Different Strategies of Sliding Mode Controller for speed control of Power factor corrected LUO Converter fed Switched Reluctance Motor

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Abstract- Among the various special machines Switched Reluctance Motor is noted for high speed operation. This feature makes the drive application extent in various fields. Bridgeless Power Factor corrected LUO converter makes it possible to drive the Switched Reluctance Motor with the utility AC supply directly. This makes the machine suitable to be used for various domestic applications. Sliding mode controller is used for improving the speed regulation. The front end bridgeless Luo converter and the two legged drive system can be controlled to achieve the required speed. The duty cycle and modulation index are controlled in different configurations and make the system flexible to meet the various demands with reduced steady state error. The different speed control strategies or Modes are simulated in MATLAB SIMULINK and the performance parameters are compared.

Keywords - Switched Reluctance Motor, Sliding mode Controller, Power factor correction, speed regulation

1. Introduction

The Switched Reluctance Motor has a double salient pole construction. It has simple structure ie. no winding, and magnet on the rotor. This makes the drive to be suited to operate in varying speed [1]. This motor has special feature of simple construction, high torque to inertia ratio and suitable to operate in hazardous environment. The major disadvantage of SRM is high torque ripple due to double salient construction which cause acoustic noise and speed fluctuation [15].SRM has less hysteresis loss and copper loss makes its use for high speed location[17]. So A suitable controller is designed to make the machine run at specified speed. If motor is supplied with ac supply, the input power factor, source side current are disturbed. Speed is regulated by optimizing the turn on and turns off angle. Researchers has developed different controller to reach the specified speed. This motor has non linear characteristics which makes selection of controller is difficult. There are two major drawbacks with the SRM. The first issue is the ripple that is contained in the torque. Because of sequential switching of the stator poles one after the other and since there exists a dead time between the energizing of each of the stator coils there is a drop in torque produced during every transition period . Further because of the intermittent switching of the stator coils the power drawn from the main power supply is also intermittent]. If the source is derived from a three phase or single phase AC utility supply the source currents exhibit rich harmonics. Researchers are keenly exploring the way in the design aspect to improve the performance of the SRM [8,14]. Electromagnetic design or finite element analysis is done to make the SRM highly efficient. Suitable pole design in rotor and stator is carried out to minimize the torque ripple produced[14]. Various controllers like ANFIS optimizing algorithm like Ant colony, Particle swarm optimisation are involved in minimization the torque ripple[3,9,11,12,19,20]. The motor is supplied with different converter like CUK, SEPIC C dump improve the source quality. The section II discuss about modelling of SRM. The section III explains the BL PFC Luo converter and its control techniques. The section IV classifies the modes of sliding mode controller. The section V comments the result and compares the result of different modes of SRM.

2. Modelling of SRM

Switched reluctance motor of 8/6 type is considered. The stator winding voltage equation of switched reluctance motor can be expressed as

$$v = Ri + \frac{d\varphi(\theta,i)}{dt} \quad (1)$$

v=stator voltage vector of phase,

ϕ=flux vector,

R=equivalent resistance of each phase.

Integrating the equation (1) gives the flux linkages can be expressed as

$$\Psi = Li = N\varphi \quad (2)$$

The voltage equation for each phase winding is

$$V = L\frac{di}{dt} + i\omega\left(\frac{dL}{d\theta}\right) \quad (3)$$

The dynamics of the mechanical subsystem can be represented by the following equation:

$$J\frac{d\omega}{dt} = T - T_l - f\omega \quad (4)$$

where,

ω − Motor speed in rad/sec

J − Total inertia as seen from rotor in Kg.m^2

T − Motor torque in N.m

T_l − Load torque in N.m

f − Friction constant N.m/(rad/sec)

The energy equation is given by

$$dw_e = dw_m + dw_f \quad (5)$$

$dw_e \quad = changeinelectricalinput$

$dw_m = increamentalmechnicalenergy$

The angular speed of the motor

$$\omega = \frac{d\theta}{dt} \quad (6)$$

$$\omega = \frac{1}{J}(T - f\omega - T_l) \quad (7)$$

Parameter Value of SRM

Stator/rotor poles	12/8
Phase	3
Speed range of constant torque	100-1500r/min
Rated Power	1.5kW
Moment inertia	0.01Kgm2
Rated torque	9.55Nm
Unaligned inductance	23mH
Aligned inductance	154mH
Stator resistance	0.9Ω
Friction coefficient	0.005Nms
Maximum flux linkage	0.986Wb

The sliding mode controller is used to control and regulate the speed and voltage in the following modes

The power factor corrected LUO converter has to supply requires DC supply power to PF corrected LUO converter fed SRM. It has Luo converter in the front end and the drive circuit at the second stage[2,4,5,6]. The system has two degree of freedom. The required speed can be reached by controlling the duty cycle of the converter or modulation index of the drive system. The two variables can be controlled to achieve different modes of operation. There are two variables to control so the system has two degree of freedom with this four modes of operation can be achieved.

A. The duty cycle of PFC LUO converter is adjusted to maintain constant DC voltage. The PWM technique is applied in two leg drive circuit to maintain the set speed.
B. The duty cycle of PFC LUO converter is fixed and it operate in open loop mode, The modulation index of the drive circuit is adjusted to regulate the required speed.
C. Single pulse modulation is applied to the driver circuit and duty cycle of the PFC LUO converter is changed to reduce the speed error.
D. In this mode the control is implemented on both front end and back end of the system to reach the required speed.

The simulation is performed in MATLAB environment and results are compared and commented. The circuit involved in the system is shown in the figure1. PFC LUO converter fed SRM requires less number of switching devices. This reduces the switching loss taking place in the overall system. The switching complexity is also reduced.

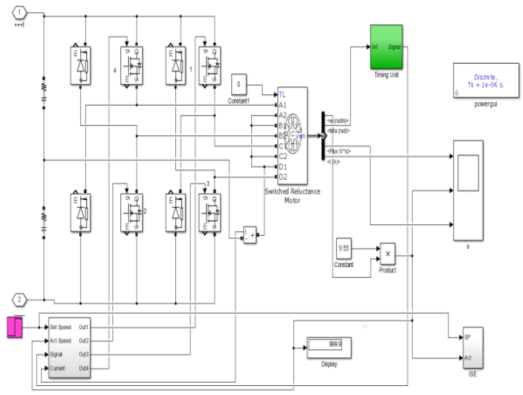


Figure 1. Two leg drive for switched Reluctance Motor

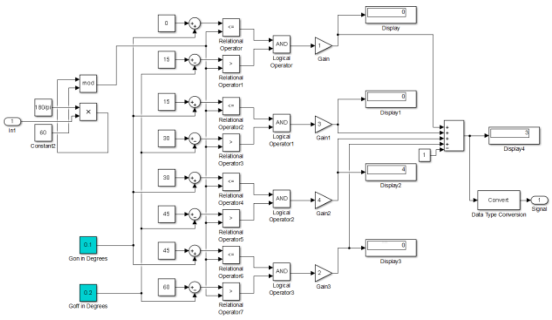


Figure 2.Sequential switching arrangement for 8/6 switched reluctance motor

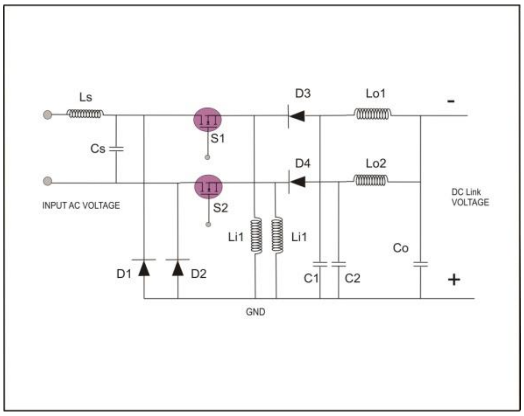


Figure 3. Frontend bridgeless LUO converter

Circuit description parameter for PFC LUO

L1,L2		0.5mH
L3,L4		1.2mH
C1		2.2µFD
C2		2.2µFD
C0		2000Mfd
S1,S2	MOSFET	IRF840
DI,D2	Diodes	
Lf		120mH
Cf		100nfd
Switching frequency		20KHz

3. Sliding Mode Controller

Sliding mode Controller is a non linear controller which does not require the transfer function and mathematical model information of the system to be controlled[7,10].The control law used in the SMC can be described by the following equations.

$u(t)$ = 1 if Actual value >ref (8)

$u(t)$ = 0 if Actual value <ref (9)

When $u(t)$=1 the manipulated variable is set at the maximum and controlled variable moves towards the set point and go past the set point. Once the controlled variable crosses past the set point the manipulated variable u (t) is set to 0 and the controlled variable starts to move in the opposite direction and the controlled variable falls below the set point .

The output equation of the PFC Luo converter

$$Vo = -(Vin * \frac{d}{1-d}) \quad (10)$$

$$Vin = VmSin\omega t \quad (11)$$

where $\omega = 2\pi f$

V_{in} –input ac supply voltage

The negative output is connected to the terminal of the drive with terminal interchanged so that it becomes positive. If SMC produces high level logic output, a PWM pulse with high duty cycle is send. If SMC output is logic zero the PWM pulse with low duty cycle is set [13,21].

Consider the example for the case the output voltage of LUO converter $Vo = (Vin * \frac{d}{1-d})$ with Vin =18V, d=0.9 then output voltage is given as Vo=18*(0.9/0.1)=162V at high level logic. At low level logic d=0.1 then Vo=18*(.1/.9)=2V. This shows when duty cycle changes from 0.1 to 0.9 then output voltage changes from 18V to 162V. The variation of the output voltage is smoothened by the L and C filter components present in the output side of the LUO converter.

3.1. Mode A operation

In this system, sliding mode controller can be applied in the LUO converter or in the drive system of the SRM. By applying a controller in the in the front end converter the voltage is maintained constant irrespective of the speed. The speed is controlled by changing the PWM in the drive circuit. Consider the output voltage of the converter should 400V for an input of 230V. ie 400=230*d/(1-d). This shows d=.635 In order to get 400V as output voltage the duty cycle is set at .635 to the converter switches. Approximately d=0.7 is set to the converter. The following steps are involved in the implementation of bridgeless converter

1. Accept the set point voltage (*Vref*)
2. Measure the actual output voltage (*Vact*).
3. If *Vact*<*Vref* turn on PWM at 0.7 Duty Cycle.
4. If *Vout*>*Vref* turn off the PWM pulse or lower the duty cycle to say 0.1
5. Goto step 1

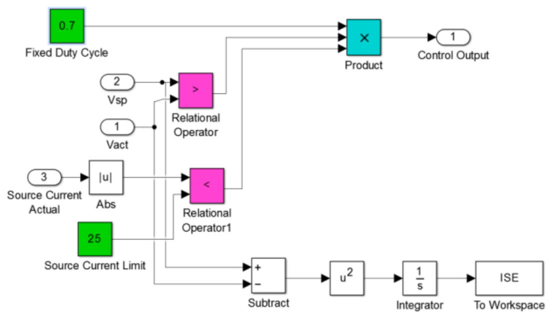


Figure 4. SMC with current limiter in MODE A operation

The current limiter regulates the current supply from the converter. The a train of PWM pulses is created from the carrier signal of 20Khz sampled to produce 70% duty cycle for high level and 30% for low level. The constant voltage in the converter makes the supply to extend for multi drive system. Proper current sharing method is implemented and makes it suitable for multi drive system.

3.2. Mode B operation

In this mode of operation no closed loop voltage regulation is maintained. Fixed high duty cycle is applied to the LUO converter. Speed control is achieved in the drive circuit of the SRM. The voltage of the converter changes for the change in speed. Variable voltage and variable speed control is achieved.

3.3. Mode C operation

In the third mode of operation a fixed single pulse PWM is applied to the phases of the SRM. The DC link voltage is controlled by an SMC. It compares the set speed and the actual speed. The result of this comparison may be either logic 1 or 0 depending upon whether the set speed is higher than the actual speed or less than the actual speed. There is a PWM section that generates the switching pulses for the MOSFETs of the PFC LUO converter. This section consists of a triangular carrier generator and a fixed duty cycle reference, say 0.65. The triangular carrier of 20 KHz and the constant reference of 0.65 are compared in a comparator to produce a train of square pulses. The square pulses derived from the comparator are AND operated with the output of the SMC comparator. Ultimately the phase windings of the SRM get fixed duty single pulse PWM and the PFC LUO are operated with a fixed duty cycle. The train of square pulses for the MOSFETs of the PFC Luo are of fixed duty cycle but are applied to the gates of the MOSFETs only if the actual speed is below the set speed. When the actual speed is more than the set speed the MOSFETs in the front end PFC LUO are turned off.

3.4. Mode D operation

In the fourth Mode of operation named herein as the control strategy Mode D control is implemented in both the PWM section of the SRM switches as well as at the front end PFC stage. In both these sections separate control systems operate. Speed of the SRM is the controlled variable in both the stages. However the manipulated variable is duty cycle for the PFC LUO switches at the front end and Modulation Index at the SRM drive stage. The four power electronic switches in the SRM drive stage use pulse width modulated multiple pulse switching train that is controlled by a separate Sliding Mode Controller. The Modulation Index at the SRM driver stage and the Duty cycle at the front end PFC stage are both constants. However their application to the gates of the MOSFETs in the respective sections is governed by the respective Sliding mode Controllers.

The Sliding Mode Controller in both the front end PFC LUO converter and that in the SRM driver stage take care of the speed of the SRM.. A fixed Modulation Index of 0.8 is used. This 0.8 reference is compared against a triangular carrier and square pulses are produced. The square pulses can reach the MOSFETs if and only if the SMC allows them. The SMC consists of a comparator wherein the set speed and the actual speed are compared. If the actual speed is less than the set speed the switching pulses can reach the gates of the MOSFETs.

3.5. Mode D operation

In this mode of operation two degrees of freedom of control in the PFC stage and the SRM drive stage are used. PWM is implemented in both the drive section of the SRM switches as well as at the front end PFC stage. Different control strategies are used in both these sections. A separate control system operates in the front end and another at the SRM drive side converter. The Speed of the SRM is the variable to be regulated in both the control systems. In the front end, the manipulated variable is duty cycle for the PFC LUO switches at the front end and modulation Index at the SRM drive stage. The bridge of four power electronic switches in the SRM drive stage use pulse width modulated multiple pulse switching trains for each of the switch that is controlled by a separate SMC. A fixed modulation index of 0.8 is used. This 0.8 reference is compared against a triangular carrier and square pulses are produced. The square pulses can reach the MOSFETs if and only if the SMC allows them. The SMC consists of a comparator in which the set speed and the actual speed are compared. If the actual speed is less than the set speed the switching pulses can reach the gates of the MOSFETs

4. Result and discussion

The converter voltage and speed profile of the SRM is shown in all the four modes of operation

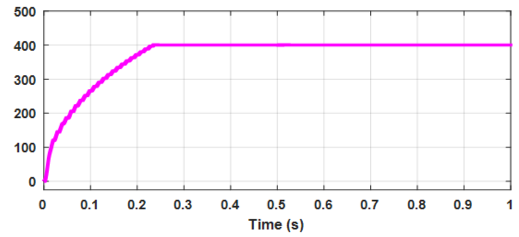


Figure 5. Voltage profile of the LUO converter in mode A

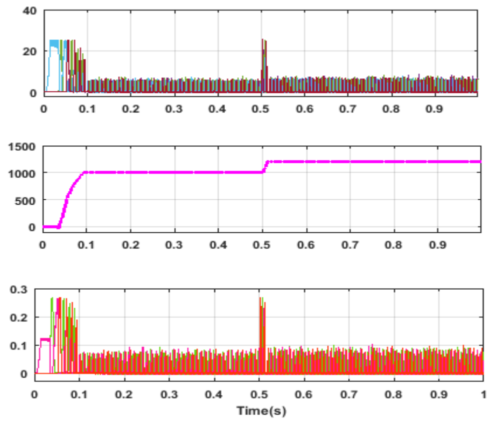
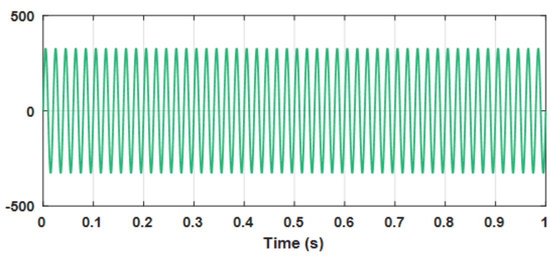
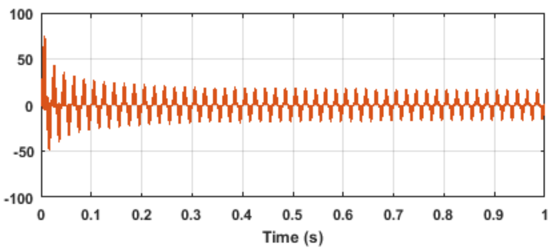


Figure 6. Phase current, speed and flux profile in mode A

In this method the converter voltage is maintained at 400V irrespective the change in speed. The speed changes from1000rpm to 1200rpm at 0.5 sec.



(a)



(b)

Figure 7. (a)source voltage (b) current profile

Here the input voltage is in phase with current and produces input power factor near to unity.

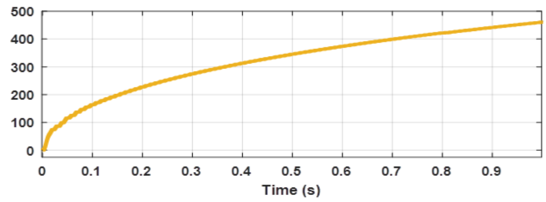


Figure 8 The rise of DC link voltage at mode B operation

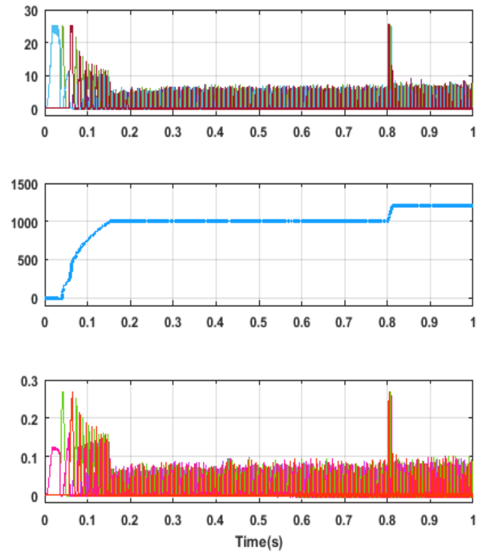


Figure 9. The Phase currents,Speed and Flux profile in mode B

The voltage of the luo converter varies with time.The voltage decreases with change in speed

The speed is changed from 1000rpm is 1200rpm at 0.8 sec. The variable voltage variable speed requirement drive can be supplied in mode B

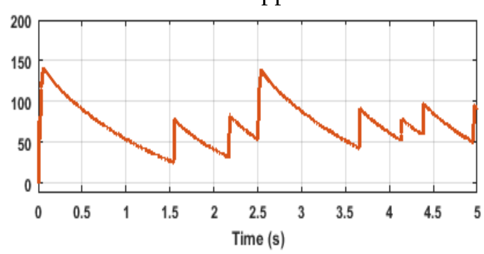


Figure 10 The DC Link voltage profile in mode C,

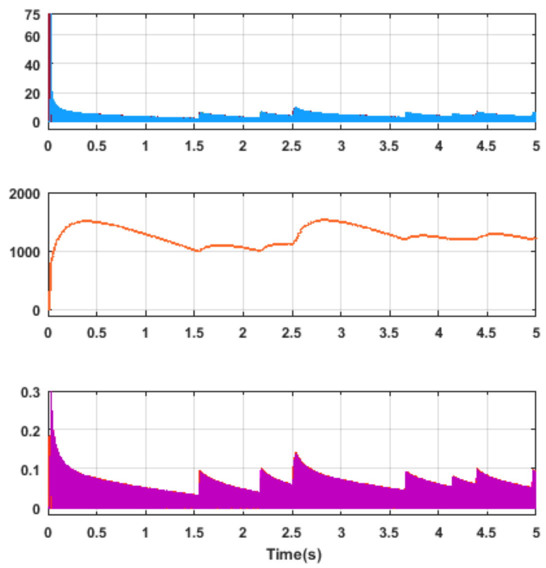


Figure 11.current speed and flux profile in mode C

The speed changes from 1000rpm to 1200 rpm at 2.5 sec. The steady state error is little high in this mode.

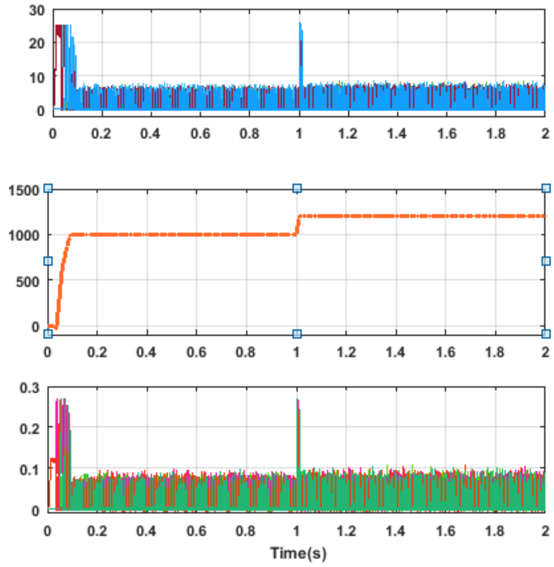


Figure12. Voltage speed and flux profile in mode D

Here two controllers operate separately for front end rectifier and drive circuit. The speed changes from 1000rpm to 1200rpm at 1sec.

The following table shows the comparison performance of the SMC controller in various modes of operation. Mode C and mode A give better result and make it suitable as a controllable drive.

Table 1 Comparison of Performance index in MODE A,MODE B, MODE C, MODE D operation of SMC

Mode A

Set Speed RPM	Actual SS Speed RPM	Steady state error RPM	Peak Overshoot RPM	ISE
1000	1012	0	12	1.1e4
1200	1217	17	1	1.3e4

Mode B

Set Speed RPM	Actual SS Speed RPM	Steady state error RPM	Peak Overshoot RPM	ISE
1000	1017	17	2	1.6e4
1200	1217	17	4	1.62e4

Mode C

Set Speed RPM	Actual SS Speed RPM	Steady state error RPM	Peak Overshoot RPM	ISE
1000	1005	5	0	0.81e4
1200	1203	3	0	0.82e4

Mode D

Set Speed RPM	Actual SS Speed RPM	Steady state error RPM	Peak Oversh Oot RPM	ISE
1000	1017	17	34	1.8e4
1200	1212	12	24	1.6e4

5. Conclusion

The power factor corrected luo converter fed 8/6 phase switched reluctance motor speed performance using sliding mode controller is discussed. The duty cycle and modulation index of the drive is adjusted to achieve the required speed. This control makes the drive to extend for various speed control method. The proposed idea has been validated using simulation in the MATLAB SIMULINK environment.

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