TORQUE RIPPLE MINIMIZATION IN DOUBLY FED INDUCTION MACHINE USED IN WIND MILLS WITH ARTIFICIAL NEURAL NETWORK

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ABSTRACT

This paper discusses an Artificial Neural Network (ANN) based method for reducing the torque ripple in a Doubly Fed Induction machine (DFIM) in which Direct Torque Control (DTC) scheme is applied. DFIM is gaining popularity as the best alternative for wind energy generation system. Often, wind energy generation demands good torque dynamic performance. ANN is used here to give pulses to the inverter in place of the conventional DTC scheme. The proposed method gives reduced torque ripple as compared to conventional DTC scheme.

Key words: Doubly Fed Induction Machine (DFIM), Field Oriented Control (FOC), Direct Torque Control (DTC) , Artificial Neural Network(ANN)

Nomenclature:

T_{em}	Electromagnetic torque
φr, φs,	Rotor and Stator flux
ir , is	Rotor and Stator current
vr , vs	Rotor and Stator voltage
ωs , ωm, ωr	Synchronous, rotor and slip speeds
Rr , Rs	Rotor and stator resistances
Lr , Ls	Rotor and Stator inductances
Lm	Mutual inductance
ρ	Pair of poles
δ	Angle between the stator and the rotor flux

1. INTRODUCTION

In industrial applications, efficiency of the drive system can be improved by using variable speed drives instead of constant speed drives. Widely used variable speed drives for small power applications are squirrel cage induction machines and synchronous machines, both supplied by IGBT-PWM based converters. Since the converters are connected at the stator terminals, they should be rated for the full motor power and hence very costly. But, if converters can be connected at the rotor terminals, the converter rating can be very less depending on the speed range required. Doubly fed induction machines provide a very economic solution for variable speed applications because, here the converter is connected at the rotor terminals.

The main difference between the singly fed induction motor and doubly fed induction motor is that the performance of doubly fed induction motor is independent of the speed. Hence a variable speed wind generator can be realized with a DFIM which permits any adjustment in the mechanical speed [1]. Also, DFIM can act as a variable speed generator in stand alone mode and grid connected applications [2]

Doubly Fed Induction Machine (DFIM) is constructed with wound rotor and slip rings.

General block diagram of a DFIM is given in figure 1. Three phase AC supply is fed directly to the stator in order to reduce the cost instead of feeding through converter and inverter. The rotor output, which is at low voltage, is fed to the rectifier. The rectified output is inverted and given to the secondary of a step down transformer and fed back to supply from the primary of the transformer.

Field oriented control (FOC) and direct torque control (DTC) are the two widely adapted methods of torque control [2]. DTC technique is characterized by simplicity, good performance and robustness. Also, with DTC, it is possible to obtain good dynamic control of torque without any mechanical transducers on the shaft and hence DTC considered as sensorless type control technique.[3],[4]. The main advantages of DTC over FOC are [5]

i) DTC provides better steady state and transient torque than FOC

ii) DTC technique does not require current regulators

iii) It does not require any coordinate transformation.

iv) No voltage modulation is required in DTC.

The main disadvantage of DTC as compared to FOC is that at very low speeds, torque control is very difficult.

The present work proposes a new methodology for minimizing torque ripple in a doubly fed induction machine. Here ANN is used for controlling the rotor switching voltage vectors in an efficient manner such that torque and the stator current ripples are very minimum as compared to the existing methods.

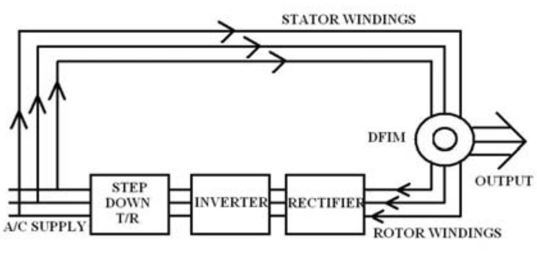

Figure 1 DFIM drive

2. MATHEMATICAL MODEL

The mathematical model of a DFIM derived from first principles is given in equations (1) to (4).

$$\vec{v}_s = R_s \vec{i}_s + \frac{d\vec{\Psi}_s}{dt} \tag{1}$$

$$\vec{v}_r = R_r \vec{i}_r + \frac{d\vec{\Psi}_r}{dt} - j\omega_m \vec{\Psi}_r \tag{2}$$

$$\Psi_s = L_s i_s + L_m i_r \tag{3}$$

$$\vec{\Psi}_r = L_r \vec{i}_r + L_m \vec{i}_s \tag{4}$$

and the electromagnetic torque is given as

$$T_{em} = \frac{3}{2} p \frac{L_m}{\sigma L_s L_r} \operatorname{im} \left[\vec{\Psi}_r^* \cdot \vec{\Psi}_s \right] \tag{5}$$

$$T_{em} = \frac{3}{2} p \frac{L_m}{\sigma L_s L_r} |\vec{\Psi}_r||\vec{\Psi}_s| \sin\delta. \tag{6}$$

Where σ =1-$L_m^2/L_s L_{rr}$ is the leakage coefficient , p=pole pair , L_m=mutual inductance , δ=torque angle .Differentiating the rotor flux linkage and the electromagnetic torque with respect to time, we get,

$$\frac{d|\vec{\Psi}_r|}{dt} = \frac{1}{|\vec{\Psi}_r|} \left[\left(\frac{R_r L_m}{\sigma L_s L_r} \right) \cos \left\{ \vec{\Psi}_r \cdot \vec{\Psi}_s \right\} - \left(\frac{R_r}{\sigma L_r} \right) |\vec{\Psi}_r|^2 + \cos \left\{ \vec{\Psi}_r \cdot \vec{v}_r \right\} \right] \tag{7}$$

$$\frac{dT_{em}}{dt} = \frac{3}{2} p \frac{L_m}{\sigma L_s L_r} \left[\left(\frac{R_s}{\sigma L_s} + \frac{R_r}{\sigma L_r} \right) \sin \left\{ \vec{\Psi}_r \cdot \vec{\Psi}_s^* \right\} - \omega_m \cos \left\{ \vec{\Psi}_r \cdot \vec{\Psi}_s \right\} + \sin \left\{ \vec{v}_s \cdot \vec{\Psi}_r^* \right\} + \sin \left\{ \vec{\Psi}_s \cdot \vec{v}_r^* \right\} \right] \tag{8}$$

$$\frac{d|\vec{\Psi}_s|}{dt} = \frac{1}{|\vec{\Psi}_r|}\left[\left(\frac{R_r L_m}{\sigma L_s L_r}\right)\cos\left\{\vec{\Psi}_r \cdot \vec{\Psi}_s\right\} - \left(\frac{R_r}{\sigma L_r}\right)|\vec{\Psi}_s|^2 + \cos\left\{\vec{\Psi}_r \cdot \vec{v}_r\right\}\right] \quad (9)$$

where the space vector representation of the various vectors are

$$\vec{\Psi}_r = |\vec{\Psi}_r| e^{j\omega_s t}$$
$$\vec{\Psi}_s = |\vec{\Psi}_s| e^{j(\omega_s t+\delta)}$$
$$\vec{v}_s = |\vec{v}_s| e^{j(\omega_s t+(\pi/2)+\delta)}$$
$$\vec{v}_r = \frac{2}{3} V_{bus} e^{j(\omega_m t+\pi/3(n-1))}$$

3. CONVENTIONAL DTC

Direct torque control (DTC) technique is applied to variable frequency drives to control the torque and thus finally the speed of three-phase AC electric motors. This involves calculating an estimate of the magnetic flux and torque based on the measured voltage and current of the motor. In fact, DTC is one form of the hysteresis or bang-bang control. Figure 2 represents the block diagram of a DTC based DFIM drive.

$$V_r = R_r \vec{i}_r + \frac{d\vec{\psi}_r}{dt} - j\omega_m \vec{\varphi}_r$$

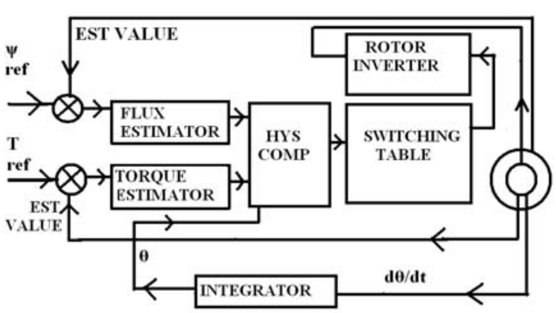

Figure 2 Block diagram of DTC based DFIM DRIVE

Here the processed values of flux and torque and the actual values from the machine are given to their respective estimators where the error value is estimated. The estimated flux magnitude and torque are then compared with their reference values. If either the estimated flux or torque deviates from the reference by more than allowed tolerance, the thyristors of the variable frequency drive are turned on and off in such a way that the flux and torque will return in their tolerance bands as fast as possible. The estimated value is then given to the Hysteresis comparators. Hysteresis is a property in which the change in the magnetization lags behind change in the magnetic field. Hysteresis comparator can be described as a comparator which compares a processed quantity with a quantity whose value is standard for hysteresis property, the difference being given to the switching table.Based upon this switching table, the pulses are given to the rotor fed inverter which drives the DFIM drive with less harmonics.

4. ANN BASED DTC

A neural network is a machine like human brain with properties of learning capability and generalization. They require a lot of training to understand the model of the plant. The basic property of this network is that it is capable of approximating complicated nonlinear functions. In this paper, neural network is used for state selection. ANN is more advantageous than the conventional DTC method. They can extract useful information even from the noisy signals.This method will minimize the torque and flux ripple further more. Hence the robustness of the drive can be improved. The torque and flux from the drive are compared with the processed value and are given as input to the ANN. The inputs to the ANN are the torque error, flux error and the position of flux in which it lies. The reference speed and the speed from the stator are given as input to the PID controller. ADALINE type of ANN, the

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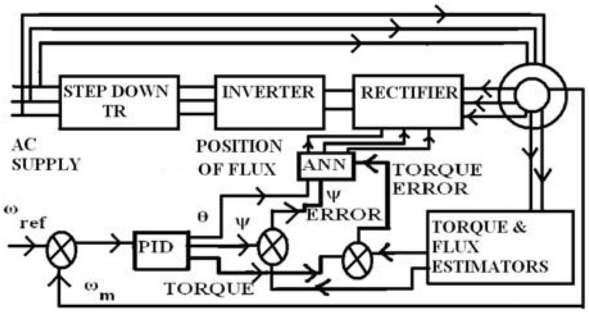

Figure 3. Block diagram of ANN based DTC

parameters of which are given in table 1, is used here to generate pulses to be given to the inverter. This drives the DFIM drive with less harmonic than by using conventional DTC method.

Table 1. ANN Parameters

S.No	Parameter	Value
1	Architecture	ADALINE
2	Activation Function	Sigmoid
3	No. of layers	3
4	Learning algorithm	Delta learning rule
5	No. of neurons in input layer	4
6	No. of neurons in hidden layer	4
7	No. of neurons in output layer	4
8	Initial weight	Random values
9	No. of iterations	1000
10	Tolerance	0.005

5. RESULTS and DISCUSSION

Results obtained from Neural network as applied to DFIM shows the superiority of the proposed scheme in improving the performance of the DFIM. A comparison is done here with the results obtained from conventional DTC, which also aims at torque ripple minimization. The results of comparison are that the torque ripple is reduced considerably with the help of Neural network as shown in figure 4(a).From figure 4(b),it clear that the electromagnetic torque in conventional DTC is highly distorted as compared to the electromagnetic torque in ANN_DTC. Similarly, Stator current with ANN tuned DFIM is very smooth as compared with that of conventional DFIM. This is very clear from figures 4(c) and 4(d). It is essential that the DC bus voltage at inverter input side is with no ripples. It is clear from figures 4(e) and 4(f) that the DC bus voltage is with very negligible ripple when ANN is used

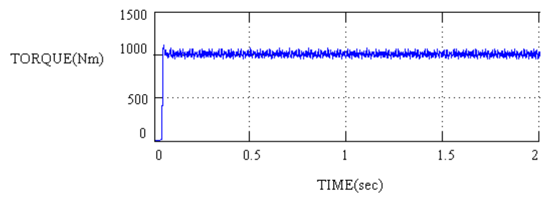

Figure 4(a). Torque output of ANN tuned DFIM

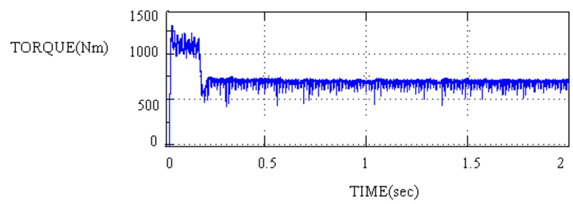

Figure 4(b). Torque output of conventional DFIM

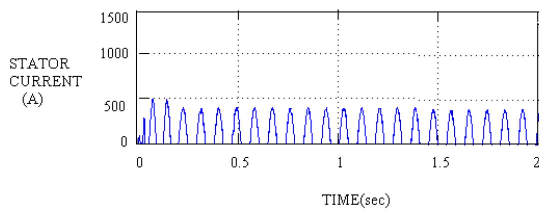

Figure 4(c) Stator current of ANN tuned DFIM

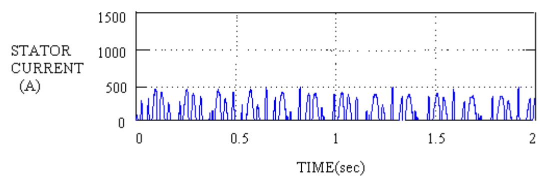

Figure 4(d) Stator current of conventional DFIM

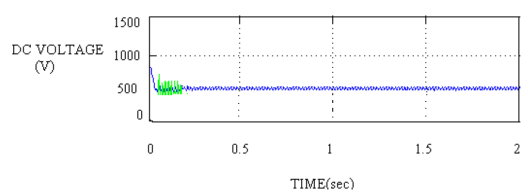

Figure 4(e) DC bus voltage of ANN tuned DFIM

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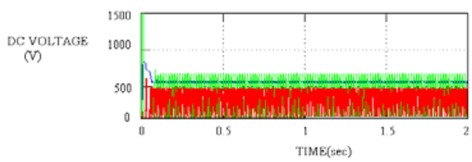

Figure 4(f) DC bus voltage of conventional DFIM

6. CONCLUSION

In this paper, an attempt is made to reduce the torque ripple in a doubly fed induction machine, which can be used as a variable speed wind generator. An improved torque response is achieved with the help of ANN_DTC than the conventional DTC. The performance is tested by simulations and comparison is made with the existing system. The results show that there is a reduction of ripple in electromagnetic torque, stator current as well as DC bus voltage when ANN is used for selecting the switching table of the voltage vectors in the DTC scheme.

Machine parameters: Wound rotor induction machine with 15kW,19Nm,380V, I_s = 55A, I_r = 32A, L_m =10.46e-3H, R_s =0.01485Ω, R_r = 0.0095Ω, L_s = 0.3027e-3 H, L_r =0.3027e-3 H.

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