IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 10, Issue 3 Ver. IV (May – Jun. 2015), PP 32-39
www.iosrjournals.org

Design and Analysis of Wind Turbine PMSG with Direct Current Vector Control

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Abstract : *This paper proposes the direct current vector control for direct driven permanent magnet synchronous generators for wind application. Permanent magnet synchronous generators based wind system is proposed in this paper and also this paper presents comparisons between the modelling of conventional method and proposed vector controlled mechanism. An optimal control configuration is presented, Total circuit configuration is designed and simulated in MATLAB software and simulation results are also presented in this paper.*
Keywords - *PMSG Based wind system, MATLAB software, SIMSCAPE Library.*

I. Introduction

Conservation of the non-renewable resources motivate to explore the new avenues of resources for electricity generation which could be clean, safe and most valuable to serve the society for a long period. The option came with huge number of hands up a source which is a part of our natural environment and eco friendly is the Renewable Energy Sources (RES).

Wind energy is today's most promptly growing renewable energy source. The wind turbine extracted power depends upon wind velocity and wind turbine structure. A wind turbine operates either at a fixed or variable speed[1]. The variable speed wind turbines are the most common type of wind energy conversion system (WECS).Because they are able to extract more power than fixed speed wind turbine. Developing new megawatt scale wind turbines based on variable-speed operation with pitch control using either a permanent magnet synchronous generator (PMSG) or a doubly fed induction generator (DFIG)is preferred by most of the manufacturers [2].Though the variable speed wind turbine with a multi-pole PMSG and full-scale/ fully controllable voltage source converters (VSCs) is considered to b more efficient , it is not popular wind turbine concept [3].

The advantages of such a PMSG configuration are
1) Gearless construction [4];
2) Elimination of a dc excitation system [5];
3) Maximum wind power extraction and grid interface; and
4) Ease in accomplishing fault – ride through and grid support [6].

Therefore, the efficiency and reliability of a VSC-based PMSG wind turbine is assessed to be higher than that of a DFIG wind turbine [7]. Due to the intensified grid codes, a PMSG wind turbine with full VSC-based insulated gate bipolar transistor (IGBT) converters are becoming more and more enhanced by the wind power industry [3]–[7].

At the present time, however, commercial PMSG technology mainly uses a passive rectifier followed by an IGBT inverter [9]–[10]. The highly efficient vector – controlled technology for a PMSG wind turbine that uses a full voltage – source IGBT converter configuration is still under investigation [11]–[12] and not widely adopted by the wind power industry. The direct-current vector control technology is a vector control technology that has been developed recently to control the synchronous generator only in a variable – speed PMSG wind turbine and for control of a VSC – based HVDC system. Compared to the conventional vector control strategies, direct – current vector control has illustrated many advantages in those applications, such as enhanced system stability, reliability, and efficiency. But it is not clear whether the direct-current vector control can be employed in a PMSG wind turbine for control of both PMSG machine – and grid- side converters (GSCs), and how the PMSG system will be have in the integrated environment for multiple PMSG control purposes.

This paper presents mechanisms for optimal control of a PMSG wind turbine system under a direct-current dq vector control configuration. Based on the proposed control structure, the overall control functions of a PMSG system are developed, including maximum power extraction control, dc link voltage control, reactive power control, and grid voltage support control.

II. PMSG Model And Integrated Controls

Permanent magnetic synchronous generator wind turbine [4] which is based on voltage source converter mainly consists of three major parts (see Fig. 1). Which are mentioned below as

1) Back to back two voltage source converters
2) Drive train of wind turbine
3) A permanent magnetic synchronous generator

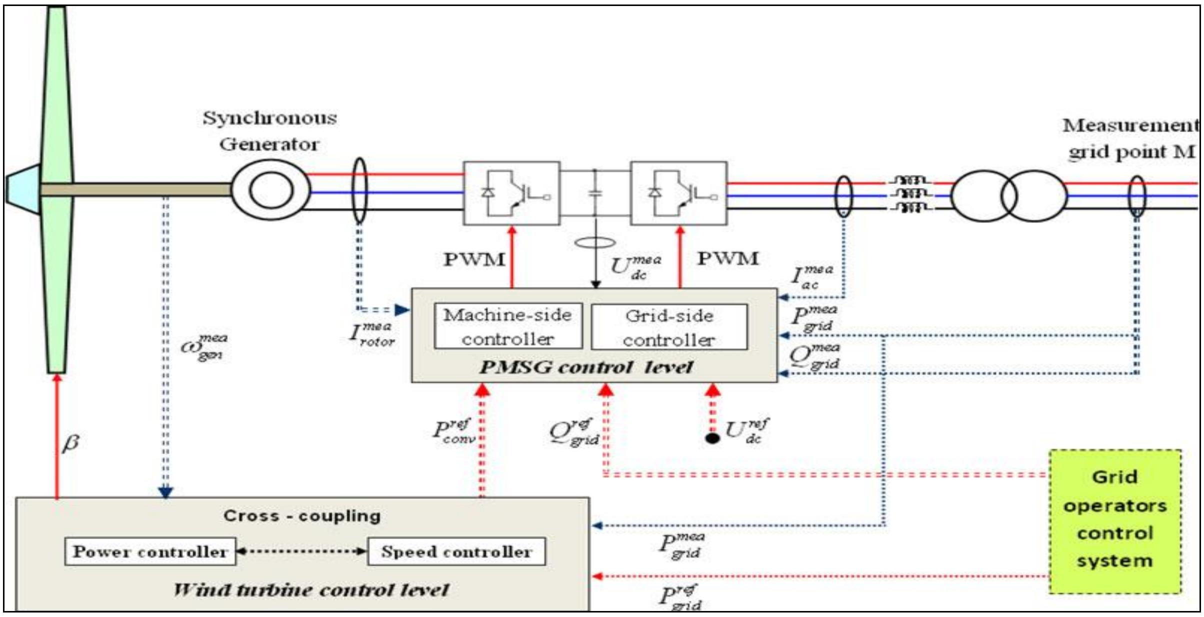

Figure2.1: Configuration of a Permanent Magnetic Synchronous Generator wind turbine.

The rotor blades of the wind turbine which are in the turbine drive train catches the wind energy which is then transferred to the generator existing in the synchronous generator. As the principle of a generator we know which converts mechanical energy to electrical energy this generator is used as a standard permanent magnet synchronous machine [5] with its stator windings through a frequency converter it is connected to the grid. The frequency converter is built by two current-regulated voltage-source PWM (pulse width modulation) converters. They are Machine Side Controller(MSC) and a Grid Side Controller (GSC) in which there is a dc voltage link in between both the pulse width modulation (PWM) converters [8].

The control of permanent magnetic synchronous generator system mainly consists of three levels:1)The Wind Turbine Level; 2)The Wind Power Plant Level;3)The Generator Level.

1) The Wind Turbine Level

At the wind turbine level, there exists a power limiting controller and a speed controller as shown in the figure1. The speed controller gives a torque or power references to the Machine Side controller (MSC) based on the principle of maximum energy capture at low wind speeds. The power limiting controller decreases or increases the pitch angle to prevent the turbine from going over the rated power at high wind speeds of wind turbine blades.

2) The Wind Power Plant Level

At the wind power plant level, based on the grid requirements the power production of the entire plant is determined. According to a grid need the central control system sends out reference power signals to each individual wind turbine [3], while the local turbine control system ensures that the reference power signal which is sent by the central control system is reached.

3) The Generator Level

As shown in the figure1 at the generator level, each of the two Voltage Source Converters are controlled through decoupled dq vector control which approaches in the conventional technology. The Machine Side Controller controls the Permanent Magnetic Synchronous Generator to achieve the following goals: To extract the maximum energy [7] from the wind and compliance with the control demand from the wind power plant control centre. The Grid Side Controller maintains a constant dc-link voltage and a reactive power absorbed from the grid is adjusted by the converter.

A. Generator Model

PMSG transient model is the Park model. Therefore the stator voltage equation is given by

$$\begin{pmatrix} v_{sd} \\ v_{sq} \end{pmatrix} = -R_s \begin{pmatrix} i_{sd} \\ i_{sq} \end{pmatrix} - \frac{d}{dt}\begin{pmatrix} \psi_{sd} \\ \psi_{sq} \end{pmatrix} + \omega_e \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}\begin{pmatrix} \psi_{sd} \\ \psi_{sq} \end{pmatrix} \tag{1}$$

where Rs is the resistance of the stator winding, ω_e is the generator electrical rotational speed, and v_{sd}, v_{sq}, i_{sd}, i_{sq}, ψ_{sd} and ψ_{sq} are the d- and q-component of instant stator voltage, current ,and flux. Then the stator flux linkages are given by

$$\begin{pmatrix} \psi_{sd} \\ \psi_{sq} \end{pmatrix} = \begin{pmatrix} L_{ls} + L_{dm} & 0 \\ 0 & L_{ls} + L_{qm} \end{pmatrix}\begin{pmatrix} i_{sd} \\ i_{sq} \end{pmatrix} + \begin{pmatrix} \psi_f \\ 0 \end{pmatrix} \tag{2}$$

where L_{ls} is the leakage inductance of the stator winding, L_{dm} and L_{qm} are the stator and rotor d- and q-axis mutual inductances, respectively, ψ_f is the flux linkage produced by the Permanent magnet. The electromagnetic torque is

$$\begin{aligned} \tau_{em} &= p\left(\psi_{sd} i_{sq} - \psi_{sq} i_{sd}\right) \\ \tau_{em} &= p\left(\psi_f i_{sq} + \left(L_d - L_q\right) i_{sd} i_{sq}\right) \end{aligned} \tag{3}$$

where

$$L_d = L_{ls} + L_{dm}$$

$$L_q = L_{ls} + L_{qm}$$

Under the steady state condition ,(1) reduces to

$$\begin{pmatrix} V_{sd} \\ V_{sq} \end{pmatrix} = \begin{pmatrix} -R_s & \omega_e L_q \\ \omega_e L_d & -R_s \end{pmatrix}\begin{pmatrix} I_{sd} \\ I_{sq} \end{pmatrix} + \begin{pmatrix} 0 \\ \omega_e \psi_f \end{pmatrix} \tag{4}$$

For a direct-driven multiple pole PMSG [9],[10] and the stator winding resistance is much smaller than the synchronous reactance and the difference between the d- and q-axis mutual inductance is very small. Therefore, (3) reduces to (5)

$$\tau_{em} = p\psi_f i_{sq} \tag{5}$$

Therefore the steady-state stator d-and q-axis currents from (4) are given by

$$\begin{aligned} I_{sq} &= -V_{sd} / (\omega_e L_q), \\ I_{sd} &= (V_{sq} - \omega_e \psi_f) / (\omega_e L_d) \end{aligned} \tag{6}$$

B. Wind Turbine Model

The mechanical power extracted by the wind turbine is given by the cube law equation

$$P_\omega = \frac{1}{2}\rho_{air} A_{blade} C_p(\beta, \lambda).v_\omega 3 \tag{7}$$

$$\lambda = R_{blade}\omega_m / \upsilon_\omega \tag{8}$$

Where ρ_{air} is the air density,

A_{blade} is the area covered by the rotor blades,

C_p is turbine performance coefficient ,

v_ω is the wind speed ,

R_{blade} is the radius of rotor ,

λ is the tip speed ratio ,is the rotational speed of the rotor

III. Direct Current Vector Control Of MSC

The direct-current vector control strategy of the MSC , is a nested loop structure as shown in Fig. 2. It consists of three parts :

1) Transformation from speed control to current control.
2) Development of a direct current control mechanism.
3) Conversion from current control signals to voltage control signals.

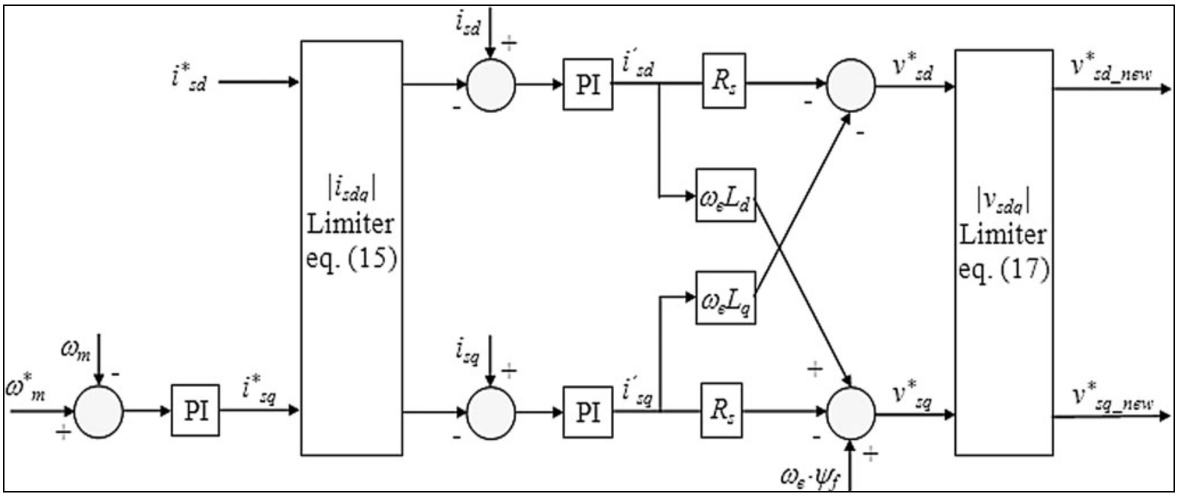

Figure 3.1 : Direct-current vector control structure of the MSC.

First, the transformation from speed control to torque control is done using a speed loop controller. Then the torque control is converted to stator d and q axis current control, while the stator d-axis current is set to zero.

Second, the reference signals to an inner current loop controller are the d and q-axis currents generated by the speed loop controller. It is necessary to give that a fast current loop controller to assure high performance operation of the synchronous generator in terms of reduced harmonics and stator current unbalance.

The direct-current vector control mechanism of the MSC outputs *d*- and *q*-axis tuning currents i'_{sd} and i'_{sq} , in which the input error signal tells the controller how much the tuning current should be adjusted through an adaptive tuning strategy

Third, due to a VSC structure of the MSC, the stator *d* and *q*-axis tuning current signals i'_{sd} and i'_{sq} generated by the current-loop controllers are transferred to stator *d*- and *q*-axis voltage signals *v*sd* and *v*sq* to control the synchronous generator. The conversion from the current to voltage control signals is given by (9)

$$\begin{aligned} v^*_{sd} &= -R_s i'_{sd} - \omega_e L_q i'_{sq} \\ v^*_{sq} &= -R_s i'_{sq} + \omega_e L_d i'_{sd} + \omega_e \psi_f \end{aligned} \tag{9}$$

IV. Conventional And Direct-Current Vector Control Of GSC

The direct-current vector control strategy of the GSC is shown in Fig. 3 is implemented through a nested-loop controller in the following way:

1) Transforming the dc-link voltage and reactive power control to d- and q-axis current control.
2) Developing a direct current control scheme.
3) Converting current control signals to voltage control signals

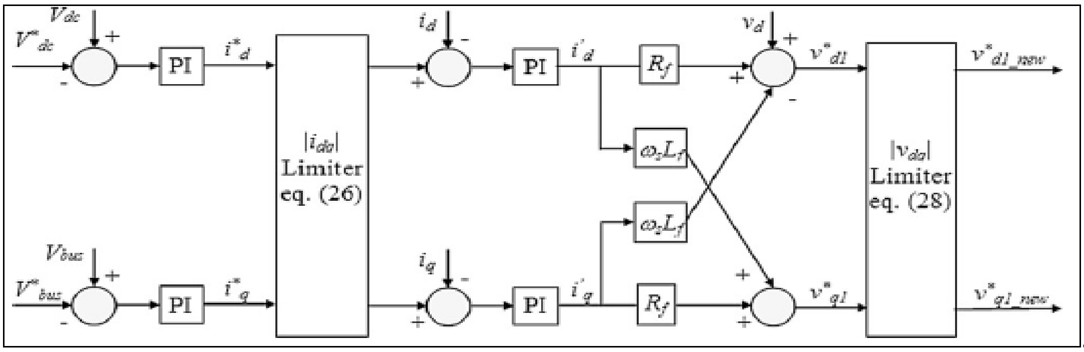

Figure 4.1 : Direct-current vector control structure of the GSC.

First, the dc-link voltage control is transformed to d-axis current control through a dc-link voltage controller, and the ac system reactive power control is transformed to q-axis current control through a reactive power controller. Second, an inner current-loop controller is developed based on a direct-current vector control mechanism by generating d- and q-axis tuning current signals i'_{sd} and i'_{sq} through an adaptive tuning strategy[11],[12]. The purpose of the current loop controller is to assure the highest power quality of the ac system in terms of harmonics and unbalance. Due to the VSC structure for the GSC, the d and q-tuning current signals i'_{sd} and i'_{sq} generated by the current-loop controllers are transferred to d- and q-voltage signals v*d1 and v*q1. The conversion from the current to voltage control signals is implemented through

$$v^*_{d1} = R_f i'_d - \omega_s L_f i'_q + v_d$$
$$v^*_{q1} = -R_f i'_q + \omega_s L_f i'_d \qquad (10)$$

V. MATLAB Modeling

In order to model the above circuit it needed to know the elements where it is available in the MATLAB library here we are using the 575v voltage source that is available in SIMSCAPE library SIMPOWER system block in electrical sources classification.

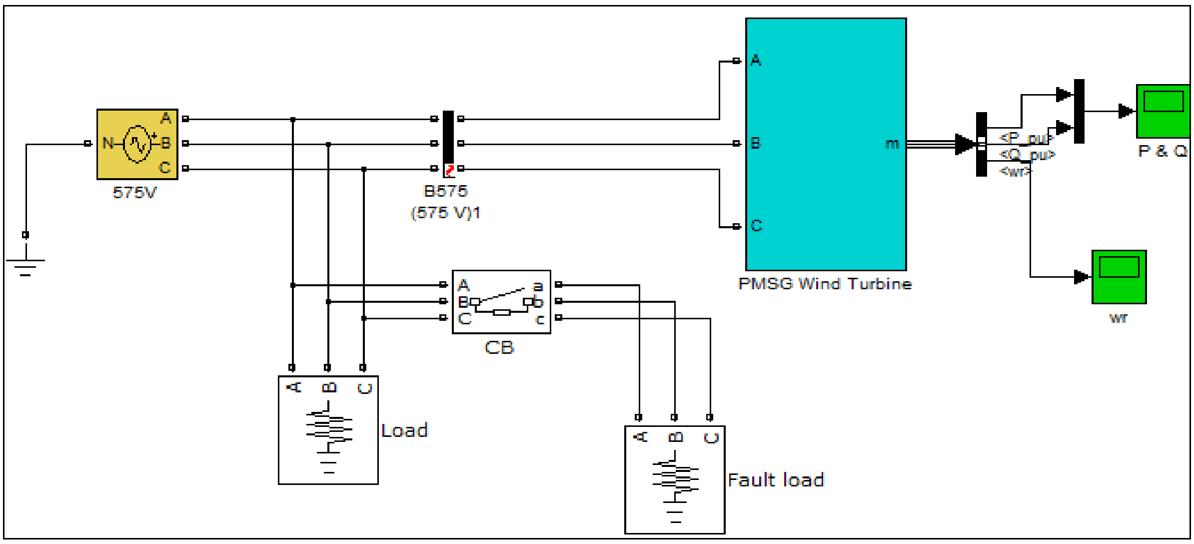

Figure 5.1: SIMULINK model of proposed converter

VI. Simulation Results

The following diagrams shows the simulation results of the proposed converter topology and following diagrams are MATLAB based results. The figure 6.1 represents the generator speed of the proposed direct-current vector control of direct-driven PMSG for wind application

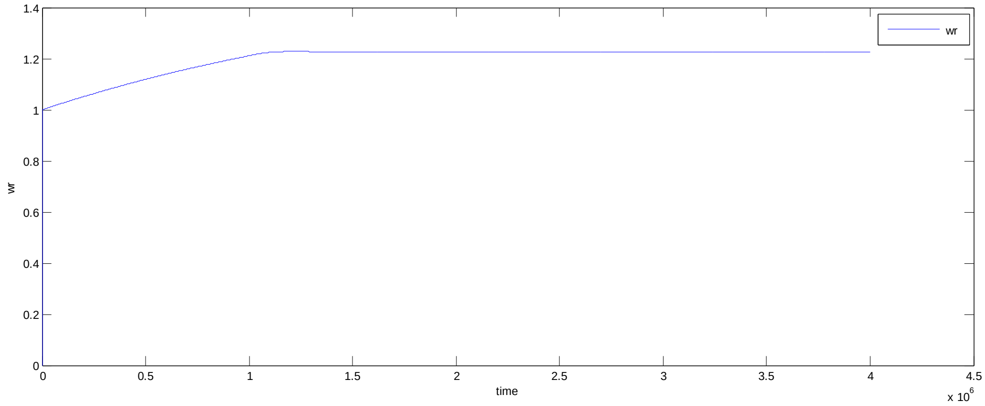

Figure6.1: Generator speed representation

The figure 6.2 represents the active and reactive power of the proposed direct-current vector control of direct-driven PMSG for wind application.

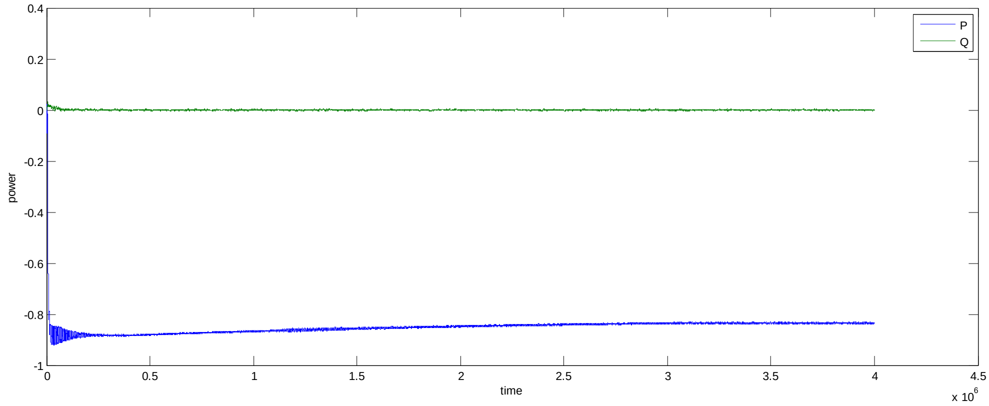

Figure6.2: active and reactive power

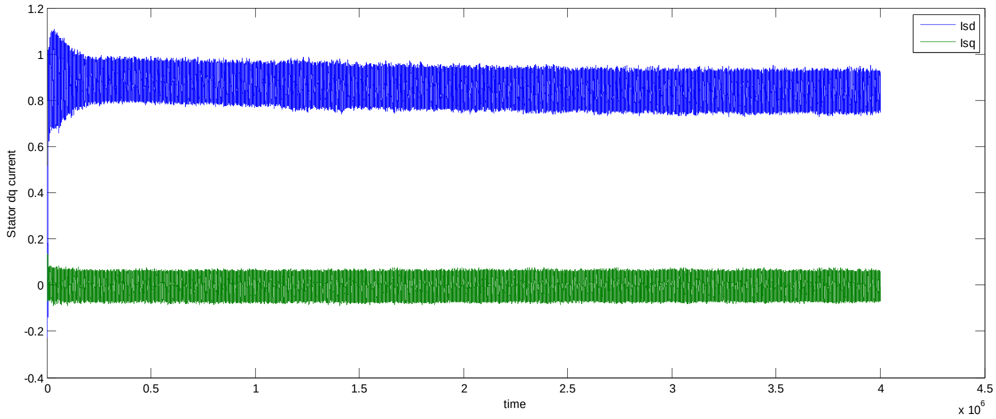

Figure6.3: stator dq current representation

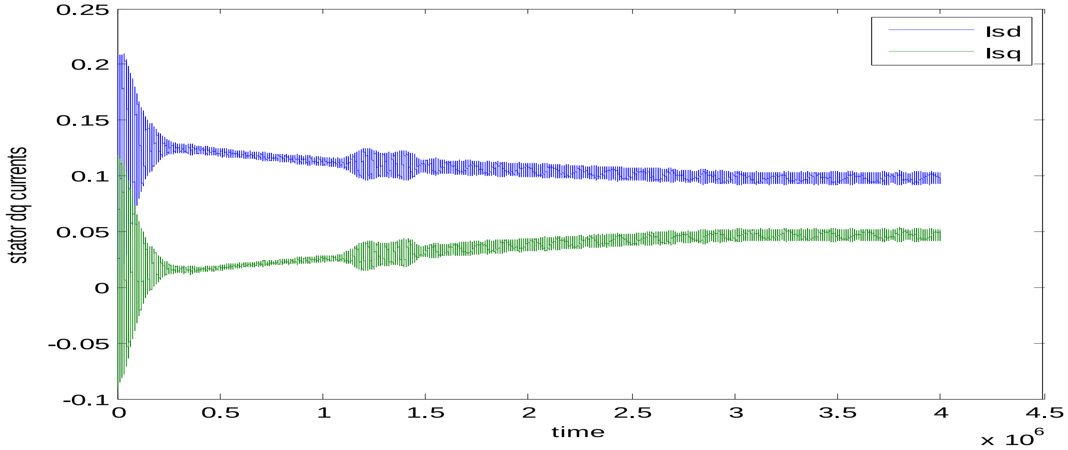

Figure 6.4: grid dq current representation

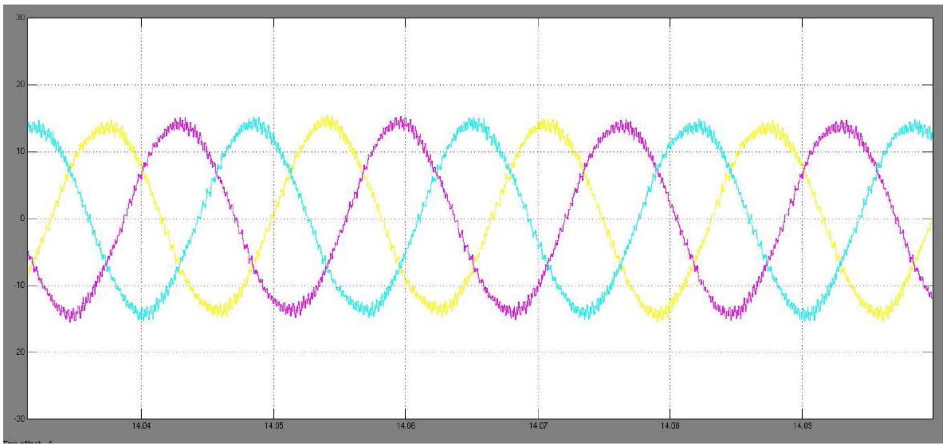

Figure 6.5: grid ABC current representation

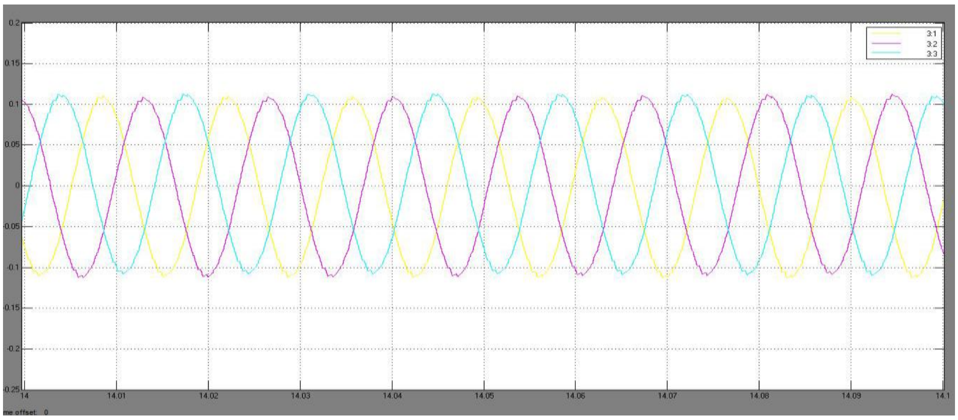

Figure 6.6: stator ABC current representation

VII. Conclusion

The modeling of the proposed direct current vector control for direct driven permanent magnet synchronous generators for wind application is simulated using the MATLAB software. Permanent magnet synchronous generators based wind system MATLAB SIMLINK modeling is proposed in this paper and also this paper successfully presents comparisons between the modeling of conventional method and proposed vector controlled mechanism. Total circuit configuration is designed and simulated in MATLAB software. Comprehensive simulation studies demonstrate that a PMSG wind turbine, based on the direct-current vector control structure, can effectively accomplish the wind turbine control objectives with superior performance within the physical constraints of the system under both steady and variable wind conditions.

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