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FPGA based Performance Analysis of Speed Control Permanent Magnet Synchronous Motor Drive with Pi and Fuzzy Logic Controller

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Abstract: ***Present research demonstrates an experimental work and simulation of FPGA based PMSM drives consists of PI and Fuzzy logic controller, for speed control under load, zero load and random change in load conditions. It also delineates the overall performance of a closed loop vector Permanent Magnet Synchronous Motor (PMSM) drive consisting of two loops, current for inner and speed for outer loops for better speed tracking systems. The resistive load which is connected across the armature of dc shunt motor and coupled with PMSM is varied. The resultant speed and torque are studied in details. Result showed that in case of fuzzy logic controller, the peak overshoot and settling time can be minimized. This FPGA based PMSM drives can be used for different paramount application under constant speed.***

Keywords: PI-controller, Fuzzy logic controller (FLC), Permanent Magnet Synchronous Motor (PMSM), FPGA

I. INTRODUCTION

Permanent Magnet Synchronous Motor (PMSM) drives having special features are able to meet fast dynamic response, high power factor, and wide operating speed range in comparison to conventional AC machine drives. PMSM drives are widely utilized in case of low, mid and high power response. Normally, winding of the rotor is replaced by PMSM system permanent magnet in order to produce the air-gap magnetic field. Owing to magnets on the rotor, electrical losses due to field winding of the machine reduced and, therefore thermal efficiency enhanced. In addition to that, due to absence of different mechanical components e.g. brushes and slip rings make the motor lighter with high aspect ratio which improves efficiency and reliability. Therefore it can be summarized that PMSM drives provide better response choice for paramount applications. It has important application in adjustable speed drives, Fiber spinning mills, Rolling mills, Cement mills, Ship propulsion, Electric vehicles, Servo and robotic drives, Starters/generators for aircraft engines, computer peripheral application etc. [1-7].

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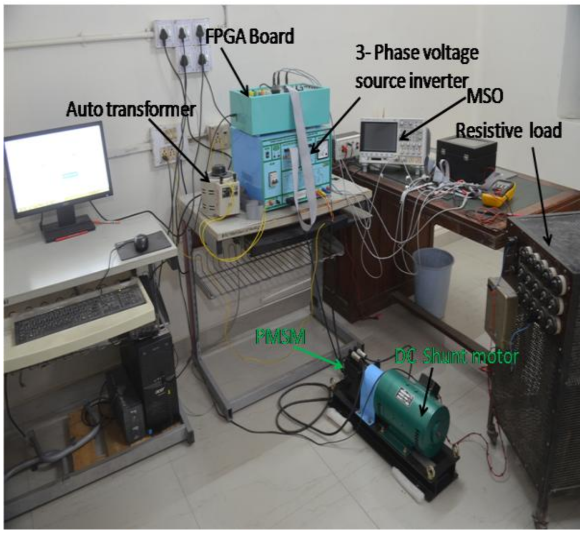
It has been reported by the previous researcher [1] that when rotor speed was increased, the response (output) was found to be slightly under damp condition. Torque pulsations were found to be varied by the use of different controllers [2]. Hysteresis band current control PWM method is used for delivering fast response and device peak current [3]. Fuzzy logic based speed controller of an interior PMSM drives were also studied under different dynamic conditions and it was demonstrated that better performance can be achieved by increasing the number of rules [4]. PI-Fuzzy controller based PMSM drive revealed better dynamic retaliation and minimum error in steady state conditions [5]. Ripple torque was found to be increased in case of hybrid-fuzzy PI controller [6], but vector control based PMSM drive using hybrid PI-fuzzy logic controller delivered fast dynamic response and reduce torque ripples [7]. Vector controlled drive has two loops, i.e. inner loop as current and outer loop as speed [8]. It was explained that the desired speed can be achieved by variation of phase voltage of rotor displacement [9]. The FPGA have fast hardware performance and it can reduce the control period of frequency in case of high speed region [10]. The direct torque control based drive system requires fast response time and less time for computation [11] The mathematical model of PMSM drive was explained under the vector control in case of current loop and fuzzy controller in case of external load in the speed loop [12]. Few investigators [13] demonstrated an adaptive fuzzy logic control of PMSM using verilog hardware description language (VHDL) as well as validated by simulation. A cost effective method based on multi-unit PMSM drive was reported by Sarayut et al. [14]. They corroborated an effective utilization of total resource. Somewhere else [15] FPGA controller are used in order to get the better dynamic response and speed up the overall calculation. Joan Nicolas et al. [16] presented PMSM drives which utilized an optimal implementation of FPGA controller with minimum resources. Hong Yang et al. [17] utilized the concept of entropy system in order to improve the performance of PI closed loop in PMSM drive system with FPGA chip. Therefore it can be concluded that PMSM have a better choice for different applications. Present paper mainly studies about PI and Fuzzy logic controller and fuzzy rules based which are used to find the output. The experimental data of the proposed control technique was carried out for FPGA based PMSM. The detailed results are shown under zero load, load and random change in speed conditions.

II. EXPERIMENTAL



. Fig. 1: Experimental set up for PI and Fuzzy logic controller for PMSM drive

In the beginning AC supply was given to the 3 phase voltage source inverter through auto transformer, then inverter was connected with the PMSM drive along with terminal RYB and DC shunt motor followed by resistive load. The FPGA mat lab interface board was connected with inverter along with 40 and 20 pins. PMSM feedback speed was connected by inverter. Auto transformer power field supply was switched on, which are connected with voltage source inverter (VSI), which are also connected with FPGA based Matlab interface board. Now LCD of FPGA board displayed the reference and actual speed. Autotransformer voltage varied from Zero to 310 V dc of DC Link voltage. Reference speed of the motor was changed which will delivered the actual speed as per accordance with variation in load. Due to varying in the resistive load connected across the armature of dc shunt motor, the current of the PMSM motor will increased and step speed will be also changed.

III. BLOCK DIAGRAM FOR PMSM DRIVE

The details block diagram of PMSM drives are presented in the Fig. 2 which clearly depicts that autotransformer is connected with 3 phase voltage source inverter which is also connected with the FPGA board which having 20 to 40 pins. The output of FPGA mat lab interface board is directly connected with blend signal oscilloscope, which displays the pulse width modulation DAC output. Three phase currents of inverter are connected with the stator of PMSM drive. The PMSM drive is mechanically coupled with the DC shunt motor which acts as the load. The resistive load is directly connected with the armature of dc shunt motor and field winding is connected with the supply.

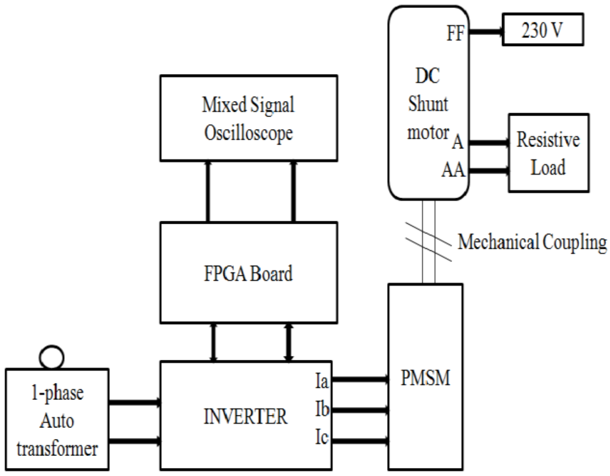


Fig. 2: Block diagram of PMSM drive.

IV. RESULT AND DISCUSSION

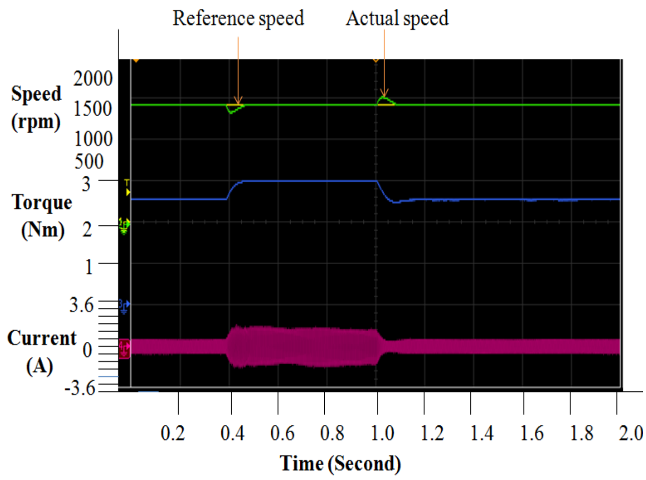


Fig.3: PI Step Load Variation

Step load variation diagram of PI are depicted in Fig. 3 which reveals the different output signal on the ordinate. In this waveform, reference speed, actual speed, load torque and load current are shown. Graph clearly demonstrates that stability begins after a period of 0.4 seconds when a certain load is randomly applied. Then speed was found to be decreased and later on render to a stable condition in a particular interval of time. It has been construed that estimated load torque has been substantially enhanced owing to increase in load. Again it was also noted that when load was reduced after certain period of time, speed was suddenly increased and later on revive in stable condition. Similarly, torque and current was found to be substantially decreased due to reduction in load. When the resistive load was given, the speed was found to be reduced and corresponding torque was increased from 2.5 to 2.9 Nm, while current was found to be increased from 0.6 to 2 ampere. It was also noted that when the load was released, pronounced effect was found on speed and corresponding torque were decreased from 2.9 to 2.4 Nm. Coherent effect were also observed in current and it was reduced from 2 to 0.6 ampere.

During applied and released load, the actual speed was treated as the reference speed which was maintained constant. Peak over shoot was found to be substantially increased in case of PI. Akin results has been reported by H. Meher et al. [7], which demonstrated that sudden changed in load condition is attributed to peak over shoot and stator flux ripple. Table I reveals the details of torque, stator current and resistive load with respect to time and reference speed in case of PI step load variation.

Table-I: PI Step Load Variation

Time (Sec)	Ref Speed (rpm)	Actua l Speed (rpm)	Torqu e (Nm)	Stator Current (A)	Resistiv e Load (KΩ)
0.2	1500	1500	2.3	0.6	No Load
0.4	1500	1300	3.0	2.0	1
0.6	1500	1500	3.0	2.0	1
0.8	1500	1500	3.0	2.0	1
1.0	1500	1700	2.3	0.6	No Load
1.2	1500	1500	2.3	0.6	No Load
1.4	1500	1500	2.3	0.6	No Load
1.6	1500	1500	2.3	0.6	No Load
1.8	1500	1500	2.3	0.6	No Load
2.0	1500	1500	2.3	0.6	No Load

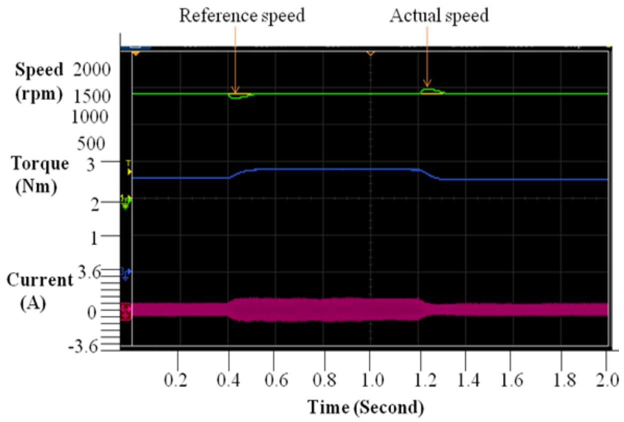


Fig.4: Fuzzy Step Load Variation

Step load variation diagram of fuzzy logic controller are presented in fig.4 which shows the different output on the ordinate. In this waveform, reference speed, actual speed, load torque, load current are demonstrated. Graph reveals that stable condition incipient after a period of 0.4 seconds when certain load is suddenly applied, then speed slightly decreased and maintains again to stable condition in a particular interval of time. It has been found that if load increased estimated load torque and load current are also increased. Again it was found that when load is reduced after some period of instance, speed was suddenly increased and later it come again to stable condition for maintaining same speed as a reference. In FUZZY control peak overshoot will be very less.

When the resistive load was given, the speed was found to be decreased and corresponding torque was increased 2.6 Nm to 2.9 Nm while current was found to be increased from 0.6 to 2 ampere. It was also construed that when the load was released the speed was found to be increased and corresponding torque and current were decreased from 2.9 Nm to 2.6 Nm and 2 to 0.6 ampere respectively. During applied and released load the actual speed was treated, later it was maintained reference as constant. Table II reveals the details of torque, actual speed, stator current and resistive load with respect to time and reference speed in case of fuzzy step load variation.

Table-II: Fuzzy Step Load Variation

Time (Sec)	Ref Speed (rpm)	Actual Speed (rpm)	Torque (Nm)	Stator Current (A)	Resistive Load (KΩ)
0.2	1500	1500	2.6	0.6	No Load
0.4	1500	1400	2.9	2.0	1
0.6	1500	1500	2.9	2.0	1
0.8	1500	1500	2.9	2.0	1
1.0	1500	1500	2.9	2.0	1
1.2	1500	1600	2.6	0.6	No Load
1.4	1500	1500	2.6	0.6	No Load
1.6	1500	1500	2.6	0.6	No Load
1.8	1500	1500	2.6	0.6	No Load
2.0	1500	1500	2.6	0.6	No Load

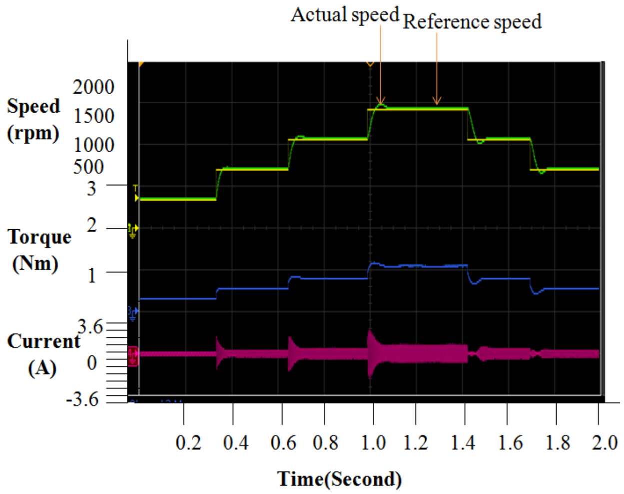


Fig.5: PI Step Speed Variation

Step speed variation diagram of PI are presented in Fig. 5 which delineated the waveform, reference speed, actual speed, load torque and load current. This graph shows that it starts with a step speed of 500,1000,1500,2000 rpm respectively. It was noted that when the speed of PMSM was 500 rpm, the corresponding torque and current were found to be 0.5 Nm and 0.6 Ampere respectively. Further, when the step speed was enhanced to 1000rpm, the corresponding torque and current were found to be 0.8 Nm and 1.2 Ampere respectively.

Table-III: PI Step Speed Variation

Time (Sec)	Step Speed (rpm)	Actual Speed (rpm)	Torque (Nm)	Stator Current (A)	Resistive Load (KΩ)
0.2	500	500	0.5	0.6	1
0.4	1000	1010	1.0	1.2	1
0.8	1500	1520	1.7	1.7	1
1.0	2000	2030	3.0	2.1	1
1.6	1500	1480	1.7	1.7	1
1.8	1000	990	1.0	1.2	1

Similarly, when the step speed was increased to 1500 rpm, the corresponding torque and current were noted to be 1 Nm and 1.7 Ampere respectively. Nevertheless, when the speed was increased to 2000 rpm, the corresponding torque and current were increased from 1.7 to 3 Nm and 1.7 to 2.1 Ampere respectively. But when the step speed was reduced from 2000 to 1500 rpm, the corresponding torque was decreased from 3 Nm to 1.7 Nm and the current were decreased from 2.1 to 1.7 Ampere. Again when the speed was decreased from 1500 to 1000 rpm, the torque was reduced to 1 Nm, while current was reduced to 1.7 Ampere. These augmentation and reduction in torque and currents in relation to change in step speed corroborates that input speed directly affects the torque and currents, which measure the effectiveness of PMSM drives. Table III reveals the details of torque, stator current and resistive load with respect to time in case of PI step speed variation.

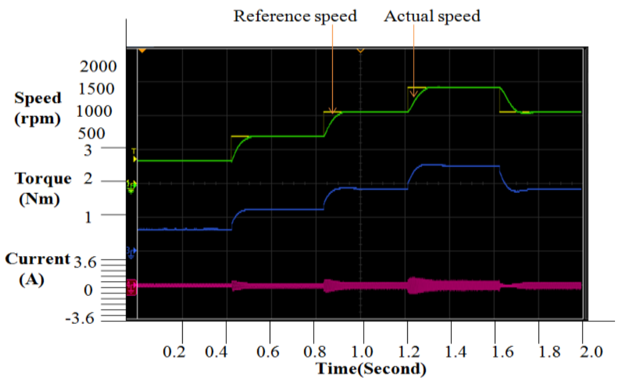


Fig.6: Fuzzy Step Speed Variation

Step speed variations of Fuzzy logic controller are presented in Fig. which reveals the different output on the ordinate. In this waveform, reference speed, actual speed, load torque, load current are demonstrated. Graph begins with 500,1000,1500,2000 rpm step speed and decreased from 2000 rpm to 1500 rpm. When the speed is 500rpm the torque is 0.5 Nm and current is 0.6 ampere. Again when the step speed is increased to 1000 rpm the torque is 1 Nm and current is 1.2 Ampere. When the step speed is again increased to 1500 rpm the corresponding torque is 1.7Nm and current is 1.7 Ampere.

Table-IV: Fuzzy Step Speed Variation

Time (Sec)	Step Speed (rpm)	Actual Speed (rpm)	Torque (Nm)	Stator Current (A)	Resistive Load (KΩ)
0.2	500	500	0.5	0.6	1
0.6	1000	1000	1.0	1.2	1
1.0	1500	1500	1.7	1.7	1
1.4	2000	2000	2.8	2.1	1
1.8	1500	1500	1.7	1.7	1

Similarly when the speed is enhanced to 2000 rpm, the respective torque and current is found to be 2.8 Nm and 2.1 Ampere. Nevertheless, when the speed is decreased from 2000 rpm to 1500 rpm, the corresponding torque is decreased from 2.8 Nm to 1.7 Nm and the current is also decreased from 2.1 Ampere to 1.7Ampere. Overshoot was not observed, also delay time was found to be minimized. Smooth speed control is achieved. Table IV reveals the details of torque, stator current and resistive load with respect to time in case of Fuzzy step speed variation.

V. CONCLUSION

In this paper, performance evaluation of the vector controlled PMSM drive using the PI and Fuzzy logic controller has been experimentally demonstrated. The results are presented under different monitoring conditions in PMSM drive like zero load, load and sudden change in speed working conditions. It was construed that Fuzzy controller has better performance than that of PI controller. Ripple torque and ripple contents of stator current flux have been reduced, which is attributed to fast dynamic responses during the steady state and dynamic conditions by controlling the torque current component. It was also found that and fast dynamic speed responses were improved considerably with the FL controller technique under transient as well as steady state operating conditions.

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