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APPLICATION OF PERMANENT MAGNET DC DRIVES FOR PAPER AND PULP MILLS

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Abstract- The aim of this work is to improve the tracking performance of Permanent Magnet Direct Current (PMDC) motors by exploring the features of Fuzzy Logic Controller. The Fuzzy Logic Controller enhances the performance and dynamics of the D.C motor in comparison to conventional PI controller. The simulations are carried out with MATLAB Simulink. The Fuzzy based PMDC Drive is suitable for vast number of industries like paper mills, Pulp mills, Textile mills etc.,
Keyword: Separately excited D.C Motor, PI Controller, Fuzzy Logic Controller.

I. INTRODUCTION

The D.C motors have staged a comeback with the advent of the Silicon Controlled Rectifiers used for power conversion, facilitating a wide range of speed control of these motors. The Permanent magnet D.C motor with PI controller is widely used in industries where the load changes are very small however in certain applications, like rolling mill or machine tools where the system parameters vary substantially the conventional controllers like PI or PID is not preferable due to the fact that the drive operates under the wide range of changing load characteristics. The modern automated industries introduce the variable speed drives, increases the productivity and thereby efficiency is increased considerably by 15 – 27%. Since the conventional controllers are delivering poor performance for the variable speed drive, it is necessary to have an efficient controller which suits for Non-linear operating condition.

The Fuzzy logic system is a robust system where no precise inputs are required. These systems can accommodate several types of inputs including vague, distorted, or imprecise data. In case the feedback sensor stops working, there is possibility to reprogram it according to the situation. The proposed scheme presents the application in estimating and controlling the speed of the PMDC drive to a set value.

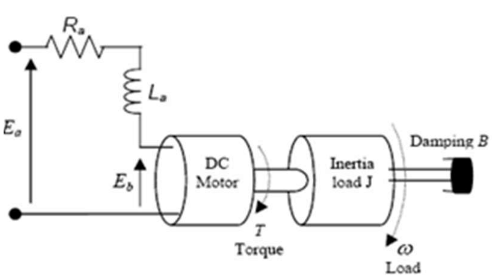

Fig.1 The Structure of DC Machine

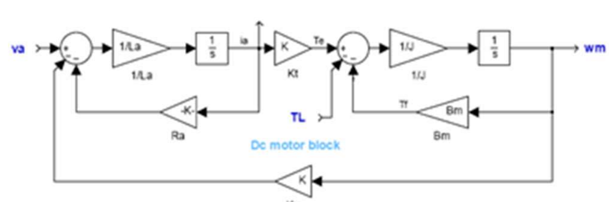

Fig. 2. Mathematical Model of DC Motor

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II Model of DC Motor

The starting performance of the separately excited D.C motor is affected by its nonlinear behavior. The speed control D.C motor is done with different control strategies. DC motors are widely used in industrial and domestic equipment. The control of the position of a motor with high accuracy is required. The electric circuit of the armature and free body diagram of the rotor are shown in the figure. 1 and mathematical model is shown in figure.2. A desired speed may be tracked when a desired shaft position is also required. In fact, a single controller may be required to control both the position and the speed. The reference signal determines the desired position and/or speed. The controller is selected so that the error between the system output and reference signal eventually tends to its minimum value, ideally zero. There are various DC motor types. Depending on type, a DC motor may be controlled by varying the input voltage whilst another motor only by changing the current input. In this paper a DC motor is controlled via input voltage as shown in figure.1.

The control design and theory for controlling DC motor via current is merely the same. However, the method works successfully for any reference signal particularly, for any stepwise time continuous function. The terminal voltage applied to a DC motor is given by,

$$V_t = I_a R_a + L_a \frac{di_a}{dt} + K_m \omega_m \tag{1}$$

Under steady state condition, Equation (1) becomes,

$$V_t = I_a R_a + E_b \tag{2}$$

$$V_t = I_a R_a + K_m \omega_m \tag{3}$$

Torque developed by the PMDC motor is given by,

$$T = K_m I_a \tag{4}$$

Where 'Km' depends on magnetic material used in PMDC motor. The relation between torque and speed under steady state condition
is derived as,

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$$V_a = \frac{T_e}{K_t} R_a + K_t \omega \quad (5)$$

$$T_e = T_1 + J \frac{d\omega_n}{dt} \quad (6)$$

Where the value of 'ω' is given by,

$$\omega = \frac{V_a}{K_a} - \frac{T_e}{(K_a)^2} R_a \quad (7)$$

Where "T_1" is given as,

$$T_1 = T_l + B\omega_n \quad (8)$$

The equations of analogous mathematical circuit are derived from Newton's law as,

Thus equation (7), can be written as,

$$T_e = T_1 + B\omega_n + J \frac{d\omega_n}{dt} \quad (9)$$

From the above derived equations, the transfer function of the PMDC motor can be obtained. The transfer function is the laplace transform of output to the laplace transform of input. Applying the laplace transform for the above equations,

$$V_a(s) = I_a(s) R_a + L_a s I_a + E_b(s) \quad (10)$$

$$E_{b(s)} = K_t \omega(s) \quad (11)$$

$$T_e(s) = K_m I_a(s) \quad (12)$$

$$T_e(s) = T_l(s) + B\omega_n(s) + sJ\omega_n(s) \quad (13)$$

III CLOSED LOOP CONTROL OF PMDC DRIVE WITH PI CONTROLLER

Closed loop control of PMDC drive with PI controller is shown in figure.3. The Speed of DC motor changes with change in load torque. The armature voltage to be varied continuously to maintain a constant speed by varying the delay angle of AC-DC Converter. In practical drive system it is required to operate the drive at a constant torque or constant power. PMDC drives are more suitable for places wherein it reduces the electricity consumption, reaches remarkably high horsepower at low voltage. Moreover, the PMDC drives possess the following advantages. A modern electrical direct drive uses a permanent magnet motor directly coupled to a paper machine without the need for gearboxes found in standard induction motors, direct drives offer multiple advantages like improved efficiency of the system, Power management, Safer operations with improved reliability, reduces the Engineering cost and reduces the footprint and maintenance requirement.

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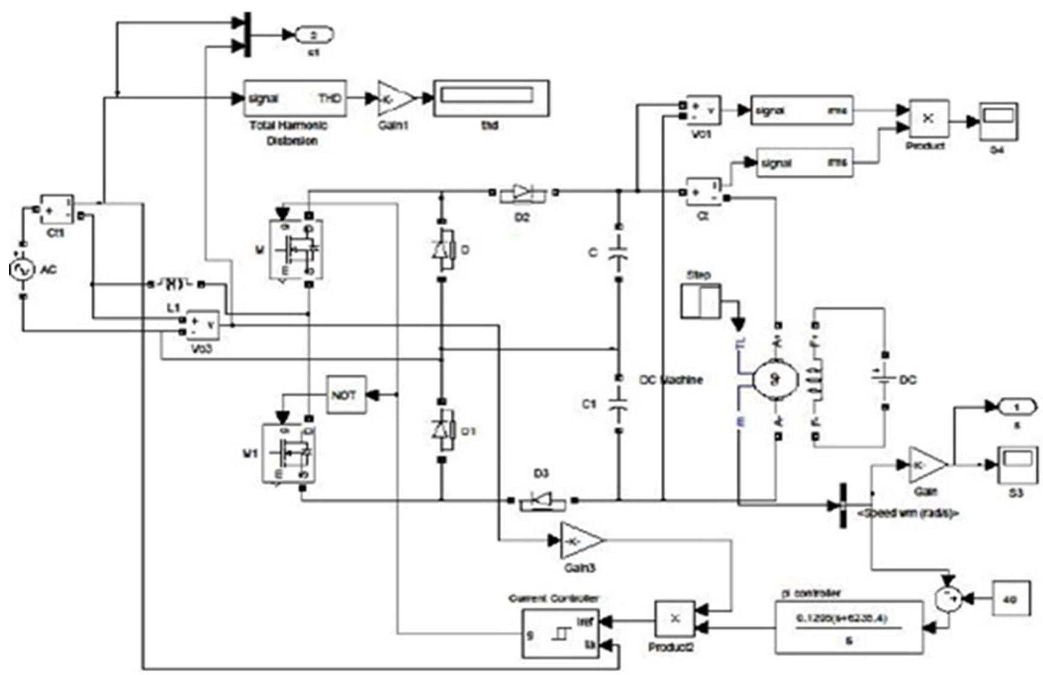

Fig. 3. Closed loop control circuit for PMDC motor using PI controller.

In addition, controlled acceleration and deceleration are required for the driver to perform the assigned task. Most industrial drives operate in closed loop feedback system. A closed loop control system has advantages like improved accuracy, fast dynamic response, and reduced effects of load disturbances. If the speed of the motor decreases due to the application of additional load torque, the speed error increases. The speed controller reduces the delay angle of the converter and increases the armature voltage of the motor. An increased armature voltage develops more torque to restore the motor speed to the original value. The drive normally passes through a transient period until the developed torque equals the load torque. From figures 5 & 6, it is clear that the sudden increase in load torque results in sudden decrease in speed. But due to the application of PI controller in the closed loop, the system regains its previous speed or set speed in 3.5 Seconds. Since the changes in the output due to external Load disturbances are not corrected automatically in the case of open loop system, the closed Loop control of PMDC drive is much preferred in all industrial applications. Similarly, as the speed decreases at 5 sec as shown in figure.5, corresponding increase in armature current and decrease in converter output voltages are obtained as shown in Fig (4).

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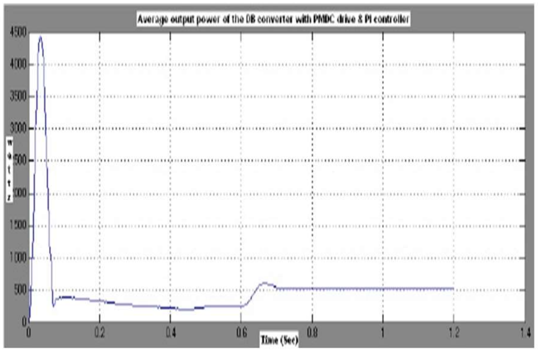

Fig. 4. Average output power of DB Converter fed PMDC motor with PI Controller

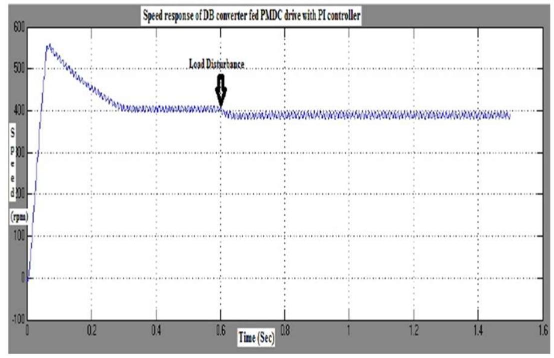

Fig 5. Speed response of DB Converter Fed PMDC drive with PI Controller

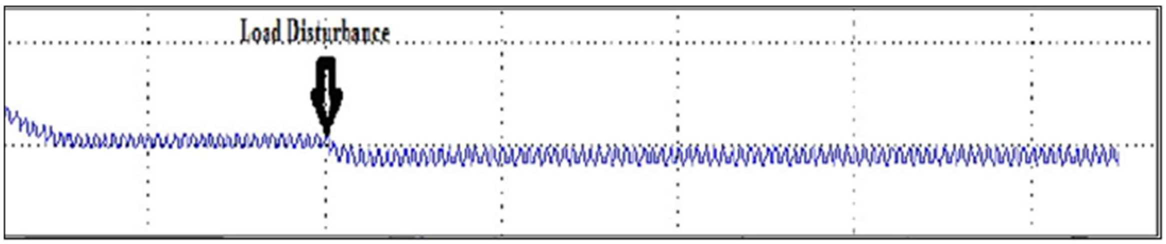

Fig 6. Speed response of DB Converter Fed PMDC drive with PI Controller (Zoomed Response).

The speed response of the PMDC drive with PI controller is shown in figures.5 & 6. It is clear that the speed of the PMDC drive drops down due to the application of load. To maintain the constant speed of PMDC drive, a PI controller is employed in the closed loop. PI controller tries to bring back the speed of the drive to match its set speed.

The ability of the PI controller to regain the drive speed by the application of load disturbance is not appreciable as shown in figures.5 & 6. To overcome the above drawbacks in PMDC drive with PI Controller, a fuzzy logic controller is employed for better Speed regulation under uncertain load conditions.

IV. Fuzzy Logic Control

Fuzzy system is a robust system where no precise inputs are required. These systems can accommodate several types of inputs including vague, distorted, or imprecise data. In case the feedback sensor stops working, one can reprogram it according to the situation. Fuzzy logic control has been widely used for nonlinear higher order and time delay systems. Because of their knowledge based nonlinear structural characteristics they are applied to nonlinear systems. Fuzzy controller can perform online and offline parameter operations. The error(e) and change in error(ce) of speed of PMDC drive is given as input to Fuzzy logic controller as shown in figure.7.

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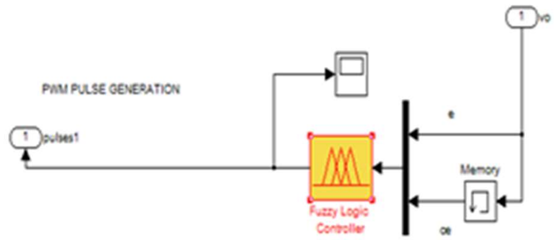

Fig 7. Fuzzy Logic Controller model

IV.I. Inputs and Outputs

The universe of discourse (range) of the inputs is divided into several fuzzy sets of desired shapes. The membership functions for the input Fuzzification of are shown in Figures 8 & 9.

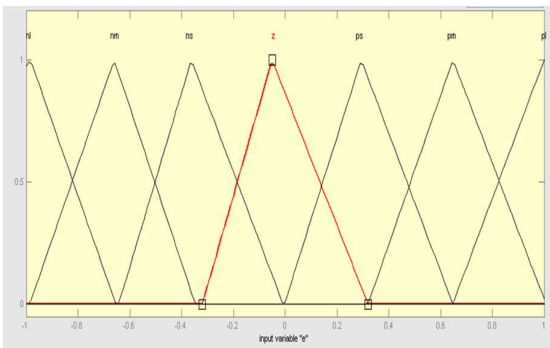

Fig.8. Input Variable (error, e) for Fuzzy Logic Controller

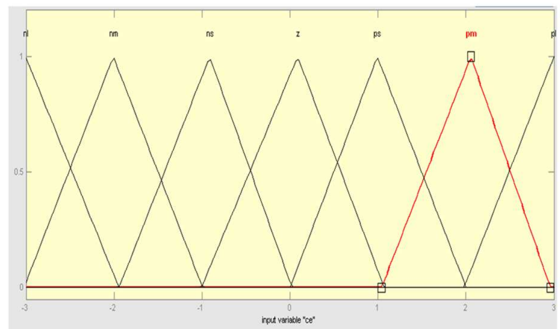

Fig.9. Input Variable (Change in error, ce) for Fuzzy Logic Controller

Outputs are also mapped into several fuzzy regions of desired shapes (For mamdhani type system) as shown in figure.10. In this specific problem, output memberships are represented by 17 sugeno type singletons taking values between -1 to 1.

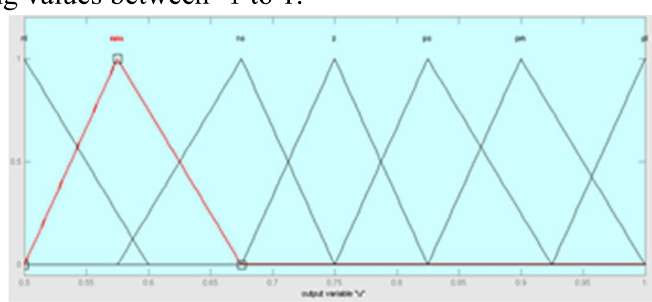

Fig.10. Output Variable for Fuzzy Logic Controller

The rules connecting the inputs and the output singletons are based on the understanding of the system. Normally the fuzzy rules have if… then… structure. The inputs are combined by AND operator. Rules developed in the work are given in Table I.

Table.1 Development of Rule Base

e / ce	NL	NM	NS	Z	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	Z

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NM	NL	NL	NL	NM	NS	Z	PS
NS	NL	NL	NM	NS	Z	PS	PM
Z	NL	NM	NS	Z	PS	PM	PL
PS	NM	NS	Z	PS	PM	PL	PL
PM	NS	Z	PS	PM	PL	PL	PL
PL	Z	PS	PM	PL	PL	PL	PL

IV.I1. Defuzzification

The output space 'fired' singletons is 'defuzzified' to get a final 'crisp' value of incremental control. Several defuzzification methods are available [2]. The Centre of gravity method is most used method which gives the defuzzified 'crisp' value as:

$$Z_0 = \sum_{i=1}^{N} C1 * Wi \Big/ \sum_{i=1}^{N} Wi \qquad (14)$$

where 'Wi' is the membership Value of the output set 'i' and 'C1' is the corresponding singleton value, and 'N' is the no of output singletons. The defuzzified value 'Zo' is multiplied by a gain to get the incremented duty ratio. The lower gain helps in reducing the oscillations of the fuzzy controller but gives slower response. Higher gains make the controller oscillatory.

V. CLOSED LOOP CONTROL OF PMDC DRIVE WITH FUZZY LOGIC CONTROLLER

A closed loop control system has advantages like improved accuracy, fast dynamic response, and reduced effects of load disturbances. The figure.12, shows the closed loop operation of PMDC drive with fuzzy logic controller. The Simulations are carried out using MATLAB. Fuzzy logic control is a control algorithm based on a linguistic control strategy, which is derived from expert knowledge into an automatic control strategy. fuzzy logic control doesn't need any difficult mathematical calculation like the other control system. While the other control system uses difficult mathematical calculation to provide a model of the controlled plant, it only uses simple mathematical calculation to simulate the expert knowledge. Although it doesn't need any difficult mathematical calculation, it can give good performance in a control system. Thus, it can be one of the best available answers today for a broad class of challenging controls problems.

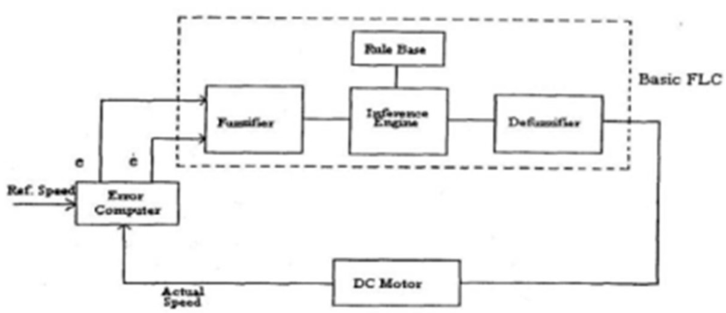

Fig. 11. Block Diagram of Fuzzy Logic Controller

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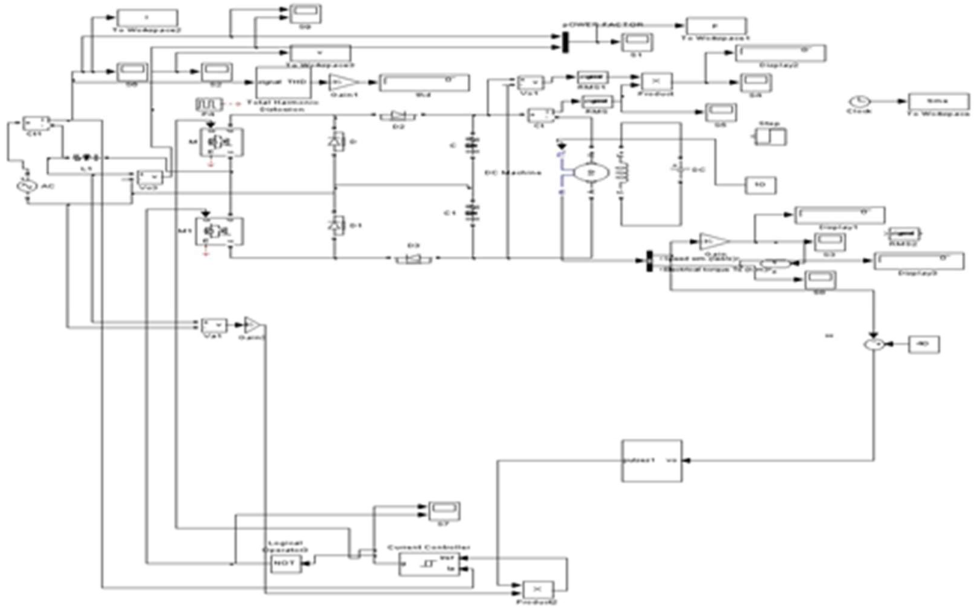

Fig.12. Closed Loop Control of PMDC Drive with Fuzzy Logic Controller

Initially, the PMDC drive is made to run at a set speed of 400 rpm, the response of the drive is obtained for a constant load torque. The responses of PI and Fuzzy logic controller for PMDC drive is shown in figure (13). The simulation results clearly shows that the PMDC drive produces lesser maximum overshoot and settling time compared to PI controller [8].

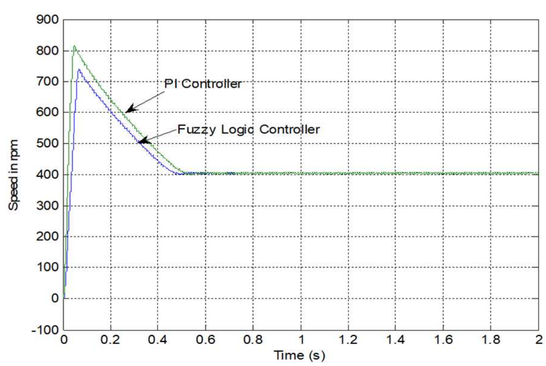

Fig.13. Response of PMDC Drive for Constant Load Torque

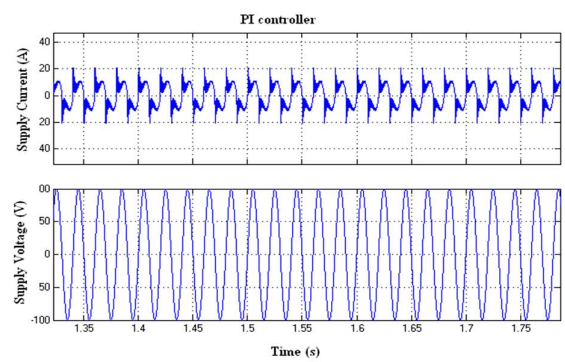

Fig.14. Supply Current & Supply Voltage for PI Controller

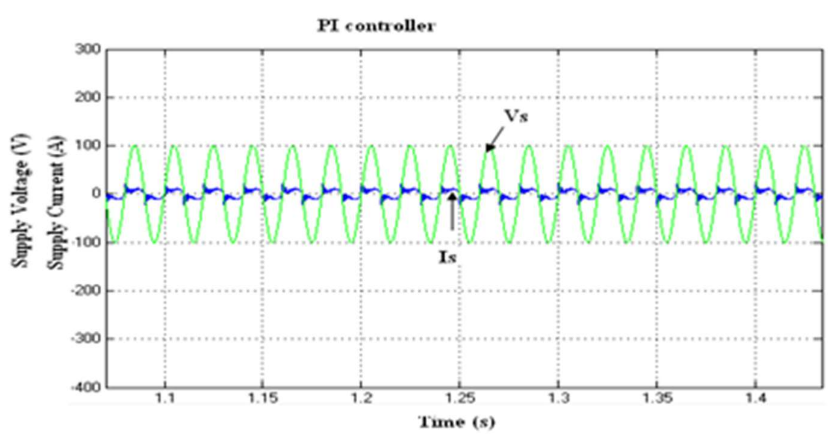

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Fig.15. Combined Supply Current Vs Supply Voltage for PI Controller

The figures (14) & (15) shows the magnitude of supply voltage and supply current and its phase difference by the application of PI Controller where as figures (16) & (17) shows the magnitude of supply voltage and supply current and its phase difference by the application of Fuzzy Logic Controller. The figure (18) reveals the effectiveness of the proposed Fuzzy Logic Controller in eliminating the supply harmonics [3].

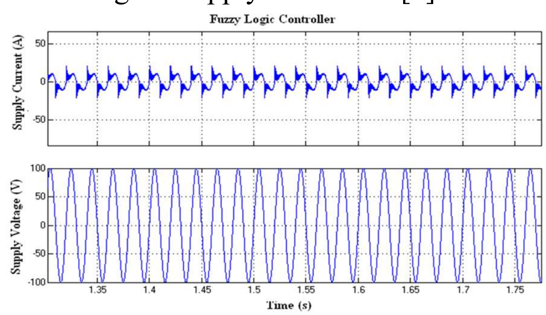

Fig.16. Supply Current & Supply Voltage for Fuzzy Logic Controller (Constant Load)

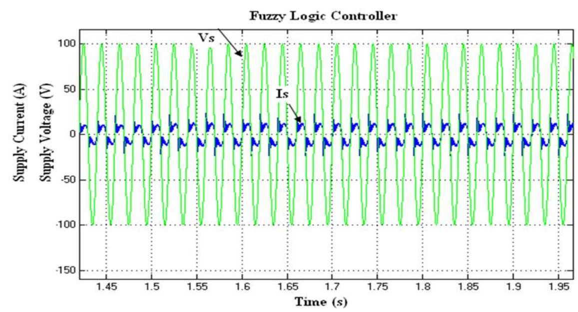

Fig.17. Supply Current & Supply Voltage for Fuzzy Logic Controller (Constant Load)

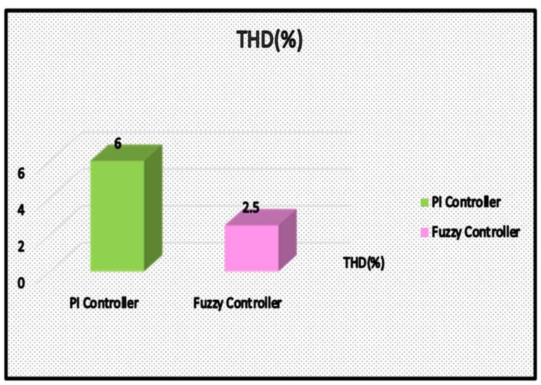

Fig.18. THD for PMDC Drive due to PI and proposed Fuzzy Logic Controller

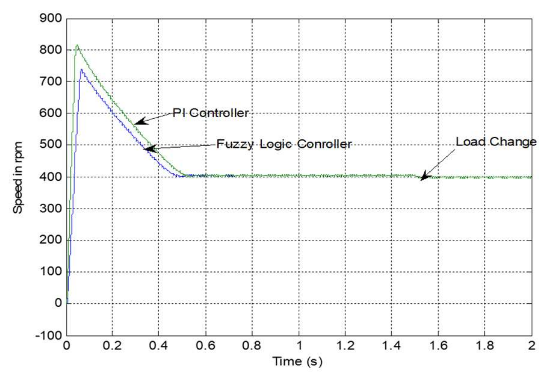

Fig.19. Response of PMDC Drive for Load Change (+20% Load variation)

The figures (20) & (21) show the magnitude of supply voltage and supply current and its phase difference by the application of PI Controller with 20% load variations. The fig (22) shows the response of PMDC Drive with positive variation in load torque. The positive variation on load torque does not affect the set speed of the PMDC drive by the application of proposed Fuzzy Logic Controller whereas it was observed in case of PI Controller.

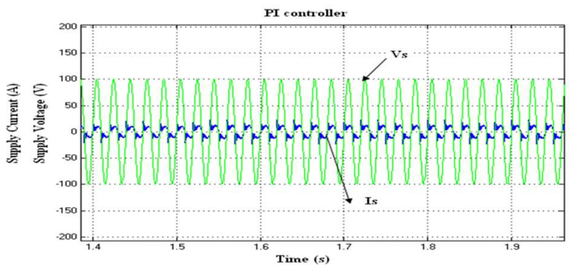

Fig.20. Combined Supply Current Vs Supply Voltage for PI Controller for Positive Load Change (+20% Load Torque Variation)

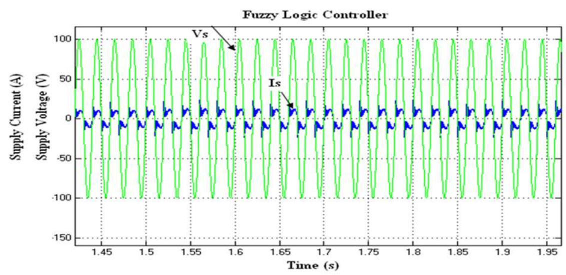

Fig.21. Combined Supply Current Vs Supply Voltage for Fuzzy Logic Controller for Positive Load Change (+20% Load Torque Variation)

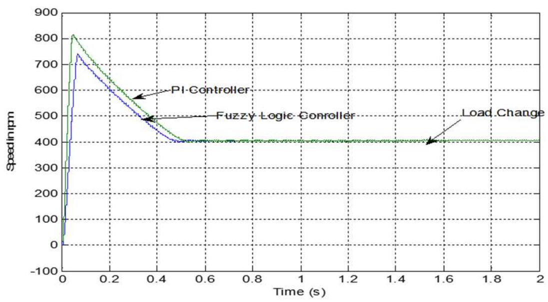

Fig.22. Response of PMDC Drive for Positive Load Change with PI & Fuzzy Logic (+20% Load Torque Variation) Controller

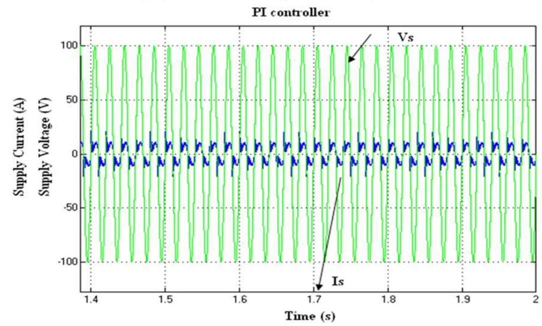

Fig.23. Combined Supply Current Vs Supply Voltage for PI Controller for Negative Load Change (-20% Load Torque Variation)

The figures (23) & (24) show the magnitude of supply voltage and supply current and its phase difference by the application of PI Controller & Fuzzy Logic Controller. The fig (25) shows the response of PMDC Drive with negative variation in load torque. The negative variation on load torque does not affect the set load torque, speed of the PMDC drive by the application of proposed Fuzzy Logic Controller whereas it was observed in case of PI Controller [5].

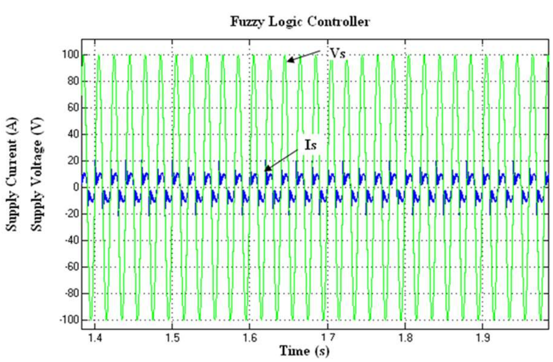

Fig.24. Combined Supply Current Vs Supply Voltage for Fuzzy Logic Controller for Negative Load Change (-20% Load Torque Variation)

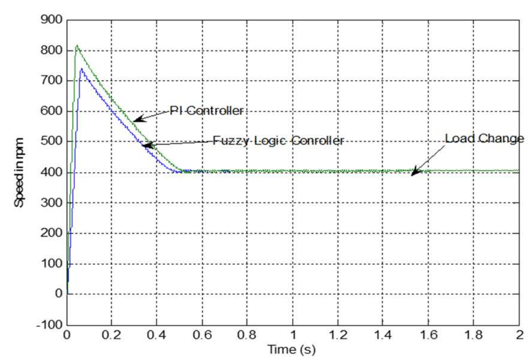

Fig.25. Response of PMDC Drive for Negative Load Change with PI & Fuzzy Logic Controller (-20% Load Torque Variation)

The stability of the PMDC drive by the application of Fuzzy logic controller was analyzed in both positive and negative load variations. In addition to that the component variation of converter (shown in fig. 26 & 27) also performed and the response of PMDC drive was investigated. All the simulation results confirm the superiority of the Fuzzy Logic Controller in terms of minimizing the supply harmonics, reducing the settling time and peak overshot of the drive's response. The simulation result also shows the Double boost converter produces the unity power factor under all load conditions, which is desirable quality of the converter for variety of modern

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industrial applications [3].

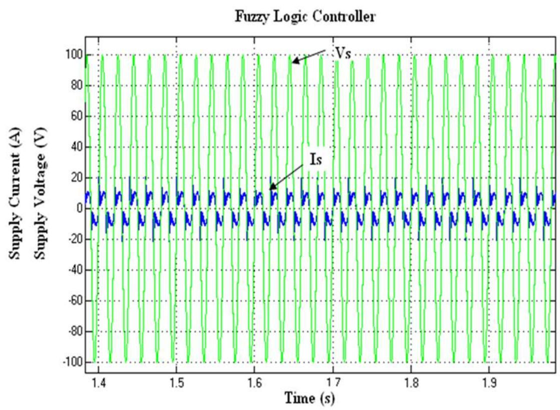

Fig.26. Combined Supply Current Vs Supply Voltage for Fuzzy Logic Controller for Capacitance Variation from 200μF to 250 μF.

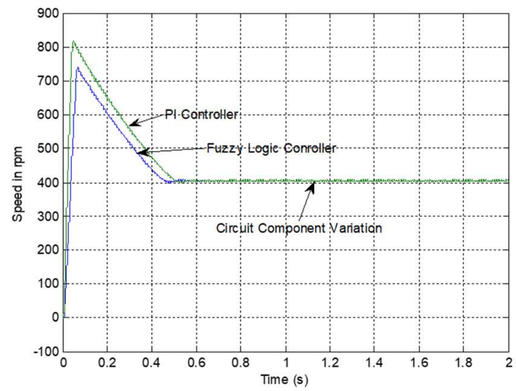

Fig.27. Response of PMDC Drive for Capacitance Variation from 200 μF to 250 μF.

The stability of the system is analyzed by finding the Time-Domain Specifications of PMDC system drive when it is applied to PI and Fuzzy Logic controller.

TABLE II: TIME DOMAIN SPECIFICATIONS ANALYZED FOR SIMULATED PMDC DRIVE

SPECIFICATIONS	PI CONTROLLER			FUZZY LOGIC CONTROLLER		
	Constant load	+20% Load	-20% Load	Constant load	+20% Load	-20% Load
Rise Time (Sec)	0.02	0.02	0.02	0.04	0.04	0.04
Peak Time (Sec)	0.04	0.05	0.04	0.06	0.06	0.06
Maximum Peak Overshoot (%)	100	100	100	85	85	85
Settling Time (Sec)	0.5	0.5	0.5	0.48	0.48	0.48
Recovery Time for Load Variations (Sec)	-	∞	∞	-	0.02	0.02
THD (%)	-	6.0	-	-	2.5	-

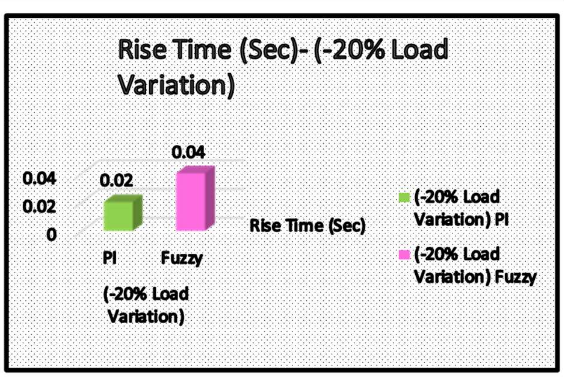

Fig.28. Rise time response of PI & Fuzzy Controller with - 20% Load variation

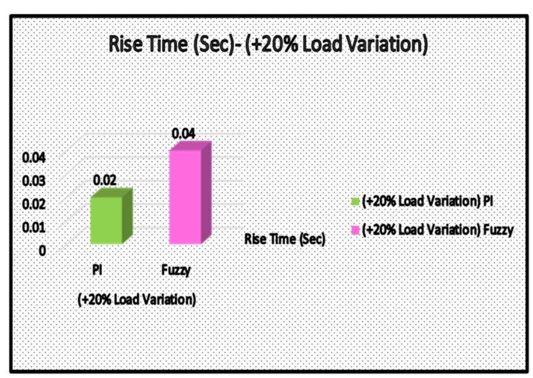

Fig.29. Rise time response of PI & Fuzzy Controller with +20% Load variation

Fig.30. Rise time response of PI & Fuzzy Controller with

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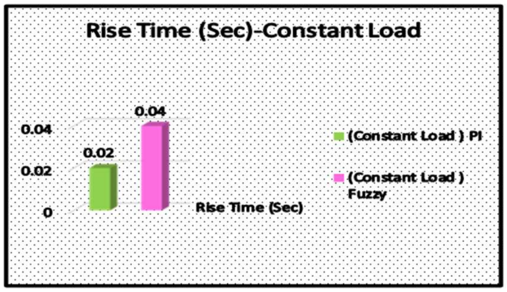

Fig.30. Rise time response of PI & Fuzzy Controller with Constant Load variation

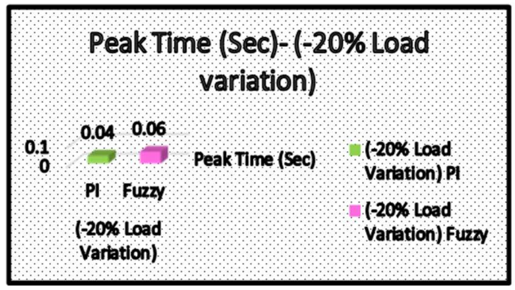

Fig.31. Peak time response of PI & Fuzzy Controller with - 20% Load variation

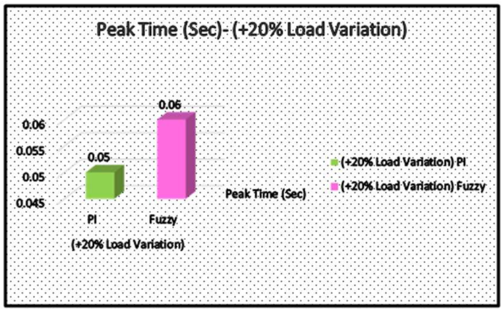

Fig.32. Peak time response of PI & Fuzzy Controller with +20% Load variation

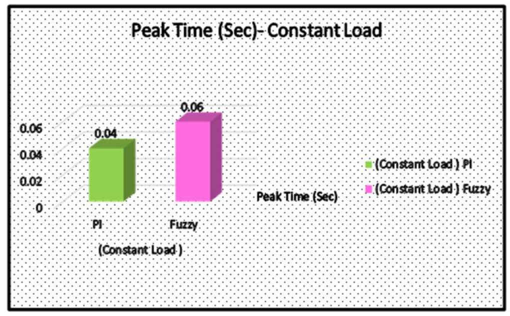

Fig.33. Peak time response of PI & Fuzzy Controller with Constant Load variation

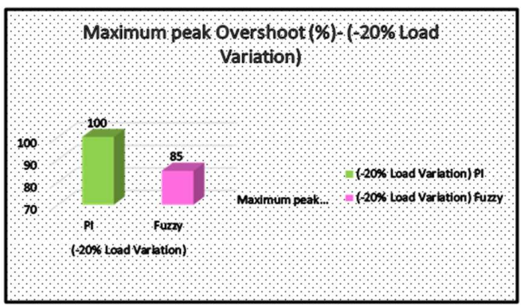

Fig.34. Maximum peak overshoot response of PI & Fuzzy Controller with -20% Load variation

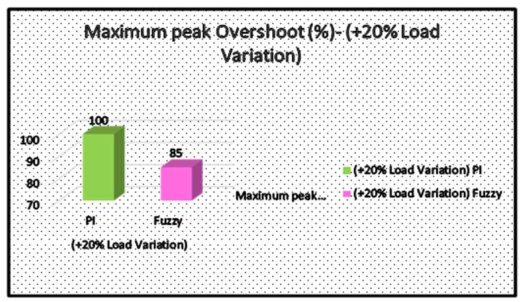

Fig.35. Maximum peak overshoot response of PI & Fuzzy Controller with +20% Load variation

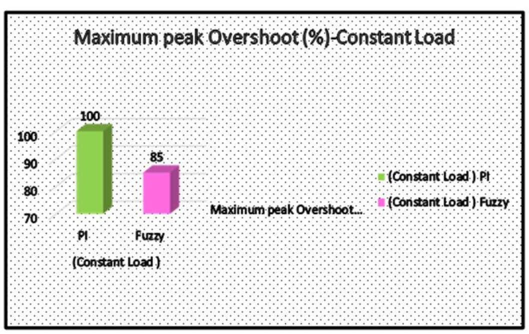

Fig.36. Maximum peak overshoot response of PI & Fuzzy Controller with Constant Load variation

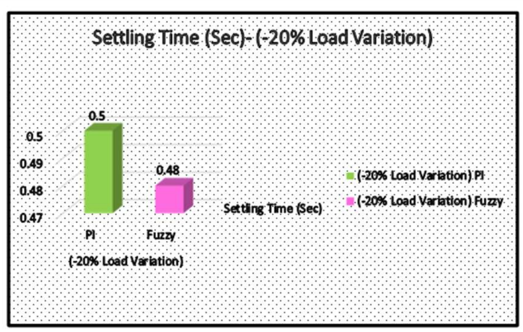

Fig. 37. Settling time response of PI & Fuzzy Controller with -20% Load variation

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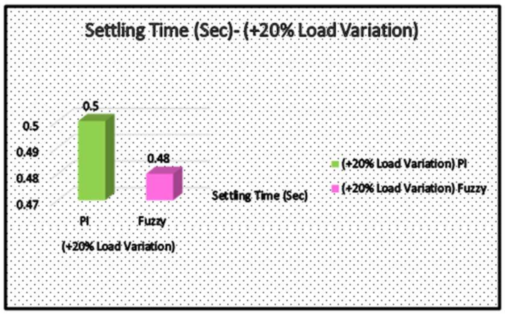

Fig. 38. Settling time response of PI & Fuzzy Controller With +20% Load variation

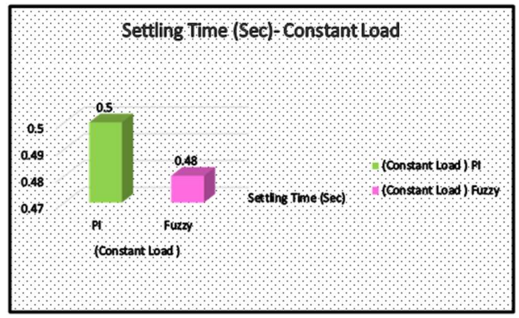

Fig. 39. Settling time response of PI & Fuzzy Controller With Constant Load variation

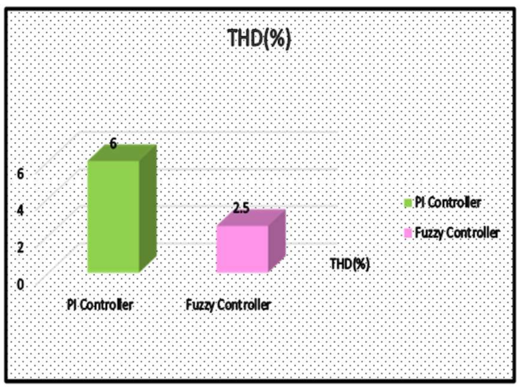

Fig. 40. THD level for PI & Fuzzy logic control

TABLE III
SPECIFICATIONS ADOPTED FOR THE SIMULATED PMDC DRIVE

Armature Resistance	R_a	0.5[Ohm]
Armature Inductance	L_a	0.01[H]
Field Resistance	R_f	240[Ohm]
Field Inductance	L_f	120[H]
Field-Armature Mutual Inductance	L_{af}	1.23[H]
Total Inertia	J	0.05[Kg.m^2]
Viscous friction Coefficient	B_m	0.02[N.m. s]
Coulomb friction torque	T_f	0[N-m]

The Simulations are carried out using MATLAB and the parameters of the PMDC drives for Conventional PI Controller and the proposed Fuzzy Logic Controller were analyzed and are tabulated in Table I. From Table I, the fuzzy Logic Controller shows its superiority under variety of load conditions like Constant load, Incremented load, and Decremented load. The Fuzzy Logic Controller also maintains the stability of the response of PMDC drive under the variation in circuit component values. The ability of the PMDC drive in maintaining constant speed with the Fuzzy Logic Controller is the most wanted characteristics of Paper mill, Rolling mill, Textile Mill and Sugar mill etc.,

VI. ROLE OF DC MACHINE IN MODERN PULP AND PAPER MILLS:

Paper mills use specialist machines equipped with large DC Motors to produce pulp from raw material, convert pulp to paper, wind to reel and post-produce by slitting, coating, printing, and packaging. Paper machine applications require particularly wide speed & torque control from the Drive system. For example, winders and coilers require the DC Drive to provide constant torque over a wide speed range down to exceptionally low motor speeds or even standstill. Large diameter paper reels present high-inertia loads to the DC motor that requires high-bandwidth control from the DC Drive – as well as the ability to regenerate back to the mains.

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Sprint Electric Digital DC Drives are installed in hundreds of paper mills globally and provide consistent and durable performance across the entire range of paper machine applications. Sprint Electric Digital DC Drives are used in the forming, press, drying and calendar sections for unwind, rewind, traverse, and general motor control applications. DC Drives are also used in post-production applications such as grinding, folding, printing, stamping, slitting, packaging, and wrapping.

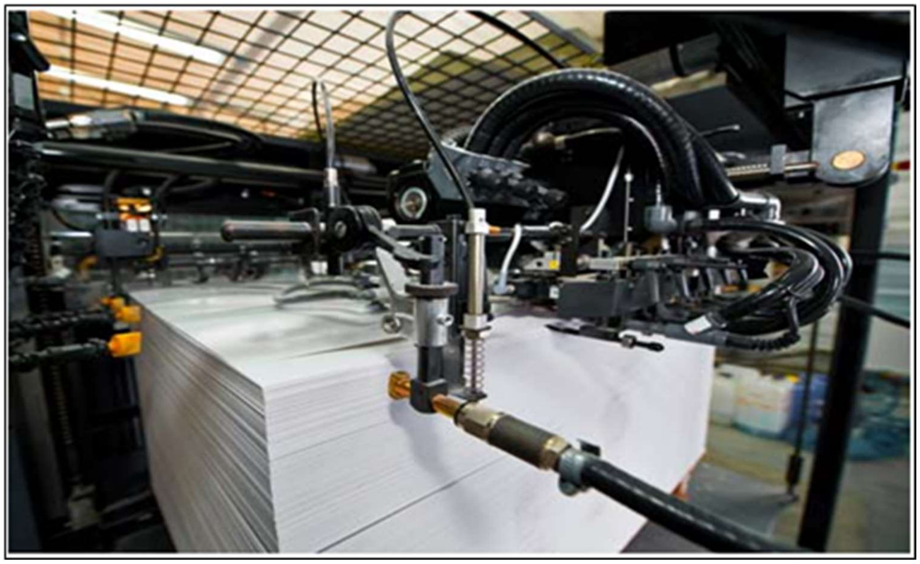

Figure.41. Modern Industrial Paper and Pulp Machinery

VI.I. PAPER PROCESSING WINDERS & REELERS

Paper must be cut into sizes, when the paper has been wound onto reels from the paper machine, that suit the downstream printing process. Re-sizing is carried out on a slitter re-winder. Paper is fed from the unwind stand, through a set of slitter knives, then driven back to a re-wind system. This process requires separate speed control and torque control to ensure consistency of paper wrap during the wind-up process. Sprint Electric Digital DC Drives provide exceptional bandwidth for high inertia loads as well as full regenerative capabilities providing energy efficient quick stop capabilities.

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Figure.42. Paper processing Winders and Reelers

IV. CONCLUSION

In this paper the performance with Fuzzy controller is compared with Conventional PI Controller. The simulation result proves that the proposed Fuzzy Controller is a robust and insensitive controller and is well suited for systems with uncertain and unknown variations in plant parameters. The response of the PMDC drive is observed to shoot up in PI based control scheme to attain stability. The speed is observed to be stable at a faster rate by using Fuzzy controller for any load variations.

The average output power delivered by the Double boost converter and the Total Harmonic Distortion (THD) on supply side are calculated for PMDC drive with PI and Fuzzy Logic Controller using MATLAB simulation, of which the Fuzzy controller produces the better results which are within the IEEE specified limit and are tabulated in Table I.

So, it is concluded that the combination of Fuzzy Logic controller with Double boost converter delivers better speed response with PMDC drive which will not affect the quality of the product. Many industrial applications suffer largely by their hormonic contents either at supply or load side. It is very clear that the "Total Hormonic Distortion (THD)" is meager in case of Fuzzy Controller compared to PI controller. The output voltage of the "Double Boost Converter" is superior and hence output quality is improvised considerably in case of Fuzzy Logic controller fed PMDC drive which is the wanted quality in case of paper mills, Textile mills etc.,

AUTHOR PROFILE

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