ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)
Vol 3, Issue 9, September 2017

Simultaneous Control of PMSG Based Wind Turbines for System Inertial Response and Power Oscillation Damping

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***Abstract*: -- To improve the power oscillation damping capability and inertial response during transient events, this investigation is considered to be an improve active-power control for changeable-speed wind turbines. The OPPT controller, which the operating point of turbine shifts from the MPPT (Maximum Power Point Tracking) curves to the VIC curves according to the frequency-deviation, it emits the "hidden" kinetic energy and offer dynamic-frequency support toward the electrical grid. The proposed system was modeled and simulated in MATLAB/Simulink environment. At this point fuzzy logic is used for controlling and comparing with PI controller, it simultaneously provide the dynamic frequency support and injects the maximum-power to electrical- grid..**

***Index Terms* —Dynamic frequency support, MPPT (Maximum Power Point Tracking), PMSG (Permanent Magnet Synchronous Generator), Optimized Power Point Tracking (OPPT), Virtual Inertia Control (VIC).**

I. INTRODUCTION

In modern years, the decreased oscillation damping capability and inertial response has became the difficult, because of the bigger wind power penetrations in the ac networks, as well from the wind turbines making and oper-ators of system get the considerable attention. Depends on these concerns, this requires not only fault ride through-ability of wind turbines and also during the system disturb-ances, consider ability to involve in the power regulations and frequency. It makes wind farms as grid friendly power generation sources. Therefore, the potential control of changeable speed wind-turbines need be discovered further to make sure the stability power networks containing large-scale wind energy. During frequency events, traditional synchronous generators with their inherent inertia are naturally contrib-uting the inertial response. Though, changeable speed of the wind turbines do not directly add to system inertia because of the decoupled control between the electrical and mechanical systems. So that additionally in the conventional synchro-nous generators set the power system stabilizer (PSS) is to provide the power oscillation damping after and during large disturbances. It is important for wind turbines to send the power fluctuation damping, due to enlarged wind penetra-tions. But this is dangerous to the weak power systems con-sisting large scale wind farms, active power contribution and also system damping of synchronous generator from the wind farms becomes important. Now, auxiliary controllers of frequency-feedback is bringing in to wind turbines to provide system-frequency response. However, the system can only follow the primary frequency response when the P/f droop controllers set in blade pitch-control, the PD controller of the converter utilizes a df /dt term to follow additional inertia in the initial frequency change period and de-loading controller to transfer the MPPT curves, the curve power tracking is shifted from the curve MPPT to the curve right sub-optimal to provide Dynamic-frequency maintenance for the electrical grid during at frequency event. However, by using these methods of controlling, is cannot be realized a smooth re-covery of the MPPT operation.

II. CONTROL OF PMSG

In this paper the regulation of power for PMSG-Based turbine, inertia and damping method of controlling is pro-posed. By using either generator side converter or grid side converter we can control the electro-magnetic power of the wind generator. In this proposed method, the generated active power can controlled directly by using grid side converter, and the generator side converter can maintaining the constant dc-link voltage. During dips in voltage the converter at the grid limits the current by reducing power transmission in order to maintain the DC of constant dc voltage. During fault, this scheme of control provides power balance automatically by improving fault ride capability. In such disturbance, the surplus power is stored in the form of kinetic energy resulting only small fluctuations of speed in PMSG. The speed of generator is within constraints by pitch control. By em-ployment of fast converter control, the generator of power can be controlled under MPPT and also reactive power can be maintained to zero. So that it provides the oscillation damp-ing. In order to improving the dynamic response of a system additional advanced scheme of loop at the grid sided con-verter. Which damps the oscillations and regulates flexible control of power? In order to follow the dynamic response of the synchronous-generators with PMSG_based wind tur-bines, highly developed control schemes are considering the grid-side converter's, power control loops need to be added the grid frequency deviation. therefore, the speed of the rotor of PMSGs are regulated to store or release the kinetic energy to create the "hidden inertia" available to the connected electrical-grid, and this flexible control power can also be used to contribute in power system oscillation damping. For a wind turbine, it necessitates to be eminent the ability to grant damping and inertia maintenance is based on condition, that the associated generator plus wind turbine and the converter system should have the standby power capability. This means, in disturbance of network, the wind turbine is working at underneath rated power, means wind turbines are generally only partly loaded.

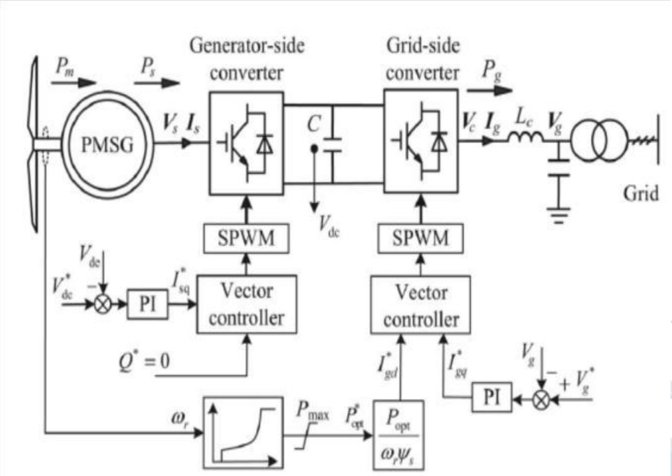


Fig. 1. Schematic control diagram of a PMSG-based wind turbine.

III. VIRTUAL INERTIA CONTROL OF VARIABLE-SPEED WIND TURBINES

A. Principle of VIC (Virtual Inertia Control):

The power system inertia constant (Htot) with variable speed of the wind turbines and synchronous generators is expressed as

$$H_{tot} = \left[\sum_{i=1}^{m} \left(J_{s\_i} \omega_e^2 \Big/ 2p^2_{s\_i} \right) + \sum_{j=1}^{n} E_{\omega\_j} \right] \Big/ S_N \;\ldots\ldots(1)$$

where $p_{s\text{-}i}$ and $J_{s\text{-}i}$ are the number of pole pairs and moment of inertia of the ith synchronous generator, respectively. In the grid where *m* and *n are* the number of connected synchronous generators and number of wind turbines, respectively. S_N is the power system of total minimum generation capability. E_ω is wind turbine of effectual kinetic energy to existing power system.

During frequency changes, variable speed wind turbines cannot utilizes the stored kinetic energy automatically, as that of traditional synchronous generators [i.e., E = 0 in (1)], are placing in conventional plants with huge numbers of changeable speed wind turbines under control of MPPT can reduce the effective inertia of the whole system. In addition, without shifting the conventional plants if lately installed wind farms are addition to the power system, SN is improved but the total available kinetic energy to the power system remains unaffected. In this case, the effectual inertia for the entire system is also reduced. This can have important effects on power system operation and its leads huge frequency deviation. as a result, it is essential to use total stored energy in wind turbines. To better depict first give the kinetic energy in rotating masses, wind turbines and the details of the virtual inertia of variable speed wind turbines. The wind turbine generator of mechanical characteristics can be expressed as

$$\begin{cases} P_m - P_e = J_\omega \omega_r \dfrac{d\omega_r}{p_\omega^2 dt} = \dfrac{J_\omega \omega_r d\omega_r}{\omega_s d\omega_s} \times \dfrac{\omega_s d\omega_s}{p_\omega^2 dt} = J_{vir} \omega_s \dfrac{d\omega_s}{p_\omega^2 dt} \ldots.(2) \\ J_{vir} = J_\omega \omega_r d\omega_r / (\omega_s d\omega_s) \end{cases}$$

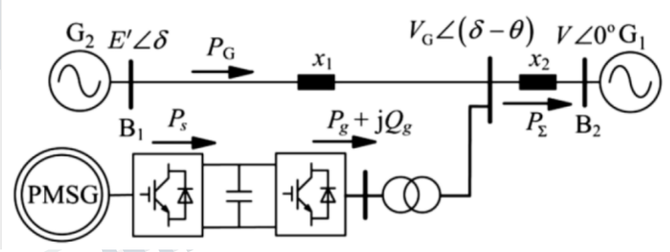


Fig. 2. Equivalent circuit of the power system with wind farms.

where Pm, Pe are mechanical and electromagnetic powers of wind turbine. Pw is wind turbine generator of number of pole pairs and ωr is angular speed of rotor electrical. Jvir and Jw are wind turbines of the virtual inertia and combined natural inertia. During a frequency varying, If wind turbine is controlled to offers dynamic support by means of its kinetic energy, the released kinetic energy (ΔEk) can be attained from_(2)-as

$$\Delta E_\omega = \int (P_m - P_e) dt = \int \left(J_{vir} \omega_s \big/ p_\omega^{\,2} \right) d\omega_s \;\ldots\ldots.(3)$$

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

$$E_\omega = (1\ 2) J_{vir} \left(\omega_e\ \ p_\omega \right)^2 \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (4)$$

From equations (1) and (4), the Htot (inertia constant) of the power system among synchronous generators and wind turbines can be expressed as

$$H_{tot} = \left[\sum_{i=1}^{m} \left(J_{s\_i} \; 2p^{2}_{s\_i} \right) + \sum_{j=1}^{n} \left(J_{vir\_j} \; 2p_{\omega}^{2}{}_{\_j} \right) \right] \omega_e^2 \; S_N \text{.....(5)}$$

where Jvir-j and pw-j are jth wind turbine of virtual inertia and kinetic energy of wind turbine can be used for inertial response by controling the generated power, and the equivalent inertia of the wind turbine can be expressed as

$$\begin{cases} J_{vir} = \dfrac{J_{\omega}\omega_r d\omega_r}{\omega_s d\omega_s} \approx \dfrac{\Delta\omega_r}{\Delta\omega_s} . \dfrac{\omega_{r0}}{\omega_e} J_{\omega} = \lambda \dfrac{\omega_{r0}}{\omega_e} J_{\omega} \\ \lambda = \Delta\omega_r / \Delta\omega_s = \left(\omega_e/\omega_{r0}\right) \times \left(J_{vir}/J_{\omega}\right) \end{cases} \text{..........................(6)}$$

where λ is defined as the virtual inertia coefficient and ωr0 is the pre-disturbance rotor speed. During a frequency event $\Delta\omega_s$ and $\Delta\omega_r$ are the variable of the grid and rotor angular speed, From (6), not only by its natural inertia the virtual inertia of the wind turbine is determined, and also by the pre interruption rotor speed ω_{r0} and the virtual inertia coefficient λ. dissimilar to the synchronous generators, whose rotor speeds are coupled directly to the system frequency, i.e., λ = 1, then the speed deviation of the changeable speed wind turbine can be much larger than the system frequency deviation because of 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.

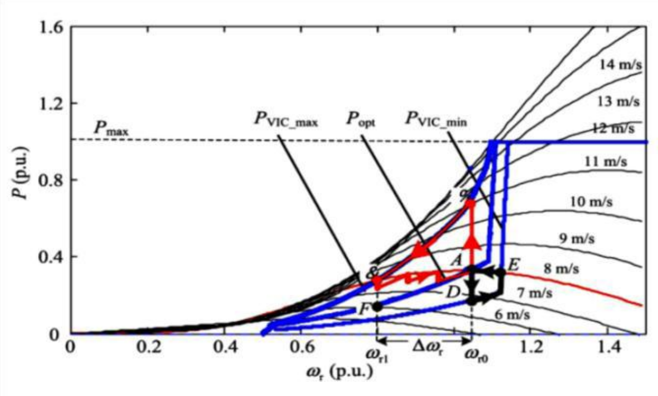


Fig. 3. Scheme of the VIC-based power point tracking curve

B. OPPT Control for the Inertial Response

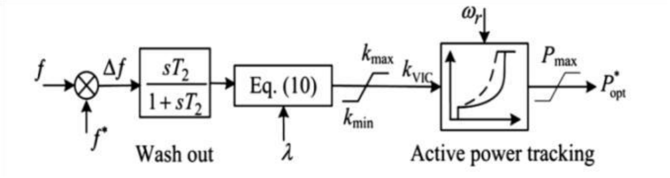
In order to achieve better inertia response, the interaction between the supplementary inertia control and the MPPT control must be avoided. The VIC proposed in this is based on the optimized power point tracking (OPPT) method. When system frequency deviation is detected, the generated power is regulated 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

$$P^{*}_{opt} = \begin{cases} k_{opt}\,\omega_r^{3} \text{ ,..} (\omega_0 < \omega_r < \omega_1) \\ \dfrac{\left(P_{\max} - k_{opt}\omega_1^{3}\right)}{\left(\omega_{\max} - \omega_1\right)} \left(\omega_r - \omega_{\max}\right) + P_{\max} \text{ ,...}(\omega_1 < \omega_r < \omega_{\max}) \\ P_{\max} \text{ ,..} (\omega_r > \omega_{\max}) \end{cases} \text{..(8)}$$

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 P − ω is used for constant speed stage, ω1 is initial angular speed in this stage. P_{max} is the maximum active power output of the PMSG. From (8), 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 kopt 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 (ωr1) can be expressed using the frequency deviation as

$$\omega_{r1} = \omega_{r\,0} + \Delta\omega_r = \omega_{r\,0} + \lambda\Delta\omega_s = \omega_{r\,0} + 2\pi\lambda\Delta f \text{ .... (9)}$$

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 kVIC can be calculated as



From (9), the VIC curve coefficient is the function of the frequency deviation and replaces the constant coefficient 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 → B → C) and 2) slow rotor speed recovery stage (C → A). Once the frequency decreases, increases from the original value and rapidly reaches its upper limit during the first stage. Then the corresponding power refer- ence curve will then be shifted from to and the turbine's operating point is shifted from A to B where its output power changed from PA to PB. Since the generated power is greater than the captured mechanical power, the rotor decelerates and the operating point moves along the curve to the operating point C. Consequently, the kinetic energy is stored in the rotating mass and is released to support the grid frequency. After the initial dynamic frequency response, the fre-quency gradually tends to stabilize with the power system's primary frequency regulation. If the power reference curve is switched from to directly, a large power step from PC to PF 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 refer-ence curve will recover to MPPT curve gradually according to (8). Fig. 3 shows a special case where the recovery pro-gress from C to A involves switching the operating point from three power reference curves. In reality, the VIC curve coefficient is continuously changed from to dur-ing 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 → D → E → 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 busV_G is the wind farm grid connection point voltage;E' is the q-axis transient voltage; V is the terminal voltage of G_1, θ ; is the phase angle between E' and V_G; δ is the phase angle between and E' and V and V_{GO} are the initial values of θ, δ and V_G , respectively. x_1 and x_2 are theline reactance. The active and reactive powers of the synchronous generator can be expressed as

$$P_G = (E'V_G/x_1)\sin\theta \qquad (10)$$

$$Q_G = (E'V_G/x_1)\cos\theta - {V_G}^2/x_1 \qquad (11)$$

The rotor motion equations of G2 can be written as

$$H_G(d\omega_s/dt) = P_{Gm} - P_G - D(\omega_s - \omega_e) \qquad (12)$$

$$d\delta/dt = \omega_s - \omega_e \qquad (13)$$

Where H_G, P_{GM}, P_G, and ω_S are the inertia constant, electromagnetic power, mechanical power, and angular velocity ofG_2,respectively.D is the damping coefficient. Assuming that mechanical power p_{GM} remains constant throughout the transient process, the rotor motion equations developed by the small perturbation method can be expressed as

$$H_G p^2 \Delta\delta + Dp\Delta\delta + \Delta P_G = 0 \qquad (14)$$

where ΔP_G is the active power variation of G_2 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 V_G can be regarded as a constant in the analysis of the active power regulation for system damping

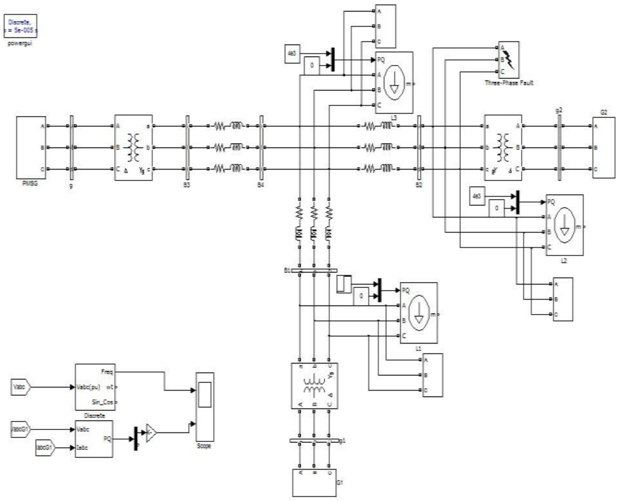


Fig.5. Simulation system Schematic diagram

VI. SIMULATION RESULTS

A. Responses Under Sudden Load Change

The impact of different virtual inertia coefficients on the wind turbine inertia response and system frequency is tested in the existing method. 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 Figures, the dy-namic responses of the network frequency, the PMSG' active power Pg, G_1' , active power output PG_1 , and G_2 's active power output P_{G2}

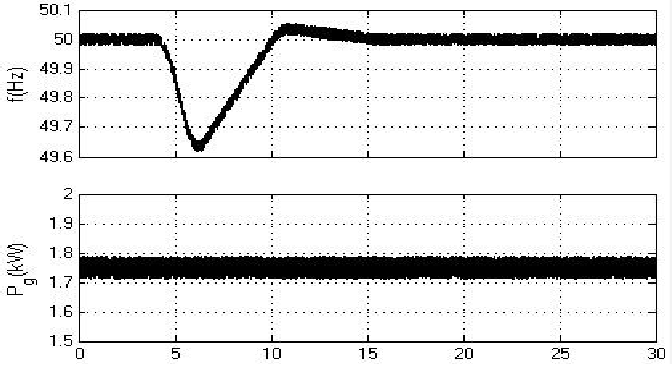
are compared for different control meth-ods and different virtual inertia coefficients . Without the proposed VIC scheme as shown in Figure, the active power of the wind turbine remains almost constant at 1.7 kW A large frequency drop of 0.55 Hz can be observed due to the small system inertia. For the OPPT control scheme, the vir-tual inertia responses of the PMSG can be regulated by adopting different value of the virtual inertia coefficient. The wind turbine switches the control mode from the MPPT control to the VIC control when the frequency deviation occurs. Results shown with $\lambda = 1$,the active power of the wind turbine is increased by 0.25 kW and a reduced fre-quency 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. It can be noticed 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. With $G_{1'S}$ 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.

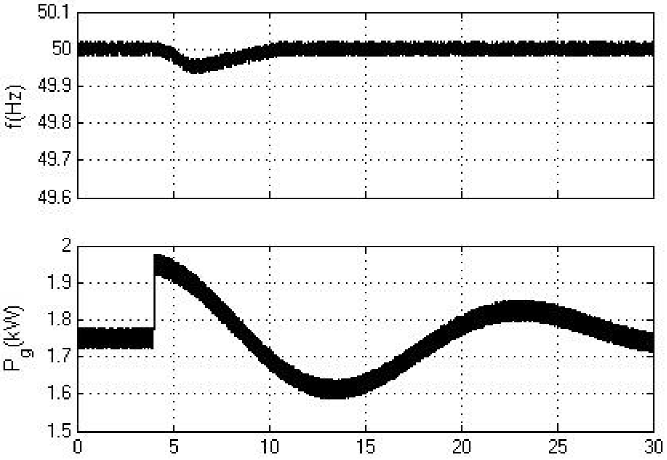
B. Comparison with Supplementary Derivative Control During Load Increase

To further illustrate the advantages of the proposed VIC scheme on inertia support and system damping, simulation results are compared for the three cases:

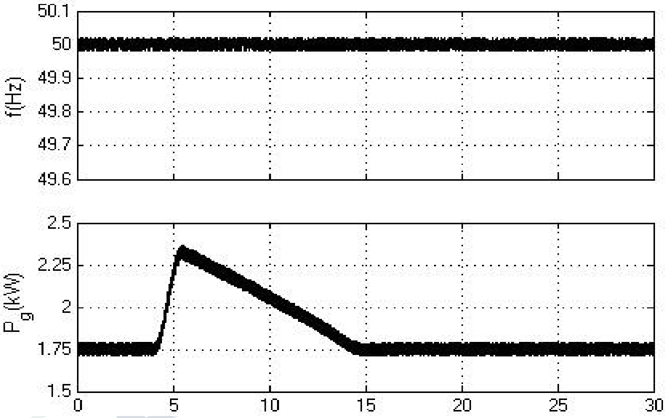
1) Case A: without inertia control; 2) Case B: with the supplementary derivative control; and 3) Case C: with the proposed OPPT control. During the tests, L_1 was increased from 5.2 to 6.2 kW and the results for the three cases are shown in Fig. 7(a)–(c), respectively.



(a)



(b)



As shown in Fig. 7, 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 inertia control shown in Fig. 7(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 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.

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 B_2 was applied. The initial wind speed was 8 m/s and λ was set to an intermediate value of 7. In Fig. 8, the ac voltage, the dc-link voltage of the PMSG's converters, the wind turbines' active power, and the active power of G_1 are compared under the three same cases illustrated in the previous section.

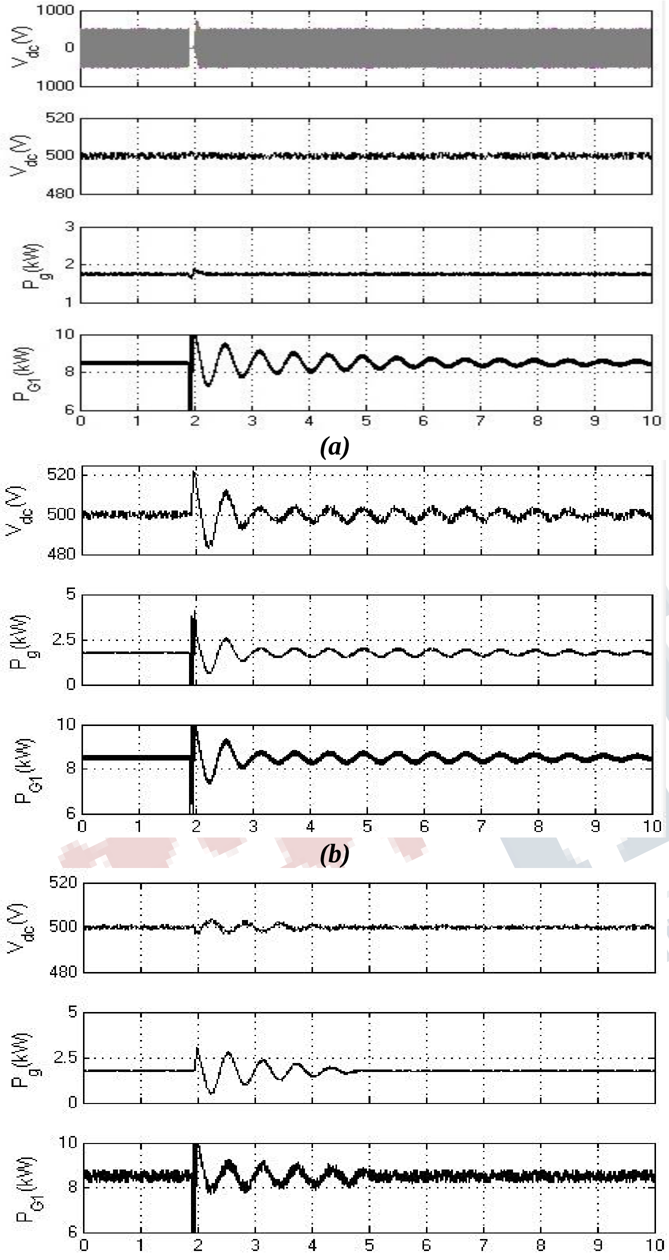


Fig. 8. Dynamic responses of the network after short-circuit fault.

(a) AC voltage. (b) Case A. (c) Case B. (d) Case C.

The severity of the three-phase short-circuit fault can be seen from the ac voltage waveforms shown in Fig. 8(a). For case A shown in Fig. 8(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 (<5%) increase. During fault period, the spare mechanical power in the wind turbines is save as kinetic energy in the wind turbines' ro-tating 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. According to shown in the Fig. 8(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**.**

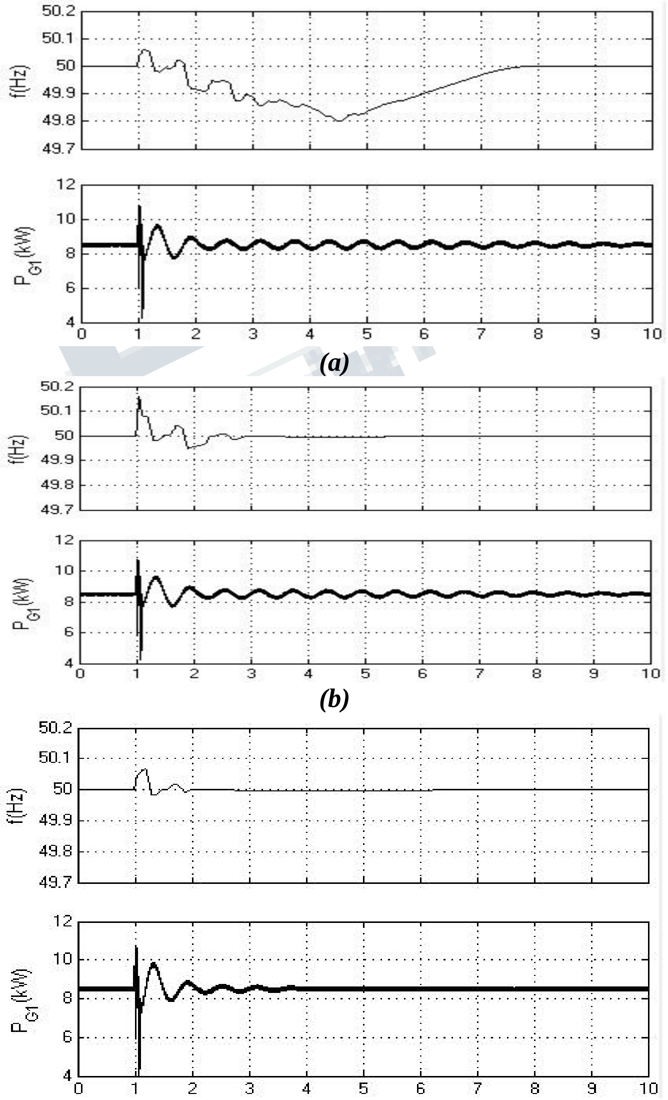


Fig. 9. Dynamic responses of the system after short-circuit fault and load increase. (a) Case A. (b) Case B. (c) Case C.

Compared to Case A, the increased dc link voltage and power oscillations can seriously affect the wind turbine op-eration and grid stability. In Fig. 8(c), with the OPPT control, power oscillations in G1 are significantly reduced. Compared to Case A, the amplitude of $G_1{}'_S$ 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

System operation during a 0.1-s three-phase short-circuit fault at Bus B2 immediately followed by a 1-kW load in-crease is tested to further illustrate the performance of the proposed OPPT control. Under such test conditions, the ini-tial 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. 9(a) and (b). However, the power oscillations are not effectively sup-pressed in Case B due to the lack of system damping. Again the proposed OPPT control has the best performance of frequency support and power oscillationdamping 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

V. CONCLUSION

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

AC networks with heavy wind power penetration are likely to have reduced effective damping capability and in-ertia Thus, wind turbines set with oscillation damping and virtual inertia functions become increasingly necessary for ensuring system stability.

Different from the supplementary derivative control, OPPT control can also contribute system damping. Thus, the projected OPPT control scheme for wind turbines has both positive damping and inertial response function, providing an improved active power support for better 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 tur-bines 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 Con-vers., vol. 19, no. 4, pp. 800–802, Dec. 2004.

[4] G. Tsourakis, B. M. Nomikos, and C. D. Vournas, “Contribu-tion 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. Ra-mos, “Frequency regulation contribution through varia-ble-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.