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Speed Control for Separately Excited DC Motor Drive (SEDM) Based on Adaptive Neuro-Fuzzy Logic Controller

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ABSTRACT

This paper presents an application of Fuzzy Logic Control (FLC) in the separately excited Direct Current (DC) motor drive (SEDM) system; the controller designed according to Fuzzy Logic rules. Such that the system is fundamentally robust. These rules have capability learning, can learn and tune rapidly, even if the motor parameters are varied. The most commonly used method for the speed control of dc motor is Proportional- Integral- Derivative (PID) controller. Simulation results demonstrate that, the control algorithms Neuro-Fuzzy logic and PID, the dynamic characteristics of the SEDM (speed, torque, as well as currents) are easily observed and analyzed by the developed model. In comparison between the Neuro-fuzzy logic controller and PID controller, the FLC controller obtains better dynamic behavior and superior performance of the DC motor as well as perfect speed tracking with no overshoot, and the proposed controller provides high performance dynamic characteristics and is robust with regard to change of motor speed and external load disturbance. This paper also discusses and compares the speed control systems of SEDM using PID- controller conventional and Fuzzy Logic-controller. The entire system has been modeled using ***MATLAB 10a/SIMULINK*** toolbox.

Keywords: Separately excited (D.C.) motor (SEDM), Fuzzy Logic Controller (FLC), Adaptive Neuro-Fuzzy Logic Controller, Proportional-Integral-derivative (PID) Controller.

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السيطرة على سرعةِ محرك تيار مستمر ذو أثارة مُنفصلة (إس إي دي إم) مستند على جهازِ السيطرة الضبابيِ العصبيِ التكيفيِ

الخلاصة:

يقدّمُ هذا البحث تطبيقَ سيطرةِ المنطقِ الضبابيةِ (FLC) في منظومة محرك تيار مستمر ذو اثارة منفصلة (SEDM). صمم جهاز السيطرة طبقاً لقواعدِ المنطقِ الضبابيةِ حتى تكون الأنظمةُ متينة. هذه القواعدِ لَها قابليةُ التعلم، يُمْكِنُ أَنْ تتعلّمَ وتتغّمَ بسرعة، حتى عند إختلاف معاملات المحرّكِ. إنّ جهازَ السيطرة المستعملَ عموماً والأكثر أنتشارا للسيطرةِ على سرعة محركات التيار المستمر هو جهاز السيطرة التناسبي التكامليُ التفاضلي (PID)، تبيّنُ نَتائِجُ المحاكاةِ بأَنَّ، خوارزميات سيطرةَ المنطقِ الضبابيِ العصبيِ وبي آي دي، الخصائص الدينامية (سرعة، عزم ، بالإضافة إلى التياراتِ) لـ (SEDM) تُلاحظُ بسهولة وحلّلتْ بالنموذجِ المتطورِ. بالمقارنة بين جهازِ سيطرة المنطقِ الضبابيِ العصبيِ وجهازِ سيطرة (PID)، حصول جهازُ سيطرة (NFLC) على السلوكِ الديناميِ الأفضلِ والأداءِ المتفوّقِ لمحرك التيار المستمر, بالإضافة إلى تعقّبُ السرعةِ المثاليةِ بدون تجاوز الاطلاق ، ويُزوّدُ جهازَ السيطرة المُقتَرَحَ خصائصَ ديناميةَ عاليةَ الأداءَ ومتينُ فيما يتعلق بتغييرِ السرعةِ المحرّكةِ وإضطرابِ الحملِ الخارجيِ. تُناقشُ في هذا البحث أيضاً وتُقارنُ أنظمةَ سيطرةِ سرعةَ المحرك باستعمال جهاز سيطرة (PID) التقليدي وجهاز سيطرة المنطق الضبابي العصبي (NFLC). نموذج النظام شُكل بأستعمال صندوق عدة الماتلاب/ سيملنـــــك(***MATLAB10a/SIMULINK***).

INTRODUCTION

The fuzzy logic controllers (FLCs) of a given process is capable of embedding, in the control strategy, the qualitative knowledge and experience of an operator or field engineer about the process [1]. Therefore, FL plays the role of a suitable 'user interface', in the task of translating designer's insight about the system into the control law, resulting in an inherently nonlinear adaptive controller, capable of outperforming other control techniques, such as model reference adaptive control and sliding mode controllers [2].

Research on fuzzy logic applications in control shows a couple of general trends. The first and the oldest one is of heuristic nature. It is based on qualitative knowledge and experience of an expert with regard to the system behavior, that is used in order to achieve a given control objective. 'Trial and error' approaches usually applied in this case in the analysis of the most appropriate domains for input/output fuzzy variables and in construction of the knowledge base [3]. The second, deterministic approach is based on a more or less systematic methodology for identification of the structure and/or parameters of a fuzzy controller [4].

The DC motor drive is a highly controllable electrical motor drive suitable for robotic Manipulators, guided vehicles, steel mills and electrical traction, position control, steel mining, paper and textile industries [5]. In some industrial application the high dynamic response of drivers is bounded by certain limitations such as transient time and steady state error. To achieve these limitations, different control strategies have been implemented to regulate the dc motor drive including PID control, adaptive control, fuzzy logic control, neural network and nonlinear digital control [6].

Direct current motor drives have been widely used where accurate speed control is required. The Proportional-Integral- derivative (P-I-D) controller is one of the conventional controllers and it has been widely used for the speed control of dc motor drives. The major features of the PID controller are its ability to maintain a zero steady-state error to a step change in reference. At the same time PID controller has some disadvantages namely; the undesirable speed overshoot, the slow response due to sudden change in load torque and the sensitivity to controller gains K_I, K_p and K_d. In recent years, new artificial intelligence-based approaches have been proposed for the speed control of dc motors [7].

Recently, fuzzy logic employing the logic of approximate reasoning continues to grow in importance, as it provides an inexpensive solution for controlling complex systems. The speed of DC motor can be adjusted to a great extent as to provide controllability easy and high performance [8]. The controllers of the speed that are conceived for goal to control the speed of DC motor to execute one variety of tasks [9].

In this paper the proposed a FLCs has some features for the speed control in SEDM drive, which the speed signal only is required in the control fuzzy logic, and the transient response is improved. Finally, the simulation results are demonstrated.

Modelling And Simulation Of Separatley Excited D.C. Motor (Sedm)

The system contains a separately excited D.C. motor (SEDM), a model based on the motor specifications needs to be obtained. As shown in **figure. (1).**

In a separately excited dc motor, the field coil is supplied from a different voltage source than that of the armature coil**.** The field circuit normally incorporates a rheostat through which the field current, and thus the motor's characteristics, can be externally controlled. This motor is mainly suitable for two types of loads; those that require constant torque for speed variations up to full-load speed, and those whose power requirements are constant for speed variations above nominal speed [10]. The field current is constant, and then the flux must be constant. The electrical armature and field circuit can model the motor. In this simple model *Ra* and *La* indicate the equivalent armature coil resistance and inductance respectively and R_f and L_f indicate the equivalent field resistance and inductance respectively, *v*a is the voltage supplied by the power source. The basic motor equations are:

$$T_d = K_f \, i_f \, i_a = K_m \, i_a \qquad \ldots\ldots. \; (1)$$

$$e_g = K_f \, i_f \, \omega_m = K_m \, \omega_m \qquad \ldots\ldots(2)$$

$$V_a = e_g + R_a \, i_a + L_a \frac{d\, ia}{dt} \qquad \ldots\ldots. \; (3)$$

$$T_d = K_m \, i_a = J \frac{d\, \omega m}{dt} + B\, \omega_m + T_L$$

$$\therefore \quad T_d - T_L = J \frac{d\, \omega m}{dt} + B\, \omega_m \qquad \ldots \; (4)$$

Where ***Km* = K_f i_f**, is a constant, e_g is the back electromotor force, T_d is the torque of the motor, T_L is the torque of the mechanical load; ***J*** is the inertia of the rotor and ***B*** is the damping coefficient associated with the mechanical rotational system of the motor.

The block diagram shown in **Figure. (2)** is obtained from these equations of the separately excited D.C. motor. The transfer function block diagram of the separately excited D.C. motor is developed in "Matlab". The Separately Excited D.C. Motor

(SEDM) parameters are: 1800 rpm, 220 Volt, L_a= 3.2 mH, R_a= 2 Ω, rotor inertia (J) = 0.11 kg/m^2, B=0.0001N.M. TL=21.4 N.M., the speed at full-load =1500 rpm.

The speed response without controller is shown in **Figure. (3).**

PID CONTROLLER:-

PID" is an acronym for "proportional, integral, and derivative." A PID controller is a controller that includes elements with those three functions. In the literature on PID controllers, acronyms are also used at the element level: the proportional element is referred to as the "P element," the integral element as the "I element," and the derivative element as the "D element." the three elements of the PID controller produce outputs with the following nature:

* P element: proportional to the error at the instant *t*. This is the "present" error.

* I element: proportional to the integral of the error up to the instant *t*, which can be interpreted as the accumulation of the "past" error.

* D element: proportional to the derivative of the error at the instant *t*, which can be interpreted as the prediction of the "future" error.

The general continuous-time PID controller has the expression [11, 12, and 13]:

$$U(t)=K_p e(t)+K_i\int_0^t e(t)dt+K_d\frac{de(t)}{dt} \qquad ...(5)$$

Where variable e(t)= r (t)-y(t) is the tracking error signal between the reference r(t) and the controlled system output y(t), this error signal will be sent to the PID controller and the controller computes both the derivative and the integral of this error signal. The signal U(t) from the controller is now equal to the proportional gain (Kp) times the magnaitude of the error plus, and (K_i)times the integral of the error plus, (K_d) times the derivative of the error [14, 15]. This is firstly converted into the frequency domain to get:

$$U =(K_p +\frac{Ki}{s} + s\ K_d)\ E(s) \qquad \ldots\ldots (6)$$

The PID controller helps get our output (velocity, temperature, position) in a short time, with minimal overshoot, while little error, and framework solves many problems and sufficiently flexible to incorporate additional capabilities [12,13].

In this paper, a result when using trial and error method of the PID controller parameters, to achieve a suitable output speed performance of the separately excited dc motor system are:

K_p =4, K_i =30, K_d =0.2. That the transient response gives input;

* Rise time	= 0.2 Sec.
* Maximum overshoot	= 25 rad/sec.
* Settling time	= 0.7 Sec.
* Steady state error	= 0%.

The simulation of the transfer function block diagram of a separately excited D.C. Motor with PID control is shown in **Figure. (4).** The output speed performance of conventional PID Tuning of separately excited dc motor under no-load and full load conditions is shown in **Figure. (5).**

ADAPTIVE NEURO-FUZZY SPEED CONTROLLER:-

The planned Neuro-Fuzzy controller incorporates fuzzy logic algorithm with a five layer artificial neural network (ANN) structure as shown in ***fig. (5).*** A tuning block is utilized to regulate fourth layer's parameters in order to right any deviation of control effort [15, 16].

The normalized speed error and the rate of change of actual speed error are the inputs of the Neuro-Fuzzy Controller. In layer 1, every node *i* is an adaptive node with a node function;

$$O_{1,i} = \mu_{Ai}(m) \text{ For } I = 1, 2 \quad \text{or}$$
$$O_{1,i} = \mu_{Bi-2}(n) \text{ For } i = 3, 4 \quad \ldots\ldots (7)$$

(Here we denote the output of the *ith* node in layer as l as $O_{l,i}$)

Where m (or n) is the input to node *i* and *Ai (or Bi-2)* is a linguistic label such as 'small' or 'large' associated with this node. The membership *function* for *A* can be any suitable parameterized membership function. In proposed scheme generalized bell function is used as a membership function given by equation (8).

$$\mu_A(m) = \frac{1}{1+\left|\frac{m-c_i}{a_i}\right|^{2b_i}} \qquad \ldots\ldots(8)$$

Where a_i, b_i and c_i are the parameter set. As the values of these parameters changes, various forms of bell shaped membership functions can be getting for fuzzy set *A*. Parameters in this layer are referred to as premise parameters. In layer 2, every node is a fixed node labeled, whose output is the product of all the incoming signals.

$$O_{2,i} = w_i = \mu_{Ai}(m)\mu_{Bi}(n), i=1, 2\ldots \quad (9)$$

Each node output represents the firing strength of a rule.

In layer 3, every node is a fixed node labeled *N*. The outputs of this layer are *normalized* firing strengths given by equation (10).

$$O_{3,i} = \overline{w_i} = \frac{w_i}{w_1+w_2}, \qquad i=1, 2 \quad \ldots.(10)$$

In layer 4, every node i, is an adaptive node with a node function given by equation (11).

$$O_{4,i} = \overline{w_i}f_i = \overline{w_i}(P_i m + q_i n + r_i) \qquad \ldots(11)$$

Where is $\overline{w_i}$ a normalized firing strength from layer 3 and P_i, q_i *and* r_i are the parameter set of this node. Parameters in this layer are referred to as consequent parameters. Layer 5 is the single node layer with a fixed node labeled, which computes the overall output as the summation of all incoming signals.

$$O_{5,i} = \sum_i \overline{w_i} f_i = \frac{\sum i\, w_i f_i}{\sum i\, w_i} \qquad \ldots\ldots(12)$$

Hybrid learning algorithm is used in proposed controller. In the forward pass of the hybrid learning algorithm, node output goes forward until layer four and the consequent parameters are identified by the least squares method. In the backward pass, the error signals propagate backward and premise parameters are updated by gradient descent [16]. The consequent parameters thus identified are optimal under the condition that the premise parameters are fixed. Thus, the hybrid approach converges much faster since it reduces the search space dimension of the original pure back propagation.

Figure. (8*)* Presents proposed equivalent ANFIS architecture. **Figure. (9a and 9b)** Shows input membership functions and **Figure. (10)** Two Input (1, 2) rules of proposed ANFIS, **Figure. (11*)*** Shows output surface of proposed *ANFIS* respectively.

Note: The appearance of the top; is represent the characteristic or behavior of fuzzy logic

THE SIMULATION RESULTS AND DISCUSSION:-

A complete simulation model for SEDM drive is developed as shown in **Figure. (12),** a comparison is made with the response of conventional PID speed controller. The parameters of the SEDM considered in this study are summarized, in. **Figure. (13)** Shows waveforms of the speed control for SEDM, by a comparison between a PID Controller and open loop. **Figure. (14)** Shows waveforms a comparison between open loop and Neuro-Fuzzy Logic Controller. **Figure. (15)** Shows waveforms a comparison between Neuro-Fuzzy Logic Controller and PID Controller as well as open loop. Then the **Figure. (16a and b)** shows the simulation of armature current and load torque versus the time for speed control of a separately excited dc motor under no loading and full loading at (21.4 N.M.) conditions. (That load (21.4N.M.) gives the speed 1500 R.P.M. (15**7** Rad. /Sec.)) from the practical calculations.

* The results show that implementing a NFLC is an effective solution to simplify the data processing that required by the PID while maintaining its like approach and control capabilities, the NFLC controller (no overshoot), therefore better than PID controller. These results shown in table (1) and figures (12, 13, and 14).

CONCLUSIONS:-

* The goal of this research is to solve the problem of high current. The procedure of efficient algorithm control (Neuro- fuzzy logic) to track the velocity, the conventional trial and error method for optimal response.

* Adaptive Neuro-fuzzy logic controller drive has some advantages. Reduced number of rules, faster speed of operation and no need for modifications in membership function by conventional
trial and error method for optimal response.

* According to the results, the NFLC is better than the PID controller. The controller presented gives satisfactory performances and possesses good robustness because of (no overshoot, minimal rise time, Steady state error = 0).

* For optimization in the speed control of separately excited D.C. motor, PID controller and the Adaptive Neuro-fuzzy logic controller were chosen and a comparison is made between them, and a good result found by using.

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Table (1) the Results Comparison between PID Controller and Adaptive Neuro- Fuzzy Controller at No -Load and Full – Load.

RESULTS	***PID CONTROLLER***		***NEURO-FUZZY CONTROLLER***	
	NO - LOAD	***FULL - LOAD***	***NO - LOAD***	***FULL - LOAD***
Maximum overshot	***25 rad/sec.***	***8 rad/sec.***	***0 rad/sec.***	***0 rad/sec.***
Rising time (Sec.)	***0.2 Sec.***	***0.3 Sec.***	***0.2 Sec.***	***0 Sec.***
Settling time (Sec.)	***0.7 Sec.***	***0.4 Sec.***	***0.2 Sec.***	***0 Sec.***
Steady state error (%)	***0 %***	***0 %***	***0 %***	***0 %***

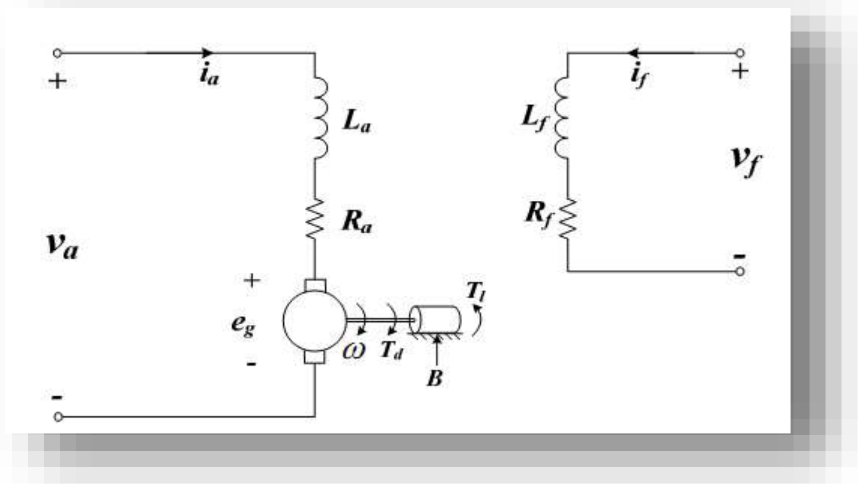

Figure (1) The equivalent circuit of separately excited dc motor.

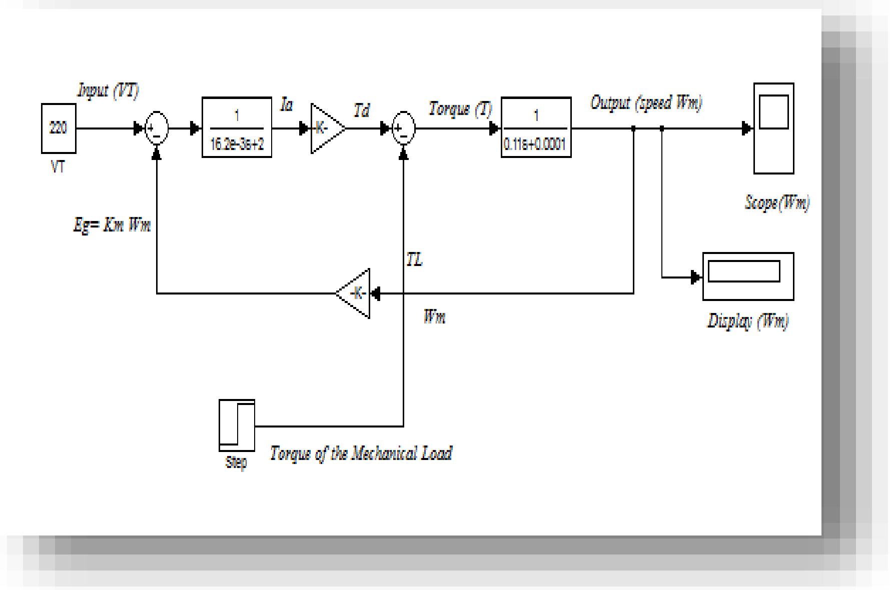

Figure (2) The transfer function block diagram of separately. Excited D.C. Motor without controller.

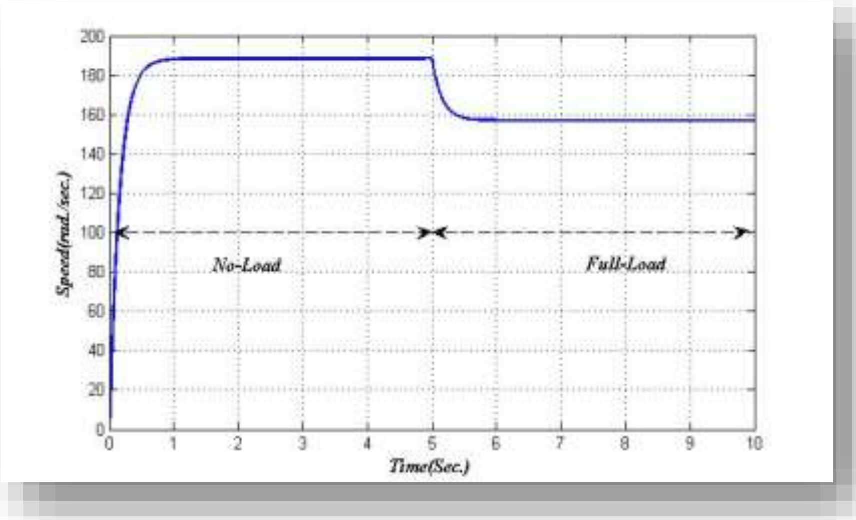

Figure. (3) The speed response (ω) of the Separately Excited D.C. Motor without controller.

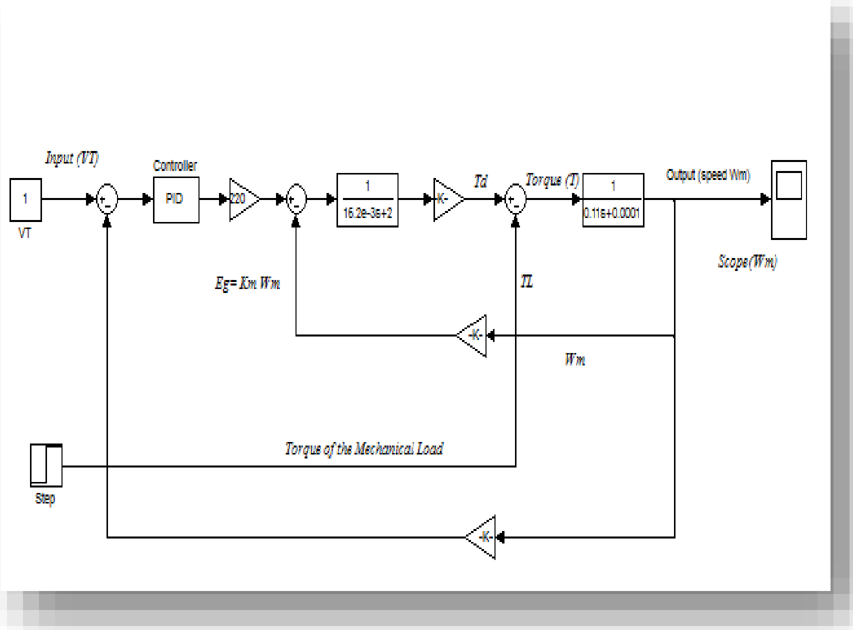

Figure (4) The transfer function block diagram of Separately Excited D.C. Motor with PID Controller.

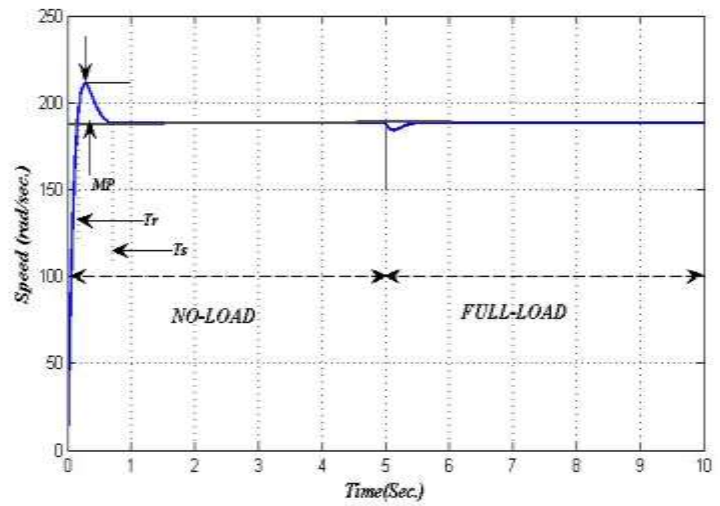

Figure (5) The speed response (ω) of the Separately Excited D.C. Motor with PID Controller.

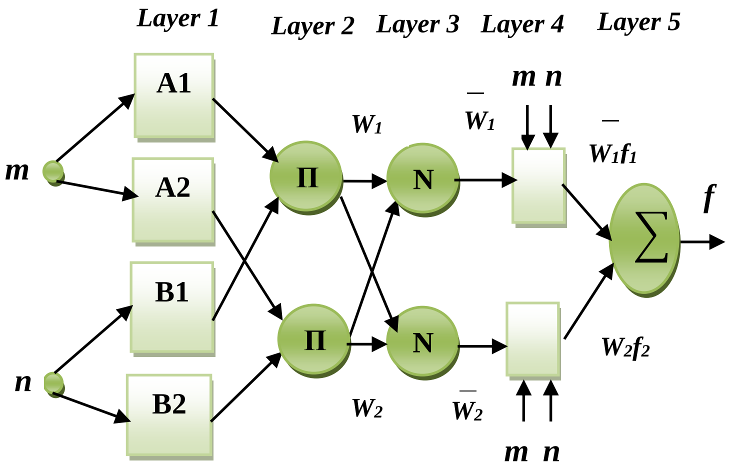

Figure (6) ANFIS design of 2-input sugeno Fuzzy model with 2 rules.

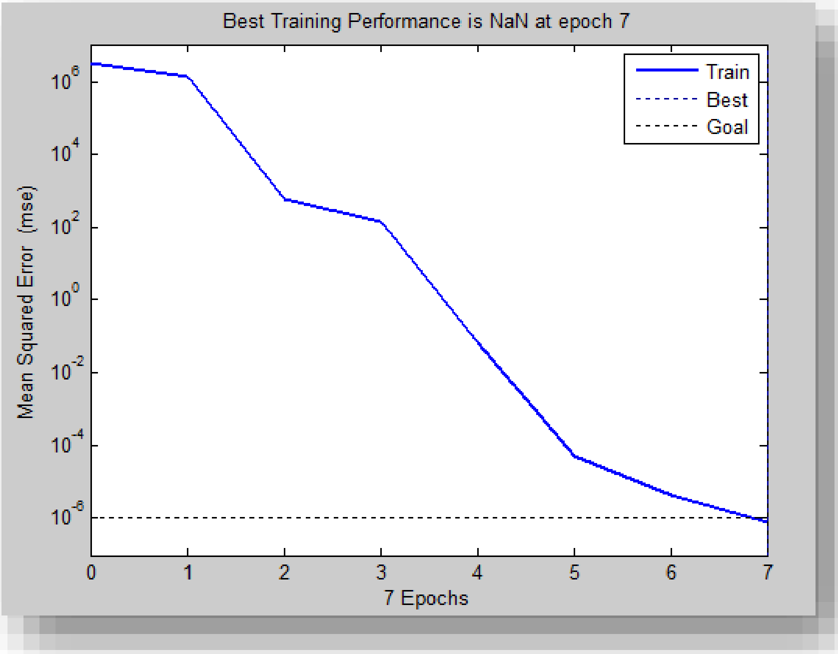

Figure (7) Mean Square Error for the Neural Network.

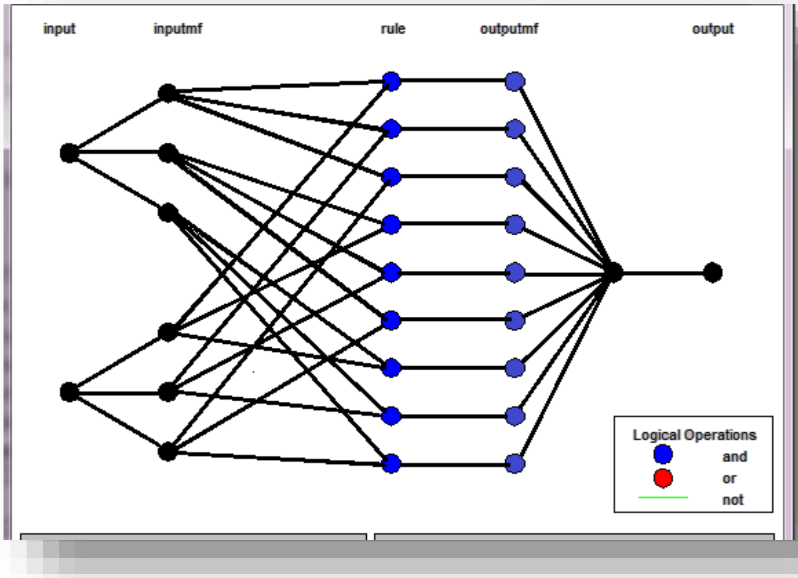

Figure (8) Proposed ANFIS Model Structure.

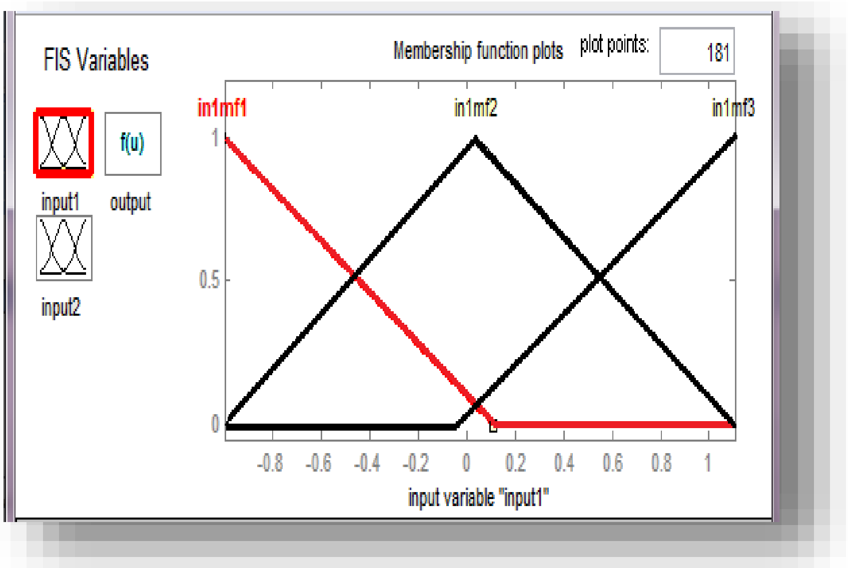

Figure (9a) (Input 1) Membership Function of Proposed ANFIS.

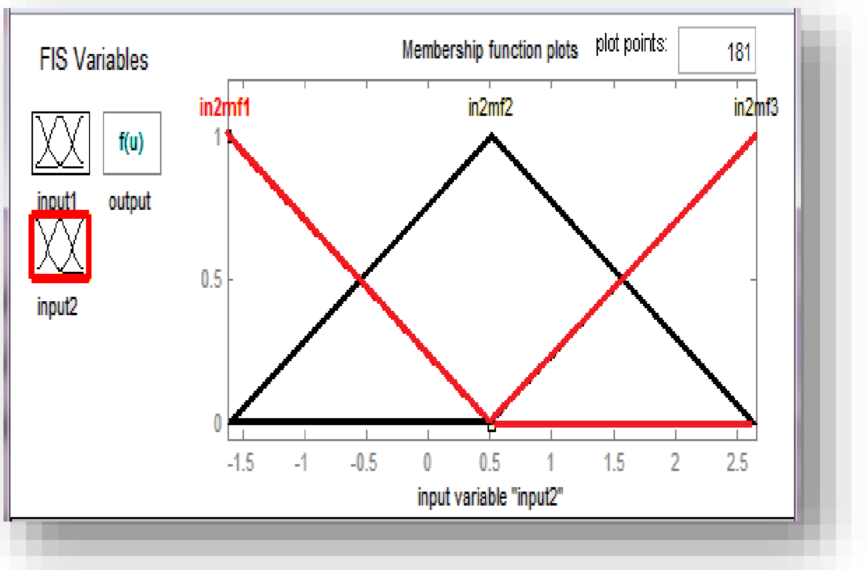

Figure (9b) (Input 2) Membership Function of Proposed ANFIS.

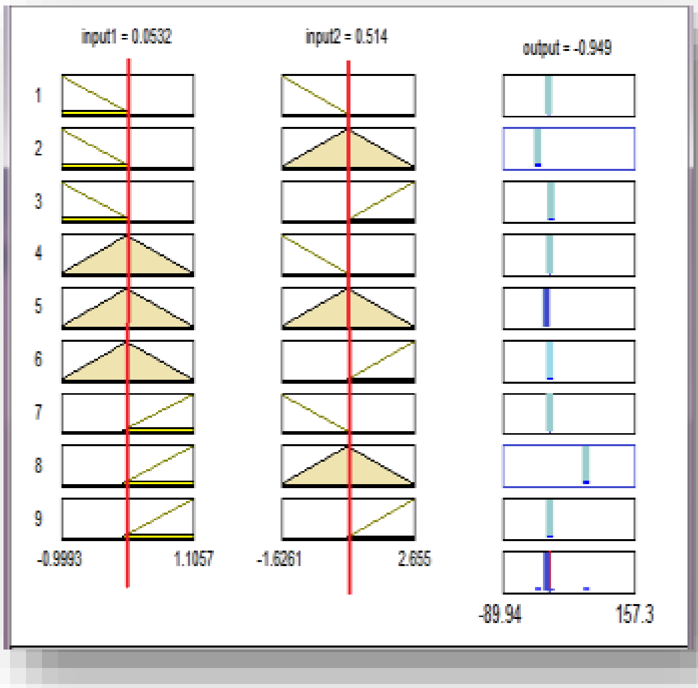

Figure (10) Input (1and 2) Rules of Proposed ANFIS.

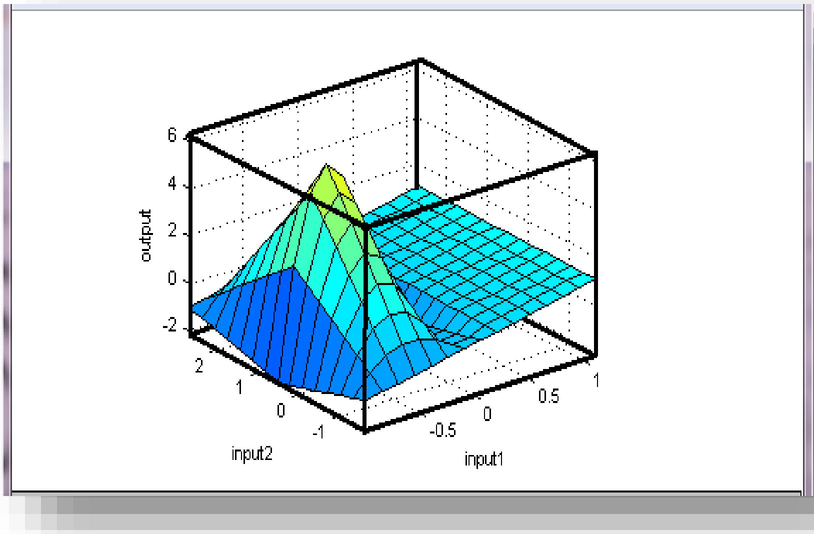

Figure (11) Output Surface of Proposed ANFIS.

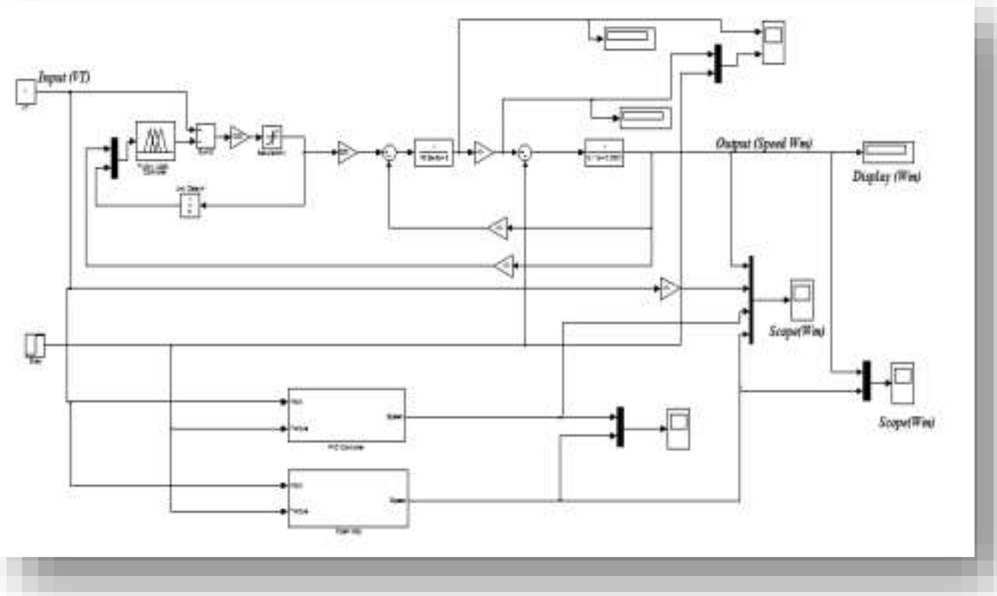

Figure (12) Developed simulation model for SEDM drive.

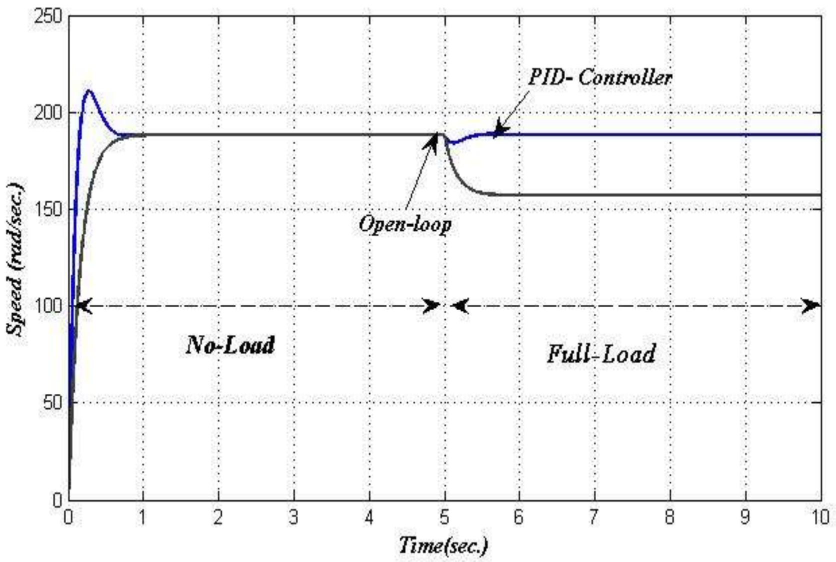

Figure (13) Waveforms of the Speed Control for SEDM with PID Controller and open loop under no-load and full-load conditions.

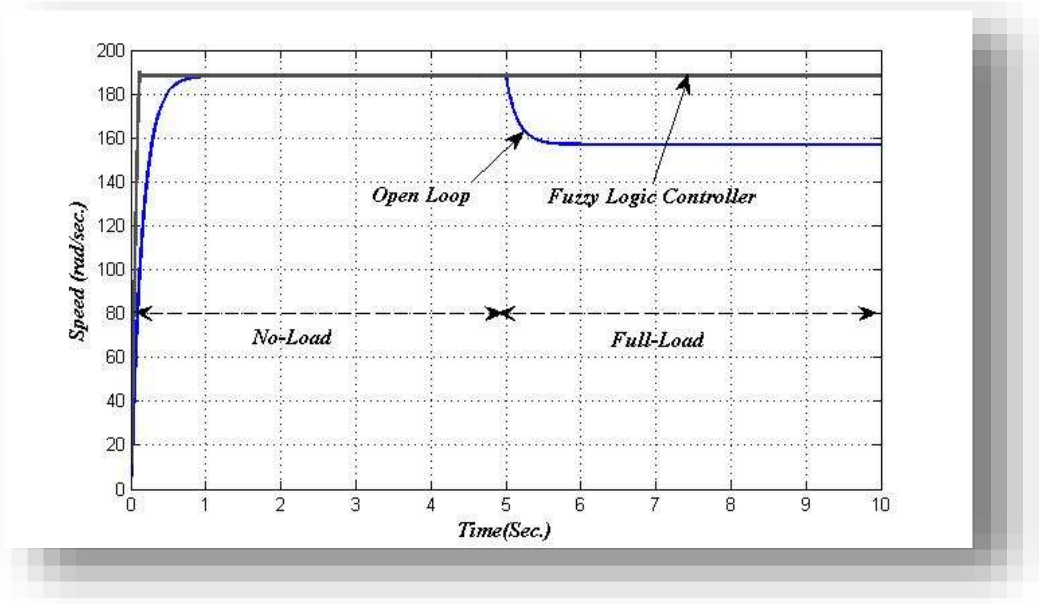

Figure (14) Waveforms of the speed control for SEDM with Neuro-fuzzy logic controller and open loop under no-load and full-load conditions.

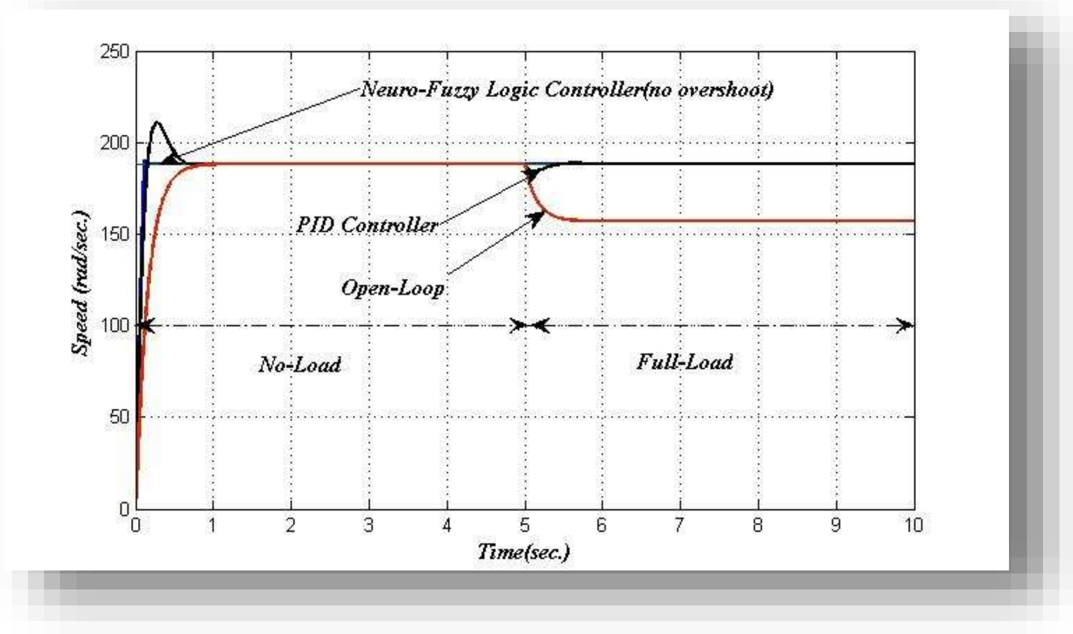

Figure (15) Waveforms of the Speed Control for SEDM with PID Controller Fuzzy Logic Controller and open loop under no-load and full-load conditions.

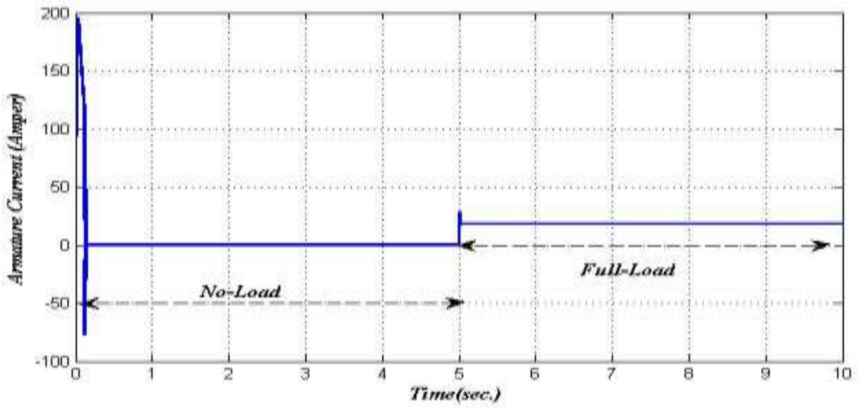

Figure (16a) Simulated armature Current (amp.) Versus Time (Sec.) under no-load and full-load conditions.

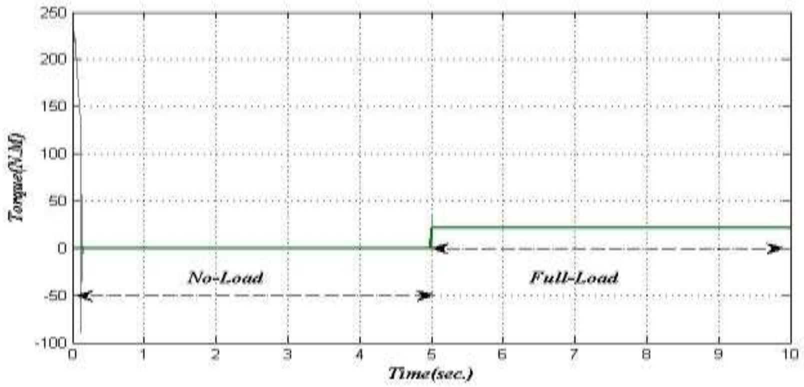

Figure (16B) Simulated Torque (N.M) Versus Time (Sec.) under no-load and full-load conditions.