5th International Conference on Control Engineering&Information Technology (CEIT-2017)
Proceeding of Engineering and Technology –PET
Vol.34 pp.43-48

DTC OF DOUBLY FED INDUCTION GENERATOR FOR WIND POWER SYSTEM BASED ON ROTOR FLUX ESTIMATION

Ameni Kadri[1] ,Hajer Marzougui[2] , Khaoula Omrani[3] , Faouzi Bacha[4]
University of Carthage, INSAT, B.P. 676, 1080, Tunis Cedex, Tunisia
[1]`ameni-kadri-ensit@hotmail.com`, [2]`marzougui.ensit@gmail.com`, [3]`omranikhaoula1@gmail.com`,
[4]`Faouzi.Bacha@esstt.rnu.tn`

***Abstract*— The popularity of renewable energy conversion systems, and especially of wind energy, has been growing in recent years. Doubly fed induction generator (DFIG)-based wind energy systems are extensively used.**

The aim of the present paper is to show the analysis of the direct torque control technique (DTC) performances applied to a doubly fed induction generator (DFIG) using a rotor flux observer which is based on modified low-pass filter (MLPF) algorithm .This method can eliminate the dynamic error of flux and reduce torque oscillations, ripple and device switching losses. The studied system control is tested and validated by numerical simulations. The obtained results show the effectiveness of the control strategy leading to best performances.

***Keywords*— Wind Energy Conversion System, DFIG, DTC, Flux Observer, MLPF.**

I. INTRODUCTION

Wind energy is the important sources of renewable energy in the world, because it is a clean energy, friendly to environment, cost-effective. Currently, Wind turbine system based on doubly fed induction generator (DFIG) is one of the most popular configurations .In the aim to develop a efficient wind energy conversion systems (WECS) connected to the grid , different algorithm control applied to double-fed induction generator (DFIG) have been studied in the literature. [2]by example, the field oriented control strategy, the non linear vector control strategy . But, those control strategies require accurate information of machine parameters which comes to compromise the robustness of the control device [1]. After this, the direct control techniques namely the direct torque control (DTC) and the direct power control (DPC), based on two hysteresis comparators were proposed and compared to the vector control strategies. Concerning DTC, it has a faster dynamic response due to the absence of the PI current controllers, simple structure and low parameter dependency, so it has become an interest of research throughout the world.. The basic principle of DTC is selecting an appropriate voltage vector from a switching table to restrict both torque and flux errors in their respective hysteresis bands. [3] [4]

The accuracy of rotor flux calculations is dependent on how accurately the rotor resistance is known. Integration problems also exist and a observer based first-order low-pass filter are used to accurately calculate the rotor flux[5] [6]. This paper presents to DTC strategy based flux estimator with compensated MLPF and detailed simulation has been carried out to verify the performance of the scheme. This paper is organized as follows. Section II presents the set of equations of the d-q model of DFIG. The concept of the estimator flux with compensated MLPF is presented in section III while in section IV is dedicated to the DTC control strategy, simulation results of the overall system which is presented in Fig.1 are presented and discussed in section V, the conclusion is drawn in section VI.

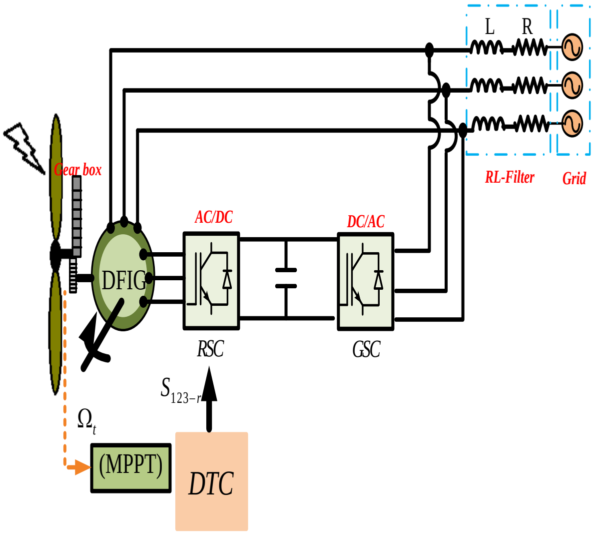

Fig1. Overall block diagram of the proposed scheme.

II. DFIG DYNAMIC EQUATIONS

A doubly-fed induction generator is as a standard wound rotor induction generator with its stator windings directly connected to the power grid and rotor connected to the power grid through the back to back convertor[7].

ISSN 2356-5608

The dynamic modeling of doubly-fed induction generator in synchronously rotating reference frame d–q involves the following equations.

$$\begin{cases} V_{ds} = R_s I_{ds} + \dfrac{d}{dt}\varphi_{ds} - \omega_s \varphi_{qs} \\ V_{qs} = R_s I_{qs} + \dfrac{d}{dt}\varphi_{qs} - \omega_s \varphi_{ds} \\ V_{dr} = R_r I_{dr} + \dfrac{d}{dt}\varphi_{dr} - (\omega_s - \omega_r)\varphi_{qr} \\ V_{qr} = R_r I_{qr} + \dfrac{d}{dt}\varphi_{qr} + (\omega_s - \omega_r)\varphi_{dr} \end{cases} \quad (1)$$

The stator and rotor fluxes can be expressed as

$$\begin{cases} \varphi_{ds} = L_s I_{ds} + L_m I_{dr} \\ \varphi_{qs} = L_s I_{qs} + L_m I_{qr} \\ \varphi_{dr} = L_r I_{dr} + L_m I_{ds} \\ \varphi_{qr} = L_r I_{qr} + L_m I_{qs} \end{cases} \quad (2)$$

The electromagnetic torque is expressed as

$$T_{em} = \frac{3}{2} p \left(I_{r\beta}\varphi_{r\alpha} - I_{r\alpha}\varphi_{r\beta} \right) \quad (3)$$

The equivalent circuit is show in figure 2.

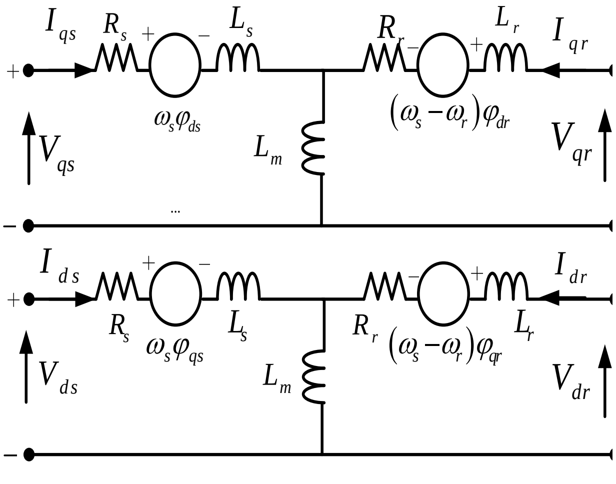

Fig2. Electrical equivalent circuit in d-q reference frame.

III. ESTIMATION OF ROTOR FLUX LINKAGE

A. Flux estimation method with the pure integrator

The voltage equation of DFIG in the stationary reference frame is given as[8] [9]:

$$\begin{cases} V_{r\alpha} = R_r i_{r\alpha} + \dfrac{d\varphi_{r\alpha}}{dt} \\ V_{r\beta} = R_r i_{r\beta} + \dfrac{d\varphi_{r\beta}}{dt} \end{cases} \quad (4)$$

Where $V_{r\alpha}$, $V_{r\beta}$, $i_{r\alpha}$, $i_{r\beta}$ and $\varphi_{r\alpha}$ $\varphi_{r\beta}$ are stator voltages, stator currents and stator flux respectively in the stationary reference frame, and R_r is the rotor resistance. The schematic diagram of the described flux estimation method is shown in figure 3.

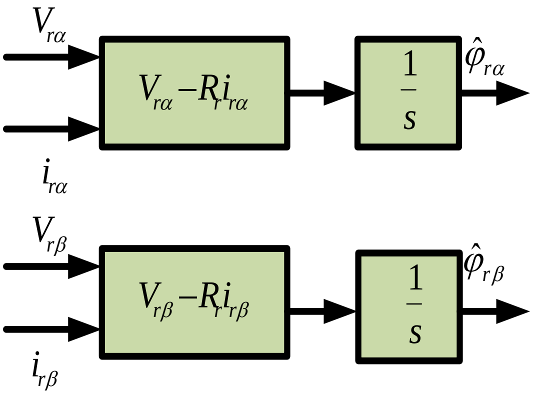

Fig 3.Flux Estimation Method with Pure Integrator

The rotor flux linkages of the DFIG can be estimated as:

$$\begin{cases} \hat{\varphi}_{r\alpha} = \int \left(V_{r\alpha} - R_r i_{r\alpha} \right) dt \\ \hat{\varphi}_{r\beta} = \int \left(V_{r\beta} - R_r i_{r\beta} \right) dt \end{cases} \quad (5)$$

The torque estimation is given by this equation:

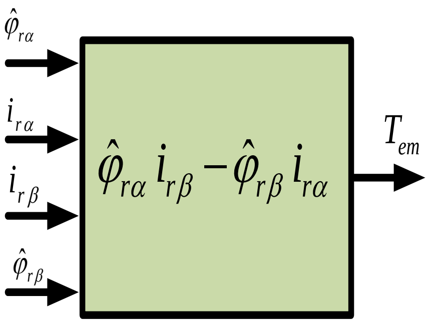

Fig4. Torque Estimation Method with Pure Integrator.

B. Flux estimation method with the Modified Low Pass Filter

In practical applications, the pure integrator is easily influenced by the DC drift and the initial value error. to resolve this problem, the pure integrator can be replaced by a Modified Low Pass Filter (MLPF) [5] [10], and the transfer function of MLPF is given as:

$$G(s)=\frac{1}{s+\omega_c} \tag{6}$$

Where ω_c is the cut off frequency of the Modified Low Pass Filter.

The phase (ϕ) and the gain (K) of MLPF are given respectively as:

$$\phi=\tan^{-1}\left(\frac{\omega_e}{\omega_c}\right) \tag{7}$$

$$K=\frac{1}{\sqrt{\omega_c^2+\omega_e^2}} \tag{8}$$

Where ω_e is the operation frequency of DFIG.

For better estimation accuracy, the outputs of MLPF need to be compensated. Actually, MLPF can be expressed as:

$$G(s)=\frac{s}{s+\omega_c}\frac{1}{s} \tag{9}$$

Equation 9 means MLPF can be seemed as a pure integrator cascaded with a high pass filter. So the estimated flux linkages $\hat{\varphi}'_{r\alpha}(s)$ $\hat{\varphi}'_{r\beta}(s)$

$$\begin{cases}\hat{\varphi}'_{r\alpha}(s)=\hat{\varphi}_{r\alpha}(s)\dfrac{s}{s+\omega_c}\\[2ex] \hat{\varphi}'_{r\beta}(s)=\hat{\varphi}_{r\beta}(s)\dfrac{s}{s+\omega_c}\end{cases} \tag{10}$$

From where

$$\begin{cases}\hat{\varphi}_{r\alpha}(s)=\hat{\varphi}'_{r\alpha}(s)\dfrac{s+\omega_c}{s}\\[2ex] \hat{\varphi}_{r\beta}(s)=\hat{\varphi}'_{r\beta}(s)\dfrac{s+\omega_c}{s}\end{cases} \tag{11}$$

The compensation method can be derived as

$$\begin{cases}\hat{\varphi}_{r\alpha}(s)=\hat{\varphi}'_{r\alpha}(s)+\hat{\varphi}'_{r\alpha}\cdot\dfrac{\omega_c}{s}\\[2ex] \hat{\varphi}_{r\beta}(s)=\hat{\varphi}'_{r\beta}(s)+\hat{\varphi}'_{r\beta}\dfrac{\omega_c}{s}\end{cases} \tag{12}$$

The compensation method in time domain can be simplified as:

$$\begin{cases}\hat{\varphi}_{r\alpha}(t)=\hat{\varphi}'_{r\alpha}(t)+\hat{\varphi}'_{r\beta}\cdot\dfrac{\omega_c}{\omega_e}\\[2ex] \hat{\varphi}_{r\beta}(t)=\hat{\varphi}'_{r\beta}(t)+\hat{\varphi}'_{r\alpha}\dfrac{\omega_c}{\omega_e}\end{cases} \tag{13}$$

According to Eq 3, Eq 10 and Eq 13, the diagram of the torque estimator based on the compensated MLPF is shown in Fig 5. In order to adapt different operation frequencies, variant cut off frequency ωc can be implemented in MLPF, and it changes proportionally to the DFIG operation frequency [11].

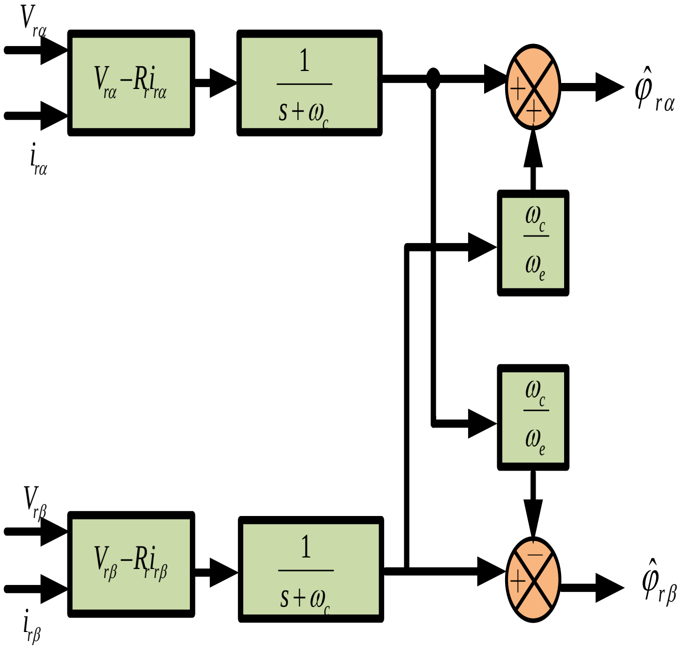

Fig5. Flux Estimator with Compensator MLPF.

IV. DIRECT TORQUE CONTROL

The proposed control strategy is the direct Torque Control (DTC) selected for having a simplest structure and the lower parameter dependency. The control scheme of the proposed DTC for a DFIG system is shown in figure 6.

The principle of DTC strategy based DFIG system is to directly select the proper rotor voltage vectors according to the rotor flux, torque errors and the rotor flux sector. As shown in Fig5, the torque and the rotor flux references are compared with the corresponding estimated values. The comes from MPPT strategy. The torque and flux hysteresis and are discredited from the torque and rotor error by using hysteresis band comparators[12].

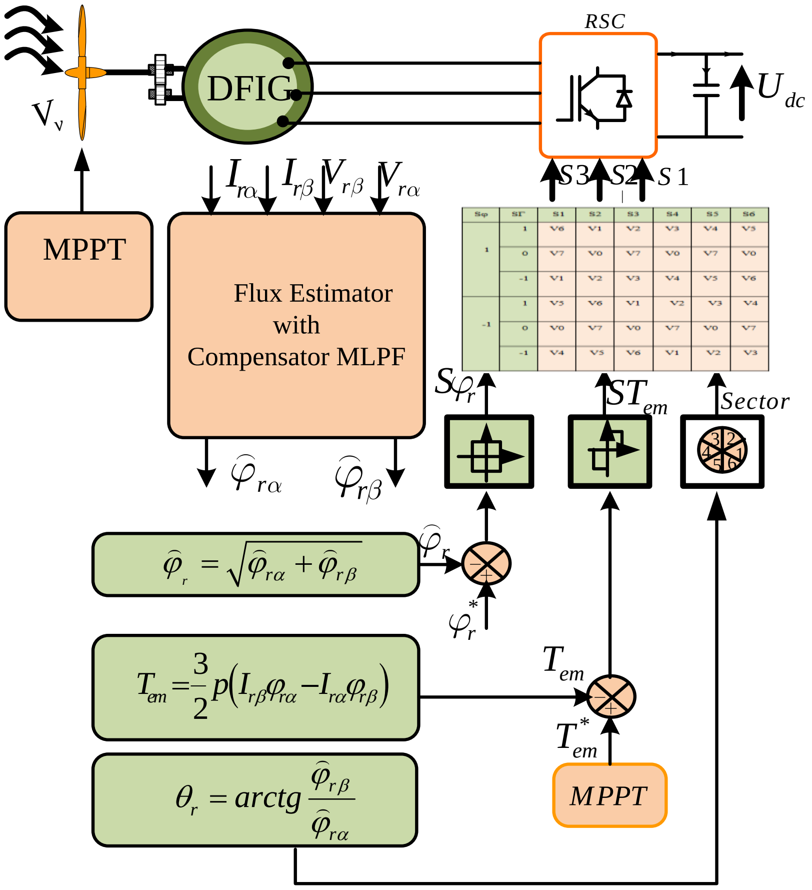

Fig 6 .Direct Torque Control structure applied to the proposed WECS.

There are eight switching combination six of them are active vectors V1-V6 and two zero vectors V0 and V7.The sector and vector placement is shown in figure 7.

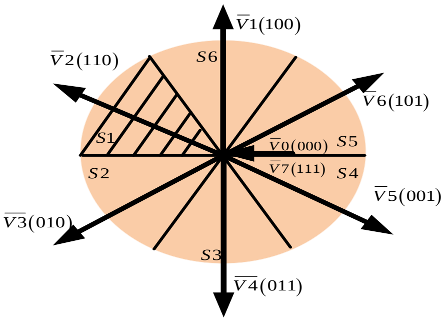

Fig7. Sector definition.

The control table illustrates the set of the switch-state combination according to the state of variable $S\varphi_r$ and ST_{em} and the position sector [12].

TABLE I
SWITCHING TABLE IN DTC METHOD

$S\varphi_r$	ST_{em}	S1	S2	S3	S4	S5	S6
1	1	V6	V1	V2	V3	V4	V5
	0	V7	V0	V7	V0	V7	V0
	-1	V1	V2	V3	V4	V5	V6
-1	1	V5	V6	V1	V2	V3	V4
	0	V0	V7	V0	V7	V0	V7
	-1	V4	V5	V6	V1	V2	V3

V. SIMULATION RESULTS

The performances and the robustness of the proposed control under a random behaviour of the wind speed are shown in this section. A 0.8kW Doubly Fed Induction Generator is used, the frequency of the power grid is 50Hz.

The parameters of the doubly fed induction generator are given in Tables II.

The wind speed profile is given in fig 8.

The waveforms of the electromagnetic torque and the magnitude of the rotor flux, with their references are illustrated respectively in figure 10 and 12.

They show reference tracking reflecting the robustness of the proposed control under random behaviour of wind speed.

Fig 14 shows the rotor flux waveform, it is circular and kept constant at 0.8 Weber.

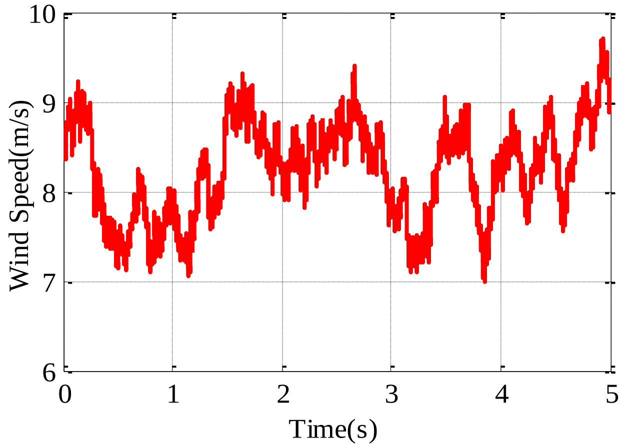

Fig8. Waveform of the wind speed.

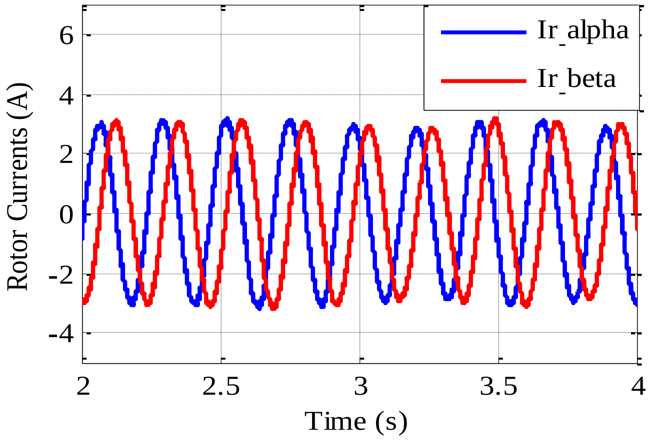

Fig9. Waveform of the rotor currents.

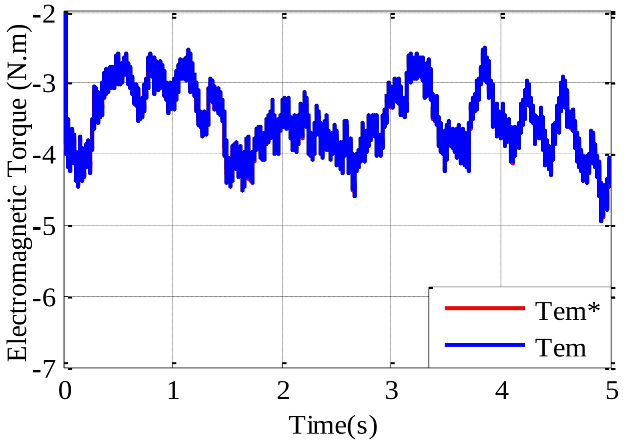

Fig10. Waveform of Electromagnetic torque and its reference.

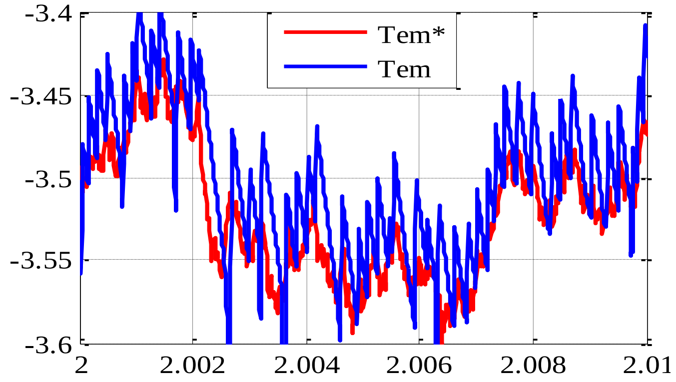

Fig11. Zoom of .waveform of Electromagnetic torque and its reference.

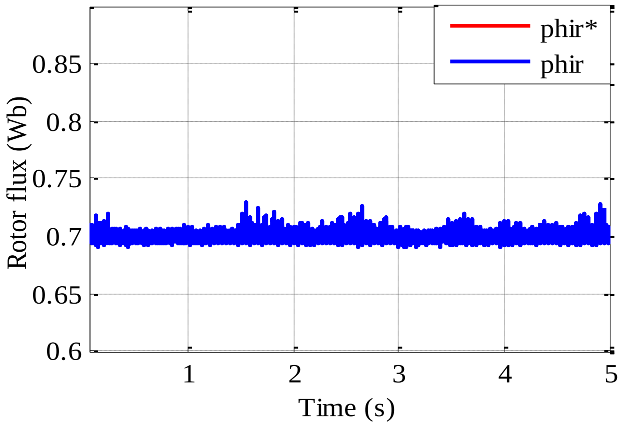

Fig12. Waveform of the magnitude of rotor flux and its reference.

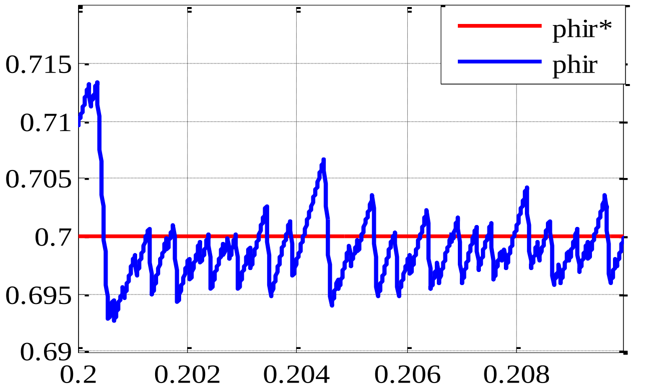

Fig13. Zoom of waveform of the magnitude of rotor flux and its reference.

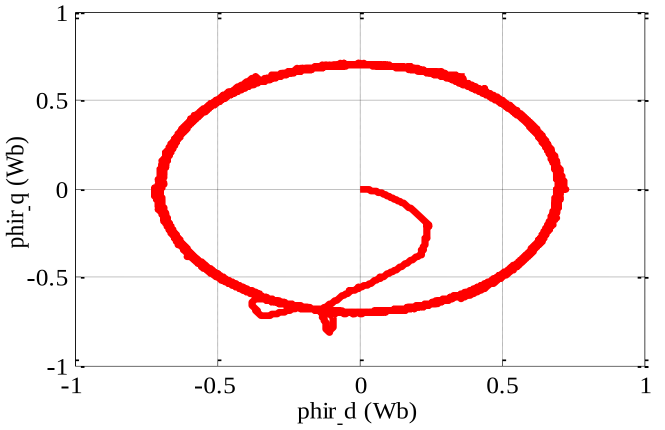

Fig 14. Waveform of the flux.

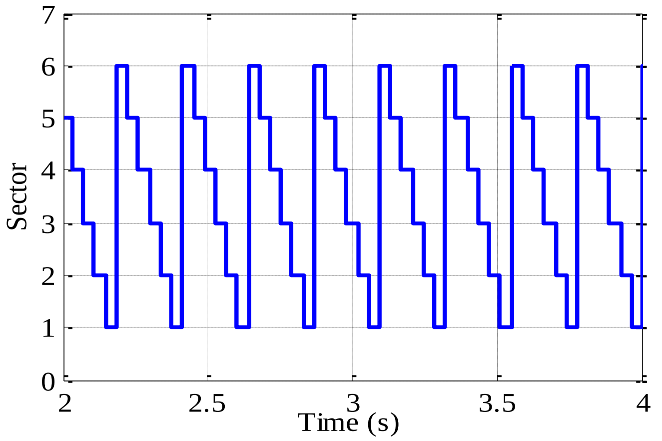

Fig 15.Sectors of rotor flux linkage.

VI. CONCLUSION

This paper analyses and examines DTC strategy which is applied for DFIG in order to control the rotor side converter. The proposed strategy is based a observer based first-order low-pass filter are used to accurately calculate the rotor flux .The simulation results are presented for various wind velocities to validate the model and also to show the effectiveness of the proposed control strategy.

The parameters of ours system are given in table

TABLE II
DOUBLY FED INDUCTION GENERATOR PARAMETRS

Parameter	Value
Rated power	800 W
Stator inductance	0.6703H
Rotor inductance	0.6675 H
Mutual inductance	0.6146 H
Stator resistance	8 Ω
Rotor resistance	7.3 Ω
Number of pair of poles	2

REFERENCES

[1] Hicham Serhoud, Djilani Benattous, “Maximal Wind Energy Tracing of Brushless Doubly-Fed Generator under Flux Oriented Vector Control”, International Journal of Renewable Energy Research (IJRER), Vol. 2, No. 2, pp. 236-242, 2012.

[2] Hee-sang Ko, Gi-Gab yoon, Nam-Ho Kyung. "Modeling and Control of DFIG-based variable Speed wind Turbine.Electric Power System Research 78, 1841-1849, 2008.

[3] F. Bonnet, P. Vidal, and M. Pietrzak-David, ”Dual direct torque control of Doubly Fed induction machine,” *IEEE Trans Ind Electron.*,vol. 54, no. 5pp 2482-2490, Oct 2007.

[4] G.Naveen, P.K.S. Sarvesh,B,Rama Krishna, DTC control strategy for doubly Fed Induction machine, International journal of Engineering and advanced Technology (IJEAT),3,pp.92-95.2013.

[5] S.I.Kim, j.H.Im, E.Y.Song and R.Y.Kim, "A New Rotor Position Estimation Method Of IPMSM Using All –Pass Filter on Hight –Frequency Rotating voltage Signal Injection"IEEE Transactions on Industrial Electronics, vol.63, no.10,pp.6499-6509,2016.

[6] Yuttana Kumsuwan, Suttichai Prem Rudeep Reechacham and Hamid A.Toliyat. "Modified Direct Torque Control Method For Induction Motor Drive Based on Amlitude and Angle Control Of Stator Flux.ELSEVIER,Journal ,27 Feb .2008.

[7] B Chitti Babu, and K.B.Mohanty, "Doubly Fed Induction Genrator For Variable Speed Wind Energy Conversion Systems-Modeling and Simulation ", International Journal Of Computer and Electrical Engineering vol.2(1),Feb 2010.

[8] W. Liu, H. Shen, L.-G. Gao, and H.-Z. Rong, “Study on direct torque control of brushless doubly-fed machines used for wind power generation,” Power System Protection and Control, vol. 38, no. 5, pp. 77–81, 2010.

[9] G.Venu Madhav and Y.P.Obulesu, " Direct Torque Control Strategy for Doubly Fed Induction Machine under Low voltage Dips ", IJPEDS,vol.2,No.4,December 2012,pp.409-416,2012.

[10] SHIN M.H, HYUN D.S, CHO S.B, CHOE S.Y, "An Improved Stator Flux Estimation For Speed Sensorless Staor Flux Orientation Control Of Induction Motors. "IEEE Trans. Power Electron. 15, (2), pp. 312–318. 2000.

[11] L. Gang, L. Du, R. Yifeng et al., “Improvement research of induction motor stator flux observation method,” Electric Drive, vol. 40, no. 8, pp. 28–30, 2010.

[12] A.Bakouri,A. Abbou, H. Mahmoudi, and K. Elyaalaoui, "Direct Torque Control of a Doubly Fed Induction Generator of Wind Turbine for Maximum Power Extraction." In IEEE Renewable and Sustainable Energy Conference, 2014,pp.334-339.