MULTILEVEL CONVERTER BASED ON HYSTERESIS CURRENT CONTROL FOR SPEED CONTROL OF INDUCTION MOTOR WITH FIELD ORIENTED CONTROL

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ABSTRACT

Most multilevel converters are controlled through the use of voltage source control methods such as the sine
carrier PWM mehod or space vector PWM scheme. This techniques ofthen are complicat methodes.

In this paper a four level converter expanded hysteresis current source contol is applied for induction motor with field oriented control and the results are compared to a two level converter.

A simple structure feed forward neural network (NN) is presented to control the speed of the induction motor in this paper. To apply the induction motor drives for high performance applications, rotor flux and motor speed must be controlled independently.

Field oriented theory is used to decouple the rotor speed and the flux amplitude. The proposed controller, without using state space dynamics and by employing only the input-output information can produce the control input for motor. However, the NN controller is robust to the bounded parameter variations and external disturbances. A qualified speed tracking and load regulating responses can be obtained by the proposed controller.

1.INTRODUCTION

Recently, due to the rapid improvement in power devices, the field-oriented control, the feedback linearization techniques and variable structure with sliding mode have made it possible to apply the induction motor drives for high performance applications [1-4]. Field orientation control of induction motor is one of the most important topics in the variable speed drive area today; its key technique is the acquisition of flux position [4]. In an ideally field-oriented control, the q-axes rotor flux is forced towards zero and d-axes rotor flux amplitude is held constant. Then motor flux and motor speed can be controlled independently. The main parametric uncertainties of the induction motor are caused by the

thermal variations and load torque disturbances. Adaptive controller can be appropriate technique for controlling the induction motor by where the parameters are constant or change very slowly [3]. In [5] speed control of induction motor using sliding mode with integral compensation is represented. The main factor in designing any controller is using suitable input information.During 1990 to1993 state variables as controller block input were used for training NN controllers with multi layer perceptron static structure[6,7]. In order for the controller with static structure can control the dynamics of the system, it should receive all of the state variable some of which may not be available. In the neural network used in this paper for control of motor speed only speed error and derivative of speed error is used and error reduction is independent of complicate and dynamics of system that should be controlled.

The general weakness in power electronics devices has been to switch power semiconductors at increasingly high frequencies in order to minimize harmonics and reduce passive component sizes. However, the increase in switching frequency increases the switching losses which become especially significant at high power levels. Several methods for decreasing switching losses have been proposed, and recently discussed [9], including constructing resonant converters and multi-level converters. Examples of resonant converter are the resonant DC link [10], and the auxiliary commutated resonant pole converter [11]. One disadvantage of resonant converters is that the inverter voltage or current peak values are considerably higher than those of corresponding hard switched devices, which increases the required device ratings. Multi-level converters offer another approach to reducing switching losses. In particular, these converters offer a high number, of switching states so that the inverter output voltage can be "stepped" in smaller increments [12],[13],[14]. This allows excellent power quality operation at a low switching frequencies and thus low switching losses.

Controlling multi-level converters presents an interesting problem since there are a large number of transistor devices to be switched. Most control methodes are based on an extension of two level converter control methods such as space vector modulation (SVM) [12] or sine-triangle modulatin [15]. SVM methods involve extensive computation is required especially for converters with a high number of levels.

In this paper , we offer an extended hysteresis current regulated control to four level inverter which is often desirable to operate in high bandwidth applications such as field oriented drives [16]. This control method has the advantage of better over current protection since the currents are directly regulated.

2.MATHEMATICAL MODEL OF THE INDUCTION MOTOR

The dynamics of the induction motor in the d-q motor reference frame, which is rotating at the synchronously speed, can be simply described by the following differential equations [4]:

$$\frac{di_{ds}}{dt} = -\left(\frac{R_s}{L_\delta} + \frac{R_r L_m^2}{L_r^2 L_\delta}\right) i_{ds} + \omega_e i_{qs} + \frac{R_r L_m}{L_r^2 L_\delta}\phi_{dr} + \frac{\omega_r L_m}{L_r L_\delta}\phi_{qr} + \frac{1}{L_\delta} V_{ds} \quad (1)$$

$$\frac{di_{qs}}{dt} = -\left(\frac{R_s}{L_\delta} + \frac{R_r L_m^2}{L_r^2 L_\delta}\right) i_{qs} - \omega_e i_{ds} + \frac{R_r L_m}{L_r^2 L_\delta}\phi_{qr} - \frac{\omega_r L_m}{L_r L_\delta}\phi_{dr} + \frac{1}{L_\delta} V_{qs} \quad (2)$$

$$\frac{d\phi_{dr}}{dt} = \frac{R_r L_m}{L_r} i_{ds} - \frac{R_r}{L_r}\phi_{dr} + (\omega_e - \omega_r)\phi_{qr} \quad (3)$$

$$\frac{d\phi_{qr}}{dt} = \frac{R_r L_m}{L_r} i_{qs} - \frac{R_r}{L_r}\phi_{qr} - (\omega_e - \omega_r)\phi_{dr} \quad (4)$$

Where i_s, ϕ_r, V_s, R, L denote stator current, rotor flux linkage, stator terminale voltage, resistance, and inductance, respectively. The subscripts s and r stand for stator and rotor, d and q are the components of a vector with respect to a synchronously rotating reference frame, ω_m and ω_e are the rotor electrical speed and synchronously rotating frequency respectively , and L_m and L_δ are the mutual and leakage inductances $(L_\delta \equiv L_s - L_m^2 / L_r)$.

The speed equation is described as:

$$J\frac{d\omega_m}{dt} = K_T(i_{qs}\phi_{dr} - i_{ds}\phi_{qr}) - \beta\omega_m - T_L \quad (5)$$

$$K_T = 3n_p L_m /(2L_r) \quad (6)$$

Where β and J denote the viscous friction coefficient and inertia constant of the motor, T_L , ω_m , n_p is the external load , the rotor mechanical speed and number of pole pairs respectively.

From (1) to (5) we know that there is coupling between d and q axes of the motor , which make the speed motor more complicate to control. In field oriented control, the rotor flux linkage axis is forced to align with the d axes, and it follows that [4]:

$$\phi_{qr} = \frac{d\phi_{qr}}{dt} = 0 \qquad (7)$$

$$\phi_{dr} = \phi_r = \text{cons}\tan\text{t} \qquad (8)$$

Substituting (7), (8) into the (3), (4), the dynamics of the rotor flux vector, ϕ_{dr} and ϕ_{qr}, can be written as

$$\frac{d\phi_{dr}}{dt} = -\frac{R_r}{L_r}\phi_{dr} + \frac{R_r L_m}{L_r} i_{ds} \qquad (9)$$

$$\omega_e = \omega_m + \omega_s\,, \quad \omega_s = \frac{R_r L_m}{L_r \phi_{dr}} i_{qs} \qquad (10)$$

For the current regulated PWM drive system in the steady state, the rotor flux linkage ϕ_{dr} in (9), (10) is given as

$$\phi_{dr} = L_m i^*_{ds} \qquad (11)$$

Where i^*_{ds} denotes the field current command.
Therefore
from (5) , (11) speed equation is given as

$$J\frac{d\omega_m}{dt} + \beta\omega_m + T_L = K_t i_{qs} \qquad (12)$$

$$K_t = K_T L_m i^*_{ds} \qquad (13)$$

According to the above analysis, the motor speed and motor flux can be controlled independently.

3.MULTI LEVEL CONVERTERS

Multilevel converters which will be described using the four level converter topology is shown in Fig.1.

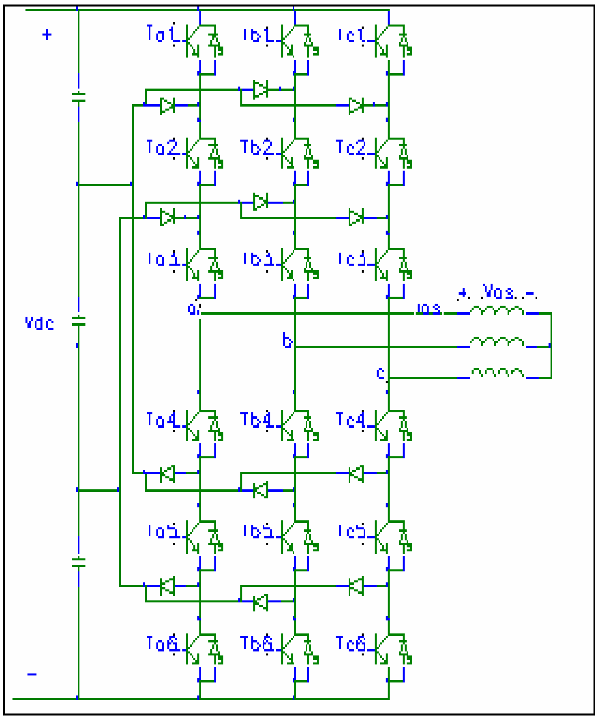


Fig.1. Four level converter topology

From Fig.1. is deduced that four different voltage levels can be selected for the phase to ground voltages v_{ag}, v_{bg}, v_{cg}. For example, the voltage v_{ag} will be 0 if transistors T_{a4} through T_{a6} are gated on , $\frac{1}{3}v_{dc}$ if transistors T_{a3} through T_{a5} are gated on , $\frac{2}{3}v_{dc}$ if transistors T_{a2} through T_{a4} are gated on , and v_{dc} if transistors T_{a1} through T_{a3} are gated on . For four level inverter
Shown in Fig.1, the phase to ground voltages can be expressed as

$$v_{xg} = \frac{l_x}{3} v_{dc} \qquad l_x = 0,1,2,3 \qquad (14)$$

Where x represents the phase which can be a, b, or c, and l_x represents the phase level selected by the gating signals.
The number of possible switching states for a four levl converter is 64.
The voltage applied to the machine stator winding with wye connected is given by [17]

$$v_{as} = \frac{2}{3}v_{ag} - \frac{1}{3}v_{bg} - \frac{1}{3}v_{cg} \qquad (15)$$

$$v_{bs} = \frac{2}{3} v_{bg} - \frac{1}{3} v_{ag} - \frac{1}{3} v_{cg} \qquad (16)$$

$$v_{cs} = \frac{2}{3} v_{cg} - \frac{1}{3} v_{ag} - \frac{1}{3} v_{bg} \qquad (17)$$

4.FOUR LEVEL HYSTERESIS CURRENT REGULATION

The objective of standard two level hysteresis current regulated control is to switch the inverter transistors in a particular phase so that the current in that phase tracks a reference current i_s^* within a specified tolerence or hysteresise level. If the phase current becomes greater than the reference current by an amount equal to the hysteresis level h, the phase is switched to its lowest level $l_x = 0$ in order to decrease the current. Likewise, if the phase current becomes less than the reference current by avalue of h, the phase is switched to its highest level $l_x = 1$ in order to increase the current.

The extension of the two level hysteresis control algorithm to the four level case is based on defining a set of 3 hysteresis levels.

Denoting the maximum allowable excursion of the actual current from the desired current as the hysteresis level h_3, the remaining 2 hysteresis levels are computed from

$$h_1 = \frac{1}{3} h_3 \;\;,\;\; h_2 = \frac{2}{3} h_3 \qquad (18)$$

As with the two level hysteresis control, the switching for a particular phase is governed by that phases current error which is defined by

$$e_x = i_{xs}^* - i_{xs} \qquad (19)$$

When the current error is positive, the controller decreases the level of phase x by one each time the error crosses a hysteresis level. Likewise, the phase level is increased when the current error is negative and crosses a hysteresis level.

The proposed four level extended hysteresis switching state is depicted by following rules:

$$\begin{array}{llll}
\text{if} & l_x = 0 & e_x < -h_1 & \text{then} \;\; l_x = 1 \\
\text{if} & l_x = 1 & e_x < -h_2 & \text{then} \;\; l_x = 2 \\
\text{if} & l_x = 1 & e_x > h_3 & \text{then} \;\; l_x = 0 \\
\text{if} & l_x = 2 & e_x < -h_3 & \text{then} \;\; l_x = 3 \\
\text{if} & l_x = 2 & e_x > h_2 & \text{then} \;\; l_x = 1 \\
\text{if} & l_x = 3 & e_x > h_1 & \text{then} \;\; l_x = 2
\end{array} \qquad (20)$$

5.NEURAL NETWORK SPEED CONTROLLER

Neural network key part is a feed forward NN with two inputs and one output. NN is divided into three layers,
named the input layer with 2 neurons, the hidden layer with 10 neurons, and the output layer with 1 neuron which is shown in Fig.2.

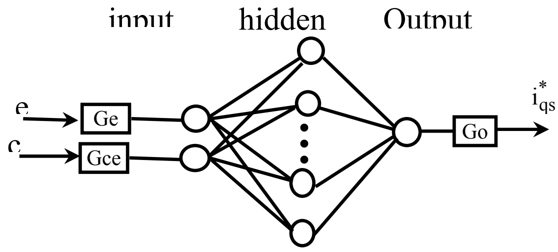


Fig.2. Structure of feedforward neural network

The activation function of the input neurons is linear while that of the output layer and hidden layer is sigmoid,

$$f_a(u) = \tanh(ku) \qquad (21)$$

Where k is constant coefficient. Training is accomplished by suitable selecting of k.

The inputs are speed error, e(k) and derivative speed error ce(k)=e(k)-e(k-1) , they are normalized by the scaling factors Ge and Gce and limited before entering in to NN. The output is multiplied by the scaling factor Go and should be tuned so that the desired output can be produced. NN training is aimed at minimizing J cost function:

$$J = \frac{1}{2}(Ae^2) \quad (22)$$

$$ce = e(k) - e(k-1) \quad (23)$$

Where A is constant coefficients.
By suitable setting Ge, Gce, Go and k we can improve system dynamics.
Training is accomplished by changing the NN weights according to back propagation algorithm. The weight changes are expressed as:

$$\Delta\omega_{jk} = -\eta \frac{\partial J}{\partial \omega_{jk}} \quad (24)$$

Where ω_{jk} is the generic weight and η is the learning rate.
The weight derivative of cost function can be described as:

$$\frac{\partial J}{\partial \omega_{jk}} = \frac{\partial J}{\partial e} \frac{\partial e}{\partial \omega_m} \frac{\partial \omega_m}{\partial i^*_{qs}} \frac{\partial i^*_{qs}}{\partial \omega_{jk}} \quad (25)$$

Where i^*_{qs} is command control input to induction motor.
The complete speed control system for the induction motor is depicted in Fig 3.

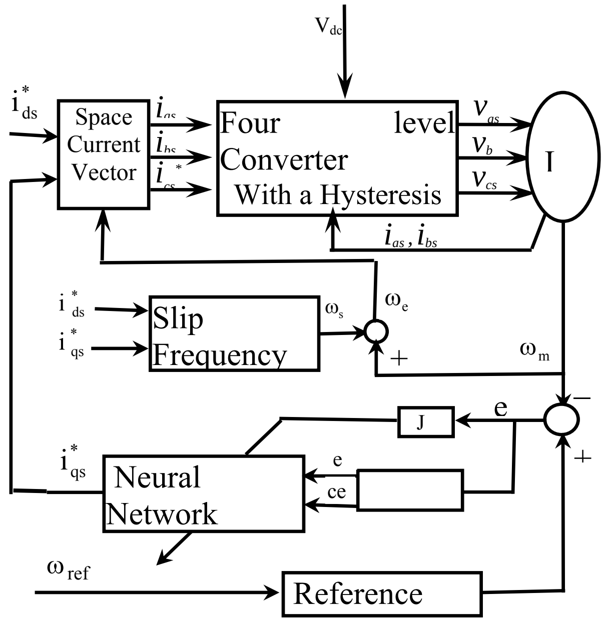
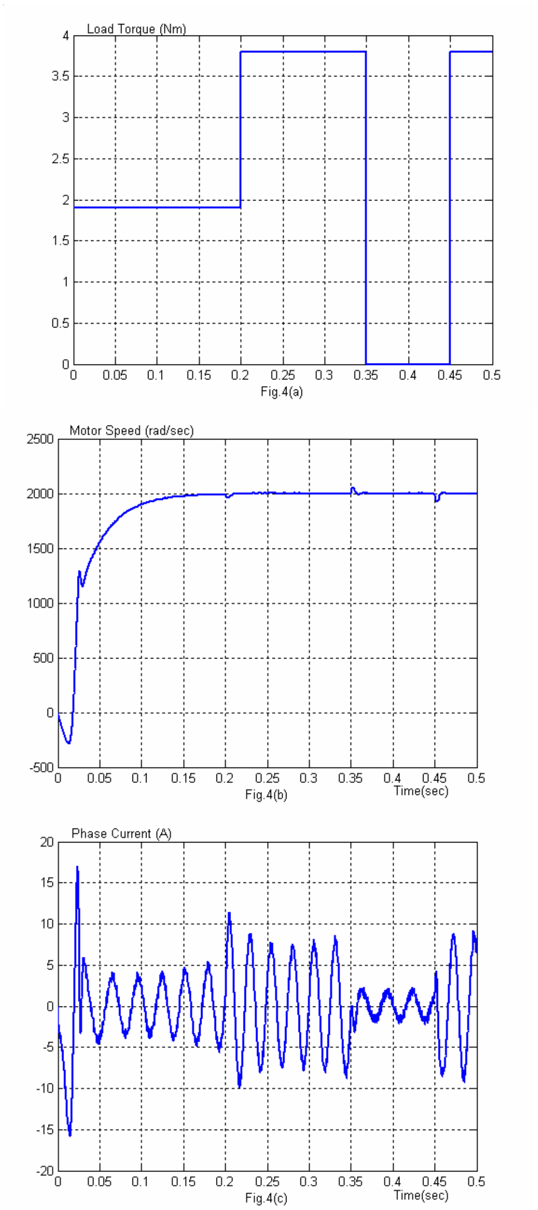


Fig3: Neural network speed control system for the induction motor

6.SIMULATION RESULT

Simulation results obtained from a 0.8kw induction motor and parameters are shown in Table 1 and Table 2.
The control system of Fig.3 is simulated on a personal computer IBM PC-486 to verify the operating of the neural network controller. At start-up, the NN weights are randomly initialized with monotonous distribution at interval 0 to 1.
During to simulation, they are changed at every sampling time. After a trial-and error simulation process, satisfactory responses for the drive speed have been achieved for $\eta = 0.2$, the scaling factors Ge, Gce, Go are 0.03,0.03,200 respectively, the number of hidden neurons is 10 and the sampling rate is 0.1 ms. The results of the most significant simulations are reported in Fig4_7. Fig4-a refer to changing on rated load torque. Fig4_b reports the responses of speed motor to step change of load torque at Fig.4_a. There is 1 percent overshoot in the speed response after the rated torque is applied at t=0.2 sec and settling time is about 10 ms. We can see that using the proposed neural network speed controller guaranteed the robustness to disturbance load. At start up to steady state, phase current at Fig.4_c is less than 3 times rated current and induction torque at Fig.4_d is less than 4 times rated torque. The wide-speed range operation is used to show the tracking capability of the neural network controller. That is, a speed reference of 2000 rpm is initially applied and it changes to 1500 rpm at t=0.2 sec, and at t=0.4 sec this reference changes to 3000 rpm. The speed response , and phase current, and induction torque without load torque are shown in Fig.5_a , and Fig.5_b and Fig.5_c , respectively.
The speed response of neural network controller is smooth in the different speed zones. That is, the good tracking and load regulating responses can be obtained by the proposed neural network controller.
Fig.6(a) and (b) show the a-phase voltage induction motor using proposed hysteresis current control.
It shoud be pointed out that the switching frequencies of four level converter at Fig.6(b) is very small than two level converter at Fig.6(a).

Fig.7 shows the speed responses with and without parameter uncertainties, J=J*, J=2J*. symbol * denotes rated amounth . From this figure, it is shown that the robustness to the variation of motor parameters is obtained.



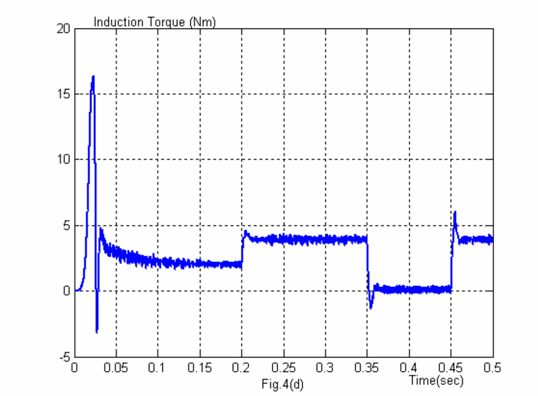


Fig.4: (a) Load torque (b) Speed motor (c) Phase current (d) Induction torque at the rated speed motor (2000 rpm) according to changing of rated load torque shown in (a).

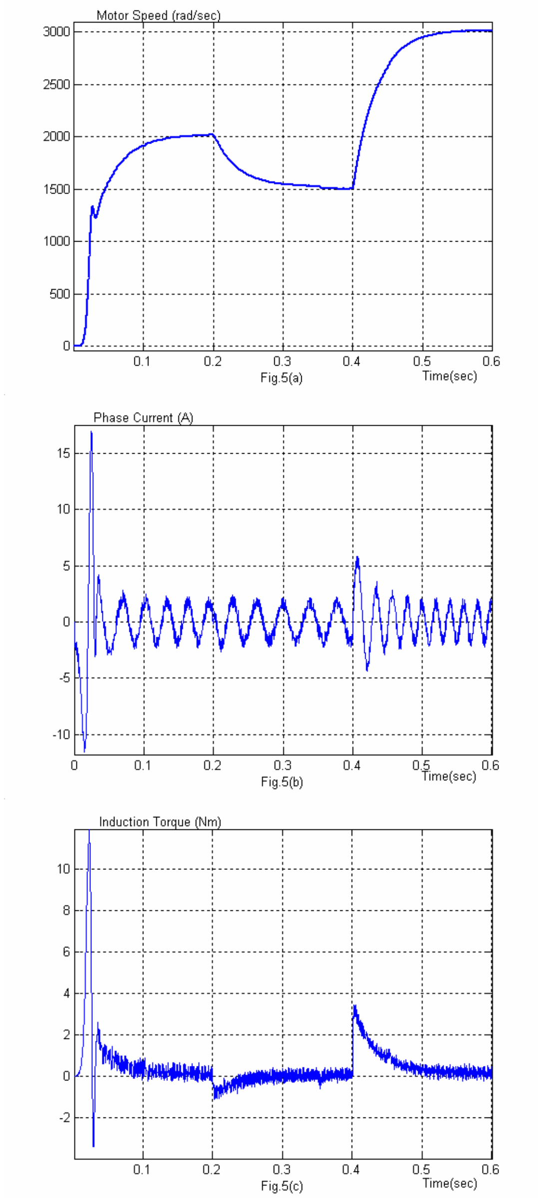


Fig5:(a)The speed response (b) Phase current (c) induction torque according to changing in speed reference at no load.

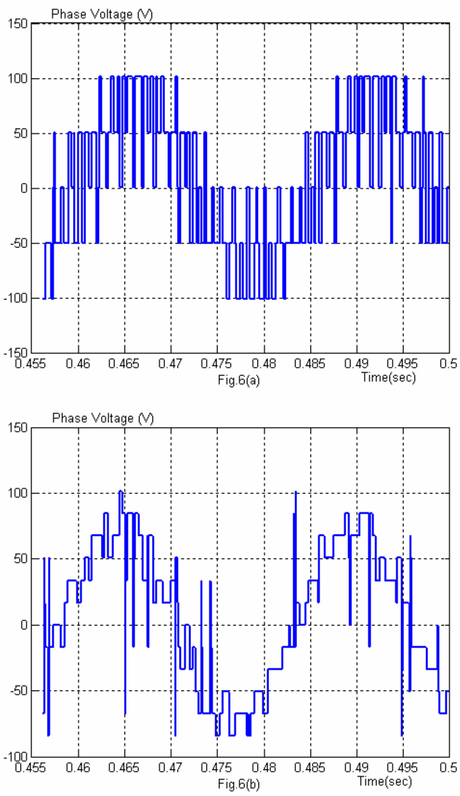


Fig.6: (a) Two level (b) Four level converter performance using hysteresis current regulation.

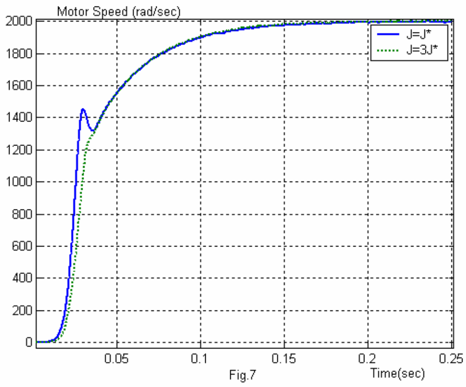


Fig.7: Speed responses at no load with and without uncertainties , J=J*, J=3J*

TABLE 1 The specifications of the induction motor

Output	800W	Torque	3.822 Nm
Voltage	120 V(rms)	Current	5.4 A(rms)
Speed	2000 rpm		

TABLE 2. The parameters of the induction motor

Rs	1.05 Ω	Rr	1.26 Ω
Ls	149 mH	Lr	149 mH
M	143 mH	np	1
J	0.000676 Nm.s^2/rad		
B	0.000515 Nm.s/rad		

7. CONCLUSIONS

In this paper a simple structure neural network (NN) is suggested for controlling the speed of the induction motor based on field oriented control theory which is used to decouple the rotor speed and the flux amplitude. Neural network controller is then designed on the basis of cost function which depends on the speed error.

NN controller does not use motor dynamics so the speed control is independent of the complicating and dynamics of the system.

In this paper a four level converter expanded hysteresis current source contol applied for induction motor with field oriented control and the results shows that reduction on switching frequencies .

NN controller is robust to the bounded parameter variation and external disturbances due to suitable setting of Ge , Gce and Go.

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SAHƏ İLƏ İDARƏ OLUNAN İNDUKSİYA MÜHƏRRİKİNİN SÜRƏTİNİ TƏNZİMLƏMƏK ÜÇÜN HİSTEREZİS CƏRƏYANININ TƏNZİMLƏNMƏSİNƏ ƏSASLANAN ÇOXSƏVİYYƏLİ KONVERTER

MƏHƏMMƏD REZA BANAİ,
SEİD XOSSEYN XOSSEYNİ

Neyron şəbəkəsini tətbiq etməklə, çoxsəviyyəli çevirici vasitəsilə induksiya mühərrikinin sürətini tənzimləmək üsulu təklif edilmişdir. Təklif olunan üsul rotorda selin və mühərrikin sürətinin bir-birindən asılı olmayaraq tənzimlənməsi ilə fərqlənir. Təklif olunan üsul yük xarakteristikalarının və sürətin yüksək keyfiyyətlə qeydə alınmasının təmin edir.

МНОГОУРОВНЕВЫЙ КОНВЕРТЕР, ОСНОВАННЫЙ НА РЕГУЛИРОВАНИИ ТОКА ГИСТЕРЕЗИСА ДЛЯ РЕГУЛИРОВАНИЯ СКОРОСТИ ИНДУКЦИОННОГО ДВИГАТЕЛЯ С ПОЛЕВЫМ УПРАВЛЕНИЕМ

МОХАММАД РЕЗА БАНАИ,
СЕИД ХОССЕЙН ХОССЕЙНИ

Предложен способ регулирования скорости индукционного двигателя с помощью многоуровневого преобразователя с применением нейронной сети. Данный способ отличается независимым регулированием потока в роторе и скорости электродвигателя. Предложенный способ обеспечивает высокое качество отслеживания скорости и нагрузочных характеристик.