ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Special Issue 1, December 2013

Direct Torque Control of Induction Motor Using Fuzzy Logic Controller

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Abstract: This paper describes direct torque control (DTC) scheme of induction motor (IM) and its comparative study using intelligent techniques under varying dynamic conditions are discussed. In conventional DTC PI controller is used in the speed controller. PI controller is more suitable in steady state condition and for linear system. But since DTC along with IM is mostly nonlinear, fuzzy controller will be more suitable. Fuzzy controller performs well in nonlinear systems than PI controller. In this paper apart from fuzzy controller ANN will be proposed to provide better motor dynamic performance and the look up table is now replaced by this ANN. The advantage of using ANN is that, in classical DTC look up table is used to select switching states, thus size requirement will increase with some advanced control. ANN will take less memory and is more reliable. In order to test performance of the DTC scheme for IM drive using intelligent techniques, a complete simulation model is developed using MATLAB/simulink.

Keywords: Direct Torque Control, fuzzy logic controller, Induction Motor, Artificial Neural Network.

I. INTRODUCTION

Induction motors are electro-mechanical devices used in most of the industrial applications for the conversion of power from electrical to mechanical form. These motors are used worldwide as the workhorse in industrial applications. Such motors are robust machines used not only for general purposes, but also in hazardous locations. In many variable speed drive applications, torque control is required, but precise, closed-loop control of speed is not necessary. The advantages of torque control in this type of application include greatly improved transient response, avoidance of nuisance over current trips, and the elimination of load-dependent controller parameters.[1]

Direct torque control (DTC) is one of the method used in variable frequency drives to control the torque (and thus finally the Speed) of three-phase AC electric motors. This involves calculating the estimate of the motor's magnetic flux and torque based on the measured voltage and current of the motor. The Direct Torque Control (DTC) method, allows direct and independent electromagnetic torque and flux control, selecting an optimal switching vector, making possible fast torque response, low inverter switching frequency and low harmonic losses. With DTC it is possible to obtain direct flux and electromagnetic torque control, indirect voltage and current control, sinusoidal current and flux, low torque ripple, superior torque dynamics and hysteresis band dependent inverter switching frequency. One of the common disadvantages of conventional DTC are high torque ripple and slow transient response to the step changes in torque during start-up.[1]

II. DYNAMIC MODELLING OF INDUCTION MOTOR

A dynamic model of the induction machine subjected to control must be known in order to understand and design vector controlled drives. Due to the fact that every good control has to face any possible change of the plant, it could be said that the dynamic model of the machine could be just a good approximation of the real plant .Nevertheless the model should incorporate all the important dynamic effects occurring during both steady state and transient operations. Such a model can be obtained by means of space vector phasor theory or two axis theory of electrical machines. A model for three phase induction motor is developed based on the stator reference frame.[2][3][4]

Voltage Equations

i) With respect to stator

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$$V_{sa}(t) = R_s i_{sa}(t) + d/dt(\Psi_{sa}(t)) \quad (1)$$

$$V_{sb}(t) = R_s i_{sb}(t) + d/dt(\Psi_{sb}(t)) \quad (2)$$

$$V_{sc}(t) = R_s i_{sc}(t) + d/dt(\Psi_{sc}(t)) \quad (3)$$

ii) With respect to rotor

$$V_{ra}(t) = R_r i_{ra}(t) + d/dt\ (\Psi_{ra}(t)) \quad (4)$$

$$V_{rb}(t) = R_r i_{rb}(t + d/dt\ (\Psi_{rb}(t)) \quad (5)$$

$$V_{rc}(t) = R_r i_{rc}(t + d/dt\ (\Psi_{rc}(t)) \quad (6)$$

Converting to dqo frame

$$\begin{bmatrix} v_{sd} \\ v_{sq} \end{bmatrix} = \frac{2\pi}{3} \begin{bmatrix} cos\theta & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ -sin\theta & -\sin(\theta - \frac{2\pi}{3}) & -\sin(\theta + \frac{2\pi}{3}) \end{bmatrix} \begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix}$$

iii) Flux Equations

$$\Psi_{sd} = [v_{sd} - i_{sd} Rs]\ 1/s \quad (7)$$

$$\Psi_{sq} = [v_{sq} - i_{sq} Rs]\ 1/s \quad (8)$$

$$\Psi_{rd} = [\omega\ \Psi_{rq} - i_{rd} R_r] 1/s \quad (9)$$

$$\Psi\ r_q = [\omega\ \Psi_{rd} - {}_{ird} R_r] 1/s \quad (10)$$

iv) Stator Current Equations

$$i_{sd} = \Psi_{sd}(L_r/L_x) - \Psi_{rd}(L_m/L_x) \quad (12)$$

$$i_{sq} = \Psi_{sq}(L_r/L_x) - \Psi_{rq}(L_m/L_x) \quad (13)$$

v) Rotor Current Equations

$$i_{rd} = \Psi_{rd}(L_s/L_x) - \Psi_{sd}(L_m/L_x) \quad (14)$$

$$i_{rq} = \Psi_{rq}(L_s/L_x) - \Psi_{sq}(L_m/L_x) \quad (15)$$

where, $L_x = L_s L_r - L_m^2$

Inorder to reduce the induction motor equation, voltage equations and obtained constant coefficient equations, parks transformation are applied.In the symmetrical three phase machine,the direct and quadrature axis stator magnitudes are fictitious. Space phasor notation allows the transformation of the natural instantaneous values of three phase system in a complex plane located in cross section of the motor. Inorder to transform the induction motor model in natural coordinates into its equivalent space phasor form, the 120 operator is introduced. All the equations have been re-

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arranged inorder to use the operator 1/s instead of p because simulink deals with the integrator better than with the derivation[4].
In an adjustable speed drive the machine normally constitute an element within the feedback loop, and therefore its transient behavior has to be taken into consideration.High performance speed control such as vector or field oriented control is based on dynamic d-q model of the machine[5].

III. DIRECT TORQUE CONTROL (DTC)

Direct torque control (DTC) is one method used in 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 motor's magnetic flux and torque based on the measured voltage and current of the motor. Direct torque control technique was claimed to have nearly comparable performance with the vector controlled drives. Conventional direct torque controller consist of two level hysteresis comparator for calculating the stator flux error and three level hysteresis comparator for calculating electromagnetic torque error. After determining the stator flux error and electromagnetic torque error the proper state of the voltage vector is selected.[8]
In a DTC induction motor drive, a decoupled control of torque and flux can be achieved by two independent control loops. The steady state as well as the dynamic performance of the drive is closely related to the efficient implementation of these two control algorithm. Most of them are voltage model based, where the flux and torques are estimated by sensing stator voltage and current. These methods based on voltage models are most preferable for sensor less drives since these are less sensitive to the parameter variations and do not require motor speed or rotor position signals. However, the estimation of stator voltage when the machine is operating at low speed introduces error in flux estimation which also affects the estimation of torque and speed in case of sensor less drive[8].

A PRINCIPL OPERATION OF DTC

According to the DTC principle, an independent control of torque and flux can be achieved by the application of appropriate voltage vectors in such a way that the error between the estimated torque and flux with their respective reference values remain within the limits of hysteresis comparators as shown in figure(1). The desired voltage vectors to compensate the errors are selected based on the output of the torque and flux hysteresis comparator as well as the locus of stator flux vector from the basic equation governing induction motor operation stator flux. In a DC motor, the magnetic field is created by the current through the field winding in the stator. This field is always at right angles to the field created by the armature winding. This condition, known as field orientation, is needed to generate maximum torque. Once field orientation is achieved, the DC motors torque is easily controlled by varying the armature current and by keeping the magnetising current constant. In direct torque control method the stator flux and stator torque directly controlled by selecting the appropriate inverter switching state.

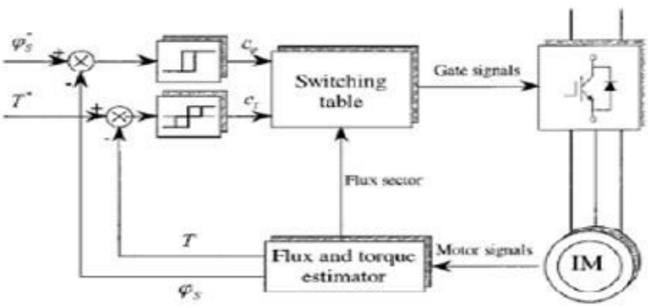

Fig. 1: Block diagram of direct torque control

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IV. SPEED CONTROLLER

The model of speed controller has been realized using the Simulink toolbox of the MATLAB software. The main function of speed controller block is to provide a reference torque which in turn is converted to reference current and is fed to reference generator. The output of the speed controller is limited to a proper value in accordance with the motor

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rating to generate the reference torque. The speed controllers realized in this study are proportional integral (PI) controller, fuzzy logic (FL) controller [9][10]

A. PI CONTROLLER

The proportional plus integral (PI) controller is one of the famous controllers used in a wide range in the industrial applications. The output of the PI controller in time domain is defined by the following equation:

$$v_c(t)= k_p(t)+ k_i \int_o^t e(t)dt \qquad (16)$$

where v_c (t) is the output of the PI controller, k_p is the proportional gain, k_I is the integral gain, and e(t) is the instantaneous error signal. The main advantage of adding the integral part to the proportional controller is to eliminate the steady state error in the controller variable. However, the integral controller has the serious drawback of getting saturated after a while if the error does not change its direction. This phenomenon can be avoided by introducing a limiter to the integral part of the controller before adding its output to the output of the proportional controller[10]. The input to the PI controller is the speed error (e), while the output of the PI controller is used as the input of reference current block as shown in fig 2.

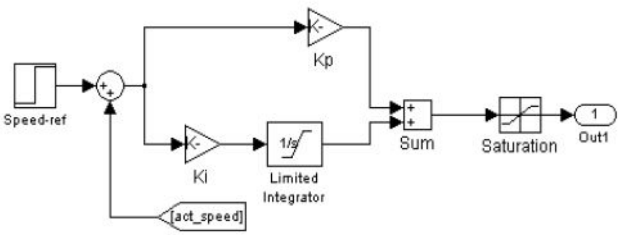

Fig 2: Block diagram of PI control system

B. FUZZY LOGIC CONTROLLER

Fuzzy logic control (FLC) is a control algorithm based on a linguistic control strategy which tries to account the human's knowledge about how to control a system without requiring a mathematical model [11]. The approach of the basic structure of the fuzzy logic controller system is illustrated in Fig.3.

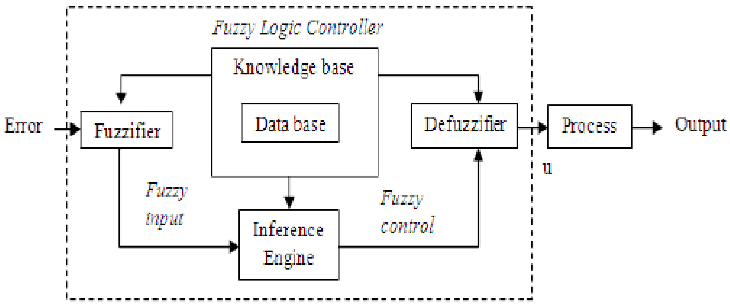

Fig 3: Structure of fuzzy logic controller

Input and output are non-fuzzy values and the basic configuration of FLC is featured in Fig.4. In the system presented in this are Mamdani type of fuzzy logic and is used for speed controller. Inputs for Fuzzy Logic controller are the speed error (e) and change of speed error. Speed error is calculated with comparison between reference speed, ωref and the actual speed, ωact

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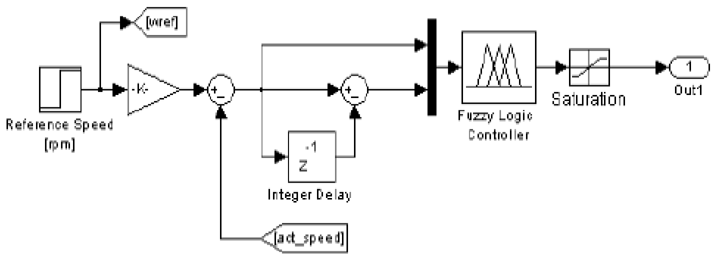


Fig 4: Block diagram of fuzzy control system

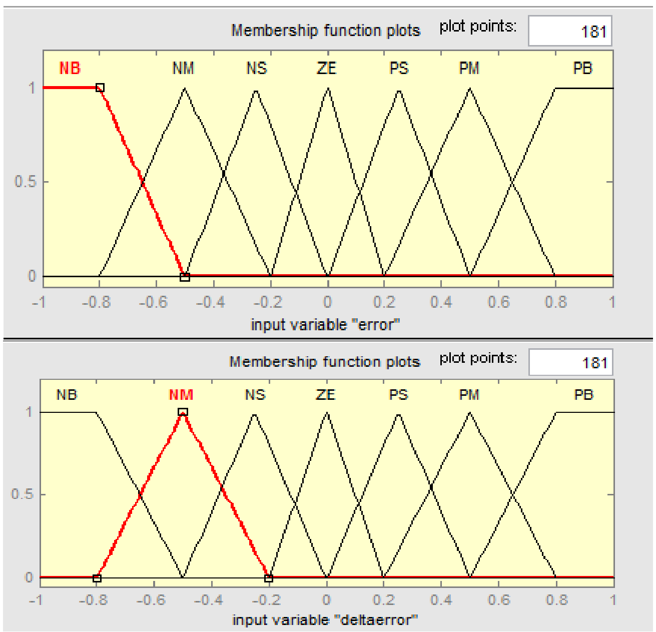
The output of the fuzzy controller u(k) is given by:

$u(k)= F_f\,[e(k)- \Delta e(k)]$

where F_f is a non-linear function determined by fuzzy parameters, e(k), Δe(k) are the error and change of error respectively. The fuzzy logic controller was used to produce an adaptive control so that the motor speed, ωact can accurately track the reference speed, ωref. The most important things in fuzzy logic control system designs are the process design of membership functions for input, outputs and the process design of fuzzy if-then rule knowledge based. Fig. 6 shows the membership function of speed error e, change in speed error ce and output u variables.[11]

C. FUZZY LOGIC CONTROLLER DESIGN

The design of a Fuzzy Logic Controller requires the choice of Membership Functions. The membership functions should be chosen such that they cover the whole universe of discourse. It should be taken care that the membership functions overlap each other. This is done in order to avoid any kind of discontinuity with respect to the minor changes in the inputs. To achieve finer control, the membership functions near the zero regions should be made narrow. Wider membership functions away from the zero region provides faster response to the system. Hence, the membership functions should be adjusted accordingly. After the appropriate membership functions are chosen, a rule base should be created. It consists of a number of Fuzzy If-Then rules that completely define the behaviour of the system. These rules very much resemble the human thought process, thereby providing artificial intelligence to the system.[11]



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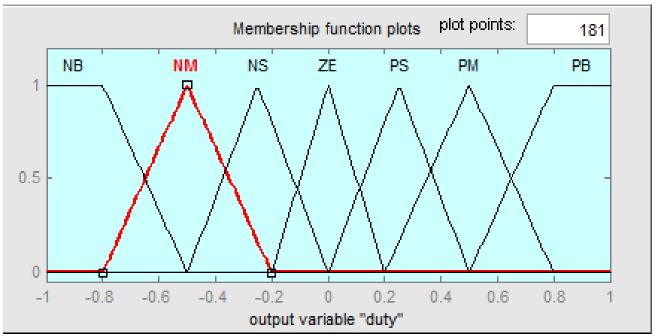

Fig 5: Membership function plots

D. RULE BASED DESIGN FOR THE OUTPUT

Table 1. Fuzzy Rule Table for Output

Δe \ e	**NL**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PL**
NL	NL	NL	NLM	NM	NMS	NS	ZE
NM	NL	NLM	NM	NMS	NS	ZE	PS
NS	NLM	NM	NMS	NS	ZE	PS	PMS
ZE	NM	NMS	NS	ZE	PS	PMS	PM
PS	NMS	NS	ZE	PS	PMS	PM	PLM
PM	NS	ZE	PS	PMS	PM	PLM	PL
PL	ZE	PS	PMS	PM	PLM	PL	PL

Figure 6 shows the DTC of induction motor using fuzzy controller[12][13][14]

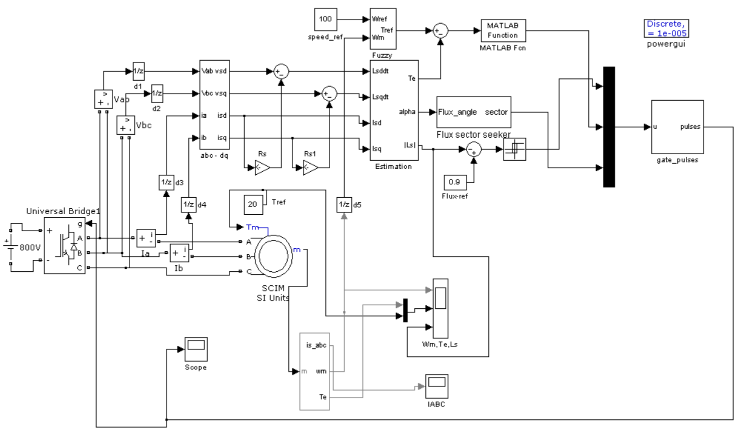

Fig 6 : DTC using Fuzzy controller

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V. SIMULATION RESULTS

In this section, the software Matlab/Simulink is used to simulate the whole DTC system to examine the performance of induction motor. The simulation conditions is given as: the speed is 100r/min and the reference flux is 0.9 Wb the initial load torque is 20N.m, when at 0.2 second, the load torque set at 30 Nm; simulation time is 0.6 second. The figure shows the comparative study of DTC with PI controller and that with fuzzy controller. Figure (7) shows the speed response in which the speed reaches steady state at 100 rev/min at 0.13,but with that using fuzzy controller speed reaches steady state much faster shown in. Figure (11).Figure (8) and fig (12) shows the torque response which reaches 20 Nm much faster with fuzzy controller. Figure (9) and fig(13) shows the stator current trajectory which give a good current response but much faster response with fuzzy controller. Figure (10) and fig (14) shows the stator flux trajectory which gives a good response with a circular shape.

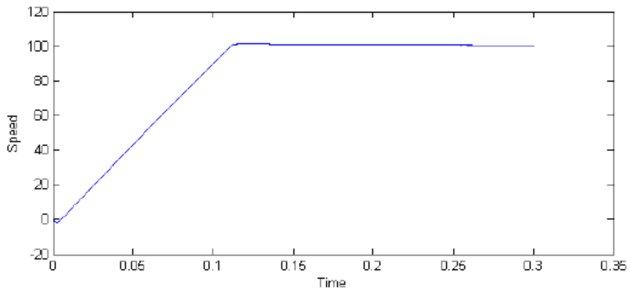

Fig 7: Speed response using PI controller

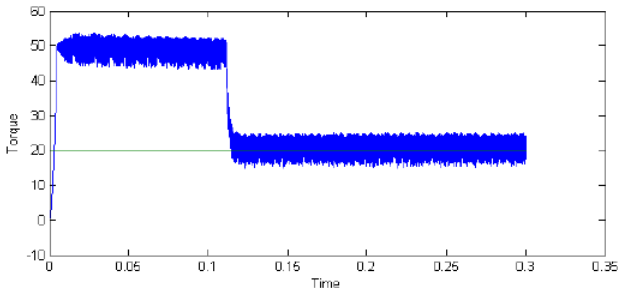

Fig 8: Torque response using PI controller

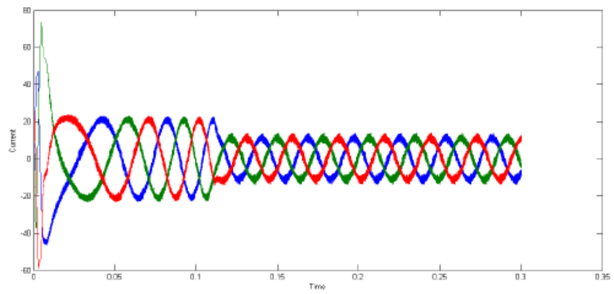

Fig 9: Stator current trajectory using PI controller

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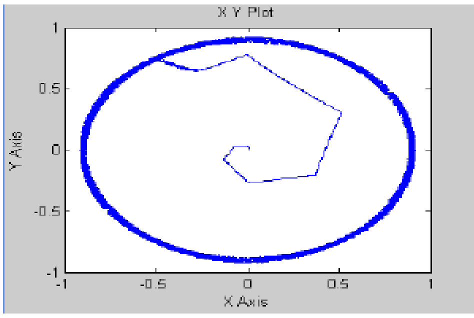

Fig 10: Stator flux trajectory using PI controller

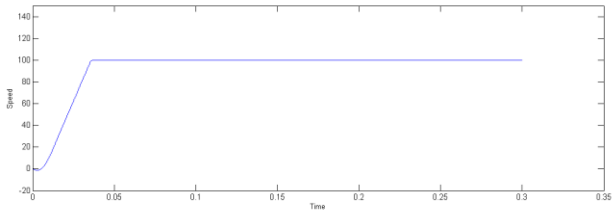

Fig 11 : Speed Response using Fuzzy controller and ANN

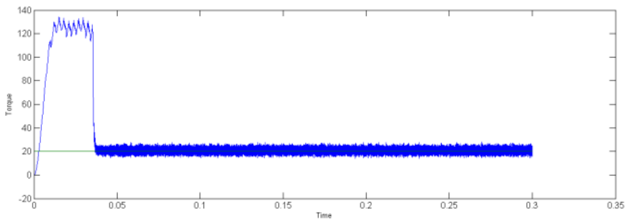

Fig 12 : Torque Response using Fuzzy controller and ANN

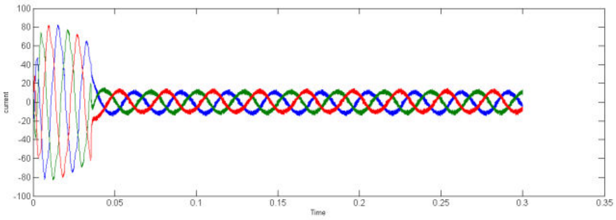

Fig 13: Stator current trajectory using Fuzzy controller and ANN

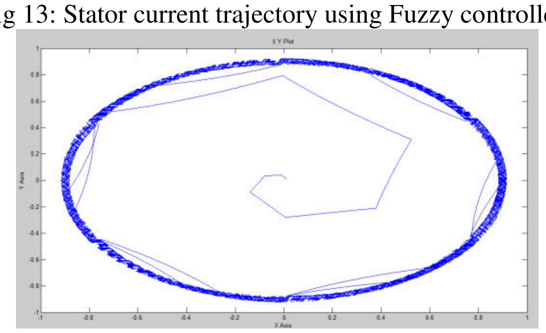

Fig 14 : Stator flux trajectory using Fuzzy controller and ANN

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

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VI. CONCLUSION

The direct torque control of induction motor with fuzzy logic controller is investigated in this paper.DTC of induction motor with fuzzy logic controller is compared with PI controller. It has been observed that the torque and the stator flux ripples are significantly reduced and a constant switching frequency is achieved in fuzzy controller. Other improvements observed in fuzzy controller are the reduction in phase current distortion ,fast torque response and increase in efficiency of the drive.

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BIOGRAPHY

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