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Novel Power Coefficient for extracting the maximum power in Wind power based Doubly fed Induction generator (DFIG) using vector control

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Abstract. This Paper shows behaviour of the Doubly fed Induction generator(DFIG) for extracting the maximum power using vector controlled mechanism. This paper present the controlling of rotor side converter(RSC) and grid side converter(GSC) through conventional method of gate triggering by using d-q theory The paper includes the simulation model of DFIG and further the maximum power extraction from wind is estimated by using power coefficient which is completely dependent on pitch angle, tip to speed ratio(TSR). The novelty in power coefficient has design to harness the maximum power. Firstly the mathematical model of DFIG is developed with incorporated wind turbine as mechanical input and then vector controlled method is used. DFIG is broadly used in wind power applications which are more robust, reliable and very efficient system. The complete system is implemented using MATLAB software tool.

Keywords—Doubly fed induction machine, vector controlled ,TSR, Wind

1. Introduction

The conventional sources of electrical energy generation are reducing at a faster rate and environmental issues are also the cause to worry about the future[1]. This situation is forcing us to think about depletion of harnessing of electrical energy generation[2]. But the demand of energy consumption increases day by day as the population density increases exponentially at a global level so it become necessary to switch to renewable sources of energy from non renewable source of energy[3].

Nowdays energy generation can also be done at small scale level using different non conventionally energy like solar power plant,wind power plant, small hydropower plant(preferred to be less than 25MW) because the infrastructure cost and operating is considered to very small as compared to large scale power generation. The hydropower plants are only installed where hydro power plant is abundant[4]. On other hand solar & wind power generation can be installed irrespective of the location because wind & solar both are freely available. So wing & solar power is generally preferred to harness energy[5]. In this Doubly fed Induction machine(DFIM) is used in both generating and motoring operation using wind power including wind turbine as a mechanical input for

DFIM[6] but the speed measurement was the biggest issue because the conventionally speed was measured through the speed sensor which shows error of 7-8% from its actual value due to the mechanical vibrations Nowdays DFIM play as significant role in wind power generation so as to recover from slip power losses to increases the efficiency, reliability of the machine so that maximum of the output can be generated[8]. DFIM in proper hostile environment, hazardous places, noiseless environment where the speed can be measured at the short accessible remote location[10]. Now the main objective to generate or absorbing the maximum power under generating or motoring mode has to be accomplished[12].For the maximum power extraction we need to consider the effect of wind turbine parameters like pitch angle ,tip speed ratio(TSR),power coefficient with latest control equations to have maximum power coefficient which is directly proportional to generated power. Basically, the energy consumption per unit time is measured by DFIM under generating and motoring mode given by

$$E = Kw^3$$

After that energy consumption is calculated for sensor speed and sensor less speed and comparison will be analyse to check the performance under both cases and to show that why sensorless is preferred to overcome its limitation[13]

2. DFIM Dynamics

2.1 Basic introduction to DFIM

Doubly fed Induction are the typical conventional induction machine which can operate as motoring as well as generating mode where the powers can be absorbed or delivered from same grid[14] but to make the system more efficient and reliable two com rotor to stator so that rotor speed is somehow controlled by rotor side converters further grid voltage is directly voltage side converter and chock coil is connected between GSC and main +grid to avoid the problem of harmonics in the supply[15]. Depends upon the operating mode of DFIM, reactive and active power behaves differently under generating mode machine absorbs reactive and active power both from the grid in that case grid side converter act as rectifier while rotor side converter works as inverter while under motoring mode machine will deliver both active and reactive power to the grid both in that case grid side converter works as inverter while rotor side converter works as rectifier[16]. Firstly, the Mathematical model of DFIG has been developed using different reference frame[17]. Secondly; the rotor currents control and voltages enable the Doubly fed induction machine to be connected with the grid under synchronization while the rotor speed varies. Nowdays variable speed operating machine is preferred to fixed speed specially in case of lower speed operation of DFIM. Thirdly converter cost is also needed to consider because certain fraction of slip power losses (25-30%) is fed back to the grid to increases the efficiency of the DFIM [18] which makes the system more immune towards disturbance. Now the speed measurement using rotor shaft is avoided to avoid the problems of mechanical vibrations, more noise, more fluctuations in the grid voltage and current and the major danger to workers who are working under the hazardous environment so we prefer sensor less scheme to measure the rotor speed to avoid the above mentioned problems by measuring the speed using rotor current signal in different reference frame i.e synchronous rotor, stationary reference frame, further in continuation rotor position is measured by taking the angle between rotor currents in synchronous and rotor reference frame[19].

2.2. Power flow in DFIG

Fig 1 represent the structure of DFIG with power flow. Generally, we know that output of electrical power of rotor P_r is completely depend on slip value under the generating mode slip is negative so power will flow in the delivering state from machine to the grid directly from the stator while both reactive and active power will be absorbed through both grid side and rotor side converter from the same grid. Machine will absorb both powers in that case GSC acting as rectifier while RSC working like inverter[20] while delivering power from grid to the machine via GSC &RSC while voltage

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across dc link this will help to maintain constant voltage across grid terminals. Now the rotor power P_r is function of stator power Ps under the steady state both the powers are equivalent to each other[21]. DC link will absorb the power to maintain the voltage constant at the grid terminal under super synchronous operation while reverse phenomenon will for motoring mode machine will absorb power from grid directly to the winding of the stator and rotor will deliver same active & reactive power at slip frequency to the grid indirectly through RSC & GSC in that case grid side converter works as inverter while rotor side converter works as rectifier[22]. Phase sequence of generated voltage on the rotor changes under sub synchronous in addition to super synchronous mode of operation it will be change from positive under subsynchronous to the negative under super synchronous mode. The chock coil was a filter to remove the harmonics from the generated AC voltage. Simulation of 2KW DFIM is designed

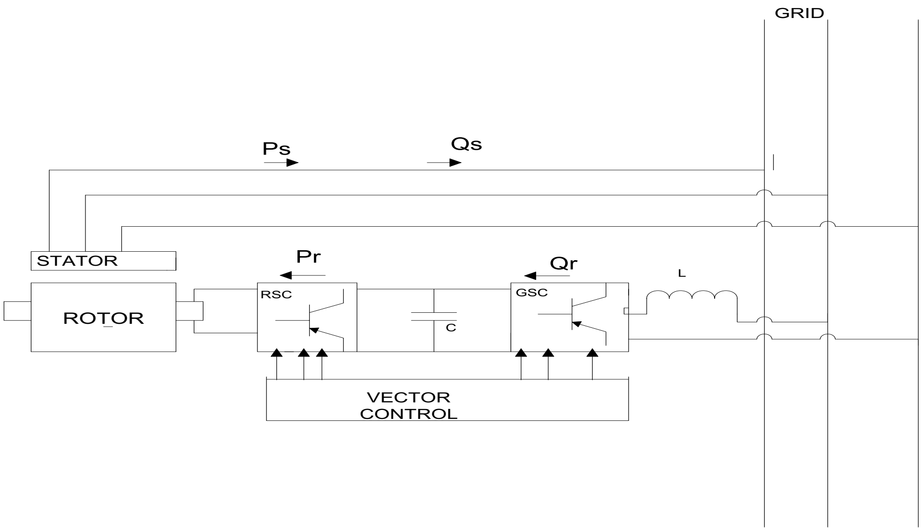

Fig.1 Power flow in DFIG

2.3 Modelling of DFIG:

The modelling of DFIG can be understood by considering the voltage source at both end (stator as well as rotor) as shown in the Equivalent circuit Diagrams of DFIG. The Doubly fed induction generator can be represented by adding a secondary voltage source V_2 to its secondary winding as shown in Fig.2 where X_r and R_r represent rotor reactance and rotor resistance referred to the stator side while R_1 and X_1 represent the stator Resistance and rotor resistance

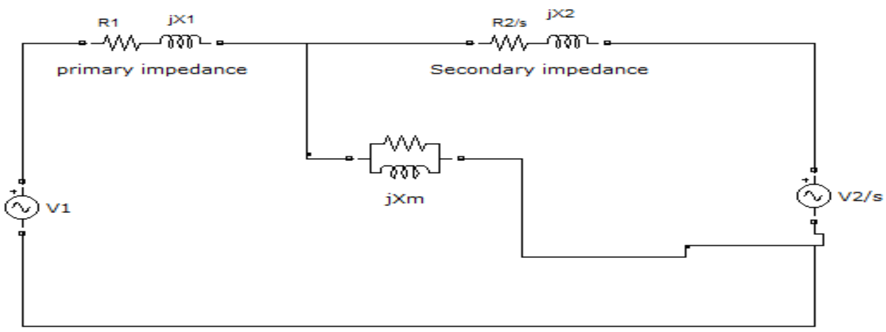

Fig.2 Equivalent Circuit Diagram of DFIG

Let $V_{qs}, V_{ds}, V_{dr}, V_{qr}, I_{qs}, I_{ds}, I_{qr}, I_{dr}$ are the corresponding stator and rotor voltages and currents in direct and quadrature axis coordinates their relationship are given below[12]

$$V_{qs} = (R_s + pL_s)I_{qs} + \omega L_s I_{ds} + pL_m I_{qr} + \omega L_m I_{dr} \quad (1)$$

$$V_{ds} = -\omega L_s I_{qs} + (R_s + pL_s)I_{ds} - \omega L_m I_{qr} + pL_m I_{dr} \quad (2)$$

$$V_{qr} = L_m pI_{qs} + \left(\omega-\omega_r\right)L_m I_{ds} + \left(R_r + pL_r\right) I_{qr} + \left(\omega-\omega_r\right)L_r I_{dr} \quad (3)$$

$$V_{dr} = -\left(\omega-\omega_r\right)L_m I_{qs} + L_m pI_{ds} - \left(\omega-\omega_r\right)L_r I_{qr} + \left(R_r + pL_r\right)I_{dr} \quad (4)$$

Electromagnetic torque is given by

$$T_e = 3\left(I_{qs}I_{dr} - I_{ds}I_{qr}\right)pL_m / 2 \quad (5)$$

Speed can be calculated by given relation

$$\omega_r = \left(T_e - T_L\right)/\left(B + pJ\right) \quad (6)$$

Where $p = \dfrac{d}{dt}$

T_L = load torque

ω = reference frame speed

for rotor reference frame $\omega = \omega_r$

for synchronous reference frame $\omega = \omega_s$

for stationary reference frame $\omega = 0$

3. Wind Turbine Dynamics:

We know that load torque is applied as mechanical input to the Doubly fed Induction Machine[23]. This load torque or mechanical torque(Tm) is completely drive by wind turbine which depends on the wind power coefficient (C_p), wind speed(V_w), density of the air(ρ̇),swept circular area(S).

$$T_m = 0.5S\rho C_p\left(\lambda,\beta\right)V_w^{\,3} / w_t \quad (7)$$

Performance parameter(C_p) of the wind turbine[8] depends on the pitch angle(β) and TSR(λ) , swept circular area S= πR^2

TSR(tip to speed ratio) is the ratio of the linear speed of the blades to the wind turbine

$$TSR = =\omega_{turbine} R / V_\omega \quad (8)$$

Where R is radius of blades, $\omega_{turbine}$ is the linear speed of the wind turbine. The characteristic between C_p and λ has been drawn for variation in pitch angle(β). For the any value of the wind speed, output power(P) as mechanical input is given by

$$P = 0.5S\rho C_p\left(\lambda,\beta\right)V_w^{\,3} \quad (9)$$

In the above equation(9) Wind power is directly dependent on (C_p) with some constant. if maximum power is to be drawn from the wind then power coefficient(C_p) should be on maximum at particular values of pitch angle and TSR. In the given characteristics (Cp-λ) as shown in the figure Fig.3 maximum power coefficient is obtained at pitch angle (β) of 0 degree with the different wind speed variation of 6,8.2,8.4,9,12 with the turbine speed of 0.2,0.4,0.6,0.8,1 and it is observed that maximum power coefficient is obtained at an angle of 0 degree. A Single graph depict drawn from Fig3. in which Characteristic between Power Coefficient (C_p) and TSR (λ) is obtained for different values of pitch angle and at pitch angle of 0 degree peak value of C_p is obtained [24].

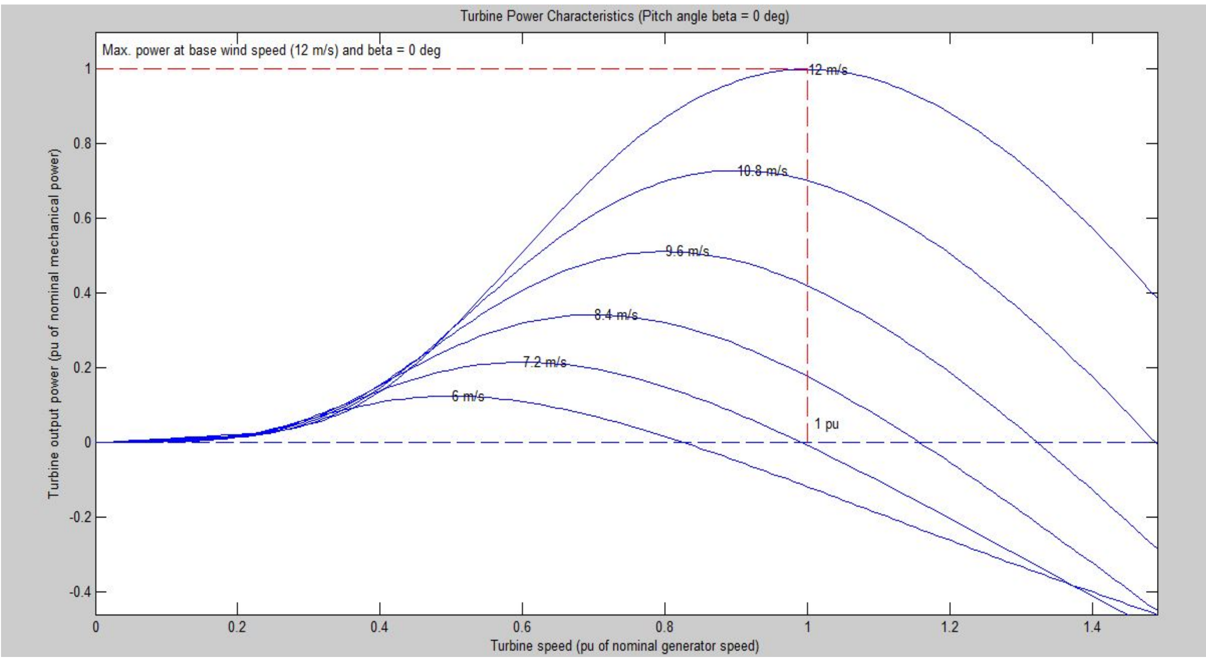

Fig.3 Power Coefficient Curve

4. Vector control of DFIG:

The equations which are used for vector controlled of DFIM is done in both RSC and GSC which is given inFig.4 and Fig.5 for the 415V and 15 KVA DFIG.

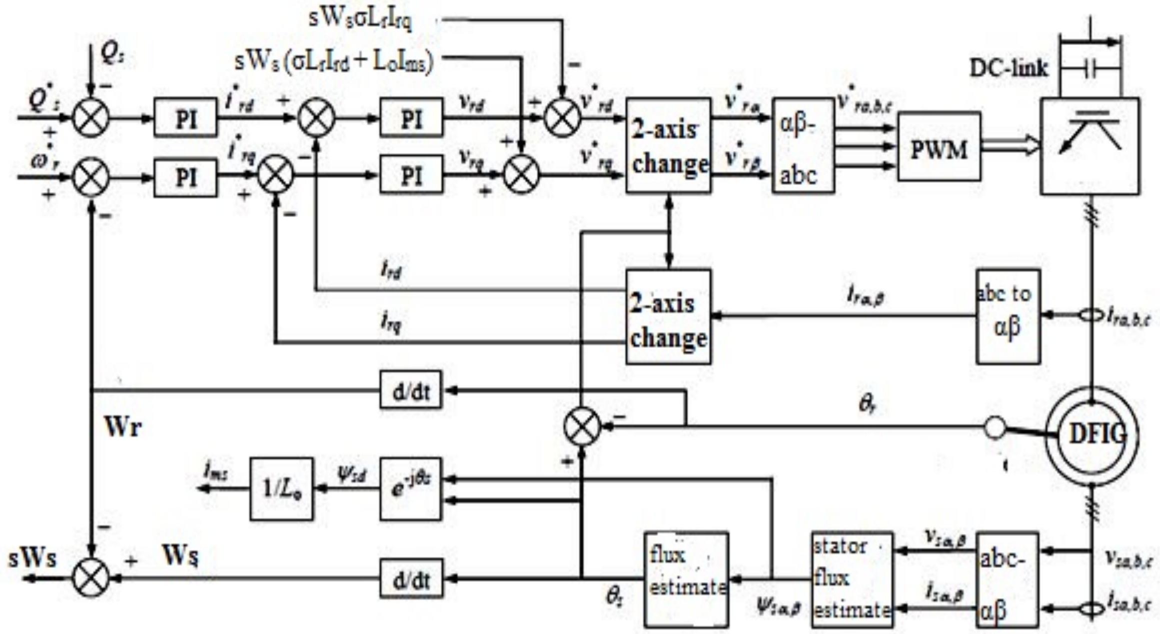

Fig.4 Vector Control of Rotor Side Converter

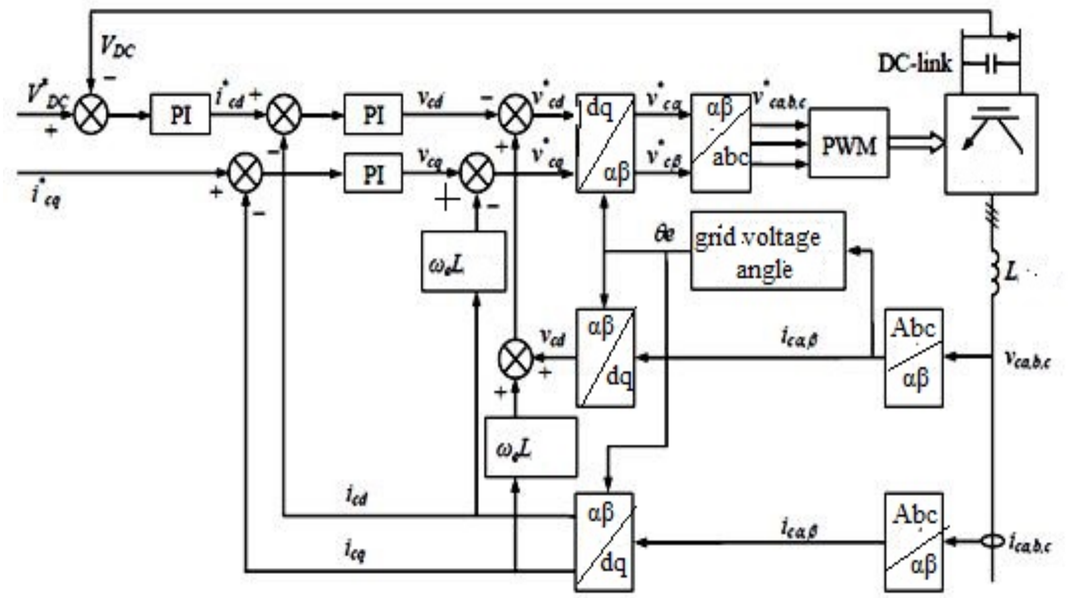

Fig.5 Vector Control of Grid Side Converter

4.1 Grid Side Converter (GSC)

Following equation for GSC are used for fig.5 as shown and for generating pulses in GSC a complete control mechanism using PI controller are represented from eq.(10) to eq.(14)

$$i_{cd}^* = (k_1 + \frac{k_2}{s})(V_{dc}^* - V_{dc}) \tag{10}$$

$$V_{cd} = (k_3 + \frac{k_4}{s})(i_{cd}^* - i_{cd}) \tag{11}$$

$$V_{cq} = (k_5 + \frac{k_6}{s})(i_{cq}^* - i_{cq}) \tag{12}$$

$$V_{cd} - w_e(L\, I_{cq}) = V_{cd}^* \tag{13}$$

$$V_{cq} - w_e(L\, I_{cd}) = V_{cq}^* \tag{14}$$

GSC is used to maintain the constant voltage across the grid by allow the dc link to absorb reactive power

4.2 Rotor Side Converter (RSC)

It is used to control the speed of the rotor in such a way to absorb more reactive power from the grid as shown in the Fig.4 through generate the different reference voltages and current by passing error through PI Controller represented from eq.(15) to eq.(20)

$$i_{rd}^* = (k_1 + \frac{k_2}{s})(Q_s^* - Q_s) \tag{15}$$

$$i_{rq}^* = (k_3 + \frac{k_4}{s})(w_r^* - w_r) \tag{16}$$

$$V_{rd} = (k_5 + \frac{k_6}{s})(i_{rd}^* - i_{rd}) \tag{17}$$

$$V_{rq} = (k_7 + \frac{k_8}{s})(i_{rq}^* - i_{rq}) \tag{18}$$

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$$V_{rd} - sw_s(\sigma L_r I_{rq}) = V_{rd}^* \quad (19)$$

$$V_{rq} + sw_s(\sigma L_r I_{rd} + L_o \mathrm{I}_{ms}) = V_{rd}^* \quad (20)$$

Table.1 Machine Parameters

Parameter	Value
resistance of stator	0.023 ohm
inductance of stator	0.18 henry
resistance of rotor	0.016 ohm
inductance of rotor	0.16 henry
Stator magnetizing inductance	0.16 henry
Frequency	50 Hz
Pole pair	2
Wind Speed	12 m/s
DC link Voltage	800 V
Filter Specification	L=24μH, R=10Ω
Rotor side converter	K1=3.6,k2=8.9,k3=7.8,k4=11.3,k5=15.26,k6=17.56,k7=18.5k8 =21.25
Grid side converter	K1=25.6,k2=18.6,k3=27.8,k4=10.3,k5=32.86,k6=19.78

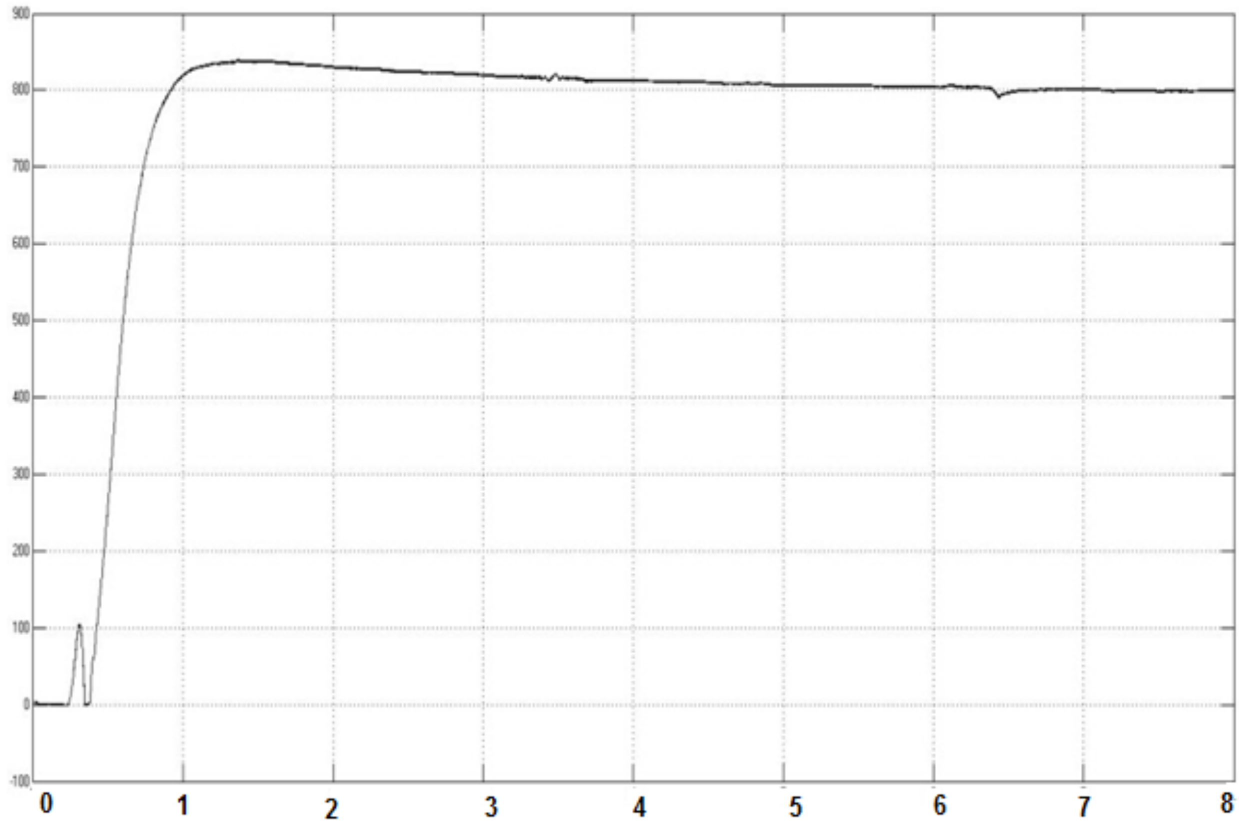

Fig.6 DC Link Voltage Waveform

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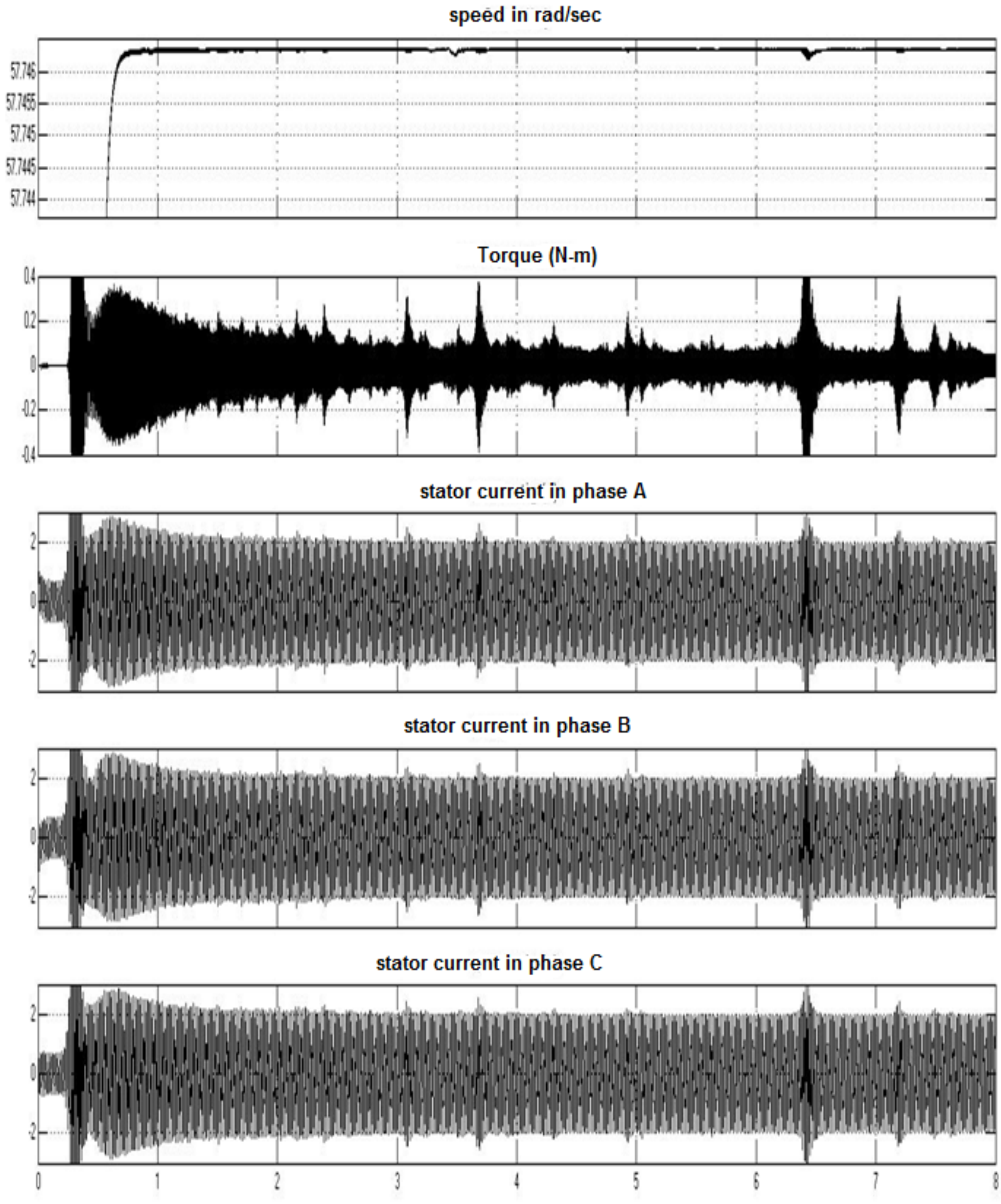

Fig.7 Graphical Representation of the Different Performance Parameter (Speed,Torque,3-Phase Current) of DFIG

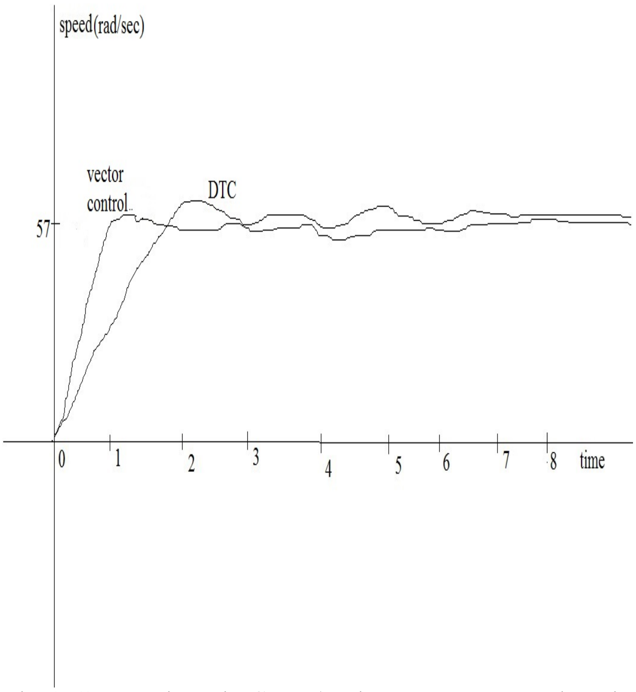

Fig.8 Comparison in Speed using vector control & DTC

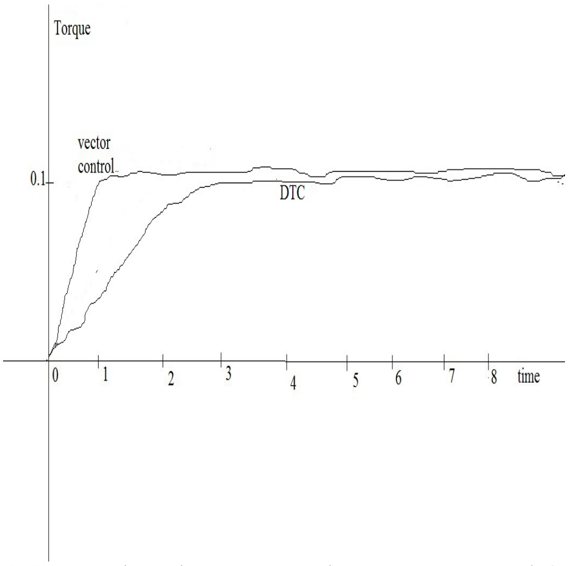

Fig.9 Comparison in Torque using vector control & & DTC

5. Result and Analysis

From the different graph obtained of the Fig.7 for speed, torque, current by using the vector control for harnessing the maximum energy From wind turbine fed to the DFIG by varying the pitch angle and its maximum value obtained at β=0 degree at the wind speed of 12m/s to obtained the maximum power coefficient which directly depends on the power to harness in the maximum way and Vector control for GSC & RSC is also performed to harness the maximum energy from wind and performance parameter must be settled

6. Conclusion

This paper presents the maximum extraction or delivering of power .it is clearly shown that after designing the model of DFIG in different reference frame specially synchronous reference frame under vector control technique. Maximum power is obtained when power coefficient is maximum for pitch angle equal to 0 degree under different value of the tip speed ratio. This shows that power can be drawn maximally from wind turbine by controlling power coefficient. By choosing the suitable value of proportional constant of PID controller for vector control of RSC and GSC voltage across dc link voltage is maintained constant. It is also shown that performance parameter like speed, torque shows the better performance when system operated in vector control in comparison to Direct torque control method because it takes lesser settling time for attaining the final value

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