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PERFORMANCE EVALUATION IN SPEED CONTROL OF CLASSIC CONVERTER FED SWITCHED RELUCTANCE MOTOR USING PI CONTROLLER

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ABSTRACT

The SRM is used in various industrial applications due to its beneficial advantages. However the robustness of SRM is the main drawback, which severely affects the dynamic performance of motor .Thus the aim of the paper, is to control the speed of switched reluctance motor using PI controller. The controller is designed and simulated by MATLAB/SIMULINK. The use of PI controller in the outer loop gives the superior performance of the motor drive. The dynamic performance of the SRM is controlled by PI controller during starting period under different load condition. This paper shows the effect of load disturbance, speed variation and motor parameter like, stator winding resistance, inertia of the motor on the speed of switched reluctance motor. The simulation results revealed that the effectiveness of PI controller on the motor performance.

Keywords: SRM, PI controller, MATLAB, classic converter, speed.

INTRODUCTION

Both stator and rotor winding have the stack of lamination, with only stator having concentric coil. (Krishnan R, 2001) There are no conductor bars or coils or permanent magnet and also no brushes on the rotor. The simple construction of the machine makes it very attractive for manufacturing. (Miller T.J.E., 1994) Switched reluctance motor is better compared with the induction motor in many ways as discussed. (Moghbdli H *et al*., 1991) Due to the doubly salient construction and magnetic saturation effect, the torque production is highly non linear function of phase current and rotor position. In conventional operation of SRM, the phase windings are switched ON, one at atime. Due to the non linear torque cue production mechanism leads to produce large amount of torque ripple. The torque ripple can cause speed ripples mainly at low speed. Such excitation also causes radial force on the rotor, leading to vibration and acoustic noise. (Cao. X *et al*., 2009; Chai J.Y *et al*., 2010).

Due to the reason, SRM could not be preferred in high performance industrial applications. The motor is suitable for hazardous area in wide range of applications such as mining, traction, domestic application. In recent years, most of the researchers focused on SRM control, and torque ripple minimization for make it a competitive to both AC and DC drives. PI CCC based switched reluctance generator is modeled in (Kannan K *et al*., 2010) and automatic control of turn on angle is used to excite the switched reluctance motor. The control of turn on angle produces either positive torque in motoring mode or negative torque in generating mode. (Colby S *et al*., 1996, Russa I *et al*., 2000) The flux linkage control was proposed as an approach to commonly used current control. Flux linkage controller performs better than flux linkage control with hysteresis current controller. (Lawperson P. J, *et al*., 1980, Lovatt H. C. 1993) Various control technique have been proposed for ripple reduction of SRM such as feedback linearization controller, on line neural network identification and adaptation technique (Cheung J.P.N.C *et al*., 2005) fuzzy control (Henriques L.O.A.P *et al*., 2000, Xue X.D *et al*., 2004, and Choi C *et al*., 2000) AI based rotor position estimation is done (Paramasivam S *et al*. 2007) and iterative learning technique (Sahoo S. *et al*., 2004) Though researchers have developed the sliding mode technique in SRM drives for speed, current and torque control. (Panda S.K. *et al*. 1996), Open loop strategies have been reported using angle and current amplitude regulation. The simplest and most commonly used control strategy for the SRM involves the use of constant input voltage. Dynamic performances can be improved by introducing feedback control. Closed-loop control strategies for switched reluctance motors are proposed in model-reference adaptive control of a variable reluctance motor for low speed, high-toque mode of operation suitable for robot’s applications has been considered. (W-Spong *et al*. 1987) The performance analysis of current controlled switched reluctance motor is done (Muthulakshmi S. *et al*., 2014). In this paper, the speed control of switched reluctance motor is controlled by PI controller. The PI controller is simulated for classic converter by MATLAB/SIMULINK. It gives the better response of motor and track the speed closer to reference value when the variation in load disturbance, motor winding parameter such as stator resistance (R), moment of inertia (J).

CLASSIC CONVERTER

Figure-1 shows a classic converter for three-phase SRM, which applies a diode bridge rectifier and a large capacitor to the front end. This capacitor can maintain the DC link voltage and stores the recovered energy of the classic converter. It consists of two power switches and two diodes per phase. They can provide independent control of each phase and phase overlap

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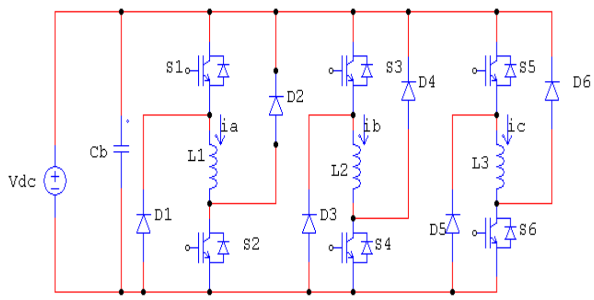

Figure-1. Classic Converter for three phase SRM.

DYNAMIC MODEL OF SRM

The phase voltage equation of the switched reluctance motor can be written as

$$V = Ri + \frac{d\lambda}{dt} \qquad (1)$$

Where, V is the bus voltage, 'i' is the instantaneous phase current, R is the winding resistance per phase and λ flux linkage per phase. The stator resistance is negligible, so the above equation can be written as

$$V = L(\theta)\frac{di}{dt} + i\,\frac{dL(\theta)}{d\theta} * \omega \qquad (2)$$

Where, ω is the rotor speed and L (θ) is the instantaneous phase resistance.

$$V * i = Li\frac{di}{dt} + i^2\frac{dL}{d\theta} * \omega \qquad (3)$$

The above equation can also be given in the form of

$$P = \frac{d}{dt}\left(\frac{1}{2}Li^2\right) + \frac{1}{2}i^2\frac{dL}{d\theta} * \omega \qquad (4)$$

Where, the first term of the above equation represents the rate of increase in the stored magnetic field energy while the second term is the mechanical energy. Thus, the torque equation per phase can be written as

$$T(\theta, i) = \frac{1}{2}i^2\frac{dL}{d\theta} \qquad (5)$$

Thus positive torque is produced by the motor when the phase is switched on during the rising inductance. Consequently, if the phase is switched on during falling inductance, negative torque will be produced

SRM BLOCK DIAGRAM

Figure-2 shows the closed loop control of SRM. The battery or rectifier supplies the dc power. The basic principle of switched reluctance motor is simple: each phase is supplied with dc voltage by its classic converter, which can develop a torque, due to the movement of the rotor poles in line with the energized stator poles in order to maximize the inductance of excited coils. The torque produced by the motor is independent of the direction of current. Rotor position sensor which is mounted on a shaft of the SRM, provide signal to the controller about the position of rotor with respect to reference axis. The PI Controller collects the rotor position feedback and also reference speed signal and suitably select the turns on and off angle, the concern power semiconductor devices of switching circuit, such that the corresponding phase winding is connected to the DC supply. The current signal is also feedback to the controller circuit to limit the motor current within permissible value. The PI controller tracks the reference speed, due to the variation in load disturbance

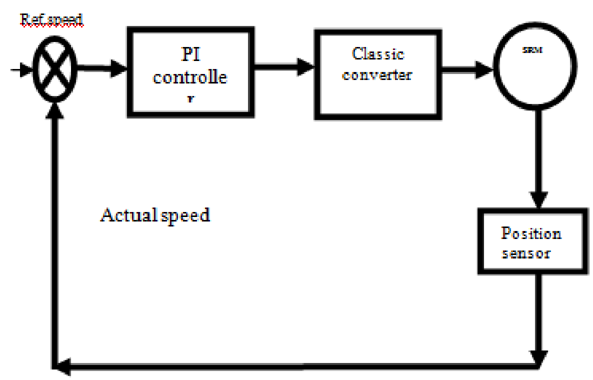

Figure-2. Shows the closed loop control of SRM.

PI CONTROLLER DESIGN

In PID controller, the derivative of the error is not used which is a PI (proportional -integral) controller. It is a control feedback mechanism used in various industrial control systems. The PI controller attempts to minimize the error which is the difference between measured variable and desired value by adjusting the process inputs. The combination of proportional and integral terms is used to increase the speed of the response and to eliminate the steady state error.

Proportional term

The output response of proportional term is equal to the current value of error. The proportional factor is adjusted by multiplying the error value by a proportional gain which is denoted by K_p

The proportional factor is written by

$$P_{out} = K_p\Delta \qquad (6)$$

Integral term

The integral term is proportional to both the magnitude and duration of the error. In PID controller, the integral term is the sum of instantaneous error over time which gives the accumulated value and it has been corrected previously.

The integral factor is written by

$$I_{out} = K_i \int \Delta dt \quad (7)$$

The integral term is used to increase the speed of the process towards the reference value and eliminates the error which occurs in pure proportional controller.
The PI controller output is given by

$$K_p\Delta + K_i \int \Delta dt \quad (8)$$

Where Δ is the error or deviation of measured value from reference speed. The speed of SRM is controlled by PI control. The PI controller has preferred to use in industrial applications. The controller has simplicity, lowest cost, zero steady state error, ease of implementation, good speed response, roboustness. It is extensively used in AC and DC drives where speed control is required. In order to provide the desirable performance of SRM, feedback control system is employed for speed control of SRM drive. The tuned values PI controllers are:
K_p= 50
K_i=0.1

RESULTS AND DISCUSSIONS

In order to verify the performance of switched reluctance motor, the classic converter using PI controller was simulated by MATLAB/simulink under different load condition are shown in Figure-3 Figure-19. Figure shows the operation of drive due to the effect of change in speed from 2000 to 4000 rpm while load is maintained constant TL= 5Nm. The controller control the speed of SRM under variable speed. The peak overshoot is minimum when the speed is changed.The performance of motor using PI controller is shown in Figure-4 Figure-6. Speed response of SRM under No load, the stator Winding resistance 0.05Ω with reference speed 2000, 3000, 4000 RPM are shown in Figure-7 Figure-9.

The sensitivity of the system is investigated when the motor is applied to uncertainities in the mechanical parameter (inertia of motor) and electrical parameter (phase resistance). Speed response of SRM load TL=2.5Nm, the stator Winding resistance 0.05Ω with reference speed 2000, 3000, 4000 RPM are shown in Figure-10 Figure-13. The phase winding resistance and moment of inertia is doubled from 0.05 Ω to 0.1 Ω under different load and different speedcondition, there is a slight change in speed but the controller able to track the motor speed close to the reference speed in Figure-7 Figure-19.

In varaiable speed drive applications, due to change in load disturbance ,the system respond quickly and maintain a constant speed. The load torque is changed from no load to TL=5Nm, there is no significant change in speed Figures 14-17. Speed response of SRM under TL=2.5Nm, the stator winding resistance0.1Ω with reference speed 4000RPM, Figure-18. The moment of inertia is doubled J=0.1 kgm^2 with TL=5Nm, speed=3000RPM Figure-19. The speed response of motor with variation in resistance and inertia of motor are shown in Table-1, Table-2 respectively.

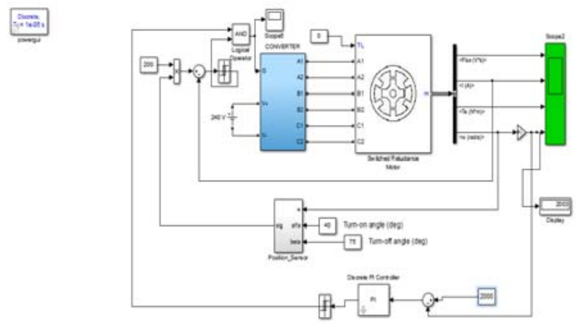

Figure-3. Simulation diagram for classic converter fed SRM using PI controller with no load and speed=2000RPM.

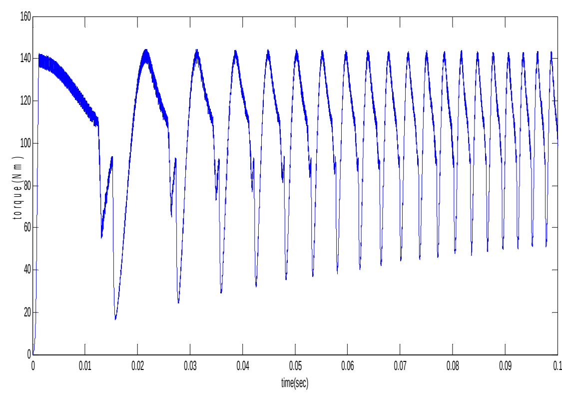

Figure-4. Torque response of SRM using PI controller.

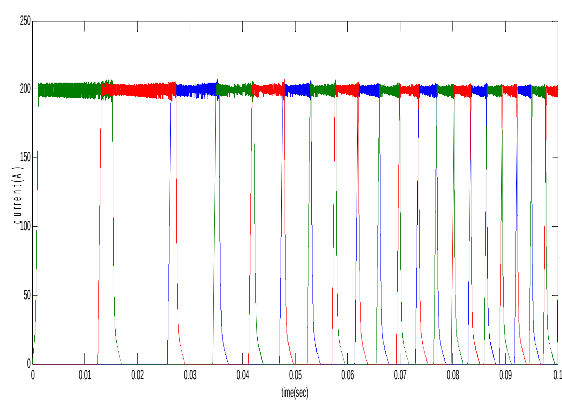

Figure-5. Current response of SRM

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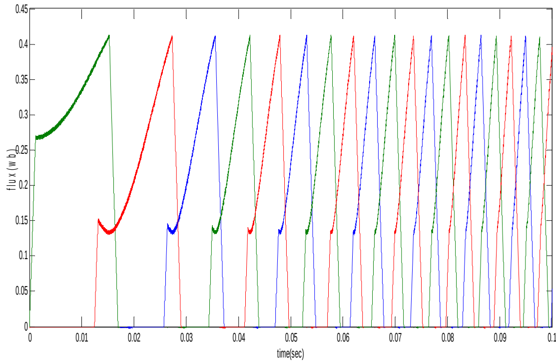

Figure-6. Flux response of SRM.

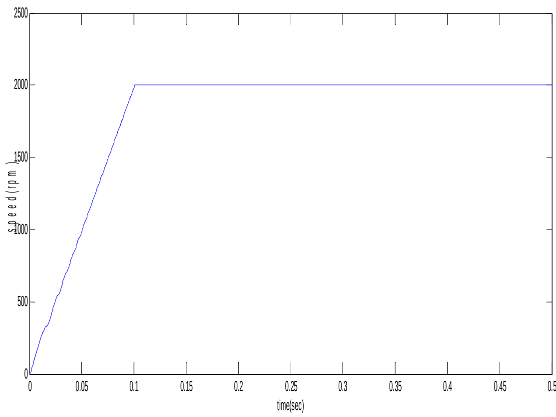

Figure-7. Speed response of SRM under No load, the stator winding resistance 0.05Ω with reference speed 2000 RPM.

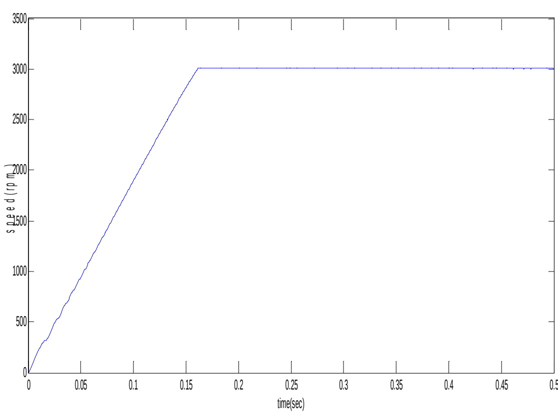

Figure-8. Speed response of SRM under No load, the stator winding resistance 0.05Ω with reference speed 3000 RPM.

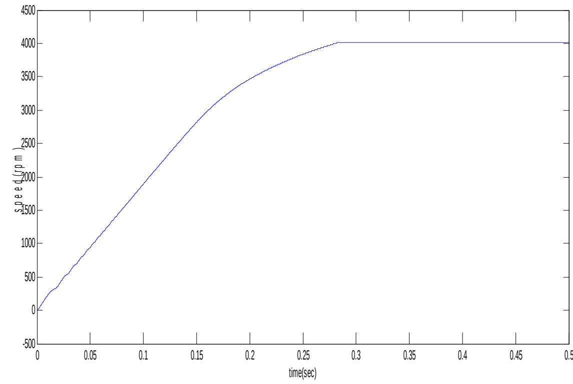

Figure-9. Speed response of SRM under No load, the stator winding resistance 0.05 with reference speed 4000 RPM.

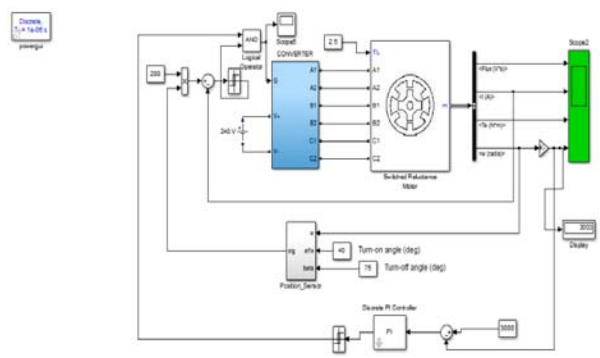

Figure-10. Simulation diagram for classic converter fed SRM using PI controller with TL=2.5Nm and speed=3000RPM.

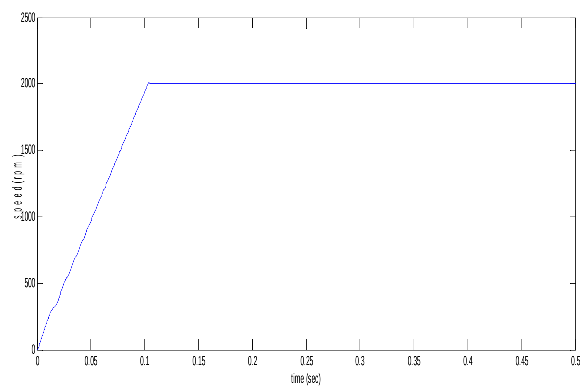

Figure-11. Speed response of SRM under TL=2.5Nm, the stator winding resistance 0.05Ω with reference speed 2000 RPM.

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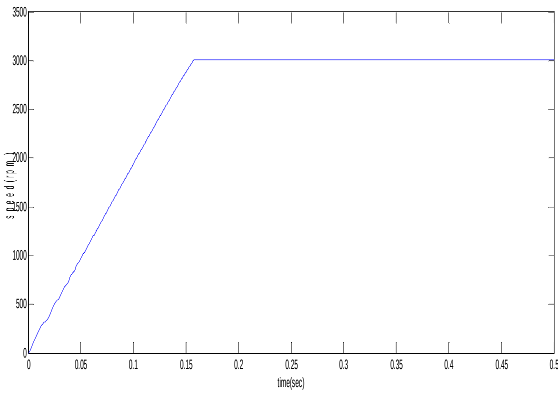

Figure-12. Speed response of SRM under TL=2.5 Nm, the stator winding resistance 0.05 Ωwith reference speed 3000 RPM.

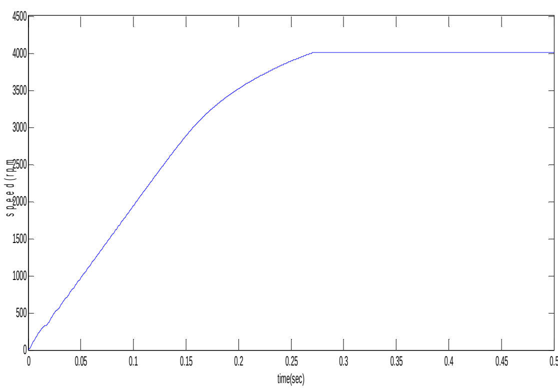

Figure-13. Speed response of SRM under TL=2.5Nm, the stator winding resistance 0.05 with reference speed 4000 RPM.

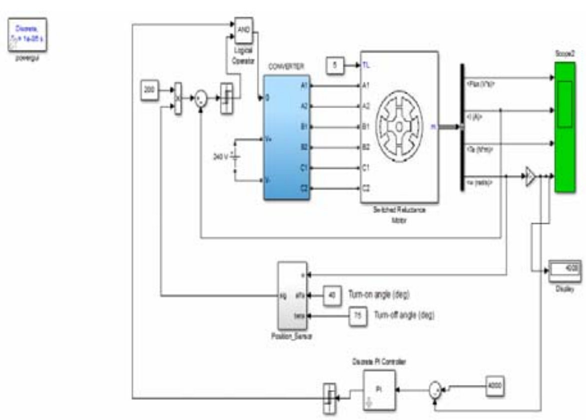

Figure-14. Simulation diagram for classic converter fed SRM using PI controller with TL=5Nm.

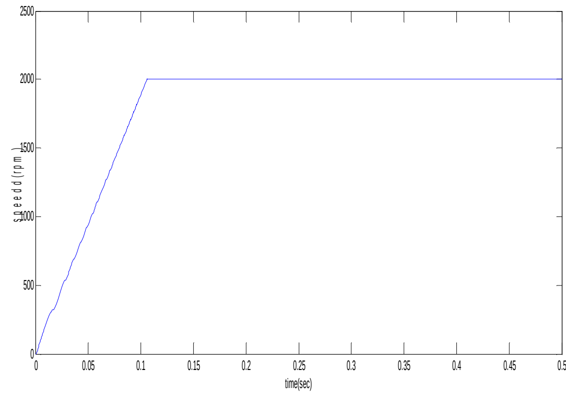

Figure-16. Speed response of SRM under TL=5Nm, the stator winding resistance 0.05 with reference speed 2000RPM.

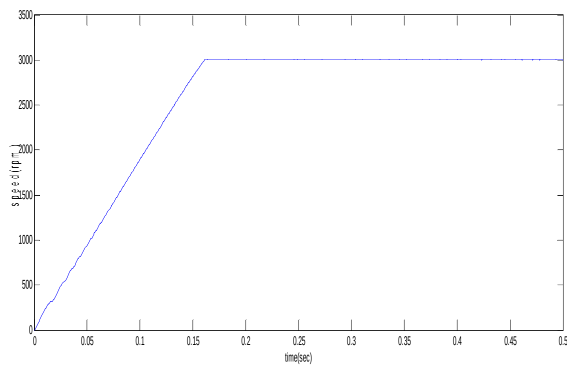

Figure-17. Speed response of SRM under TL=5Nm, the stator winding resistance 0.05 With reference speed 3000 RPM.

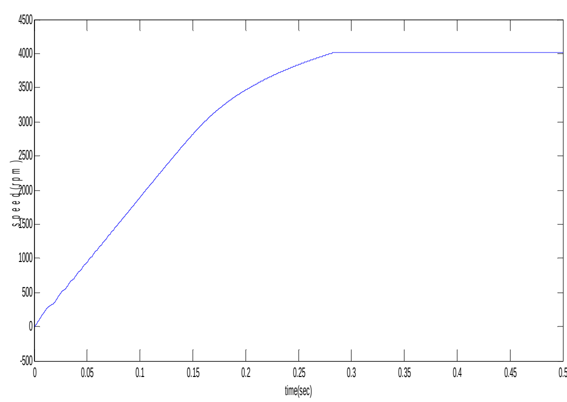

Figure-15. Speed response of SRM under TL=5Nm, the stator winding resistance 0.05Ω with reference speed 4000RPM.

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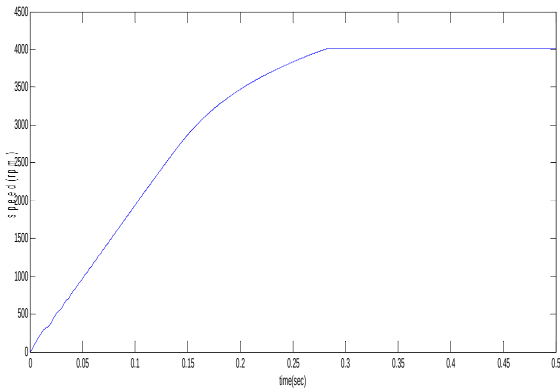

Figure-18. Speed response of SRM under TL=2.5Nm, the stator winding resistance 0.1Ω with reference speed 4000 RPM.

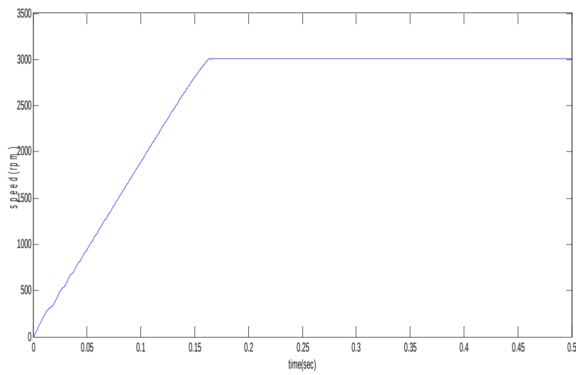

Figure-19. Speed response of SRM under TL=5 Nm, the moment of inertia=0.1kgm^2 with reference speed 3000 RPM.

Table-1. Speed response of SRM with variation in Inertia of motor (J) Kgm^2.

	Speed	J=0.05	J=0.1	Ts(sec)
NOLOAD	2000	2003	2004	0.11
	3000	3004	3009	0.14
	4000	4001	3999	0.26
TL=5Nm	2000	2005	2006	0.1
	3000	3003	3009	0.16
	4000	4008	3998	0.28

Table-2. Speed response of SRM with variation in Phase resistance of motor (Ra) Ω.

	Speed	Ra=0.05	Ra=0.1	Ts (sec)
NOLOAD	2000	2003	2004	0.11
	3000	3004	3006	0.15
	4000	4001	4009	0.26
TL=5Nm	2000	2005	2004	0.1
	3000	3003	3005	0.18
	4000	4009	4008	0.27

CONCLUSIONS

There is a growing demand for SRM for various applications like robotics, traction, mining and oil industries and products such as fans, pumps and electrical vehicle. The SRM was well suited for low speed and high torque capability. Due to these characteristics, the switched reluctance motor is well suitable for direct drive applications. In this paper, the performance of switched reluctance motor is obtained under different load condition using PI controller. The PI controller for switched reluctance motor is designed and simulated by MATLAB/SIMULINK. The PI controller gives the better performance at low speed. This paper also shows the effect of motor parameter like inertia of the motor, winding resistance and load, speed variation on the performance of SRM.

Machine details

DC supply -240V
Stator pole -6
Rotor pole -4
Stator resistance- 0.05Ω
Moment of inertia-0.05 kgm^2
Current- 200A

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