International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Impact Factor (2012): 3.358

Sensorless Control of PMSG in Wind Energy Conversion System Using PID Controller

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Abstract: ***In this paper the strategy is sensorless control of PMSG using PID controller at both generator as well as grid side. The sensorless control applied in WECS is now being approached due to its low cost, high reliability and better capability. By using genetic tuning rule optimal setting from an Integral Squared Error criterion point of view is derived. The optimal controller results to be a PI controller. This optimal controller at the starting point introduces derivative action that can increase controller robustness. PID controller reduces the steady state error and also increases the stability. On the other hand, PI controller doesn't change anything in the stability it only reduces the steady state error. Self-tuning PID control is the combination of two controllers: (i) a self-tuning PID controller, which drives the tracking error to zero and (ii) a supervisory controller, based on the system's nonlinearities. The supervisory controller guarantees the stability of closed-loop nonlinear PID control system.***

Keywords: WECS, Sensorless control, PMSG, PID controller

1. Introduction

Wind power in India began in 1990's and has significant increase in last few years. India is fifth largest installed wind power capacity in the world and in in 2009-10 its growth rate is greater than top four countries.

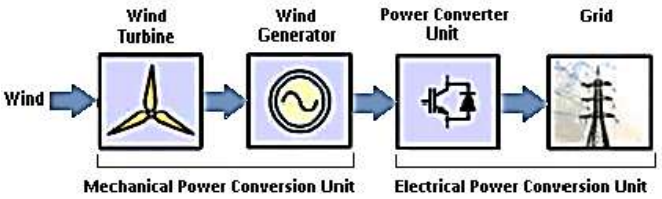

Figure 1: Wind conversion system

WECS is divided into two units as shown in the Figure 1.

1) Mechanical Power Conversation Unit: In this part the wind energy is converted into mechanical energy though wind turbine. This mechanical energy is then given to the wind generator. This wind generator converts mechanical energy of wind into electrical energy.
2) Electrical Power Conversation Unit: In this unit the electrical energy is given to the converter unit and then fed to the grid part where this electrical energy distributed.

Here in this paper sensorless control of PMSG is done using PID controller. To have maximum possible speed in WECS it is necessary to have optimum speed of rotation. To obtain this we use sensorless control due to its low cost, high reliability and better capability. As the name suggest sensorless so in this the speed sensor is eliminated due to which the ruggedness and reliability of overall system is increased also it gives high performance. Two techniques can be used in sensorless control – (a) machine model based and (b) rotor saliency based. Rotor saliency based technique is suitable for interior PMSG. [1]

Also in this paper PID controller is being used instead of PI controller due to is simple design and good performance such as low present overshoot and small settling time. PID makes continuous effort in improving quality and robustness of the system. From integral square error an optimum controller results to be a PI controller. Integral square error is a measure of system performance formed by integrating the square of the system error over a fixed interval of time; this performance measure and its generalizations are frequently used in linear optimal control and estimation theory. This optimal controller at the starting point introduces derivative action that can increase controller robustness. PID controller reduces the steady state error and also increases the stability. On the other hand, PI controller doesn't change anything in the stability it only reduces the steady state error.

2. Modeling of WECS

Power coefficient C_P used for converting efficiency is given as: [2] – [5]

$$C_P = \frac{Captured\ mechanical\ power}{Available\ wind\ power} = \frac{P_w}{(1/2)\rho AV^3} \quad (1)$$

Where,
P_w – Captured mechanical power
ρ – Air density
A – Blade swept area
V – Wind speed

From equation (1) the output mechanical power of WECS is given as:

$$P_w = 1/2\rho\pi C_p(\lambda,\beta)R^2V^3 \quad (2)$$

Where,
R – Turbine radius
λ – Tip speed ratio
β – Pitch angle. In this project β is set zero.
The tip speed ratio is given as:

$$\lambda = R\omega_r/V_w \quad (3)$$

Where ω_r is Turbine angular speed. The wind turbine mechanical torque output T_m is given as:

$$T_m = \frac{1}{2}\rho AC_p(\lambda,\beta)V^3\frac{1}{\omega_r} \quad (4)$$

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3. Modeling of PMSG

In PMSG, the DC field winding of rotor is replaced by permanent magnet. In this the excitation field is provided by permanent magnet of coil. Neither they require DC supply for excitation circuit, nor do they have slip rings and contact brushes.

Advantages:
i. Elimination of field copper loss
ii. Higher power density
iii. Lower rotor inertia
iv. Robust construction of rotor
v. No gearbox

Stator voltage equation by space vector theory is: [6] – [8]

$$v_d = L_d \frac{di_d}{dt} - R_s i_d + p\omega_r L_q i_q \quad (5)$$

$$v_q = -L_q \frac{di_q}{dt} - R_s i_q + p\omega_r(-L_d i_d + \Psi_f) \quad (6)$$

Where,
R_s- Stator resistance
$v_d \& v_q$- 2-axis machine voltage
$i_d \& i_q$- 2-axis machine current
p- Number of poles
ω_e - Generator electrical rotational speed

Mechanical output torque is given as:

$$T_e = \frac{3}{2} P\,[\,\Psi_f i_q - (L_d - L_q) i_d i_q\,] \quad (7)$$

When, $L_d = L_q = L_s \& i_d = 0$:

$v_d = \omega_e L_s i_q$ (8)

$$v_q = -L_s \frac{di_q}{dt} - R_s i_q + \omega_e \Psi_f \quad (9)$$

and electromagnetic torque is given as:

$$T_e = \frac{3}{2} P \Psi_f\, i_q \quad (10)$$

4. PID Controller

PID controller consists of three parameters proportional (k_p), integral (k_i) and derivative (k_d). With the setting of these parameters dynamic response is improved, overshoot is reduced steady state error is eliminated and the stability of the system is increased [9]

Nature of elements used in PID is as follows:

i. Element P: proportional to the error at the instant t.
ii. Element I: proportional to the integral of the error upto instant t.
iii. Element D: proportional to the derivative of the error at the instant t.

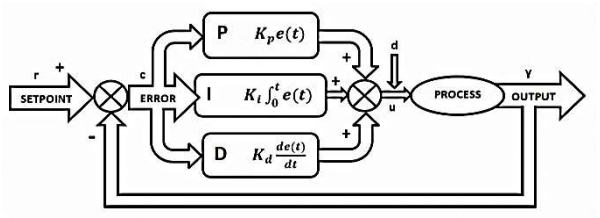

Figure 2: Block diagram of PID controller

The working principle is monitors the error between process variable and a desired set point; from this error, a corrective signal is computed and is eventually fed back to the input side to adjust the process. The differential equation of the PID controller is [10]:

$$u(t) = K_p e(t) + T_i D^{-1} e(t) + T_d D e(t) \quad (11)$$

PID controller is the controller that takes the present (k_p), the past (k_i) and the future (k_d) error into consideration. The transfer function of PID controller is given as:

$$G_c(s) = K_p \left(1 + \frac{1}{sT_i} + T_d s\right) = K_p + \frac{K_i}{s} K_d s \quad (12)$$

5. Sensorless Control

The PMSG drive requires two current sensors and an absolute-rotor-position sensor for the implementation of any control strategy. Elimination of both types of sensors is desirable in many applications, particularly in low cost but high volume applications, cost and packaging considerations. The rotor position is sensed with an optical encoder or a resolver for high performance applications. The position sensors compare to the cost of the low power motor, thus making the total system cost very non-competitive compared to other types of motor drives. As for the current sensors, they are not as expensive as the rotor position sensor. Hence, the control an operation of PMSG drive without a rotor position sensor would enhance its applicability to many cost sensitive applications and provide a backup control in sensor based drives during sensor failure. [11]

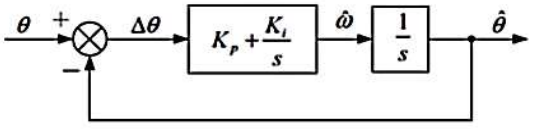

Figure 3: Block diagram of sensorless control

The value of e_{sd} and e_{sq} can be getting by following equation:

$$u_{sd} = R_s i_{sd} + L_d \frac{di_{sd}}{dt} - \omega L_q i_{sq} - e_{sd} \quad (13)$$

$$u_{sq} = R_s i_{sq} + L_q \frac{di_{sq}}{dt} - \omega L_d i_{sd} - e_{sq} \quad (14)$$

Ignoring the current differential, $\Delta\theta$ can be described as:

$$\Delta\theta = arctan\left(-\frac{e_{sd}}{e_{sq}}\right) = arctan\left(-\frac{u_{sd} - R_s i_{sd} + \omega L_q i_{sq}}{u_{sq} - R_s i_{sq} - \omega L_d i_{sd}}\right) \quad (15)$$

6. Generator Side Control

Voltage equation for generator side control used in PMSG is given as:

$$u_{sd} = R_s i_{sd} + L_d \frac{di_{sd}}{dt} - L_q \omega i_{sq} \quad (16)$$

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$$u_{sq} = R_s i_{sq} + L_q \frac{di_{sq}}{dt} + L_d \omega i_{sd} + \omega \Psi \quad (17)$$

Where, u_{sd} ,u_{sq} and i_{sd} , i_{sq} - d-axis, q-axis component of stator voltage and current.

$L_s$andR_s - Generator inductance and resistance.
ω -Generator speed
Ψ - Magnet flux

When using i_{sd}= 0 control method, the electromagnetic torque can be given by:

$$T_e = \frac{3}{2} P \Psi i_{sq} \quad (18)$$

Where P is the pole pair numbers of generator. Block diagram of Generator side control is given in Figure 4. [12]

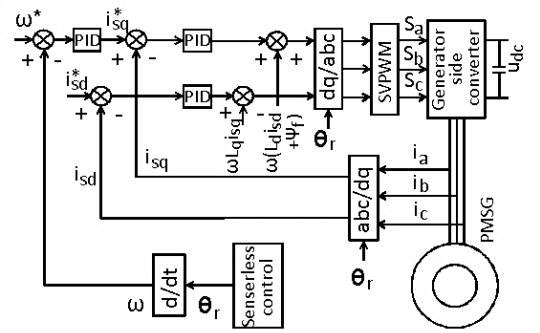

Figure 4: Block diagram of generator side control

7. Grid Side Control

Dynamic model for Grid side control by voltage space vector technique is given as:

$$\begin{bmatrix} \frac{di_d}{dt} \\ \frac{di_q}{dt} \\ \frac{dU_{dc}}{dt} \end{bmatrix} = \begin{bmatrix} -\frac{R}{L} & \omega_g & -\frac{S_d}{L} \\ -\omega_g & -\frac{R}{L} & -\frac{S_q}{L} \\ \frac{3S_d}{2C} & \frac{3S_q}{2C} & 0 \end{bmatrix} \begin{bmatrix} i_d \\ i_q \\ U_{dc} \end{bmatrix} + \begin{bmatrix} \frac{1}{L} & 0 & 0 \\ 0 & \frac{1}{L} & 0 \\ 0 & 0 & -\frac{1}{C} \end{bmatrix} \begin{bmatrix} u_d \\ u_q \\ i_g \end{bmatrix} \quad (19)$$

Where,
i_d, i_q - d-axis, q-axis current component of grid side converter.
S_d , S_q - d-axis and q-axis switch function respectively in d_q reference frame which are transferred from S_k (k = a b c) in 3-phase stationary reference frame.
U_{dc} - DC voltage
L and R - Inductance and resistance of the output inductor.
C - DC side capacitance
i_g- Grid side current.

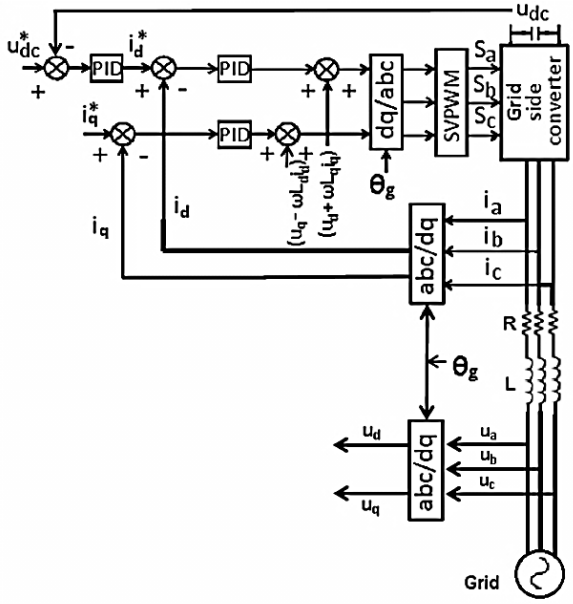

Figure 5: Block diagram of grid side control

8. Simulation Results

Simulation model is built with Matlab/Simulink, where the system parameters are: the PMSG L_d =L_q = 1.5731mH, Ψ_f = 6.5029Wb, R_s = 0.821mΩ, P = 26; the PWM rectifier DC side capacitor C = 18.8mF; grid-connected inductor L = 1.1mH.

Initial wind speed be set as 8 m/s and will be change as 12 m/s at 0.2s. It can be seen that the DC-link voltage was obtained 1200V.

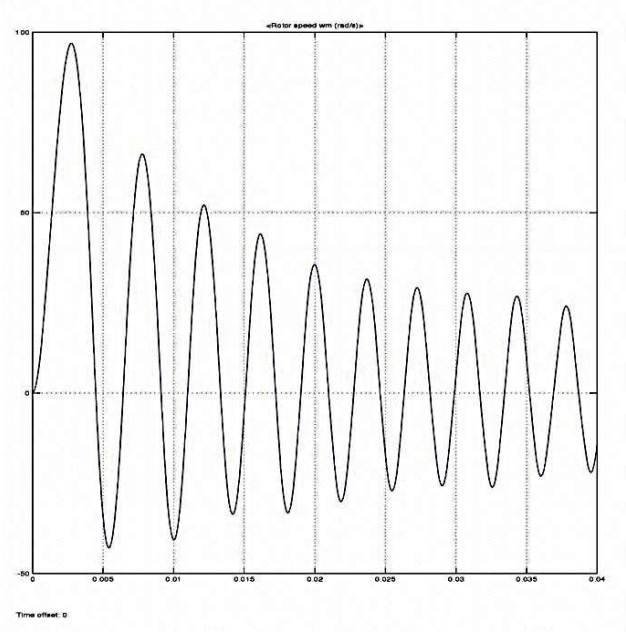

Figure 6: Scope of wind speed

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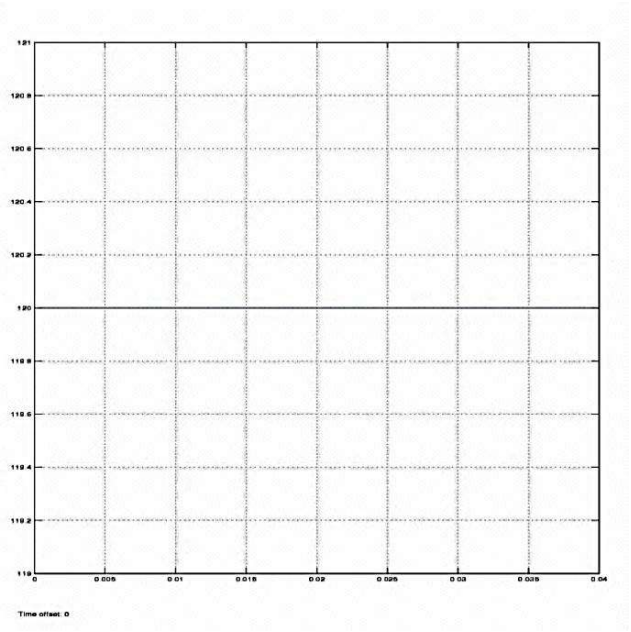

Figure 7: Scope of DC Voltage

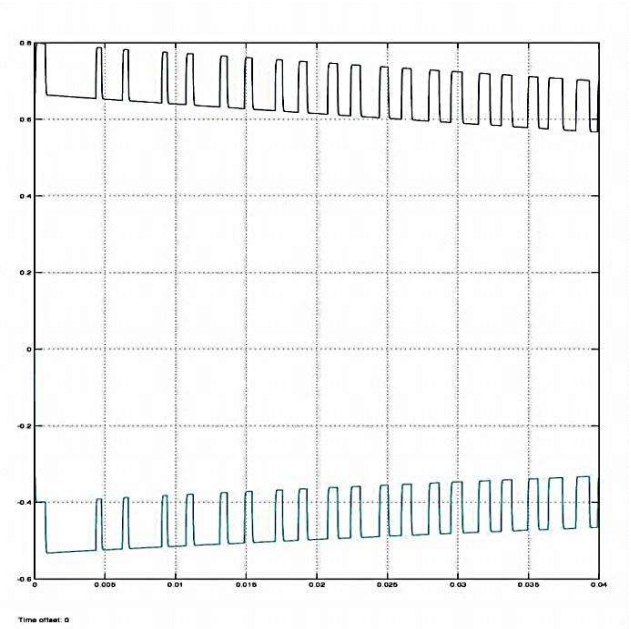

Figure 8: Scope of grid current

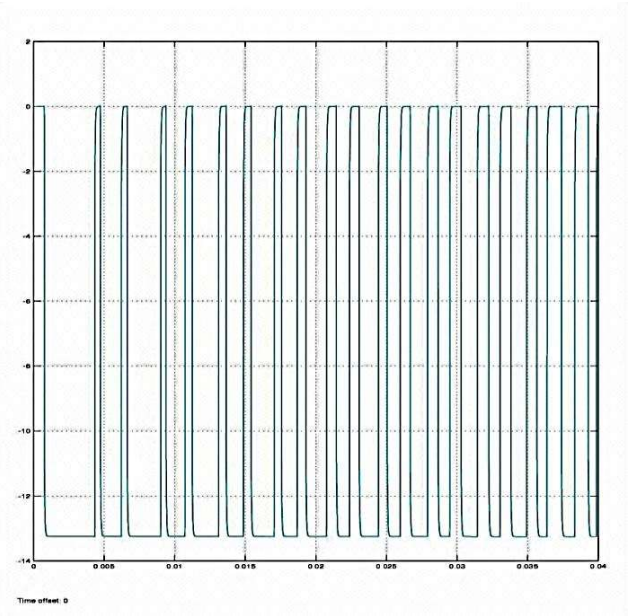

Figure 9: Scope of grid voltage

9. Conclusion

This paper presents a strategy to sensorless control permanent magnet wind power system, PWM technique is used both in generator side rectifier and in grid-side inverter. Also in this project PID controller is used instead of PI controller. PID controller reduces the steady state error and also increases the stability. On the other hand, PI controller doesn't change anything in the stability it only reduces the steady state error. DC-link voltage is maintained at 1200V at the grid-side. Simulation results proved good performance and confirmed that the strategy works well.

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