2017 7th IEEE International Conference on System Engineering and Technology (ICSET 2017), 2 - 3 October 2017, Shah Alam, Malaysia

Variable Hysteresis Current Controller with Fuzzy Logic Controller Based Induction Motor Drives

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***Abstract*— One of the most popular and easy to implement control strategy for the inverter in induction motor drive system is the hysteresis current control. The most drawbacks associated with the conventional hysteresis current controller is the variable switching frequency due to the constant hysteresis band. This paper aims to develop variable hysteresis band with fuzzy logic controller which can produce constant switching frequency. Matlab/Simulink environment was utilized to conduct the simulation of induction motor drives with three different configuration of hysteresis control; fixed hysteresis band, variable hysteresis band and fuzzy hysteresis band .The obtained results shows that, fuzzy hysteresis band produce better results than the fixed and variable band in which constant switching frequency, less ripple and reduced harmonics contents in the current waveforms. Hence fuzzy based hysteresis current controller proved to be superior in terms of switching frequency and harmonics contents.**

***Index Terms*—Induction motor; hysteresis current controller; hysteresis band, fuzzy hysteresis, constant switching frequency**

I. INTRODUCTION

In the last decades, induction motor drives have been the main focus for numerous researchers and industries [1]. Since the development of vector control of induction motor, it became very popular in most industrial applications due to its robustness, easy implementation, less maintenance required [2] [3] [4]. Vector control made the process of controlling induction motor is similar the case of DC motor by utilizing the phase transformation [5].

FOC is one of the most control method used for induction motor drives, which consists of controlling the stator currents represented by a vector [6] [7]. This control is based on projections which transform a three phase time and speed dependent system into a two co-ordinate (d and q co-ordinates) time invariant system. These projections lead to a structure similar to the DC machine control. Voltage Source Inverter (VSI) is one of the essential components of the FOC system.

Inverter is utilized to convert the DC energy into AC energy in order to be fed into the induction motor .Inverter can be found as conventional two level [8], three level [9] or multilevel inverter [10] [11] [12].In order to make the inverter work perfectly and produce optimum results it is very important to consider the consider the control strategy applied to the inverter. Among the control methods utilized for the inverter are hysteresis current control [10], Sinusoidal Pulse Width Modulation (SPWM) [12] and Space Vector Pulse Width Modulation (SVPWM) [13].In induction motor drives, hysteresis current control is widely used to control the three phase inverter due to its simplicity in design and implementation [14]. The working concept of hysteresis current control in IM drives can be visualized by considering three phase current coming from the motor and compare them with the reference currents produced from the feedback controller. The comparison output is fed into hysteresis controller to produce switching pulse to be applied to the inverter [15]. The implementation of fixed band hysteresis current controller for inverter have been usually used which variable switching frequency associated with such methods. The variable switching frequency can produce harmonics distortions to the currents as well as cause the load current to not fit the predefined band.

In order to eliminate the issues associated with the fixed hysteresis band, many researchers have proposed new variable hysteresis controller which can produce constant switching frequency [16]. K. M. Rahman [17] has proposed a variable hysteresis band using two different controllers. One of the controller is used to add sinusoidal band to the fixed band while the other one is for equidistant band. The study compare the proposed methods with the fixed hysteresis band and claimed this controller is superior to the fixed band controller by which can producing constant switching frequency. Hence, the current distortion is reduced and load current is fit with predefined band. However, the combination band control schemes method is complex and requires extensive mathematical knowledge of the system.

Another study introduced by Ahmed E.kalas [18] which develop variable hysteresis band for the voltage source inverter fed to the induction motor drive. The study discussed the effects of variable switching frequency in the drive system and proposed a new variable hysteresis band to eliminate these effects. This new controller mainly depends on two parameters which are instant value of current and change of current at certain period. Then, the controller uses the older switching pulse to predict the load currents. However, this method seems to have difficulty to determine the suitable gains for the instantaneous current and corresponding current change for the band calculation.

Li Xia [19] proposed variable hysteresis current controller with fuzzy logic applied to shunt active filter. The study claimed a novel hysteresis band to improve the performance of active shunt power filter by designing the fuzzy logic rules ~~of~~ so that the hysteresis band is varied and maintain the switching frequency nearly constant.

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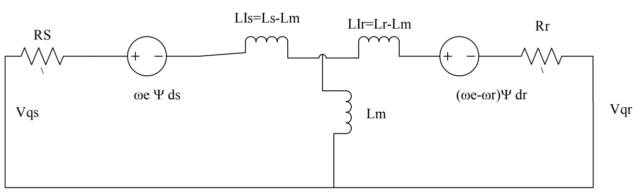
The main drawback of the previous studies concerned about the variable hysteresis band is complexity of the hysteresis based control which is dependent on the highly mathematical formulation. However, this paper mainly focused in proposing variable hysteresis band by applying fuzzy logic controller to select the variable band. The main aim of this study is to proposed a method that can vary the hysteresis band while maintain the switching frequency constant. MATLAB/SIMULINK environment is utilized to design and simulate the system. Comparison are made the fixed band, variable band and fuzzy variable band hysteresis current controllers. From the results obtained, it is shown that fuzzy variable hysteresis band is superior to the other controllers in terms current distortions, torque oscillation, and load current THD.

II. INDUCTION MOTOR MODEL

The induction motor is mathematically modelled and can be represented in various reference frame. Different references frame of induction motor is discussed in [20] [21]. Squirrel cage induction motor in rotary reference frame is presented in Figure 1, which the q-axis and d-axis circuit is shown [22].



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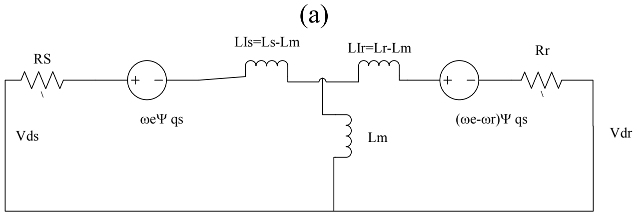

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Figure 1: equivalent circuit of induction motor in rotary reference frame (a) q-axis frame, (b) d-axis frame.

Referring to the equivalent circuit of induction motor represented in Figure 1, voltage in q-axis and d-axis of rotor and stator can be expressed as follow [22]:

$$\psi_{dr} = L_{lr} i_{dr} + L_m (i_{ds} + i_{dr}) \tag{1}$$

$$V_{qs} = R_s i_{qs} + \frac{d\psi_{qs}}{dt} + \omega_e \psi_{ds} \tag{2}$$

$$V_{ds} = R_s i_{ds} + \frac{d\psi_{ds}}{dt} + \omega_e \psi_{ds} \tag{3}$$

$$V_{qr} = R_r i_{qr} + \frac{d\psi_{qr}}{dt} + (\omega_e - \omega_r)\psi_{dr} \tag{4}$$

$$V_{dr} = R_r i_{dr} + \frac{d\psi_{dr}}{dt} + (\omega_e - \omega_r)\psi_{qr} \tag{5}$$

And V_{qr}, V_{dr} =0 and the flux equation as follow:

$$\psi_{qs} = L_{ls} i_{qs} + L_m (i_{qs} + i_{qr}) \tag{6}$$

$$\psi_{qr} = L_{lr} i_r + L_m (i_{qs} + i_{qr}) \tag{7}$$

$$\psi_{ds} = L_{ls} i_{ds} + L_m (i_{ds} + i_{dr}) \tag{8}$$

The electromagnetic torque can be expressed as follow:

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}(\psi_{dr} i_{qs} - \psi_{qr} i_{ds}) \tag{9}$$

The number of induction motor poles are represented by P, once the vector control is achieved d frame of rotor side is zero. Hence, the motor torque is controlled by q frame of stator side as modelled in equation 10:

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}(\psi_{dr} i_{qs}) \tag{10}$$

The full drive system of induction motor is presented in Figure 2 in which the system consists of speed controller, phase conversion, hysteresis current controller, inverter, motor and encoder.

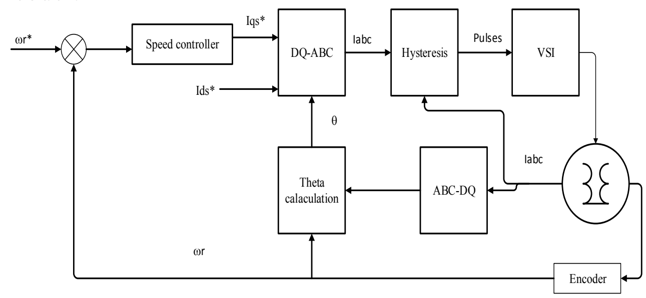


Figure 2: Induction motor drive based Hysteresis current controller

The FOC drive system presented in Figure 2 is based on hysteresis current controller in which the inverter pulses are generated by utilizing hysteresis band. The speed control is based on fuzzy logic controller which process the speed error between actual speed of the motor and reference speed to produce the torque current reference current iq* .The iq* current is gathered with constant id* and transformed into three phase quantities. These three phase quantities are the three phase reference currents which compared with the three phase actual motor currents. The resultant of the comparison between the actual and reference currents is then fed into hysteresis control to generate the required switching pulses for the three phase Voltage Source Inverter (VSI).

In this paper, three different type of hysteresis current controllers will be applied while the other part of the drive system and parameters are maintain unchanged .The main aim is to study the variable hysteresis band and constant switching frequency output by designing variable band and fuzzy variable band hysteresis with the fixed band hysteresis

III. CONTROLLERS DESIGNS

Hysteresis current controller can be visualized from the diagram shown in Figure 3 in which the actual and reference current are compared with defined band of hysteresis in order to generate the ON and OFF pulses for the inverter.

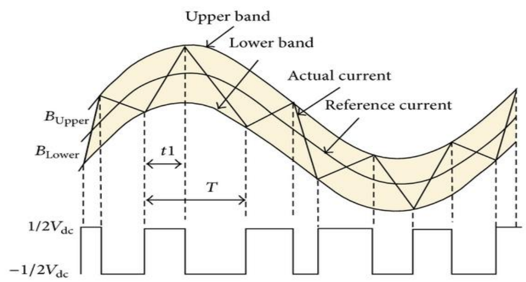


Figure 3: Hysteresis band block diagram

In this study, three different hysteresis band controllers are presented which are, fixed band, variable band and fuzzy variable band hysteresis controllers.

A. Fixed band hysteresis

This type of hysteresis controller is the commonly used hysteresis current controller due to the simple and easy implementation. It has a fixed or specified band for the currents to be compared as referred to Figure 3. In the fixed band hysteresis the upper and lower band can be specified once and the currents must confine with this band. The block diagram of the fixed hysteresis band is depicted in Figure 4.

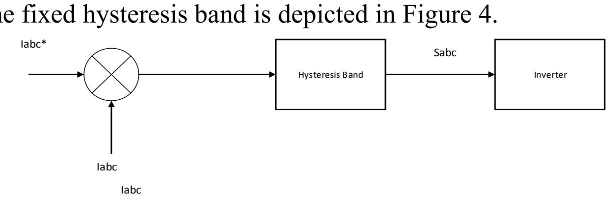


Figure 4: Fixed band hysteresis current controller block diagram

B. Variable band hysteresis

The main drawbacks of the fixed band controller is that it has constant band value and produce variable switching frequency. Variable hysteresis band designed to overcome these issues associated with the fixed band hysteresis. The block diagram of the proposed variable hysteresis band is shown in Figure 5.

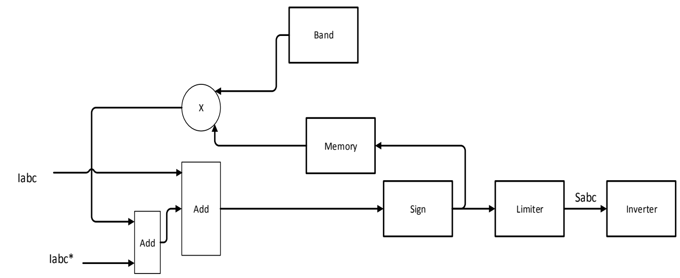


Figure 5: Block diagram of the proposed variable hysteresis band

In this proposed controller, the generated pulse depends upon the changes of the hysteresis band according to the change in the current error. The hysteresis band and current are in proportional relationships in which any increase in the error will results in changes in the hysteresis band. Hence, the current harmonic will be kept constant when the current error changes, also the switching frequency will be kept constant with variable band.

C. Fuzzy variable band hysteresis

In order to ensure variable hysteresis band while maintaining the switching frequency constant, fuzzy logic controller was added to the variable hysteresis band to control the band width .The fuzzy controller connect to the speed error and its rules designed to provide the required band based on the speed error. Hence, the hysteresis band will be varied based on the speed error the induction motor drive system. The block diagram of the fuzzy variable hysteresis band is presented in Figure 6 in which fuzzy logic controller is fed into the hysteresis band to provide the required band based on the speed error.

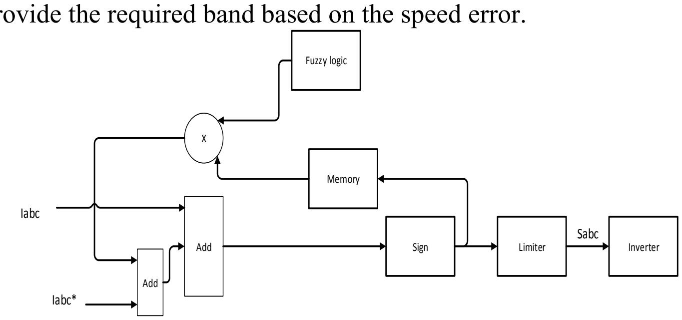


Figure 6: Fuzzy variable hysteresis band block diagram

The motor drive block diagram including the fuzzy variable hysteresis is presented in Figure 7, in which the fuzzy logic controller control the hysteresis band based on the speed error.

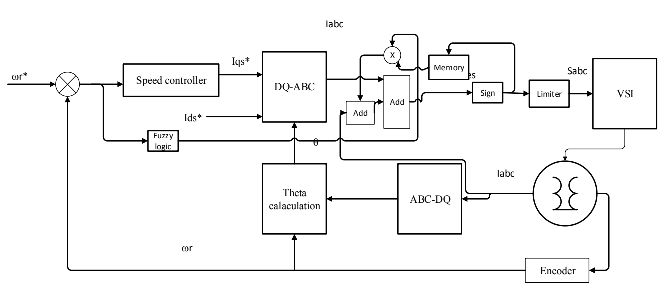
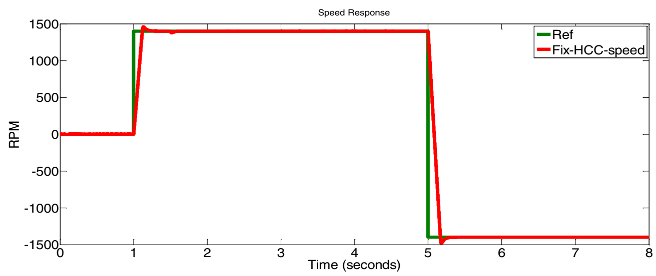


Figure 7: IM drive with variable hysteresis band

IV. Simulation Results

As mentioned earlier three different controllers were utilized in this paper, variable hysteresis band and variable hysteresis with fuzzy were proposed. Simulation analysis carried out using the Simulink and Fuzzy Tolls Matlab. A 2Hp, 4 poles, 380V three phase induction motor is used for this analysis. The motor parameters are given in Appendix A. For the purpose of comparison the commonly known fixed band hysteresis is used as a reference point in order to verify the superiority of the proposed controller performance. The speed performance at rated 1400rpm of the three different controllers is presented in the Figure 8.



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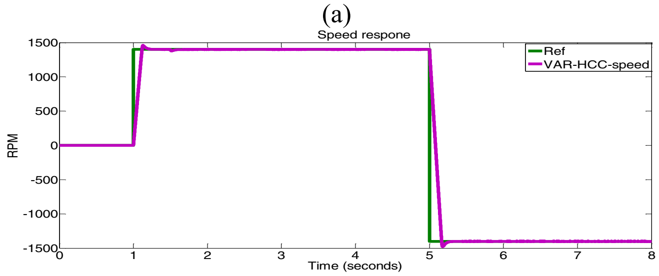

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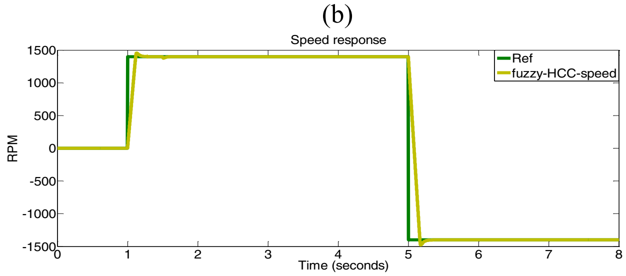

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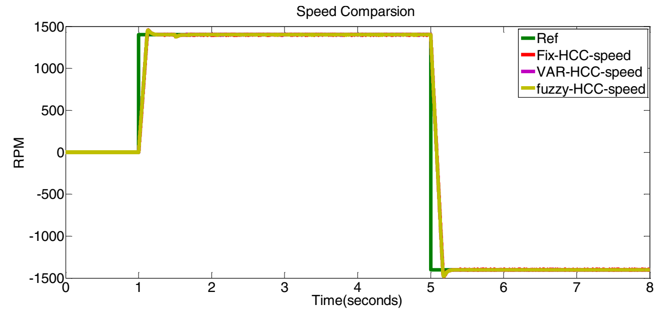
Figure 8: speed response of hysteresis controllers (a) fixed band hysteresis, (b) variable band hysteresis and (c) fuzzy variable band hysteresis.

As can be seen from the speed responses presented, the fuzzy hysteresis controller produce the best speed compared to the other controllers, also the variable hysteresis is superior to the fixed type hysteresis. Figure 9 shows the comparison of the speed response with close view at start up to show the better performance of the fuzzy hysteresis controller. The rising time for fuzzy hysteresis is 0.15s while 0.136 and 0.169 for variable and fixed band hysteresis band respectively.



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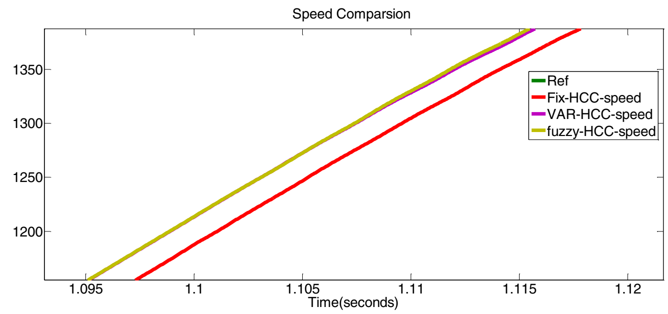


(b)

Figure 9: (a) speed comparison, (b) close up view

In in addition, the output torque of the motor with the hysteresis controllers is shown in Figure 10, in which the fuzzy hysteresis has less ripple compared to the variable and fixed band controller with 0.025%, 0.03795% and 0.059604% respectively. The variable hysteresis band mechanism varies with the speed error. Hence, variable band is obtained and minimize the switching frequency variation. Finally results in reducing the output torque ripple.

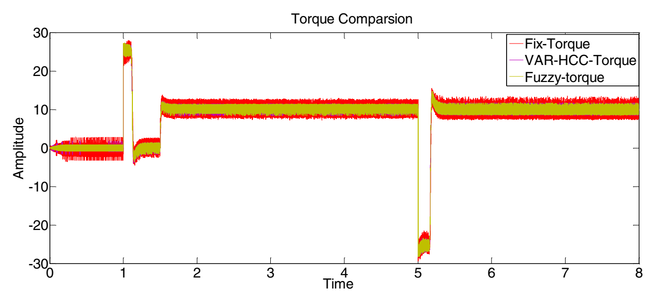
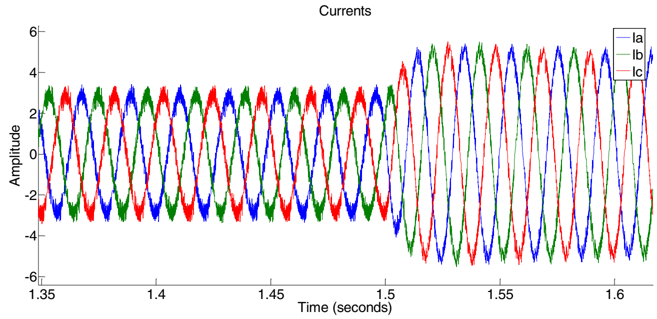


Figure 10: Output torque of the three hysteresis controllers

Moreover, the output current of the inverter is mainly affected by the hysteresis controller and any changes in the hysteresis band can results in harmonics contents in the output currents. The three phase currents of inverter with three type of hysteresis controllers are presented in Figure 11. The maximum peak value of the current amplitude is 6A.



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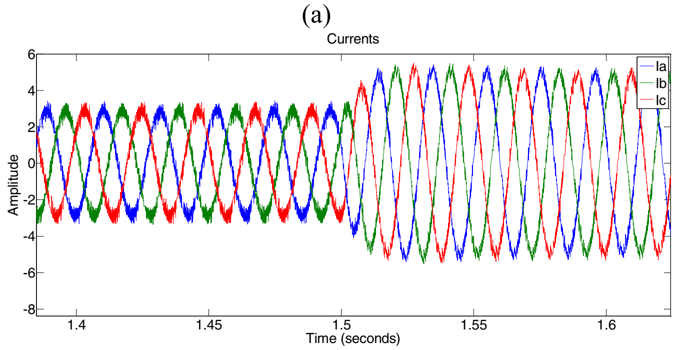

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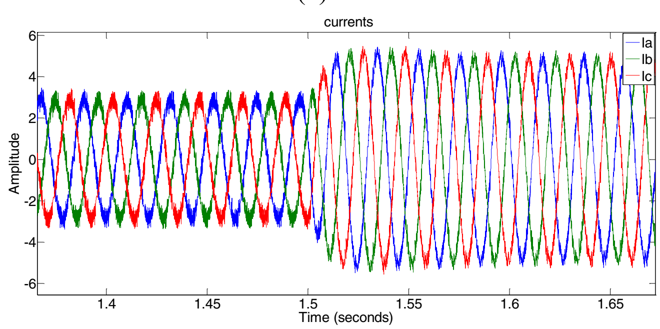

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Figure 11: Inverter output currents (a) fixed hysteresis, (b) variable hysteresis and (c) fuzzy hysteresis

The comparison between phase A Currents utilizing these controllers are presented in Figure 12.

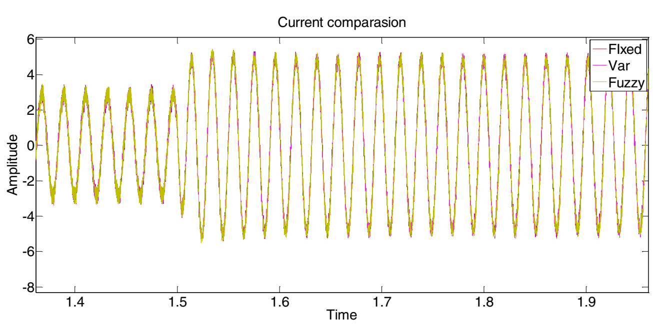
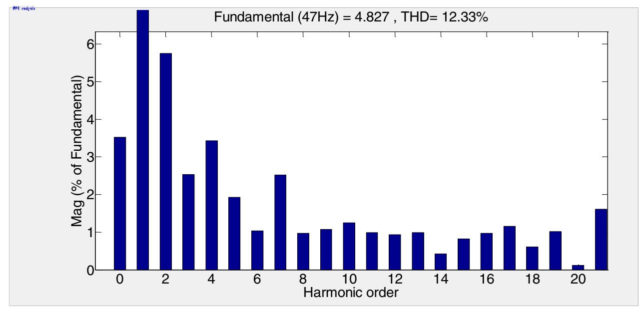


Figure 12: current comparison of different hysteresis controllers.

A part from that, the THD analysis has been achieved for the output current of Phase A for each controller .The results shows that the fuzzy hysteresis controller has the lowest THD contents .Fuzzy hysteresis control the band of the hysteresis based on the speed error so that variable band with constant switching frequency is obtained. Hence, the harmonics contents is minimized. Figure 13 shows THD analysis of the currents in Phase A for the three different controllers. THD value of fuzzy hysteresis controller is 7.75% compared to 9.76% for the variable hysteresis and 12.33% for the fixed band hysteresis.



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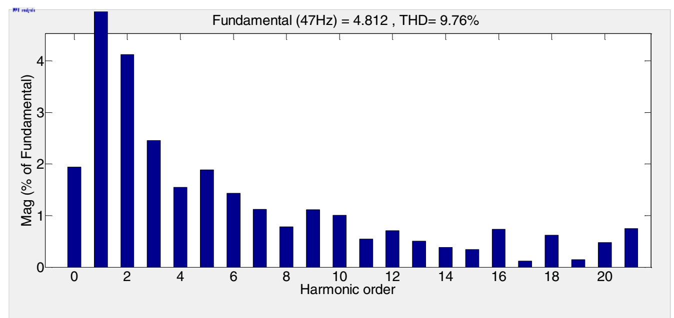

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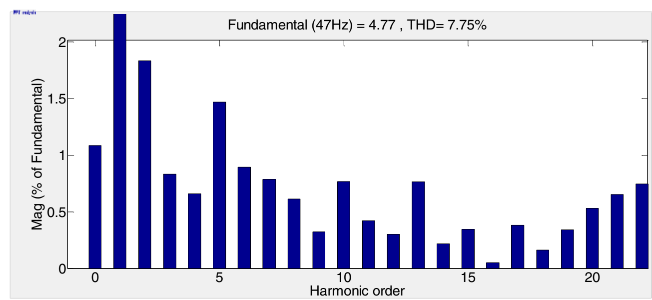

(c)

Figure 13: THD analysis of Phase A currents (a) Fixed hysteresis, (b) variable hysteresis and (c) fuzzy hysteresis

V. Conclusion

In summary, this paper proposed new variable hysteresis controller with fuzzy logic controller based speed error which achieved better performance of the motor drive by changing the hysteresis band based on the speed error. Performance comparisons are made between the hysteresis controllers were at rated speed (1400 rpm) operation load and unload condition. Comparison is carried out during the steady state operation for current and torque ripples performance as well as the current harmonics. The obtained results have shown the superiority of fuzzy hysteresis controller in comparison to the variable hysteresis and fixed band hysteresis during transient and steady state operation. Constant switching frequency is maintained and the harmonics ~~and~~ ripples are reduced.

ACKNOWLEDGMENT

The authors would like to gratefully acknowledge the funding support provided by UTeM and the Ministry of Education Malaysia under the research grant No: FRGS/1/2015/TK04/FKE/02/F00258

APPENDIX A

INDUCTION MOTOR PARAMETERS

Vs (rated)=537V,f_s(rated) =50Hz,P(poles)=4,ω_r (rated)=1400,Rs=3.45 □ ,Rr=3.6141 □, Ls=0.3252H, Lr=0.3252H, Lr=0.3117H, J=0.3252H=0.02kgm^2

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