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Comparison of PMSG and DFIG in Wind Turbine and Implementation of SVPWM Schemes of Inverter

V. Meenakshi[1] and S. Paramasivam[2]

ABSTRACT

In support of Advanced Energy Initiative objective to expand the use of wind energy. Wind energy use expanded in the wake of oil shortages and environmental concerns. Wind is a renewable power source, and overall, using wind to generate energy has fewer environmental impacts than many other energy sources. Wind turbines do not release emission that can pollute the air or water, and they do not want water for cooling purpose. Wind energy system may also reduce the amount of electricity generated from fossil fuels, which reduces the total amount of atmosphere greenhouse gasses, carbon dioxide emissions, and water used for electricity generation. This paper intends in comparing the total harmonic distortion (THD) for Permanent Magnet Synchronous Generator (PMSG) and Doubly Fed Induction Generator (DFIG) and has been implemented in MATLAB/Simulink interface.

Keywords: DFIG, PMSG, PMSM, SVPWM, WEC

1. INTRODUCTION

The liability of a wind energy system is to capture mechanical energy in the airflow and convert it to electrical energy. Usually it consists of a wind turbine, generator, converters and grid .In former periods wind turbine rotor are used and in latter period electrical machines like synchronous machines, induction generator, DFIG are used for conversion energy systems. The difference in the wind speed is one of the factors that affect the specifications of wind energy systems [1]. In other words design of the wind systems components demands individual concern. The quantity of mechanical energy depends on the size of the wind turbine and the wind regime of the site.

The wind turbines was developed in last century and enhanced from 1970s.Nowadays it is the most important renewable energy resources because of the safekeeping of nuclear power plant, oil price increasing, pollution etc [2].In recent years maximum power from wind speed are extracted by using the rapid development of power electronic devices [3].The power electronics equipment cost is less while using in variable speed wind turbine.

Modeling and controlling of stator/rotor flux in DFIG are done [4]-[6]. Eigen values are determined and system dynamics in DFIG are studied [7].DFIG are modeled and analysis done in grid side [8].Control schemes for DFIG are developed and it improves the system stability, short term frequency [9].The authors describe the modeling of PMSG [10]-[14].Previous studies are done either on PMSG or DFIG used in wind turbine for wind energy conversion system. This paper focused on both PMSG and DFIG mathematical modeling. This paper written in simple manner Section II describes about mathematical modeling of PMSG are briefly describe, mathematical modeling of DFIG are discussed in Section III, Section IV present simulation in MATLAB/ Simulink are done for PMSG and DFIG, the results are compared and concluded in Section V.

[1] Research Scholar, Dept. EEE, Sathyabama University, Jeppiaar Nagar, Chennai-600 119, India, *Email: meenagovind1@yahoo.in*

[2] R&D Head, ESAB Group, Sriperumpudur Taluk, Kanchipuram District, Chennai-602 105, India.

2. MATHEMATICAL MODELLING OF PMSG

In order to convert mechanical energy into electrical energy PMSG plays a vital role in variable speed wind turbine for generating power .A precise mathematical modeling of PMSG is done to study its steady-state and dynamic characteristics of wind energy conversion systems .Examination of PMSG in abc stationary reference frame and dq synchronously rotating reference are developed .The torque equation, electrical energy equation are given below.

2.1. Mathematical Modeling of a PMSG in the abc three-phase stationary reference frame

The prior assumption are made to model a PMSG, they are neglecting eddy current and hysteresis losses, neglecting magnetic saturation effects, considering back EMF in stator winding as sinusoidal, neglecting oscillatory effects in the rotor.

The terminal voltages can be written as follows:

$$V_{as} = R_s i_{as} + \frac{d}{dt}\lambda_{as} \tag{1}$$

$$V_{bs} = R_s i_{bs} + \frac{d}{dt}\lambda_{bs} \tag{2}$$

$$V_{cs} = R_s i_{cs} + \frac{d}{dt}\lambda_{cs} \tag{3}$$

Where, V_{as}, V_{bs}, V_{cs} are the instant stator voltages, and ias, ibs, ics are the instantaneous stator currents, Rs is the stator winding resistance per phase, λ_{as}, λ_{bs}, λ_{cs} are the instantaneous flux linkages induced by the three-phase AC currents.

The flux linkages are given by

$$\lambda_{as} = L_{aa} i_{as.} + L_{ab} i_{bs.} + L_{ac} i_{cs.} + \lambda_r \cos\theta_r \tag{4}$$

$$\lambda_{bs} = L_{ba} i_{as.} + L_{bb} i_{bs.} + L_{bc} i_{cs.} + \lambda_r (\cos\theta_r - \frac{2\pi}{3}) \tag{5}$$

$$\lambda_{cs} = L_{ca} i_{as.} + L_{cb} i_{bs.} + L_{cc} i_{cs.} + \lambda_r (\cos\theta_r + \frac{2\pi}{3}) \tag{6}$$

Where Laa, Lbb, Lcc are self inductance of *a*, *b*, *c* phases and Lab, Lac, Lba are mutual inductance.λ_r are rotor flux linkages.

2.2. Mathematical Modeling of the PMSG in the dq-axes synchronously rotating reference frame

The three phase abc quantities are transformed into two phase quantities by Park's transformation in order to analysis the PMSG in simple manner. The voltage equation in the axis are given by

$$V_{sd} = R_S i_{sd} + L_d \frac{di_{sd}}{dt} - w_e L_q i_{sq} \tag{7}$$

$$V_{sq} = R_S i_{sq} + Lq \frac{di_{sq}}{dt} + w_e L_d i_{sd} + w_e \lambda_r \tag{8}$$

The electrical equation of PMSG is given by

$$P_m = \frac{3}{2} w_e (\lambda_d i_{sq} - \lambda_q i_{sd}) \tag{9}$$

$$T_e = 3/2(p/2)(\lambda_r i_{qs} + (L_d - L_q) i_{sq} i_{sd}) \tag{10}$$

The number of pole in the machine is denoted as *P*.

3. MATHEMATICAL MODELLING OF DFIG

The DFIG consist of stator and rotor. The stator is connected to the grid through transformer and the rotor is connected via ac/dc/ac converter. In order to model DFIG following assumption are made they are the direction of rotation between stator and rotor is taken as 90^{o}, considering stator current positive, neglecting dc component, neglecting higher order harmonics components in rotor voltage .

The terminal voltages of the DFIG are represented by state space model using the synchronously rotating reference frame (dq-frame).

$$u_{sq} = R_s i_{sq} + w_e \lambda_{sd} + \frac{d}{dt} \lambda_{sq} \tag{11}$$

$$u_{sd} = R_s i_{sd} - w_e \lambda_{sq} + \frac{d}{dt} \lambda_{sd} \tag{12}$$

$$u_{rd} = R_r i_{rd} + (w_e - w_r) \lambda_{rq} + \frac{d}{dt} \lambda_{rd} \tag{13}$$

$$u_{rq} = R_r i_{rq} + (w_e - w_r) \lambda_{rd} + \frac{d}{dt} \lambda_{rq} \tag{14}$$

Where u_{sq}, u_{sd}, u_{rq}, u_{rq} are stator state space voltage and rotor state space voltage. Rsis stator resistance and *Rr* is rotor resistance. We angular reference speed, Wr rotor angular speed λ sd, λ sq, λ rd, λ rq are the fluxes of stator and rotor in *d*-axis and *q*-axis.

The linkage flux of stator and rotor are given by

$$\lambda_{sq} = l_s i_{sq} + l_m i_{rq} \tag{15}$$

$$\lambda_{sd} = l_s i_{sd} + l_m i_{rd} \tag{16}$$

$$\lambda_{rq} = l_m i_{sq} + l_r i_{rq} \tag{17}$$

$$\lambda_{rd} = l_m i_{sd} + l_r i_{rd} \tag{18}$$

The stator current and rotor currents are obtain from the above equation are as follows

$$i_{sq} = \frac{1}{\sigma L_S} \lambda_{sq} - \frac{L_m}{\sigma L_s L_r} \lambda_{rq} \tag{19}$$

$$i_{sd} = \frac{1}{\sigma L_S} \lambda_{sd} - \frac{L_m}{\sigma L_s L_r} \lambda_{rd} \tag{20}$$

$$i_{rq} = -\frac{L_m}{\sigma L_S L_r} \lambda_{sq} + \frac{1}{\sigma L_r} \lambda_{rq} \tag{21}$$

$$i_{rd} = -\frac{L_m}{\sigma L_S L_r}\lambda_{sd} + \frac{1}{\sigma L_r}\lambda_{rd} \tag{22}$$

$$\sigma = L_s L_r - L_m / L_s L_r$$

power equation are given by

$$P_s = -\frac{3}{2} w_e (\psi_{sq} i_{sd} - \psi_{sd} i_{sq}) \tag{23}$$

$$P_r = -\frac{3}{2}(w_e - w_r)\ (\psi_{rq} i_{rd} - \psi_{rd} i_{rq}) \tag{24}$$

The torque equation of DFIG is given by

$$T_e = \frac{3}{2}(\psi_{sq} i_{sd} - \psi_{sd} i_{sq}) \tag{25}$$

4. SIMULATION RESULT FOR PMSG AND DFIG

4.1. Implementation of SVPWM Switching Techniques for PMSG:

A 400v, 60 hz supply is given to rectifier than it is boosted and given to inverter. From inverter it is given to 3000 rpm, 300v, 0.8Nm PMSG. The PMSG is controlled by direct torque method .The PMSG speed is taken and it is compared in subsystem1(speed controller). The output of speed controller is feed to subsystem 2(SVPWM block).The v/f output from SVPWM block is given to inverter gate pulse and finally to three phase load through dc link capacitor and rectifier shown in (Fig. 1)

The statorcurrent abc, dq axis statorcurrent, stator voltage, rotor speed, rotor angle thetam, electromagnetic torque are shown in (Fig. 2, Fig. 3, Fig. 4, Fig. 5).

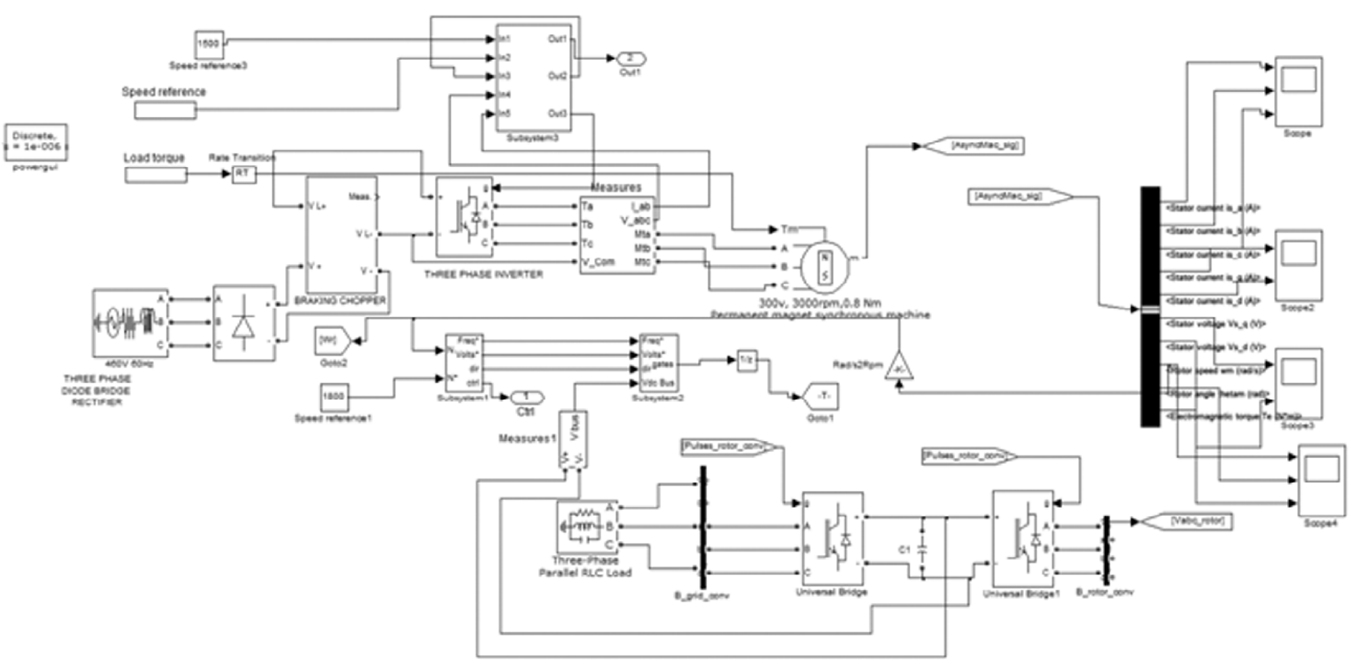


Figure 1: PMSG using SVPWM switching Techniques

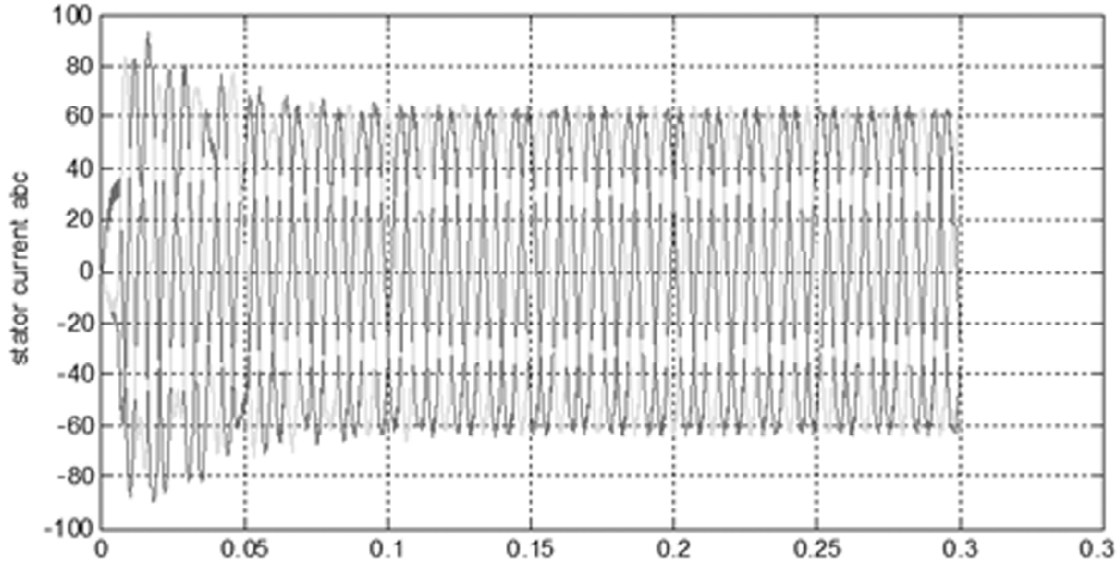


Figure 2: Stator current abc

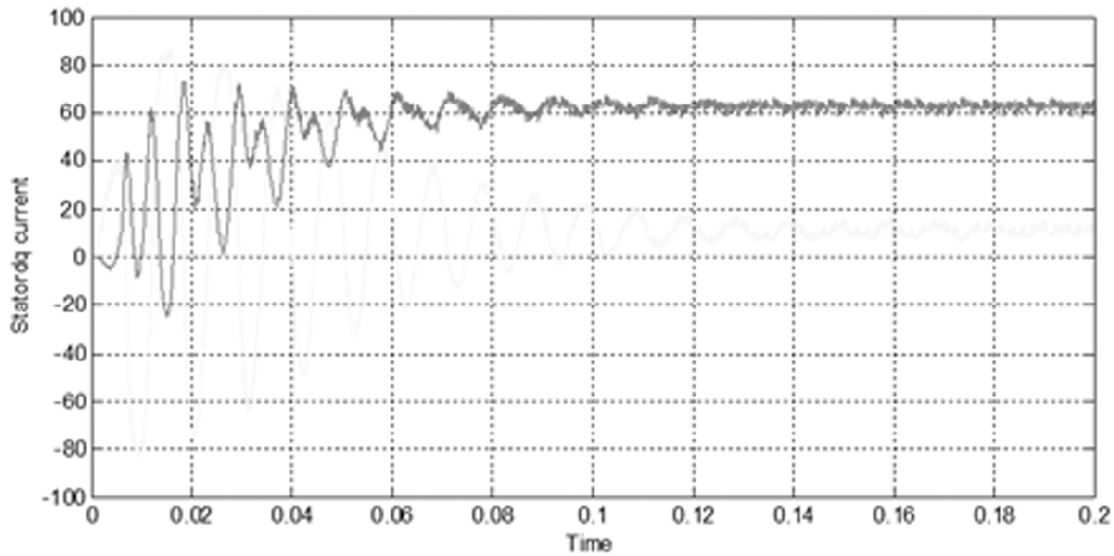


Figure 3: dq axis stator current

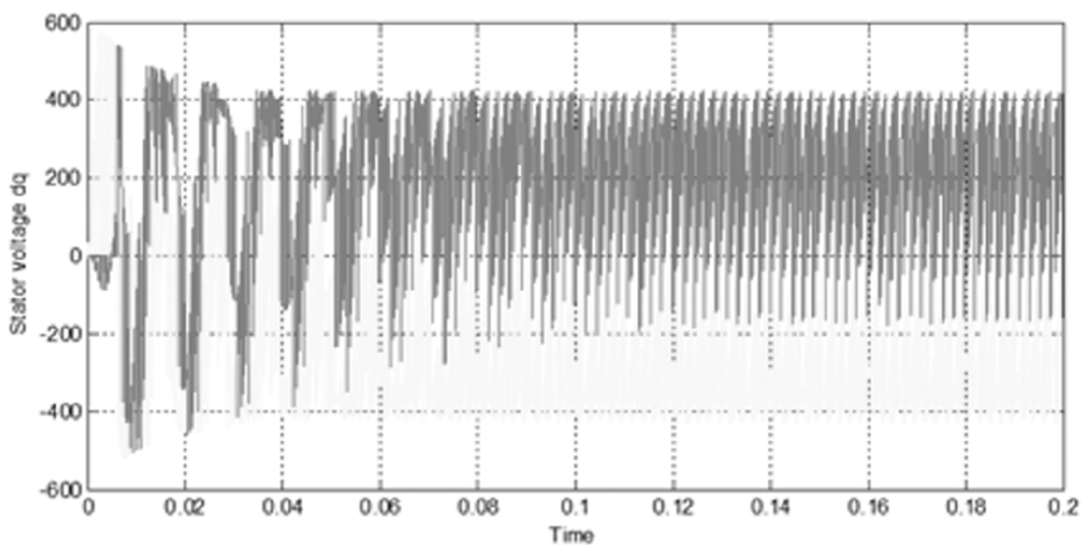


Figure 4: Stator Voltage dq

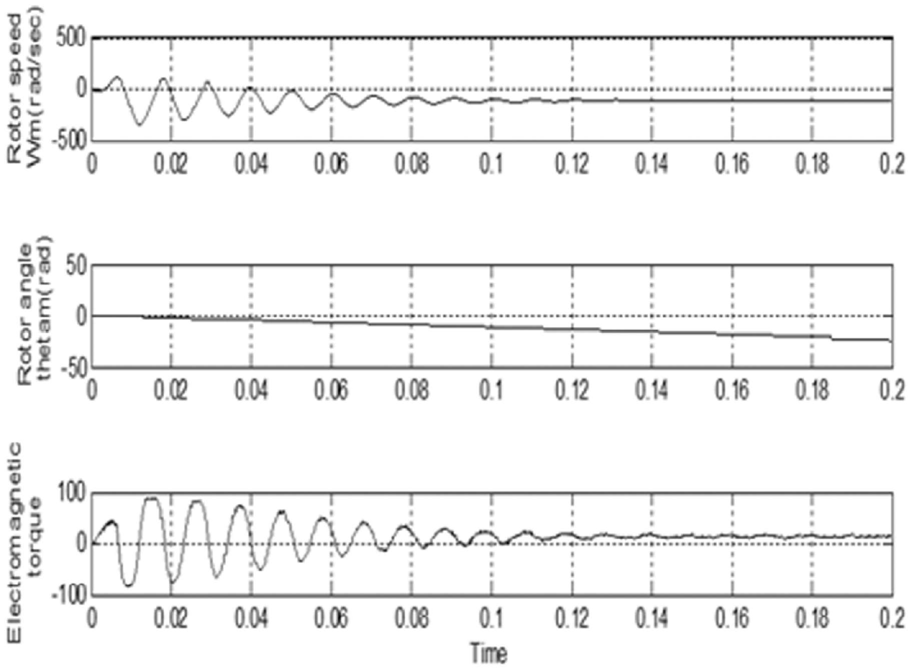
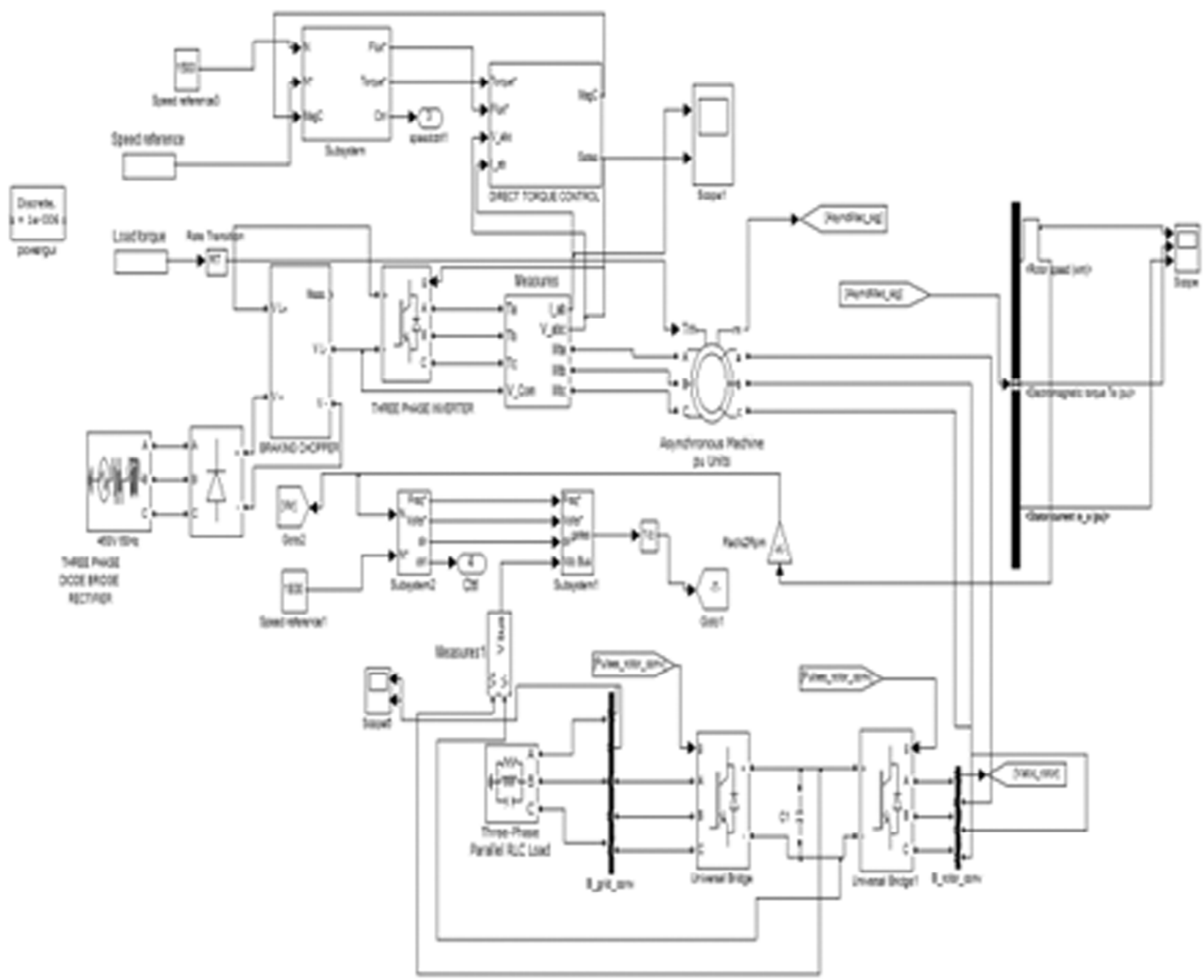


Figure 5: Rotor Speed(rad/sec), Rotor angle thetam (rad), Electromagnetic torque (Nm)

4.2. Implementation of SVPWM Switching Techniques for DFIG:



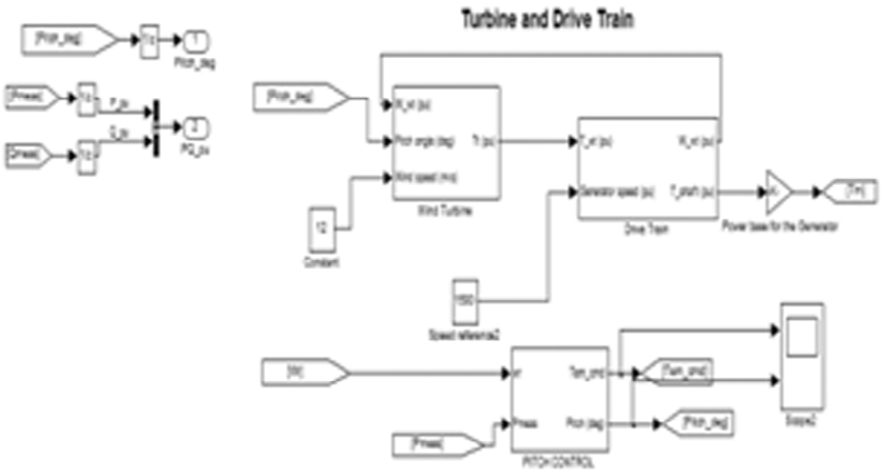


Figure 6: DIFG using SVPWM switching Techniques

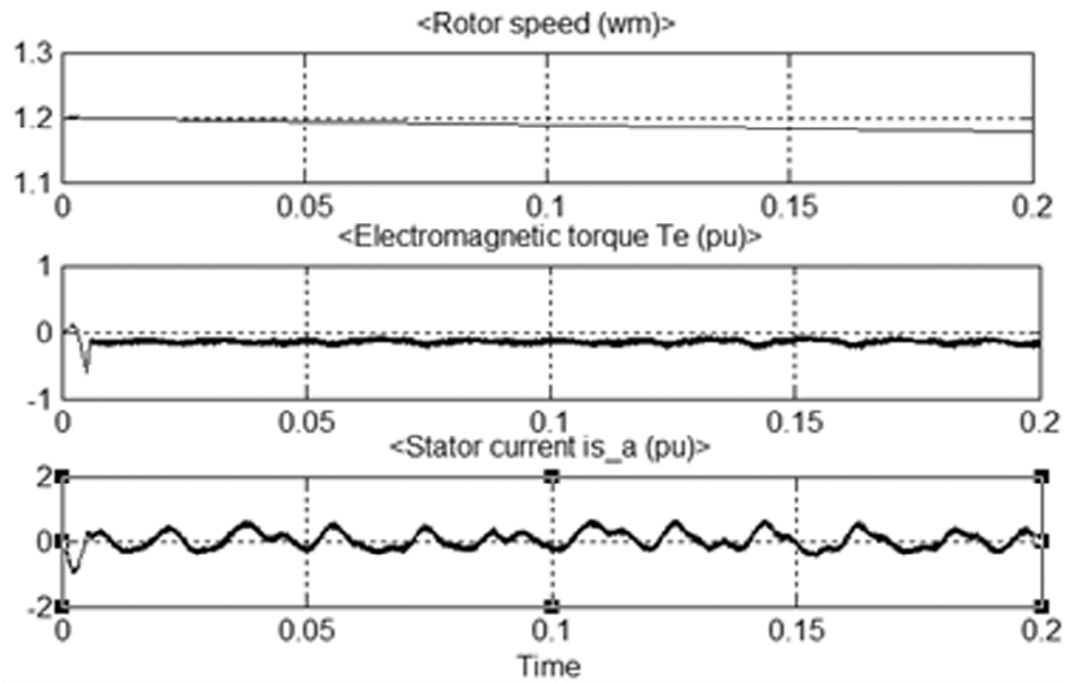


Figure 7: Rotor Speed, Electromagnetic torque(pu),Stator current

A 400v, 50Hz, 1.5 Hp DFIG is used (shown in Fig. 6).The DFIG rotor speed is given to speed controller block(subsystem1), the output of this block is feed to SVPWM block(subsystem2).The v/f output from SVPWM is given as gate pluse inverter and finally connected to 3 phase load. DFIG rotor speed, electromagnetic torque, stator current are shown in (Fig. 7)

Tabulation 1
Comparison of THD for PMSG and DFIG

S. No	*Electrical & Mechanical Quantities*	*Simulation results for PMSG in SVPWM*	*Simulation results for DFIG in SVPWM*	Total Harmonic distortion, THD in %	
				PMSG	*DFIG*
1	Rotor speed ω_m	125 (rad/sec)	1.172	47.29	67.30
2	Stator current $i_a$inp.u	0.8	1	80.65	202.42
3	Electromagnetic torque,Te in p.u	18	- 0.5	47.29	108.08

5. CONCULSION AND FUTUREWORK

In this paper presents the mathematical modeling of PMSG and DFIG for wind energy conversion systems are done .Simulation results for PMSG and DFIG using SVPWM techniques are compared in the above Table.1.THD for PMSG and DFIG are validated .In future it can be carried out by using adaptive PWM technique.

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