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Intelligent Sensing and Control of grid connected PV and Wind Farms

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Abstract

Inertial Response, Power oscillations, system flexib ility, and Balance of systems these are all some of the problems that affect the performance and power quality of PV and PMSG Wind Energy Conversion Systems. These problems are easily rectified using a MPPT (Maximum Power Point Tracking) Controller, This paper investigates and attempts at modifying the MPPT controller to work on optimized parameters.

This novel Implementation can effectively improve the operational efficiency of FACTS devices and grid connected inverters.

I. INTRODUCTION

In Recent years, the reduced inertial response and powerd amping capability, as the result of increased wind power penetration in ac networks, have been receiving considerable attention from wind turbine manufactures and system operators. Tackling these issues requires not only fault ride through capability of the wind turbines, but also the ability to participate in frequency and power regulation during system disturbances so as to make the wind farms grid-friendly power generation sources. Thus, the control potential of variable speed wind turbines need be further explored to ensure the stability of power networks containing large-scale wind energy. Traditional synchronous generators naturally contri bute to inertial response with their inherent inertia during frequency events. However, variable speed wind turbines do not directly contribute to system inertia due to the decoupled control between the mechanical and electrical systems, thus preventing the generators from responding to system frequency changes. In addition, the power system stabilizer (PSS) is normally equipped in the traditional synchronous generators to provide power damping during and after large disturbances. With increased wind penetration, it also becomes essential for wind turbines to provide power oscillation damping. This can be critical for weak power systems containing large-scale wind farms, as damping from synchronous generators may be in sufficient and active contribution from wind farms becomes essential. At present, auxiliary controllers with frequency feedback are introduced to wind turbines to provide system frequency response, such as P/*f* droop controller, PD controller, and de loading controller by shifting the maximum power point tracking (MPPT) curves. However, the P/*f* droop controller equipped in the blade pitch control system can only emulate the primary frequency response [9], [10]. While the PD controller of the converter employs a d*f*/d*t*term to emulate additional inertia in the initial frequency change period, and in and, the power tracking curve is shifted from the MPPT curve to the right suboptimal curve to provide dynamic frequency support for the grid during a frequency event. However, a smooth recovery to the MPPT operation cannot be realized by these control approaches. Moreover, the damping capabilities of these controllers during grid disturbance are not analyzed. The traditional PSS has been introduced to the DFIG to damp power system oscillations but no frequency support was considered. For all the work reported,

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simultaneous inertia and damping control cannot be achieved.

The purpose of this study is to investigate new system control to simultaneously provide inertia response and positive damping during frequency and oscillation events. Smooth recovery of wind turbine operation after inertia response can also be achieved. Due to the increase popularity of PMSG-based wind turbine for applications in large wind farms in this paper, the proposed integrated control scheme is performed onthe PMSG-based wind turbine. This paper is organized as follows. The basic control of the PMSG is briefly introduced first. The concept of the virtual inertia of PMSG-based variable speed wind turbineis presented, and the design of the virtual inertia controller for dynamic frequency support is described. The damping capability of the proposed virtual inertia controller is analysed to ensure positive damping coefficient.

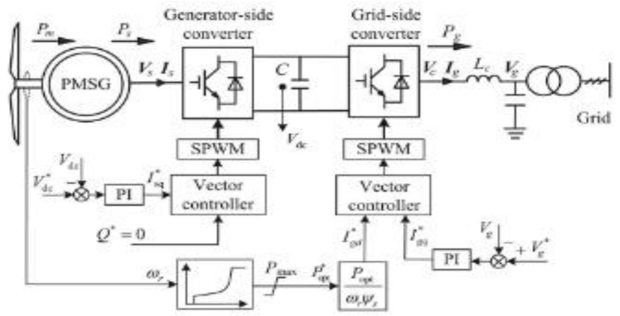

Fig. 1. Schematic control diagram of a PMSG-based wind turbine.

CONTROL OF PMSG

The proposed inertia and damping 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 generator-side converter or the grid-side converter. In this paper, the grid-side converter directly controls the generated active power, whereas the generator-side converter isused to maintain a constant dc-link voltage, as seen in Fig. 1.Since the grid-side converter can fall into current limit during ac voltage dip with reduced power transmission, the generators ide converter as the dc voltage control station automatically reduces power generation in order to maintain a constant dc voltage. This control scheme provides automatic power balance during ac fault and simplifies fault ride through control of the PMSG. The surplus power in the turbine during such disturbances is stored as the kinetic energy of the large rotating masses but only results in a relatively small speed fluctuation of the PMSG. If required, the acceleration of generator speed can be limited using the pitch control to prevent it from going above 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 be regulated to maintain the stator voltage or minimize the power loss of the generator. Therefore, the wind turbines do not naturally response to frequency change or provide power system oscillation damping. In order to emulate the dynamic response of synchronous generators using PMSG-based wind turbines, advanced control schemes considering grid frequency deviation need be added to the grid-side converter's power control loops. Thus, the rotor speed of the PMSGs is regulated to release/store the kinetic energy to make the "hidden inertia" available to the connected grid, and its flexible power control can also be utilized to participate in power system oscillation damping.

It needs to be noted that the ability for a wind turbine to provide inertia support and damping is based on the condition that the wind turbine and associated generator and converter system have the spare power capability.

This means that prior to the network disturbance; the wind turbine is operating at be low rated power, which is usually the case, as wind turbines are usually only partially loaded.

Principle of Virtual Inertia Control (VIC)

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

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

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where m and n are the numbers of connected synchronous generators and wind turbines in the grid, respectively. Pare the numbers of pole pairs and moment of inertia for synchronous generator i, respectively. Eis the effective kinetic energy of the wind turbine available to the power system. SW is the total nominal generation capacity of the power system. As the stored kinetic energy in variable speed wind turbines cannot be automatically utilized during frequency changes as that of conventional synchronous generators [i.e., E=0 in], replacing conventional plants with large numbers of variable speed wind turbines under MPPT control can significantly reduce the effective inertia of the whole system. In addition, if newly installed wind farms are added to the power system without changing the conventional plants, Sis increased but the total kinetic energy available to the power system remains unchanged. In this case, the effective inertia of the whole system is also reduced. This can have significant implications for power system operation and could lead to large frequency deviation. Therefore, it is important to make full use of the stored energy in the wind turbines. To better describe kinetic energy in wind turbines' rotating masses, the definition of the virtual inertia of variable speed wind turbines is given first.N The mechanical characteristics of a wind turbine generator can be expressed as

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

If the wind turbine is controlled to provide dynamic support using its kinetic energy during a frequency change, the released kinetic energy ΔE

ΔEwk can be obtained from (2) as

$$\Delta E_w = \int (P_m - P_e) dt = \int (J_{vir} \omega_s / p_w^2) d\omega_s.$$

If the converter 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 asynchronous generator can be expressed as

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

The inertia constant Hof the power system with synchronous generators and wind turbines can be expressed as

$$H_{tot} = \left[\sum_{i=1}^{m} (J_{s\_i} / 2p_{s\_i}^2) + \sum_{j=1}^{n} (J_{vir\_j} / 2p_{w\_j}^2) \right] \omega_e^2 \Big/ S_N$$

where pwj and Jare the numbers of pole pairs and virtual inertia for wind turbine j, respectively. It can be seen from 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 described as

$$\begin{cases} J_{vir} = \dfrac{J_w \omega_r d\omega_r}{\omega_s d\omega_s} \approx \dfrac{\Delta\omega_r}{\Delta\omega_s} \cdot \dfrac{\omega_{r0}}{\omega_e} J_w = \lambda \dfrac{\omega_{r0}}{\omega_e} J_w \\ \lambda = \Delta\omega_r / \Delta\omega_s = (\omega_e / \omega_{r0}) \times (J_{vir} / J_w) \end{cases}$$

are the changes of the grid and rotor angular speed during a frequency event, respectively, λ is defined as the virtual inertia coefficient, and ωis the pre disturbance rotor speed.

It can be observed 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 and the virtual inertia coefficient λ. Different to synchronous generators, whose rotor speeds are coupled directly to the system frequency, i.e.,λ =1, the speed variation of the variable speed wind turbine can be much greater than the system frequency variation due tothe asynchronous operation, i.e., Δωrr0and thus λ>1.

Therefore, the virtual inertia of the PMSG-based wind turbine can be several times of its natural inertia. However, the stored energy in the wind turbine changes with its rotor speed and is dependent on the wind velocity. Thus, the available virtual inertial so depends on the pre-disturbance rotor speed of the wind turbine.

Supplementary Derivative Control

>Δωe

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As proved in (2) and (6), the generated power of the PMSG can be controlled according to the grid frequency deviation to emulate inertial response. The auxiliary power reference P can be derived from (2) as

$$P_m - P_e = P_m - (P^*_{\mathrm{opt}} - P^*_f) \approx P^*_f = J_{\mathrm{vir}}(\omega_s \mathrm{d}\omega_s / p^2_w \mathrm{d}t).$$

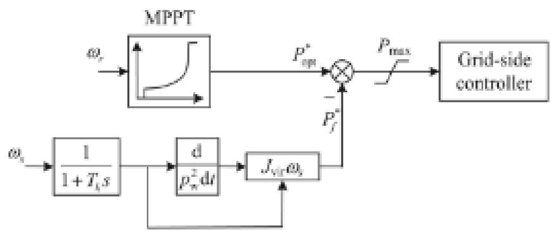


Fig. 2. Block diagram of wind turbine inertia response.

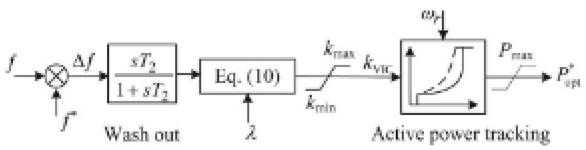
Thus, the virtual inertia can be emulated using a supplementary control loop in addition to the normal MPPT controller. Fig. 2 shows the principles of such wind turbine inertia response for system frequency support, and similar scheme shave also been investiga ted in previous research and tested in variable speed wind turbines. However, simply combining the MPPT controller with the supplementary inertia controller can result in impaired inertia response due to their interaction during rotor speed change. For example, if grid frequency drops, the supplementary controller will try to reduce the rotor speed by increasing its active power output to release kinetic energy. However, the power reference from the MPPT controller reduces as the rotor decelerates. Thus, the combined power increase for frequency support can be limited. This interaction also exists during rotor speed recovery process after primary frequency regulation, which affects the smooth recovery of the system. In addition, special attention should also be given to its impact on system power oscillations. Although larger positive gains of the derivative control can provide better inertia support to the grid, system damping is likely to be reduced leading to increased power oscillations. This will be further investigated in Section IV and validated by experimental results in Section V.

OPPT Control for the Inertial Response

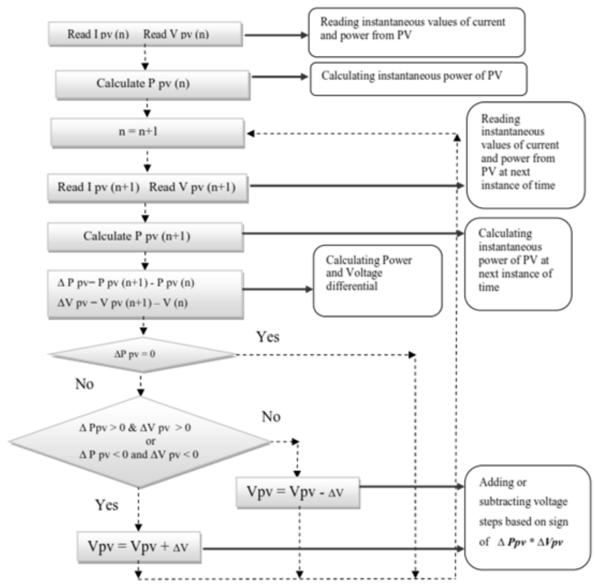
In order to achieve better inertia response, the above-described interaction between the supplementary inertia control and the MPPT control must be avoided. The VIC proposed in this paper is based on the optimized power point tracking (OPPT) method. When system frequency deviation is detected, the generated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

$$P^*_{\mathrm{opt}} = \begin{cases} k_{\mathrm{opt}}{\omega_r}^3, & (\omega_0 < \omega_r < \omega_1) \\ \dfrac{(P_{\max} - k_{\mathrm{opt}}{\omega_1}^3)}{(\omega_{\max} - \omega_1)}(\omega_r - \omega_{\max}) & \\ \quad + P_{\max} (\omega_1 < \omega_r < \omega_{\max}) & \\ P_{\max}, & (\omega_r > \omega_{\max}) \end{cases}$$

Structure diagram of the OPPT regulator-based VIC.



PO-MPPT Algorithm



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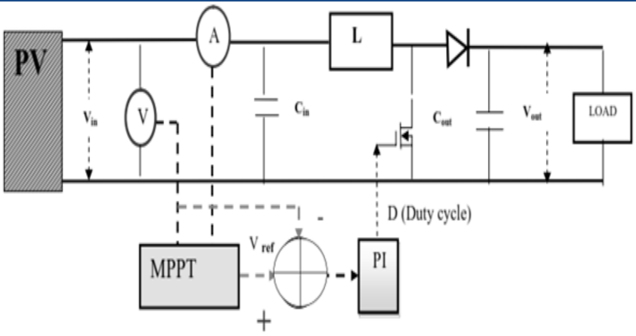


In continuous conduction mode, the output voltage of converter can be calculated using equation.

V in is the input voltage *V*

Pv,Vout is the output voltage *V* and *D* is the duty cycle of the converter. For designing boost converter values of inductance L and capacitance C has been calculated. *Dc* The parameter *L* shall be as per equation

$$L \geq [(1-D)^2 D]\min \times \frac{R_{min}}{2f_{IGBT}}$$

*f*is the switching frequency of IGBT (6kHz has been assumed for the purpose of design)For the purpose of this research, total power rating for PV panel considered is 2856 watts. The IGBT voltage at MPP for each panel is 40.5 Volts and Current rating of each panel at MPP is 5.88 Amps. The power rating of each panel is 238 Watts.

At STC the voltage at maximum power point is 40.5 × 4 = 162

At an ambient temperature of 50°C at irradiance of 1000 Watts /m², voltage at maximum power

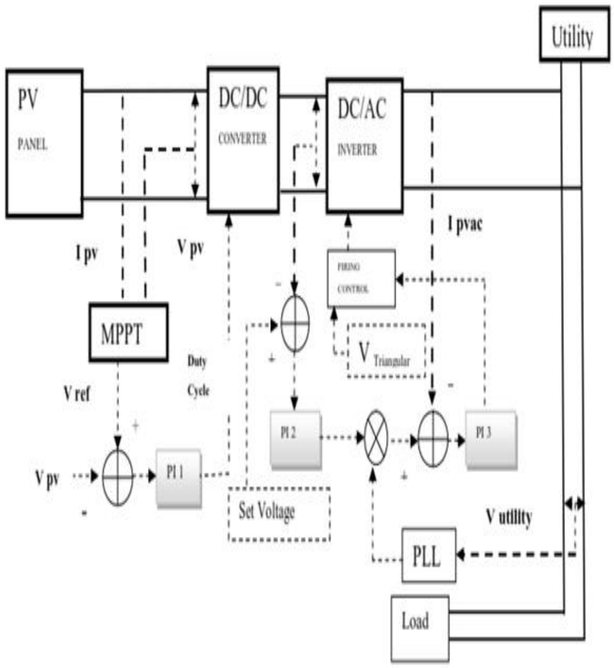
point = (34.2 × 4 = 137 a.c. approximately)The duty cycle will therefore vary between the requirements at STC and at 50°C and the boundary limits shall be as shown below:

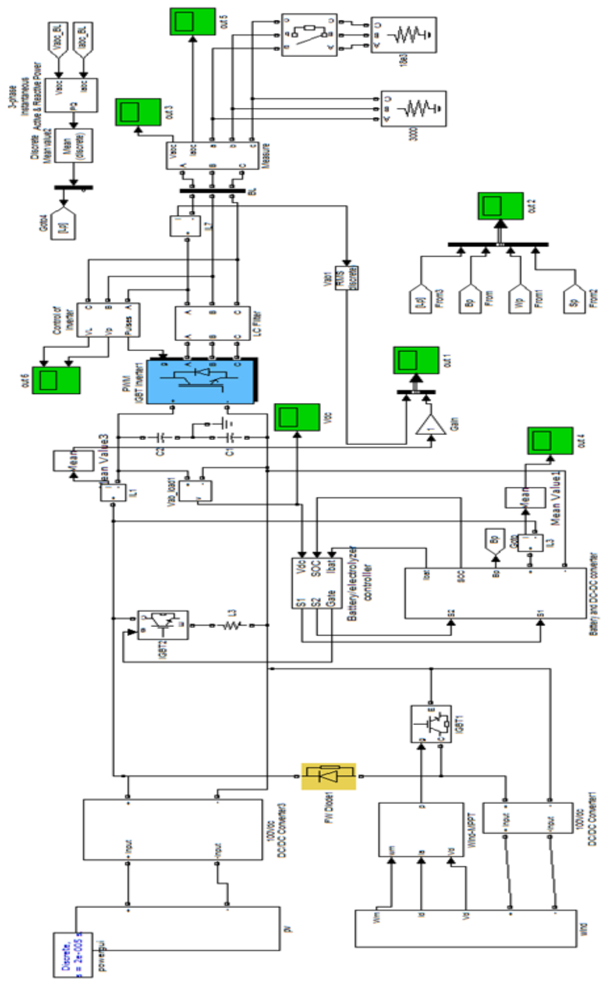
$$1-\left(\frac{162}{400}\right) < D < 1-\left(\frac{137}{400}\right)$$

$$0.59 < D < 0.65$$

$$[(1-D)^2 D]min = [(1-0.65)^2 \times 0.65] = 0.0796$$

$$L \geq 0.0796 \times \left(\frac{56}{2 \times 6000}\right) \geq 371\mu H (0.0003H)$$





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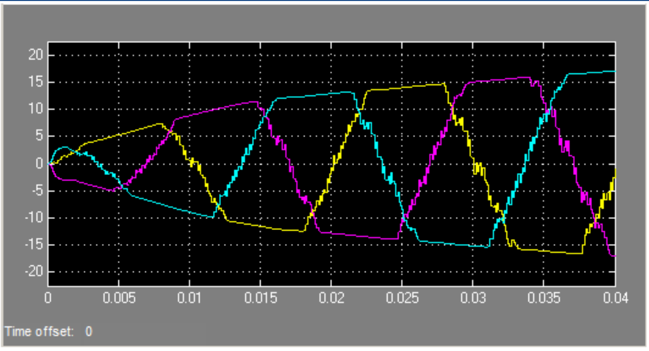
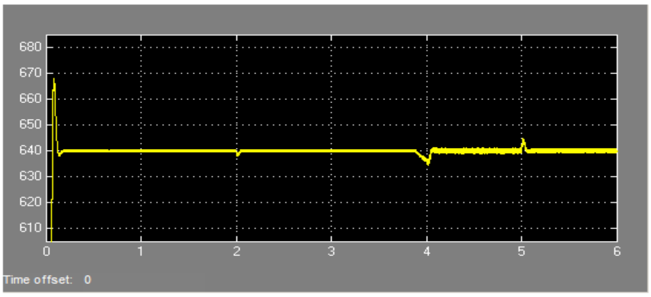


Optimised MPPT Output of PMSG Wind Energy Conversion Systems.



Optimised MPPT Output of PV Cell Arrays.

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