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Steady State Analysis of Wind Energy Conversion System Using PMSG With d-q Reference Frame

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***Abstract:** this project work reports the steady state behavior of the grid connected wind energy conversion system(WECS) in d-q frame. The generator used for the study is the permanent magnet synchronous generator. Simulation analysis is performed to inspect how PMSG characteristics are affected by different d-q control conditions, such as torque, and reactive power versus speed characteristics.*

***Keywords:** Permanent magnet synchronous generator , d-q vector control, MATLAB*

I. INTRODUCTION

In recent years, wind energy has been regarded as one of the significant renewable energy sources. Among the existing wind power generation systems, their generators can be categorized into four main types : 1) fixed-speed squirrel-cage induction generator; 2) variable-speed wound rotor induction generator that employs variable rotor resistance;3) variable-speed doubly fed induction generator that employs a frequency converter between the grid and its rotor windings; and 4) variable-speed synchronous generator, which is either a wound rotor synchronous generator or a permanent-magnet synchronous generator (PMSG). Due to the fact that a multiple pole design can be easily realized in the synchronous generator, it is the only type that provides a realistic opportunity to implement gearless operation and hence, the features of lightweight and low maintenance can be obtained in this type of wind generation system.

The PSMG wind turbine has higher efficiency than other variable speed wind turbine. PMSG has one disadvantage that the permanent magnet excitation are costs for permanent magnet materials. The steady- state study of PMSG is depends on the equivalent circuit at the synchronous speed .the speed of PMSG varies with the turbine power varies .The stato r voltage depends in the d-q control . the d-q control regulates PMSG speed but also it changes all other parametric data of a PMSG such as torque, reactive power.

This paper proposes the steady state analysis of PMSG under d-q reference frame. First the paper models the steady state model of PMSG under d-q reference frame. Simulation is carried to investigate characteristics of PMSG under d-q control and summarized with a conclusion.

II.MODELLING OF PERMANENT SYNCHRONOUS GENERATOR IN d-q REFERENCE FRAME

The most widely used PMSG model is park model[12,13]. Then the stator voltage equation becomes

$$\begin{pmatrix} V_{sd} \\ V_{sq} \end{pmatrix} = -R\begin{pmatrix} i_{sd} \\ i_{sq} \end{pmatrix} - \frac{d}{dt}\begin{pmatrix} \psi_{sd} \\ \psi_{sq} \end{pmatrix} + \omega_m \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}\begin{pmatrix} \psi_{sd} \\ \psi_{sq} \end{pmatrix} \quad (1)$$

Where,

R_s - Resistance of the PMSG stator winding

V_{sd} , V_{sq} – d-q components of stator voltages

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ψ_{sd} , ψ_{sq} - d-q components of stator fluxes

ω_m - Angular speed of turbine rotor in electrical angle

And the stator flux equations becomes

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

Where,

L_{ls} – leakage inductance of the PMSG stator winding.

L_{dm} ,L_{qm} - stator and rotor mutual inductances in the d-q reference frame.

Comparing the equation (1) and (2), we get

$$\begin{pmatrix} V_{sd} \\ V_{sq} \end{pmatrix} = -R_s \begin{pmatrix} i_{sd} \\ i_{sq} \end{pmatrix} - \frac{d}{dt} \begin{pmatrix} L_d i_{sd} + \psi_f \\ L_q i_{sq} \end{pmatrix} + \omega_m \begin{pmatrix} -L_q i_{sq} \\ L_d I_{sd} + \psi_f \end{pmatrix} \quad (3)$$

Where,

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

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

In steady state condition, the derivative item is reduced to zero. So the equation (3) becomes

$$\begin{pmatrix} V_{sd} \\ V_{sq} \end{pmatrix} = \begin{pmatrix} -R_s & -\omega_m L_q \\ \omega_m L_d & -R_s \end{pmatrix} \begin{pmatrix} i_{sd} \\ i_{sq} \end{pmatrix} + \begin{pmatrix} 0 \\ \omega_m \psi_f \end{pmatrix} \quad (4)$$

From the equation (4), the stator current equations are derived

$$i_{qs} = ((w_m L_d V_{ds}) + (R_s v_{qs}) - (w_m R_s G_f) / (-(w_m^2 L_d L_q) - (R_s^2)) \quad (5)$$

$$i_{ds} = V_{ds} / (-R_s - ((w_m L_q)((w_m L_d V_{ds}) + (R_s v_{qs}) - (w_m R_s G_f)) / ((-w_m^2 L_d L_q) - (R_s^2))) \quad (6)$$

The torque and stator reactive power can be obtained from (7) and (8) respectively in the d-q reference frames.

$$T_{em} = \psi_f i_{sq} + (L_d - L_q) i_{sd} i_{sq} \quad (7)$$

$$Q_s = V_{sd} i_{sq} - V_{sq} i_{sd} \quad (8)$$

III. SIMULATION RESULTS

Steady state simulation under d-q vector controls

Figure.1 shows the torque characteristics over V_{sd} under constant speed condition of w_m = 0.4p.u and the stator voltage V_{sq} is constant. From the figure, it can be observed that the torque characteristics is linearly proportional to V_{sd} control and in V_{sq} control, it's not influenced. For the negative values of V_{sd} , the PMSG runs in generating mode whereas in positive values of V_{sd} as motoring mode. The electromagnetic torque is higher for the larger negative values of V_{sd}.

Torque –speed characteristics under V_{sd} control

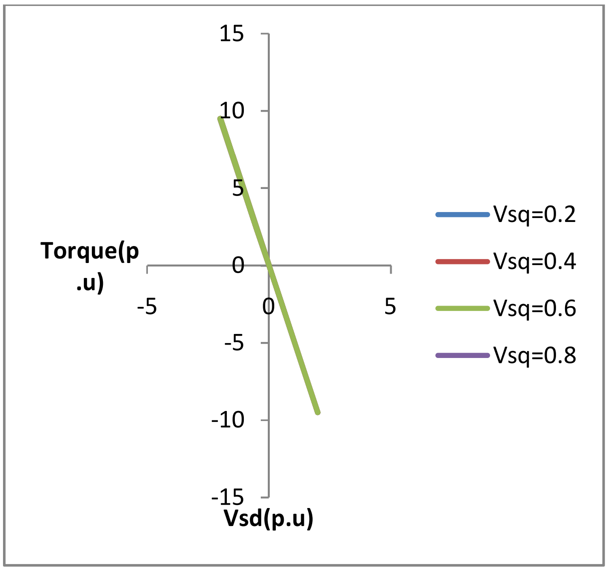

Figure.1 torque characteristics under V_{sd} control with constant wind speed

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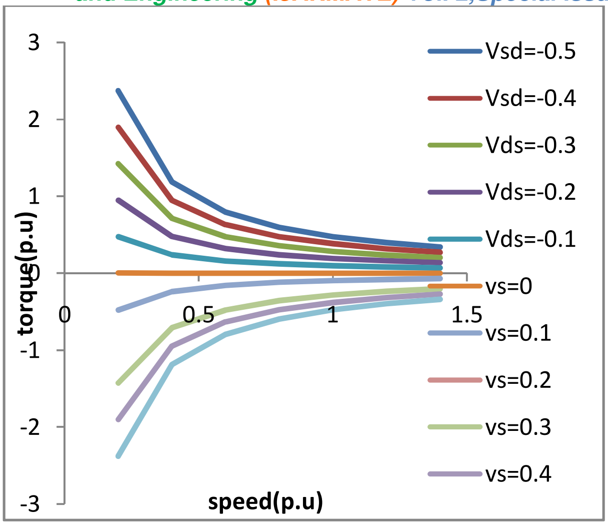

Figure.2 torque characteristics under V_{sd} control with different wind speed

Torque –speed characteristics under V_{sq} control

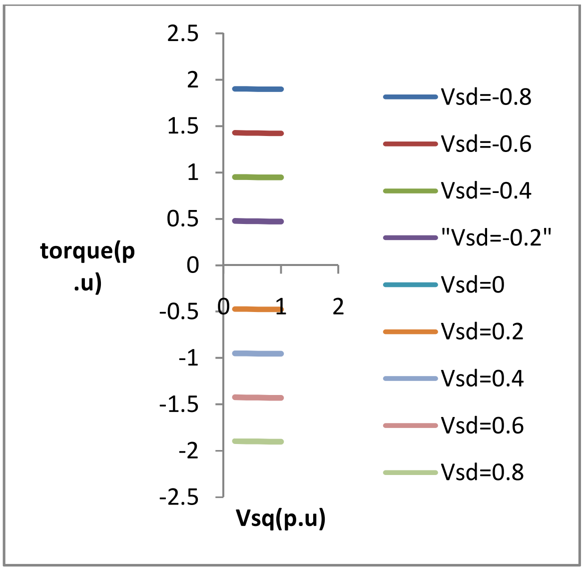

Figure 3. torque characteristics under V_{sq} with constant speed (W_m=0.4 p.u)

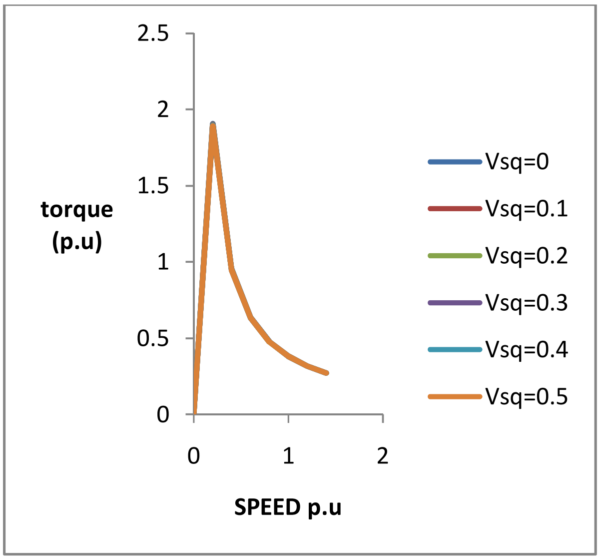

Figure 4. torque characteristics under V_{sq} with variable wind speed

Figure.3 shows the torque characteristics under V_{sd} control with variable wind speed. From the figure, the following properties are observed. The torque is higher for the higher V_{sd} values at the speed. And the torque is higher for the smaller speed in same Vsd control condition under different speeds. Torque characteristics is become trivial in the influence of Vsq control under constant Vsd control except for low speed.

Figure.4 shows the torque characteristics under Vsq control. In this Vsq control, Vsq changes from 0 to 1 p.u whereas Vsd remains constant for fixed speed as well as variable speed. It shows that the Vsq control of PMSG is ineffective for the torque control.

Reactive power characteristics under V_{sd} control

In reactive power characteristics, two conditions are considered. Variable Vsd while vsq remains constant and another one is variable Vsd while stator voltage is constant as 1p.u.

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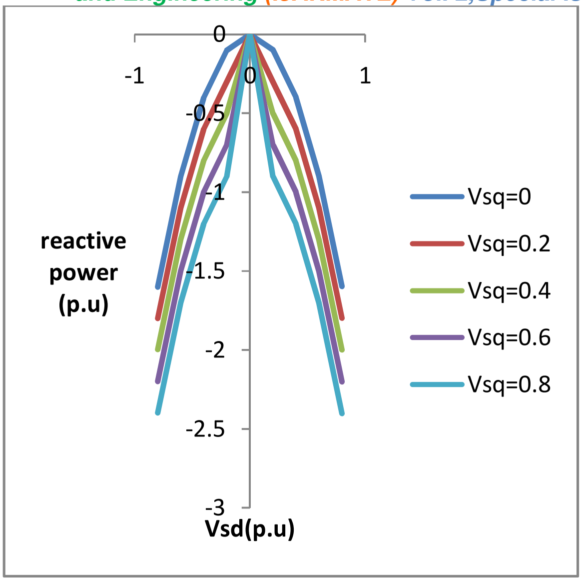

Figure 5. Reactive power characteristics under V_{sd} control with constant wind speed(w_{m}= 0.4 p.u)

Figure.5 shows the reactive power characteristics under Vsd control with constant speed. The following properties are identified from the figure. The reactive power absorbed is more for the larger value of Vsd whereas Vsq remains unchanged.

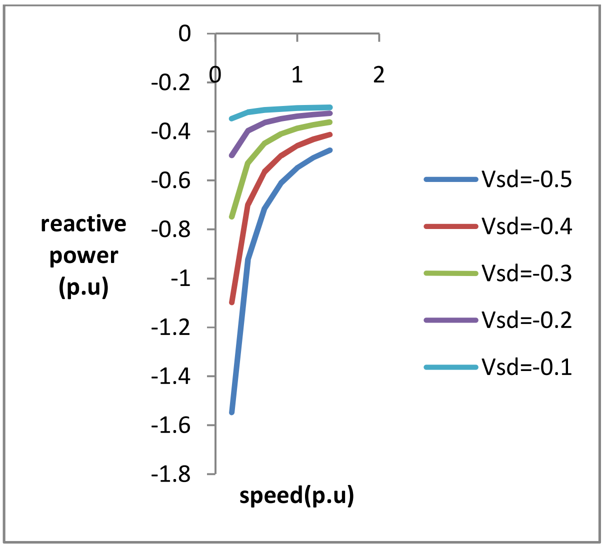

Figure 6. Reactive power characteristics under V_{sd} control with variable wind speed

Figure.6 shows the reactive power characteristics under Vsd control with variable speed.

It can be seen from the figure that the reactive power depends on the operating speed of the generator. The reactive power is absorbed more from the machine side converter for smaller speed. It is also important to indicate that even though the PMSG has an advantage of reducing gear box, it creates another problem of reducing energy conversion efficiency especially at a low speed.

Reactive power characteristics under V_{sq} control

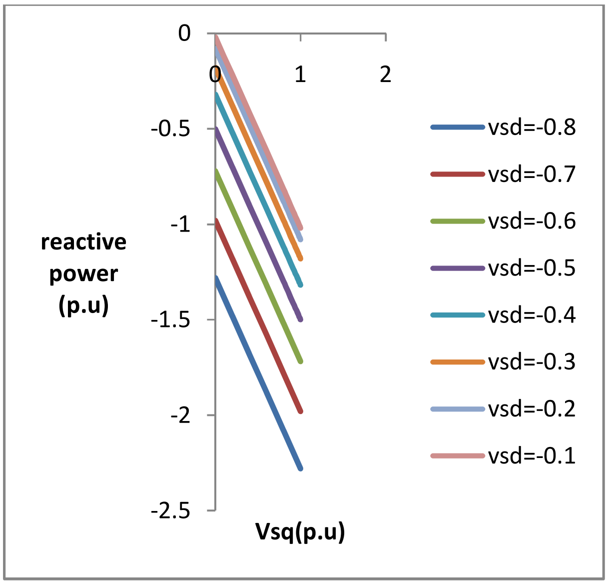

Figure 7. Reactive power under V_{sq} control with constant wind speed

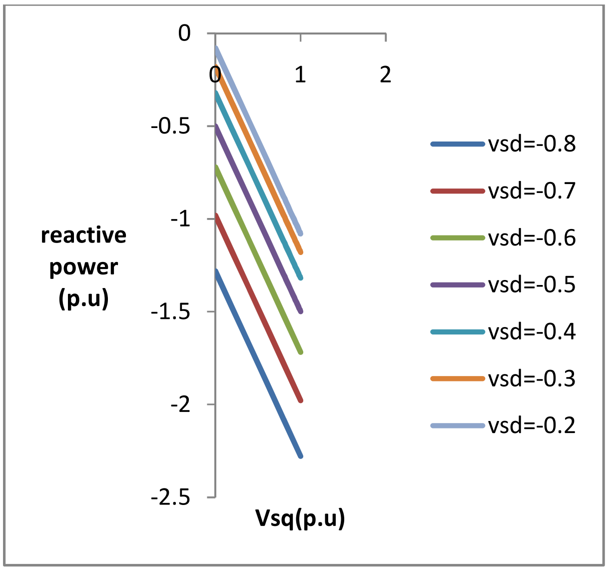

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Figure 8. Reactive power under V_{sq} control with variable wind speed

Figure.7 & 8 shows the reactive power characteristics under Vsq control with constant speed and variable wind speed. It can be seen from the figure

IV.CONCULSION

In this paper, simulation study on PMSG characteristics under d-q control is carried out.

It is observed that torque characteristics of PMSG are linearly proportional under V_{sd} control. In V_{sq} control, it's not influenced. Torque is higher when the speed is smaller under different wind speed.

In reactive power characteristics, if the stator voltage is higher with constant speed, the reactive power consumption by the generator is high. In constant d-q control condition, while increasing the speed gives less consumption of reactive power and decreasing the speed gives more consumption of reactive power. The PMSG stator voltage should be adjusted rather than fixed in order to benefit PMSG energy conversion efficiency.

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