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Advanced Single Current Sensing Device for High Performance SRM Drive

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Abstract

Thesingle current control methodology depends on coordination between magnetic characteristics of SRM drive and rotor position. API regulated single current controlled strategy is appliedfor anasymmetric 6/4 SRM drive system. The simulation results of the single current control technique are compared with those of the three wired current control method.The study shows the superior performance of the single current control method in respect of torque ripple minimization compared to three current sensor control methodology.

Keywords–Single Current Sensor; PI Regulator, Switched Reluctance Motor Drive; Asymmetric Converter Topology.

I. INTRODUCTION

Simple structure and very low expenditure are the important things for the acceptance of SR motors. Itis gaining a good share in the highly aggressive market of adjustable speed drives. SRM drives have successful entrance into assorted sectors of industry such as automotive, aerospace and domestic appliances, due to its rugged design, non-presence of magnets and rotor windings [1], [3].The authentic knowledge of the rotor position is necessary for the operation of switched reluctance motor. In fact, excitations of the SRM phases are to be appropriately synchronized with the rotor position for effective control of torque, speed and torque pulsations. But it needs a mechanism to ascertain the rotor position for actual operation [2]-[6].

Extensive research is going on to dispense with direct rotor position sensors basically by indirect determination of the rotor position to reduce the extra cost and size. Because of the unreliable nature with the external position sensors, development of a reliable and precise sensorless control scheme at minimal cost is desirable [6]. Foraccurate control of SRM drive, excitation of stator needs to besynchronized with the rotor position. Various sensorless position apprehension techniques have been developed in the last few decades [7]-[10] to replace the unreliable & high expensive physical position sensors.The performance of the sensorless methods are evaluatedin respect of cost and torque ripple minimization.The sensorlessSRM drive system has the possibility of mis-operationin machine windings, converter topologies and current sensing apparatus may cause loss of synchronism.The capital abstraction behindall of the sensor less methods is that the salient anatomy of SRM drive makes its phase inductances/magnetic status as afunction of rotor position.If one of the phase windings, converter legs or current/voltage sensors is damaged, the absolute timing to the parameters like EMF/inductance informationin thephase might be lost. Due to loss of sensing devices the drive system works under unrealistic manner.

The assorted methods suggested have their own advantages & disadvantages depending on their operating principle. So as to appear with a technique to absolutely detect the rotor position for the switched reluctance motor drive the single current sensing device is introduced instead of sensorless methods. The main abstraction for rotor position apprehension is to use the phase currentand the flux linkages [11]-[13]. Authors use the abstractions of single current control sensing method with PI regulation for rotor position to control the SRM drive. Likewise, the main advantage of utilizing a single current control is more affordable and it can cope withessential uncertainty in the input signals. Therefore, in terms of real-time sensorless SRM operation, it could be said that PI regulationmethodsare an ideal choice in some reasonable sense.

This paper categorizes theasymmetrical converter topology fed SRM drive with single current sensor method for optimal estimation of rotor position for the SRM drive characteristics [14]-[18]. With a specific end goal to get the better transient response, the proposed system is executed in closed loop setup with PI controller.The MATLAB computer simulation results are depicted in this paper to validate the steady state and dynamic analysis of the proposed single currentsensor strategy. Section II presents the operating principle of SR drive, section III describes the mathematical model of SRM drive, and section IV represents the computer simulations, section V final conclusion for this paper.

II. OPERATING PRINCIPLE OF SRM

Switched reluctance motor (SR drive) is very simple design compared to synchronous & induction machines.

The SRM has a stator with concentrated coils and a rotor without windings. Fabrication of stator & rotor stacks using steel laminations to cut into yield for required range of rotor poles and required range of stator poles and one of the valuable features is that the stator & rotor need not have the same range of poles. Pertaining windings are located over the teeth of the stator and coils areinterfaced to form concernedphases. The proposed three phase switched reluctance motor driveis shown in Fig.1.

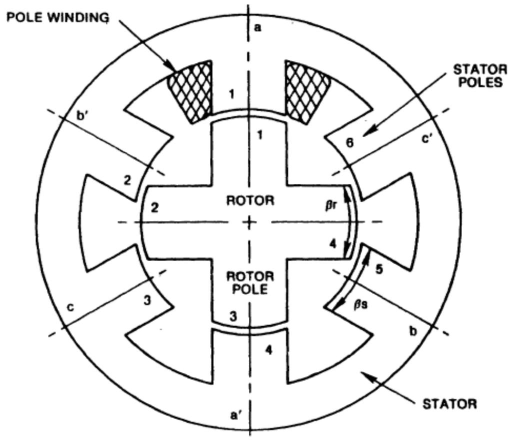


Fig. 1 Basic four phase 6/4 SRM

Excitations are switched sequentially from phase to phaseforproduction of reluctance torque, which may tends to adjust the rotor as well as stator poles is acquired. The torque is attained through its tendency foractuality ofimperativemodelis accepted with respect to minimal reluctance.Production of motoring torque, if a particular phase is excited over the interval when the maximizing the inductance value. The straight forward stator current must be initiated for an operating torque and speed at predefined committed rotor angel. Exact timing of phase winding excitation merely depends on rotor position and then direct or indirect position sensor device is a required for the control scheme so as to attain accurate current pulse to SR drive [20].

A. *Structure of 6/4 SR Drive with Control Scheme*

The intrinsic features of power semi-conductor based switching device for individual phase of the SR drive consists of two major parts, utilization of controlled IGBT switch is interfaced to the input DC source and to the stator coil winding so as to develop the current when concern switch is turned ON, adiversified path for the flow of current, because of trapped energy in particular winding can be used for other mode by a particular switch should be turned or in OFF state condition. Fig.2 depicts the schematic diagram of the integrated drive circuit for SR drive operating under closed loop manner using the PI regulation scheme [21]. The several converter topologies such as bifilar type, resonant type, split phase type, R-dump type, all over these converter asymmetric bridge converters performs accurately and have favourable advantages like quick rate of fall for phase current, no chance of shoot through fault, self-governing phase control action, low distortions.In this asymmetric topology have 3 phases in each phase, comprises of IGBT switches and uncontrolled diodes which are connected asymmetric in an H-bridge manner as depicted in fig.2 as well as authorizes the input DC link voltage to be enables the inverter DC-link voltage to be exploitedacross the specific load terminals.

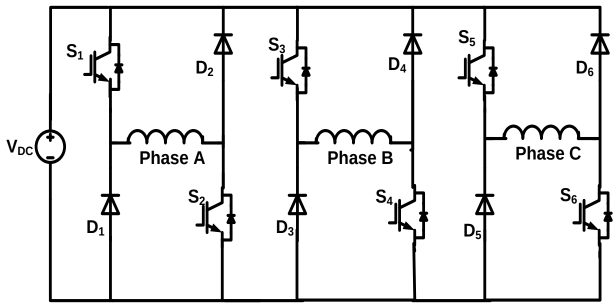


Fig.2Schematic Diagram of Asymmetric Bridge Configuration for 3-Phase 6/4 SRM Drive System

Fig.2 depicts the schematic diagram of asymmetric bridge type converter module for 3-phased SRM drive by using controlled IGBT switch and uncontrolled diode to energizing the particular phase and the dc link voltage to be enabled with the exploited throughout the specified phase terminals.

Fig.3 depicts the energization of phase-A winding by conduction of the concern switches S1 & S2, based on these pertaining switches to be conducted with respect to DC source, the phase A to be short-circuited with DC source, then phase-A goes to energize which may create minimal reluctance to drive the SR motor, the prescribed path for phase-A energization as shown clearly.

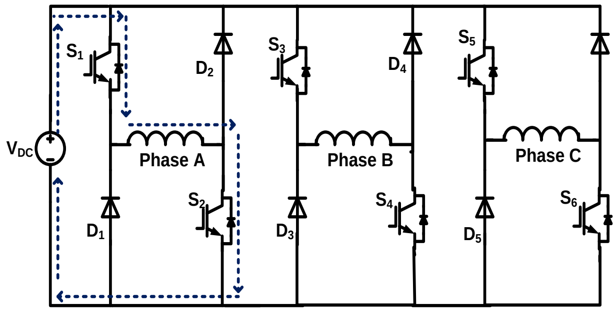


Fig 3.Energization of Phase-A Winding Current Path

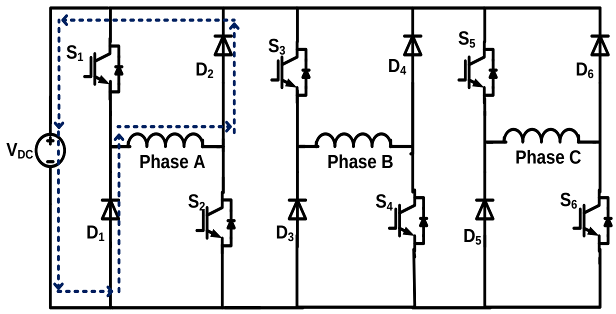


Fig 4.De-energization of Phase-A Winding Current Path

Fig.4 depicts the De-energization of phase-A winding by non- conduction of the concern switches S1 & S2, based on these pertaining switches to be non-conducted with respect to uncontrolled switches, by switching on D1 & D2 the stored energy to be circulated to protect the semi-conductor type IGBT switch due to circulating currents then phase-A goes to de-energized which may create, the prescribed path for phase-A de-energization as shown clearly in the above diagram.

For getting a good dynamic response, the closed loop fashion of the overall drive system is implemented usingthe advanced control principleis merely preferred for this 6/4 SRM drive.Theclosed-loop control execution of the SRM drive framework with the embraced control scheme. Sense the actual speed ω_actual coming from the drive and compare that actual speed respect to reference speed ω_ref then get error value, the mistake in the outcome speed is supported to the PI regulator as depicted in fig.5. The voltage controller (PI controller) forms the failure indicator and produces proper current gain I_ref value. Based on this I_ref current signal is subtracted from the I_actual signal coming from the actual source current value to handle the reference current signal and send to relay to generate switching pulse to that particular switch S1 [22]. The current controller embraced is a hysteresis current controller [10].The current controlled hysteresis band limiter is highly utilized for generating gating pulses based on reference & actual current values then get some of error, that error should be transferred to hysteresis upper band & in between the lower band and may get switching states, due to its simple construction and also fast response, no need of any knowledge of load side parameters.

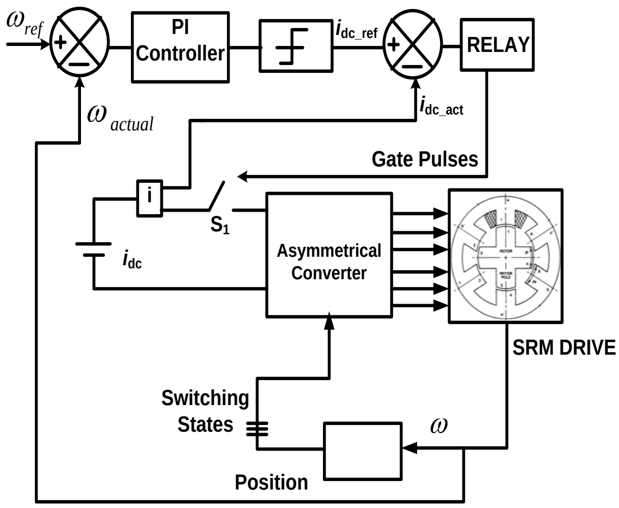


Fig.5Overall Closed Loop Control Design of SRM Drive System with Single Sensing Device

III. MATHEMATICAL REPRESENTATION OF SRM DRIVE

The SRM drive has a very simple design, but the evaluation of its equivalent models is very difficult because of non-linear dominant categorization. Moreover, the flux linkage is a division of two variables such as the current (I)& rotor position (θ). The equivalent model from the equivalent circuit is:

$$V_j = RI_j + \frac{d\Psi_j(i,\theta)}{dt} \quad (1)$$

Then, j = 1, 2….4

Wellwritten as:

$$V_j = RI_j + \frac{d\Psi_j(i,\theta)}{di}\frac{di}{dt} + \frac{d\Psi_j(i,\theta)}{d\theta}\omega \quad (2)$$

Where j=1,2….4 &$\omega = \frac{d\theta}{dt}$
The rotor motion equation is

$$J\frac{d\omega}{dt} = T_e - T_l - f\omega \quad (3)$$

It is anactof 4 non-linearizeddifferentiated partial equations, then neglecting non-linearity of the magnetic saturation.

$$\Psi(i,\theta) = iL(\theta) \quad (4)$$

So asso written as

$$V_j = RI_j + L(\theta)\frac{di}{dt} + i\frac{dL(\theta)}{d\theta}\omega \quad (5)$$

J=1,2….4

$$T_e = \frac{1}{2}\frac{dL(\theta)}{d\theta}i^2 \quad (6)$$

Evaluation of average torque value to bemarked as the principle of superposition of the supported torque of the one by one motor phases;

$$T_e = \sum_{phase-1}^{n} T_{phase} \quad (7)$$

Where V is terminal voltage, I is phase current, R is resistance of phase winding, Ψ is flux linked by the windings, f is friction, J is moment of inertia, L(θ)is instantaneous inductance & Te is total electromagnetic torque.

IV. MATLAB/SIMULINK MODELLING AND SIMULATION RESULTS

The simulation results of SRM drive arediscussed in this section. The results prove that the proposed single current sensor based scheme is estimating the rotor position of the SRM drive with a low error controlled by PI regulator. Simulated results have beenverified successfully at different speeds. Simulation is carried out in different cases, 1) Classical Open Loop & Closed Loop Control of 6/4 SRM Drive operating under three current sensors. 2) Proposed Open Loop & Closed Loop Control of 6/4 SRM Drive operating undera single current sensor.

Case 1: Classical Open Loop & Closed Loop Control of 6/4 SRM Drive Operating Under Three Current Sensors

Fig.6 depicts the computer simulation model of classical three current sensor devices operating under open loop configuration of 6/4 SRM drive topology forMatlab/Simulink tool. SRM Drive is controlled by exact position of the consecutive phase currents with respect to rotor position. The conduction period is used for development of torque on the SRM drive. Here three current sensors method is used for sensing the position of the SRM drive for an exact valuation of drive condition and it is operated under open loop strategy.

Fig.7depicts the current, electromagnetic torque, and speed of classical three current sensor devices operating under open loop circuit of 6/4 SRM drive configuration. somewhat delay to achieve steady state of 6/4 SRM Drive Configuration, due to open loop circuit somewhat delay to achieve a steady state condition. Moreover, need 0.45 Sec elapsed time to get steady state response because of a steady state error, operated in unstable condition for minimizing this error replace that open loop with closed loop model, get fast response with low error values and the system may operate highly in unstable region.

Fig.8 depicts the computer simulation model of classical three current sensor devices operating under closed loop control of 6/4 SRM drive configuration by using Matlab/Simulink tool. SR Drive is controlled by exact position of the consecutive phase currents with respect to rotor position, the conduction is period are used for development of torque on the SRM drive. Here need three current sensors for sensing the position of the SR drive for an exact valuation of drive condition and it is operated under closed loop strategy get favorable advantages, overall system operated under stable nature.

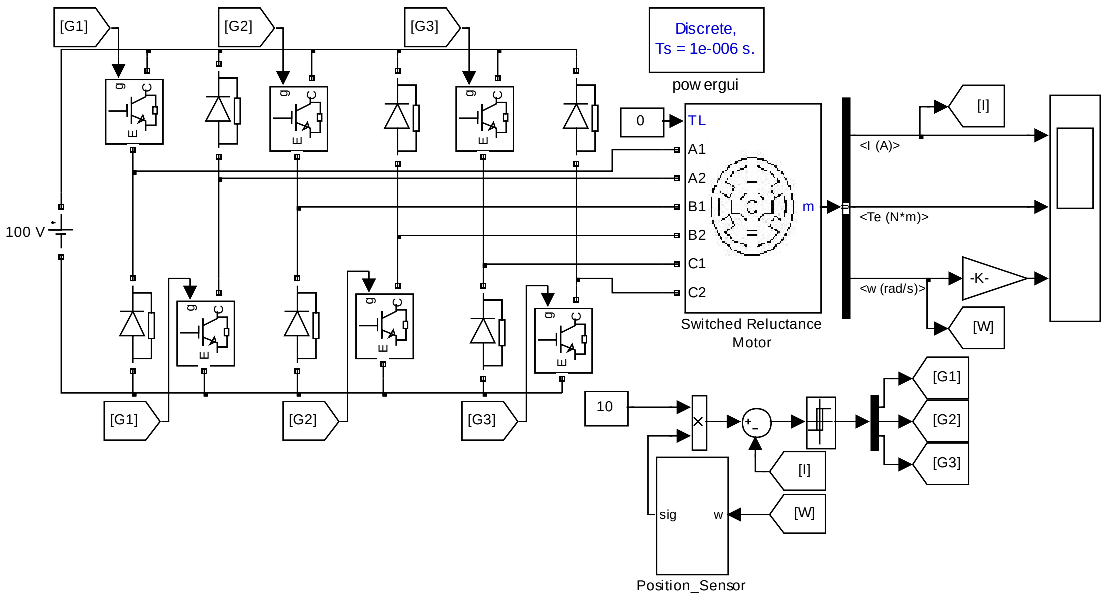
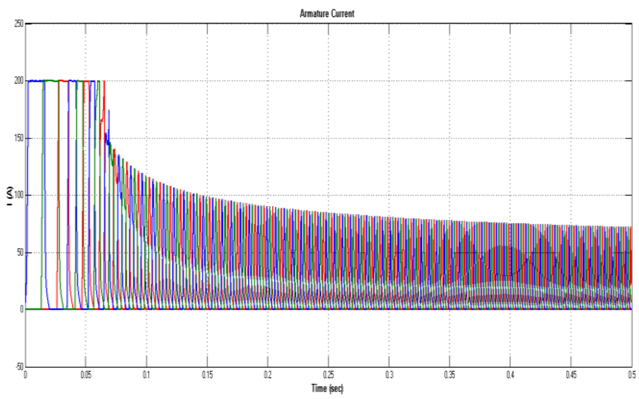
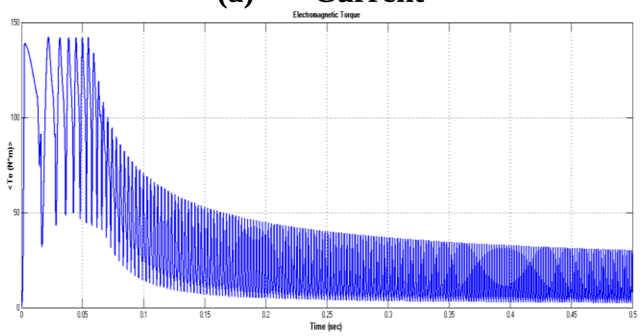


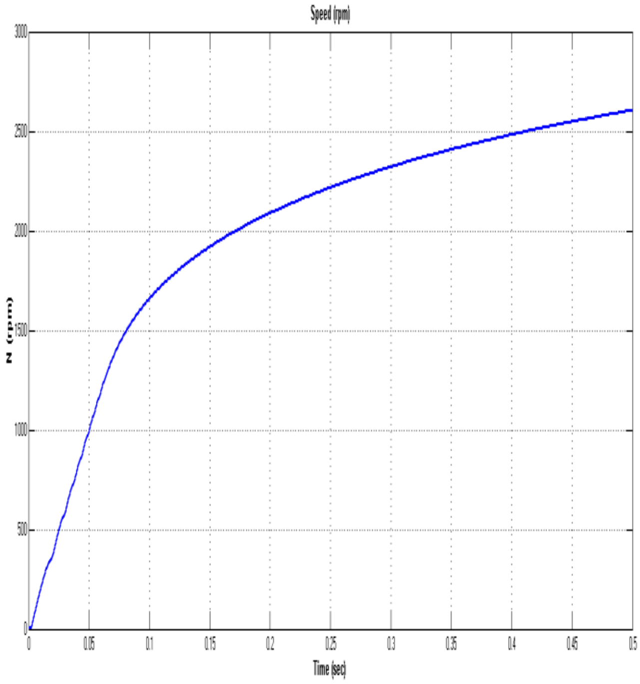
Fig.6Matlab/Simulink Model of Classical Open Loop configuration of 6/4 SRM Drive Operating Under Three Current Sensors



(a) Current



(b) Electromagnetic Torque



(c) Speed

Fig.7 Current, Electromagnetic Torque, Speed of Classical Open Loop Model of 6/4 SRM Drive Configuration.

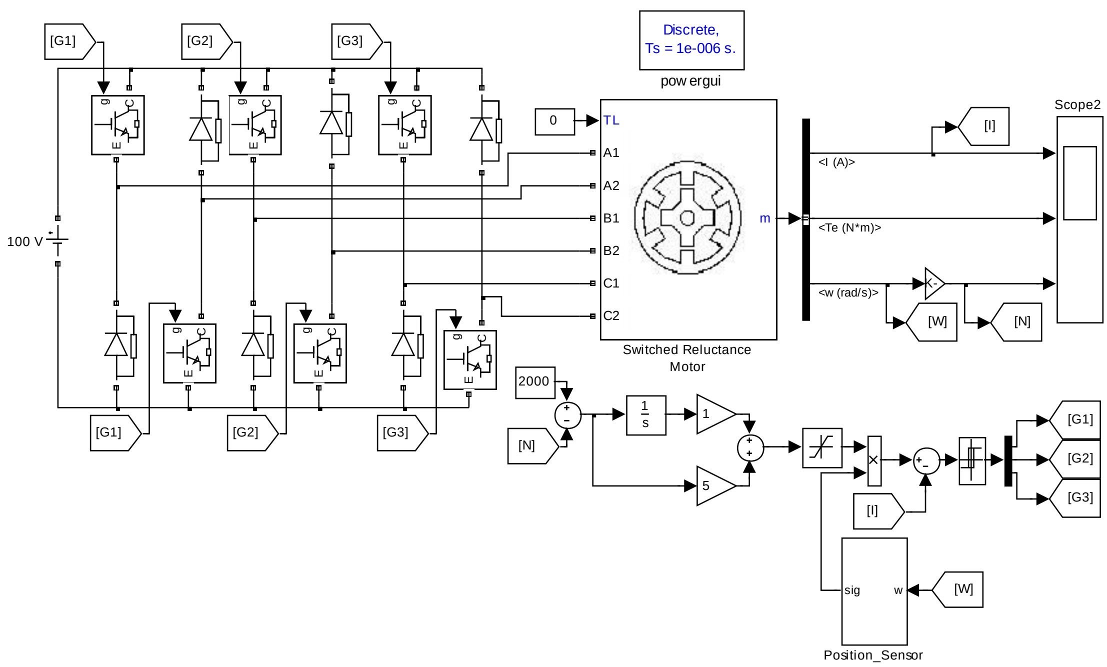
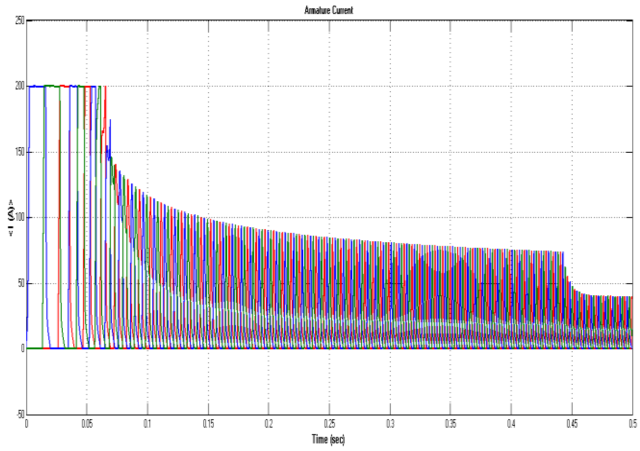
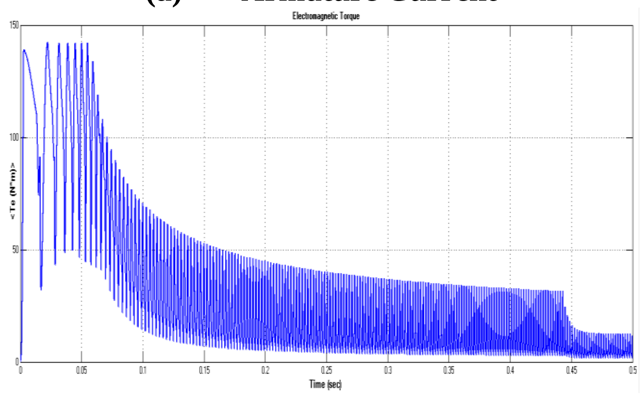


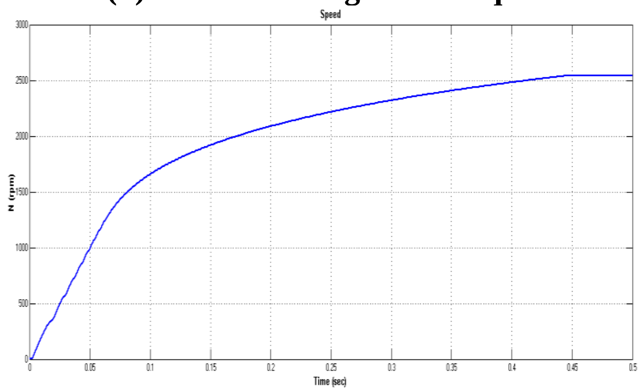
Fig.8Matlab/Simulink Model of Classical Closed Loop Control of 6/4 SRM Drive Operating Under Three Current Sensors



(a) Armature Current



(b) Electromagnetic Torque



(c) Speed

Fig.9 Current, Electromagnetic Torque, Speed of Classical Closed Loop Control Model of 6/4 SRM Drive Configuration.

Fig.9 depicts the current, electromagnetic torque, and speed of classical three current sensor devices operating under closed loop circuit of 6/4 SRM drive configuration, due to closed loop circuit achieve fast response with low steady state error. Due to the closed loop circuit no delay to achieve a steady state condition. Moreover, need 0.23 Sec time to get steady state response because of the error free response, for minimizing this error with closed loop model, get fast response with low error values and the system may operate in more stable condition.

Case 2: Proposed Open Loop & Closed Loop Control of 6/4 SRM Drive Operating Under Single Current Sensor

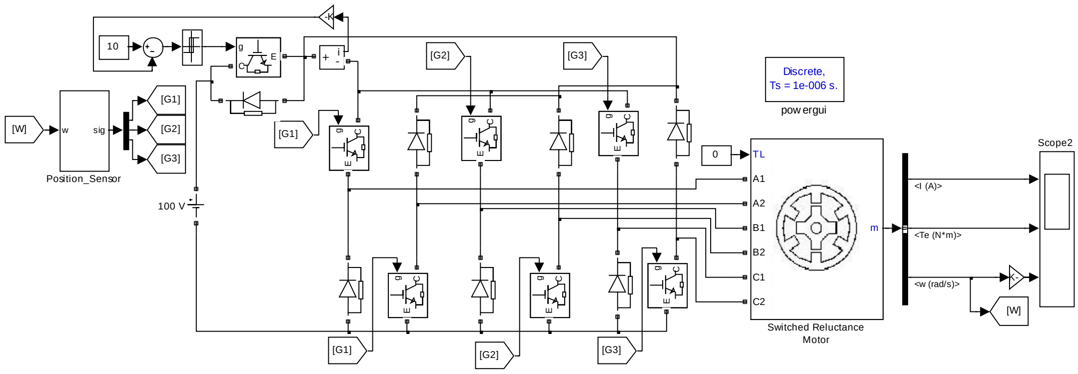
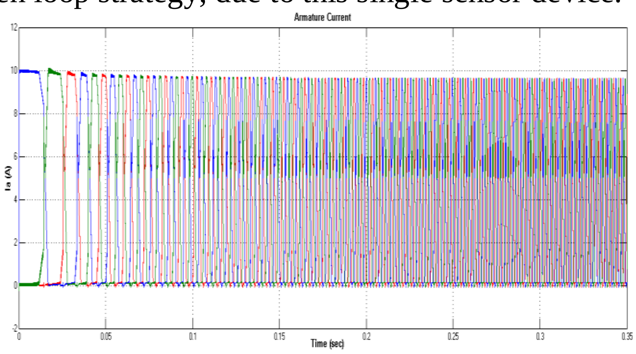
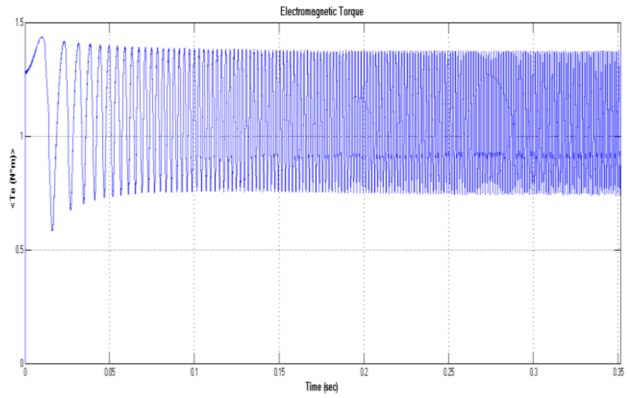


Fig.10 Matlab/Simulink Model of Proposed Open Loop configuration of 6/4 SRM Drive Operating Under Single Current Sensors

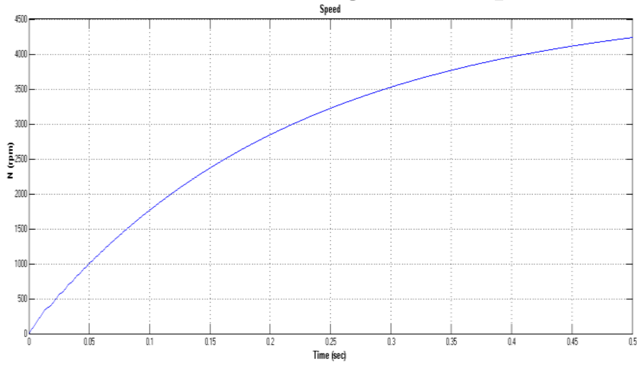
Fig.10 depicts the computer simulation model of proposedsingle current sensor devices operating under open loop configuration of 6/4 SRM drive topology by using Matlab/Simulink tool. SR Drive is controlled by exact position of the consecutive phase currents with respect to rotor position; the conduction period is used for development of torque on the SRM drive. Here need single current sensor for sensing the position of the SR drive for exact valuation of drive condition and it is operated under open loop strategy, due to this single sensor device.



(a) Armature Current



(b) Electromagnetic Torque



(c) Speed

Fig.11 Current, Electromagnetic Torque, Speed of Proposed Open Loop Model of 6/4 SRM Drive Configuration.

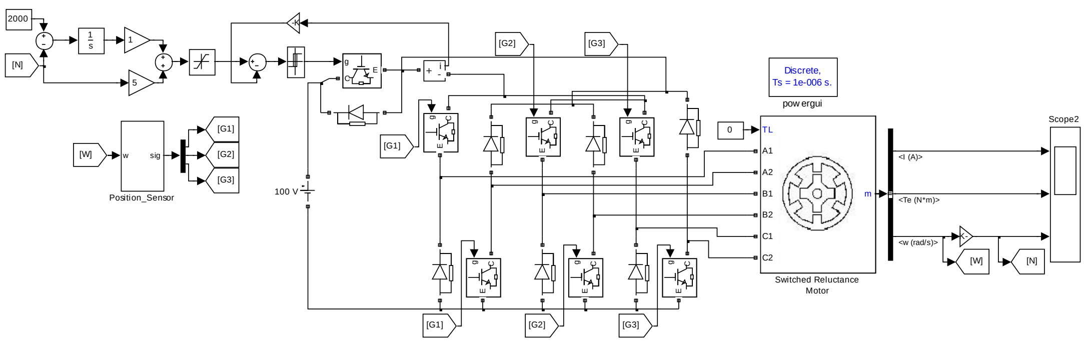


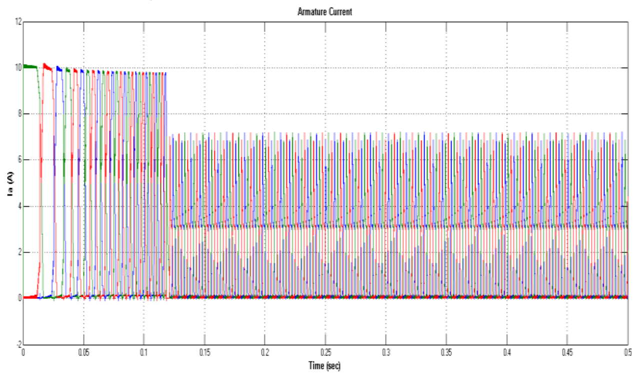
Fig.12 Matlab/Simulink Model of ProposedClosed Loop configuration of 6/4 SRM Drive Operating Under Single Current Sensors

Fig.11 depicts the current, electromagnetic torque, and speed of proposedsingle current sensor devices operating under open loop circuit of 6/4 SRM drive configuration somewhat delay to achieve steady state, due to open loop circuit somewhat delay to achieve a steady state condition. Moreover, need 0.48 Sec elapsed time to get steady state response because of a steady state error, operated an unstable region.

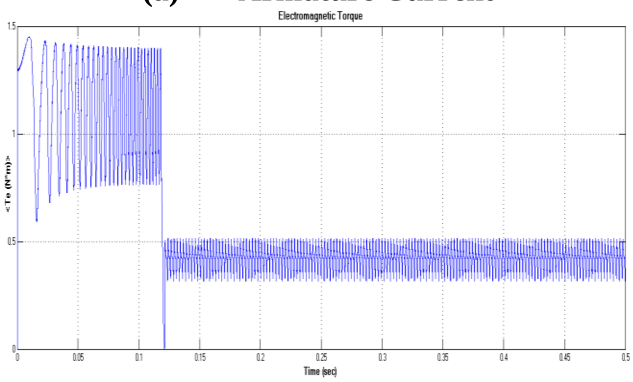
Fig.12 depicts the computer simulation model of proposed single current sensor devices operating under closed loop configuration of 6/4 SRM drive topology by using Matlab/Simulink tool. SR Drive is controlled by exact position of the consecutive phase currents with respect to rotor position, the conduction period is used for development of torque to drive the SR motor. Here need a single current sensor for sensing the position of the SR drive for an exact valuation of drive condition and it is operated under closed loop strategy using a PI regulator, due to this single sensor device get favorable advantages.

Fig.13 depicts the current, electromagnetic torque, and speed of proposedsingle current sensor devices operating under closed loop circuit of 6/4 SRM drive configuration, due to closed loop circuit achieve fast response with low steady state error. Moreover, need 0.12 Sec time to get steady state response because of the error free response, for minimizing this error with a closed loop model with the

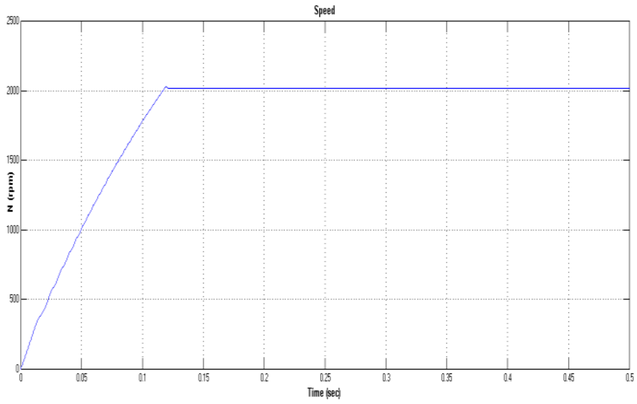
PI regulation scheme; get fast response with low error values and the system may operate in more stable regions.



(a) Armature Current



(b) Electromagnetic Torque



(c) Speed

Fig.13 Current, Electromagnetic Torque, Speed of ProposedClosed Loop Model of 6/4 SRM Drive Configuration.

Table I: Comparative Analysis of Torque Ripple Quantities with Three Sensing Device & Single Sensing Device operating under Closed Loop Asymmetric Converter fed SRM Drive

Torque Ripple Calculation (%)	Asymmetric Converter fed SRM Drive Operating under Closed Loop Condition		
	Using Three Sensing Devices	Using Single Sensing Device	(%) Reduction of Torque Ripple in Te
Electromagnetic Torque (Te)	80.1%	30.23%	49.87%

As above table I depict the comparative analysis of the torque ripples quantities with three sensing devices & single sensing device operate under closed loop asymmetric converter fed SRM drive. By using three sensing devices the torque ripple is about 80.1% &for single sensing device is about 30.23%. Using this advanced methodology reduction of the torque ripples is about 49.87%, due to this the drive moves freely with low noise, technically it is perfect and also commercially perfect because of low cost, low space requirement, ease control.

V. CONCLUSION

This paper categorizesanew approach for estimation of rotor position using single sensing device in SRM drive applications. The estimation of rotor position or rotor angle using unique relationship between phase current & flux linkages with a PI regulatorgives less error value to maintain good stability factor, minimized torque ripples with unique sensing device.Equivalent modelling & computer simulations play a vital role in drive system analysis. Effective simulation results are presented to represent the validity of this proposed drive control scheme.

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