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Application of ANFIS to Minimize Total Harmonic Distortion in Brushless DC Motor

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Abstract: Total harmonic distortion provides direct impact on power quality in distributed systems. The work presents reduction of Total harmonic distortion (THD) in Brushless DC motor (BLDC) using adaptive neuro controller. The configured controller is provided with a rule base, input and output membership functions. The BLDC motor is modelled in MATLAB-SIMULINK with load variation that have direct impact on the functioning of a system. The parameters include load, resistance and inertia of BLDC motor. The work results are obtained after simulating BLDC system under different load configurations. The conclusion is provided with the calculation of THD so produced using Adaptive neuro configured controller.
Keywords: Brushless DC motor, THD, Adaptive Neuro

I. INTRODUCTION

In current situation power quality of distributed systems is directly proportional to the harmonics so produced during the operation. BLDC motors are universally applied in variety of comprehensive electrical applications when related to conventional induction and synchronous reluctance motors as it benefits in providing determined competence, simple conservation, and great uniform flux density. Previously, the variety of conventional controllers have been used in calculating the speed characteristics. But while the working of BLDC motor there will be production of noise which is called as THD – Total Harmonic Distortion along with mechanical work. Total harmonic distortion (THD) is a quantity related to voltage or current distortion range created because of harmonics in the signal. THD is a key feature in acoustic, networks, and power systems and should be as low.

Instigating advanced observing methods like adaptive, variable structure and grouping of fuzzy with neural network, the preferred speed matched can be achieved with a reduced harmonics during BLDC motor application. Therefore an adaptive neuro fuzzy controller have been developed and was applied for reducing the THD during the process.

Electrical energy fluxes also can be distorted, though usually not on purpose. The presence of harmonic distortion in a power load can cause problems. The total harmonic distortion (THD) of an electrical current is the total degree of distortion in comparison to the ideal. The majority of domestic electrical systems employ linear loads. The peaks and troughs of a linear current sine curve are smooth, even, and sinusoidal. In residential circuits, some distortion can occur, but not to the extent that it causes substantial efficiency difficulties. Non-linear loads, on the other hand, are used in many industrial and commercial applications. Harmonic distortion (the consequence of merging numerous waves of changing frequency) introduced by generators, converters, and power supplies can substantially degrade the efficiency of a power system. These loads are inductive and have a low power factor, which means that the quantity of non-working power inside a particular load is a substantial fraction of total apparent power. When a load has a greater power factor, its THD factor decreases and the system becomes more efficient.

II. LITERATURE SURVEY

From the sources of [1],[2],[3] and [4], the BLDC modelling, parameters and the response of the system under various controllers were studied based on which it was observed that fuzzy controller provides best response in categories of speed and torque control when compared to conventional P, PI, PID controllers.

Though research have been done on the usage of adaptive fuzzy based networks in the implementation of BLDC motor [5], since THD plays an effective role in defining the impact on the application of BLDC motor, the work presents the usage of adaptive neuro practice for lessening of total harmonic distortion in Brushless DC motor. The rule base and learning methods of artificial neural networks were studied from [6]. Based on the changes made in the rule base it was observed that the considered controlling method provides economical production in total harmonic distortion.

III. BLOCK DIAGRAM

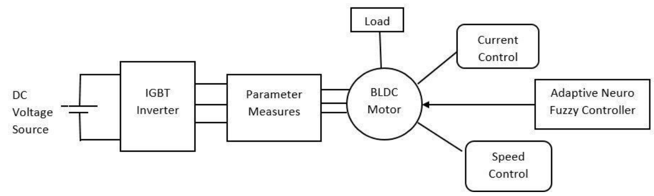

Fig.1 Block diagram representation

The process is initiated by providing DC source to IGBT inverter. This makes the conversion of Direct current supply to the Alternating current supply with frequency and phase that eases the operation of BLDC motor. Based on the alternations in the parameters provided, the current and speed responses are analysed. The responses are evaluated after developing a rule base and membership functions in the adaptive neuro controller. In the end the total harmonic distortion is computed from the responses under diverse functioning circumstances in addition to load distinctions.

IV. BRUSHLESS DC SERVOMOTOR DRIVE SYSTEM MODELLING

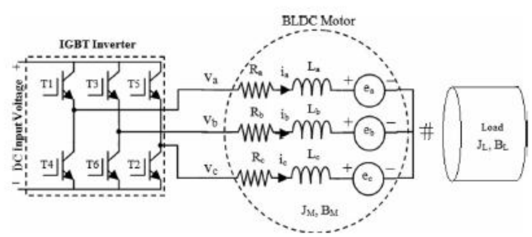

Fig 2. Equivalent circuit

A DC power source is sent to the IGBT inverter, and the output from the inverter is an AC supply. The BLDC motor will get this supply. Given certain improvements, the fuzzy PID and PID controllers are tested in a variety of load and speed varying conditions. According to mathematical relations, the voltages between the lines of a BLDC's equivalent circuit are given by

$$\begin{bmatrix} V_{ab} \\ V_{bc} \\ V_{ca} \end{bmatrix} = \begin{bmatrix} Ra & -Ra & 0 \\ 0 & Rb & -Rb \\ -Rc & 0 & -Rc \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} La-Mb & Mb-La & 0 \\ 0 & Lb-Mc & Mb-Lc \\ Mc-La & 0 & Lc-Ma \end{bmatrix} \times \frac{di}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a-e_b \\ e_b-e_c \\ e_c-e_a \end{bmatrix}$$

Because self-inductance is given higher priority than mutual inductance, the same matrix equation can be evaluated as

$$\begin{bmatrix} V_{ab} \\ V_{bc} \\ V_{ca} \end{bmatrix} = \begin{bmatrix} Ra & -Ra & 0 \\ 0 & Rb & -Rb \\ -Rc & 0 & -Rc \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} La & -La & 0 \\ 0 & Lb & -Lb \\ -Lc & 0 & Lc \end{bmatrix} \times \frac{di}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a-e_b \\ e_b-e_c \\ e_c-e_a \end{bmatrix}$$

Where Li and Mi are the self and mutual inductances of each line a, b and c respectively. R is the winding resistor. The electromotive forces are e_a, e_b and e_c ; i_a, i_b and i_c are the phase streams of individual lines.

The torque developed is

$$T = (e_a i_a + e_b i_b + e_c i_c)/\omega \ ;$$

$where\ \omega = K_t I\ and\ I = i_a = i_b = i_c$, ω is the angular velocity and torque constant is symbolized as K_t. As the electromagnetic torque can be applicable to overwhelm the conflicting load and inertia torques,

$$T_e = T_L + J_M \frac{dw}{dt} + B_L \omega$$

Here load torque factor is indicated by T_L, inertia factor is indicated by J_M and friction factor of the BLDC servomotor is B_L . The T_L, is communicated by $J_L$and $B_L$components as

$$T_L = J_L \frac{dw}{dt} + B_L \omega$$

V. DESIGN OF CONTROLLERS

The designed controllers were fuzzy PID and ANFIS

A. Fuzzy PID controller

Fuzzy logic is a sophisticated mathematical method for solving difficult simulated problems with numerous input and output variables. Because fuzzy logic can provide recommendations for a specific interval of output state, it is critical that this mathematical method be distinguished from more familiar logics such as Boolean algebra.

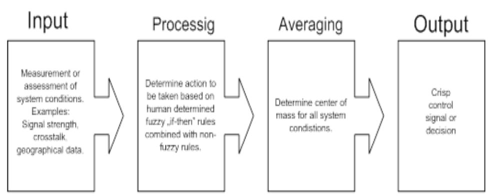

Fig. 3 Flow of Information in Fuzzy

The rule base built under uncertainty settings is often evaluated using human thinking levels, and the developed systems under these conditions demonstrate nonlinearity in dealing with varied sectors. Fuzzification, rule matrix, inference system, and defuzzification are commonly used in the development of fuzzy based controllers.

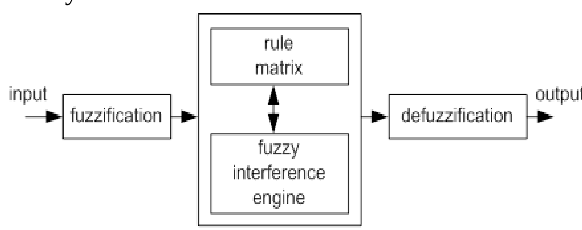

Fig. 4.Fuzzy Controller

The major stage of the fuzzy process involves contributing the relationship between the input components of the investigated fuzzy system and the output result. The examined criteria are muddled by the use of pre-defined input membership functions. All of these membership duties might take many forms. The most commonly used membership functions are triangular, trapezoidal, sinusoidal, and exponential in form. With each input parameter there will be a unique membership function connected. These functions possess a weighting factor by values of input and the operative rules respectively. The degree of membership of each active rule are evaluated by these weighting factors. The membership values and rule base implemented are as follows

e	Δe						
	nb	nm	ns	zr	ps	pm	pb
nb	nb	nb	nb	nm	nm	ns	zr
nm	nb	nb	nm	nm	ns	zr	ps
ns	nb	nm	nm	ns	zr	ps	pm
zr	nm	nm	ns	zr	ps	pm	pm
ps	nm	ns	zr	ps	pm	pm	pb
pm	ns	zr	ps	pm	pm	pb	pb
pb	zr	ps	pm	pm	pb	pb	pb

Fig. 5.Fuzzy Associative Memory for the proposed system

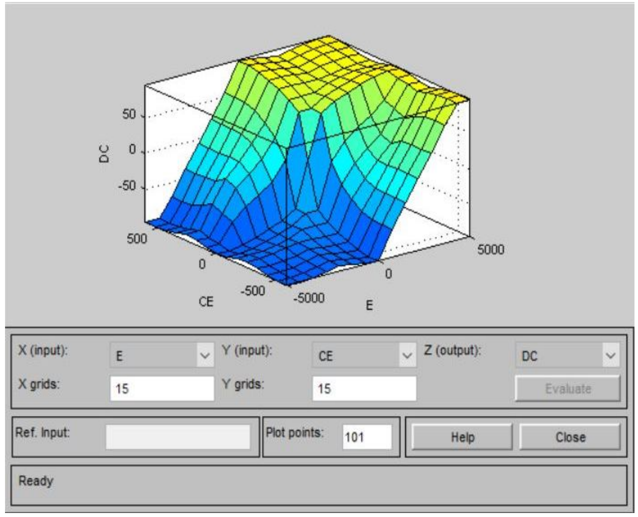

Fig. 6. Surface View of Fuzzy rule base

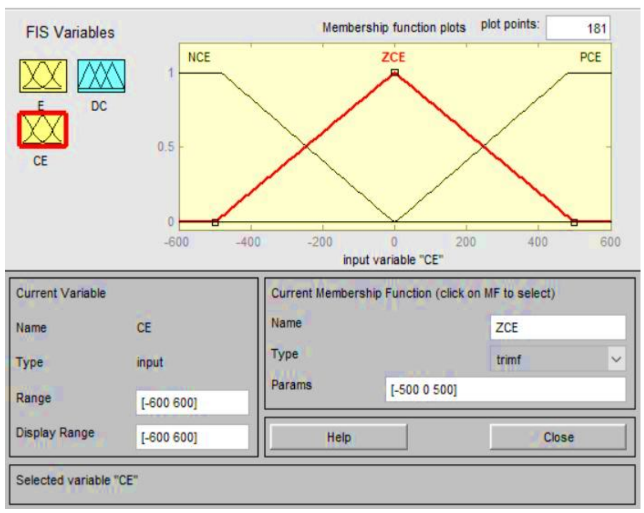

Fig. 7. Input Membership function

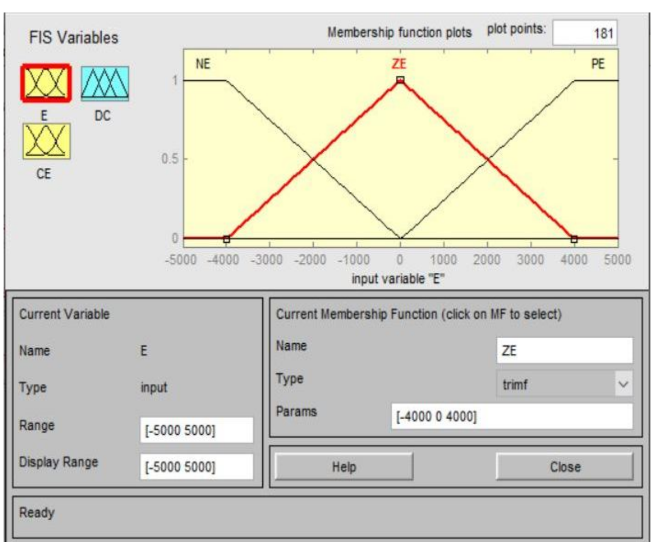

Fig. 8. Input Membership function of ‘e’

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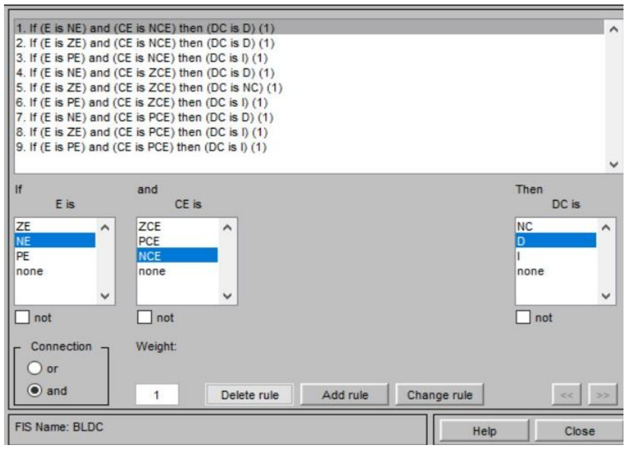

Fig. 9.Rule Editor

B. Adaptive Neuro Fuzzy Controller

The considered controller is an Adaptive neuro fuzzy inference system controller which is based on Takagi-Sugeno fuzzy inference system. Neuro-fuzzy systems are distinguished by their ability to combine the benefits of fuzzy logic with neural networks. The core idea behind a neuro-fuzzy system is to mimic a fuzzy logic system with a neural network and then use neural network learning techniques to adjust that fuzzy system. Numerous neuro-fuzzy networks that combine natural language descriptions of fuzzy systems and neural network learning features have been created, with ANFIS being one of the most well-known and commonly used neuro-fuzzy designs. Except for the neural network block, the basic ANFIS control structure comprises the same components as the fuzzy inference system. The network structure is made up of a collection of units (and connections) organised in five interconnected network levels, from layer 1 to layer 5. The suggested ANFIS controller structure is made up of four major components: fuzzification, knowledge base, neural network, and defuzzification. Layer 1 is made up of input variables (membership functions) and membership functions that are triangular or bell shaped. Layer 2 is the membership layer, which examines the weights of each membership function. It gets the first layer's input structure is automatically tuned. The ANFIS strategy can be applied to a variety of control applications due to its adaptability. values and acts as membership functions to represent the fuzzy sets of the corresponding input variables. Layer 3 is known as the rule layer, and it accepts input from the preceding layer. Each node (each neuron) in this layer conducts fuzzy rule pre-condition matching. This layer computes each rule's activation level, and the number of layers equals the number of fuzzy rules. This layer's nodes calculate the weights that will be normalised. Layer 4 is the defuzzification layer, which delivers the output values from rule inference. Layer 5 is referred to as the output layer since it aggregates all of the inputs from Layer 4 and converts the fuzzy classification results into a crisp number. A single output should be produced by weighted average defuzzification. It is required that all output membership functions be of the same type and either linear or constant. It must not share rules; that is, it cannot allow different rules to use the same output membership function.

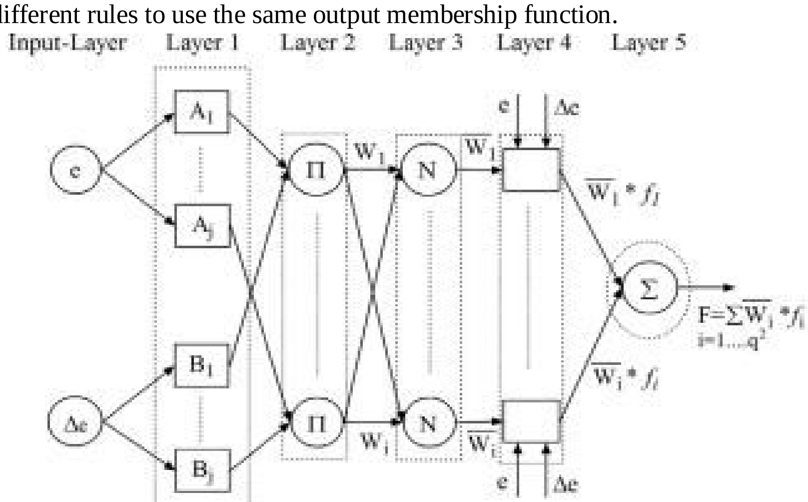

Fig. 10. Structure of ANFIS

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VI. SIMULATION RESULTS

The BLDC motor is used in settings of constant speed, changing speed, and load input. For the fuzzy PID controller and ANFIS, the corresponding responses of the Brushless DC motor and control system parameters are monitored and analysed. The response is computed using a frequency analysis of the THD produced by the motor

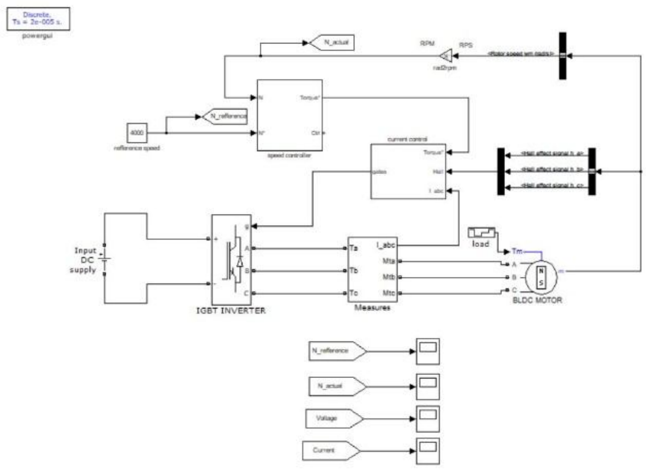

Fig. 11. Simulation diagram developed for the BLDC motor

The responses were computed using various characteristics such as load and inertia.

The system's specs are as follows:

Rated Voltage	36V
Rated Current	5A
No. of Poles	4
No. of Phases	3
Rated Speed	4000 RPM
Rated Torque	0.42 N.m
Torque Constant	0.082 N.m/A
Mass	1.25 Kg
Inertia	23e-06 kg-m^2
Resistance per Phase	0.57 ohms
Inductance Per Phase	1.5 mH

Table. 1. System Specifications

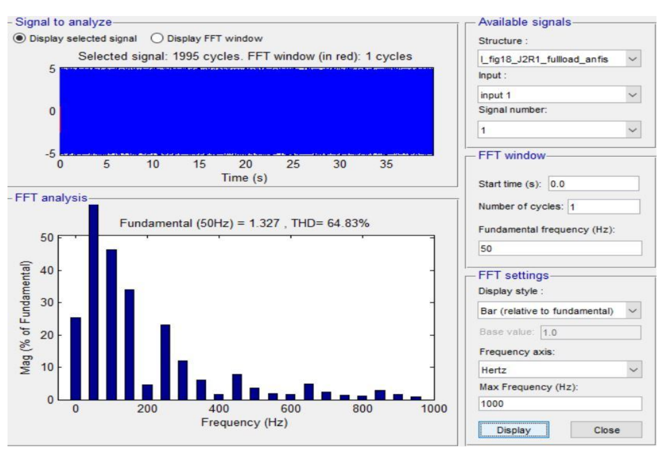

Fig. 12. ANFIS controller response of J2 & R1 with full load

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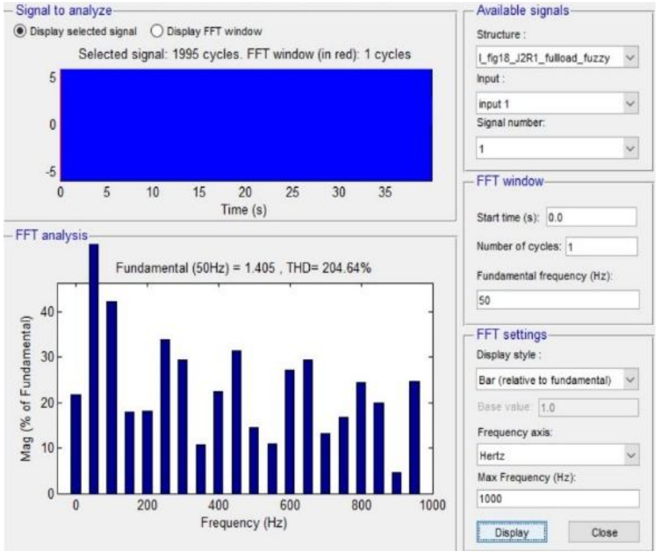

Fig. 13. Fuzzy PID controller response of J2 & R1 with full load

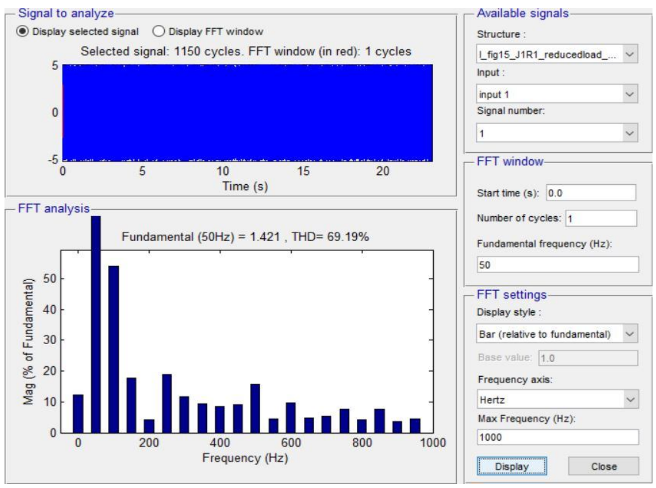

Fig. 14. ANFIS controller response of J1 & R1 with reduced load

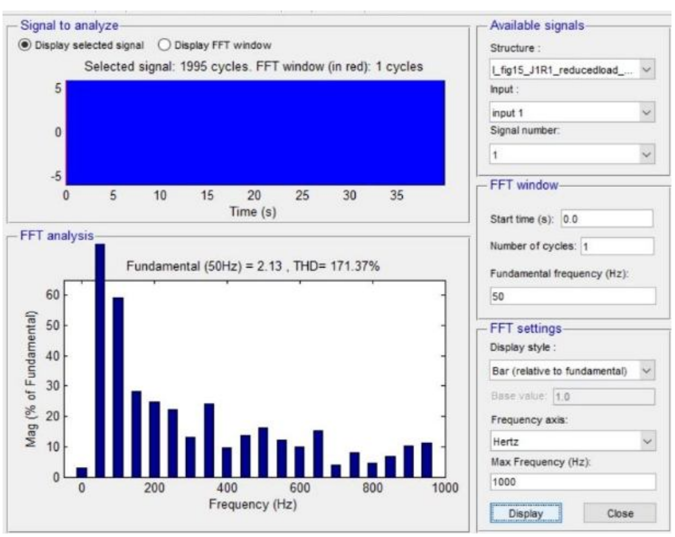

Fig. 15. Fuzzy PID controller response of J1 & R1 with reduced load

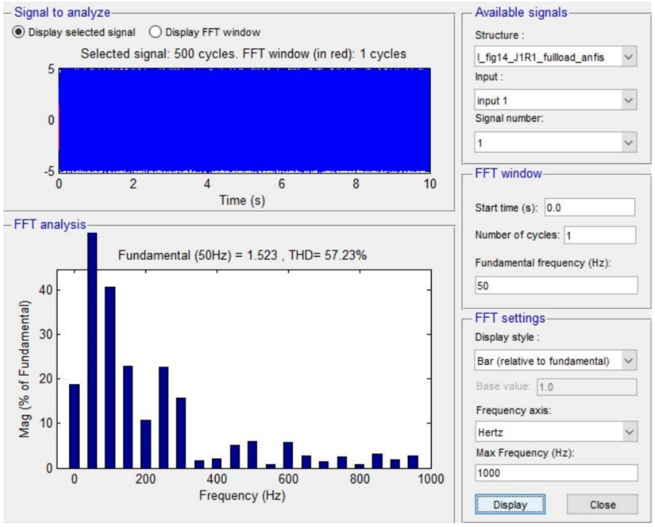

Fig. 16. ANFIS controller response of J1 & R1 with full load

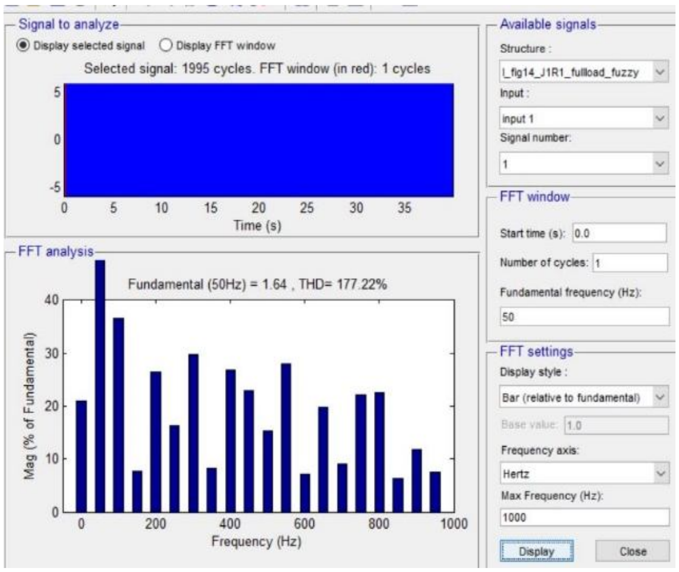

Fig. 17. Fuzzy PID controller response of J1 & R1 with full load

VII. CONCLUSION

The intended BLDC system was simulated in MATLAB utilising the Fuzzy PID and ANFIS controllers. Under parameter fluctuations, the performance of the ANFIS controller appears to be superior than that of the Fuzzy PID controllers in decreasing harmonic distortion, as measured by the FFT response in the current and voltage waveforms.

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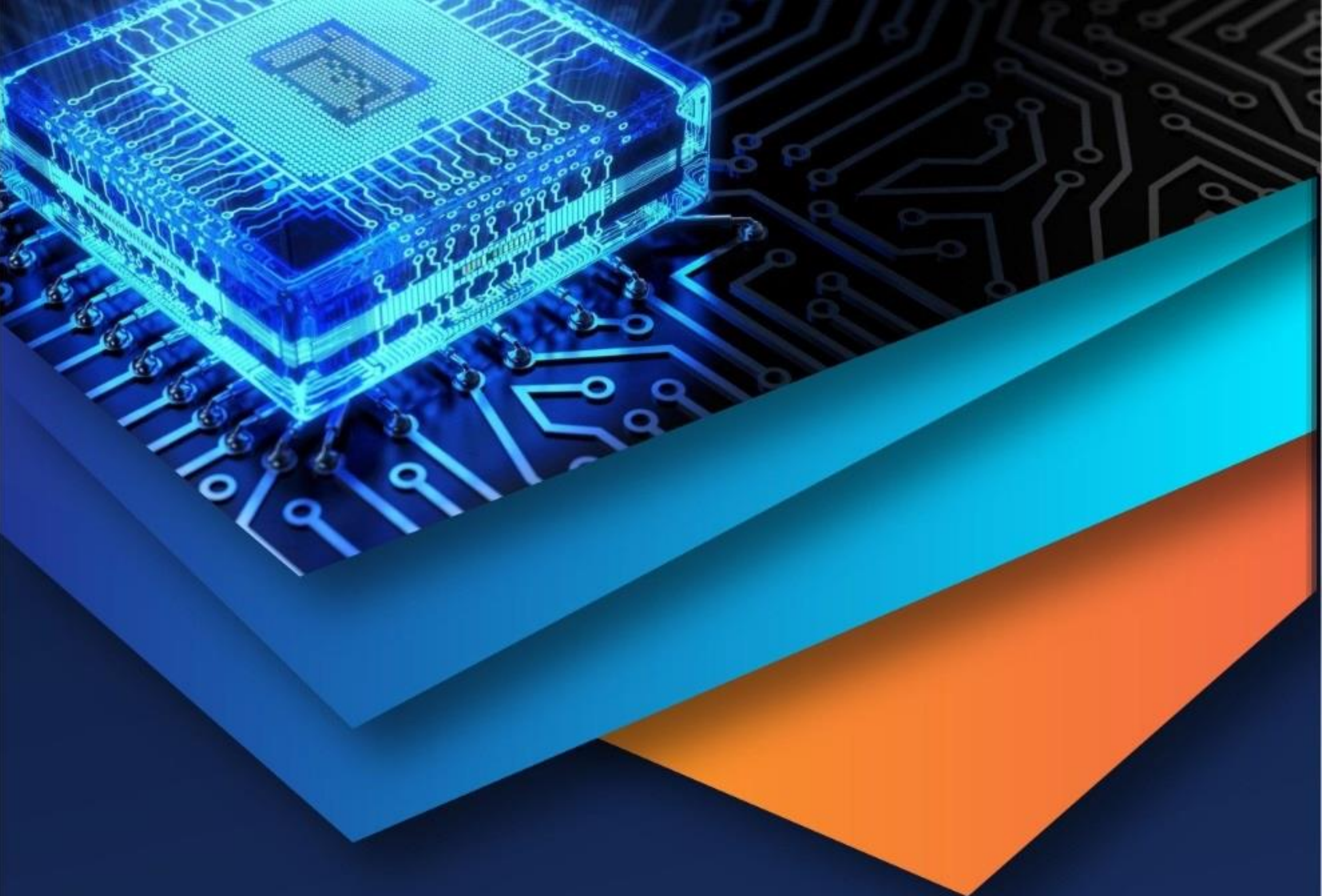

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