

Certain Investigations on the Performance of the Power Electronic Drive Using SHEPWM for SCIM

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Abstract

This paper proposes a Pulse Width Modulation (PWM) for reducing electromagnetic torque amplitude and pulsation during start-up of a three-phase induction motor. At the time of starting of three phase induction motor high torque pulsations are occurred. This leads to reduce the stability of motor, torque pulsations vary periodically with rotor position and are reflected as speed ripple. This paper presents a novel scheme for the mitigation of ripples in the starting torque of squirrel cage induction motor (SCIM).Selective harmonic elimination technique is adopted by eliminating selected low order harmonics. The FFT analysis of simulated output voltage waveform confirms the effectiveness of proposed method proves that it is much applicable in the industrial applications by virtue of its suitability in real time applications. To prove the selective harmonic elimination technique is the promising technique to reduce the torque pulsations and to eliminate or reduce the lower order harmonics like 5^{th}, 7^{th},11^{th},13^{th} harmonics. The performance of this method is demonstrated by simulation using MATLAB/Simulink software.

Keywords: *Selective harmonic elimination, adaptive neuro fuzzy inference, pulse width modulation, pulsation, rotor position, ripple, prominent torque results.*

INTRODUCTION

Advent of power electronics and proliferation of nonlinear loads in industrial applications, power harmonics and their effects are of great concern. Harmonics are electric voltages and currents that appear on the electric power system as a result of certain kinds of electric loads. Harmonic frequencies in the power grid were a frequent cause of power quality problems. The harmonic distortion travels back into the power source and can affect other equipment connected to the same source [1-3].

One of the most widely used strategies for controlling the AC output of power electronic converters is the technique known as pulse width modulation. But PWM techniques alone are not able to eliminate lower order harmonics totally. Alternative approach is to select the switching angles consequently that specific higher order harmonics such as the 5th, 7th, 11^{th} and 13^{th} are suppressed in the output voltage of the controller. This method is known as selective harmonic elimination (SHE) or programmed PWM techniques. In this technique, set of nonlinear equations can be solved by iterative techniques such as the Newton Raphson method [4-6]. As compared to the traditional angle controlled soft starting schemes the proposed methodology offers the definite advantages of reduced torque ripple and reduced source current harmonics. The proposed method uses the digital implementation of the Hopfield Neural Network for solving the trigonometric transcendental equations pertaining to SHEPWM and thus the real time estimation of the multiple switching instants of multiply switched AC voltage controllers.

In the proposed method the total conduction duration is equally spread over the entire positive and negative half cycle periods. The conduction and non conduction periods are symmetrically

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distributed over each half cycle interval. In each half cycle ten switching instants are symmetrically placed rendering quarter wave symmetry. Finding the location of switching instants in the case of SHEPWM involves solution of a set of nonlinear algebraic transcendental equations. The switching instants on the time axis are obtained by solving a set of nonlinear algebraic transcendental equations by two popular approaches. In first approach numerical iterative techniques such as the Newton Raphson method is proposed. The second approach is optimization technique which is used to get a minimized objective function values. With gradual increase of modulation index under all possible modulation indices the switching instants are selected in such a way that the selected harmonics are eliminated. The ripples in the electromagnetic torque produced are approximately eliminated due to elimination from source side current.

ADAPTIVE NEURO FUZZY INFERENCE SYSTEM

The Adaptive network based fuzzy inference system (ANFIS) is a hybrid system comprising of the neural network and the fuzzy logic. It is a data driven procedure which can be used to provide the solution of function approximation problems in a neural network platform. Here at first a fuzzy inference system comprising of an initial fuzzy model is formed, based on the fuzzy rules extracted from the input output data set. In the next step the neural network is used to fine tune the rules of the initial fuzzy model that was built. Using ANFIS methodology the network is trained. The number of training data used in the ANFIS is drastically reduced by applying an optimal data selection criterion [7].

The Adaptive Neuro Fuzzy Inference System (ANFIS) is a fuzzy system and used in classification, modeling and control problems. It is based on Takagi and Sugeno's fuzzy if-then rules representation [8]. The ANFIS neuro-fuzzy system uses the training data set to build the fuzzy system in which, membership functions are adjusted using the back propagation algorithm, allowing that the system learns with the data that it is modeling. A network-type structure similar to that of a neural network, which maps inputs through input membership functions and associated parameters, and then through output membership functions and associated parameters to outputs, can be used to interpret the input/output map. The fuzzy logic takes into account the imprecision and uncertainty of the system that is being modeled while the neural network gives it a sense of adaptability [9]. Using this hybrid method, at first an initial fuzzy model along with its input variables are derived with the help of the rules extracted from the input output data of the system that is being modeled. The Adaptive network based fuzzy inference system (ANFIS) is a hybrid system comprising of the neural network and the fuzzy logic. It is a data driven procedure which can be used to provide the solution of function approximation problems in a neural network platform.

Here at first a fuzzy inference system comprising of an initial fuzzy model is formed, based on the fuzzy rules extracted from the input output data set. In the next step the neural network is used to fine tune the rules of the initial fuzzy model that was built. Using ANFIS methodology the network is trained. The number of training data used in the ANFIS is drastically reduced by applying an optimal data selection criterion as shown in Figure 1.

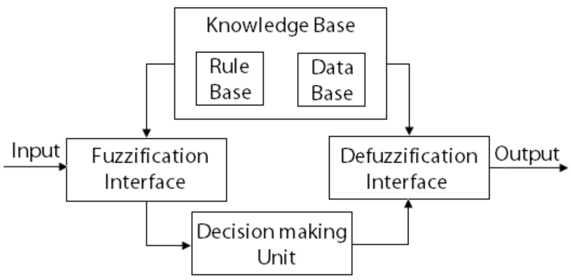

Figure 1. ANFIS Topology

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ANFIS ARCHITECTURE

The ANFIS architecture is shown in Figure 2. If the firing strengths of the rules are *w1* and *w2*, respectively, for the particular values of the inputs Ai and integral of Bi, then the output is computed as weighted average.

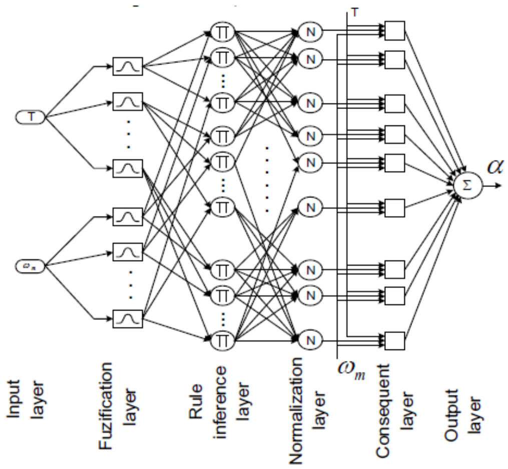

Figure 2. Architecture of ANFIS Controller

Layer1 is the input layer. Neurons in this layer simply pass external crisp signals to Layer 2.

Layer 2 is the fuzzification layer. Neurons in this layer perform fuzzification.

Layer 3 is the rule layer. Each neuron in this layer corresponds to a single Sugeno-type fuzzy rule. A rule neuron receives inputs from the respective fuzzification neurons and calculates the firing strength of the rule it represents. In an ANFIS, the conjunction of the rule antecedents is evaluated by the operator product. Thus, the output of neuron i in Layer 3 is obtained (1), where the value of μ_1 represents the firing strength, or the truth value, of Rule 1.

$$y_i^{(3)} = \prod_{j=1}^{k} x_{ji}^{(3)}$$

$$y_{\Pi 1}^{(3)} = \mu_{A1} \times \mu_{B1} = \mu_1, \qquad (1)$$

Layer 4 is the normalisation layer. Each neuron in this layer receives inputs from all neurons in the rule layer, and calculates the normalised firing strength of a given rule (2).

$$y_i^{(4)} = \frac{x_{ii}^{(4)}}{\sum_{j=1}^{n} x_{ji}^{(4)}} = \frac{\mu_i}{\sum_{j=1}^{n} \mu_j} = \bar{\mu}_i$$

$$y_{N1}^{(4)} = \frac{\mu_1}{\mu_1 + \mu_2 + \mu_3 + \mu_4} = \bar{\mu}_1 \qquad (2)$$

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Layer 5 is the defuzzification layer. Each neuron in this layer is connected to the respective normalisation neuron, and also receives initial inputs, x_1 and x_2. A defuzzification neuron calculates the weighted consequent value of a given rule as, where is the input and is the output of defuzzification neuron i in Layer 5, and k_{i0}, k_{i1} and k_{i2} is a set of consequent parameters of rule i (3).

$$y_i^{(5)} = x_i^{(5)} \left[k_{i0} + k_{i1}\, x1 + k_{i2}\, x2\right] = \bar{\mu}_i \left[k_{i0} + k_{i1}\, x1 + k_{i2}\, x2\right] \quad (3)$$

Layer 6 is represented by a single summation neuron. This neuron calculates the sum of outputs of all defuzzification neurons and produces the overall ANFIS output (4), y

$$y = \sum_{i=1}^{n} x_i^{(6)} = \sum_{i=1}^{n} \bar{\mu}_i \left[k_{i0} + k_{i1}\, x1 + k_{i2}\, x2\right] \quad (4)$$

An ANFIS uses a hybrid learning algorithm that combines the least-squares estimator and the gradient descent method. In the ANFIS training algorithm, each epoch is composed from a forward pass and a backward pass.

CONTROL OF INDUCTION MOTOR USING ANFIS

Intelligent, self-learning or self-organizing controls using expert systems, artificial intelligence, fuzzy logic, neural networks, hybrid networks, etc have been recently recognized as the important tools to improve the performance of the power electronics based drive systems in the industrial sectors.

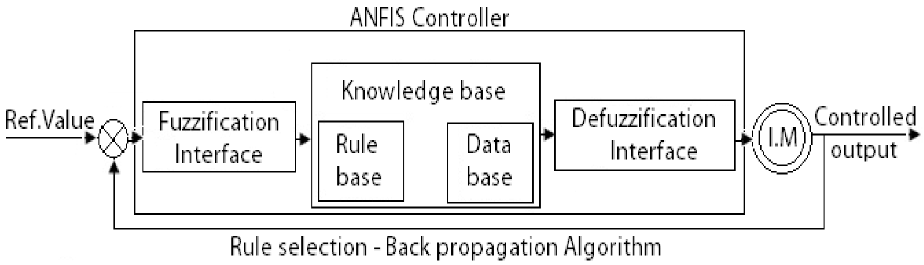

Figure 3. Induction motor control using ANFIS

A controller is a device which controls each and every operation in the system making decisions. From the control system point of view, it is bringing stability to the system when there is a disturbance, thus safeguarding the equipment from further damages. It may be hardware based controller or a software based controller or a combination of both. The development of the control strategy for control of various parameters of the induction machine such as the speed, torque, and voltage is presented using the concepts of ANFIS control scheme, the block diagram of which is shown in the Figure 3.

The fuzzification maps the 2 input variables to linguistic labels of the fuzzy sets. The fuzzy coordinated controller uses the linguistic labels. Each fuzzy label has an associated membership function. The membership function of triangular type is used in this work. The inputs are fuzzified using the fuzzy sets and are given as input to ANFIS controller. The rule base for selection of proper rules using the back propagation algorithm. The inference involves a set of rules for determining the

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output decisions. As there are 2 input variables and fuzzified variables, the controller has a set of rules for the ANFIS controller. Out of these rules, the proper rules are selected by the training of the neural network with the help of back propagation algorithm and the selected rules are fired. Further, it has to be converted into numerical output, i.e., they have to be de-fuzzified.

SELECTIVE HARMONIC ELIMINTION METHOD (SHE)

The ANFIS architecture is shown in Figure 2. If the firing strengths of the rules are *w1* and *w2*, respectively, for the particular values of the inputs Ai and integral of Bi, then the output is computed as weighted average.

Selective Harmonic Elimination (SHE) offers several advantages compared to traditional modulation methods including acceptable performance with low switching frequency to fundamental frequency ratios, direct control over output waveform harmonics, and the ability to leave triple harmonics uncontrolled to take advantage of circuit topology in three phase systems [6]. SHE a viable alternative to other methods of modulation in applications such as ground power units, dual-frequency induction heating. Selective harmonic elimination is normally a two-step digital process. First, the switching angles are calculated offline, for several depths of modulation, by solving many nonlinear equations simultaneously. Second, these angles are stored in a look up table to be read in real time.

A method for calculating and implementing Selective Harmonic Elimination (SHE) switching angles was proposed and by varying the periodicity of the carrier signal Modulation index improved. This improves THD. The method is based on modulation rather than solution of nonlinear equations. This approach is based on a modified carrier waveform which can be calculated based on concise functions requiring only depth of modulation as input as shown in Figure 4. It rapidly calculates the desired switching waveforms while avoiding iteration and initial estimates. Calculation time is insensitive to the switching frequency ratio so elimination of many harmonics is straightforward. It is conceivable the technique could be realized with low-cost microcontrollers for real-time implementation.

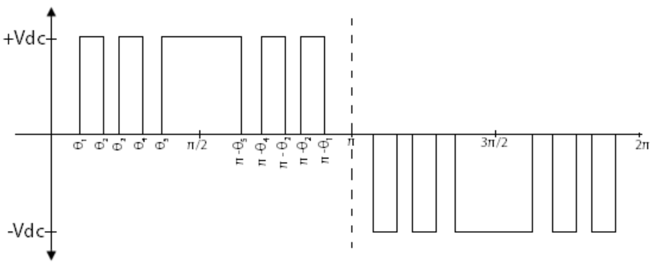

Figure 4. SHEPWM Technique

By placing notches in the output waveform at proper locations, certain harmonics can be eliminated. This allows lower switching frequencies to be used lower losses, higher efficiency. The main challenge involved in SHEPWM is to solve nonlinear equations involved, which are transcendental in nature and therefore have multiple solutions. Several algorithms have been introduced to concerning methods of solving the resultant non-linear transcendental equations, which describes the SHEPWM. For SHEPWM, the switching instants are determined by solving a set of non-linear equations.

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The common characteristic of the Selective Harmonic Elimination Pulse Width Modulation (SHE–PWM) method was that the waveform analysis was performed using Fourier theory.

General Fourier series of wave is given by (5-9):

$$v(t) = \sum_{n=1}^{\infty} (a_n \cos n\omega t + b_n \sin n\omega t) \quad (5)$$

where $$a_n = \frac{1}{\pi} \int_0^{2\pi} v(t) \cos(n\omega t) d(\omega t) \quad (6)$$

and $$b_n = \frac{1}{\pi} \int_0^{2\pi} v(t) \sin(n\omega t) d(\omega t) \quad (7)$$

For a waveform with quarter-cycle symmetry, only the odd harmonics with sine components will appear, i.e. a_n=0

and $$v(t) = \sum_{n=1}^{\infty} b_n \sin n\omega t \quad (8)$$

where $$b_n = \frac{4}{\pi} \int_0^{2\pi} v(t) \sin(n\omega t) d(\omega t) \quad (9)$$

Thus we have K variables (i.e. α_1, α_2, α_3 ... α_K) and we need K simultaneous equations to solve for their values. With K αangles, K-1 harmonics can be eliminated.

Consider the 5th and 7th harmonics (the 3rd order harmonics can be ignored if the machine has an isolated neutral). Thus K=3 and the equations can be written as:

Fundamental: $$b_1 = \frac{4}{\pi}(1 - 2\cos\alpha_1 + 2\cos\alpha_2 - 2\cos\alpha_3) \quad (10)$$

5th Harmonic: $$b_5 = \frac{4}{5\pi}(1 - 2\cos 5\alpha_1 + 2\cos 5\alpha_2 - 2\cos 5\alpha_3) = 0 \quad (11)$$

7th Harmonic: $$b_7 = \frac{4}{7\pi}(1 - 2\cos 7\alpha_1 + 2\cos 7\alpha_2 - 2\cos 7\alpha_3) = 0 \quad (12)$$

RESULTS AND DISCUSSIONS

The simulation research for the proposed system is carried out using the MATLAB/simulink. This section shows the comparisons of characteristics between ANFIS based Extinction Angle Control and Selective Harmonic Elimination techniques. The motor investigation is

- Power -10HP (7.5KW)
- Voltage input- 400V
- Frequency -50Hz
- Speed -1440RPM three phase squirrel cage induction motor

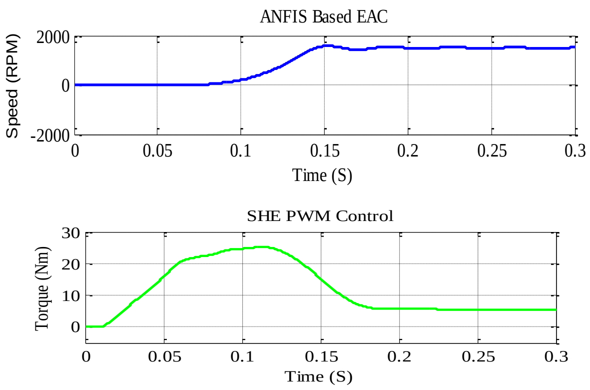

Figure 5. Response of time to reach rated speed

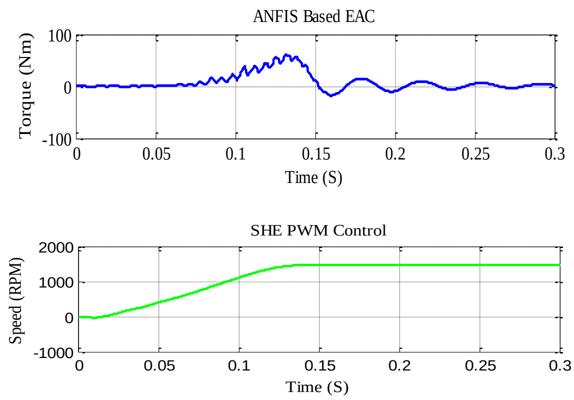

Figure 6. Response of torque at the starting instant

The cause of pulsations in electromechanical torque at the supply frequency is the uncontrolled switching of three motor phases to the supply on the first voltage cycle. Simultaneous switching of the three motor phases always gives rise to a considerable pulsating torque component.

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Figure 5. shows the variation of fundamental component of motor voltage with motor speed for two control strategies. It is clear from this figure that the motor speed variation with motor terminal voltage is better in SHEPWM technique.

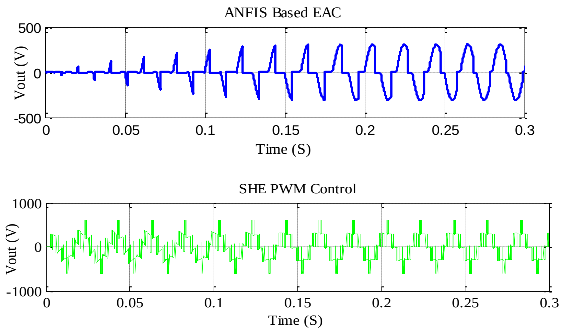

Figure 7. Response of output voltage

It is clear that the SHE PWM control strategy have the best efficiency. This high efficiency is due to the low harmonic distortion in SHEPWM technique.

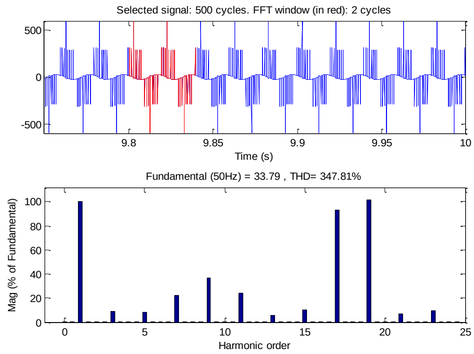

Figure 8. FFT Analysis of voltage for Modulation Index, M = 0.1

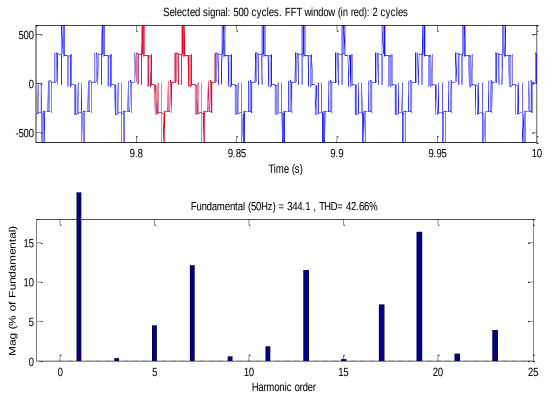

Figure 9. FFT Analysis of voltage for Modulation Index, M = 0.5

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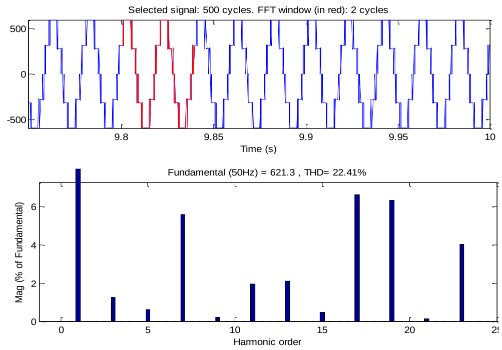

Figure 10. FFT Analysis of voltage for Modulation Index, M = 0.7

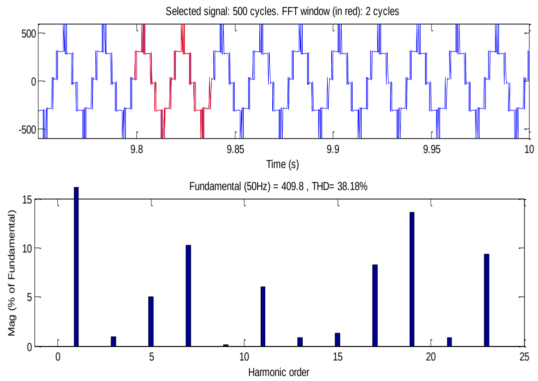

Figure 11. FFT Analysis of voltage for Modulation Index, M = 0.9

Figure 6 and Figure 7 shows the electromagnetic torque developed and voltage with rotor speed for different firing angle and on no load. The speed reaches to its steady state at time 0.22 seconds for ANFIS based extinction angle control, 0.13 for selective harmonic elimination technique the torque is pulsating with a magnitude of 61Nm, 25Nm respectively.

In these cases, all baseband harmonics are eliminated. In three-phase systems, triple harmonics may cancel in the currents automatically if neutral current does not flow.

Therefore it is not always necessary to eliminate them by design in the selective harmonic elimination (SHE) process. By applying these switching angles, the 5th, 7th, 11th and 13th harmonics will be reduced from the output voltage waveform as shown in Figures 8, 9, 10 and 11. And comparisons of lower order harmonics of three techniques are shown in Table 1.

Table 1: Comparison of harmonics (%) for various control strategy.

Parameter	**5th harmonic**	**7th harmonic**	**11th harmonic**	**13th harmonic**
ANFIS based EAC	30.84	16.002	11.02	4.84
SHE	0.62	5.57	1.95	2.09

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CONCLUSIONS

In this paper, novel PWM topology for the SCIM has been carried out. By comparing the techniques like ANFIS and selective harmonic elimination for different modulation indices torque, speed and output voltage is obtained. The elimination of specific low-order harmonics from a given voltage waveform achieved by Selective Harmonic Elimination (SHE) technique and It is found to be that all the targeted harmonics are absent and the fundamental is controlled at a predefined value. When compared with the ANFIS based EAC technique SHEPWM method offers significant benefits for increased modulation index. The selective harmonic elimination method has emerged as a promising harmonic elimination method.

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