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Design and Control of SRM Drive System Utilizing Adaptive Neural Fuzzy Inference System

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***Abstract* - This manuscript represents the simulation and modeling of adaptive Neural-fuzzy inference system (ANFIS) to controlling "switched reluctance motor (SRM)" speed. The SRM control is accordingly hard to be being used in nonlinear applications, especially in speed control in vehicles. The ANFIS includes the benefits of fuzzy and neural network system. This controller is incredible extra useful than neural network and fuzzy-based controller, whereas it has capacity of self-learning the gain esteems and adjusts as per circumstances, accordingly accumulating much adaptability to controller. A hybrid learning (HL) method, that consolidates the linear least-squares estimation method and back propagation (BP) technique, distinguishes the factors of ANFIS. After training, ANFIS torque method and ANFIS flux linkage method are in best agreement with exploratory flux linkage estimations and determined torque information. At last, we utilize an ANFIS torque and ANFIS current method to survey on SRM dynamic execution. The accuracy of method was assessed by correlation with lab estimations of machine's torque and current-speed attributes. The method is very exact. A total simulation, very much intended to nonlinear method of SR Drive was planned utilizing MATLAB/ SIMULINK.**

Keywords - Adaptive neural fuzzy system (ANFIS), Artificial neural networks (ANNs), Drive, Switched reluctance machines (SRMs), FLC, Fuzzy logic (FL), Neural network (NN), Switched Reluctance (SR).

INTRODUCTION

The SRMs are utilized much commonly in latest years in field of electric power, electric transmission, variable speed, and motor starting due to easy structure, high productivity, minimal expense, and fault tolerance. Nevertheless, the doubly salient structure of SRMs outcomes in high nonlinearities in their torque and magnetic qualities, subsequently making it much critical to infer a complete numerical method for conduct of machines. A few strategies are suggested and utilized to depict nonlinear magnetic attributes of SRM that might be usually separated into 5 groups: 1) insertion techniques [1] in provided nonlinear magnetic information have been stored in lookup table; 2) the analytical strategies [2]–[4] in appropriate analytical expressions have been determined to describe torque and flux linkage in regard to rotor and current position; 3) the magnetic equivalent circuit models [5], [6] that have been generally utilized to calculate the magnetic qualities of SRM; 4) the "finite element models (FEM)" [7], [8] give exact outcomes yet need huge computational exertion and mathematical systems; 5) ANN techniques [9], [10] are executed rotor position assessment, where analog circuit is utilized to estimate flux linkage. The above techniques have either quick calculation or great precision, yet not both. In latest times, several journals have described utilizing ANFIS strategies for magnetic attributes computation [11] and rotor position assessment of SRM [12], [13]. The ANFIS might execute and simulate the planning connection among i/p and o/p data through a learning method to upgrade factors of provided "fuzzy inference system (FIS)". It joins advantages of FIS and ANNs in single method. So it has capability to accommodate information and current expert information about good and issue ability features. In [11], ANFIS utilized to estimate SRM phase inductance, and ANFIS test outcomes were in excellent concurrence with FEM outcomes. In [12], [13], ANFIS and ANNs were utilized to assess position of rotor with "digital flux linkage" computation that confirmed the capacity of sensorless SRM drives. Nevertheless, nothing from what was just mentioned papers have utilized ANFIS to calculate the torque and flux linkage features for demonstrating of SRM. Hence, this manuscript utilizes a new model dependent on ANFIS to demonstrate torque and flux linkage for 6/4 SRM. The manuscript is structured as follows. Segment II explains indirect strategy to estimate the co-energy model and flux linkage data to estimate torque data. Segment III explains torque and flux linkage method of SRM utilizing ANFIS.

CONTROLLER DESIGN OF PROPOSED MODEL

The essential structure of suggested "ANFIS organization controller" intended to controlling SRM speed. The block image representation of suggested controller is displayed in Figure. 1.

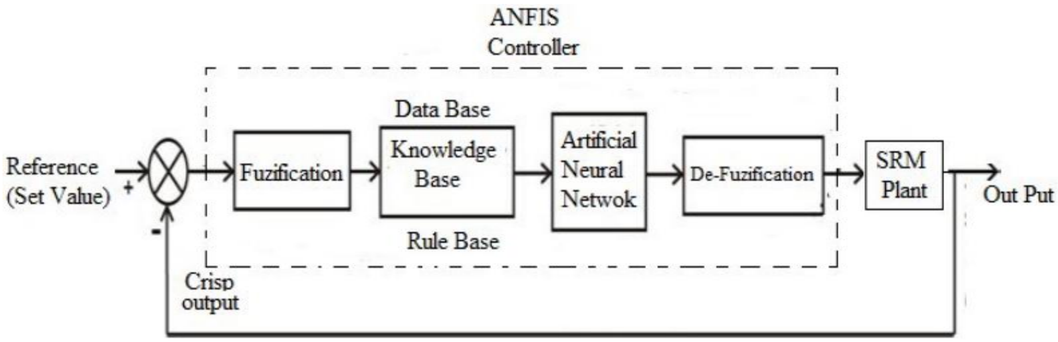

FIG. 1
ANFIS CONTROLLER BLOCK DIAGRAM FOR SRM PLANT

The change in error and error are considered as Inputs to ANFIS controller. Eq (1) and (2) as follows:

$$e(k) = \omega_{ref} - \omega_r \tag{1}$$

$$\Delta e(k) = e(k) - e(k-1) \tag{2}$$

Where,

$e(k)$ Is the error

$\Delta e(k)$ Is the change in error

ω_{ref} Is the reference speed

ω_r Is the actual rotor speed

The fuzzification factors have been feed as i/p to rule based block, which has been connected to NN block. The BP method is utilized for NN training in turn to select proper set of rule base. When reasonable principles are picked and terminated, the control signal needed to achieve optimal outputs has been generated. This hybrid strategy provides a comparatively best approximation of speed and is vigorous to factor varieties and much important outcomes.

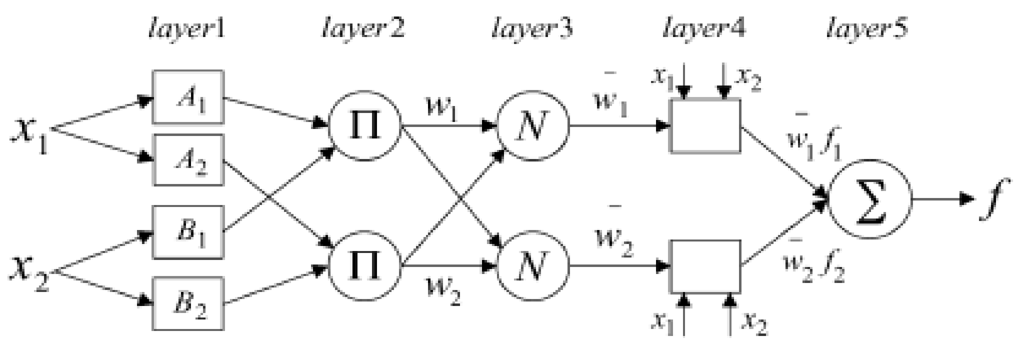

FIGURE 2
ARCHITECTURE OF ANFIS

SRM MODELING BASED ON ANFIS

From above depiction, torque T and flux linkage have been described by rotor 0 and current I position are highly nonlinear capacities. The joined NN, fuzzy frameworks are emerging regions of survey in realm of soft computing. The fuzzy NN has 2 benefits of simple to-communicate human information and self-learning capacity. Utilizing the NN and FL is much powerful method in building an intricate and nonlinear connection among a set of i/p and o/p data. In this manuscript, calculated torque and deliberate flux linkage information from co-energy technique were trained by ANFIS.

Architecture of ANFIS: In [15], ANFIS has shown to be a superb capacity estimation device. Fig. 2 displays a common ANFIS structure with 2 inputs (x1 and x2) and one o/p (f). The ANFIS executes a "first-order Sugeno-style fuzzy framework".

$$O_{1,i} = \mu_{Ai}(x_1), \quad i = 1,2$$
$$O_{1,i} = \mu_{B(i-2)}(x_2), \quad i = 3,4 \tag{3}$$

Here Ai and Bi are fuzzy sets in antecedent; pi, qi, and ri are design factors have been determined during training procedure. The ANFIS network has been formed with 5 layers is shown in Figure 2. Layer 1: Each node of layer 1 is square node signified with function of node.

$$\mu_{Ai}(x) = \frac{1}{1 + \left[\left(\frac{x-c_i}{a_i}\right)^2\right]^{b_i}} \tag{4}$$

$$\mu_{Ai}(x) = \exp\left\{-\left(\frac{x-c_i}{a_i}\right)^2\right\} \tag{5}$$

Where {ai, bi, ci} is set of parameter, which varies MF shape that have been mentioned to as premise factors. In this manuscript, (5) is selected as input MF. Layer 2: Each node of layer 2 is circle node labeled that multiplies incoming signals and sends the product out. For example

$$O_{2,i} = w = \mu_{Ai}(x_1) \times \mu_{Bi}(x_2), \quad i = 1,2. \tag{6}$$

Every node output signifies firing strength of rule. Layer 3: Each node of layer 3 is a circle node labeled as N:

$$O_{3,i} = \overline{w}_i f_i = \frac{w_i}{w_1 + w_2}, \quad i = 1,2. \tag{7}$$

For accessibility, outputs of this layer is named "normalized firing strengths". Layer 4: Each node of layer 4 is adaptive node, and output is

$$O_{4,i} = \bar{w}_i f_i = \bar{w}_i(p_i x_1 + q_i x_2 + r_i), \quad i = 1,2 \tag{8}$$

Where {pi, qi, ri} is set of parameter that have been named as consequent factors. Layer 5: Each node of layer 5 is labeled fixed node calculates complete o/p as summation of whole input signals

$$O_{5,i} = \sum_i \bar{w}_i f_i = \frac{\sum_i w_i f_i}{\sum_i w_i}. \tag{9}$$

HYBRID LEARNING METHOD

It might be observed from above depiction, which ANFIS has 2 significant sets of flexible factors; specifically premise factors in layer 1 and subsequent factors in layer 4. Thus, it has been seen, which provide premise factor values, the general output might be expressed as linear grouping of subsequent factors. More exactly, output in Fig. 2 might be revised as

$$\begin{aligned} f &= \overline{w}_1 f_1 + \overline{w}_2 f_2 = \sum_{i=1}^{2} \overline{w}_i (p_i x_1 + q_i x_2 + r_i) \\ &= (\overline{w}_1 x_1) p_1 + (\overline{w}_1 x_2) q_1 + (\overline{w}_1) r_1 + (\overline{w}_2 x_2) p_2 \\ &\quad + (\overline{w}_2 x_2) q_2 + (\overline{w}_2) r_2. \end{aligned} \tag{10}$$

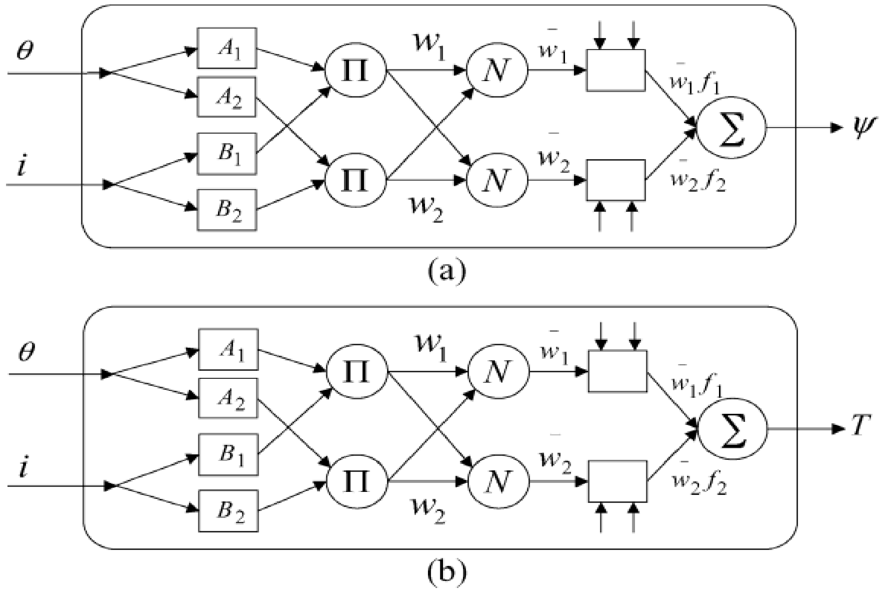

FIGURE 3

ANFIS METHODS FOR CALCULATION TORQUE AND FLUX LINKAGE: (A) CALCULATION OF FLUX LINKAGE, (B) CALCULATION OF TORQUE

In [15], HL methods were utilized for identification of these consequent and premise factors. There are 2 passes in HL methods for ANFIS: they are forward and backward pass. In [11], HL method, which joins BP method and linear LS strategy were utilized to adapt and train FIS. This method is 2-step procedure. Initially, consequent factors have been identified utilizing LS model, whereas the values of premise factors have been held fixed. Then, consequent factors have been held fixed whereas error is propagated from o/p end to i/p end, and premise factors have been updated by standard BP method. This method joins more quickly since it lessens the component of the exploration of BP method.

EXPERIMENTAL STUDY

The experimental outcomes of SRM drive utilizing various regulators under load and no load condition have been seen. Under the case of no-load, the drive speed is spans to commanded drive speed. From figure 5, exhibition attributes of SRM i.e, time vs speed, with ANN, FL, and ANFIS controllers have been noticed. The unique attributes of reaction of SRM drive framework is displayed in table 1. The experimental outcomes displays that by utilizing various controllers the presentation feature like settling time, rise time, peak overshoot, and peak time have been estimated. Utilizing FL controller, for 315 rad/sec set speed, the speed arrives at 0.519 seconds ideal value; peak overshoot (biggest mistake) in framework is 2.47%, and 0.2734 seconds rise time.

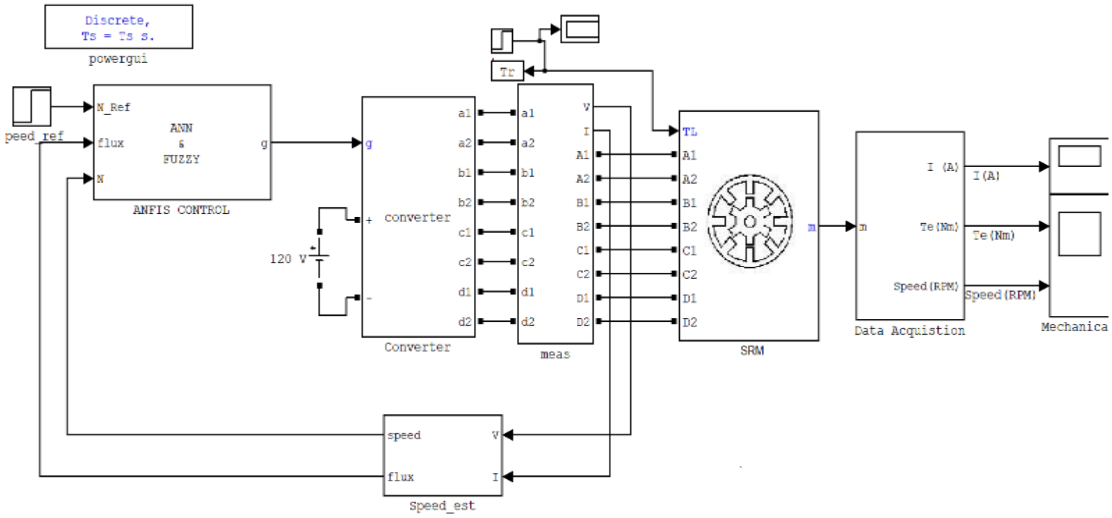

FIG. 4

SIMULATION MODEL OF SRM WITH ANFIS CONTROL SYSTEM

Utilizing ANFIS and ANN regulator, for set command, the speed arrives at its ideal value in 0.3233 and 0.3777sec individually. Hence, the framework strange period is diminishes due to ANFIS regulator. Framework balances out in a less time contrasted with different techniques. Utilizing ANFIS and ANN regulator the peak overshoot diminishes from 2.47% to 0.30% and 2.47% to 1.54% from individually. So that, the change or motions accordingly is diminishes and rise time is additionally diminishes to 0.2603sec, 0.2733sec, separately. With aim of framework speed expands due to ANFIS regulator.

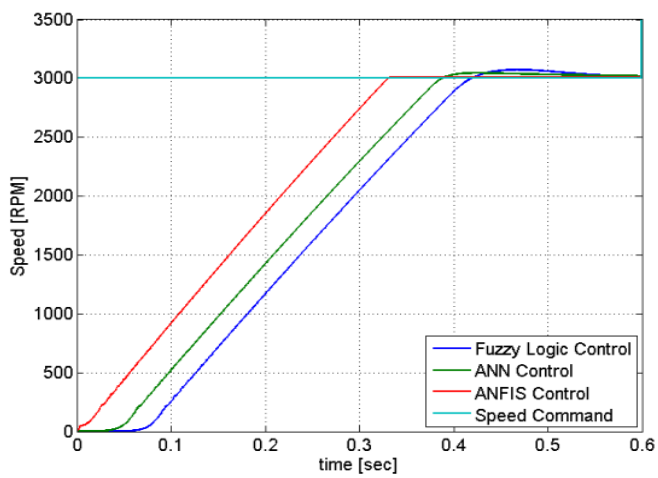

FIG. 5

RESPONSE OF SRM SPEED CONTROL UTILIZING ANFIS, ANN, AND FUZZY WITH 3000 RPM SPEED COMMAND

Same as for ANFIS Controller, the other performance qualities of torque versus time have been displayed in figure 6. Through abnormal time or transient time, speed is linearly improved to set command (3000 rpm) and torque is fluctuating among 0 and 15 N-M.

TABLE I

THE PERFORMANCE EXAMINATION OF ANN, FL AND ANFIS CONTROLLERS WITH 4000 RPM SPEED COMMAND

Controllers	Rise Time	Peak Time	Settling Time	Peak Overshoot
Fuzzy Logic	0.1229	0.8049	0.2967	1.39%
ANN Control	0.1	0.7605	0.2866	0.85%
ANFIS Control	0.0962	0.7308	0.118	0.20%

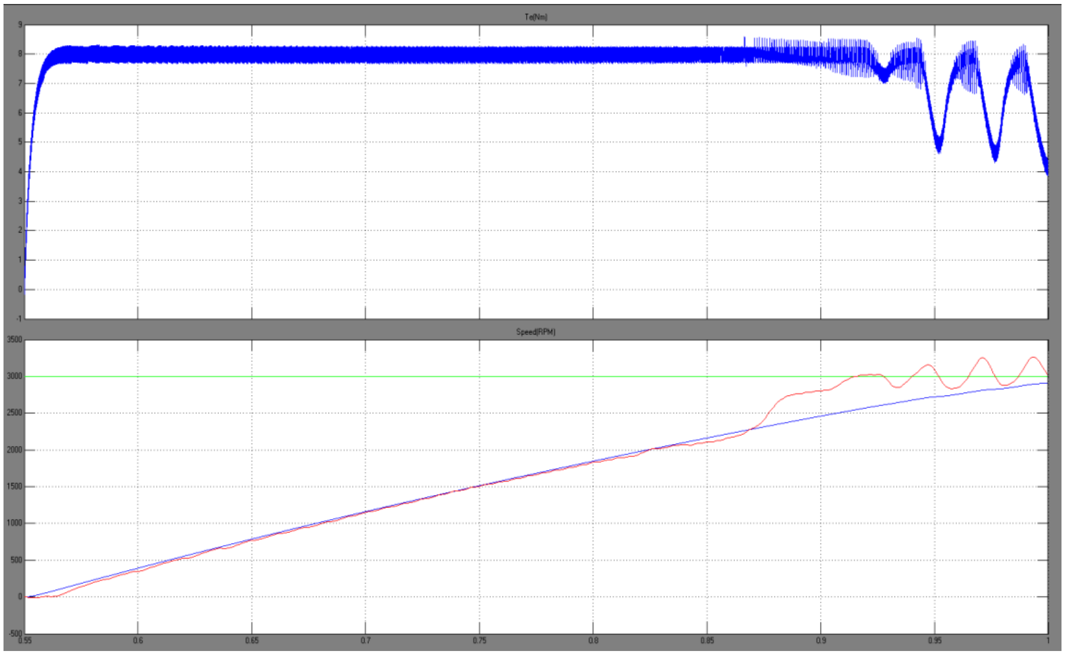

FIG. 6
ANN BASED SRM DRIVE SYSTEM WITH 4000 RPM (CONVENTIONAL SYSTEM)

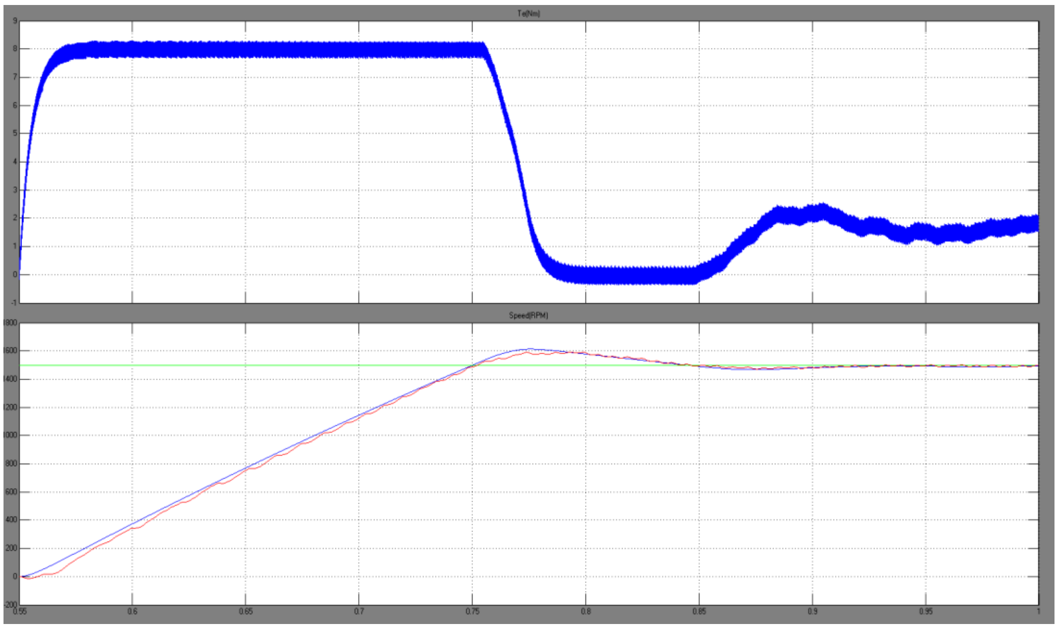

FIG. 7
ANFIS BASED SRM DRIVE WITH SPEED 4000RPM (PROPOSED SYSTEM)

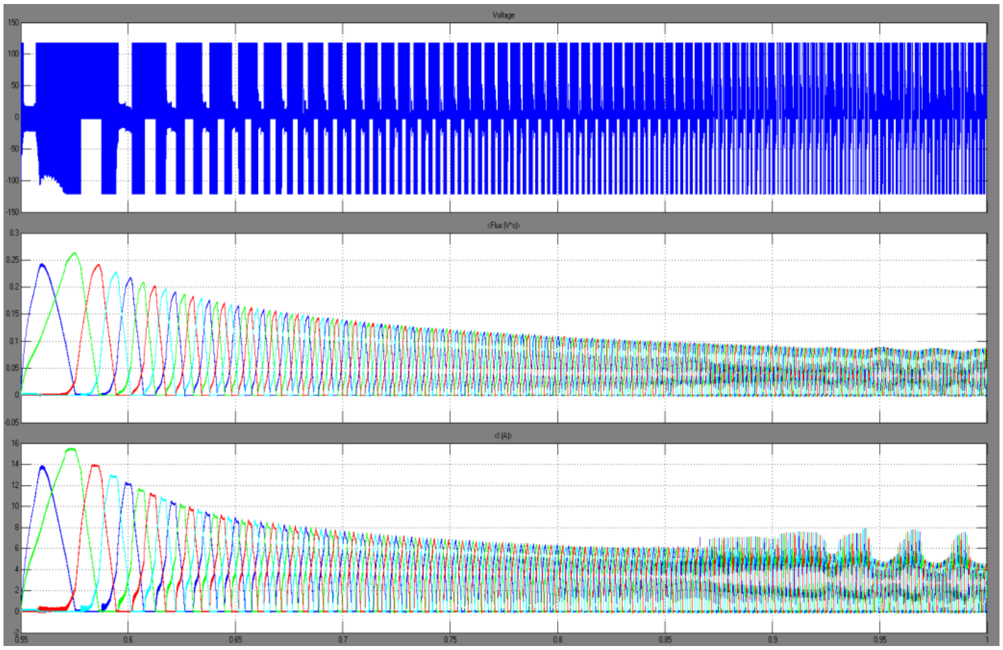

FIG. 7
ANN BASED VOLTAGE, FLUX, & CURRENT (CONVENTIONAL SYSTEM)

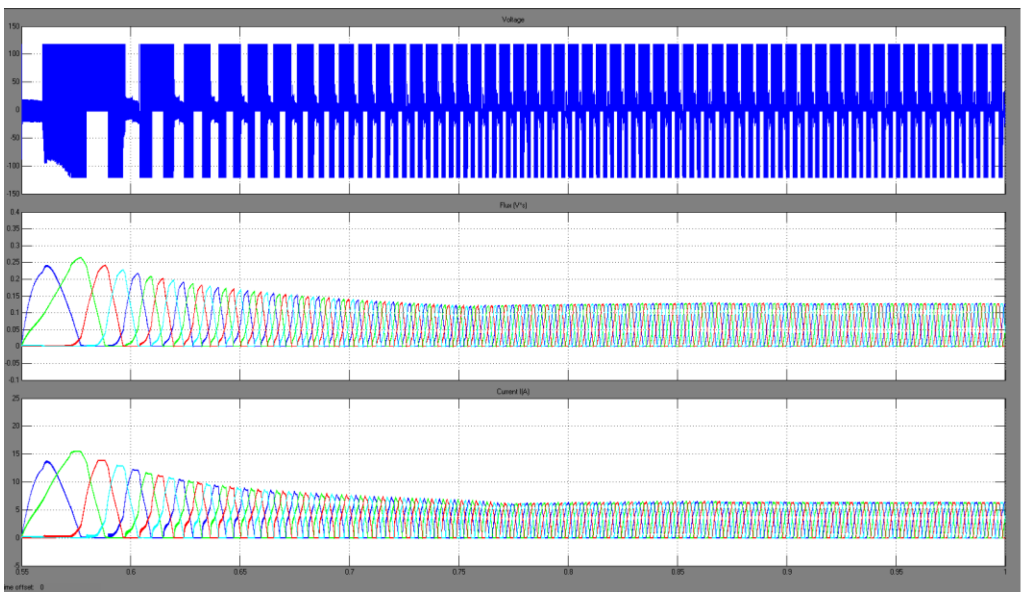

FIG. 7
ANFIS BASED VOLTAGE, FLUX, & CURRENT (PROPOSED SYSTEM)

Utilizing ANFIS Controller, figure 5 displays the performance qualities of torque versus time. The command of speed is varied from 3000rpm-4000rpm again torque is swaying among 5N-M & 15N-M. Through this strange time, the speed is linearly expanded to set order (4000 rpm).

CONCLUSION

In this manuscript, ANFIS-based regulator is introduced for SR drives. The torque and speed control strategy present in this manuscript and comparing with past control plans (ANN and fuzzy), whereas it tends to be utilized in load and no load operating conditions and speeds incorporating torque and speed transients, startup, and zero-speed standstill, and doesn't assume the direct qualities of SR motor. Also, the suggested procedure doesn't need of difficult estimations to be done during real time operation, and no difficult numerical method of SR motor is essential. A principle thought in exploration is reliability and robustness of speed controlling strategy. The investigation clearly displays that ANFIS is ability for creating high precision yield results. The accuracy of attained simulation outcomes and error reflect percentage which method is appropriate and accurate for additional applications to anticipate precisely the dynamic behaviors of SRM.

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