

# Hysteresis Band Controller Based Vector Control Of PMSG For Wind Power

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**ABSTRACT**— In the recent years Permanent magnet Synchronous Machines have proved themselves fairly suitable to be used as power generators in variable speed wind energy conversion systems. Due to their high power factor operation and maintenance free operation these machines are gaining attention of researchers and manufacturers. In this paper A PMSG based wind energy system has been proposed, where the PMSG is connected to the grid through two back to back bidirectional converters. This work only emphasizes on the control of the machine side converter and the dc link voltage is assumed to be constant. The machine-side converter (MSC) is controlled by a vector control strategy which employs a conventional PI controller and three hysteresis band controllers for the control of torque and speed. Due to the vector control strategy decoupled control of torque and flux has been achieved in this paper. The whole modeling and simulation has been performed in MATLAB/SIMULINK and the results has been analyzed in the paper.

**KEYWORDS**— Permanent magnet synchronous generator(PMSG), Vector control scheme, Hysteresis band controller.

## I. INTRODUCTION

Wind energy is regarded as a significant renewable energy source in recent years. These are getting a lot of attention, because they are cost competitive, environmentally clean and safe renewable energy sources, if we compare them to fossil fuel and nuclear power generation. Variable-speed wind energy systems have many advantages over fixed-speed generation such as increased energy capture, Operation at maximum power point, improved efficiency, and power quality [14,16,17]. There are several configurations available in variable speed wind generation systems [14], the most common in high power turbines being the doubly fed induction generator (DFIG)[18]. In this topology, the stator is directly connected to the grid

and the speed is controlled through the rotor by a bidirectional back to back converter. However permanent magnet synchronous generators (PMSG) have received much attraction in wind-energy application. Due to the fact of easy realization of multiple pole design in synchronous generators, it provides a realistic gearless operation. The absence of a gearbox and the lack of moving contacts on the PMSG increase the reliability and decreases the maintenance requirements also enable the wind energy system to be light-weight [1-6]. Moreover it has a property of self-excitation, which allows an operation at a high power factor and high efficiency [1-6]. The use of permanent magnet in the rotor of the PMSG makes it unnecessary to supply magnetizing current through the stator for constant air-gap flux; the stator current need only to be torque producing. Hence, for the same output, the PMSG will operate at a higher power factor because of the absence of the magnetizing current and will be more efficient than other machines [7-13]. A sensor-less scheme is proposed in the whole wind energy system to further improve the characteristics. Problems related with electromagnetic interferences in the position signals and failures in the position sensor are avoided by implementing the scheme [2]. Additionally, wind generation system are not operated at a very low speeds, therefore the difficulties associated with low back-emf for flux estimation in sensor less strategy are not severed in this application. The sensor less scheme proposed here is based on a synchronous  $d-q$  frame phase-locked loop (PLL) as those used in phase detection for grid connected converters [2].

In this paper the modelling and dynamic behavior of direct driven variable speed medium power based PMSG has been emphasized. This paper has been embodied with the concept of vector control with hysteresis band controller to control the decoupled active and reactive power. The whole system is simulated in Matlab / Simulink environment and results have been analysed. his document is a template.

II. SYSTEM OVERVIEW

The wind energy conversion system shown in Fig.3 comprises of wind turbine, PMSG, Hysteresis Band Current Controller and PWM bidirectional converter.

The output of PMSG is not suitable for use because it generates power at variable voltage and frequency due to variable wind speed. So it is converted to constant DC voltage at the DC link to be directly used as a dc source or for storage or further inverted into AC and synchronized to a grid. A vector controlled IGBT based inverter is used to regulate the speed, active power and reactive power of the PMSG during the wind speed variation.

III. MODELING OF PMSG

Generally machine models are expressed in d-q reference frame, because if it is modeled in abc reference frame then the equations describing the machine ,involves time varying inductances, so it is complex to solve by any analytical method. To alleviate this shortcomings ,by park's transformation the time varying machine equations are transferred to time invariant(dc)equations in a synchronously rotating frame. In this paper d-q reference based equations have been described [15].

$$v_{ds} = r_a i_{ds} + L_d \frac{d}{dt} i_{ds} - L \omega i_{qs} \tag{1}$$

$$v_{qs} = r_a i_{qs} + L \frac{d}{dt} i_{qs} + L \omega i_{ds} + \omega \psi \tag{2}$$

Where

$v_{ds}$  =stator voltage in d-axis

$v_{qs}$  = stator voltage in q-axis

$i_{ds}$  = stator current in d-axis

$i_{qs}$  = stator current in q-axis

$L_d = L_q = L_s$  =Stator Inductance

$\omega$  =synchronous speed of stator

$\psi$  =Rotor's magnetic flux linkage

And the torque equation for generator can be given as

$$T_e = \frac{3}{2} n_p \psi i_{qs} + \frac{3}{2} n_p (L_d - L_q) i_{ds} i_{qs} \tag{3}$$

$n_p$  =Pair of poles

The rotors of wind turbine and generator are connected directly, so they can be expressed as

$$J \frac{d\omega_g}{dt} = T_e - T_m - B_m \omega_g \tag{4}$$

Where

$T_e$  = electromagnetic torque,

$T_m$  = load torque,

$J$  = rotor inertia including turbine.,

$\omega_g$  = mechanical speed of the generator.

$B_m$  =damping coefficient

The active and reactive power taken by the machine can be represented by the following equations

$$P = V_{ds} i_{ds} + V_{qs} i_{qs} \tag{5}$$

$$Q = V_{qs} i_{ds} - V_{ds} i_{qs} \tag{6}$$

IV. INVERTER MODEL

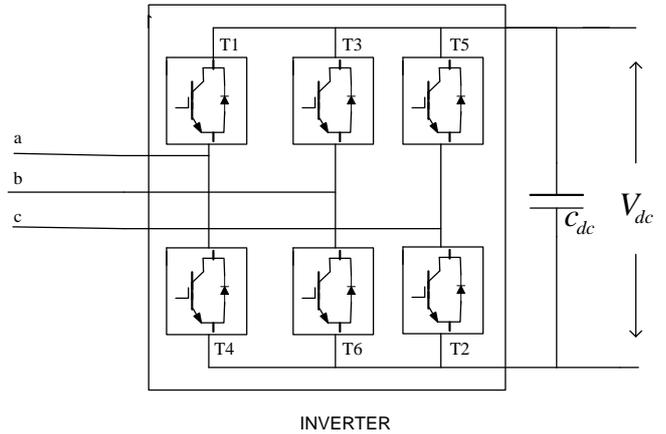


Fig.1 Bidirectional PWM converter structure

A voltage source inverter is used in order to get the variable voltage variable frequency alternating current supply [16]. A simplified PWM inverter model diagram is shown in the Fig.1.

$$V_a = \frac{V_{dc}}{6} [2s_a - s_b - s_c] \tag{7}$$

$$V_b = \frac{V_{dc}}{6} [2s_b - s_a - s_c] \tag{8}$$

$$V_c = \frac{V_{dc}}{6} [2s_c - s_a - s_b] \tag{9}$$

Where,

$V_a$  ,  $V_b$  ,  $V_c$  are the phase voltages,

$V_{dc}$  = DC link voltage

$$s_a = 2T1 - 1$$

$$s_b = 2T3 - 1$$

$$s_c = 2T5 - 1$$

Where T1,T3,T5 are the switches.

V. CONROL STRUCTURE

The short-comings of the scalar control is that due to the inherent coupling effect, the response of the machines is sluggish. So to get rid of the demerits of Scalar control, vector control is used profusely. The vector control resembles the separately excited dc machine analogy i.e. d-axis and q-axis currents analogous to the field current and armature current respectively. In this paper the d-axis component of current is aligned with flux vector and q-

## Hysteresis band vector control of PMSG for wind power application

axis component current is 90 degree ahead of it. The d-axis current controls the reactive power and q-axis current controls the active power. So the active and reactive power are decoupled and can be controlled easily and independently [16].

In the vector control block diagram as shown in the fig() the reference current  $i_{qs}^*$  has been derived from a speed control loop. In this speed control loop a PI controller has been used having the control structure as shown in the fig().the mathematical model for PI is

$$u(t) = K_p e(t) + K_i \int e(t) dt \quad (10)$$

Where 'u(t)' is the controller output, e is the error, 'K<sub>p</sub>' and 'K<sub>i</sub>' are the proportional and integral gains of the PI controller.

Here the rotor angle  $\theta$  and rotor speed  $\omega$  has been tracked from the generator and converted to its electrical equivalent. The error signal of the measured speed and reference speed is processed through a PI controller to get  $i_{qs}^*$ . The d-axis generator current reference is set as,  $i_{ds}^* = 0$ , because the rotor flux is supplied by the Permanent Magnet.

The current tracked from the generator and the converted reference currents are compared and pass through a Hysteresis Band controller. The Hysteresis Band controller has been described the following equations:

$$U = \begin{cases} 1 & \text{If } e > \text{HB} \\ 0 & \text{If } e < -\text{HB} \end{cases} \quad (11)$$

Where e=error signal

U = output of the hysteresis band controller

HB = hysteresis band width.

In this work the hysteresis band width is set to 0.1 and it remains constant throughout the control process. Adaptive hysteresis band width schemes are also available but this paper doesn't emphasize on this schemes. The hysteresis band working is described by the Fig.2.

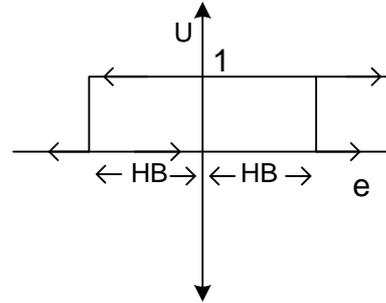


Fig.3 Hysteresis band controller

The signals generated by the hysteresis band controller have been given to the Inverter through Switching Signal Generator.

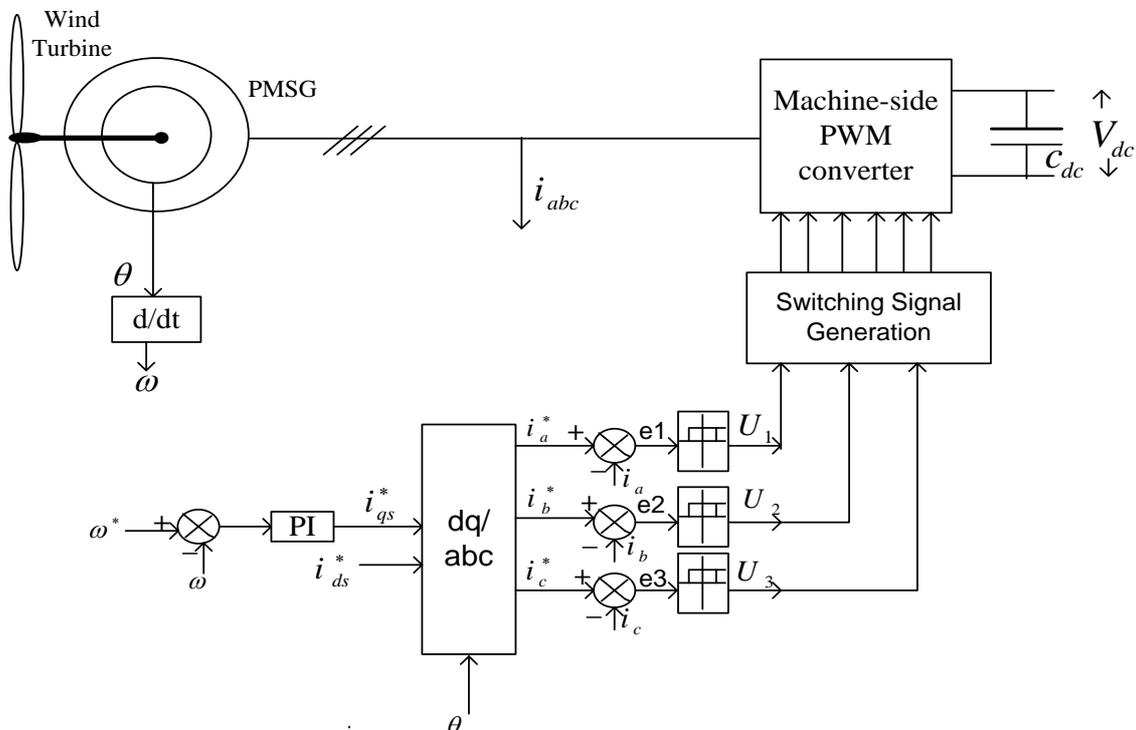


Fig.3 Wind energy conversion system structure with control

VI. SIMULATION AND RESULTS

A. Dynamic response with the step change in reference speed.

The Fig.4 entitles the speed versus time characteristic in which speed overshoots to 334rad/sec(electrical) and settles down within 0.4 sec.The system has been subjected to a step change in speed from 314rad/sec to 250rad/sec at time 3 sec.

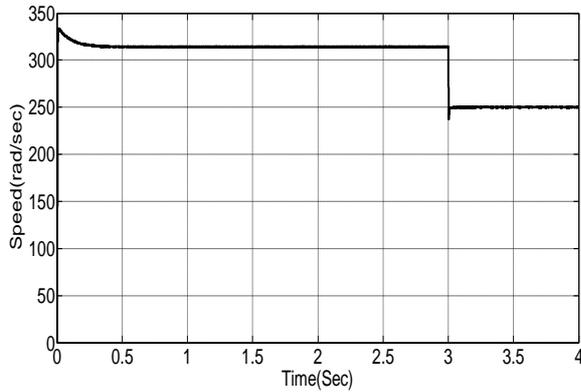


Fig.4 Speed response during change in reference speed

Within this period the mechanical torque has been kept constant at -25Nm.And it has been observed that the variation of torque is for a transient time and overcomes retaining its initial value within 0.04sec.

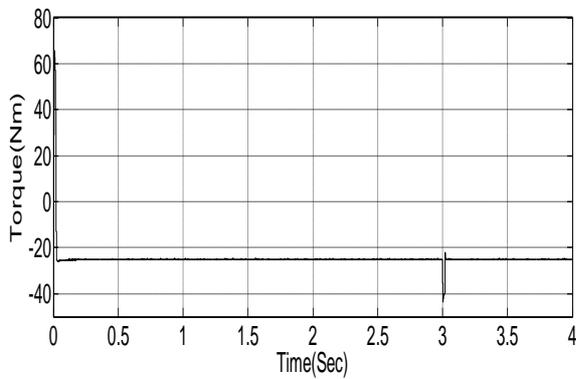


Fig.5 Electromagnetic torque response during change in reference speed

Fig.6 shows the active and reactive power response of the PMSG. As the speed is reduced from 314 rad/sec to 250 rad/sec the active power generation drops from -1000 watts to -800 watts. There is a reduction in reactive power but it is not so significant.

Under constant torque drive the power factor has been observed that it remains constant except it deviates slightly at the change of the step time 3 sec. And this is the beauty of vector control of PMSG using Hysteresis band current controller. It's value is 0.99 as observed in the Fig.7

The Fig.8 depicts the PMSG stator phase current having magnitude 9.5Amp,when the system is subjected to a speed change with constant torque drive. At the

transition time at 3 sec, it overshoots to 44Amp for a transient time as observed in the Fig.8. It can also be noticed that as the speed reduces there is a reduction in stator current frequency

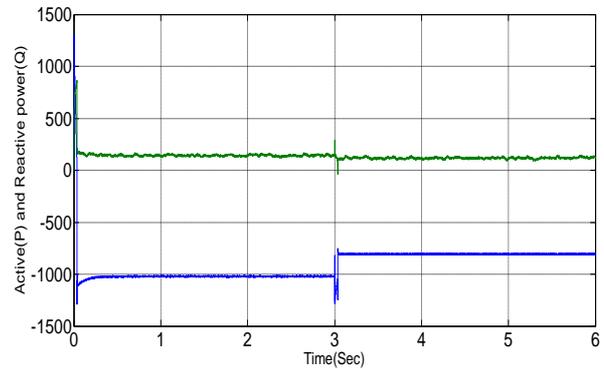


Fig.6 Active and reactive power during change in reference speed

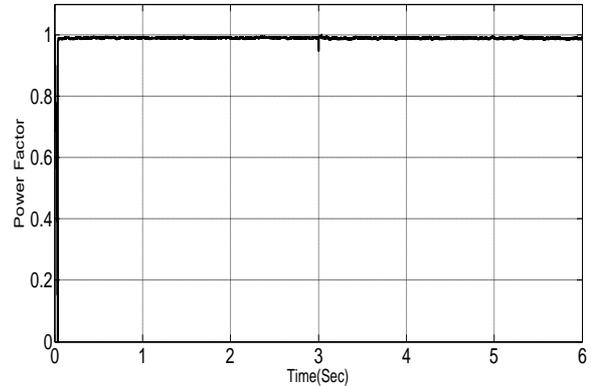


Fig.7 Power factor during change in reference speed

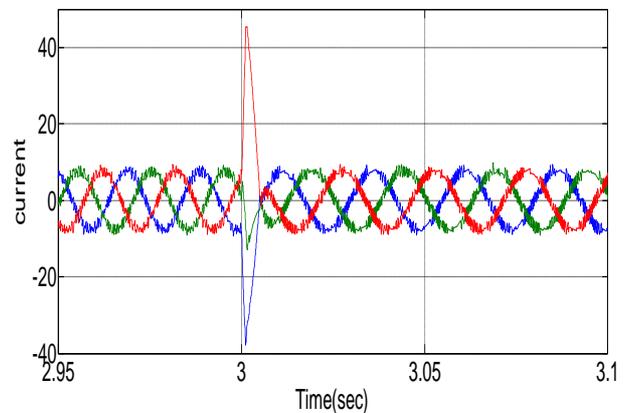


Fig.8 Phase current response during change in reference speed

B. Dynamic response with the step change in Turbine torque.

To observe the dynamic behaviour of the PMSG,it has been subjected to a sudden change of mechanical torque from -25Nm to -40Nm.With this condition the speed excursion ceases immediately to the steady state 314rad/sec(electrical) with a mere overshoot nearly 6rad/sec at the transition time 3 sec.

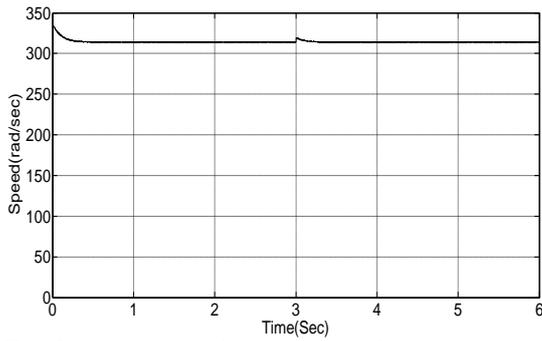


Fig.9 Speed response during change in turbine torque

The torque characteristic observed in the Fig.10 shows the it settles down to steady state within a transient time of 0.05 sec, which is quite fast.

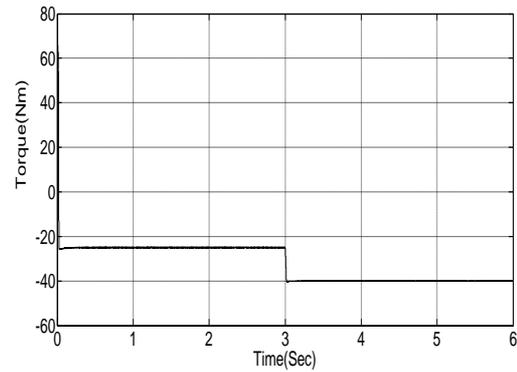


Fig.10 electromagnetic torque response during change in turbine torque

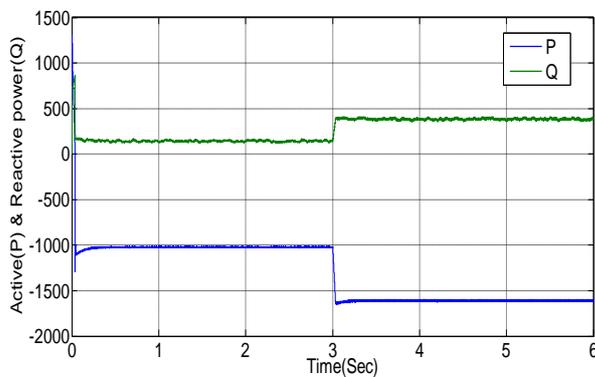


Fig.11 Active and reactive response during change in turbine torque

As the system is subjected to more turbine torque the speed tends to increase but the reference speed is set at a constant value and more flux is needed to keep the speed constant. But as the rotor is a permanent magnet it is incapable of supplying the extra flux. So the machine draws more reactive power from the grid to generate the extra amount of air-gap flux which can be noticed from Fig.11. As the torque increases the active power generation also increases and it is also evident from the above mentioned figure.

As the PMSG draws some reactive power ,so its power factor is about 0.99.And also after the sudden change of the Turbine torque, the power factor changes to 0.97. So the power factor is maintained constant nearer to unity by the Hysteresis band current controller as shown in the Fig.12.

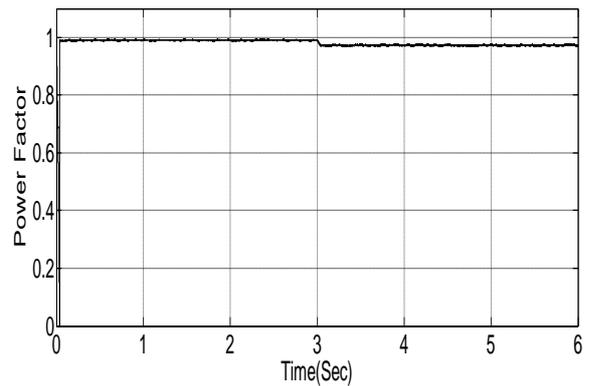


Fig.12 Power factor during change in turbine torque

The Fig.13,gives the phase current of the PMSG. The phase current under the impact of mechanical torque-25Nm has been observed 9.5Amp.And with sudden change of torque -40Nm it increases to 13Amp.

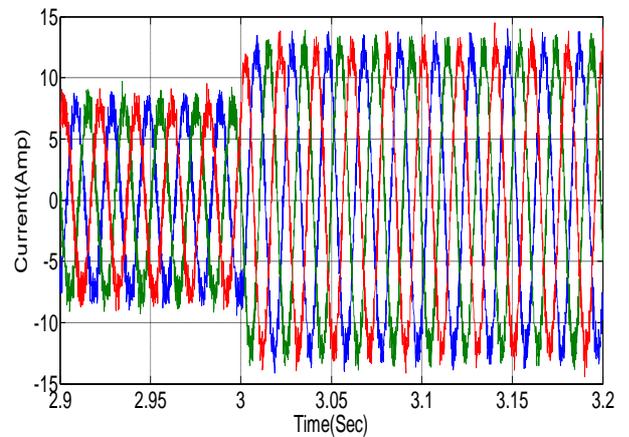


Fig.13 Phase current response during change in turbine torque

## VII. CONCLUSION

The wind energy system employing PMSG as the wind power generator has been successfully modeled and simulated in the proposed work. The result analysis clearly shows that the vector control strategy for the control of the machine side converter works well, which in turn enables decoupled control of torque and speed. The power factor at which the PMSG generates power is above 0.95 which is quite good, in wind energy system point of view. The system gives quite fast response which proves the proposed model is efficient for variable speed wind power extraction.

APPENDIX

Table-I

controller	Kp	Ki
PI	0.85	8.7

Table-II

Poles (P) = 4	Rated KW : 6
Rated Current: 12 A	Rated voltage: 340 V
Rated speed, N=600rpm	Stator resistance, $R_s=0.425 \Omega$
Rotor flux = 0.433 wb	Inertia of rotor, $J=0.02\text{kg-m}^2$
Stator Inductance, $L_d = L_q = 0.0084 \text{ H}$	Damping Factor, $B= 0 \text{ N-rad/sec}$

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