A PWM RECTIFIER BASED HIGH PERFORMANCE SRM DRIVE

DANIEL MANOJ NETHALA
Assistant Professor, Department of EEE
St. Martin's Engineering College, Dhulapally, Secunderabad, Telangana, India.
Email.ID: manojeee@smec.ac.in

Abstract: Switched Reluctance Motor is often utilized in several industrial applications. It straightforward to construct and has salient pole mechanical device and rotor. The rotor doesn't have any winding, commutators and brushes. This drives offer high dependableness fast dynamic response and fault tolerance. However this SRM drives suffer from the disadvantage of getting low power factor issue. The low power factor issue led to high losses in grid. In this paper, a pwm rectifier is proposed to enhance the power factor of Switched Reluctance Motor (SRM) drives. PWM rectifier is a source side device is placed with advantage of rising low power issue and eliminating high input line. The PWM rectifier is changed SRM drive have six two-way self-commutated switches. By applying PWM rectifier controller to a SRM provides higher performance and high robustness than those obtained by the appliance of conventional controllers.
Keywords: Switched Reluctance Motor (SRM), PWM (Pulse Width Modulation) Rectifier, Power Factor Correction

I. INTRODUCTION

Switched Reluctance Motor (SRM) drives suffer from the disadvantage of getting a harmonic current issue. This can be caused by the special salient structure and operational characteristics of switched reluctance motor drives. The low power factor issue can clearly lead to unduly high losses within the facility. Hence, algorithms for correcting or up the power factor issue of SRM drives become a really difficult analysis study. Poor power factor issue, torque ripple that causes undesirable vibration and acoustic noise with major drawback in switched reluctance motor drive system. Torque ripple is reduced either by motor style or by appropriate controlling methods. Low power issue will increase power distribution system losses. Therefore, power factor improvement is crucial to enhancing their demand [2]. These current harmonic circuits embody usually some inductors and capacitors, and consequently those strategies are applicable to tiny ratings of SRM drives and that they are usually not appropriate for high power ratings due to the capability, size, and price of those devices. Moreover, these current harmonic circuits can end in additional difficult topologies and controls for the SRM drives. The system planned in [1] consists of a change power convertor with power factor correction (PFC) and therefore the convertor for the motor drive. The switch angles (triggering pulses angles) are power factor management parameters for SRM drives. The study from [6] shows that the switch angles have a good impact on the output characteristics of the SRM drives and therefore the efficiency is improved by adjusting the switch angle and therefore the turn-off angle. The simulation analysis given in [7] indicate that considered power factor of the SRM drive relies upon the change angles. Therefore, this study tries to enhance the power factor issue supported the any work of [7] by adjusting the change angles instead of mistreatment hardware circuits.

The novel strategy to enhance the power factor in considered SRM drives is summarized as follows: the ability issue is improved by continuous changing of the pulse angles and therefore the turnoff angle. Hence, this study tries to increase the power factor for considered SRM drives by implementing the PWM technique. In PWM Control both the switches are turned on simultaneously at high frequency. During the conduction angle, the average voltage is applied to the phase winding. The voltage is DV_{DC}, where D is the duty ratio and VDC is the input voltage to the converter. It's clear that any extra external hardware circuit isn't required for the strategy planned during this concept. In contrary to the previous ways, the planned strategy is less complicated in topology and management, encompasses a lower value, and is appropriate for not solely little, however additionally high ratings of SRM drives. The contribution of this text is represented in brief as follows.

II. OPERATION OF SRM

The basic operating principle of the SRM is quite simple; as current is passed through one of the stator windings, torque is generated by the tendency of the rotor to align with the excited stator pole. The direction of torque generated is a function of the rotor position with respect to the energized phase, and is independent of the direction of current flow through the phase winding. Continuous torque can be produced by intelligently synchronizing each phase's excitation with the rotor position. By varying the number of phases, the number of stator poles, and the number of rotor poles, many different SRM geometries can be realized.

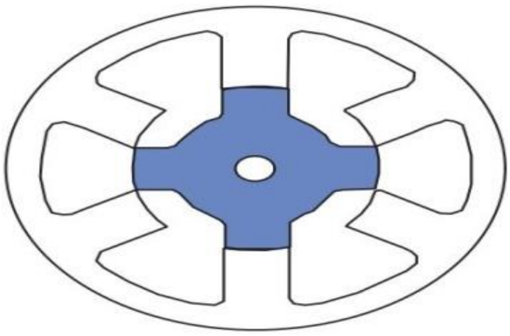

Fig.1. SRM with 6 Rotor Poles 4 Stator poles.

The aligned position of a phase is defined to be the situation when the stator and rotor poles of the phase are perfectly aligned with each other (θ_1-θ_2), attaining the minimum reluctance position and at this position phase inductance is maximum (La). The phase inductance decreases gradually as the rotor poles move away from the aligned position in either direction. When the rotor poles are symmetrically misaligned with the stator poles of a phase (θ_3-θ_s), the position is said to be the unaligned position and at this position the phase has minimum inductance (Lu). Although the concept of inductance is not valid for a highly saturated machine like SR motor, the unsaturated aligned and unaligned incremental inductances are the two key reference positions for the controller. The positions of rotor at aligned and unaligned are shown as fig.2. and fig.3.

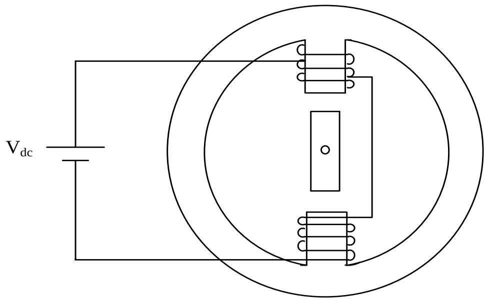

Fig.2. Aligned position

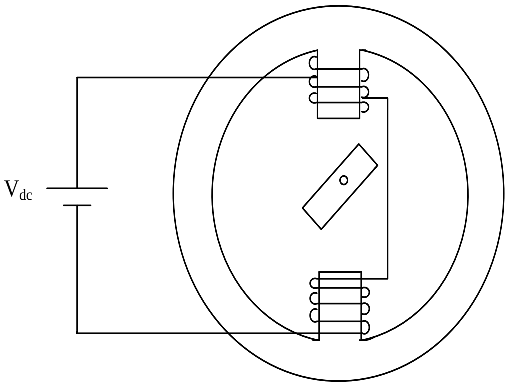

Fig.3. Unaligned position

III. SRM CONVERTER

Since the torque in SRM drives is independent of the excitation current polarity, the SRM drives require only one switch per phase winding. Moreover, unlike the ac motor drives, the SRM drives always have a phase winding in series with a switch. Thus, in case of a shoot-through fault, the inductance of the winding limits the rate of rise in current and provides time to initiate the protection. Furthermore, the phases of SRM are independent and, in case of one winding failure, uninterrupted operation is possible. Following are some configurations of converters used in SRM drives. Fig.4. shows the asymmetric bridge converter. Turning on the two power switches in each phase will circulate a current in that phase of SRM. If the current rises above the commanded value, the switches are turned off. The energy stored in the motor phase winding will keep the current in the same direct until it is depleted.

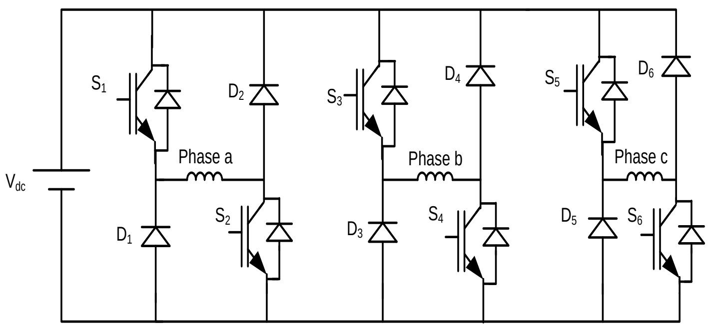

Fig.4. Proposed 6/4 SRM Converter.

When S1 and S2 are turned on, phase A is energized by applying the source voltage across the phase winding. The current can be limited to the set level by controlling either S1 or S2, or both. Similarly, phase B can be energized by S3 and S4, phase C by switches S5 and S6. The merit of this converter is higher utilization of power devices due to the shared switch operation. Nevertheless, the circuit provides restricted current control during overlapping phase currents.

IV. RECTIFIER FED SRM DRIVE

The conventional SRM drive with unipolar power converter is shown in Fig.5. The drive circuit has a three phase diode rectifier, a bulk dc link capacitor and an asymmetric bridge converter. Conventional SRM drive is very simple, but the capacitor charges and discharges, which draws a pulsating ac line current, and results in a low Power Factor. The low Power Factor of the motor increases the reactive power of the power line and decreases efficiency of drive system.

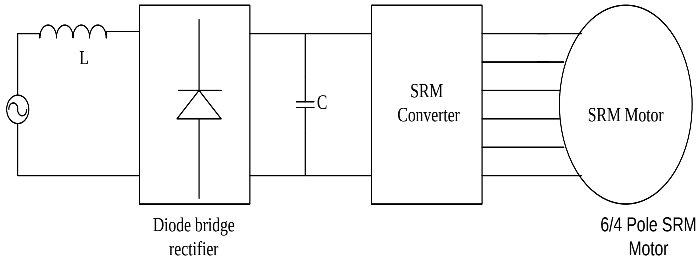

Fig.5. Conventional SRM drive.

Proposed PWM Rectifier SRM Drive can be seen in Fig.6. Front end converter in first stage is placed as controllable rectifier diodes with advantage of improving low power factor and eliminating high input line harmonics (PWM Rectifier). Phase winding energizing is done by machine side converter as second stage [6, 7]. The PWM Rectifier in modified SRM drive has six bidirectional self-commutated switches. No short circuit must be applied to the mains filtering capacitors and No open circuit must be applied to the output current.

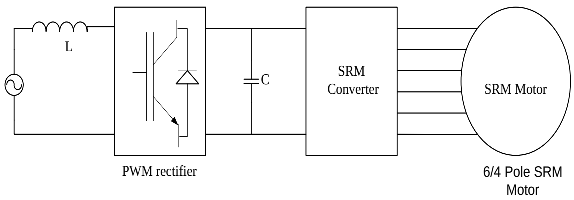

Fig.6. Proposed SRM drive.

V. DESIGN OF SRM DRIVE

The design of an improved power quality 2 Kw SRM drive consists of selection of interface inductors, intermediate DC link capacitors and switching devices for a VSC and a VST.

Selection of DC Link Voltage and Intermediate DC link Capacitor

The VSC is supplied by a single-phase 220 V AC supply. The selection of minimum DC link voltage depends on amplitude of AC voltage and desired rated DC link voltage of a SRM Drive. Tt must be greater than or equal to the peak value of supply voltage and equal to desired rated DC link voltage of the SRM Drive.

$$V_{dc} \geq V_m = V_{rated} \qquad (1)$$

Where Vm is peak value of single-phase supply voltage and Vrated is desired rated DC link voltage of a power of the SRM Drive.

A 400V DC link is selected and for maintaining the constant DC link voltage, an intermediate DC link capacitor is used. The selection of a DC link capacitor is given as,

$$C_{dc} = I_{dc}/2\omega V_{dcripple} \qquad (2)$$

where Ide is the DC link current which is obtained as,

$$I_{dc} = \frac{P_{dc}}{V_{dc}} = 5A \qquad (3)$$

w is the angular frequency in rad/s and V_{de}ripple is the I% of rated DC link voltage. The DC link capacitor is obtained as 1900 IIF, using Eq. (2).

Selection of Interface Inductor

An interface inductor is used between AC supply and AC terminals of a single-phase VSC. The inductor is used to absorb PWM voltages. The fundamental rms voltage Vc at VSC terminal is given as,

$$V_c = (mV_{dc})/\sqrt{2} \qquad (4)$$

Where m is modulation index, and it is considered I. Vde is the reference DC link voltage (400V). The fundamental ms voltage at VSC terminals obtained as 282.88V using Eq. (4). The relation between fundamental voltages at VSC terminals is given as,

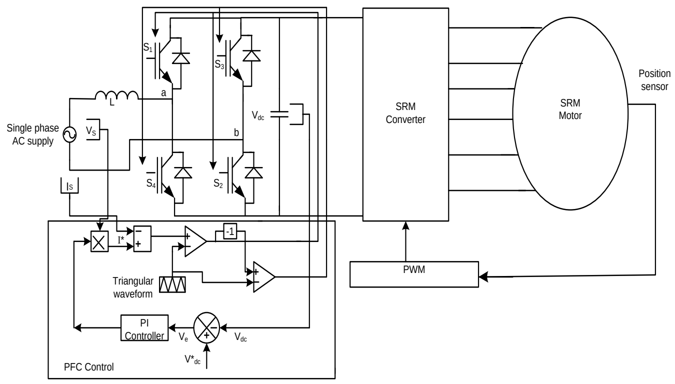

Fig.7.Control Scheme for PWM rectifier fed SRM Drive.

$$V_c = \sqrt{[}V_s^2 + (I_s^2 X_1^2) \qquad (5)$$

Where Vs is rms value of input supply voltage which is taken as 220V and Is is rms value of supply current as,

$$I_s = \frac{P_{in}}{V_s} = 9.09amp \qquad (6)$$

Therefore, interface inductor is obtained using Eq. (5) is 17 mH.

Design of Voltage Source converter (VSC)

The voltage source converter (VSC) is designed on the basis of apparent power through the VSC. The rms current through each leg of VSC is obtained 9.09A using Eq. (6). Where P_{in} the input power at VSC terminals. The maximum current through IGBTs is calculated as [18],

$$I_{max} = 1.25\{I_{p-p} + \sqrt{2}I_{vsc}\} \qquad (7)$$

Considered 10 % peak-peak ripple current, the maximum current through IGBT is obtained 17 Amp. Therefore 25A, 600V IGBT's are used for the VSc.

Design of Voltage Source Inverter (VSI)

The VSI consists of six IGBTs switches. The selection of IGBTs is based on rated current of a SRM. The stall current of SRM is 8.45A, as obtained from manufacturer data sheet and maximum current through IGBT in each phase is obtained as,

$$I_{max} = 1.25\{I_{pp} + \sqrt{2}I_{vsi}\} \qquad (8)$$

Considered 10% peak-peak ripple in stall current, maximum current through IGBTs is obtained as 15A. Therefore 15A, 600V IGBT's are selected for a three-phase VSI.

CONTROL ALGORITHMS:

A .Control Algorithm for Bidirectional AC-DC Converter

The control algorithm for bidirectional AC-DC converter is based to regulate DC link voltage under change in loading condition. Equations used in mathematical modeling are as, A.I Regulated DC link voltage: The reference DC link voltage (Vde*) is compared with the sensed DC link voltage (Vde). If, at the kth instant of time, Vde*(k) is the reference DC link voltage and Vde(k) is the voltage sensed at the DC link, then the voltage error Ve(k) is given as

$$V_e(k) = V_{dc}^*(\text{k})\text{-}V_{dc}(k) \qquad (9)$$

The voltage error V_e(k) is fed to a proportional-integral (PI) controller. The output of a PI controller is given as,

$$I_c(k) = I_c(k-1) + \{V_e(k) - V_e(k-1)\} + K_i V_e(k) \qquad (10)$$

Where Kp and Ki are the proportional and integral gain constants of the PI controller. Estimation of Reference VSC Current The reference current for the control of a VSC is obtained as,

$$I_s^* = I_c(k)u_{vs} \qquad (11)$$

Where Uvs is the unit template of the voltage at input AC mains. It is generated by introducing a gain with input AC supply voltage. The gain is considered (11325) in this study.

B. PWM Controller

For the control of a VSC, a unipolar switching scheme is employed. Leg A and B of the full-bridge converter are controlled separately by comparing carrier signal with reference signals. The reference input current of PWM rectifier Is* is compared with sensed current (Is) to generate the current error Δl* = (Is*- Is). This current error is compared with fixed frequency triangular signal md(t) to get the switching signal for the lGBT's of leg A.

When current error Δ I* > md(t) then S1 =on

ΔI* < md(t) then S4 =on

For the switching of TGBT's of leg 'B' the current error M* is multiplied by unit negative gain and compared with triangular waveform md(t).

When the $\Delta I*$ > md(t) then S3=on

$\Delta I*$ < md(t) then S2=on

C. Control Algorithm for VSI

The VST is used as an electronic commutator. The reference speed (ω_r^*) is compared with sensed speed (ω_r). The speed error (ω_e) is fed to the speed PI controller. The output of speed PT controller is multiplied with resolver output, to generate estimated reference current (I*a,I*b and I*c). These reference currents are compared with sensed currents (Ia, Ib and Ic) of SRM and error is given to the PWM current controller which generates switching pulses for a VSI.

VI. MATHEMATICAL MODELLING OF SRM DRIVE

An accurate analysis of the motor behavior requires a formal, and relatively complex, mathematical approach. The instantaneous voltage across the terminals of a single phase of a SRM drive winding is related to the flux linked by the winding. The flux linkage is a function of two variables, the current i and the rotor position (angle θ). The mathematical model describes the equivalent circuit for one phase (Figure 8).

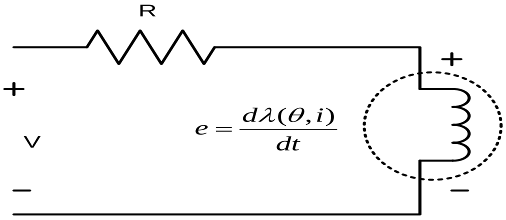

Fig.8. Equivalent circuit of switched reluctance motor

$$V = Ri + \frac{d\lambda(\theta,i)}{dt} \qquad (12)$$

Where V is the applied phase voltage to phase, R is the phase resistance, and *e* is back EMF.

Ordinarily, e is the function of phase current and rotor position, and flux λ can be expressed as the product of inductance and winding current:

$$\lambda(\theta,i) = iL(\theta,i) \qquad (13)$$

And from (8) and (9), the function can be rewritten as:

$$V = Ri + \frac{d\lambda(\theta,i)}{di}\frac{di}{dt}+\frac{d\lambda(\theta,i)}{d\theta}\frac{d\theta}{dt} \qquad (14)$$

The general torque expression is:

$$\mathrm{T}(\theta,i) = \frac{\partial \int_0^1 \lambda(\theta,i)}{\partial\theta} \qquad (15)$$

In general, the dynamical model of a SRM is characterized by the rotor angular speed and angular position relationship:

$$\omega = \frac{d\theta}{dt} \qquad (16)$$

$$\mathrm{T}\text{-}T_{load} = J\frac{d\omega}{dt} + F\omega \qquad (17)$$

Where T load is load the electromagnetic torque, T is the rotor torque, ω is the rotor angular speed and F is the friction coefficient. It is a set of four non-linear partial differential equations. Its solution, neglecting the nonlinearity due to magnetic saturation as equation (8). The function can be written as:

$$V = Ri + L(\theta,i)\frac{di}{dt}+i_{\omega}\frac{dL(\theta,i)}{d\theta} \qquad (18)$$

The average torque can be written depending on the number of phases of the SRM as:

$$\mathrm{T}=\sum_{phase=1}^{n} T_{phase} \qquad (19)$$

VII. RESULTS AND DISCUSSIONS

Case I: Diode Bridge based Switched Reluctance Motor.

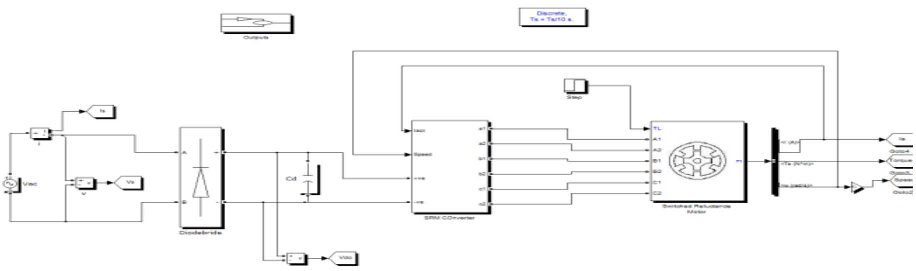

Fig.9. Simulation model of proposed SRM with Diode Bridge Rectifier.

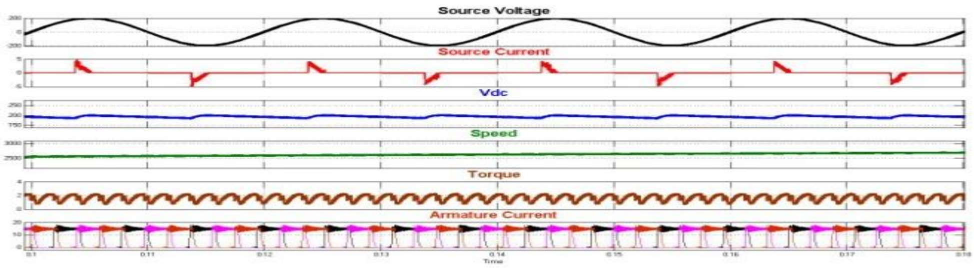

Fig.10. Simulation output waveforms of Source voltage, source current, rectifier output voltage, speed, torque and armature current of SRM.

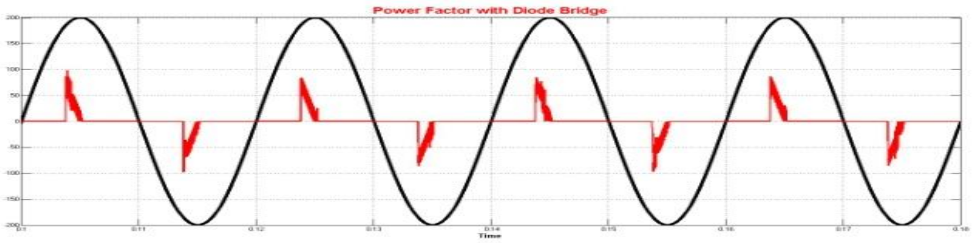

Fig.11. Simulation output wave form of Power factor with Diode Bridge Rectifier based SRM.

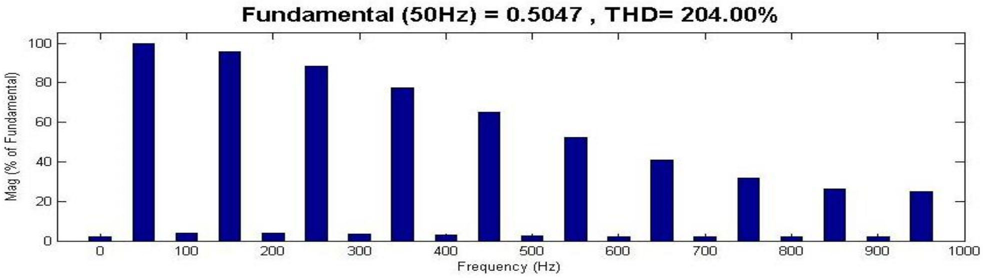

Fig.12. Total Harmonic Distortion of Source Current with Diode Bridge Rectifier based SRM.

Case II: PFC Rectifier based Switched Reluctance Motor at starting condition.

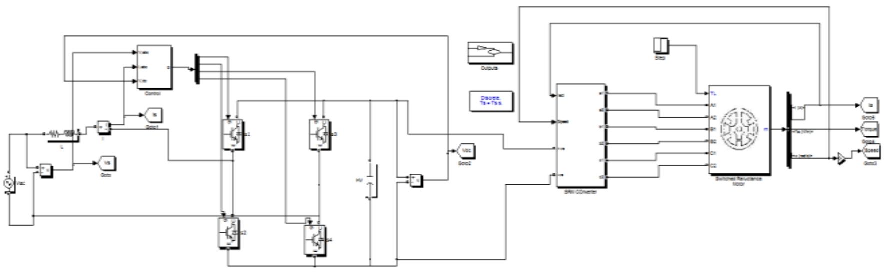

Fig.13. Simulation model of proposed SRM at starting condition with PFC Rectifier.

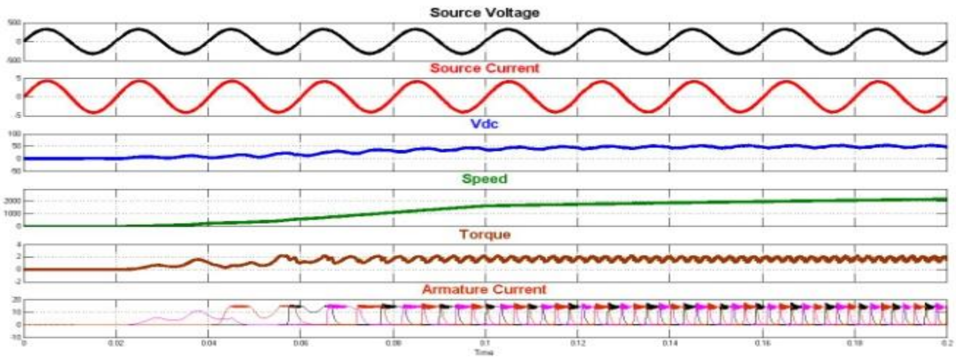

Fig.14. Simulation output waveforms of Source voltage, source current, rectifier output voltage, speed, torque and armature current of SRM.

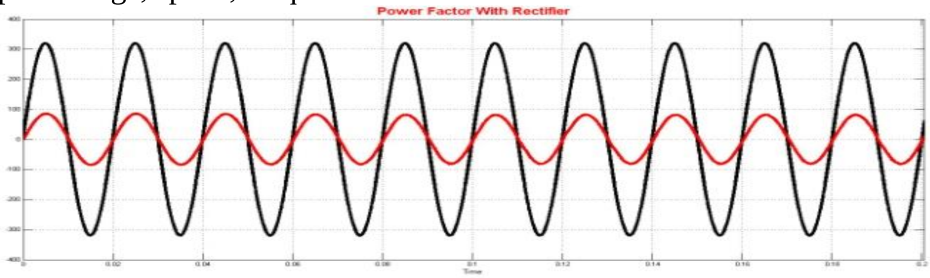

Fig.15. Simulation output wave form of Power factor with PFC Rectifier based SRM.

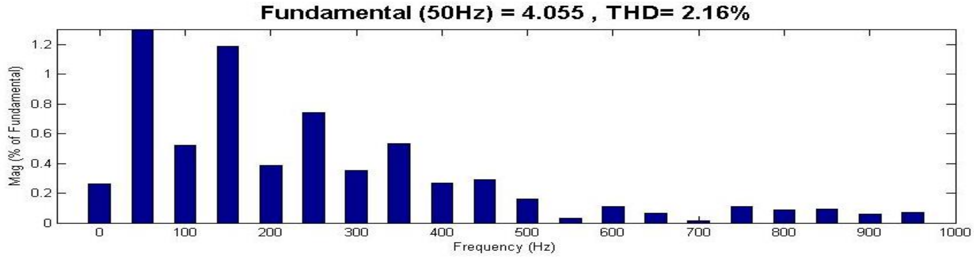

Fig.16. Total Harmonic Distortion of Source Current with PFC Rectifier based SRM.

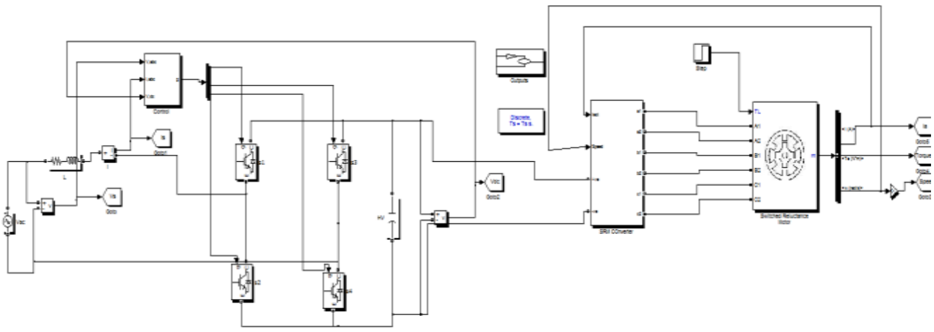

Fig.17. Simulation model of proposed SRM with PFC Rectifier at step variation of Voltage from 100V to 150V.

Case III: PFC Rectifier based Switched Reluctance Motor with step variation of Voltage from 100V to 150V.

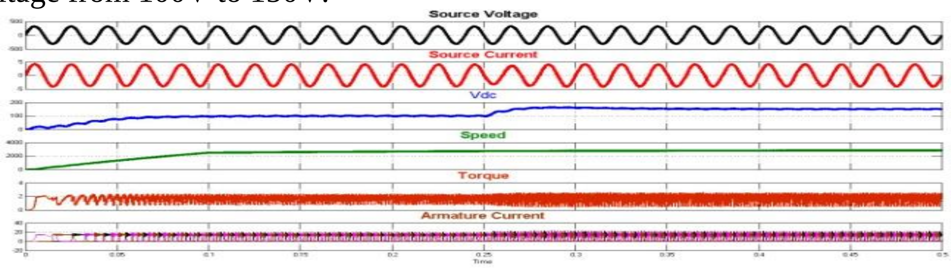

Fig .18. Simulation output waveforms of Source voltage, source current, rectifier output voltage, speed, torque and armature current of SRM at step variation of Voltage from 100V to 150V.

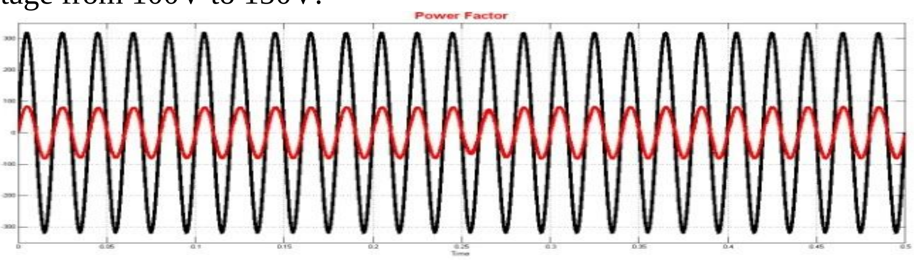

Fig.19. Simulation output wave form of Power factor with PFC Rectifier based SRM at step variation of Voltage from 100V to 150V.

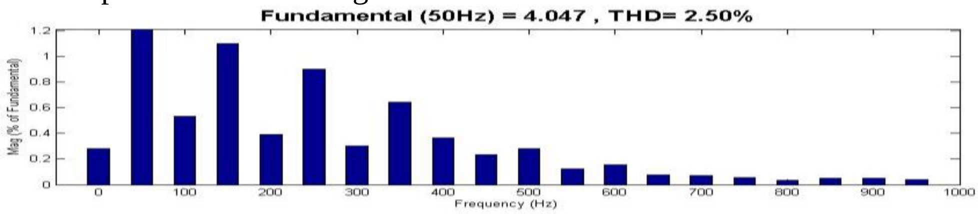

Fig.. Total Harmonic Distortion of Source Current with PFC Rectifier based SRM.

Case IV: PFC Rectifier based Switched Reluctance Motor with 200 input Voltage.

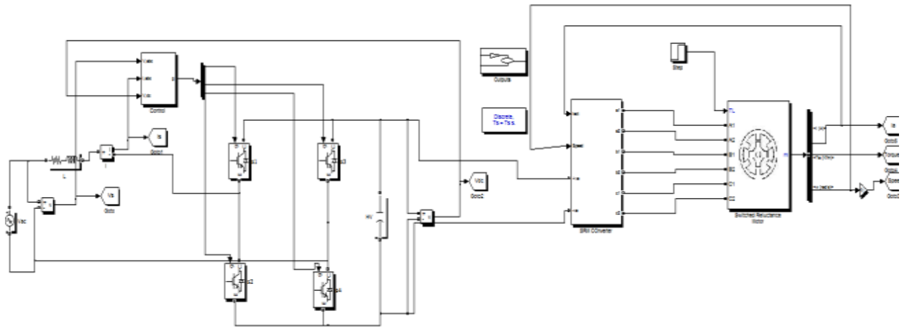

Fig.20. Simulation model of proposed SRM with PFC Rectifier with 200 input Voltage.

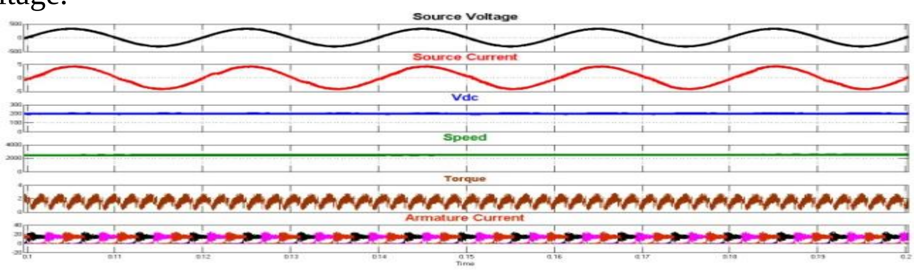

Fig.21. Simulation output waveforms of Source voltage, source current, rectifier output voltage, speed, torque and armature current of SRM with 200 input Voltage.

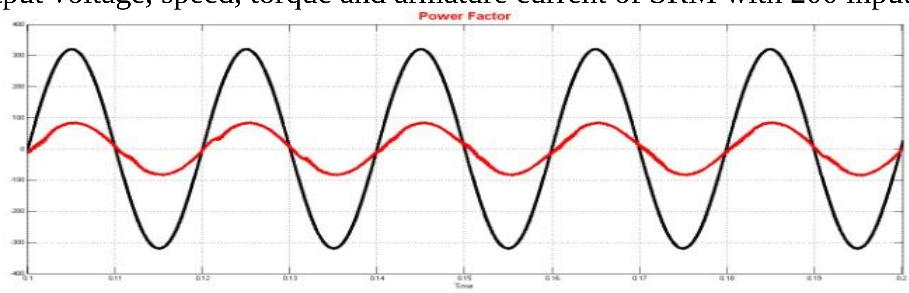

Fig.22. Simulation output wave form of Power factor with PFC Rectifier based SRM with 200 input Voltage.

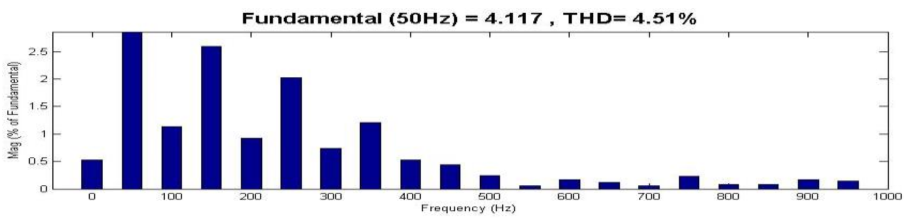

Fig.23. Total Harmonic Distortion of Source Current with PFC Rectifier based SRM.

Case V: PFC Rectifier based Switched Reluctance Motor with step variation of Voltage from 320V to 220V.

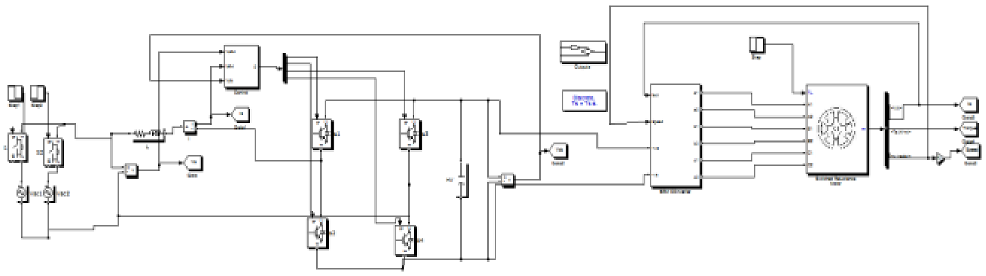

Fig.24. Simulation model of proposed SRM with PFC Rectifier at step variation of Voltage from 320V to 220V.

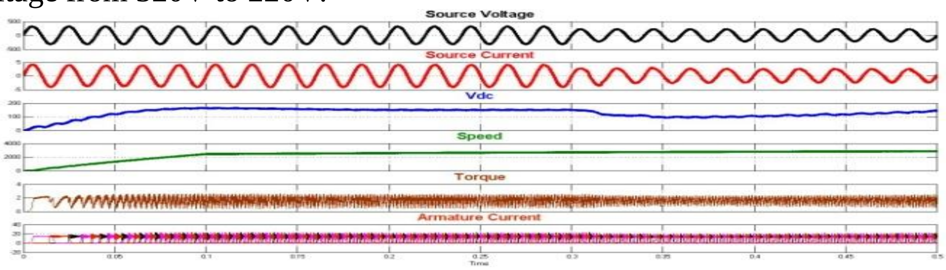

Fig.25. Simulation output waveforms of Source voltage, source current, rectifier output voltage, speed, torque and armature current of SRM at step variation of Voltage from 320V to 220V.

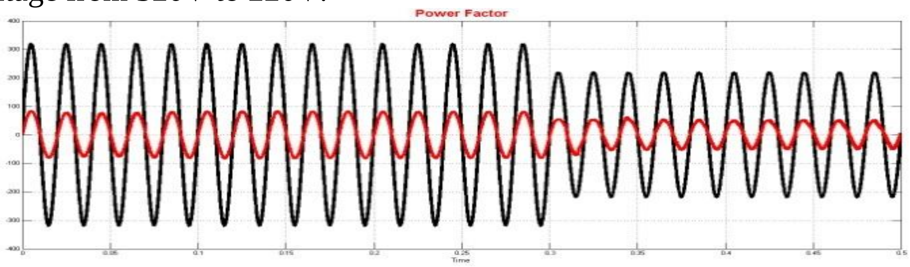

Fig.26. Simulation output wave form of Power factor with PFC Rectifier based SRM at step variation of Voltage from 320V to 220V.

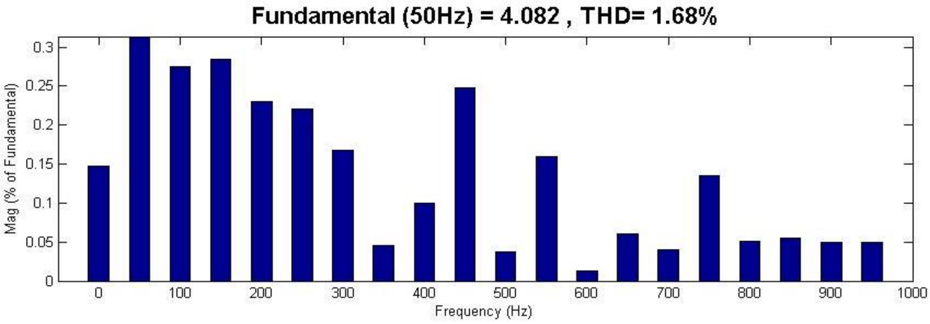

Fig.27. Total Harmonic Distortion of Source Current with PFC Rectifier based SRM.

CONCLUSION

Optimizing the switch angles in switched reluctance motor drives with PWM controller have been planned and successes with simulation implementation. The principle of operation, with parameters and PWM rectifier concerns and simulation results has been conferred. The switch on and switch off angles are used in PWM is optimized so as to get considered a high power factor SRM drives and to take care of the desired speed. To increase the ability issue of SRM drives is consummated by variable the switch on and turns off angles along with adjusting the typical voltage applied to the stator. The switch on and switch off angles is definitely enforced exploitation the PWM controller. The planned strategy is appropriate for both lower ratings and higher ratings of SRM drives. From the simulation analysis it's a good strategy to enhance the power factor for considered SRM drives.

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