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Direct Torque Control of B4-Inverter Fed BLDC Motor using Fuzzy Logic Controller

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Abstract-Brushless DC motors (BLDC) are extremely used in large number of industrial applications because of the key features like high efficiency, high power density and low size. The performance of BLDC motor is mostly affected by torque ripples. To minimize the torque ripple and improve the performance of the BLDC motor, Direct Torque Control (DTC) method has been used because of its attractive features like fast dynamic response, lesser parameter dependence and does not require rotor position sensors. They are also less sensitive to parameter variations and do not require coordinate transforms which makes the method simple. To improve the dynamic characteristic of the system, Fuzzy Logic Control (FLC) has been implemented. In a Fuzzy Logic Controller, the control parameters of the systems are adjusted by a fuzzy rule based system. The advantages of FLC over the other Conventional systems are, the former does not need a detailed mathematical model; it can be applied to any complex and non linear problems.

Combination of DTC with Fuzzy Logic Controller greatly reduced the torque ripple of the BLDC motor compared to the traditional method. The simulation results of the proposed topology are verified using MATLAB R2013a.

Index Terms— ***Brushless DC motor, direct torque control, torque ripple, fuzzy logic controller.***

I. INTRODUCTION

BLDC motor is conventionally defined as a permanent magnet synchronous motor with a trapezoidal Back EMF Waveform shape. BLDC motors do not use brushes for commutation; instead they are electronically commutated. In recent years, variable speed drives equipped with BLDC motors are extensively integrated in various applications, especially in automotive industry utilities [1]. However, in a BLDC drive, significant torque pulsations may arise due to the back-EMF waveform departing from the ideal, as well as phase current ripple resulting from commutation events, pulse width modulation (PWM), and cogging. Torque ripple due to phase current commutation is usually considered to be one of the main drawbacks of BLDC drives, compared to brushless ac (BLAC) drives with sinusoidal back-EMF and current waveforms. The torque ripple, which occurs every 60˚elec.in a traditional three-phase BLDC machine with two-phase 120˚ elec. conduction, is reduced by employ a hybrid two- and three-phase switching mode during the commutation periods. It adaptively adjusts the phase current waveform to maintain constant electromagnetic torque so that commutation torque ripple, which would have resulted with traditional DTC, particularly at high rotational speeds, is effectively eliminated[3]. In this method analyzing of both two and three phase mode is required for minimum torque ripples. DTC produces a global minimum torque ripple, which satisfies the root-mean-square (rms) criteria of torque ripple. Global minimum torque ripple in DTC is a two-step design. In the first step drive the torque error to zero at the end of the control period. And, the second step reduces the torque ripple bias and rms ripple by modifying the asymmetry switching patterns of the applied voltage vectors of the first step into symmetry ones [7]. DTC of induction machine is known to have a simple control structure with comparable performance to that of the field oriented control technique. Two major problems that are associated with DTC drives are: 1) switching frequency that varies with operating conditions and 2) high torque ripple. To solve these problems, and the same time retain the simple control structure of DTC, a constant switching frequency two level Torque controller is proposed to replace the conventional hysteresis-based controller. A direct torque control (DTC) technique with two level torque controller for brushless dc (BLDC) motor using a four-switch inverter has been introduced to reduce the torque ripple. The application of a Fuzzy logic controller in the field of electric drives especially in switched reluctance motor, induction motor and BLDC motors have increased in recent times.

Fuzzy logic controller with direct torque controller has been used to minimize the torque ripple in the BLDC motor.

II. PROPOSED FOUR-SWITCH DTC OF BLDC MOTOR DRIVE

The four-switch DTC of a BLDC motor drive in the constant torque region is to estimate the electromagnetic torque correctly similar to the six-switch DTC. Using DTC technique for the BLDC motor with four-switch three-phase inverter has some distinct advantages over its six

switch counterpart: reduced price due to reduction in number of switches, reduced switching losses due to the absence of the phase replaced with the spilt capacitors, reduced probability of destroying the switches due to lesser interaction among switches, and reduced number of interface circuits to supply logic signals for the switches.
A BLDC motor needs quasi square current waveforms, to generate constant output torque. Also, at every instant only two phases are conducting and the other phase is inactive.

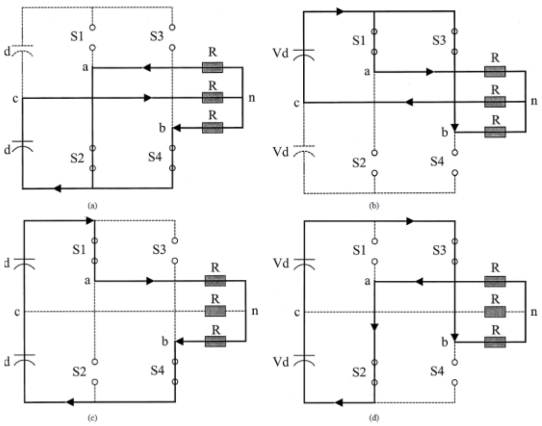

Fig.1 Four switching status of B4-inverter

In the four-switch design, there are four switching status as shown in fig.1, such as (0,0), (0,1), (1,0), and (1,1). The motor load is replaced by a resistive load and the switches are replaced by simple ideal switches. In the B4-inverter, “0” means that the lower switch is turned on and “1” the upper switch is turned on. The two switches are turn on and off concurrently. In the six-switch converter, switching status (0,0) and (1,1) are consider as zero-vectors, so there is no flow of current in the load. But, in the four-switch converter, one phase of the motor is always connected to the dc-link capacitors, so the current is flowing even at the zero-vectors, as shown in fig1. In the case of (0,1) and (1,0), the phase which is connected to the midpoint of dc-link capacitors is uncontrolled and only the resulting current of the other two phases flow through this phase. If the load is symmetric, so there is no current in the (0,1) and (1,0) vectors.
Using four switching vectors, one can noted that obtained the 120˚ conduction and a 60˚ non-conducting period current profile is inherently difficult based on the “asymmetric voltage pwm”.

III. DIRECT TORQUE CONTROL

DTC is one of the methods used in variable frequency drives to control the torque of three-phase AC electric motors. This method involves, calculating the motor’s magnetic flux and torque on the measured voltage and current of the motor. DTC was originally developed for induction machine drive and directly controls the flux linkage and electromagnetic torque, considering the electrical machine, the electronic inverter, and the control strategy at the system level. It exhibits better dynamic performance than traditional control methods, such as vector control, and it is less sensitive to parameter variations, and is simpler to execute. The application of DTC, to a BLDC drives operating in the 120˚ conduction mode to achieve direct torque control and reduced torque ripple. Stator flux linkage is calculated by integrating the stator voltages. Torque is calculated as a cross product of estimated stator flux linkage vector and measured motor current vector. The calculated flux magnitude and torque are then compared with their reference values. If either the calculated flux or torque deviates from the reference more than permissible tolerance, the transistors of the variable frequency drive are turned off and on in such a way that the flux and torque errors will return in their tolerant bands as fast as possible. Thus the DTC have hysteresis or bang-bang control. Torque pulsations are linked mainly with the flux harmonics, the influence of higher order harmonics in the stator winding inductance usually being negligible.

A.CLARKE TRANSFORM:

Let us apply the *Clarke* transform to the average phase voltages, such that

$$\begin{bmatrix} \boldsymbol{V\alpha} \\ \boldsymbol{V}\beta \end{bmatrix} = \sqrt{\frac{2}{3}} * \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3/2} & \sqrt{\frac{3}{2}} \end{bmatrix} * \begin{bmatrix} va \\ vb \\ vc \end{bmatrix}$$

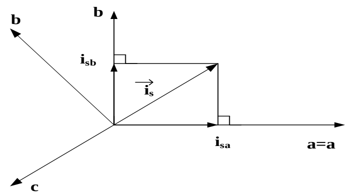

Fig. 2 Clarke Transformation

Va, Vb, Vc ⟹ phase voltages of the BLDC motor

$V\alpha(\text{us}\alpha), V\beta(\text{us}\beta)$ ⟹ Measured phase voltages in the stationary reference frame

SWITCHING STATES, STATOR PHASE VOLTAGES, THEIR CLARKE COMPONENTS AND CORRESPONDING VOLTAGE VECTORS

TABLE 3.1

S1,S2	V_{as}	V_{bs}	V_{cs}	$V\alpha_s$	$V\beta_s$	V1
(0 0)	-Vdc/6	-Vdc/6	Vdc/3	$-Vdc/2\sqrt{6}$	$-Vdc/2\sqrt{2}$	V1
(1 0)	Vdc/2	-Vdc/2	0	$3Vdc/2\sqrt{6}$	$-Vdc/2\sqrt{2}$	V2
(1 1)	Vdc/6	Vdc/6	-Vdc/3	$Vdc/2\sqrt{6}$	$Vdc/2\sqrt{2}$	V3
(0 1)	-Vdc/2	Vdc/2	0	$-3dc/2\sqrt{6}$	$Vdc/2\sqrt{2}$	V4

IDENTIFICATION OF THE SIX SECTORS IN THE $\alpha-\beta$, PLANE BASED ON THE HALL-EFFECT SIGNALS

Sector	**1**	**2**	**3**	**4**	**5**	**6**
(Habc)	**(1 1 0)**	**(0 1 0)**	**(0 1 1)**	**(0 0 1)**	**(1 0 1)**	**(1 0 0)**

B.ELECTROMAGNETIC TORQUE EQUATION

The back-EMF waveform of BLDC drives is quasi-trapezoidal in practical, should be used in BLDC DTC to predict the instantaneous electromagnetic torque. The angular position of the stator flux linkage vector is calculated in a similar manner to its BLAC counterpart, and it is used to find out the commutation points for BLDC operation.

In BLDC DTC, a satisfactory performance can be achieved with torque control alone in constant torque region, which results in easy control strategy. The switching signals of the inverter are determined according to the torque status τ and the sector in which the stator flux-linkage vector lies during the sampling interval. Torque is calculated as a cross product of calculated stator flux linkage vector and measured motor current vector. The stator flux-linkage vector can be obtained from the measured stator voltages $u_s\alpha$and $u_s\beta$

$$\varphi_{s\alpha} = \int(u_{s\alpha} - R\, i_{s\alpha})dt \qquad (3.1)$$

$$\varphi_{s\beta} = \int(u_{s\beta} - R\, i_{s\beta})dt \qquad (3.2)$$

where, R is the stator winding resistance.
The currents ($i_{s\alpha}$ and $i_{s\beta}$) are given by

$$i_{s\alpha} = i_a \qquad (3.3)$$

$$i_{s\beta} = (i_a + 2 * i_b)/\sqrt{3} \qquad (3.4)$$

$i_s\alpha$, $i_s\beta$ = current in the stationary reference frame.
The rotor flux linkages can be deduced from the stator flux linkages.

$$\varphi_{r\alpha} = \varphi_{s\alpha} - Ls * i_{s\alpha} \qquad (3.5)$$

$$\varphi_{r\beta} = \varphi_{s\beta} - Ls * i_{s\beta} \qquad (3.6)$$

The electromagnetic torque equation for BLDC motor is given as

$$T=\frac{3}{2} * \frac{p}{2} * \left[\frac{d\varphi_{r\alpha}}{d\theta e} * i_{s\alpha} + \frac{d\varphi_{r\beta}}{d\theta e} * i_{s\beta}\right] \qquad (3.7)$$

Where $\frac{d\varphi_{r\alpha}}{d\theta e} = \frac{e\alpha}{\omega e}$, $\frac{d\varphi_{r\beta}}{d\theta e} = \frac{e\beta}{\omega e}$,

$\omega e = \frac{d\theta e}{dt}$,$\omega e = rotor\ spee\theta e$ =rotor electrical angle
The back emf in the stationary reference frame is given as

$$\begin{bmatrix} e_\alpha \\ e_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} * \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3/2} & \sqrt{\frac{3}{2}} \end{bmatrix} * \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix}$$

e_α, e_β ⟹ Back EMF in the stationary reference frame

C.TWO LEVEL TORQUE CONTROLLERS

A torque control scheme for BLDCM's at low speeds and maximum efficiency based on the d-q reference frame has been proposed. The back-EMF waveforms in natural a-b-c reference frame are transformed to the d-q-0 reference frame. Torque is estimated as a cross product of estimated stator flux linkage vector and measured motor current vector. Consequently, the optimum phase current waveforms are obtained by transforming the d-q-0 variables to a-b-c.

$$T\frac{\omega e}{p} = \frac{3}{2} eq\ iq$$

From the above equation, component iq can be obtained as follows:

$$iq = \frac{2}{3}\, T\frac{\omega e}{p}\frac{1}{eq}$$

Each optimum phase current waveform can be derived by transforming the d-q-0 variables to the a-b-c ones inversely

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = c^{-1} \begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix}$$

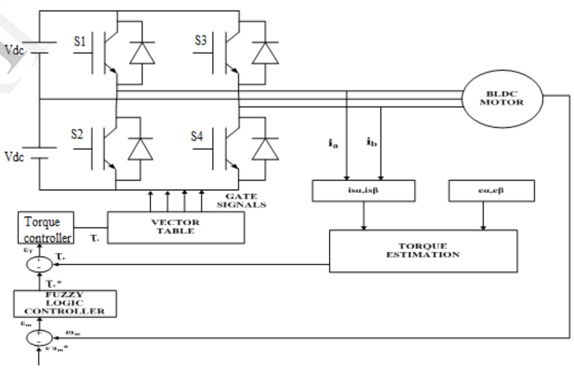

Fig .3 Block diagram of proposed DTC of B4-inverter fed BLDCM

D.FUZZY LOGIC BASED DTC

Fuzzy logic controller converts a linguistic control strategy based on expert knowledge in to automatic control strategy. The components of FLC are 1) Fuzzification 2) Inference 3) Defuzzification.

Defuzzification:
Defuzzification yields a crisp, non fuzzy control action from an inferred control action. However our proposed work at implementation of fuzzy logic controller for the Direct torque controller of BLDC motor. The centre of area method has been used for the defuzzification. In our proposed work, five triangular fuzzy sets have been used to partition the input and output spaces: Negative big (NB),negative small (NS),zero(ZE),positive small (PS),positive big(PB),the rule set then contains twenty five(5*5) rules to account for every possible combination of the input fuzzy sets. The rules are of the form, IF(x is{NB,NS,ZE,PS,PB}) and Y is {NB,NS,ZE,PS,PB}) THEN {output},where output is one of the fuzzy sets used

to partition the outer space. The two input space uses a total of fifteen triangles, so the string to represent a given rule set and membership function combination would have twenty five bits as shown in Fig .2 and Table.3 additional bits are needed for the output triangles because their base length is fixed.

TABLE 3.2
RULE BASE FOR FUZZY LOGIC CONTROLLER

E(u),CE(U)	NB	NS	ZE	PS	PB
NB	NB	NB	NB	NS	ZE
NS	NB	NB	NS	ZE	PS
ZE	NB	NS	ZE	PS	PB
PS	NS	ZE	PB	PB	PB
PB	ZE	PS	PB	PB	PB

Fig 4.1 shows the actual speed, Fig 4.2 shows the reference speed and Fig 4.3 shows the reference torque.

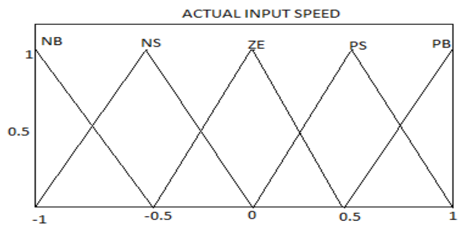

Fig 4.1 Actual speed input to FLC

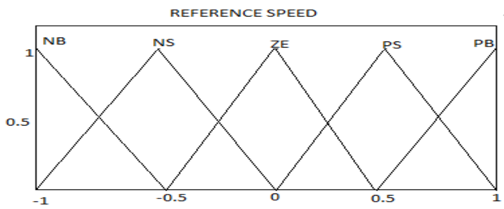

Fig 4.2 Reference speed input to FLC

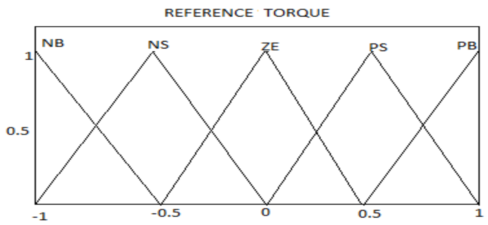

Fig 4.3 Reference Torque output to FLC

IV. SIMULATION RESULTS

Parameters Of BLDC motor

Rated power	96 watts
Rated Torque	1.12 Nm
Rated voltage	24V
Rated Current	4A
Stator resistance	3.8Ω
Stator inductance	0.0008H
Pole pairs	10
Moment of inertia	0.0006329 kgm^2

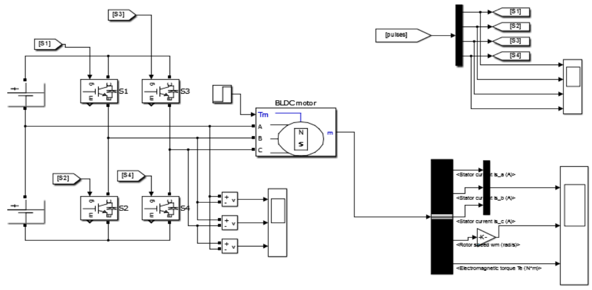

Fig .5 Proposed Simulation Diagram Of Bldc With Four Switch Inverter

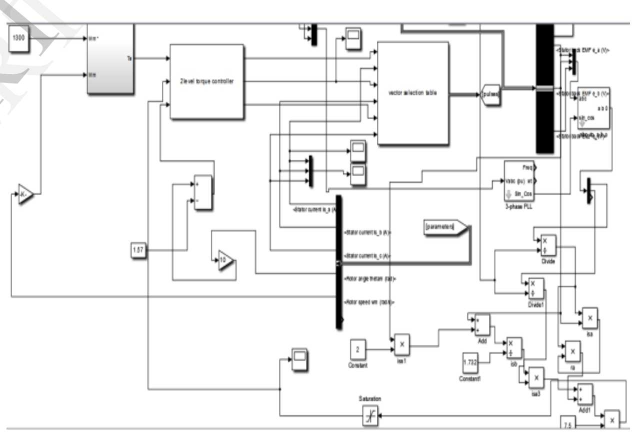

Fig.6 Simulation for Direct Torque controller with Fuzzy logic controller

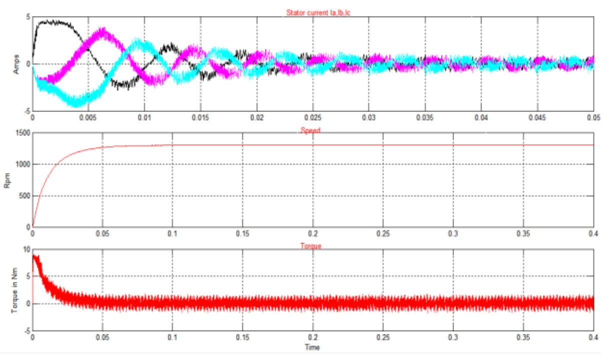

Fig .7 Simulation results of DTC with Fuzzy logic controller

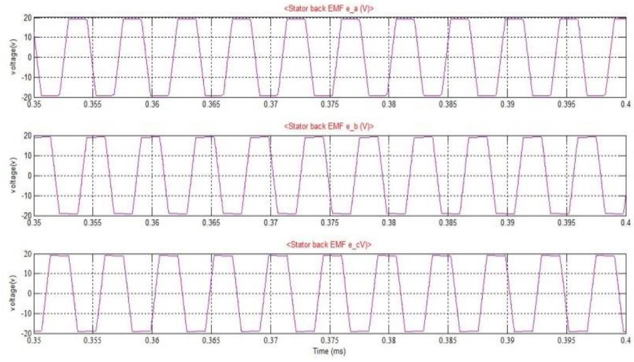

Fig.8 Simulation result of Back EMF

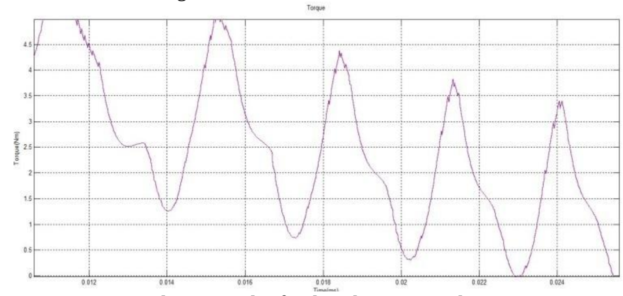

Fig.9 Simulation result of reduced torque ripple using FLC

To verify the applicability of the proposed DTC scheme using the fuzzy logic controller for the BLDC motor, simulations were carried out using Mat lab.

Fig. 5 and 6 shows the simulation of the conventional DTC with fuzzy logic controller. The torque ripple is minimised compared to the PI controller is shown in the figure9. This has been achieved by Two-level torque controller. The figure 7 shows the three-phase voltage, speed and torque waveforms for the proposed DTC. The back EMF waveforms obtained as trapezoidal for BLDC motor is shown in figure 8.

V. CONCULSION

Brushless DC Motor producing ripple-free torque based on Direct Torque Control with Fuzzy Logic Controller have been simulated using MATLAB. The simulated results of DTC with Fuzzy Logic Controller have shown the improved dynamic performance over the conventional method. It has been seen that DTC with FLC, reduce the torque ripples due to commutation. This makes the motor suitable in applications such as electrical vehicle and hybrid vehicle etc., In this proposed method only Fuzzy Logic Control is used instead of PI controller. In future hybrid PI Fuzzy Logic Controller can be used to improve the performance of the system.

REFERENCE

[1] Mourad Masmoudi, Bassem EI Badsi, and Ahmed Masmoudi, "Direct torque control of brushless DC motor with improved reliability", IEEE transactions on industry applications,vol.,2014.

[2] H.Melkote and J.Khorrami, "Nonlinear Adaptive drive contro, of direct drive brushless DC motors and applications to robotic manipulators", IEEE/ASME trans.mechatronics,vol.4,no.1,pp.71-81,1999.

[3] P.J.Sung, W.P.Han, L.H Man and F.Harashima, "A new approach for minimum-torque ripple maximum-efficiency control of BLDC motor",IEEE trans.Ind.Electron., vol.47,no,pp.109-114,2000.

[4] N.R.N.Idris, and A.H.M. Yatim, "Direct torque control of induction machines with constant switching frequency and reduced torque ripple",IEEE trans.Ind.Electron.,vol.51, no.4,pp.758-767,2004.

[5] M.Hajian, J.Soltani,G.A.Markadesh and S.Hosseinnia, "Adaptive nonlinear direct torque control of sensor less IM drives with Efficiency optimization",IEEE trans.Ind.Electron., no.3,pp.975-985,2010.

[6] Z.Zhifeng, T.Renyuyan, B.Boadong and X.Dexin, "Novel direct torque control based on space vector modulation with adaptive stator flux observer for induction motors", IEEE trans.magnetics, vol.48,no.8,pp.3133-3136,2010.

[7] K.K.Shyu, J.k.lin,V.T.Pham, M.J. Yang and T.W,ang. "Global minimum torque ripple design for direct torque control of induction machine drives", IEEE trans.Ind.Electron.,vol.57, no.9,pp.3148-3156,2010.

[8] A.B. Jidin,N.R.B.N.Idris,A.H.B.M.Yatim,M.E Elbuluk and T.Sutikno, "A wide-speed high torque capability utilizing over modulation stategy in DTC of induction machines with consatant switching frequency controller", IEEE trans.power electron., vol .27, no.5,pp.2566-2575,2012.

[9] B.EL.Basdi,B.Bouzidi and A.masmoudi, "Bus-clamping based DTC:an attempt to reduce harmonic distortion and switching losses", IEEE trans.Ind.Elec., vol.60,no.3,pp.873-884,2013.

[10] K.B.Lee and F. Blaabjerg, "sensor less DTC-SVM for induction motor driven by a matrix converter using a parameter estimation strategy", IEEE trans.Ind.Electron.,vol.55,no.2,pp.512-521,2008

[11] Z.Q.Zhu and J.H.Leong,"Analusis and mitigation of torsional vibration PM Brushless AC/DC Drives with direct torque controller", IEEE Trans,Ind.Appl., vol.48,no.4, pp. 1296-1306,2012.

[12] F.G.Capponi, G.D.Donato, .D.Ferrraro, O.Honorati M.C.Harkeand R.D.Lorenz, "AC brushless drive with low – resolution hall effect sensors for surface-mounted PM machines",IEEE trans.Ind.Appl.,vol.42,no.2,pp.526-535,2006.