PMSG Based Wind Turbines Control for System Inertial Response and Power Oscillation Damping by Fuzzy

K. Harinath Reddy¹, P. Bhaskara Prasad² B. Tejaswi³

¹Assistant Professor, Dept. EEE, A.I.T.S-Rajampet, A.P, INDIA.

²Assistant Professor, Dept. EEE, A.I.T.S-Rajampet, A.P, INDIA.

³PG Student, Dept. EEE, A.I.T.S-Rajampet, A.P, INDIA.

Abstract

To enhance the inertial response and damping capability during transient events this paper investigates an improved active power control for variable speed wind turbines. The optimized power point tracking (OPPT) controller, which swings the turbine operating point from the maximum power point tracking (MPPT) curve to the virtual inertia control (VIC) curves by the frequency deviation, is proposed to release the "hidden" kinetic energy and provide dynamic frequency support to the grid. The VIC effects on power oscillation damping capability are theoretically evaluated. The proposed control scheme can provide fast inertial response, and also increase the system damping capability during transient events when compared to the conventional supplementary derivative regulator-based inertia control. Thus, power oscillation damping and inertial response function can be obtained in a single controller by the proposed OPPT control. Here fuzzy logic is used for controlling and compared with PI controller the Simpower systems tool has proved that the combined system will at the same time inject maximum power and provide dynamic frequency support to the grid.

Keywords: Frequency support, Power oscillation damping, variable speed wind turbine, Permanent magnet synchronous generator (PMSG), Virtual inertia control (VIC).

I. INTRODUCTION

IN RECENT years, the reduced inertial response and power damping capability as become a problem due to increased wind power penetration in ac networks, also receiving considerable attention from wind turbine productions and system operators. Depends on these issues it requires not only fault ride through capability of the wind turbines and also the ability to participate in power regulation and frequency during system disturbances, it make the wind farms grid-friendly power generation sources. Thus, the potential control of variable speed wind turbines need be explored further to ensure the stability of power networks containing large-scale wind energy. Outmoded synchronous generators with their inherent inertia naturally contribute to inertial response during frequency events.

Though, variable speed wind turbines do not directly contribute to system inertia due to the decoupled control between the electrical and mechanical systems, thus preventing the generators the system frequency varies.

So that in addition, the power system stabilizer (PSS) is generally equipped in the outmoded synchronous generators to provide power damping, after and during large disturbances. Due to increased wind penetration it is essential for wind turbines to deliver power oscillation damping. But it is critical for weak power systems containing large scale wind farms, damping from synchronous generators may be insufficient and active contribution from wind farms becomes essential.

Now, auxiliary controllers with frequency feedback are introduced to wind turbines to provide system frequency response. However, P/f droop controller equipped in the blade pitch control system can only emulate the primary frequency response, PD controller of the converter employs a df/dt term to emulate additional inertia in the initial frequency change period and deloading controller to shifts the maximum power point tracking (MPPT) curves, the power tracking curve is moved from the MPPT curve to the right suboptimal curve to provide dynamic frequency maintenance for the grid during a frequency event.

However, a smooth recovery to the MPPT operation cannot be realized by these control methods. Moreover, the damping capabilities of these controllers during grid disturbance are not analyzed. The outmoded PSS has been introduced to the DFIG to damp power system oscillations but no frequency support was considered. For all the above work reported, simultaneous damping and inertia control cannot be achieved.

The drive of this study is to investigate different system control to provide simultaneously inertia response and positive damping during oscillation and frequency events. Smooth recovery of wind turbine operation after inertia response also be attained. Due to the increase fame of PMSG-based wind turbine for applications in large wind farm, the proposed integrated control scheme is performed on the PMSG-based wind turbine.

This scheme is organized as follows. The basic control of the PMSG is introduced first. Next the concept of the virtual inertia of PMSG-based variable speed wind turbine and the design of the virtual inertia controller for dynamic frequency support. The damping capability of the proposed virtual inertia controller is analysed to ensure damping test positive coefficient. Based on simulated cases in the MATLAB/Simpower systems environment power system containing two

synchronous generators and a PMSG-based wind turbine are shown to determine the effectiveness of the proposed schemes on providing inertia response and oscillation damping. Finally, the conclusion is drawn in Section VI.



Fig. 1. Schematic control diagram of a PMSG-based wind turbine.

II. CONTROL OF PMSG

The proposed damping and inertia control methods are developed considering the power regulation of PMSG-based wind turbine.

The electromagnetic power of the generator can be controlled using either the gridside converter or generator-side converter. In this paper, the generator-side converter is used to maintain a constant dc-link voltage, whereas the grid-side converter directly controls the generated active power as shown in Fig. 1. So the grid-side converter can fall into current limit during ac voltage dip with reduced power transmission, the generator side converter as the dc voltage control position automatically decreases power generation in order to maintain a constant dc voltage.

This control system provides automatic power balance during ac fault and simplifies fault ride through the control of PMSG. The excess power in the turbine during such disturbances is stored as the kinetic energy of the large rotating masses but only results small speed fluctuation of the PMSG. If required, the acceleration of generator speed can be limited using the pitch control to avoid it from going beyond its rated value.

Under normal operation, the generated power of the wind turbine is controlled under the MPPT according to its rotor speed, and is independent of the grid frequency due to the fast converter control. The reactive power of the PMSG can be controlled to zero or minimize the power loss of the generator or be controlled to maintain the stator voltage. Therefore, the wind turbines do not naturally response to frequency change or provide power system oscillation damping. In order to survey the dynamic response of synchronous generators using PMSG-based wind turbines, advanced control scheme grid frequency deviation need be extra to the grid-side converter's power control loops. Thus, the rotor speed of the PMSGs is regulated to release/store the kinetic energy and to make the "hidden inertia" available to the connected grid, and its flexible power control also be utilized in power system oscillation damping.

It needs to be distinguished the ability for a wind turbine to provide inertia maintenance and damping is based on the condition that the wind turbine and associated generator and the converter system must have the spare power capability. This means that the network disturbance, the wind turbine is operating at below rated power, means wind turbines are usually only partially loaded.

III. VIRTUAL INERTIA CONTROL OF VARIABLE SPEED WIND TURBINES

A. Principle of Virtual Inertia Control (VIC)

The inertia constant H_{tot} of a power system with variable speed wind turbines and synchronous generators can be expressed as

$$H_{\text{tot}} = \left[\sum_{i=1}^{m} (J_{s_i} \omega_e^2 / 2p_{s_i}^2) + \sum_{j=1}^{n} E_{\omega_j}\right] / S_N$$
(1)

where *m* and *n* are the numbers of connected synchronous generators and wind turbines in the grid, respectively. p_{s_i} and J_{s_i} are the numbers of pole pairs and moment of inertia for synchronous generator *i*. E_w is the effective kinetic energy of the wind turbine to the available power system. S_N is the total minimal generation capacity of the power system.

As the stored kinetic energy in variable speed wind turbines during frequency changes cannot be automatically utilized as that of conventional synchronous generators [i.e., $E_w = 0$ in (1)], substituting conventional plants with large numbers of variable speed wind turbines under MPPT control can reduce the effective inertia of the whole system. In addition, without changing the conventional plants if newly installed wind farms are added to the power system, S_N is increased but the total kinetic energy available to the power system remains unchanged. In this case, the effective inertia for the whole system is also reduced.

This can have significant effects for power system operation and could lead to the large frequency deviation. Therefore, it is important to use full stored energy in the wind turbines. To better describe kinetic energy in wind turbines' rotating masses, the explanation of the virtual inertia of variable speed wind turbines is firstly given. The mechanical characteristics of a wind turbine generator can be expressed as

$$Pm - Pe = J_{w}\omega_{r} \frac{dw_{r}}{p_{w}^{2}dt} = \frac{J_{\omega}\omega_{r}d\omega_{r}}{\omega_{s}d\omega_{s}} \times \frac{\omega_{s}d\omega_{s}}{p_{w}^{2}dt} = J_{vir}\omega_{s}\frac{d\omega_{s}}{p_{\omega}^{2}dt}$$
$$J_{vir} = J_{w}\omega_{r}d\omega_{r}/(\omega_{s}d\omega_{s})$$
(2)

112

where p_w is the number of pole pairs of the wind turbine generator and ω_r is the rotor electrical angular speed. P_m and P_e are the mechanical and electromagnetic powers of the wind turbine. J_w is the combined natural inertia of the wind turbine system. J_{vir} is defined as the virtual inertia of the wind turbines.

If wind turbine is controlled to provide dynamic support using its kinetic energy during a frequency change, the released kinetic energy ΔE_k can be obtained from (2) as

$$\Delta E_w = \int (p_m - p_e) dt = \int (J_{vir} \omega_s / p_\omega^2) d\omega_s \tag{3}$$

If converter controls J_{vir} to be constant, by adjusting the rotor speed and to move away from the MPPT point, the effective kinetic energy of the wind turbine compared with a synchronous generator can be expressed as

$$E_w = (1/2) J_{\rm vir} (\omega_e / p_w)^2 \tag{4}$$

According to (1) and (4), the inertia constant H_{tot} of the power system with wind turbines and synchronous generators can be expressed as

$$H_{tot} = \left[\sum_{i=1}^{m} (J_{s_i}/2p_{s_i}^2) \sum_{j=1}^{n} (J_{vir_j}2p_{\omega_j}^2)\right] \omega_e^2 s_N$$
(5)

where p_{w_j} and J_{vir_j} are the numbers of pole pairs and virtual inertia for wind turbine *j*, respectively.

From (3) that the kinetic energy of the wind turbine can be utilized for inertial response by regulating the generated power, and the equivalent inertia of the wind turbine can be expressed as

$$J_{\text{vir}} = \frac{J_{\omega} \,\omega_r d\omega_r}{\omega_s d\omega_s} \approx \frac{\Delta \omega_r}{\Delta \omega_s} \cdot \frac{\omega_{r^0}}{\omega_e} J_{\omega} = \lambda \,\frac{\omega_{r^0}}{\omega_e} J_{\omega} \tag{6}$$
$$\lambda = \Delta \omega_r / \Delta \omega_s = (\omega_e / \omega_{r^0}) \times (J_{\text{vir}} / J_w)$$

where $\Delta \omega_s$ and $\Delta \omega_r$ are the changes of the grid and rotor angular speed during a frequency event, λ is defined as the virtual inertia coefficient and ωr_0 is the pre disturbance rotor speed.

From (6) that the virtual inertia of the wind turbine is determined not only by its natural inertia, but also by the pre disturbance rotor speed ω_{r0} and the virtual inertia coefficient λ . Different to the synchronous generators, whose rotor speeds are coupled directly to the system frequency, i.e., $\lambda = 1$, then the speed variation of the variable speed wind turbine can be much greater than the system frequency variation due to the asynchronous operation, i.e., $\Delta \omega_r > \Delta \omega_e$ and thus $\lambda > 1$. Therefore, the virtual inertia of the PMSG-based wind turbine can be determined several times of its natural inertia.

B. OPPT Control for the Inertial Response

In order to achieve better inertia response, the interaction between the supplementary inertia control and the MPPT control must be avoided. The VIC proposed in this is based on the optimized power point tracking (OPPT) method. When system frequency deviation is detected, the generated power is regulated quickly by switching the turbine operating point from the MPPT curve to the defined VIC curves. By this way, the kinetic energy in the wind turbines can be fully utilized to emulate the inertia response.

The generated power based on the conventional MPPT control can be expressed as

$$\begin{cases}
k_{opt}\omega_r^3, \quad (\omega_0 < \omega_r < \omega_1) \\
\frac{(P_{max} - k_{opt}\omega_1^3)}{(\omega_{max} - \omega_1)}(\omega_r - \omega_{max}) + \\
P_{max} (\omega_1 < \omega_r < \omega_{max}) \\
P_{max}, \quad (\omega_r > \omega_{max})
\end{cases}$$
(7)

where k_{opt} is defined as the MPPT curve coefficient and ω_0 is the cut-in angular speed. To avoid an abrupt power change around the maximum speed ω_{max} , a droop characteristic of



Fig. 3. Scheme of the VIC-based power point tracking curve.

 $P - \omega$ is used for constant speed stage, ω_1 is initial angular speed in this stage. P_{max} is the maximum active power output of the PMSG.

From (7) it can be observed that different curve coefficients will generate a series of power tracking curves, as VIC curves. Thus, the regulation of the PMSG's operation point can be achieved by moving it from the MPPT curve with coefficient k_{opt} to the VIC curve with coefficient k_{VIC} .

The principle of the OPPT control scheme for virtual inertial response is shown in Fig. 3. The wind velocity is assumed to remain at constant 8 m/s in this example. The impact of such wind speed variation, on the effectiveness of the OPPT control will be

further explored in future work. In the event of a system frequency drop, the wind turbine needs to decelerate to release the stored kinetic energy. Thus, the coefficient k_{opt} is increased and the power tracking curve is switched to the VIC curve. The operating point moves from the initial point A to B and then along the P_{VIC_max} curve to C. The rotor speed at point C (ω_{r1}) can be expressed using the frequency deviation as

$$\omega r 1 = \omega r 0 + \Delta \omega r = \omega r 0 + \lambda \Delta \omega s = \omega r 0 + 2\pi \lambda \Delta f.$$
(8)

If the speed of wind remains constant, the captured active power at point A can be considered to be similar to that at point C for small rotor speed range. Thus, the VIC curve coefficient k_{VIC} can be calculated as

$$k_{\rm VIC} = \left[\omega_{r0}^3 / (\omega_{r0+} 2\pi\lambda\Delta f)^3 \right] k_{\rm opt}$$
(9)

From (9), the VIC curve coefficient k_{VIC} is the function of the frequency deviation and replaces the constant coefficient k_{opt} of the MPPT curve. As illustrated in Fig. 3, in the event of a frequency drop, the dynamic response of the VIC can be divided into two stages: 1) fast dynamic frequency support stage (A \rightarrow B \rightarrow C) and 2) slow rotor speed recovery stage (C \rightarrow A). Once the frequency decreases, k_{VIC} increases from the original value k_{opt} and rapidly reaches its upper limit during the first stage. Then the corresponding power reference curve will then be shifted from P_{opt} to P_{vic_max} and the turbine's operating point is shifted from A to B where its output power changed from *P*A to *P*B. Since the generated power is greater than the captured mechanical power, the rotor decelerates and the operating point moves along the P_{vic_max} curve to the operating point C. Consequently, the kinetic energy is stored in the rotating mass and is released to support the grid frequency.



Fig. 4. Structure diagram of the OPPT regulator-based VIC.

After the initial dynamic frequency response, the frequency gradually tends to stabilize with the power system's primary frequency regulation. If the power reference curve is switched from P_{vic_max} to P_{opt} directly, a large power step from *P*C to *P*F will be injected to the grid, which may result in further frequency oscillation during this recovery progress. Though, using the proposed VIC method, the power reference curve will recover to MPPT curve gradually according to (9). Fig. 3 shows a special case where the recovery progress from C to A involves switching the operating point from three power reference curves. In reality, the VIC curve

coefficient is continuously changed from k_{max} to k_{opt} during the frequency recovery due to the continuous variation of the frequency deviation. Therefore, the rotor speed of the DFIG will smoothly recover to the initial MPPT point. In a similar way, the regulation progress during grid frequency increase can be described as the circle line of $A \rightarrow D \rightarrow E \rightarrow A$ in Fig. 3. In Fig. 4 A wash out filter is used to eliminate the steady-state dc component of the frequency error.

IV. IMPACT OF VIC ON POWER OSCILLATION DAMPING

Normal variable speed wind turbines generate power in accordance with the wind speed and do not respond to grid disturbance such as power oscillations. The high wind penetration may experience higher oscillations after disturbance due to reduced system damping. However, if the VIC regulator is implemented in the wind turbines, the fluctuation of the generated active power as the result of inertia control can also affect power oscillation, which could lead to further reduction of system damping. Such potential risk on stable system operation with reduced power oscillation damping may prevent inertial control from being widely applied to wind turbines, even if an improved frequency performance can be achieved.

The equivalent circuit of a three-machine power system, as shown in Fig. 5, is used here for the theoretical evaluation of the effect on damping capability. In Fig. 5, Bus B₂ is the swing bus; V_G is the wind farm grid connection point voltage; E' is the q-axis transient voltage; V is the terminal voltage of G₁; θ is the phase angle between E' and V_G ; δ is the phase angle between E' and V; and δ_0 , θ_0 , and V_{G0} are the initial values of δ , θ , and V_G , respectively. x_1 and x_2 are the line reactance.



Fig. 5. Equivalent circuit of the power system with wind farms.

The active and reactive powers of the synchronous generator G2 can be expressed as

$$P_{\rm G} = (E'V_{\rm G}/x_1)\sin\theta \tag{10}$$

$$Q_{\rm G} = (E'V_{\rm G}/x_1)\cos\theta - V_{\rm G}^2/x_1 \tag{11}$$

The rotor motion equations of G2 can be written as

$$H_{\rm G}({\rm d}\omega_{\rm s}/{\rm d}t) = P_{\rm Gm} - P_{\rm G} - D(\omega_{\rm s} - \omega_{\rm e}) \tag{12}$$

$$d\delta/d \ t = \omega_s - \omega_e \tag{13}$$

where H_G , P_{Gm} , PG, and ωs are the inertia constant, electromagnetic power, mechanical power, and angular velocity of G2, respectively. D is the damping coefficient.

Assuming that mechanical power PGm remains constant throughout the transient process, the rotor motion equations developed by the small perturbation method can be expressed as

$$H_{GP}^2 \Delta \delta + D_p \Delta \delta + \Delta P_G = 0 \tag{14}$$

where ΔPG is the active power variation of G2 and p is the differential divisor. In a linear system, the impact of the active power regulation and the grid voltage variation for the system damping can be described by a set of linear ordinary equations, which can be solved, respectively. Hence, the connection point voltage VG can be regarded as a constant in the analysis of the active power regulation for system damping.



Fig.6. Simulation system Schematic diagram.

V. FUZZY LOGIC CONTROL

The Fuzzy logic control consists of set of linguistic variables. Here the PI controller is replaced with Fuzzy Logic Control. The mathematical modelling is not required in FLC. FLC consists of

1. Fuzzification

Membership function values are assigned to linguistic variables. In this scaling factor is between 1 and -1.

2. Inference Method

There are several composition methods such as Max-Min and Max-Dot have been proposed and Min method is used.

3. Defuzzificaion

A plant requires non fuzzy values to control, so defuzzification is used. The output of FLC controls the switch in the inverter. To control these parameters they are sensed and compared with the reference values. To obtain this the membership functions of fuzzy controller are shown in fig (7).

The set of FC rules are derived from

$$u = -[\alpha E + (1 - \alpha) * C]$$
 (15)

Where α is self-adjustable factor which can regulate the whole operation. E is the error of the system, C is the change in error and u is the control variable. A large value of error E indicates that given system is not in the balanced state. If the system is unbalanced, the controller should enlarge its control variables to balance the system as early as possible.



Fig.7. Fuzzy logic Controller



VI. SIMULATION RESULTS *A. Responses Under Sudden Load Change*

(c) Fig. 8. Dynamic responses of the network during load L1 sudden increase 1 kW. (a) Without VIC. (b) VIC ($\lambda = 1$). (c) VIC ($\lambda = 9$).

The impact of different virtual inertia coefficients on the wind turbine inertia response and system frequency is tested first, and the results are shown in Fig. 8.

The wind velocity was set as 8 m/s by the motor-based emulator and the PMSG-based turbine initially operated at the maximum power point. During the test, Load L1 was increased from 5.2 to 6.2 kW causing a temporary fall of the system frequency. In Fig. 8(a)–(c), the dynamic responses of the network frequency, the PMSG' active power Pg, G1's active power output PG1, and G2's active power output PG2 are compared for different control methods and different virtual inertia coefficients λ . Without the proposed VIC scheme as shown in Fig. 8(a), the active power of the wind turbine remains almost constant at 1.7 kW

A large frequency drop of 0.55 Hz can be observed due to the small system inertia. For the OPPT control scheme, the virtual inertia responses of the PMSG can be regulated by adopting different value of the virtual inertia coefficient λ . The wind turbine switches the control mode from the MPPT control to the VIC control when the frequency deviation occurs. Results shown in Fig. 8(b) with $\lambda = 1$, the active power of the wind turbine is increased by 0.25 kW and a reduced frequency drop of 0.45 Hz is observed compared to system without VIC. To further increase the virtual inertia of the wind turbine, $\lambda = 9$ is used and the results are shown in Fig. 8(c).

It can be seen from Fig. 8(c) that the wind turbine output active power is increased by 0.63 kW, which results in a much smaller frequency drop of 0.21 Hz. This represents 61.8% reduction in frequency deviation compared to system without VIC shown in Fig. 8(a). With G1's primary frequency regulation, the frequency deviation gradually reduces and the system frequency recovers to its normal value after 16 s. During the recovery progress, the output power of the PMSG decreases slowly to avoid unnecessary disturbances and provides a smooth recover even with the large λ of 9.

B. Comparison with Supplementary Derivative Control During Load Increase

To further illustrate the advantages of the proposed VIC scheme on inertia support and system damping, simulation results are compared for the three cases: 1) *Case A*: without inertia control; 2) *Case B*: with the supplementary derivative control; and 3) *Case C*: with the proposed OPPT control. During the tests, L1 was increased from 5.2 to 6.2 kW and the results for the three cases are shown in Fig. 9(a)–(c), respectively. As shown in Fig. 9, compared to Case A, the frequency nadir and the change rate are reduced when inertia control is applied in Case B and Case C. Furthermore, Case C with the proposed VIC has the smallest frequency drop and smoothest reactance.

This can be explained by observing the wind turbine power outputs between the proposed OPPT controller and the supplementary controller. As shown, the output power of the wind turbine with the supplementary inertia control shown in Fig. 9(b) only provides frequency support for the initial 5 s, while the duration of the more effective power support in Case C is about 10 s. In contrast to Case B where significant oscillations are observed during recovery, Case C provides a stable and smooth recovery after inertia support. In fact, the variation of p_{opt}^* of the MPPT controller.



Fig. 9. Comparison of the inertia response during sudden load increase. (a) Case A. (b) Case B. (c) Case C

C. Comparison With Supplementary Derivative Control on Power Oscillation Damping After Short Circuit Fault

In order to compare the effects of the OPPT control and the supplementary derivative control on power system oscillation damping, a 0.1-s three-phase short-circuit fault at Bus B2 was applied. The initial wind speed was 8 m/s and λ was set to an intermediate value of 7. In Fig. 10, the ac voltage, the dc-link voltage of the PMSG's converters, the wind turbines' active power, and the active power of G1 are compared under the three same cases illustrated in the previous section. The severity of the three-phase short-circuit fault can be seen from the ac voltage waveforms shown in Fig. 10(a).



Fig. 10. Dynamic responses of the network after short-circuit fault. (a) AC voltage with Case A. (b) Case B. (c) Case C.

For case A shown in Fig. 10(a), when the short-circuit fault happens, the grid-side converter goes into current limit and its active power export to the grid is reduced. Since the generator-side converter controls the dc-link voltage, it automatically reduces power output from the PMSG and consequently the dc-link voltage remains stable with only less than 5% increase.

During the fault period, the surplus mechanical power in the wind turbine is stored as kinetic energy in the wind turbines' rotating masses. However, the power oscillation in this weak network cannot be damped effectively, since the wind turbine makes no contribution to system damping under this basic control scheme. As shown in Fig. 10(b) for Case B, the fast active power response from the wind turbine to the network frequency variation is generated by the supplementary derivative controller. Due to the adverse effect of this control resulting in reduced system damping, the system oscillates for a prolonged period after fault clearance. Compared to Case A, the increased dc link voltage and power oscillations can seriously affect the wind turbine operation and grid stability.

In Fig. 10(c), with the OPPT control, power oscillations in G1 are significantly reduced. Compared to Case A, the amplitude of G1's power oscillation is much lower and its duration is reduced from around 6 to 3s. This proves that the active power fluctuation of the wind turbines generated by the proposed controller helps damp the power oscillation. The dc-link voltage also well maintained. Therefore, Case C achieves the best power oscillation damping performance among the three cases.

D. Comparison with Supplementary Derivative Control After Short-Circuit Fault and Load Increase



Fig.11. Dynamic responses of the system after short-circuit fault and load increase. (a) Case A. (b) Case B. (c) Case C.

System operation during a 0.1-s three-phase short-circuit fault at Bus B2 immediately followed by a 1-kW load increase is tested to further illustrate the performance of the proposed OPPT control. The experimental results for the three cases are shown in Fig. 11.

Under such test conditions, the initial frequency change and power oscillations are generated by the short-circuit fault. The system frequency then decreases due to load increase. The dynamic response of the network frequency with supplementary derivative control is better than that with no inertia control as evident from Fig. 11(a) and (b). However, the power oscillations are not effectively suppressed in Case B due to the lack of system damping. Again the proposed OPPT control has the best performance of frequency support and power oscillation damping among the three cases. This is due to the fact that the proposed OPPT control provides simultaneous inertia response and system damping. Thus, the controller can provide additional benefit for dynamic stability of power systems and is well suited for wind power applications

VII. CONCLUSION

This paper investigates power regulation of PMSG-based wind turbines during transient events for enhancing the grid inertial response and damping capability. VIC based on OPPT for PMSG-based wind turbine is proposed to provide inertial response and power oscillation damping. The MATLAB/Simpower systems simulation shows sensible performances of this controller. Here fuzzy controller is used compared to alternative controllers because of its accurate performance. The main conclusions drawn from the proposed control method are as follows.

1) AC networks with high wind power penetration are likely to have reduced effective inertia and damping capability Thus, wind turbines equipped with virtual inertia and oscillation damping functions become increasingly necessary for ensuring system stability.

2) Equated with the supplementary derivative control, the proposed OPPT control scheme avoids negative interactions between inertia response and the MPPT control. The OPPT method can change the emulated inertia of the wind turbines by adjusting the virtual inertia coefficient, a smoother recovery is also achieved after inertia support.

3) Different from the supplementary derivative control, OPPT control can also contribute system damping. Thus, the proposed OPPT control scheme for wind turbines has both inertial response and positive damping function, providing an improved active power support for improved system stability.

REFERENCES

[1] N. Miller and P. E. Marken, "Facts on grid friendly wind plants," in *Proc. IEEE Power Energy Soc. Gen. Meeting*, 2010, pp. 1–7.

- [2] J. Morren, S. de Haan, W. Kling, and J. Ferreira, "Wind turbines emulating inertia and supporting primary frequency control," *IEEE Trans. Power Syst.*, vol. 21, no. 1, pp. 433–434, Feb. 2006.
- [3] J. Ekanayake and N. Jenkins, "Comparison of the response of doubly fed and fixed-speed induction generator wind turbines to changes in network frequency," *IEEE Trans. Energy Convers.*, vol. 19, no. 4, pp. 800–802, Dec. 2004.
- [4] G. Tsourakis, B. M. Nomikos, and C. D. Vournas, "Contribution of doubly fed wind generators to oscillation damping," *IEEE Trans. Energy Convers.*, vol. 24, no. 3, pp. 783–791, Sep. 2009.
- [5] J. M. Mauricio, A. Marano, A. G. Expósito, and J. L. M. Ramos, "Frequency regulation contribution through variable-speed wind energy conversion systems," *IEEE Trans. Power Syst.*, vol. 24, no. 1, pp. 173–180, Feb. 2009.
- [6] D. Gautam, L. Goel, R. Ayyanar, V. Vittal, and T. Harbour, "Control strategy to mitigate the impact of reduced inertia due to doubly fed induction generators on large power systems," *IEEE Trans. Power Syst.*, vol. 26,no. 1, pp. 214–224, Feb. 2011.
- [7] G. Lalor, A. Mullane, and M. O'Malley, "Frequency control and wind turbine technologies," *IEEE Trans. Power Syst.*, vol. 20, no. 4, pp. 1905–1913, Nov. 2005.
- [8] J. M. Mauricio, A. Mano, A. G. Exposito, and J. L. M. Ramos, "Frequency regulation contribution through variable-speed wind energy conversion systems," *IEEE Trans. Power Syst.*, vol. 24, no. 1, pp. 173–180, Feb. 2009.
- [9] L. R. C. Chien, W. T. Lin, and Y. C. Yin, "Enhancing frequency response control by DFIGs in the high wind penetrated power systems," *IEEE Trans. Power Syst.*, vol. 26, no. 2, pp. 710–718, May 2011.
- [10] Z. X. Miao, L. L. Fan, D. Osborn, and S. Yuvarajan, "Control of DFIG based wind generation to improve inter area oscillation damping," *IEEE*.
- [11] F. M. Hughes, O. A. Lara, N. Jenkins, and G. Strbac, "A power system stabilizer for DFIG-based wind generation," *IEEE Trans. Power Syst.*, vol. 21, no. 2, pp. 763–772, May 2006.
- [12] D. Gautam, V. Vittal, R. Ayyanar, and T. Harbour, "Supplementary control for damping power oscillations due to increased penetration of doubly fed induction generators in large power systems," in *Proc. IEEE Power Syst. Conf. Expo.*, 2011, pp. 1–6.
- [13] L. L. Fan, H. P. Yin, and Z. X. Miao, "On active/reactive power modulation of DFIG-based wind generation for inter area oscillation damping," *IEEE Trans. Energy Convers.*, vol. 26, no. 2, pp. 513–521, Jun. 2011.

AUTHOR'S PROFILE:

B.TEJASWI : She was born in 1992. She obtained her Bachelor degree in Electrical and Electronics Engineering in 2013 from RVPECW, Kadapa. Currently Pursuing her Post Graduation in Electrical Power Engineering in AITS, Rajampet, Kadapa(dist.).