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Modification the Hysteresis Method of the Stator Currents Controller to SVM for Improving the Performance of the PMSM

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تعديل طريقة التباطؤ في تيار العضو الثابت الى المتجهات الفراغية المعدلة لتحسين أداء المحرك التزامني
ذو المغناطيس الدائم

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<https://doi.org/10.36772/arid.aijst.2021.473>**ABSTRACT**

This paper aims to reduce the torque ripples in the motor torque, reduce the total harmonics distortion in the motor currents and improve the dynamic response of the permanent magnet synchronous motor. To carry out this study, a modification model was used and compared to conventional model. The main control method used here is a field-oriented control. It was used to generate two decoupled currents control. With help of rotor position, these currents changing into three-phase reference currents. These reference currents were compared to the actual three-phase motor currents. The errors among these currents are introduced to hysteresis current controller to get pulses. These pulses used to drive the voltage source inverter which produces three-phase voltage to drive the motor under study. This technique suffers from some problems as high torque ripples, high total harmonics distortion, the dynamic response isn't very high because at the beginning of the error and the deviation of the output signal becomes large. This is a conventional model. To overcome these problems, the hysteresis current controller was replaced by gain impedance. The output of this gain is the three-phase voltages. These voltages generate pulses through space vector modulation to drive the inverter to get suitable voltage for the permanent magnet synchronous motor. This modification has decreased the torque ripples and the THD in comparison to the conventional controller. To more improvement in the motor performance, one PI torque current controller and load torque estimator were used to damp the overshooting and decrease the rise time.

Keywords: Field orientated control; hysteresis current controller; PI controller; space vector modulation; THD.

الملخص

تهدف هذه الورقة الى تحسين تموجات عزم الدوران وتقليل التشوه في تيار العضو الثابت للمحرك التزامنى وتحسين الأداء الديناميكي للمحرك التزامنى ذو المغناطيس الدائم. لتوضيح ذلك دعنا نبدا بطريقة التحكم المستخدمة في هذه الورقة بدون اى اضافات ثم بعد ذلك سوف نقوم بتوضيح الإضافات التي تمت ومدى تأثيرها على الأداء. طريقة التحكم المستخدمة هنا هي التحكم بتوجيه المجال. انها تستخدم تيارين مرجعيين على محورين متعامدين اى ان اى منهما لا يؤثر على الاخر. يتم استخدام هذين التيارين مع زاوية المجال لتوليد تيارات ثلاثية الأوجه متغيرة مع الزمن. هذه التيارات المرجعية يتم مقارنتها بالتيارات الحقيقية الخاصة بالمحرك الكهربى الذى تحت الدراسة. الخطاء الناتج من هذه المقارنة يتم إدخاله الى وحدة تباطؤ التيار لتوليد نبضات تسلط على العاكس لانتاج جهد يسلط هذا الجهد المحرك الكهربى لادارته. هذا النموذج يعانى من بعض المشاكل مثل زيادة تموجات العزم وتشوهات التيار والمشاكل الديناميكية عند البدء. للتغلب على هذه المشاكل تم استبدال وحدة التحكم في التباطؤ بوحدة تسمى كسب المعاوقة. يتم ادخال الخطاء في التيار الى هذه الوحدة ويكون خرجها جهد متغير ثلاثى الأوجه الذى يتم إدخاله الى وحدة المتجهات الفراغية التي تقوم ببناء على قيم هذا الجهد توليد نبضات تسلط على العاكس لانتاج جهد ثلاثى الأوجه يتم تسليطه على المحرك لادارته حيث نجد انه قد تم حدوث تحسن في تموجات العزم حيث انخفضت قيمتها وانخفض التشوه في التيار. ولتحسين الأداء الديناميكي تم إضافة وحدة تحكم تناسبي تكاملى للتحكم فى تيار العزم ونموذج حسابى لحساب عزم الحمل.

الكلمات المفتاحية: التحكم في التيار بالتباطؤ، التحكم بتوجيه المجال، التحكم التناسبي التكاملي، المتجهات الفراغية المعدلة، التشوه التوافقى الكلي.

1- INTRODUCTION

The Permanent Magnet Synchronous Motors (PMSM'S) spread in many industrial applications this because it has high efficiency, fast acceleration, and deceleration, no copper loss in the rotor, absent spark due to absent brushes, high torque to current ratio, high power to volume ratio, maintenance less and low maintenance cost.

There are many methods used to control PMSM'S. These methods can be classified into simple methods and complex methods. The simple methods as scalar control and the complex methods as vector control and direct torque control. The scalar control is favorite in the applications which don't require a high dynamic response but when this is required the vector and direct torque controls are used. Here the Field-Oriented Control (FOC) is used for this reason. The FOC appeared for the first time by Blaschke in Siemens company [1].

In FOC, the PMSM imitates the DC motor in the behavior. This can be done by splitting the resultant stator current vector in the space into two components one of them represents the flux and the other represents the torque. This can be applied by known the rotor position. To get that position sensor or encoder can be used to detect that. With constant parameters and constant load, the FOC works by good method but when the parameters change or load change, the controller will generate some errors to get rid of this problem some method of control can be used as the current control methods or voltage control methods.

Some researchers introduced effect of hysteresis current controller of the permanent magnet synchronous motors as in [2,3]. From that can be concluded that, the motor torque is highly torque ripples and the stator currents have highly Total Harmonic Distortion

(THD). Some methods of the controller used the hysteresis current to generate pulses to drive the inverter which produces three-phase voltages. These voltages were applied to the motor to drive it. Another research used AMESim software to show the advantages and disadvantages of Hysteresis Current Controller (HCC) as in [4]. The classical FOC with HCC can be seen in Fig. 1. This Fig. was represented by some of the blocks. These blocks are the main field orientation and stator current blocks, comparator block, hysteresis band block, voltage source inverter, and PMSM.

Fig. (1): Classical FOC with HCC

The inputs of the main field orientation block are reference motor speed and actual motor speed. The output of this block is the three-phase reference currents for different phases. In the comparator block, the three-phase reference currents are compared to the actual three-phase stator currents and errors introduced to the hysteresis band to generate the six pluses to drive the inverter to drive the motor. This method of switching has some drawbacks as highly distortion in the motor currents, highly distortion in the stator flux, and has more ripples in the torque. To overcome these problems, some paper design fast HCC to improve the dynamic response of FOC but the waveforms of the flux and current still have more distortion and the motor torque has high ripples as in [5]. The software was used to improve the performance of the PMSM as in [6] but it takes a very long time in calculations. P. Mamta et al [7] used a formula to adapt the hysteresis band but it doesn't

introduce more improvement in the motor current distortion and torque ripples. Hamdy Soliman, S. Hakim introduce an improvement in the THD and torque ripples with using HCC and Proportional Integrator (PI) controller but this leads to increase in the switching frequency of the inverter [8]. Some researches use the fuzzy logic controller to control in the hysteresis band to make the switching frequency of the inverter is constant this leads to some improvement in the ripples and reduces the harmonics as in [9] but these methods depend upon the learning and experiment. Also, predictive current controller is used to improve the performance of PMSM [10]. Another method to adapt the hysteresis band using fuzzy logic can be seen in [11]. Particle swarm used to improve the performance of the PMSM with HCC can be seen as in [12] but this method more complicated.

Also, some researchers used Space Vector Modulation (SVM) to improve the performance of the AC motor as in [13,14] who explains what is meant by SVM. Jacob & Chitra [15] use SVM with PI current controllers to improve the performance of the PMSM but this method suffers from slow response also, at the beginning of the error, the deviation of the output signal becomes large. Alsofyani and Lee [16] uses discrete Space Vector Modulation of PMSM without Flux Error-Sign and Voltage-Vector lookup table. In [17] SVM used with the multilevel inverter to improve the performance of the PMSM but this method has some drawbacks as using more IGBT's which make the system more complicated and has a higher cost. Haidari et al [18] uses predictive current control with SVM to improve the ripples in the motor torque and distortion in the motor currents but this method is also more complicated.

In this paper, the HCC was replaced by gain impedance. The input of the gain impedance is the error in the stator current. This error comes from comparing the reference stator current and actual stator current. The output of the gain impedance is the reference stator voltage. This reference voltage is the three-phase voltages. These three-phase voltages

were converted into two-phase voltages. These two-phase voltages used to generate six pulses to drive the inverter. The output voltage waveforms from the inverter applied to the motor to drive it. With this modification, the total harmonic distortion of the stator current will improve and the torque ripples will reduce. This modification is very good in reducing the distortion and ripples but it isn't approximately effecting the rise time, overshooting, and undershooting. This bad effect can be reduced by applying the PI torque current controller. The method was used in this paper is very simple, very fast response, reduces the torque ripples, reduces THD and improve the dynamic response. This paper can be divided into; the proposed system, a mathematical model of the three-phase induction motor, Pulse Width Modulation (PWM) control using Space Vector Modulation (SVM), simulation results, the conclusions and the recommendations.

2- Proposed System

Fig. 2 shows the proposed model to drive the PMSM. This Fig. contains some blocks. Each block has its own function. The first block is a field orientation block. it is used to generation $\chi \delta$ -axes currents. This occurs through two signals (reference speed and measured speed). The measured speed has two functions. The first function is to deduce the reference flux current component through a lookup table ($\dot{i}_{\chi s}^*$) and the other function is compared to the reference speed and the error between them introduced to the PI speed controller to generate the torque current component ($\dot{i}_{\delta s}^*$). This occurred when the load torque is constant and this can be seen in Fig. 3 but when the load is varying the torque current component deduced by another method as in Fig. 4. From Fig. 4 can be deduced that

Fig. (2): Proposal model to drive the PMSM.

Fig. (3): Inside the field orientation block in case of constant load

Fig. (4): Inside the field orientation block in case of varying load

The χ -axis flux current component can be deduced from the lookup table with help of measuring motor speed as before but the δ -axis torque current component can be deduced by estimating the motor torque with help of the stator current and rotor position and introduced to field orientation block this estimating torque can be used with frictional torque and acceleration torque or deceleration torque to estimate the load torque. The frictional torque can be deduced from multiplying the measured speed in fractional coefficient (B) also, the acceleration torque or deceleration torque can be calculated by subtracting the reference

speed from the actual speed and the result divided into sampling time. The load torque compared to the reference torque and the error was introduced to the PI torque current controller to get the final δ -axis current component. The output of the orientation block ($i_{\chi s}^* & i_{\delta s}^*$) with the rotor position introduced into the reference stator current block use to get the reference stator current i_{abc}^* . These currents were compared to actual stator currents through the regulator current block to get the errors in the stator currents Δi_{abc}^* . These errors in the stator currents introduced to the impedance gain block to get the reference stator voltages v_{abc}^* . These reference stator voltages introduced to the SVM block to estimate the pulses of the inverter. These pulses were applied to the inverter to get suitable voltages to drive the PMSM.

3- Mathematical Model of the Three Phase PMSM

The mathematical model of the three-phase PMSM in synchronous frame is

$$v_{\chi s} = R_s i_{\chi s} + L_{\chi} \rho i_{\chi s} - \omega_e L_{\delta} i_{\delta s} \quad (1)$$

$$v_{\delta s} = R_s i_{\delta s} + L_{\delta} \rho i_{\delta s} + \omega_e L_{\chi} i_{\chi s} + \omega_e \psi_{pm} \quad (2)$$

$$T_e = \frac{3}{2} \frac{P}{2} \psi_{pm} i_{\delta s} \quad (3)$$

$$J \rho \omega_m = T_e - T_L - B \omega_m \quad (4)$$

$$\omega_e = \frac{P}{2} \omega_m \quad (5)$$

$$\theta_e = \int \omega_e dt \quad (6)$$

Where $v_{\chi s}, v_{\delta s}$ are χ, δ axes stator voltages, $i_{\chi s}, i_{\delta s}$ are χ, δ axes stator currents, L_{χ}, L_{δ} are χ, δ axes stator inductance, R_s is the stator resistance for each phase, T_e is electromagnetic torque, T_L is the load torque, B is the fractional coefficient, ω_m is the mechanical speed of the motor, ω_e is the electrical frequency of the motor, J is the moment of inertia, ρ is a derivative factor, θ_e is the electrical rotor position, P is the number of poles and is the permanent magnet of the rotor flux.

4- PWM CONTROL USING SVM

FOC is similar to separately excited DC motor so, the phasor diagram of the PMSM under FOC can be represented as shown in Fig. 5. With help of inverse Clark and Park transformation, the reference stator current can be calculated as,

Fig. (5): Phasor diagram of PMSM with FOC and stator current

$$\begin{bmatrix} i_{as}^* \\ i_{bs}^* \\ i_{cs}^* \end{bmatrix} = \begin{bmatrix} \cos \theta_e & -\sin \theta_e \\ \cos(120^\circ - \theta_e) & -\sin(120^\circ - \theta_e) \\ \cos(240^\circ - \theta_e) & -\sin(240^\circ - \theta_e) \end{bmatrix} \begin{bmatrix} i_{\chi s}^* \\ i_{\delta s}^* \end{bmatrix} \quad (7)$$

These reference stator currents were compared to the actual stator currents to generate the errors in these currents. These errors in the stator currents are the input of impedance gain unit. The output of this unit is the reference stator voltages. These references of the voltages were used to generate the pulses of the inverter to reshape the output voltage of

the inverter. The pulses form depending upon some vector voltages. These voltage vectors are the zero-vector and non-zero vector (adjacent voltages). The switching states of the inverter have eight states. Two of them are non-active voltages (v_0 - v_7). The others (six active voltages vector) are from v_1 to v_6 . All active and non-active states can be seen in Fig. 6. From Fig. 6, the switching state and responding voltage can be seen in table 1.

Fig. (6): Inverter hexagon and sector

The line to line and phase voltages depending upon the switching state of the inverter which shown in table 1 can be calculated as in eqs. 8 and 9. as follows,

$$\begin{bmatrix} v_{ab} \\ v_{bc} \\ v_{ca} \end{bmatrix} = \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} V_{dc} \quad (8)$$

$$\begin{bmatrix} v_{an} \\ v_{bn} \\ v_{cn} \end{bmatrix} = \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} \frac{V_{dc}}{3} \quad (9)$$

Where v_{ab}, v_{bc}, v_{ca} are line to line output voltage of inverter, v_{an}, v_{bn}, v_{cn} are phase output voltage of inverter, V_{dc} input voltage of inverter and a, b, c, operator of the phase voltages.

Depending upon the reference of three-phase stator voltages which entered to the SVM block to generate the pulses to drive the inverter can be simulated as,

Table(1): switching state and cross-ponding voltages

Voltage vector	Switching on	Line to neutral voltages			Line to line voltage		
		v_{an}	v_{bn}	v_{cn}	v_{ab}	v_{bc}	v_{ca}
V_0	T_1, T_3, T_5	0	0	0	0	0	0
V_1	T_2, T_3, T_5	$2/3$	$-1/3$	$-1/3$	1	0	-1
V_2	T_2, T_4, T_5	$1/3$	$1/3$	$-2/3$	0	1	-1
V_3	T_1, T_4, T_5	$-1/3$	$2/3$	$-1/3$	-1	1	0
V_4	T_1, T_4, T_6	$-2/3$	$1/3$	$1/3$	-1	0	1
V_5	T_1, T_3, T_6	$-1/3$	$-1/3$	$2/3$	0	-1	1
V_6	T_2, T_3, T_6	$1/3$	$-2/3$	$1/3$	1	-1	0
V_7	T_2, T_4, T_6	0	0	0	0	0	0

The three-phase reference voltages converter into two-phase voltages as follows,

$$\begin{bmatrix} v_{\alpha s} \\ v_{\beta s} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_{an} \\ v_{bn} \\ v_{cn} \end{bmatrix} \quad (10)$$

With these voltages, the reference voltage as the vector can be seen in Fig. 7 and can be calculated as,

$$v_{ref} = \sqrt{v_{\alpha s}^2 + v_{\beta s}^2} \quad \text{and} \quad \alpha = \tan^{-1} \frac{v_{\beta s}}{v_{\alpha s}} \quad (11)$$

Fig. (7): The reference voltage

The time duration (T_1, T_2, T_s) can be calculated from Fig. 7 as,

$$\begin{aligned}
m_{in dx} v_{ref} \cos \alpha &= \frac{T_1}{T_s} V_1 + \frac{T_2}{T_s} V_2 \cos \alpha \\
m_{in dx} v_{ref} \sin \alpha &= + \frac{T_2}{T_s} V_2 \sin 60^\circ \\
T_0 &= T_s - (T_1 + T_2)
\end{aligned} \tag{12}$$

Where $m_{in dx}$ is the modulation index and $T_s = \frac{1}{\text{switching frequency}}$

From (12) the duration time in each sector can be calculated as follows,

$$\begin{aligned}
T_1 &= \frac{\sqrt{3}}{2} m_{in dx} T_s \sin\left(\frac{n\pi}{3} - \alpha\right) \\
T_2 &= \frac{\sqrt{3}}{2} m_{in dx} T_s \sin\left(\frac{(n-1)\pi}{3} - \alpha\right)
\end{aligned} \tag{13}$$

Where n is the sector number

Depending upon this, the switching time can be written as in table 2 and the voltages can be gotten.

Table(2): Switching time calculation

Sector	Upper switches	Lower switches
1	$s_1 = T_1 + T_2 + \frac{T_0}{2}, s_3 = T_2 + \frac{T_0}{2}, s_5 = \frac{T_0}{2}$	$s_2 = \frac{T_0}{2}, s_4 = T_2 + \frac{T_0}{2}, s_6 = T_1 + T_2 + \frac{T_0}{2}$
2	$s_1 = T_2 + \frac{T_0}{2}, s_3 = T_1 + T_2 + \frac{T_0}{2}, s_5 = \frac{T_0}{2}$	$s_2 = T_2 + \frac{T_0}{2}, s_4 = \frac{T_0}{2}, s_6 = T_1 + T_2 + \frac{T_0}{2}$
3	$s_1 = T_1 + T_2 + \frac{T_0}{2}, s_3 = T_2 + \frac{T_0}{2}, s_5 = \frac{T_0}{2}$	$s_2 = T_1 + T_2 + \frac{T_0}{2}, s_4 = T_2 + \frac{T_0}{2}, s_6 = \frac{T_0}{2}$
4	$s_1 = \frac{T_0}{2}, s_3 = T_2 + \frac{T_0}{2}, s_5 = T_1 + T_2 + \frac{T_0}{2}$	$s_2 = T_1 + T_2 + \frac{T_0}{2}, s_4 = T_2 + \frac{T_0}{2}, s_6 = \frac{T_0}{2}$
5	$s_1 = T_2 + \frac{T_0}{2}, s_3 = \frac{T_0}{2}, s_5 = T_1 + T_2 + \frac{T_0}{2}$	$s_2 = T_2 + \frac{T_0}{2}, s_4 = T_1 + T_2 + \frac{T_0}{2}, s_6 = \frac{T_0}{2}$
6	$s_1 = T_1 + T_2 + \frac{T_0}{2}, s_3 = \frac{T_0}{2}, s_5 = T_2 + \frac{T_0}{2}$	$s_2 = \frac{T_0}{2}, s_4 = T_1 + T_2 + \frac{T_0}{2}, s_6 = T_2 + \frac{T_0}{2}$

5- Simulation Results

Here the simulation results of the proposed system were compared to the conventional system to show the advantages of the proposed system. This occurred at different loads. These loads are constant load. Dynamic load, sudden applied load, and sudden removal load. The motor data was used in this simulation can be seen in Table 3.

5-1 Constant Load

The shapes of the stator currents, motor torque, and motor speed with the conventional system and with the proposed system when the load is constant can be seen here. The variation of the stator current with conventional and proposal methods can be seen in Fig 8 and Fig 9 respectively. Fig. 8 shows that the stator currents are highly distorted (conventional system) and Fig. 9 shows the stator currents become less distorted with the proposed system. The variation in the motor torque with conventional and proposal methods can be seen in Fig 10 and Fig 11 respectively. Fig. 10 shows that the motor torque contains high ripples (conventional system) if it is compared to motor torque with the proposed system.

Fig 12 and Fig. 13 show that the variation of the motor speed with two methods under study. It is approximately the same.

Table(3): Motor data

Motor parameters	values
Power	900 Watt
voltage	110 Volt
Frequency	50 Hertz
Stator resistance	0.43 Ohm
χ -axis inductance	6.97 mH
δ -axis inductance	6.97 mH
Permanent magnet flux inductance	0.18 Weber
Moment of inertia	0.0011Kg.m ²
Frictional coefficient	0.001 Nm.sec/rad
Number of poles	6

Fig. (8): The stator current with conventional system

Fig. (9): The stator current with proposal system

Fig. (10): The motor torque versus load torque with conventional system

Fig. (11): The motor torque versus load torque with proposal system

Fig. (12): The motor speed versus reference speed with conventional system

Fig. (13): The motor speed versus reference speed with proposal system

The following table (table 4) shows the value of the THD in the motor current and the torque ripples in the motor torque. From this table can be concluded that the THD was improved with the proposed system if it is compared to the conventional drive system. Also, when looking up to the torque ripples it is found that the torque ripples were improved with the proposed drive system compared to the conventional drive system.

Table(4): THD and torque ripples

System types	THD	Torque ripples
Conventional drive system	2.2	1.7
Proposed drive system	0.71	0.52

5-2 Dynamic Load

Here the dynamic load is applied from zero sec. up to 0.15 sec, the load increased gradually starting from no-load up to rated value, from 0.15 sec. up to 0.35 sec. the load still at rated value, from 0.35 sec up to 0.5 sec. the load decreased gradually from rated value up to no-load. When using the impedance gain it found that this gain improves only the torque ripples and THD in the current and in the motor flux but it isn't affecting the dynamic behavior so another modified was added to improve the dynamic performance. In this modified, the motor torque was estimated. With this torque, frictional torque, and with acceleration or deceleration torque the load torque is

calculated and compared to the reference torque. The error from this comparison introduced to another PI torque current controller and the output of this PI is a torque current component which used to improve the dynamic behavior and this can be seen here and when the load is gradually changing. The variation of the stator current with conventional and proposal methods can be seen in Fig 14 and Fig 15 respectively. Where Fig. 14 shows the stator currents with the conventional drive model and Fig. 15 shows the stator currents with the proposed system. From these Figs. It is found that the distortion of stator current decreased with the proposed drive system.

Fig. (14): The stator current with conventional system

Fig. (15): The stator current with proposal system

The variation in the motor torque with conventional and proposal methods can be seen in Fig 16 and Fig 17 respectively. Fig. 16 shows that the motor torque contains high ripples (conventional system) if it is compared to motor torque with the proposed system. Fig 18 and Fig. 19 show the variation of the motor speed with two methods under study. From these Figs. It is found that the motor speed with proposed method is approximately not effecting by variation of the load if it is compared to conventional method due to estimate the load torque and use PI torque current component.

Fig. (16): The motor torque versus load torque with conventional system

Fig. (17): The motor torque versus load torque with proposal system

Fig. (18): The motor speed versus reference speed with conventional system

Fig. (19): The motor speed versus reference speed with proposal system

5-3 Sudden Applied Load and Sudden Removal Load

Here the shape of the load can be explained as follows; from zero sec. up to 0.15 sec, no-load is on the motor, at the instant of 0.15 sec. the rated load is suddenly applied and the motor continuous with this load up to 0.35 sec. at the instant of 0.35 sec the load was suddenly removed. The variation of the stator current with conventional and proposal methods can be seen in Fig 20 and Fig 21 respectively. Where Fig. 20 shows the stator currents with the conventional drive model and Fig. 21 shows the stator currents with the proposed system. From these Figs. It is found that the distortion of stator current decreased with the proposed drive system. The variation in the motor torque with conventional and proposal methods can be seen in Fig 22 and

Fig 23 respectively. Fig. 23 shows that the motor torque fewer ripples (proposed system) if it is compared to motor torque with the conventional system. Also, due to adding PI torque controller the effect of suddenly applied load or sudden removal load can be neglected with the proposed drive system if it compared to the conventional system.

Fig. (20): The stator current with conventional system

Fig. (21): The stator current with proposal system

Fig 24 and Fig. 25 show the variation of the motor speed with two methods under study. From these Figs. can be concluded that adding the PI torque current controller damped the effect of the variation of applied or remove the load. This means that the proposed model is more effective in the keeping of the motor speed if it compared to the conventional model.

Fig. (22): The motor torque versus load torque with conventional system

Fig. (23): The motor torque versus load torque with proposal system

Fig. (24): The motor speed versus reference speed with conventional system

Fig. (25): The motor speed versus reference speed with proposal system

6- CONCLUSIONS

This paper studied the problems of the distortion in the stator current, the torque ripples of the PMSM, and the dynamic behavior of the PMSM. This paper produced solutions to these problems. These solutions depend upon improving the THD in the motor current, improving the torque ripples, and improving the dynamic behavior of the motor. The solution depends upon replacing the hysteresis controller by impedance gain to generate the reference voltages which improve the pluses introduced to the inverter through the SVM. Also, it used torque estimator and PI torque current controller to improve the dynamic performance of the PMSM. The simulation showed the importance of the proposed drive system to improve the performance of the PMSM overall.

7- RECOMMENDATIONS

The recommendation for the future work can be summarized as the follows;

- 1- Use the PMSM with taking into account the saturation effect.
- 2- Use the PMSM with taking into account the core loss effect.
- 3- Apply this modification on the other motors as induction motor.

List abbreviations

PMSM's	The Permanent Magnet Synchronous Motors
FOC	Field-Oriented Control
THD	Total Harmonic Distortion
HCC	Hysteresis Current Controller
PI	Proportional Integrator
SVM	Space Vector Modulation
PWM	Pulse Width Modulation

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