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Implementation of PI Controller for 4Φ SRM Drive Using TMS320F28335

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ABSTRACT

This paper presents the experimental investigation of DSP based 4Φ Switched Reluctance Motor (SRM) Drive. SRM is a doubly-salient, singly-excited machine and having very simple construction, has a low inertia and allows an extremely high-speed operation. The control system of SRM is highly complex due to non linear nature. In such a system for implementing control algorithm needs high speed processor. In this work TMS320F28335 DSP processor is used to implement the inner loop PI current controller and outer loop PI speed controller. The TMS320F28335 is highly integrated, high performance solution for challenging control applications. The various experimental tests are carried out in 1 HP 4Φ SRM. The experimental results are reported in order to verify the steady state, transient and robustness performance of the controller.

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1. INTRODUCTION

The SRM have a simplest construction of all electrical machines and only the stator has windings. The rotor contains no permanent magnets. It consists of steel laminations stacked onto a shaft. The rotor is aligned whenever the diametrically opposite stator poles are excited. The magnetic circuit rotating part prefers to come to the minimum reluctance position at the instance of excitation and two rotor poles are aligned to the two stator poles, the other set of rotor poles is out of alignment with respect to a different set of stator poles [1]. Then, this set of stator poles is excited to bring the rotor poles into alignment. It is because of this simple mechanical construction that SRMs carry the low manufacturing cost, and also it provides high reliability, wide-speed range at constant power, fast dynamic response, ruggedness and fault-tolerance, 80% efficiency depending on the application and high starting torque [2]-[3]. This in turn has motivated a large amount of research on SRMs in the last decade. The SRM operation is extremely safe and the motor is used in industrial and domestic applications like robotics, aerospace, washing machine and also vacuum cleaner. In [11], a speed control of 4Φ 8/6 SRM using DSP TMS320F2407A was proposed. The converter is fed through a DC split converter was discussed in [7]. The speed is regulated through a PWM controller in which, the average phase voltage during the conduction period is controlled by varying the duty ratio of the switches. The implementation of speed controller for switched reluctance motor drive using fuzzy logic controller was proposed in [14]. This speed controller show that the FLC is more robust and, hence it is a suitable replacement of the conventional controllers for the high-performance SRM drive applications. In [9], A New Random Switching Technique using DSP TMS320F2812 was presented. This technique brings acoustic noise decrease by combining the varying turn-on, turn-off angle and RPWM. The experimental results show that the harmonic intensity of output voltage is better than other conventional methods.

In this work the PI controller is used for control the speed of the motor. The control algorithm have developed and tested by TMS320F28335 processor. The experimental analysis is performed to test the controller with respect to steady state, transient. The robustness is the controller also tested by varying the load torque. This paper is organized as follows, brief about SRM and converter in section 1 & 2, Section 3 discusses the TMS320F28335 processor. Section 4 discusses the control structure of SRM. The experimental setup and implementation of DSP processor discussed in section 5. Experimental results discussed in section 6 and concluding remarks in section 7.

2. SWITCHED RELUCTANCE MOTOR DRIVE

The SRM is electromagnetic and electrodynamics equipment that converts the electrical energy into mechanical energy. A Switched Reluctance or Variable Reluctance Motor does not contain any permanent magnets. The stator is similar to a brushless dc motor. However, the rotor consists only of iron laminates. The iron rotor is attracted to the energized stator pole. The polarity of the stator pole does not matter. Torque is produced as a result of the attraction between the electromagnet and the iron rotor. It is a doubly salient and singly excited machine in which the electromagnetic torque is developed due to variable reluctance principle [1]. The SRM has strong similarity to series excited DC and synchronous reluctance machines, but in control, it is very remotely connected to these machines, and therefore analogous control development is not possible. The Figure 1 shows the Doubly Salient Structure of 8/6 SRM Drive. The specification of SRM used in this work as given in table 1.

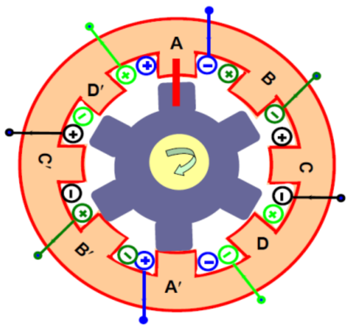

Figure 1. Doubly salient structure of 8/6 SRM drive

Table 1. Specifications of SRM drive

Parameters	Values
Number of Phases	4 phase
Number of Stator Poles	8
Number of Rotor Poles	6
Rated speed	4000 Rpm
Rated torque	3.5 Nm
Nominal Phase Resistance	1.2 Ω
Aligned Inductance	40mH
Unaligned Inductance	8mH
Rated Current	3A
Rated Voltage	380V

2.1. Power Converter

The split-link converter is consists of IGBT switches and diodes. If both the devices of same leg are ON the voltage is applied to the winding of motor. If both the switches are open, the freewheeling diode maintains the current flow in the winding. If any of the switches is ON and other one in OFF condition, then the freewheeling diode provides short circuit path of the current. The split-link converter circuit is shown in the Figure 2.

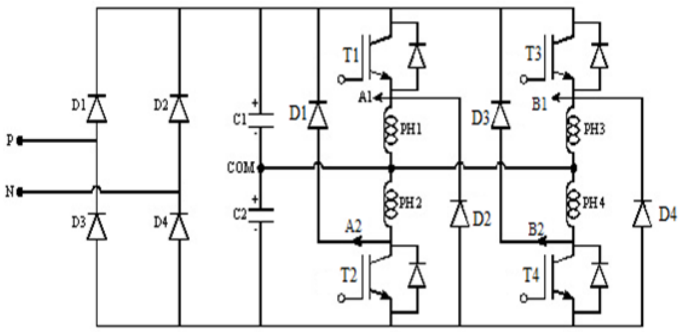

Figure 2. Split-link converter circuit for SRM drive

The supply dc voltage Vdc, by utilizing only half its value at any time and also the currents in the windings are balanced. It is used to minimizing the cost of the converter. This type of power converter has high efficiency and more output power than any other counterpart under heavy load conditions and/or in high speed operation.

3. TMS320F28335 PROCESSOR

The TMS320F28335 is highly integrated, high-performance solutions for demanding control applications. The TMS320F28335 is a standalone development platform that enables user to evaluate and develop applications. It has a wide range of application environments. The TMS320F28335 is designed to work with Code Composer Studio. Code Composer communicates with the board through an On Board JTAG emulator. The functional architecture of TMS320F28335 is shown in Figure 3.

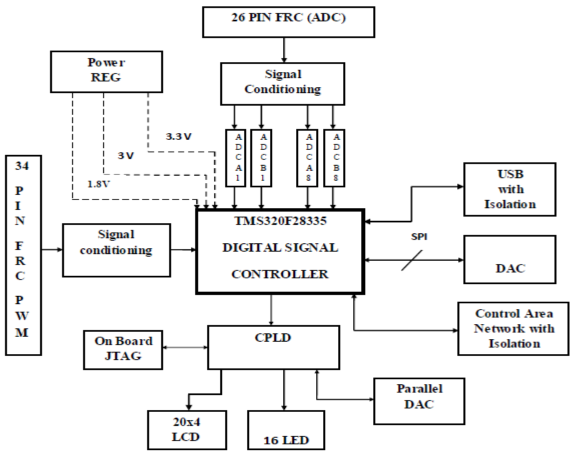

Figure 3. Architecture of TMS320F28335

The controller having the key features, A Texas Instruments TMS320F28335 device with a Digital Signal Controller and can be operated up to 150 MHz frequency, single voltage power supply (+5V) and Configurable boot load options.

4. SRM CONTROL STRUCTURE

The SRM control structure is shown in Figure 4. It consists of inner loop PI current controller and outer loop PI speed controller. The speed command ω* is compared to the speed signal ω to produce a speed error signal. This signal is processed through a proportional-plus-integral (PI) controller to determine the torque command. The armature current command i* is compared to the actual armature command i to have a zero current error. The PI controller produces the equivalent control signal when an error signal is occurred. The control signal hence modifies the triggering angle α to be sent to the converter for implementation.

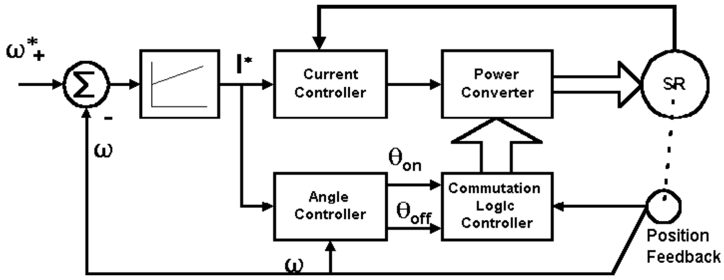

Figure 4. PI control structure of SRM drive

4.1. Design Speed Controller

The reference speed (ω*) is compared to the speed signal (ω) to produce a speed error signal (e). Then I* is achieved by integral gain (KI), proportional gain (Kp) and speed error (e). The PI based speed controller is shown in Figure 5.

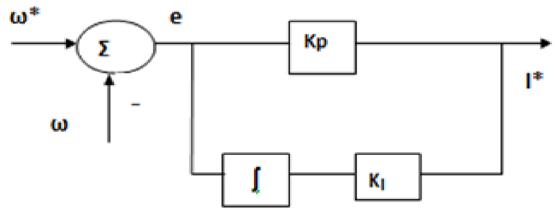

Figure 5. PI based speed controller

Where,

Ki: Integral gain
Kp: Proportional gain
e: Error

$$e = \omega^* - \omega$$

The proportional and integral terms is given by:

$$I^* = ek_p + \int ek_I$$

4.2. Design Current Controller

The reference current (I*) is compared to the actual current signal (I) to produce a current error signal (e1). Then u is achieved by integral gain (KI1), proportional gain (Kp1) and error (e1). The PI based Current Controller is shown in Figure 6.

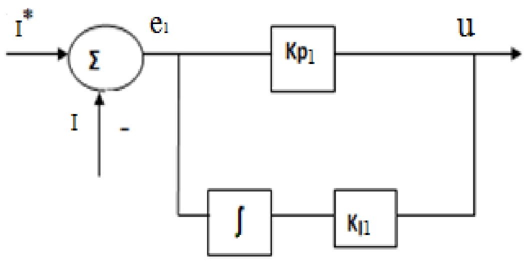

Figure 6. PI based current controller

$$e_1 = I^* - I$$
$$u = K_{P1}e_1 + \int e_1 K_{I1}$$

5. EXPERIMENTAL SETUP

The development control system is tested on DSP based SRM drive setup in Electrical Drives and Control laboratory at K.S.Rangasamy college of technology. The SRM is a 4Φ 120V, 1Hp, 8/6 prototype machine. A diode rectifier with split-link converter is assembled in a SRM power module. An encoder type position sensor was used to provide accurate information for the angle control as in the form of voltage pulses. A shunt DC motor was coupled in the SRM shaft. It excitation is controlled by 30V DC power supply and generator resistor to a load. Hall-effect current sensors are used for measuring the current. A load cell is used to measure the torque and its values are indicated in torque indicator. The total drive system is controlled by DSP320F28335 processor. The block diagram of Experimental setup and DSP controlled SRM drive is shown in Figure 7.

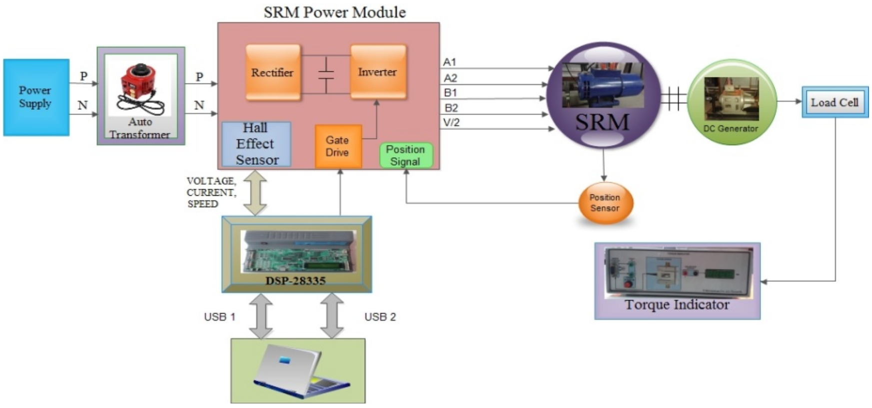

Figure 7. Block diagram of SRM drive

5.1. Implementation of PI Controller

The PI speed control algorithm source code has been developed using code composer studio and downloaded in to the target TMS320F28335 processor. The PC machine and the target processor were interfaced using USB cable. The photograph of the experimental setup is shown in Figure 9. Flow chart for the various steps involved in the implementation of PI control algorithm is shown in Figure 8.

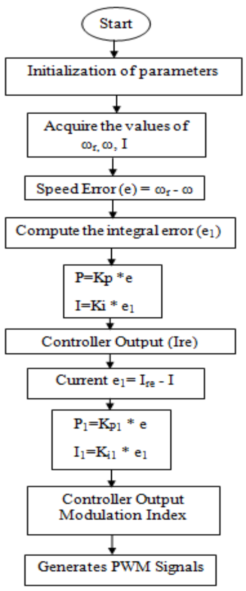

Figure 8. Implementation of PI control Algorithm

6. EXPERIMENTAL RESULTS AND DISCUSSION

The various experimental results are obtained from experimental setup at different load conditions. The steady state analysis, Transient analysis and robustness analysis are performed.

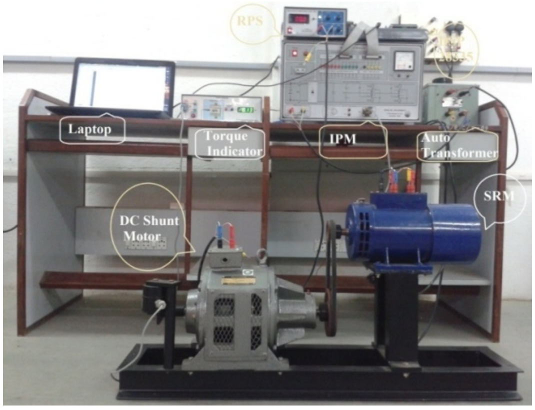

Figure 9. Experimental setup of DSP based SRM drive

6.1. Steady State Analysis

a) Constant Speed at No Load

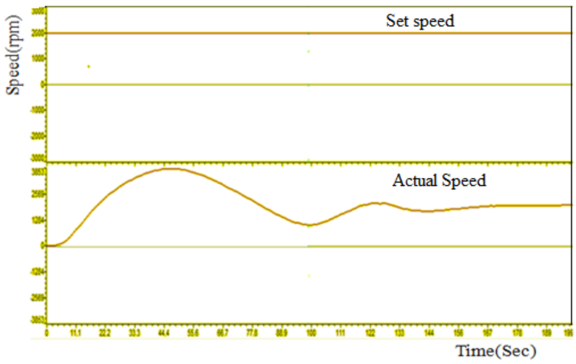

Figure 10. Speed response at No Load

b) Constant Speed with Constant Torque

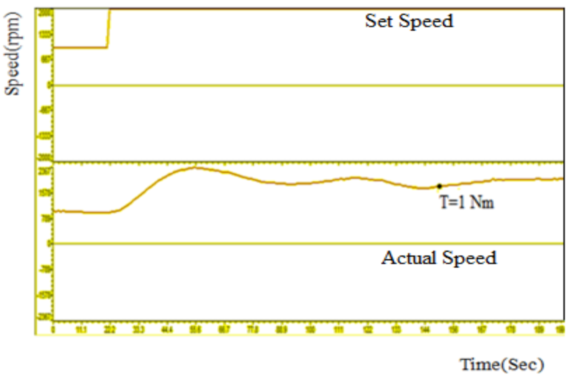

Figure 11. Speed Response with Constant Torque

c) Constant Speed with Variable Torque

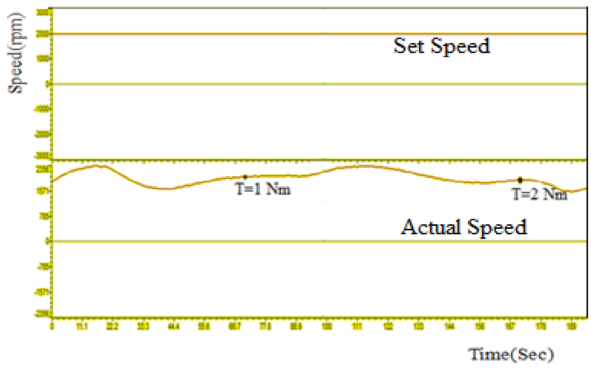

Figure 12. Speed Response with Variable Torque

The steady state analyses responses are shown in Figure 10 - 12. In steady state analysis, initially the motor speed will reaches peak value and then attain the set speed value. It will take more time to reach the actual speed.

6.2. Transient Analysis

a) Speed Changes at No Load

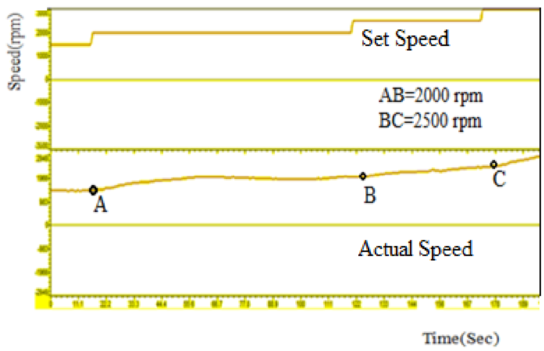

Figure 13. Transient Response at No Load

b) Speed Changes with Constant Torque

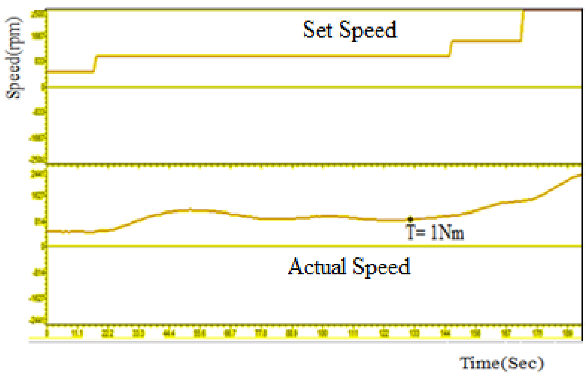

Figure 14. Transient Response with Constant Torque

c) **Speed Changes with Variable Torque**

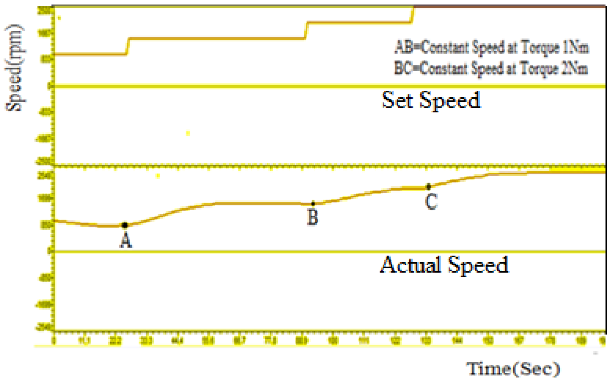

Figure 15. Transient Response with Variable Torque

The transient analysis responses are shown in the Figure 13-15. In this system the speed of the motor to be continuously changed and torque to be constant/variable. During that period speed of the motor will be reduced and then attain the actual value shown in the Figure 14-15.

6.3. Robustness Analysis

a) **Sudden Load Injection**

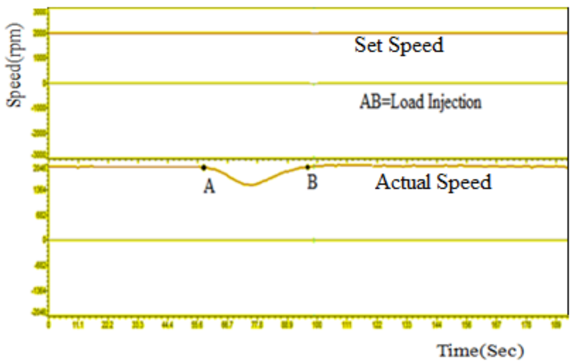

Figure 16. Robustness Response at Sudden Load Injection

b) **Sudden Load Rejection**

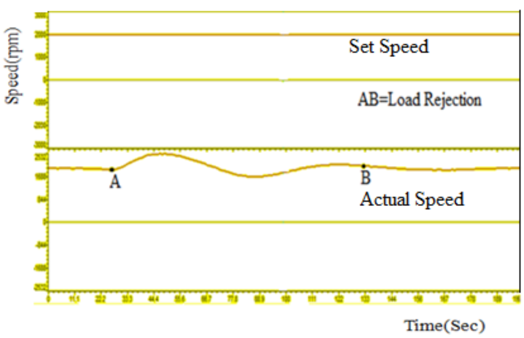

Figure 17. Robustness Response at Sudden Load Rejection

In robustness analysis is to find the toughness and strength of the conventional SRM drive. The robustness responses are shown in the Figure 16-17.

7. CONCLUSION

In this work TMS320F28335 DSP processor is used to implement the inner loop PI current controller and outer loop PI speed controller. The TMS320F28335 is highly integrated, high performance solution for challenging control applications. This project can serve a complete literature survey about various experimental results for determination of electromagnetic characteristic of SRM. The various experimental tests are carried out in 1 HP 4Φ SRM. The experimental results are reported in order to verify the steady state, transient and robustness performance of the controller. It is hoped that this proposed method and the discussion on how to further improve the measurement accuracy and how to reduce the noise and vibration may serve as a helpful reference for researchers to precisely determine the magnetic characteristics of the SRM.

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