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ANFIS MODEL METHOD FOR WIDE RANGE OPERATION OF HIGH-SPEED BLDC MOTOR

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Abstract:- In industries the applications requiring the involvement of high speed BLDC motors are increasing rapidly and hence the study of improving the performance and wide range operation of BLDC motors is of great importance. In general, sensorless BLDC motors use Pulse Amplitude Modulation (PAM) or Pulse Width Modulation (PWM) methods as drive. This paper proposes ANFIS model drive technique for controlling the drive of brushless DC (BLDC) motor. In the paper, we used ANFIS model to combine PAM and PWM suitably and therefore advantages of both methods are utilized. Proposed method is compared with PAM and PWM methods and results obtained demonstrates that the proposed method exhibits better performance as compared with conventional methods (PAM & PWM)

Keywords: Brushless DC motor (BLDC), Pulse Amplitude Modulation (PAM) and Pulse Width Modulation (PWM).

1. Introduction

The popularity and usage of BLDC motors in various industrial applications is increasing steadily now a days due to their numerous advantages like low maintenance, high efficiency, compactness and reasonable cost etc [1-3]. Tremendous developments in bearing technologies helped in reaching the higher speed of BLDC motors [4-5]. BLDC motors are generally driven by PWM technique or PAM technique based on the power applications [6-7]. In [8-17], different types of PWM methods were addressed for controlling the BLDC motor. In all these cases, firing pulses to the driver circuit which controls the input voltage of the motor are controlled and generated with suitable angle shift. PWM technique struggles with ripples and high amount of current at moderate and high speeds [18-19]. In [20], it is reported that PWM is preferable for low speed applications rather than medium and high speed applications. In [21], six pulse inverter of three phase type was proposed for BLDC motor. In [22], a novel sensorless PWM technique is proposed for low power BLDC motor. The results from the literature implies the fact that no PWM method till now is capable of ensuring the effective performance of BLDC motor at all speeds.

In [23], BLDC motor driven by PAM method was proposed, which controls the firing pulses for inverters through six step mode. This method appeared to be superior to PWM method. In [24], Advantages and disadvantages of PWM and PAM methods were listed. Different PAM and PWM methods proposed for variable speed BLDC motors in [25]. In [26], quasi current source inverter employed to adjust DC link voltage and thereby improving the performance of BLDC motor. Buck-Boost converters were proposed in addition to normal inverters to enhance and control the voltage thereby increasing the performance of BLDC motor [27-29].
This paper first presents the Harmonic Compound Analysis when PWM is used as control technique and then proposes an ANFIS model which combines the advantages of PWM as well as PAM methods. Later part of the paper discusses the simulation diagram and comparison of results obtained through conventional and fuzzy methods. In the last part of the paper, conclusion and scope for further extension, limitations of the work are detailed.

2. Harmonic Component Analysis

Fig.1 shows the BLDC motor diagram which is helpful for developing the mathematical model.
This paper analysis depends on harmonics, therefore fundamental and harmonics are expressed as

$$E_{af} = \sqrt{2}E\sin(\omega t) = E_m \sin(\omega t) \qquad (1)$$

$$\begin{aligned} E_{bf} &= \sqrt{2}E\sin(\omega t - 120^o) \\ &= E_m \sin(\omega t - 120^o) \end{aligned} \qquad (2)$$

$$E_{cf} = \sqrt{2}E\sin\left(\omega t + 120^{o}\right) = E_m \sin\left(\omega t + 120^{o}\right) \tag{3}$$

$$E_{abf} = \sqrt{6}E\sin\left(\omega t + 30^{o}\right) = \sqrt{3}E_m \sin\left(\omega t + 30^{o}\right) \tag{4}$$

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$$E_{bcf} = \sqrt{6}E\sin\left(\omega t - 90^{o}\right) = \sqrt{3}E_m \sin\left(\omega t - 90^{o}\right) \tag{5}$$

$$E_{caf} = \sqrt{6}E\sin\left(\omega t + 150^{o}\right) = \sqrt{3}E_m \sin\left(\omega t + 150^{o}\right) \tag{6}$$

Where E_{af} , E_{bf} and E_{cf} are fundamental phase voltages, E_{abf} , E_{bcf} and E_{caf} are fundamental line voltage. E_m is maximum voltage.

For PWM control, chopper signals are used for modulating line-to-line voltages. For example, the fundamental wave of the signal u which is to be modulated can be written as:

$$u_{abf} = M \times U_m \times \sin\left(\omega t + \phi\right) \tag{7}$$

$$u_{bcf} = M \times U_m \times \sin\left(\omega t + \phi\right) \tag{8}$$

$$u_{caf} = M \times U_m \times \sin\left(\omega t + \phi\right) \tag{9}$$

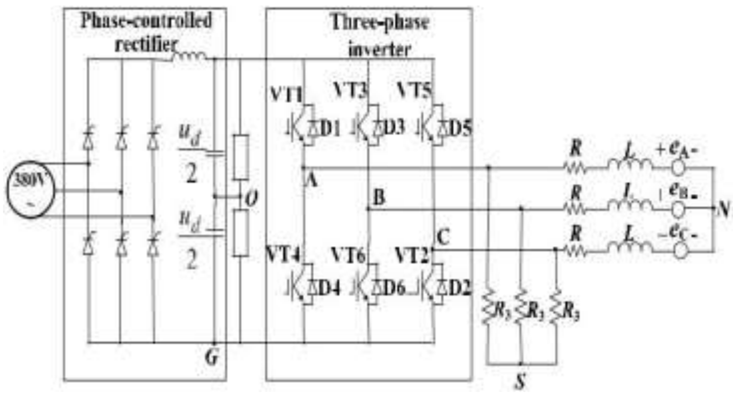

Fig.1 BLDC motor with rectifier and inverter.

The value of modulation index varies between 0 to 1. We used the scheme of PWM generator in [30]. Then two parameters alpha1 and 2 are defined as:

$$\alpha_1 = -\frac{\pi}{2} - \frac{M \times \pi \times \sin\left(\omega t + \phi\right)}{2} \tag{10}$$

$$\alpha_2 = \frac{\pi}{2} + \frac{M \times \pi \times \sin\left(\omega t + \phi\right)}{2} \tag{11}$$

Fourier decomposition is written as:

$$u_{ao} = \frac{u_d}{2}\left(\begin{array}{l} M \times \sin(\omega t + \phi) + \\ \sum_{n=1}^{\alpha} \frac{4}{n \times \pi} \times \sin \left(\begin{array}{l} \frac{Mn\pi}{2} \\ \sin(\omega t + \phi) \\ + \frac{n\pi}{2} \end{array} \right) \\ \cos(n\omega_s t) \end{array} \right) \quad (12)$$

$$u_{bo} = \frac{u_d}{2}\left(\begin{array}{l} M \times \sin(\omega t - 120^o + \phi) + \\ \sum_{n=1}^{\alpha} \frac{4}{n \times \pi} \times \sin \left(\begin{array}{l} \frac{Mn\pi}{2} \\ \sin \left(\begin{array}{l} \omega t - \\ 120^o \\ + \phi \end{array} \right) \\ + \frac{n\pi}{2} \end{array} \right) \\ \cos(n\omega_s t) \end{array} \right) \quad (13)$$

$$u_{co} = \frac{u_d}{2}\left(\begin{array}{l} M \times \sin(\omega t + 120^o + \phi) + \\ \sum_{n=1}^{\alpha} \frac{4}{n \times \pi} \times \sin \left(\begin{array}{l} \frac{Mn\pi}{2} \\ \sin \left(\begin{array}{l} \omega t + \\ 120^o \\ + \phi \end{array} \right) \\ + \frac{n\pi}{2} \end{array} \right) \\ \cos(n\omega_s t) \end{array} \right) \quad (14)$$

Using the above equations, the line values of decomposition is written as:

$$u_{abf} = \frac{u_d}{2}\left(\begin{array}{l} M \times \sin(\omega t + \phi) \\ - M \times \sin(\omega t - 120^o + \phi) \end{array} \right) \quad (15)$$

$$u_{abf} = \frac{\sqrt{3}}{2} M u_d \sin(\omega t + \phi + 30^o) \qquad (16)$$

Harmonic quantity between phases a & b can be written as:

$$u_{abh} = \left(\begin{array}{l} (-1)^{\frac{n+1}{2}} \left(\frac{4}{n\pi} \right) \\ J_k \left(\frac{Mn\pi}{2} \right) \\ \frac{u_d}{2} \sum_{n=1}^{\infty} \sum_{k=2}^{\infty} \times 2 \sin\left(\frac{k\pi}{3} \right) \sin \left(\begin{array}{l} \left(\begin{array}{l} k\omega \\ + n\omega_s \end{array} \right) t \\ + k \\ (\phi - 60^o) \end{array} \right) \end{array} \right) \quad (17)$$

Where J indicates Bessel function of kth order

3. Proposed method

From the literature, it is identified that PAM control is best suitable for high speed applications and PWM control is best suitable for remaining speeds. Therefore, the proposed method involves two parts of training data, the first part involving the PWM behaviour and second part including the PAM behaviour in such a way the ANFIS data is taken to train the membership functions and rules.
The proposed structure is shown in figure 2.

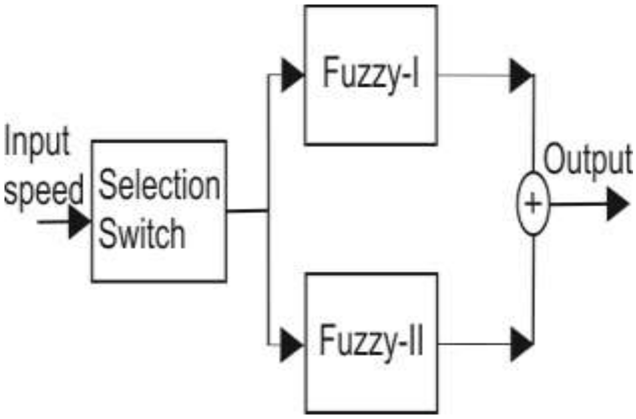

Fig.2 Two level fuzzy system

Fig.2 shows the proposed structure of two level ANFIS, it consists of selection switch, fuzzy-I and fuzzy-II. The switch works based on input speed and connects the controller to respective fuzzy unit for controlling purpose. In this study, the speed less than or equal to 1500rpm is considered as low speed and above 1500 rpm is treated as high speed. Depending upon the speed of the motor, this switch connects fuzzy-I for low speed applications and fuzzy-II for high speed applications.
Fuzzy-I and fuzzy-II are ANFIS models which are tuned based on previous data of low and high speeds. Fuzzy-I works effectively for low speed applications and this output connects to pulse generator of multilevel inverter based on pulses, the output of multilevel inverter changes the output voltage connected to BLDC motor. Similarly fuzzy-II is designed.

4. Results & Discussion

Fig.3 shows the simulation diagram.

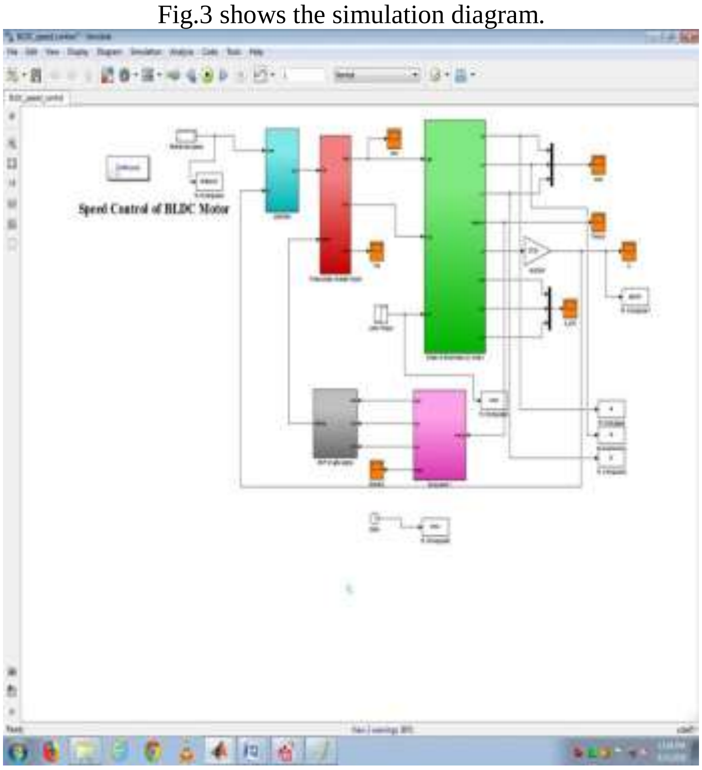

Fig.3 Simulation diagram of BLDC motor.

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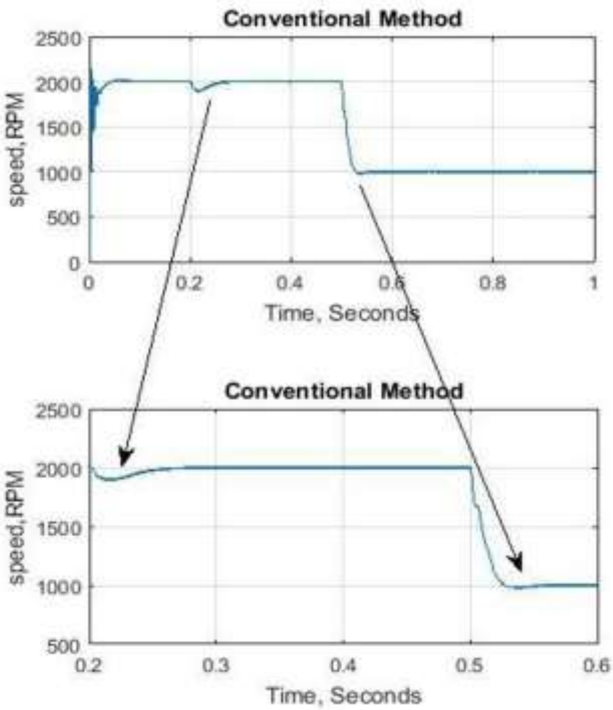

Fig.4 Speed control with conventional method.

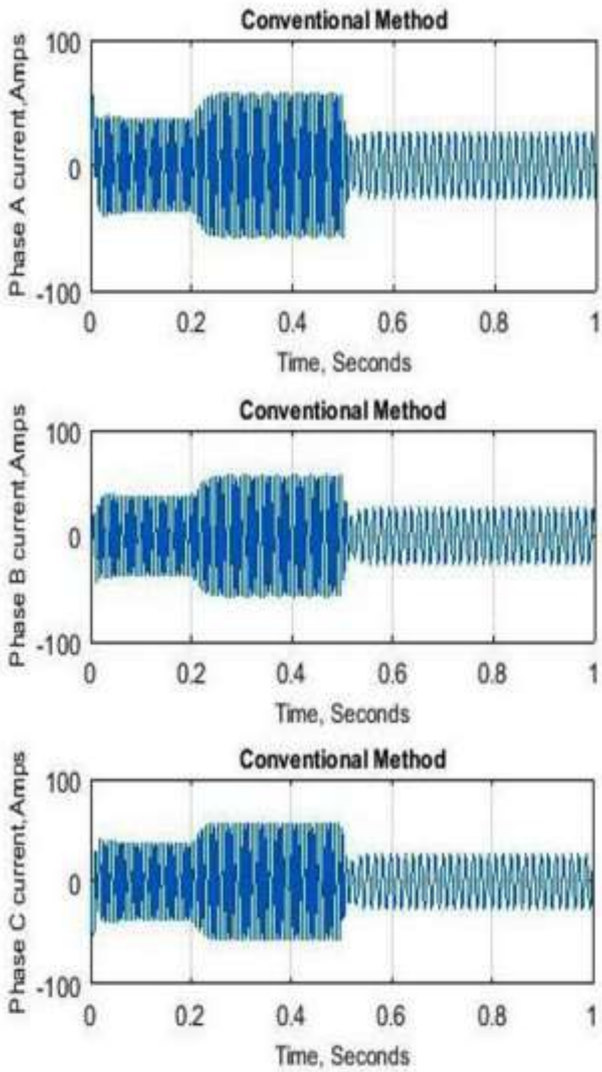

Fig.5 Phase currents of BLDC with conventional method

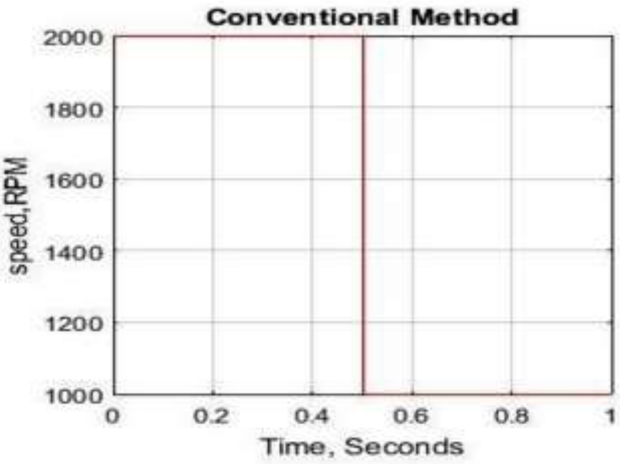

Fig.6 Reference speed for both Conventional & Fuzzy speed control

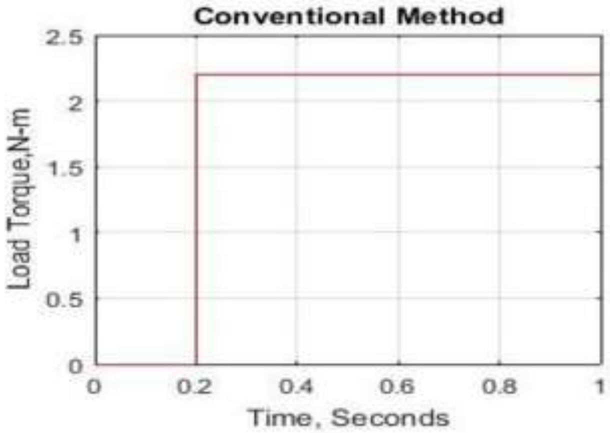

Fig.7 Load Torque for both Conventional & Fuzzy control.

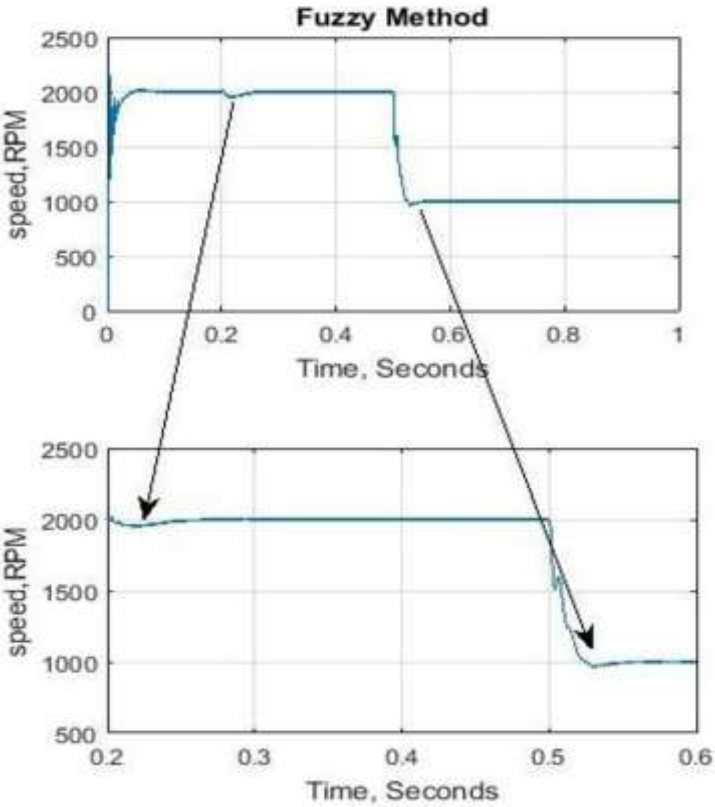

Fig.8 Speed control with Fuzzy controller.

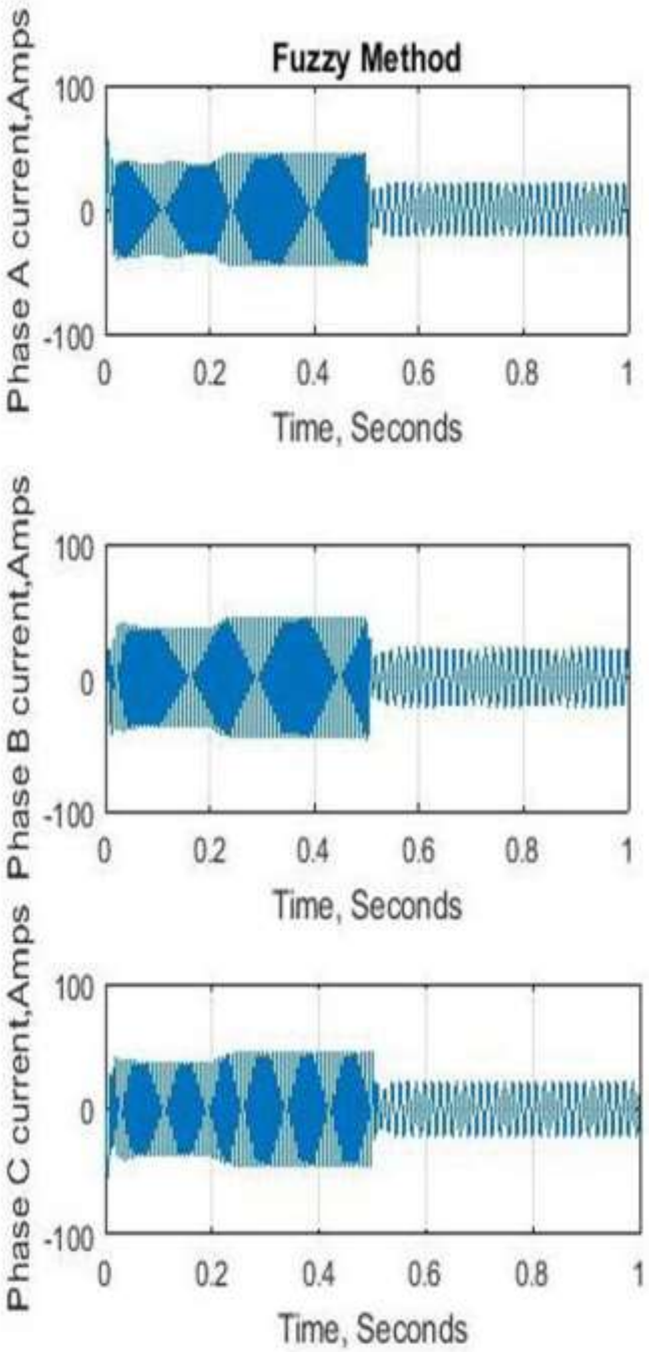

Fig.9 Phase currents of BLDC with Fuzzy controller.

In this study, load torque of 2.2N-m is applied to BLDC motor at 0.2 seconds and reference speed of 2000rpm at 0 second is changed to 1000 rpm at 0.5 seconds, which are shown in figures 6 and 7 respectively.

After the application of load torque at 0.2 seconds, the speed of the motor after load torque deviation took 0.26 seconds in conventional method and 0.25 seconds in ANFIS method to reach 2000 rpm with reduced magnitude impact. At 0.5 seconds when the reference speed is changed from 2000 rpm to 1000 rpm, BLDC drive is taking the time from 0.5 to 0.56 seconds in conventional method and from 0.5 to 0.54 seconds in ANFIS method to change the speed of the motor to 1000 rpm, which are shown in figures 4 and 8 respectively.

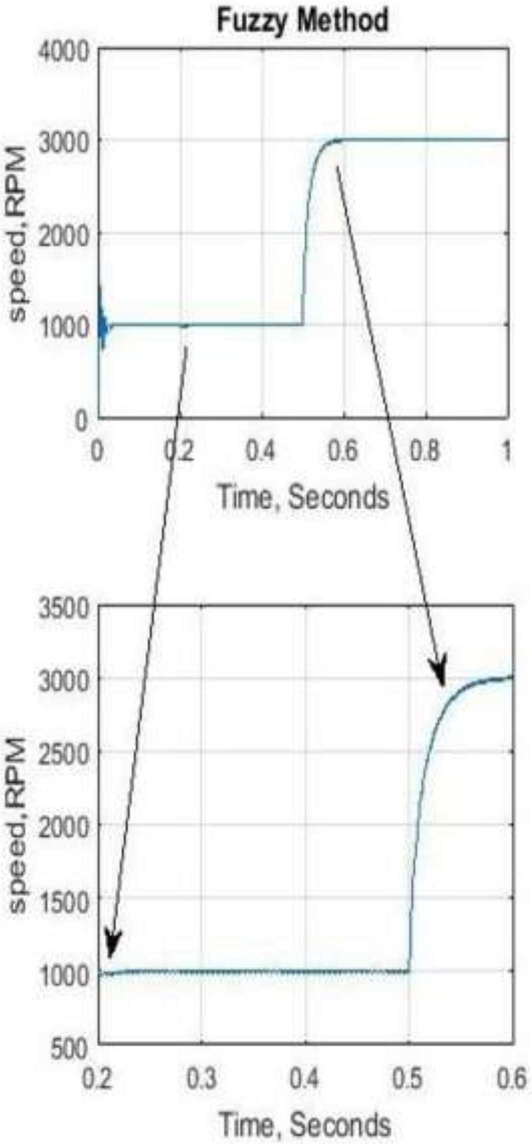

Fig.10 Speed control with Fuzzy controller (speed changing from 1000 t0 3000 rpm).

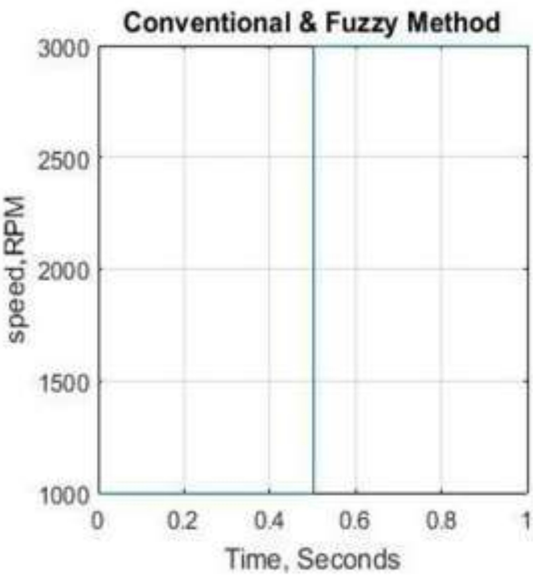

Fig.11 Reference speed for both Conventional & Fuzzy.

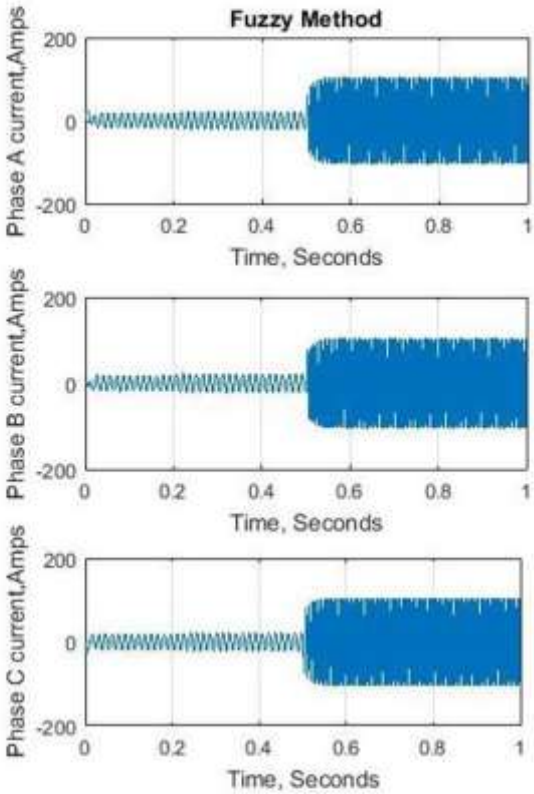

Fig.12 phase currents of BLDC motor with Fuzzy controller (speed changing from 1000 to 3000 rpm).

Similarly, the proposed method is tested with another set of speed variation by changing the reference speed from 1000 to 3000 rpm. In all the above cases, proposed method is working effectively as compared to conventional method (as per figures 10 to 12).

5. Conclusion

Accepting the concluded results from past studies about PWM and PAM techniques that PAM gives high-handed performance at medium and high speeds while PWM is more competent at low speeds, a hybrid ANFIS model is proposed combining both PWM and PAM control and tested for different speed control applications, load variations. The obtained results are compared with conventional control method and from the results, it can be inferred that proposed method controls speed effectively as compared to conventional methods under different speed applications and load applications.

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