage across the dc-link capacitor C_{dc} will be transmuted gradually. So, customarily, the sampling interval for the MPPT will be at least four to five times more immensely larger than the time constant of the system. The algorithm is designed to perpetually monitor the slope variation of the dc-link voltage. The slope is quantified at instants different from the sampling times designed for the MPPT algorithm flow chart is shown in figure.2. This is so that if there is an abrupt vicissitude in the wind speed, a very steep slope will be descried on the dc-link voltage. Additionally, if the wind speed is going down, the available torque will be much less than the commanded torque to the generator. Thus, in a very short time, the generator will lose the energy stored in the system inertia and will stop if the generator torque is not adjusted. So, more expeditious monitoring of the dc-link voltage slope is needed to rapidly adjust the current command in replication to a sudden wind speed change. The algorithm is designed to perpetually monitor the slope variation of the dc-link voltage. The slope is quantified at instants different from the sampling times designed for the

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$$\Delta i_L^{ref} = K_2 \times (slope) \tag{13}$$

Where, Δi_L^{ref} is the reference inductor current step size in the next execution cycle. In fact, is a prediction of the amount of the available torque from wind. The slope will determine the sign of the compensating current command, and $K2$ is a factor determined based on the system characteristics. While the slope of the dc-link voltage remains within the threshold, the normal P&O mode with adaptive step size is executed In this mode, the power at the current calculated and compared with the previous one, i.e.,

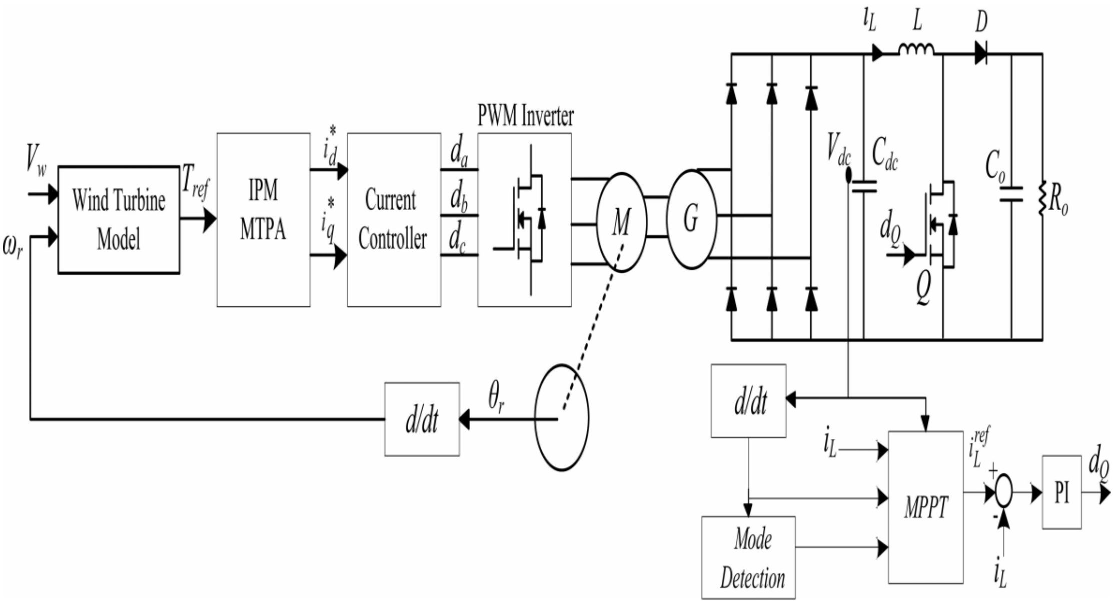

Figure.3. Schematic for the designed WECS with the proposed MPPT

$$\Delta_P = P_K - P_{k-1} \tag{14}$$

and then, the reference inductor current of the current cycle is compared with the previous one

$$\Delta i_L = i_L(K) - i_L(K-1) \tag{15}$$

Based on these two comparisons, the next step size and direction are determined according to the following:

$$\text{If}(\Delta P \times \Delta i_L > 0 \rightarrow \Delta i_L^{ref} = K_1 \Delta P \tag{16}$$

$$\text{If}(\Delta P \times \Delta i_L < 0 \rightarrow \Delta i_L^{ref} = -K_1 \Delta P \tag{17}$$

where, $K1$ is a factor determined judiciously. After running the algorithm, the step size and direction will be determined from either the normal P&O mode or the prediction mode and will be applied to the next cycle:

$$i_L^{ref}(K+1) = i_L^{ref}(K) + \Delta i_L^{ref} \tag{18}$$

In summary, the proposed MPPT algorithm will run as mundane adaptive step size P&O algorithm unless a wind speed change causes the system to rapidly expedite or decelerate. In this case, the system will counteract the expedition/deceleration by transmuting the reference current felicitously and moving the operating point much more proximate to the incipient MPP. Then, the algorithm will then resume normal P&O mode. This method results in a saliently conspicuous tracking speed enhancement. More importantly, the system is averted from sudden stalling during sudden wind speed reductions.

IV.SIMULATION RESULTS & STUDIES

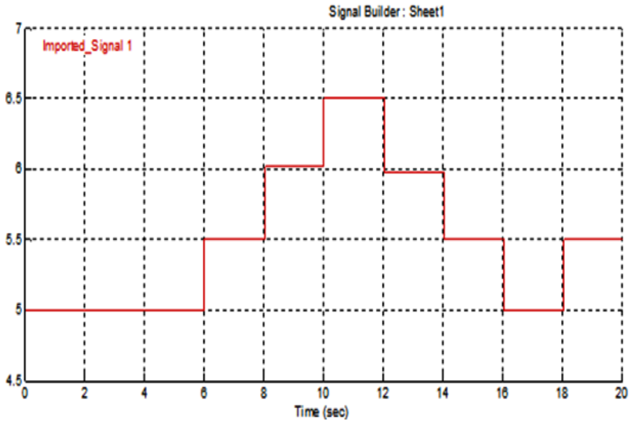

Fig 4: Wind velocity variations

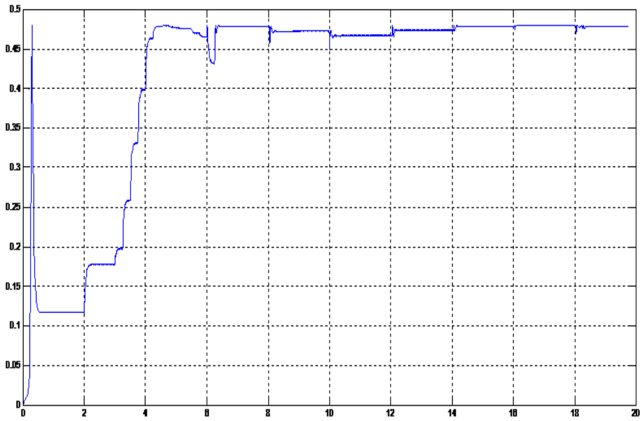

Fig 5: Cp Variations without MPPT Controller

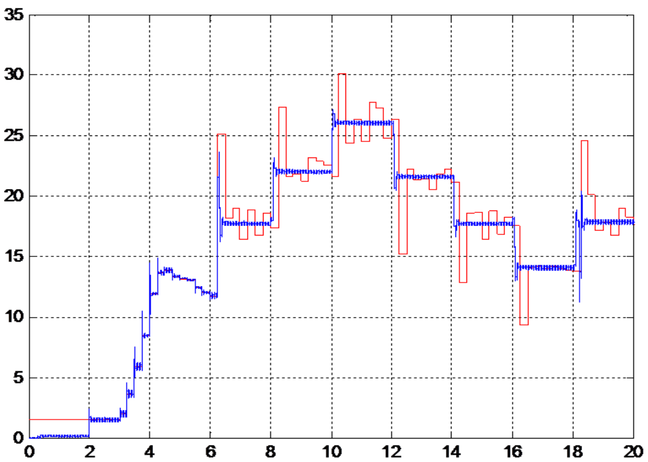

Fig 6: Inductor Current

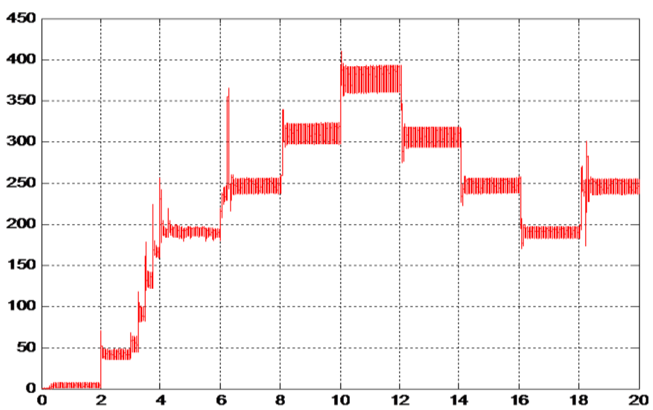

Fig 7: Power Variations

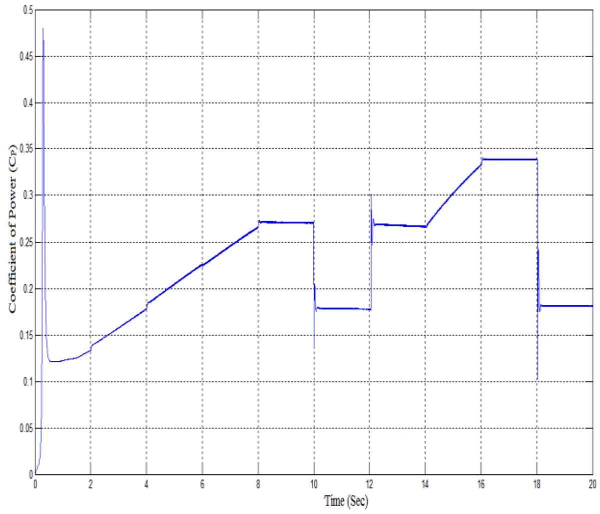

Fig 8. Cp Variations with MPPT Controller

The proposed algorithm has been tested under turbulent wind velocity conditions as shown in Fig. 4. The selected wind velocity profile demands the wind turbine to track maximum power point within 6 seconds and jumps to 6.5 sec maximum.. The proposed algorithm is tested in simulation on a 10 kW wind energy conversion system. Suitable controller is developed to track the reference input inductor current generated by the MPPT algorithm. Effective tracking feature of the proposed MPPT algorithm is verified with fast tracking of reference inductor current as shown in Fig. 6. There is a maximum current where beyond that value the generation stops, and that point represents the maximum torque point of the wind turbine. The current command for a specific wind speed should not exceed the maximum current curve to continue generation Maximum power point tracking capability of the wind energy conversion system is proved by observing the power coefficient, C_p, of the system. As shown in Fig. 5, coefficient of power is regulated at 0.47 against the wind velocity variations without MPPT. This result proves the operation of the wind energy conversion system at maximum power point. The other problem, which is of more concern, is that the next perturbation direction can be misled owing to the fact that the P&O algorithm is blind to the wind speed change. This scenario is shown in fig. 7 unlike the conventional adaptive P&O algorithms; the proposed method uses the dc-link voltage slope information to scale the step size during sudden wind speed change conditions with MPPT shown in fig.8. The current command will follow the MPP during slow wind variation where normal P&O mode is in charge and will abruptly change to follow fast wind speed changes as well through the prediction mode. The overall performance of the proposed algorithm shows fast tracking capabilities with minimum calculation required making it competitive and simple implementation algorithm. The proposed algorithm prevents the generator from stalling under fast wind speed change by utilizing the wind speed change detection capability through the dc-link voltage Information compared with P&O mode [21].

V. CONCLUSION

In this paper, a MPPT algorithm for WECS has been proposed. The algorithm utilizes the dc-side current as the perturbing variable, while the dc-link voltage slope information is utilized to detect expeditious wind speed change. Predicated on the wind conditions, the algorithm works on one of two modes of operation: normal P&O mode under slow varying wind speed conditions. In this mode, the algorithm finely tune to the MPP as long as the wind speed is gradually varying or steady. The other mode of operation is the prediction mode under expeditious wind speed change conditions. And this mode is responsible for bringing the operating point near the MPP whenever the wind speed rapidly vicissitudes in speed or direction. This proposed mode of operation obviates the generator from stalling under sudden wind speed slowdown scenario as well, where conventional P&O methods may fail under this scenario due to their slow replication. The step size of the perturbing variable is opted to be a scaled measure of the voltage slope while in the presage mode and of the power increment while in the mundane P&O mode. Compared to the conventional P&O methods, the proposed one does not have the direction bamboozling quandary and the adaptive step size scaling factor tuning is optimum irrespective of the loading conditions or the wind speed range. Yet, like other methods, the proposed algorithm does not require anemometer or generator speed quantifications.

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