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Research paper

Performance evaluation of PI and PI-fuzzy logic controller FPGA based permanent magnet synchronous motor drive

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Abstract

This paper depicts an experimental validation and simulation for speed control under load and no load conditions. It delineates the detail study of a closed loop vector controlled permanent magnet synchronous motor drive. This system consists of two loops for smooth speed tracking as well as reduced torque undulation. PMSM drives facilitate better dynamic responses during both steady state and dynamic conditions by monitoring the component of torque current. The resistive loads are varied and resultant speed and torque are studied. Experimental work has been performed on PMSM drives under different conditions and results are compared with conventional PI and Fuzzy logic controller.

Keywords: *PI-Controller; PI-Fuzzy Logic Controller ;Permanent Magnet Synchronous Motor(PMSM); Field Programmable Gate Array(FPGA).*

1. Introduction

From literature survey, it was construed that the permanent magnet synchronous motor drives with special features will be able to meet different requirement for instance better dynamic response, elevated power factor and broad operating speed range as compared to conventional AC machine drives. PMSM drives have better application in case of low, mid and high power response. In the DC field, winding of the rotor is reinstated by permanent magnet synchronous motor drives system in order to produce the air-gap magnetic field. Owing to magnets on the rotor, some of the electrical losses due to field winding of the machine get reduced and improve the thermal efficiency. Also due to non-existence of different mechanical components likes brushes and slip rings makes the motor lighter, high aspect ratio, which improves efficiency and reliability. It was found from literature [1] that when rotor speed was increased, the response was found to be slightly under damp. It was also construed from literature that owing to use of different controllers renders to different torque pulsations [2]. Some of the investigator used hysteresis band current control PWM method [3], which delivered fast response and device peak current. 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]. Fuzzy–PI controller based PMSM drive revealed better dynamic retaliation and minimum error in steady state conditions [5]. Ripple torque was found to be augmented in case of hybrid- fuzzy PI controller [6], but vector control based PMSM drive using hybrid PI-fuzzy logic controller depicted 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 could 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]. Therefore it can be concluded that PMSM is a better choice for different applications. It has paramount 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 and in many other fields [7].
This paper mainly studies about PI and Fuzzy PI controller and fuzzy rules based which are used to calculate the response. Both PI and Fuzzy PI control technique was carried out for FPGA based permanent magnet synchronous motor drive. The detailed responses were demonstrated under no-load, load and sudden change in speed conditions

2. Experimental

The details of experimental set up is presented in Fig. 1, which depicts the systematic details of permanent magnet synchronous motor (PMSM) drive system with field programmable gate array (FPGA). In this system, first of all AC supply was given to the 3 phase voltage source inverter through auto transformer. Afterwards, inverter was connected with the PMSM drive along with terminals RYB and DC shunt motor. This DC motor was connected with resistive load. The field programmable gate array (FPGA) MATLAB interface board was connected with inverter with 40 and 20 pins. PMSM feedback speed was connected with the inverter.

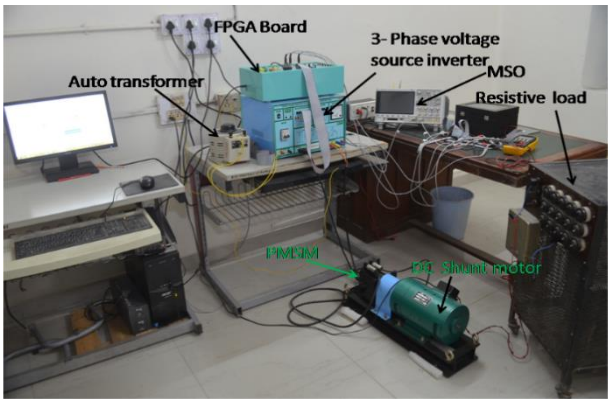

Fig. 1: Experimental Details of PI and PI-Fuzzy Logic Controller for PMSM Drive.

Auto transformer power field (F&FF) supply was switched on which are connected with FPGA based Mat-lab interface board which are also connected with voltage source inverter (VSI). Now LCD of FPGA board displayed reference speed and actual speed. Autotransformer voltage were varied from minimum (Zero) to 310 V dc of DC Link voltage. Now, reference speed of the motor was varied which will give the actual speed and will maintain constant because of its running in closed loop condition. Owing to varying in the resistive load connected across the armature of dc shunt motor, the current of the PMSM motor will be increased and step speed will be also changed. The rated power, voltage, current, speed and torque of permanent magnet synchronous motor were 750 watt, 230 V AC, 3.8 A, 3000 rpm and 3 Nm respectively. Similarly, rated power, voltage, speed and field current of DC shunt motor were 1 HP, 220 V DC, 3000 rpm and 0.4 A respectively.

3. 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 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 connected with the armature of dc shunt motor and field winding is connected with the supply. FPGA MATLAB interface board is connected with digital oscilloscope which displays the output of the PMSM drives.

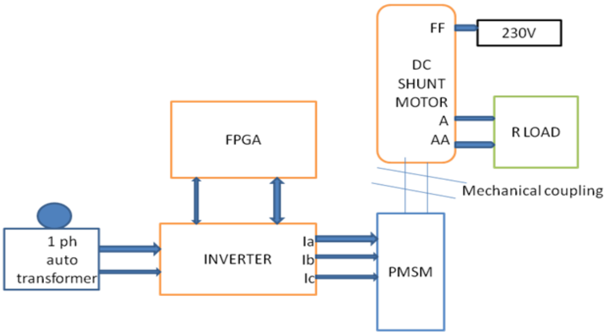

Fig. 2: Block Diagram of Permanent Magnet Synchronous Motor Drive.

4. Result and discussion

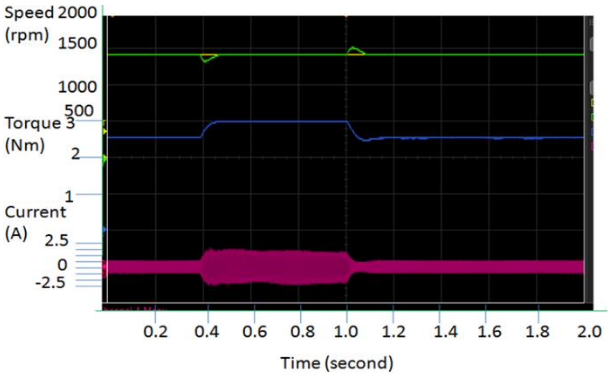

Fig. 3:PI Step Load Variation.

Step load variation diagram of PI are presented in Fig.3 which reveals 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 is slightly decreased and maintains again to stable condition in a particular interval of time. It has been found that estimated load torque increased due to increase in load. Again it was found that when load is reduced after some period of time, speed was suddenly increased and later regain in stable condition. Similarly, torque and current was found to be decreased due to reduction in load.

When the resistive load was given, the speed was found to be decreased 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 construed that when the load was released then speed was found to be increased and corresponding torque and current were decreased from 2.9 to 2.4 Nm and 2 to 0.6 ampere respectively. During applied and released load, the actual speed was treated as the reference speed which is maintained constant. Peak over shoot was found to be enhanced in case of PI fuzzy. The details of step load variation of PI with respect to time and reference speed are listed in Table 1.

Table 1: PI Step Load Variation

Time(Second)	Reference Speed(rpm)	Actual Speed (rpm)	Torque (Nm)	Stator Current (A)	Resistive 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

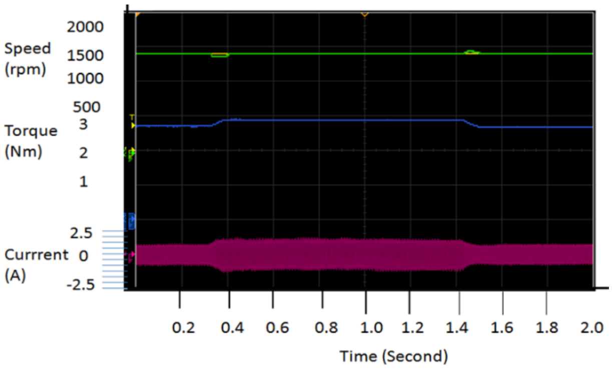

Fig.4: PI-Fuzzy Step Load Variation.

Step load variation diagram of PI-Fuzzy are demonstrated in Fig. 4, which depicts the different variation on the ordinate in which reference speed, actual speed, load torque, load current have been presented. Graph incipient under stable condition after a period of 0.4 seconds when a certain load is suddenly applied, then it was found that speeds is slightly decreased and maintain again to stable condition within a particular interval of time. It has been observed that estimated load torque has been increased due to enhancement in load. Again it was also found that when load was reduced after some period of time, speed was suddenly increased and later regains in stable condition. It can be also delineated that torque and current was also found to be decreased due to release of load.

When the resistive load was given, the speed was found to be decreased and corresponding torque was increased from 2.8 to 3 Nm, while the current was found to be increased from 0.6 to 2 A. it can be also delineated that when the load was released, the speed was found to be increased and corresponding torque and current were decreased from 2.9 to 2.6Nm and 2 to 0.6 ampere respectively. In PI-Fuzzy control, overshoot may be found to be negligible. Fig. 4 depicts that ripple torque has been minimized in contrary to A. V. Sant et al. [6], which revealed the promising ripple torque. Nevertheless, Coherent results has been reported by H. Mehar et al. [7], which also revealed reduce ripple torque in case of vector control based PMSM drive using hybrid PI-fuzzy logic controller. The details of step load variation of PI-Fuzzy with respect to time are listed in Table 2.

Table 2:PI-Fuzzy Step Load Variation

Time(Second)	Step Speed (rpm)	Actual Speed (rpm)	Torque (Nm)	Stator Current (A)	Resistive Load (KΩ)
0.2	1500	1500	2.8	0.6	No Load
0.4	1500	1495	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	1500	2.9	2.0	1
1.2	1500	1500	2.9	2.0	1
1.4	1500	1505	2.9	2.0	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

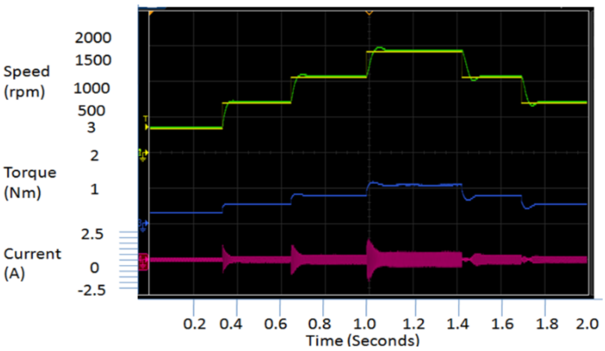

Fig.5: PI Step Speed Variation.

Step speed variation diagram of PI are shown in fig.5, which depicts the different output in the form of actual speed, load torque and load current. Graph clearly reveals that it starts with step speed of 500, 1000, 1500 and 2000 rpm.It has been delineated that when the reference speed is 500 rpm, the corresponding torque and current were found to be 0.5 Nm and 0.6 A respectively. Again, when the step speed was increased from 500 to 1000rpm, the corresponding torque and current were noted to be 0.8 Nm and 1.2 A respectively. Similarly, when the step speed was enhanced from 1000to 1500 rpm, then torque and current were augmented to be 1 Nm and 1.7 A respectively. It was also observed that when the step speed was enhanced from 1500 to 2000 rpm, the corresponding torque and current were increased from 1.7 to 3 Nm and 1.7 to 2.1 Ampere respectively. Nevertheless, when the step speed was decreased from 2000to 1500 rpm, the corresponding torque was decreased from 3 Nm to 1.7 Nm, while the current decreased from 2.1 to 1.7 Ampere. Again, it was also observed that when the speed was decreased from 1500 to 1000rpm, the corresponding torque and current were reduced to 1 Nm and 1.7 A respectively. It can be corroborated that when the speed is increased, corresponding torque and current were increased but when speed was decreased, corresponding torque and current were decreased respectively. This can be attributed to sudden change in load conditions and speed change. In PI control, peak overshoot will be substantial. The details of step speed variation of PI with respect to time are listed in Table 3.

Table 3: PI Step Speed Variation

Time(Second)	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

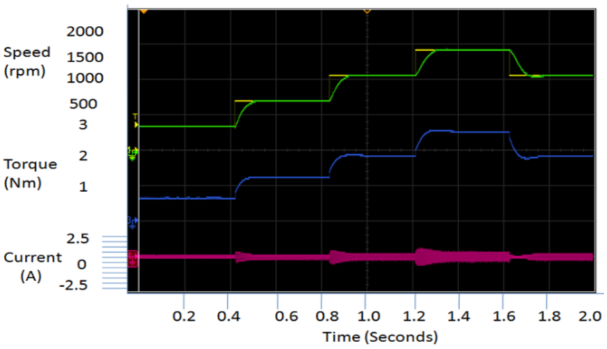

Fig.6: PI-Fuzzy Step Speed Variation.

Step speed variation of PI Fuzzy are depicted in Fig.6, which reveals that graph begins with the step speed of 500,1000,1500,2000rpm and later on reduced up to 1500 rpm. It can be construed that when the speed was 500rpm, the corresponding torque and current were observed to be 0.5 Nm and 0.6 A respectively. Similarly, when the step speed was enhanced to 1000 rpm, the torque was found to be1 Nm, while current was noted to be 1.2 A. Coherent results were obtained, when the step speed was increased to 1500rpm.Similarly, when the speed was enhanced to 2000 rpm, the torque and current were observed to be 2.8 Nm and 2.1 A. Nevertheless, when the speed was decreased from 2000 rpm to 1500 rpm, the corresponding torque were decreased from 2.8 Nm to 1.7 Nm, while current were decreased from 2.1 Ato1.7A.

This fluctuation in current and torque in relation to step speed were attributed to sudden change in resistive load. Overshoot was not observed in the waveform and delay time was also found to be minimized. It can be concluded that better speed control can be more pronounced in the case of PI- Fuzzy logic controller. The details of step speed variation of PI- Fuzzy with respect to time are listed in Table 4.

Table 4: PI-Fuzzy Step Speed Variation

Time(Second)	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

5. Conclusion

In this paper, performance evaluation of the vector controlled PMSM drive using the PI and PI-Fuzzy logic controller has been experimentally demonstrated. It was construed that PI -Fuzzy controller has better performance than that of PI controller. It has been demonstrated that the ripple contents of stator current flux and torque are minimized considerably. It was also found that, and the dynamic speed responses were augmented considerably with the hybrid PI-FL controller technique under transient as well as steady state operating conditions. The results are presented under different monitoring conditions in PMSM drive like no load, load and sudden change in speed.

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