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# Lyapunov based Control Strategy for DFIG based Wind Turbines to Enhance stability and Power

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**ABSTRACT-** The Doubly Fed Induction Generators (DFIG) based wind turbine is fed with maximum power point tracking is presented in this paper in proposed technique the proportional coefficient tuned adaptively as per wind changes and compare with traditional approaches. This novel method uses three control laws to adjust the proportional gain adaptively to wind speed variations. The intended electrical torque is determined via feedback linearization in the first control law, which makes the assumption that the power capture coefficient and target rotor speed are instantly determined. The second control law uses a Lyapunov-based analysis to determine the power capture coefficient as per changes in wind speed, and the third control law establishes the required rotor speed. As a result of these control principles, the operating point of the turbine shifts in a direction that increases the power capture coefficient, leading the rotor speed to adaptively adjust in the direction of the desired speed. The proposed maximum power tracking method differentiates itself from the perturb-and-observe strategy by removing the need to include a dither or perturbation signal and reliably slipstream the trajectory of maximum power points even in the circumstance of a sudden change in wind velocity, which can cause the perturb-and-observe practice to fail.

**Keywords:** Doubly Fed Induction Generator (DFIG), Maximum Power Point Tracking (MPPT), Lyapunov Approach, nonlinear Control, Wind Turbines.

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## 1. INTRODUCTION

The literature has offered a wide range of control strategies for wind turbines looking to produce the maximum electrical Energy. Most of them are based on various nonlinear control methods that fall under the umbrella of traditional techniques. [1]-[2]. In regular traditional methods Most of the times the controller gain is not tuned as per the turbulent wind, so unable to generate required electrical torque and optimum power tracking [22] and in all the traditional methods the electrical torque is proportional to square of rotor speed. The method described here is significant because it enables adaptive tracking of the rotor speed via power coefficient calculation even in the case of turbulent wind. The approach described in this article can trace the maximum power points without the need for a perturbation or dither signal.

The Lyapunov-based stability technique is one of the best used methods for calculating the stability parameters of nonlinear electrical systems. It mainly focuses on a transient stability and gives exact fault clearance time. Lyapunov-based methods are founded on the fundamental tenet that every physical system includes an energy with a positive value that may be represented by an energy function. (EF) [3]. The system is stable if and only if the energy of the system is positive and its time derivative is negative or if it is equated it to zero then the system is stable and will get maximum value of real power [4] otherwise any system can deteriorate. In [4], When two unique WTs were connected to a single grid, and EF was used to ensure the system's stability. The proposed Lyapunov control strategy developed for wind turbine is used to ensure system stability and tracking path of maximum value of real powers with the help of power electronic based controllers [7]-[8].

### 1.1 Operating regions of wind turbine

Three separate locations have wind turbines. When the wind speed is lower than what is necessary, a turbine should be capable of generating the most electricity. In this case, the generating torque control keeps track of the rotor speed while the pitch angle is fixed. The turbine must operate in area III as shown in fig1 at its rated power continually. Here, there is more wind energy available than can be measured for collection. The turbine works with less efficiency, as a result. The generating torque is kept constant, and the rotor speed is constrained by pitch control, reducing changes in output

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power. The output power must be considered because it is affected by the rotor speed and torque product and must be kept constant at its rated value. Both constant torque and constant power techniques are pertinent to Region III in *fig.1* The blade pitch and generator torque work together to control the rotor speed in Region II in *fig 1*, which is sandwiched between Regions I and III. Due to its connection to the region of maximum power, this region might occasionally be disregarded.

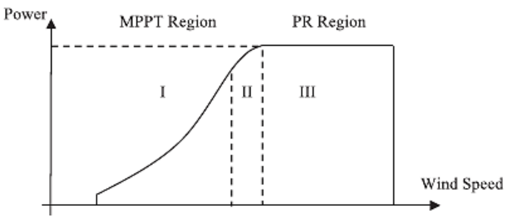


**Fig. 1:** Operating regions of wind turbine

## 2.PROPOSED CONTROL STRATEGY of MPPT

Figure 1, By developing highly effective power electronic converters, wind systems can better integrate with the grid and provide higher-quality power. Before wind power can be developed and used to generate the maximum power, many issues must be resolved. Utilizing as much power as possible will boost productivity of wind energy conversion system. But existing P&O strategy can fail when the wind speed changes so quickly. The proposed technique in this paper will track the maximum power point effectively for wind changes. Unfortunately, the perturb-and-observe(P&O) technique necessitates the introduction of a dithering or perturbation signal that deviates from the track of maximum power points.

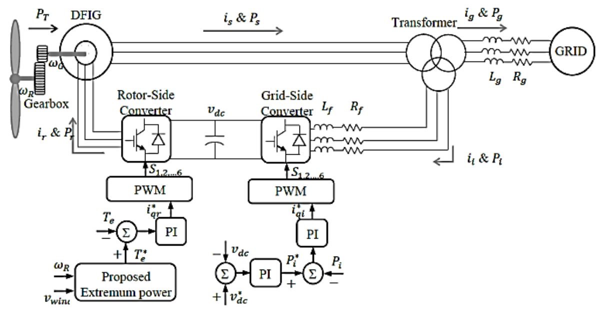


**Fig. 2:** Block diagram of DFIG Based Wind Energy Conversion System

The proposed method uses three control loops. The rotor speed squared determines the electrical torque, and three control rules allow for real-time adaptive adjustment of the proportional coefficient. Once the intended rotor speed and power capture coefficient are determined, the first control law uses feedback linearization to calculate the target electrical torque instantly. The real time power capture values determined by second control law; the required speed of rotor is generated by third control law.

### 2.1 Control law 1: Electrical/generator torque, $T_e^*$

Due to nonlinear nature of wind the generated aerodynamic torque is also nonlinear in nature i.e.

$$Te^* = \widehat{Cp} f(v, W_R) - u(t) \quad (1)$$

The system will become linear by using feedback linearization through variable input signal. Using this feedback linearization, the nonlinear terms in torque and power equations can be cancelled and we can estimate the exact value of power capture coefficient using the following formula

$$f(v, \omega_R) = (\rho A v^3 / 2\omega_R) \propto \omega_R^2 \quad (2)$$

The equation of motions

$$J\dot{\omega}_R + C_D \omega_R = u(t) \quad (3)$$

From above three equations the Generated torque will be proportional to desired torque.

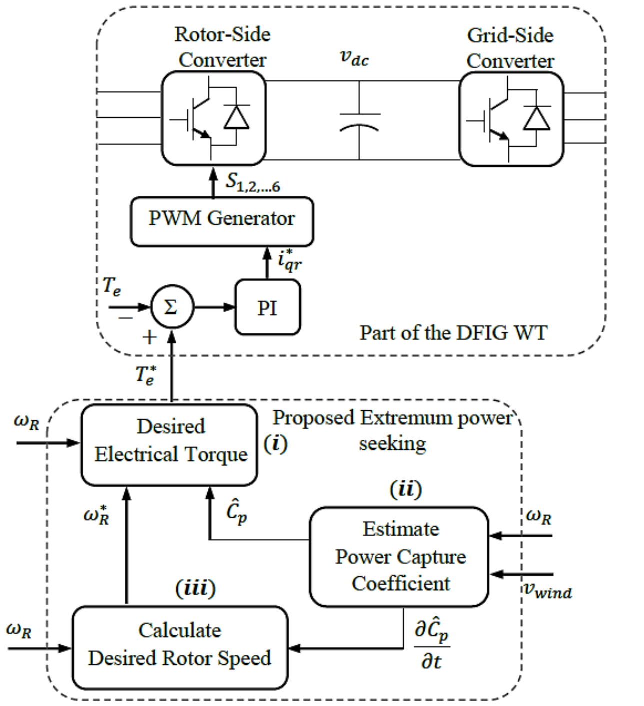


**Fig. 3:** Proposed Method of MPPT

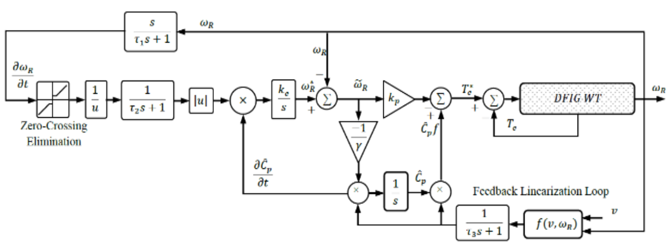


**Fig. 4:** Proposed control strategy loops to extreme power seeking

## 2.2 Lyapunov Approach to Estimate Cp: Control Law 2

In this work, by using Lyapunov function the $C_p$ is estimated and Lyapunov function V, is chosen as

$$V = \frac{1}{2}J\tilde{\omega}_R^2 + \frac{1}{2}\gamma\tilde{C}_p^2 \tag{4}$$

where $\gamma$ is a constant to be determined, $\tilde{\omega}_R = \omega_R^* - \omega_R$ and $\tilde{C}_p = C_p^* - \hat{C}_p$, in which $C_p^*$ is the maximum value of $C_p$. Derivation of V is

$$\dot{V} = J\tilde{\omega}_R\dot{\tilde{\omega}}_R + \gamma\tilde{C}_p\dot{\tilde{C}}_p \tag{5}$$

Applying $\dot{\tilde{\omega}}_R = \dot{\omega}_R^* - \dot{\omega}_R$ and $\dot{\tilde{C}}_p = \dot{C}_p^* - \dot{\hat{C}}_p$ yields

$$\dot{V} = J\tilde{\omega}_R\left(\dot{\omega}_R^* - \dot{\omega}_R\right) + \gamma\tilde{C}_p\left(\dot{C}_p^* - \dot{\hat{C}}_p\right) \tag{6}$$

Then substituting $\dot{\omega}_R$ and neglecting damping viscosity the equation of motion yields

$$\dot{V} = J\tilde{\omega}_R\left(\dot{\omega}_R^* - \frac{1}{J}(T_{aero} - T_e)\right) + \gamma\tilde{C}_p\left(\dot{C}_p^* - \dot{\hat{C}}_p\right) \tag{7}$$

$$\dot{V} = J\tilde{\omega}_R\dot{\omega}_R^* - \tilde{\omega}_R(T_{aero} - T_e) + \gamma\tilde{C}_p\left(\dot{C}_p^* - \dot{\hat{C}}_p\right) \tag{8}$$

Which can be simplified by substituting $T_{aero} = f(v, \omega_R)C_p(\lambda, \beta)$ and $T_e$ from equations

$$\dot{V} = J\tilde{\omega}_R\dot{\omega}_R^* - \tilde{\omega}_R\left(C_pf - \left(\hat{C}_pf - u\right)\right) + \gamma\tilde{C}_p\left(\dot{C}_p^* - \dot{\hat{C}}_p\right) \tag{9}$$

$$\dot{V} = J\tilde{\omega}_R\dot{\omega}_R^* - \tilde{\omega}_R\left(C_pf - \hat{C}_pf + u\right) + \gamma\tilde{C}_p\left(\dot{C}_p^* - \dot{\hat{C}}_p\right) \tag{10}$$

$C_p^*$ is chosen (i.e., desired value of power capture coefficient is to be chosen as Betz constant). So, differentiation of $C_p^*$ results 0. Therefore, the above equation can be rewritten as

$$\dot{V} = J\tilde{\omega}_R\dot{\omega}_R^* - \tilde{\omega}_R\left(C_pf - \hat{C}_pf + u\right) + \gamma\tilde{C}_p\left(0 - \dot{\hat{C}}_p\right)$$

$$\dot{V} = J\tilde{\omega}_R\dot{\omega}_R^* - \tilde{\omega}_R\left(C_pf - \hat{C}_pf + u\right) - \gamma\tilde{C}_p\dot{\hat{C}}_p \tag{11}$$

Substituting $\tilde{C}_p = C_p^* - \hat{C}_p$ in *equation (10)*, yields

$$\dot{V} = J\tilde{\omega}_R\dot{\omega}_R^* - \tilde{\omega}_R\left(C_pf - \hat{C}_pf + u\right) - \gamma\dot{\hat{C}}_p\left(C_p^* - \hat{C}_p\right) \tag{12}$$

The above equation can be rewritten as

$$\dot{V} = J\tilde{\omega}_R\dot{\omega}_R^* - \tilde{\omega}_RC_pf + \tilde{\omega}_R\hat{C}_pf - \tilde{\omega}_Ru - \gamma\dot{\hat{C}}_pC_p^* + \gamma\dot{\hat{C}}_p\hat{C}_p$$

$$\dot{V} = \hat{C}_p\left(\tilde{\omega}_Rf + \gamma\dot{\hat{C}}_p\right) - \tilde{\omega}_Ru + J\tilde{\omega}_R\dot{\omega}_R^* - \tilde{\omega}_RC_pf - \gamma\dot{\hat{C}}_pC_p^* \tag{13}$$

The strategy is to make $\dot{V}$ a non-positive quantity. So, the first term in *equation (13)* is chosen to be zero, that is,

$$\hat{C}_p\left(\tilde{\omega}_Rf + \gamma\dot{\hat{C}}_p\right) = 0 \tag{14}$$

Therefore, the equation (12)is simplified as

$$\dot{V} = -\tilde{\omega}_Ru + J\tilde{\omega}_R\dot{\omega}_R^* - \tilde{\omega}_RC_pf - \gamma\dot{\hat{C}}_pC_p^* \tag{15}$$

Herein, $\hat{C}_p$ in *equation (14)* is not equal to zero and other term which is in parenthesis will become zero. Therefore

$$\dot{\hat{C}}_p = -\frac{1}{\gamma}\tilde{\omega}_Rf(v, \omega_R) \tag{16}$$

the solution of above equation gives the value of Cp accordingly chosen the control input as $u(t) = k_p\omega_R$.

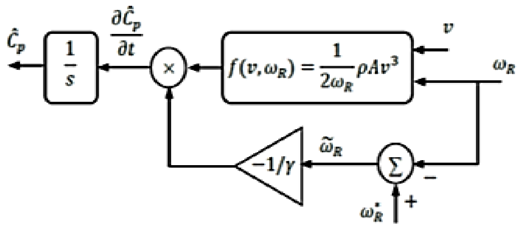


**Fig. 5:** Control law diagram to estimate power coefficient.

Therefore, the second control law written as *equation (17)*

$$T_e^* = \hat{C}_pf(v, \omega_R) - u(t)$$

$$T_e^* = \left(\int \dot{\hat{C}}_pdt\right)f(v, \omega_R) - k_p\omega_R \tag{17}$$

Substituting *equation (12)* in above equation yields

$$T_e^* = -\frac{1}{\gamma}f(v, \omega_R)\int \tilde{\omega}_Rf(v, \omega_R)dt - k_p\omega_R \tag{18}$$

The adaptive PT controller result including power capture co efficient estimation with feedback linearization can be written as:

$$T_e^* = -k_{I1}(t)\int \tilde{\omega}_Rk_{I2}(t)dt - k_p\omega_R \tag{19}$$

Where $k_{I1}(t)$ and $k_{I2}$ are time varying parameters.

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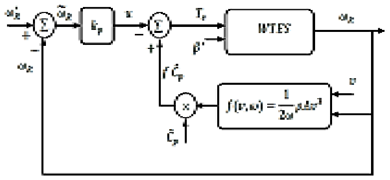


**Fig. 6:** Diagram represents Speed Control Law

### 2.3. Control Law 3

The maximum-Power Tracking seeking law can also be extracted by. Substitution of $u(t) = k_p\tilde{\omega}_R$ and $\dot{\hat{C}}_p$ from *equations (17) & (15)*

$$\Rightarrow \dot{V} = -\tilde{\omega}_R{}^2 k_p + J\tilde{\omega}_R\dot{\omega}_R^* + (C_p^* - C_p)\tilde{\omega}_R \quad (20)$$

From above equation the, $\dot{\omega}_R^*$ is calculated to ensure that (20) is always a non-positive value. In order to maintain a non-positive value $\dot{V} \leq 0$ in *equation (16)*, one can select $\dot{\omega}_R^* \propto (-\tilde{\omega}_R)$ and proportional constant $k_p$ adequately as much as high to maintain large non positive value with respect to third term in *equation 16*. therefore, the required speed of rotor can be formulated as

$$\dot{\omega}_R^* = k\dot{\hat{C}}_p \quad (21)$$

At this point where $(\partial P_T/\partial\omega_R)$=0 gives optimum power and peak value of Cp with constant wind velocity.

## 3. DISCUSSION AND RESULTS WITH SIMULATION

The Wind turbine of 1.5MW capacity system includes transmission line integration model, power converters with back-to-back connections along with DFIG driven gear system of turbine is modeled in MATLAB/Simulink in order to verify proposed control strategy mentioned in this paper.

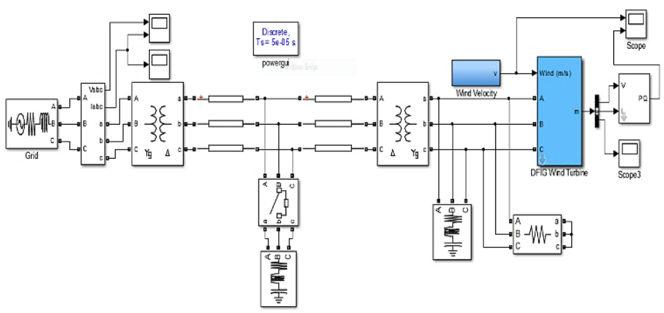


**Fig. 7:**Simulation Diagram of Proposed MPPT Wind Energy Conversion System

The wind speed profile with two step changes is considered as input, The feasibility of the suggested technique was examined using abrupt step increases in wind speed and turbulent unsteady wind in region 2 of the wind turbine, and the findings are provided in this section. Control parameters, $\gamma$, *kp*, *ke* were taken to get result of control strategy10x106and10x105,0.002 respectively. According to *fig9*. At t=1.7 sec, a step shift from 7 m/sec to 20 m/sec occurs, and second shift happened at t=7 sec to 20m/sec. At times t=3 sec and t=7 sec, the recommended MPPT control is in its ON and OFF states. The results of the simulation and the control circuit are depicted in the diagram below, along with the wind speed, real and VAR powers, rotor speed, produced torque, and power capture coefficient. In order to test the viability of the suggested control strategy/ technique, wind speed profiles and abrupt step changes in wind speed with turbulent wind in second region of wind turbine with 1.5MW rating were used. The results are presented in this section.

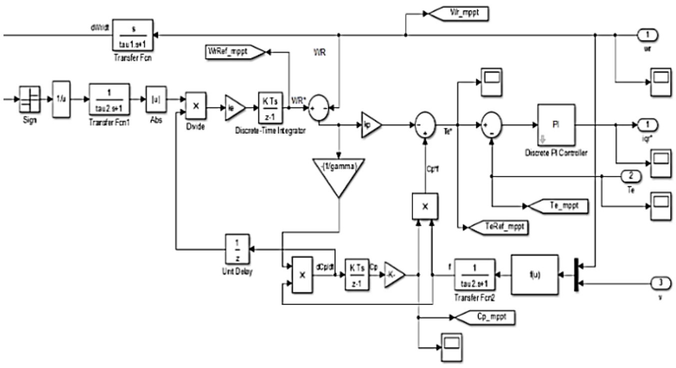


**Fig. 8:** Simulation Block of Control Circuit

According to results shown in *fig 9,10,11*, the determined rotor speed automatically in tune to maintain *Cp* (0.37 p.u.) at maximum value. For various wind speed conditions, the controller adjust the parameters to maintain desired speed and power capture coefficient. From the above three control loop operations irrespective of wind velocity profiles the coefficient of power is always trying to reach maximum value.

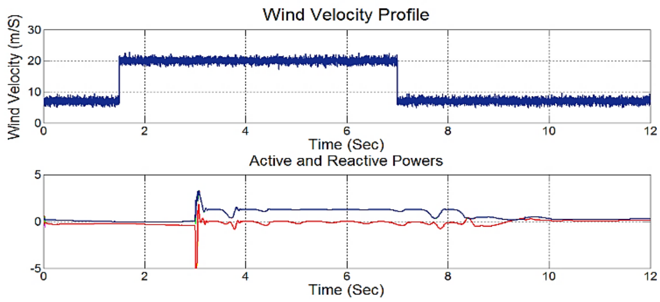


**Fig.9:** Wind Profile, Real and VAR Power Changes

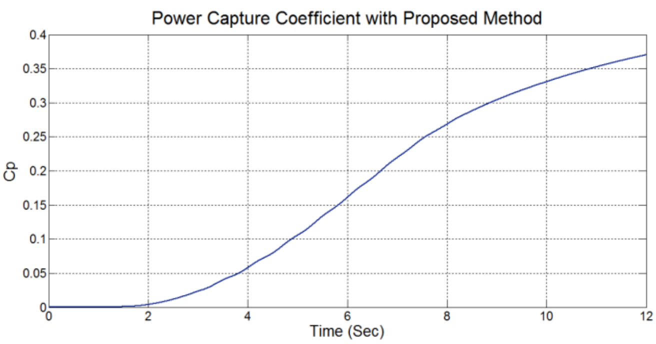


**Fig. 10:** Proposed Control Strategy of Power Capture Coefficient

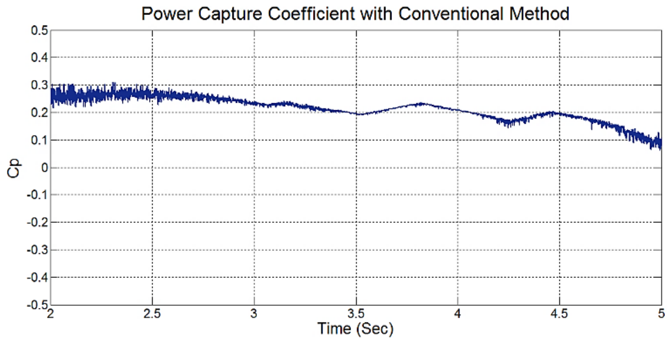


**Fig. 11:** Power Capture Coefficient with the Traditional Method

## 4. CONCLUSIONS

In this paper, combining feedback linearization method and Lyapunov analysis, developed an adaptive tuned nonlinear control strategy for DFIG based wind turbines. The control scheme comprised three control strategies: *(i)* determination of the preferred generator torque, *(ii)* Optimum power calculation by tuning the rotor speed as per wind changes and *(iii)* approximation of power capture coefficient for chosen wind turbine. The control strategy was adapted to the actual wind and rotor speed measurements and predicted the wind power capture coefficient. The simulation was carried out on the GE 1.5MW DFIG Turbine, by incorporating back-to-back converters with DFIG connected through transmission lines to grid. The proposed control strategy has been simulated using MATLAB/ Simulink. All the control laws showed stable and dynamic characteristics under turbulence of wind and abrupt changes in speed.

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