Analysis Of Brushless DC Machines Pulsating Torque In Two Drive Systems

Maged N.F.Nashed **Mona N. Eskander**
Electronics Research Institute
Cairo, Egypt

Abstract

Brushless permanent magnet DC machines generate parasitic torque pulsation owing to distortion of the stator flux linkage distribution, variable magnetic reluctance at stator slots, and secondary phenomena. Pulsating torque minimization in brushless dc motors (BDCM) is essential in drives, where speed fluctuation, vibration, and noise should be minimized. In this paper, a study is done on the effect of the ratio of the input voltage "V_s": to input frequency "f" on the torque harmonics produced in two drive systems; the BDCM fed by square wave inverter, and the BDCM fed by PWM inverter. For each drive system, the ratio of V_s/f at which minimum torque harmonics occur is deduced. A comparison is then done between this value of V_s/f in the two drive systems. Results showed that minimum torque harmonics take place at higher values of V_s/f in the square-wave inverter-fed BDCM drive. Hence it is concluded that, at a given speed, lower torque harmonics occur at relatively higher values of load torque in the square-wave inverter-fed BDCM drive. Two fuzzy logic controllers (FLC) are designed for each drive system to control Vs/f, while keeping the motor current within limit. Smooth start-up speed and electromagnetic torque are obtained in both drive systems due to the use of FLC.

List of Symbols

P : the number of pole pairs
T_L : the load torque (N.m.)
B : the damping coefficient(N.m./rad./sec.)
ω_r : the rotor speed (rad./sec.)
J : the moment of inertia(N.m./rad./sec^2.)
r_s: stator resistance (ohm)
i_s : stator current(amp)
V_s : motor input ac voltage (vollt)
f : inverter frequency (Hz.)
ψ_s: stator flux linkage (web)
T_{e0} : fundamental electromagnetic torque (N.m.)

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With the recent increasing demand of high-performance permanent magnet brushless dc motors (BDCM), it is important to evaluate and reduce torque ripples. These ripples are responsible for irregularities of speed, which can be compensated only to a certain extent by means of speed control. There are three main sources of torque production in BDCM, i.e. cogging torque, reluctance torque, and mutual torque. Cogging torque is generated by the interaction of rotor magnetic flux and angular variation in stator magnetic reluctance. Reluctance torque results from the interaction of the current mmf with the angular variation in the rotor magnetic reluctance. Mutual torque results from the mutual coupling between the stator winding current and the rotor magnetic field. A great deal of study has been devoted to identifying and minimization of torque ripples [1]-[6]. One of the approaches used to cancel the pulsating torque components is to use programmed excitation waveforms for the phase currents [1]. This approach assumes that sufficient information is available about the pulsating torque characteristics of the specific PM machine to derive the necessary excitation current waveforms to achieve the desired cancellation. In reference [2], a complex Fourier series decomposition was used to find a closed form solution for current harmonics that eliminate torque ripples. In references [3-5], various estimation and observer techniques for torque and flux have been proposed to generate the necessary feedback signals for suppressing the pulsating torque components. However, flux estimation algorithm still depends on pre-knowledge of motor resistances and inductances, as well as the torque constant, which are sensitive to changes in motor temperature. A technique for commutation torque minimization is described in reference [6], where PWM excitation pulses are introduced during intervals when each motor phase would normally be unexcited. This technique suffers from the fact that they are open loop in nature, requiring customized tuning for each set of machine parameters.

In this paper, a study is done on the effect of the ratio of input voltage V_s : to input frequency "f" on the torque harmonics produced in two BDCM drive systems. The first drive is a BDCM fed by square- wave voltage-source inverter. The second drive is a BDCM fed by a current-regulated voltage-source PWM inverter. For each drive system the ratio of V_s/f at which minimum torque harmonics occur $(V_s/f)_{op}$ is deduced. A comparison is then done between $(V_s/f)_{op}$ in the two drive systems. The torque spectrum for variable V_s/f ratio is plotted as a percentage from the fundamental electromagnetic torque, to set a basis for comparison. Results showed that minimum torque harmonics take place at higher values of $(V_s/f)_{op}$ in the square-wave inverter-fed BDCM drive. This result indicates that at a certain reference speed, lower electromagnetic torque harmonics occur at relatively higher values of load torque in the square-wave inverter-fed BDCM drive. This means that for the square-wave inverter-fed BDCM drive better performance is obtained at high load torque, while for the PWM inverter-fed BDCM better performance is obtained at relatively lower values of load torque. Two fuzzy logic controllers (FLC) are designed for each drive system to control Vs/f, while keeping the motor current within limit. Smooth start-up speed and electromagnetic torque are obtained in both drives systems due to the use of FLC.

II. System Description

Two drive systems employing permanent magnet brushless dc motors 'BDCM' are investigated. In the first system, a square-wave voltage-source inverter, whose dc input is supplied from a Cuk converter, feeds the BDCM. The Cuk converter dc voltage and the inverter frequency are controlled via two fuzzy logic (FL) controllers. In the second system a current regulated voltage source PWM inverter whose dc input is supplied from a Cuk converter feeds the BDCM. The modulation ratio and the modulation index of the PWM inverter are varied using two fuzzy logic (FL) controllers. The controllers are also responsible for adjusting the input current to be within the rated value of the BDCM, at different values of load torque.

III. Mathematical Model of Brushless DC Machine (BDCM)

In the stationary reference frame (denoted by the superscript "s", the voltage equation of the stator winding of a salient- pole BDCM is given in space vector notation as follows [7]:

$$\mathbf{V}^s_s = r_s \mathbf{i}^s_s + d\,\Psi^s_s/d\tau \tag{1}$$

where,

$\mathbf{V}^s_s$ is the stator voltage, $\mathbf{i}^s_s$ is the stator current, r_s is the winding resistance, and Ψ^s_s is the stator flux linkage, $\tau = \omega_s t$, and ω_s is the angular stator frequency.

The stator flux linkage is composed of a contribution from the stator current, and of the component Ψ_{sf} relating to the permanent magnet field of the rotor:

$$\Psi^s_s = \mathbf{L}^s_s(\delta) * \mathbf{i}^s_s + \Psi^s_{sf}(\delta) \tag{2}$$

and the saliency of the rotor is expressed by the inductance matrix given as:

$$L^s_s = \begin{bmatrix} 0.5(L_d + L_q) + 0.5(L_d - L_q)\cos(2\delta) & 0.5(L_d + L_q)\sin(2\delta) \\ 0.5(L_d + L_q)\sin(2\delta) & 0.5(L_d + L_q) + 0.5(L_d - L_q)\cos(2\delta) \end{bmatrix} \tag{3}$$

This matrix reflects the influence of the d-axis inductance L_d and the q-axis inductance L_q in the stator as a function of the angular rotor position δ.

From equations (1) -(3), the voltage equation becomes:

$$\mathbf{V}^s_s = r_s \mathbf{i}^s_s + d(\mathbf{L}^s_s * \mathbf{i}^s_s)/d\tau + d\,\Psi^s_{sf}(\delta)/d\tau \tag{4}$$

In order to decouple the variables and simplify the equations, the rotor –fixed reference frame is used. The coordinate transformation leads to the following equation removing the superscript "s":

$$\tau_s * d\mathbf{i}_s/d\tau + \mathbf{i}_s = -j\,\omega\,\tau_s * \mathbf{i}_s - [j\,\omega\Psi_{sf} + \omega\, d(\Psi_{sf}(\delta)/d\delta)]/r_s + \mathbf{V}_s/r_s \tag{5}$$

The term $-j\,\omega\,\tau_s * \mathbf{i}_s$ indicates that the stator winding rotates at the angular velocity -ω against the reference frame. The stator time constant is expressed by:

$$\tau_s = \mathbf{L}_s / r_s \tag{6}$$

where,

$$L_s = \begin{bmatrix} L_d & 0 \\ 0 & L_q \end{bmatrix} = C * L^s_s(\delta) * C^T \tag{7}$$

is the matrix of the stator inductance in rotor coordinates. It is obtained by using the transformation matrix:

$$C(\delta) = \begin{bmatrix} \cos(\delta) & \sin(\delta) \\ -\sin(\delta) & \cos(\delta) \end{bmatrix} \tag{8}$$

The magnet-induced back EMF in eq. (5) is :

$$\mathbf{V}_i = -j\,\omega\Psi_{sf} + \omega\, d(\Psi_{sf}(\delta)/d\delta)| = \mathbf{V}_{i1} + \mathbf{V}_{ih} \tag{9}$$

The first term in (9) is the fundamental back-EMF component $\mathbf{v}_{i1}$ which is aligned with the q-axis, and its magnitude is proportional to the angular velocity ω. The second term describes the variation of the flux linkage Ψ_{sf} with the rotor position angle δ. This variation is zero in rotor coordinates if the spatial distribution of the permanent magnet flux linkage is sinusoidal. In a real PM machine, the flux density distribution is approximately rectangular, hence this term exists defining the space vector of the back EMF harmonics in the stator winding.

The electromagnetic torque generated by the fundamental distributions is expressed as:

$$T_{eo} = [\Psi_s \times \mathbf{i}_s] = [(L_s * \mathbf{i}_s + \Psi_{sf}) \times \mathbf{i}_s] \tag{10}$$

The torque contribution of the flux linkage harmonics is derived from the equivalence of electrical and mechanical power as:

$$T_h(\delta) = (\mathbf{V}_{ih} \cdot \mathbf{i}_s)/\omega \tag{11}$$

The mechanical system dynamics is described by the following equation of motion:

$$d\omega/dt = [T_{eo} + T_h(\delta) + T_{sh}(\delta) - T_L - B\omega]/J \tag{12}$$

where, T_{eo} is the fundamental electromagnetic torque, $T_h(\delta)$ is the harmonic torque caused by non-sinusoidal flux linkage distribution, $T_{sh}(\delta)$ is the torque due to stator slotting (cogging torque), and T_L is the load torque.

IV.BDCM Characteristics with Square-Wave Voltage Source Inverter

In this case the machine is fed with square-wave voltage whose magnitude and frequency could be varied independently. Using Fourier series, the input voltage waveform can be represented as follows:

$$V_s(wt) = \sum_{n=1}^{\infty}(a_n \cos nwt + b_n \sin nwt) \tag{13}$$

Assuming the input voltage waveform is half-wave symmetrical, and that the stator winding is star connected without neutral, a_n and b_n are given by[8]:

$$a_n = 0 \tag{14}$$

$$b_n = \sum_{n=1,5,7,..} (4\,V_d/n\pi)\cos n\pi/6 \tag{15}$$

where V_d is the magnitude of the dc input voltage and n is the order of harmonic, $n = 6k+1$ for positive sequence harmonics, $n=6k-1$ for negative sequence harmonics, and $k=0,1,2,3,\ldots$ The pulsating torque is produced by the interaction of flux harmonics with current harmonics of different order.

From equations (1) through (15) the torque harmonics of the square wave inverter-fed BDCM.are derived.

(i) Torque harmonics at constant input voltage and variable input frequency

In this study, the converter voltage is kept constant at its rated value., while the inverter frequency is varied. The torque spectrum for variable V_s/f ratio is plotted as a percentage from the fundamental electromagnetic torque, to set a basis for comparing between torque harmonics at different loading conditions. The torque harmonics magnitude relative to the fundamental electromagnetic torque magnitude at V_s/f values of 2.2, 4.4, and 5. are shown in Fig.(1). From this plot it is clear that minimum torque harmonics occurred at V_s/f equals 2.2.

(ii) Torque harmonics at variable input voltage and variable input frequency

In this study both the input voltage V_s and the inverter frequency f are varied. The torque harmonics magnitude as a percentage from the fundamental electromagnetic torque magnitude are calculated at two values of V_s /f for each inverter frequency (100Hz., 75Hz, 50Hz, 45Hz, and 40Hz). The results are plotted in Figures (2)-(6) respectively. The plotted harmonic spectrum shows that minimum magnitude of electromagnetic torque harmonics is obtained at V_s/f equals 2.2 for all frequencies. These results prove that minimum magnitude of torque harmonics takes place at the same value of V_s/f for all speeds. According to this analysis, it is concluded that for a specific BDCM; minimum torque harmonics are obtained at a single value for V_s/f.

It is worth mentioning that testing torque harmonics at values of V_s/f lower than 2.1 led to failure in the drive performance. Also values of V_s/f higher than 5 may cause saturation.

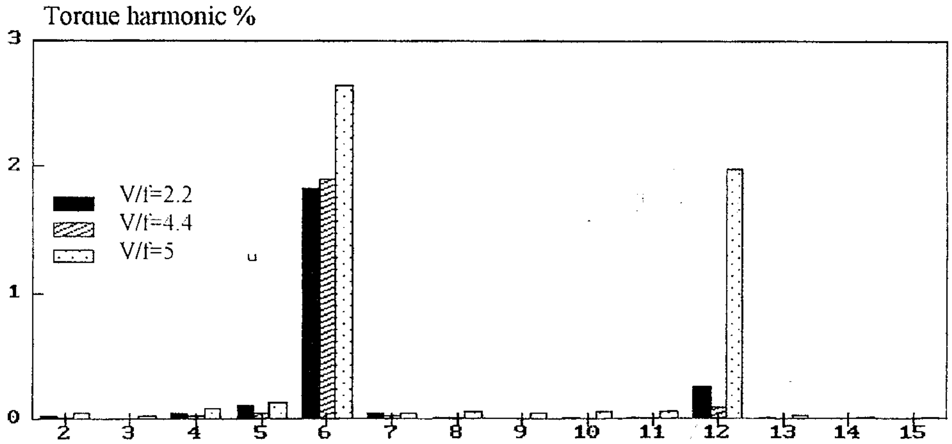

Fig. (1).Torque Harmonic Spectrum at Rated Input Voltage and Variable Inverter Frequency

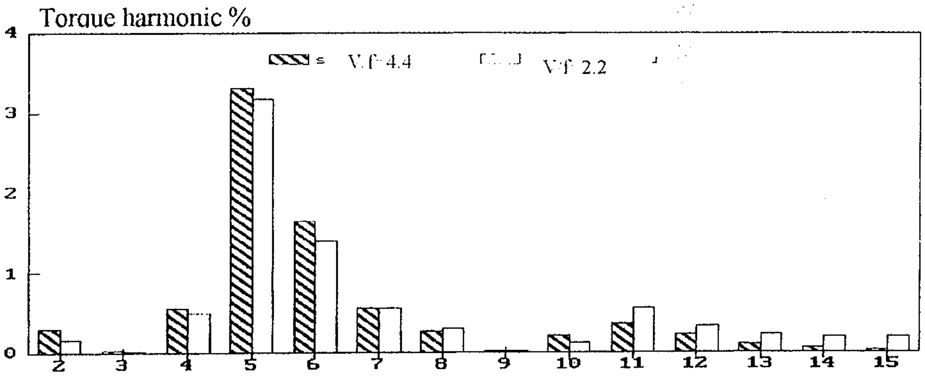

Fig.(2).Torque Harmonic Spectrum at Two Values of V_s/f for f=100Hz.

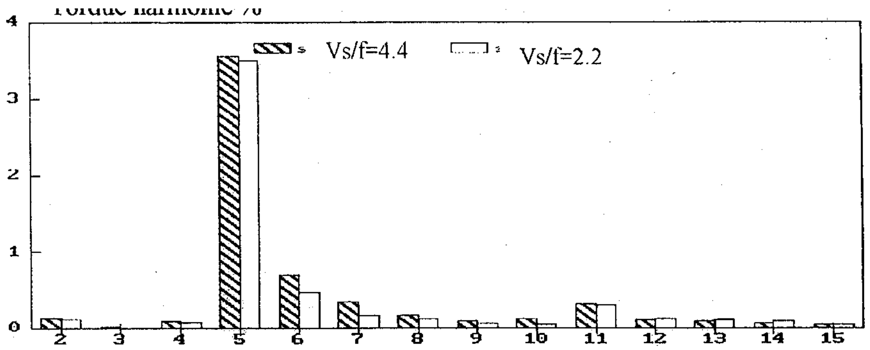

Fig.(3).Torque Harmonic Spectrum at Two Values of V_s/f for f=75Hz

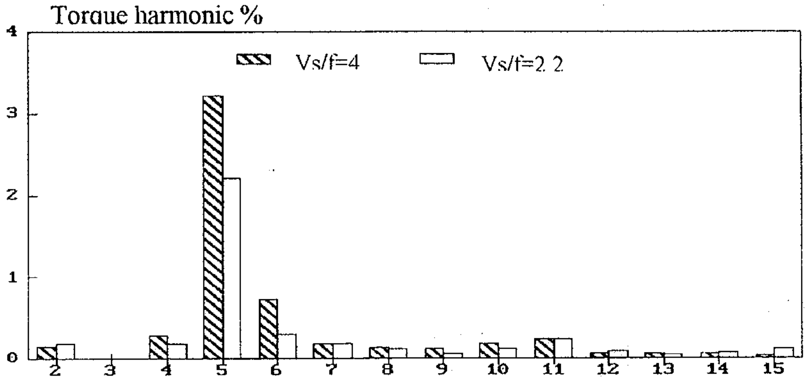

Fig.(4).Torque Harmonic Spectrum at Two Values of V_s/f for f=50Hz

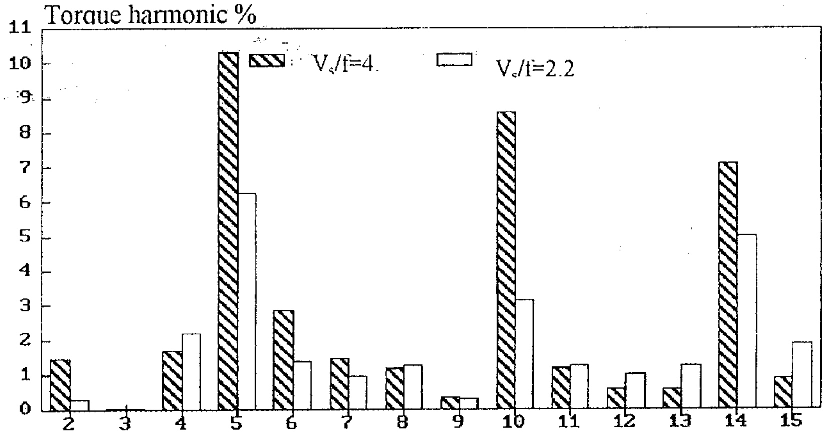

Fig.(5).Torque Harmonic Spectrum at Two Values of V_s/f for f= 45Hz

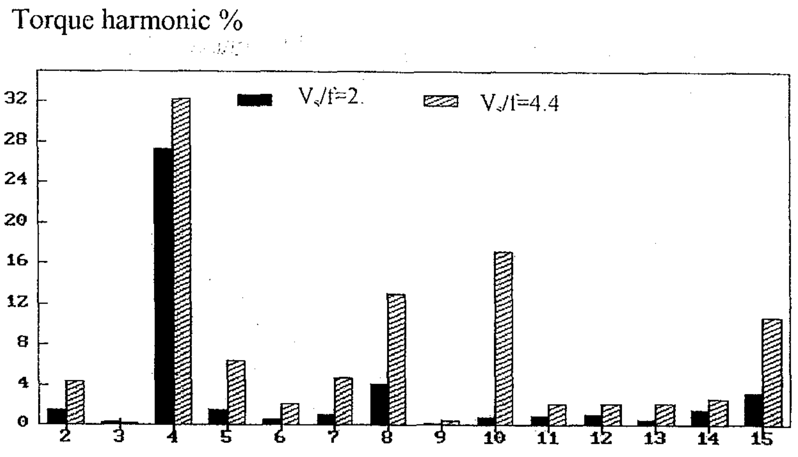

Fig.(6).Torque Harmonic Spectrum at Two Values of V_s/f for f= 40 Hz

(iii) Applied Fuzzy Logic Controllers

Fuzzy logic controllers (FLC) are known by their insensitivity to parameter variation, as well as their ability of smooth starting of electric drives [9]. These advantages are highly required for the BDCM driven by the square-wave voltage source inverter. Hence two fuzzy logic controllers are designed to control the converter voltage and inverter frequency with a control scheme shown in Fig. (7). In this control scheme, the d-q current components, after limiting to rated value, are used to calculate the torque and compare it with the torque command. The first controller (FLC_1) adjusts the dc voltage of the Cuk converter. The inputs to FLC_1 are the speed error and the change in the speed error. The output of FLC_1 is adjusted to produce the duty cycle of the Cuk converter. The second controller (FLC_2) adjusts the frequency of the inverter while regulating the input BDCM currents. The inputs to FLC_2 are the torque command error, and the output of FLC_1 after tunning, to be indicative of the emf voltage. The output is tuned to adjust the inverter frequency.

In order to apply the fuzzy logic controllers for achieving the goal of minimum electromagnetic torque harmonics at a given load, a lookup table is first composed to relate the value of input voltage with the inverter frequency to get $(V_s/f)_{op}$ at which minimum harmonics occur. These results are obtained from simulating the BDCM, (parameters given in Appendix) within the allowable values of load torque and speed range. From these results, the rules relating the input and output variables of FLC_1 to achieve the goal of minimum torque harmonic within the operation range considered, taking the current limit into consideration, are concluded as given in Table I. While those relating inputs with output of FLC_2 are given in Table II. Seven triangular membership functions are chosen for the inputs and outputs of FLC_1, while five triangular membership functions are chosen for the inputs and outputs of FLC_2. The linguistic variables of these functions are defined as:

hn (high negative), mn (meduim negative), ln (low negative),ze(zero), lp(low positive), mp (meduim positive), and hp(high positive).

The speed and electromagnetic torque at start-up for the FL-controlled BDCM fed by square-wave inverter are shown in Fig.(8). The motor reaches steady state slowly due to applying rated load at starting.

Table I

		error						
		hn	mn	ln	ze	lp	mp	hp
Change Of error	hn	ze	lp	lp	mp	hp	hp	hp
	mn	ln	ze	lp	lp	mp	hp	hp
	ln	ln	ln	ze	lp	lp	mp	hp
	ze	mn	ln	ln	ze	lp	lp	mp
	lp	hn	mn	ln	ln	ze	lp	lp
	mp	hn	Hn	mn	mn	ln	ze	lp
	hp	hn	Hn	hn	mn	mn	ln	ze

TableII

		Error of voltage				
		hn	ln	ze	lp	hp
Error Of Torque	hn	hn	hn	ln	ln	ze
	ln	hn	ln	ln	ze	lp
	ze	hn	ln	ze	lp	lp
	lp	ln	ze	lp	lp	hp
	hp	ze	lp	hp	hp	hp

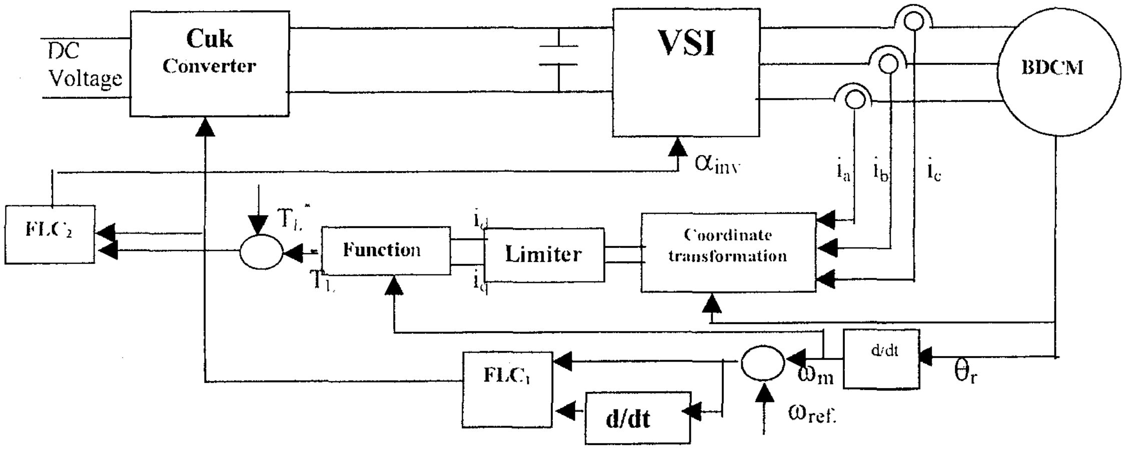

Fig.(7) Control Scheme of Square Wave Inverter-Fed BDCM

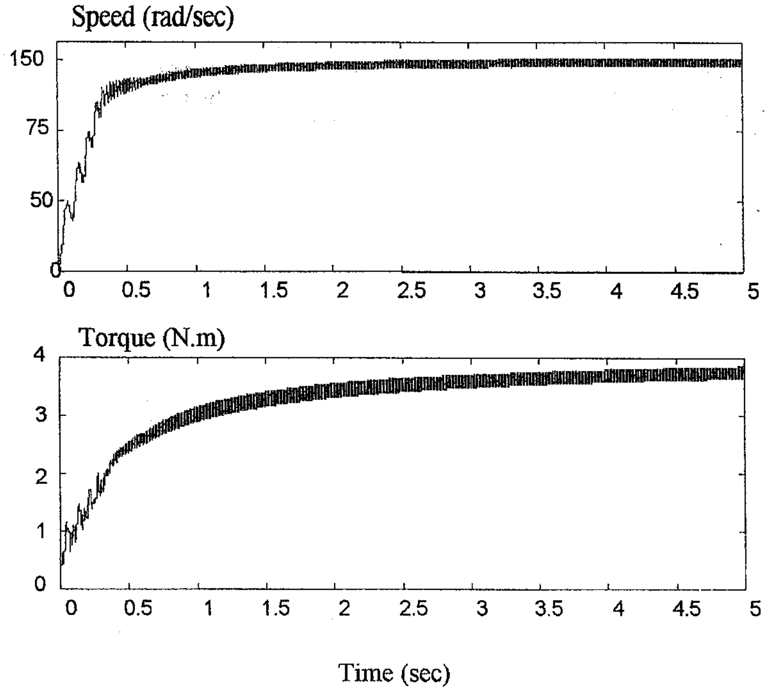

Fig.(8) Speed and Electromagnetic Torque at Startup for the BDCM Fed by Square-Wave Inverter

(v).BDCM Characteristics with PWM Voltage Source Inverter

The dc power available at the converter output is filtered and converted to ac power using a current regulated voltage source PWM inverter.The inverter output consists of sinusoidally modulated train of carrier pulses, both edges of which are modulated such that the average voltage difference between any two of the 3-phase output varies sinusoidally. Varying the dc side voltage of the PWM inverter leads to an inverter topology with hybrid characteristics of current and voltage source configurations. The sawtooth frequency is kept constant at 1 KHz. This low sawtooth frequency is chosen to reduce the switching losses in the MOSFETs used to build the PWM inverter. Also since the BDCM rating is less than 1 KW, high inverter losses will severely affect the system efficiency.The n^th^ harmonic component of the modulated phase voltage, as given by Fourier analysis, is:

$$V_{\text{nphase}} = \frac{V_I}{2n\pi}\sum_{k=1}^{r} + \cos(n\theta_{1,k} - nM\gamma_{\max}\sin(\theta_{1,k})) - \cos(n\theta_{2,k} - nM\gamma_{\max}\sin(\theta_{2,k})) \qquad (16)$$
$$+\cos(n\theta_{3,k} - nM\gamma_{\max}\sin(\theta_{3,k})) - \cos(n\theta_{2,k} - nM\gamma_{\max}\sin(\theta_{2,k}))$$

Where V_d is the input dc voltage, M is the modulation index, n is the harmonic number, r is the modulation ratio, γ is the maximum displacement of the edge, and $\theta_{1,k}$, $\theta_{2,k}$, and $\theta_{3,k}$ are defined as:

$\theta_{1,k} = (2k-2)*\pi/r$; $\theta_{2,k} = (2k-1)*\pi/r$; $\theta_{3,k} = 2k*\pi/r$

(i)Torque harmonics at variable V_s/f ratio

In this study the modulation index of the PWM inverter is changed hence changing the average voltage input to the BDCM and the input frequency, i.e. changing the ratio of average output inverter voltage to inverter frequency. The spectrum of the electromagnetic torque harmonics magnitude relative to the fundamental electromagnetic torque magnitude at different values of V_s/f are shown in figures (9) (10) and (11) for clearer view. Figure (9) shows the harmonic spectrum for three values of V_s/f, namely, 4.4, 2.2, and 1.8. Figure (10) shows the harmonic spectrum for Vs/f values of 1.65,1.5 and 1.1. Figure (11) shows the harmonic spectrum for V_s/f values of 1, 0.88, 0.66, and 0.44. Comparing these three figures shows that the magnitude of electromagnetic torque harmonics is minimum at V_s/f equals 0.44. Lower values of V_s/f led to unstable operation of the drive.

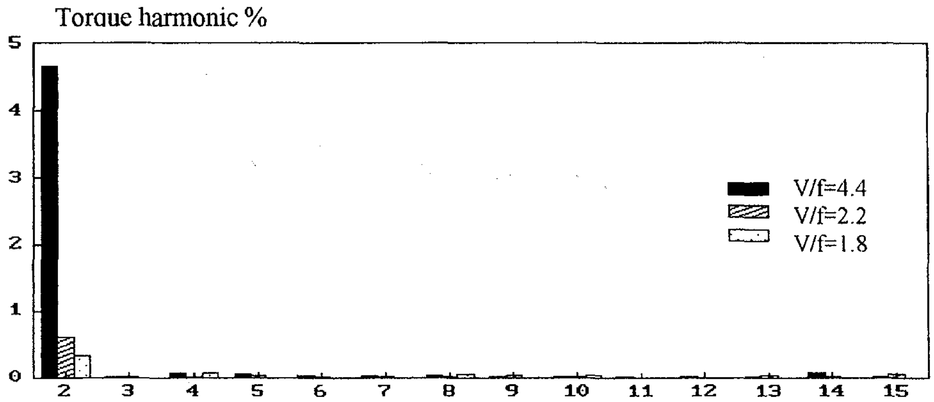

Fig.(9) Torque Harmonic Spectrum at High Values of V_s/f for PWM Inverter Fed BDCM

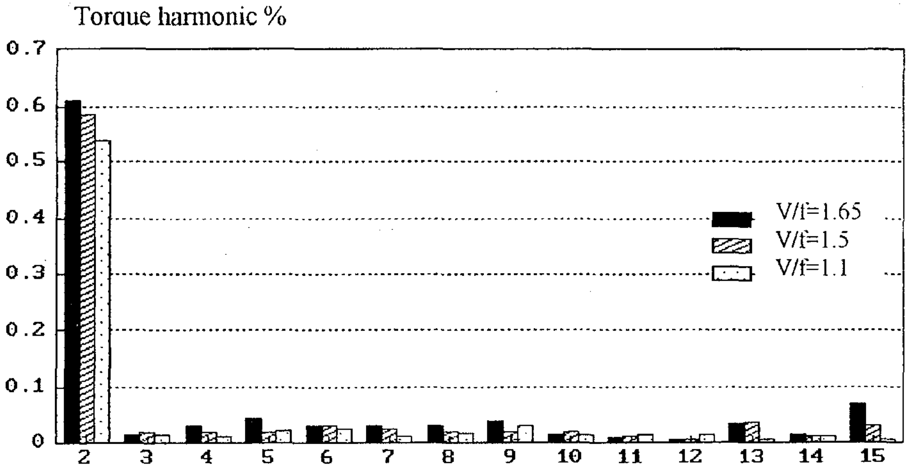

Fig.(10) Torque Harmonic Spectrum at Lower Values of V_s/f for PWM Inverter Fed BDCM

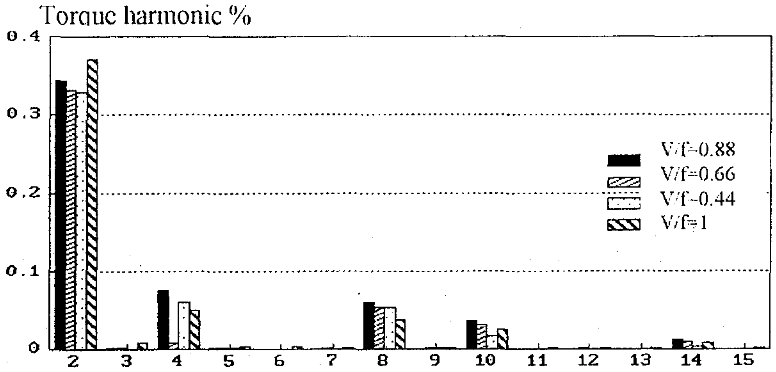

Fig.(11) Torque Harmonic Spectrum at Lowest Values of V_s/f for PWM Inverter Fed BDCM

(ii) Applied Fuzzy Logic Controllers

A similar control scheme as designed in the case of square-wave inverter fed BDCM is applied to the PWM inverter fed BDCM, as shown in Fig.(12). A lookup table is first composed to relate the value of input voltage with the inverter frequency to get Vs/f at which minimum harmonics occur It differs from the lookup table of the of square-wave inverter fed BDCM due to the different values of Vs/f at which minimum harmonic torque occur. The lookup table is composed depending on simulation results described in previous sections and given in Table III for both FLC_1 and FLC_2 , where the five, previously described triangular membership functions are chosen for the inputs and outputs of FLC_1 and FLC_2. The output of FLC_2 is compared with the sawtooth carrier frequency and output gives the three phase pulses of PWM inverter.

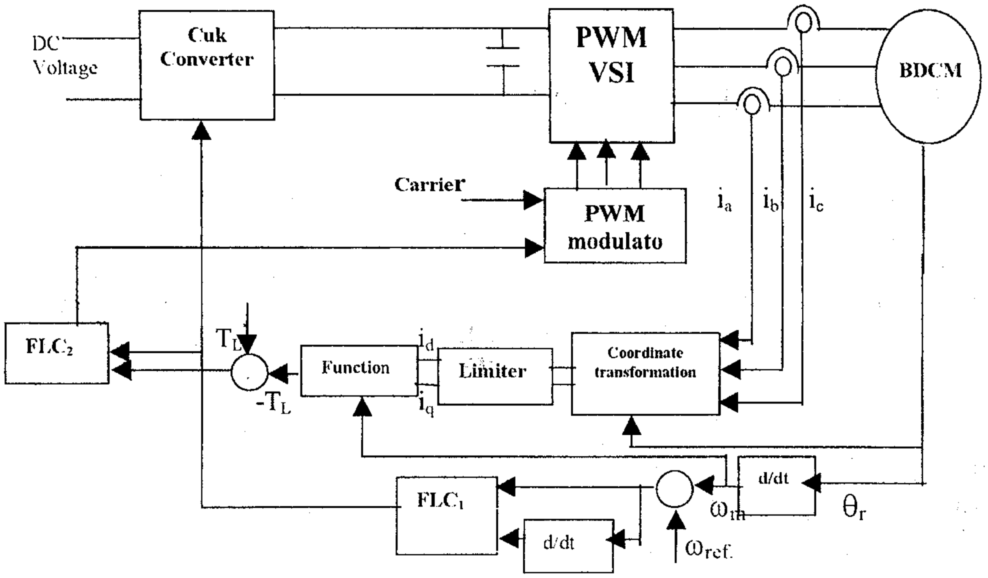

Fig.(12) Control Scheme of Current-Regulated Voltage Source PWM Inverter-Fed BDCM

Table III

	Error of voltage					
		hn	ln	ze	lp	Hp
Error Of Torque	hn	hp	hp	lp	lp	Ze
	ln	hp	lp	lp	zc	Ln
	ze	lp	lp	ze	ln	Ln
	lp	lp	ze	ln	ln	Hn
	hp	ze	ln	ln	hn	Hn

The starting torque characteristics for this optimum ratio of V/f is shown in Figs.(13), where smooth steady state torque is reached within reasonable time.

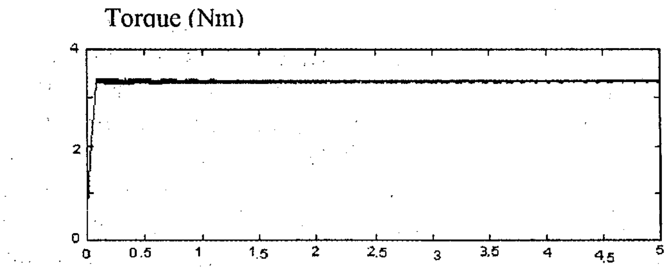

Fig.(13) Starting Torque of PWM Fed BDCM

VI.Comparison Between V_s/f for the two Drive Systems

To conclude the operating conditions that lead to minimum electromagnetic torque harmonics for the two studied drive systems, a comparison is done between the values of $(V_s/f)_{op}$ that leads to minimum harmonics in both systems. Comparing figure (1) with figure (9) shows that at $V_s/f = 4.4$, torque harmonics are higher in the PWM inverter-fed BDCM. While comparing figure. (1) with figure (11) shows that operation of the PWM inverter fed BDCM is possible at values of V_s/f much lower than the square wave inverter fed BDCM. It is also concluded that there is a lower limit for V_s/f below which unstable operation of the drives occur. This lower limit is found to be 2.2 for the square wave inverter fed BDCM, while it equals 0.44 for the PWM inverter fed BDCM. Hence it is recommendable to operate the square wave inverter fed BDCM at higher load torque than the operating load torque of the PWM inverter fed BDCM.

VII.Conclusion

In this paper, the electromagnetic torque harmonics generated in two systems of BDCM drives are studied and compared. The first system is a BDCM drive fed by square- wave voltage source inverter while the second system is a BDCM drive fed by a voltage source PWM inverter. The study aimed at finding the ratio of average input voltage to input frequency that leads to minmum electromagnetic torque harmonics. The harmonics are calculated as a ratio to the fundamental torque magnitude to put a base for comparison between the operating conditions of the two drive systems.. For the square-wave inverter fed BDCM it is concluded that reasonable operation range of the drive is within $2.1 < V_s/f < 4.4$, and minimum electromagnetic torque harmonics occur at $V_s/f = 2.2$ at all speeds. For the PWM inverter fed BDCM, lower values of V_s/f at which minimum electromagnetic torque harmonics occur were possible. Also the range of reasonable operation is wider where V_s/f ranged from 0.44 to 4.4.

It is also concluded that it is recommendable to operate the square wave inverter fed BDCM at relatively high load torque as compared to the operating load torque of the PWM inverter fed BDCM.

For each system two Fuzzy Logic Controllers (FLC) are designed to achieve the goal of minmum electromagnetic torque harmonics at different values of load torque. Lookup tables are concluded from the simulation results and used to design the fuzzy logic controllers. The main benefit of FLC is the insensitivity to parameter variations and the easiness of implementation.

The starting torque is presented for each system, showing smooth starting in both BDCM drives. These characteristics also prove the high performance of the designed fuzzy logic controllers for both systems.

VIII.References

[1].H. Le-Huy, R.Perret, and R. Feuillet, "Minimization of Torque rippl in Brushless DC Motor Drives", IEEE Trans. IA, vol.22, no.4, July/August 1986, pp.748-755.

[2].J.Hung and Z.Ding,"Design of Current to Reduce Torque Ripple in Brushless Permanent Magnet Motors", IEE Proc.,vol.140,no.4, July 1993,pp260-266.

[3].D.Hanselman, 'Minimum Torque Ripple,Maximum Efficiency Excitation of Brushless Permanent Magnet Motors",IEEE on IE,vol.41,no.3,June 1994,pp292-300.

[4].K.Y.Cho, J. Bae, S.Chung, and M.Youn,"Torque Harmonics Minimization in Permanent Magnet Synchronous Motor with Back EMF Estimation',IEE Proc.Elec. Power App.,vol 141,no.6,1994,pp323-330.

[5]. J.Holtz, and L. Springob"Identification and Compensation of Torque Ripple in High-Precision Permanent Magnet Motor Drives',IEEE on IA,vol.43,no.2,April 1996,pp309-320.

[6].S.Park,M.Lee,and .Harashima," A New Approach for Minimum Torque Ripple Maximum Efficiency Control of BLDC Motor', IEEE on IE, vol.47,no.1,February 2000, pp109-113.

[7]. F.Blaabjerg, J Pedersen, and P. Thoegersen, "Improved Modulation Techniques for PWM-VSI Drives", IEEE Trans. on IE, vol.44, no.1, February 1997.

[8].B.K.Bose, "Power Electronics and Variable Frequency Drives", IEEE Press, 1996.

[9]. Pierre Guillemin "Fuzzy Logic Applied to Motor Control" IEEE Trans. on IA, vol.32, no.1, Jan/Feb. 1996.

Appendix

Rated power=800 W   Rated speed = 1500 rpm
No. of Pole=4; L_q= 0.61mH; $J=2*10^{-3}$Kg.m^2
φ=0.175 Wb; r_s=90 ohm; L_d =0.24mH
Cuk converter Capacitor= 480 μf   Cuk converter frequency =15KHz

الفرش ذات التغذ يه بالتيار المستمر

د/ ماجد نجيب فهمى ناشد **د/منى نجيب أسكندر**
معهد بحوث الالكترونيات

تعانى المحركات عديمة الفرش ذات المغناطيسية الدائمة والتغذ يه بالتيار المستمر من وجود توافقيات فى العزم الكهرومغناطيسى ناتج من عدة أسباب وهى الشوشرة فى الخطوط المغناطيسية للعضو الثابت والتغير فى الممانعه المغناطيسية عند ممرات العضو الثابت و الظواهر الثانويه. ومن أهم الضروريات فى المحركات عديمة الفرش ذات المغناطيسية الدائمة والتغذ يه بالتيار المستمر والتى تعمل فى نظم القيادة تقليل توافقيات العزم الكهرومغناطيسى حيث ينبغى ثبات السرعه والأقلال من الشوشره

وقد تم فى هذا البحث دراسة تأثير جهد الدخل وتردده على توافقيات العزم الكهرومغناطيسى وذلك لنظامين من نظم القياده وهما المحرك عديمة الفرش ذو المغناطيسية الدائمة المغذى بقلاب ذو موجه مربعه وأيضا المحرك عديمة الفرش ذو المغناطيسية الدائمة المغذى بقلاب من نوع **PWM**

وفى كلا المحركين تم استنتاج قيمة نسبة جهد الدخل الى تردده والتى يتم الحصول عندها على أقل نسبه من توافقيات العزم الكهرومغناطيسى

وتلا تلك الدراسه عمل مقارنه بين تلك القيمه فى نظامى القيادة المذكورين ومن تلك المقارنه تم استنتاج ان قيمة نسبة جهد الدخل الى تردده والتى يتم الحصول عندها على أقل نسبه من توافقيات العزم الكهرومغناطيسى تقل كثيرا فى حالة المحرك عديم الفرش ذو المغناطيسية الدائمة المغذى بقلاب من نوع **PWM** عنها فى حالة المحرك عديم الفرش ذو المغناطيسية الدائمة المغذى بقلاب ذو موجه مربعه مما يؤدى الى استنتاج انه عند سرعه معينه يكون من الأفضل استخدام المحرك عديم الفرش ذو المغناطيسية الدائمة المغذى بقلاب ذو موجه مربعه لعزم حمل أعلى من عزم الحمل فى حالة المحرك عديم الفرش ذو المغناطيسية الدائمة المغذى بقلاب من نوع **PWM**

كما تم فى البحث تصميم محكمان من نوع المنطق الغير محدد وذلك للتحكم فى نسبة جهد الدخل الى تردده لكلا النظامين المدروسين بحيث يظل تيار المحرك فى الحدود المسموح بها

وقد أظهرت النتائج عند بدء تشغيل نظامى القياده المقترحان انسيابية البدء فى التشغيل وذلك ناتج من استخدام المنطق الغير محدد في التحكم.