A NEW TECHNIQUE OF FUZZY CONTROL FOR D.C MOTOR [+]

تقنية جديدة للمتحكم الضبابي للسيطرة على سرعة محرك تيار مستمر

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Abstract:

This paper presents a design of a multi input single output fuzzy controller (MISOF) to control the speed of a DC motor. The new technique used in this work is by inserting besides the Proportional Integral fuzzy controller another input (w_r), which will decide the required base rule in order to get the required firing angle for triggering the thyristor bridge. In this paper, the MISOF controller is designed to control the armature voltage in order to maintain the motor speed. The fuzzy system decides the region of operation according to the required speed, also use the error and change of error of the speed to control the system speed. Simulation results show that the speed response of the DC motor controlled by the MISOF controller have a zero overshoot and zero steady-state error for different values of the reference speed. The paper describes application of fuzzy logic controller in a speed control system that uses a phase-controlled bridge converter and a shunt dc machine.

Index terms: - DC motor drive, controlled rectifier, speed control, fuzzy logic controller, PI controller.

المستخلص:

يُقدّمُ هذا البحث تصميم نظام سيطرة ضبابي ذو إدخال متعدد وإخراج وحيد للتحكم في سرعةَ محرك تيار مستمر. التقنية الجديدةَ المستخدمة في هذا البحث تتمِ بإضافةً إدخال ثالث إلى نظام السيطرة الضبابيِ التفاضلي التكامليِ وهو السرعة المطلوبة (w_r)، والذي سَيُقرّرُ دوال الحالة الأساسيةَ المطلوبةَ التي سيتم استخدامها للمسيطر الضبابيَ لكي نحْصلَ على زوايا القدح المطلوبة لتشغيل الثايرستور . ُصمّمُ النظام الجديد للسَيْطَرَة على فولطيةِ المولّدةَ لكي تبقي سرعةَ المحرّك ثابتة. يُقرّرُ النظامُ الضبابيُ المقترح منطقةُ العمل طبقاً للسرعةِ المطلوبةِ، يَستعملُ الخطأَ أيضاً وتغييرَ خطأِ السرعةِ للسَيْطَرَة على السرعةِ للنظامَ. تبين نَتائِجَ المحاكاةِ بأنّ محرك التيار المستمر بان قيمة تجاوز الهدف (overshoot) وقيمة استقرار الخطأ (steady-state error) تساوي صفرا لكل قيم السرع المستخدمة

Introduction:

Electric machines play an important role in industry as well as in our day-to-day life. They are used to generate electrical power in power plants and provide mechanical work in industries. They are also an indispensable part of our daily lifes. Direct current (DC) motors

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have been used in industry for speed control since the late 19th century. DC motors still dominate as traction motors used in transit cars and locomotives as the torque-speed characteristics of DC motor can be varied over a wide range while retaining high efficiency [1].

The applications of fuzzy logic control FLC was mainly focused on certain systems that are structurally difficult to model due to their inherent natural nonlinearities and other modeling complexities [2]. However, the conventional FLC still has two main drawbacks: (1) The fuzzy rules are obtained from human trial-and-error work, and (2) it still lacks the systematic or mathematical methodologies to ensure the system stability[3]. The fuzzy approach is a convenient method to design a controller with a desired nonlinear dependence between the input and the output of the controller. However, the fuzzy controller parameters must be properly chosen to form the desired controller. Fuzzy logic controllers (FLCs) have been reported to be successfully used for a number of complex and nonlinear processes [4]. Fuzzy controllers are supposed to work in situations where there are large uncertainties, disturbances or unknown variations in plant parameters. Generally the basic objective of adaptive control is to maintain consistent performance of a system in the presence of these uncertainties [5].

In recent years, feedback linearization approach have been used to design the nonlinear controller by changing the original nonlinear dynamics into linear one, thus all the standard linear control techniques can be used[6]. Therefore in practical application, this method may not be very acceptable when the back EMF is added as another output, the resulted dynamic model can be of no zero dynamic unstable problem [7].

The objective of this work is to design a fuzzy speed controller FSC to have the closed loop response with minimum overshoot, and the suggested controller will cover a variable range of speed using an armature voltage control for speed set points under the reference speed (w_r) to follow the operation of armature voltage control for speed set points above the reference speed (w_r). The MISOF consist of three inputs to the fuzzy controller blocks, one with Proportional Integral (PI) for controlling the armature voltage circuit, a second is Proportional (P) for field current control and a third is a common reference input to decide the reference required speed. The controller mechanism of the three phase controlled rectifier, as shown in Figure (1) , uses Error signal (*E*), the Integration of Error signal (IE) and reference speed (w_r) as inputs and u(t) as output, as shown in Figure (2) .

<u>Mathematical Model of D.C Motor</u>:

The mathematical model of dc motor (permanent magnet type) can be expressed by these equations [8].

$$v_a = R_a i_a + L\frac{di_a}{dt} + e_a \qquad (1)$$

Where $e_a = Kw_m$

$$T_e = J\frac{dw_m}{dt} + B_m w_m \qquad (2)$$

Where

$T_e = Ki_a$

The model is simulated based on [9]

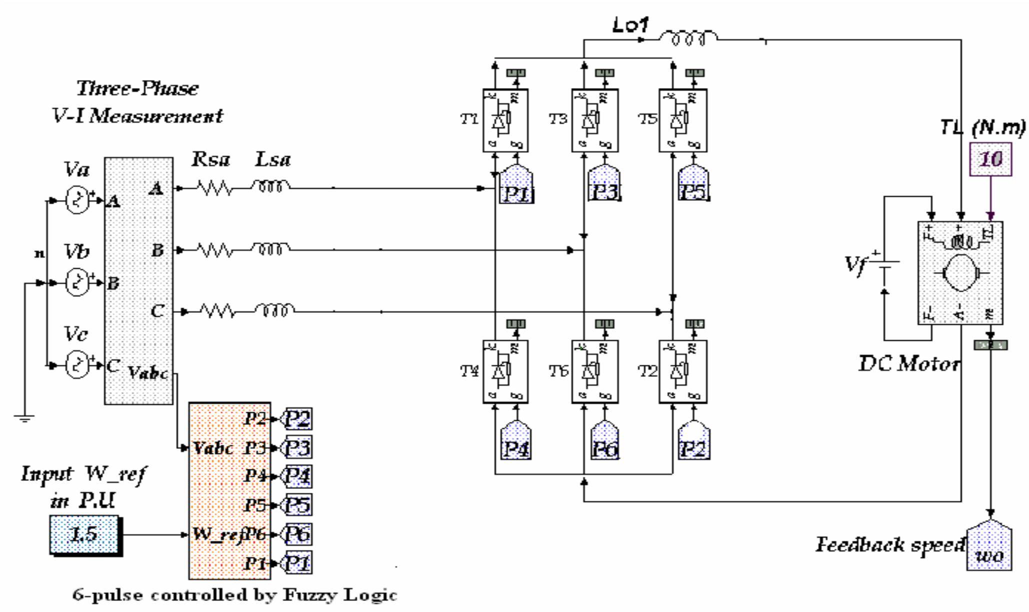

Figure (1): Simulation of a three-phase controlled rectifier by Matlab.

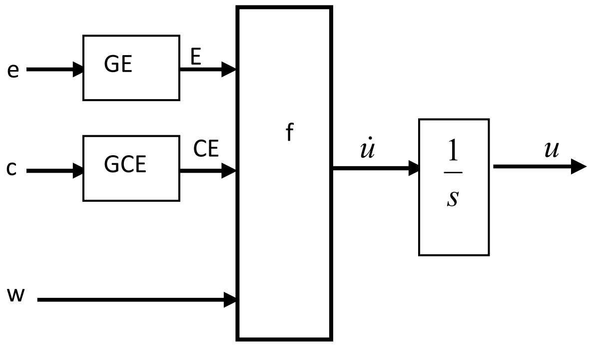

Figure (2): A block diagram of a PI fuzzy control system

Figure (3) represents the general form of a continuous closed loop system, where r(t) and c(t) are the input and output of the system respectively, e(t) represents the error signal which is fed to the controller (Fuzzy Controller) and the output u(t) will be the control signal to the plant.

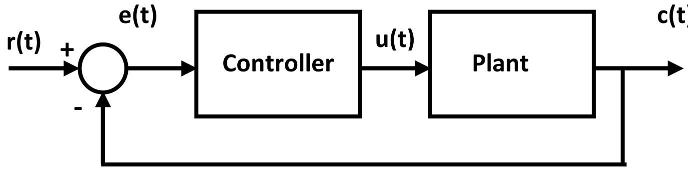

Figure (3) General block diagram of the system

The Fuzzy Logic Controller:

In this section a detailed solution is provided based on fuzzy Logic control. The fuzzy controller performs the three following functions:

(a) Fuzzification converts the input values of the variables into a fuzzy value. The operation includes a lot of searching in lookup tables and comparisons.

(b) Rule-base table: represents & applies all the rules and produces a fuzzy output value. The operations include truncation and convolution of the membership functions.

(c) Defuzzification converts the fuzzy output value produced by the rules to analogue control signal. The operations here include computing the centroid of the backend membership functions. This is the last step, an optimization can be obtained by reducing unnecessary

parameter, using normalizing function to limit variation interval. The equation giving a conventional PI-controller equation can be written as [10], [11]:

$$u(t) = K_P.e(t) + K_I \int e(t).dt \qquad (3)$$

Where K_P and K_I are the proportional and the integral constant coefficients respectively. Since the input to the fuzzy controller is the error and change of error, the derivative of equation (3) will give:

$$\dot{u}(t) = K_P.\frac{de(t)}{dt} + K_I.e(t) \qquad (4)$$

$$u(t) = \int \dot{u}(t)\, dt \qquad (5)$$

Then an integration of equation (4) will give the required control signal u(t). A block diagram for a fuzzy control system is shown in Figure (2).

Design of Fuzzy Controller:

In the fuzzy mechanism, the membership functions (MF's) for controller inputs, i.e., error (*e*) and change of error (ce) are defined on the common interval of (-2, 2) as shown in Figure (4) and Figure (5), whereas the membership functions for the third input(w_r) on the interval [0 , 2000] as shown in Figure (6), the output membership functions for the control signal is defined in the interval of (0,90) as shown in Figure (7).

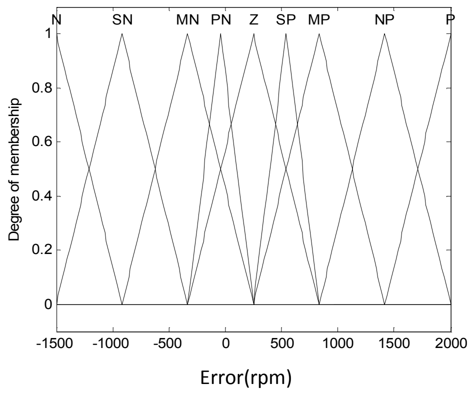

Figure (4) Membership function for error

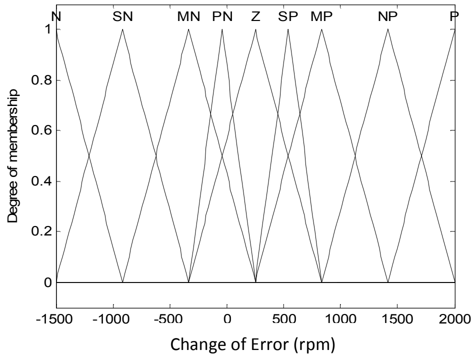

Figure (5) Membership function for change of error

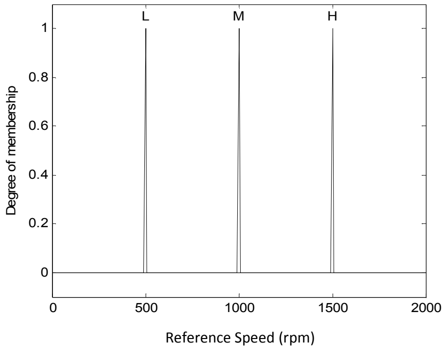

Figure (6) Membership function for reference speed

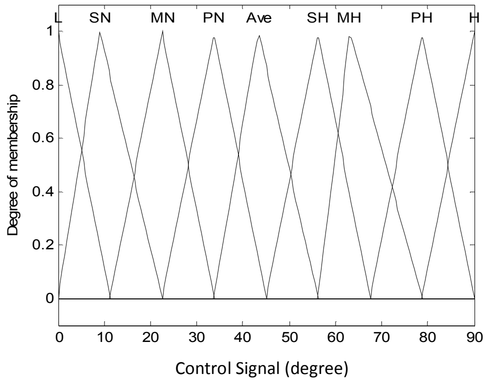

Figure (7) Membership function for control signal output

Experimentally, it is found that to have a speeds of (500, 1000, 1500 rpm) for the dc motor used in this work, the firing angles should be approximately ($45^\circ, 30^\circ, 10^\circ$) at load ($T_L$=10 N.m)respectively. Thus the rule base for computing the control signal (firing angle), can be classified into multi regions (three regions in this work) according to the required reference speeds (500, 1000, 15000 rpm …..etc). The regions in this work are separated as follows:

1. First region with low reference speed (500 rpm).
   If *E* is *MP* and CE is MP and w_r = L (Low speed) is 500 rpm then output is MH.
   If *E* is *MP* and CE is SP and w_r = L (Low speed) is 500 rpm then output is SH.
   If *E* is *Z* and CE is Z and w_r = L (Low speed) is 500 rpm then output is Ave.
   And so on for other rules.
2. Second region with medium reference speed (1000 rpm).
   If *E* is *NP* and CE is NP and w_r = M (Medium speed) is 1000 rpm then output is SH.
   If *E* is *SP* and CE is SP and w_r = M (Medium speed) is 1000 rpm then output is Ave.
   If *E* is *Z* and CE is Z and w_r = M (Medium speed) is 1000 rpm then output is PN.
   And so on for other rules.
3. Third region with high reference speed (1500 rpm).
   If *E* is *P* and CE is P and w_r = H (High speed) is 1500 rpm then output is PN.
   If *E* is *NP* and CE is NP and w_r = H (High speed) is 1500 rpm then output is MN.
   If *E* is *Z* and CE is Z and w_r = L (High speed) is 1500 rpm then output is SN.
   And so on for other rules.

Where Z: no-change, M: medium, P: positive, N: negative, L: low, H: high, S: small and Ave.: average.

Simulation of Fuzzy Speed Controller:

The purpose of this work is to design a PI fuzzy controller that sets the speed of a DC motor for different operation values. The speed of the motor can be controlled by changing the firing angles of the six thyristors to control the armature voltage of the DC motor. The fuzzy controller will compensate any change in speed set point value. However, when the reference speed is (500 rpm), the speed, armature current and the developed torque are shown in Figures (8,9,10) respectively.

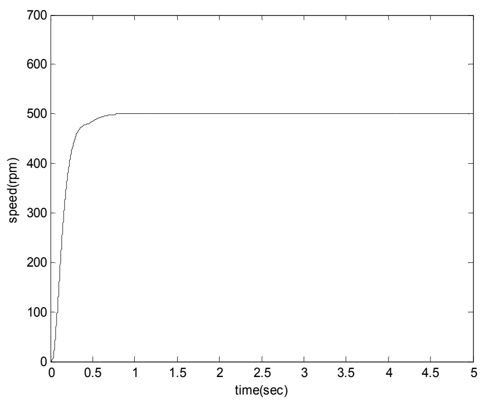

Figure (8) Speed of dc motor for 500 r.p.m. set point

When the reference speed is (1000 rpm) the simulation results for speed ,the armature current and the developed torque are shown in Figures (11,12,13)respectively. When the reference speed is (1500 rpm) the simulation results for speed ,the armature current and the developed torque are shown in Figures (14,15,16)respectively. Then the robustness of the proposed controller is examine by change the motor speed for three steps of speed (from 500 rpm to 1000 rpm and to 1500 rpm), the output response of the motor speed is shown in Figure(17).

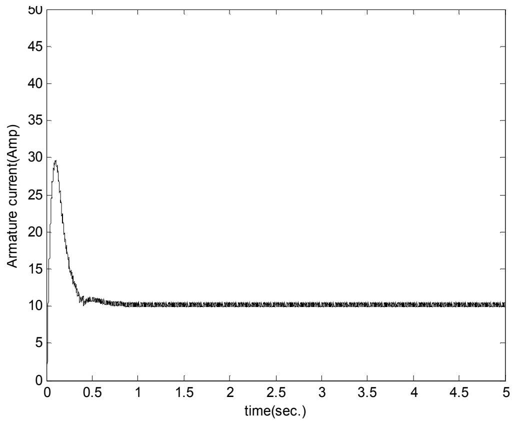

Figure (9) Armature current of dc motor for 500 r.p.m. set point

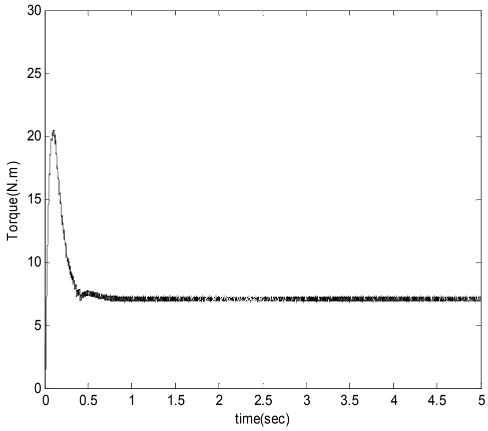

Figure (10) Electrical torque produced by dc motor for 500 r.p.m. set point

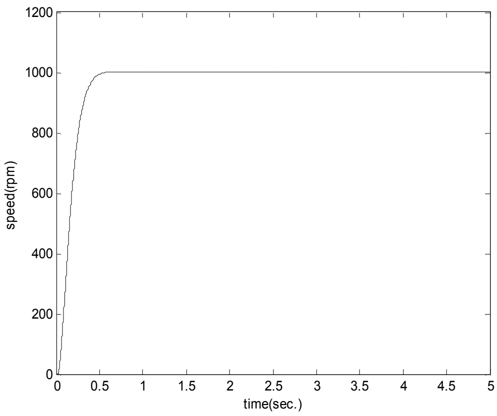

Figure (11) Speed of dc motor for 1000 r.p.m. set point

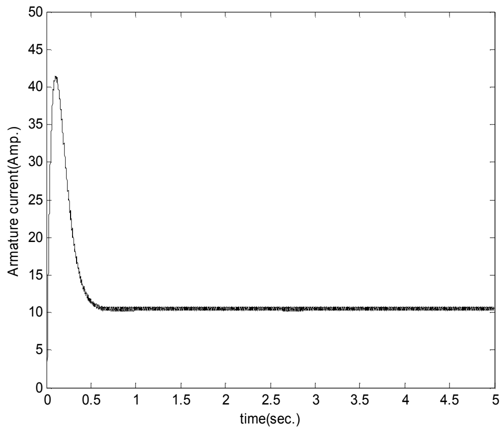

Figure (12) Armature current of dc motor for 1000 r.p.m. set point

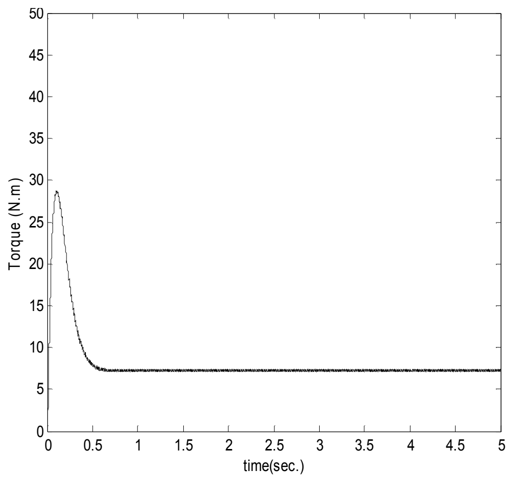

Figure (13) Electrical torque produced by dc motor for 1000 r.p.m. set point

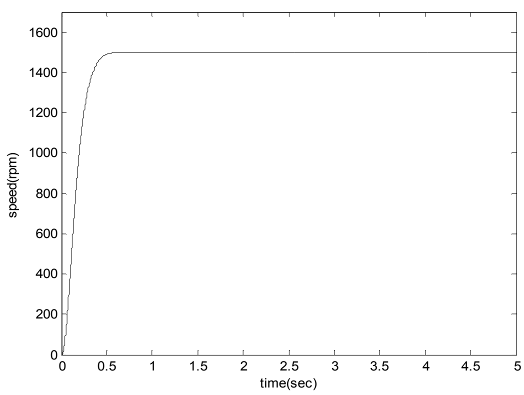

Figure (14) Speed of dc motor for 1500 r.p.m. set point

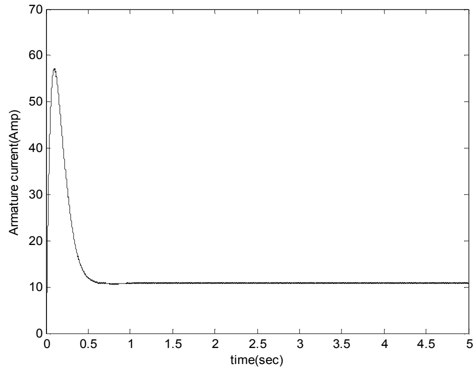

Figure (15) Armature current of dc motor for 1500 r.p.m. set point

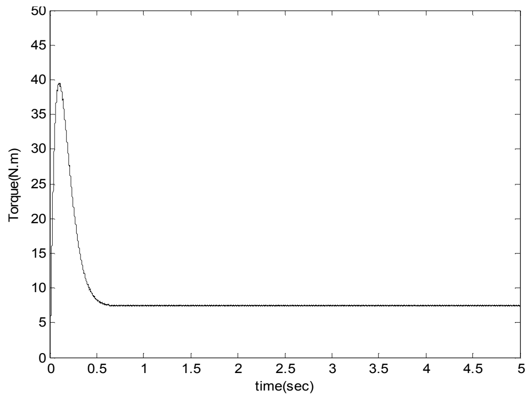

Figure (16) Electrical torque produced by dc motor for 1500 r.p.m. set point

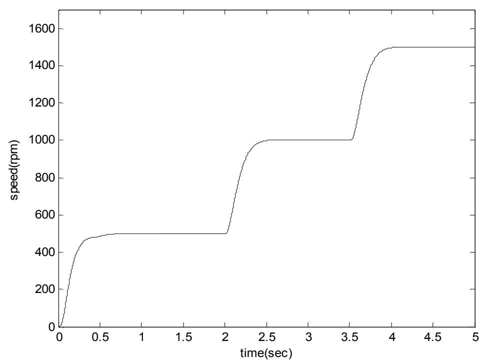

Figure (17) Variable speeds of DC motor set point

Conclusion:

In this paper, speed control of DC-drive based on Fuzzy Logic and PI-controller with a 3-phase Bridge controlled rectifier is presented. The speed of DC motor is controlled by varying the firing angle (α) of the controlled rectifier in order to generate a variable DC output voltage to achieve speed required. Simulation results with Matlab/Simulink program show that speed control method will provide a wide range for DC drive speed between (500 -1500) rpm, and regulated quickly against the variation in load. The combination of Fuzzy Logic PI-controller improves the speed response of the dc motor. This method improved the characteristics of dc motor such as smooth starting, acceleration, precision, performance, and small change of reference speed that will be with over shoot and robustness in speed drive controller if compare with conventional speed drive controller as to reliability. Also the system set provides excellent output voltage regulated.

References:

1- M. Bodson and J. Chiasson, "*Differential geometric methods for control of electric motors*", Int. J. Robust Nonlinear Control, vol. 8, 1998, pp. 923-954

2- H.X. Li, H.B. Gatland, " *A new methodology for designing a fuzzy logic controller*", IEEE Trans. Systems Man Cybernet. 25 (3) (1995),pp. 505–512.

3- Y.C. Chang, B.S. Chen, "*A nonlinear adaptive H∞ tracking control design in robotics systems via neural networks*" IEEE Trans. Control Systems Technol. 5 (1) (1997),pp. 13–29.

4- M. Sugeno, *"Industrial Applications of Fuzzy Control",* (Elsevier, Amsterdam, 1985.

5- A. Isidori*," Nonlinear Control Systems*", Springer, Berlin, 1989.

6- B.J. Choi, S.W. Kwak, B.K. Kim, " *Design of a single-input fuzzy logic controller and its properties, Fuzzy Sets and Systems*", 106 (3) (1999) pp. 299–308.

7- Z. Liu and F. Luo, "*Nonlinear MJMO speed sensorless controller for dc motor field weakening"*, Electric Machines and Power Systems, 28, pp. 69-77, 2000

8- Katsuhiko Ogata, "*Modern Control Engineering",* By Prentic-Hall, Inc. 2002. ISBN 0-13-227307-1.

9- Basil M. Saied and Rakan Kh. Antar," Line injection technique for harmonic reduction in a three-phase bridge controlled converter ", 6th JIEEEC 2005,Jordan.

10- Leonid Reznik,*"Fuzzy Controller"*, Victoria University of Technology, Melbourne, Australia. HB NEWNES , 1997. ISBN 0 7506 3429 4, Printed in Great Britain by Biddles Ltd, Guildford and King's Lynn.

11- M. Bogumila, M. Zbigniew, "*Modeling and fuzzy control of dc drive*", 14-th European Simulation Multiconference ESM, p.p 186-190 ,May 23-26,2000