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Design and Analysis of Closed Loop Control of SRM Drive with Power Factor Improvement

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Abstract: This concept deals with an input power quality improvement in an Asymmetric Converter based switched reluctance motor (SRM) drive at ac mains using a Reactor circuit. Normally an asymmetric converter is used as a power converter for SRM drive. Conventionally three phase ac mains fed bridge rectifier is used as a dc source to feed this power converter which produces high content of harmonics at ac mains with a very low power factor. The proposed circuits with an asymmetric converter fed SRM drive enhance the power factor at ac mains with low current harmonics. By this method we can get almost constant dc link voltage which can be applied to the converter. The proposed SRM drive is modeled and its. The controls of two power stages are properly designed and digitally realized using a common digital signal processor. Good winding current and speed dynamic responses of the SRM drive are obtained. In addition, the static operation characteristics are also improved. In the charging mode, the power devices that were embedded in the SRM converter and the three motor-phase windings are used to form a buck-boost switch-mode rectifier to charge the battery from utility with good power quality. The validity and effectiveness of the proposed approach is shown by simulation results. In concept proposed concept has been implemented the closed loop speed control of the SRM drive.

Keywords: Switched Reluctance Motor Drives, Converter Topology,Power Factor Correction, Asymmetrical Converter.

I. INTRODUCTION

Switched reluctance motors (SRM) are used in number of variable speed application. This motor is rugged, reliable, requires low maintenance and its fault tolerant. The main disadvantage of this motor is that it requires power converters for its operation. Many types of power converters for SRM drive are reported in the literature [1]. These converters need stable dc supply for its operation. Various converter topologies are available to energize the phase of the SRM but most effective & commonly used topology is two switched per phase asymmetric converter. There are many converter topologies are published in the literature. The objectives of the topologies are to reduce the number of switches per phase, reduce the cost of converter and firing circuit [2-4]. F o r the simplicity and to get full flexibility in simulation of SRM drive the asymmetric convertor topology is used. The main drawback of this configuration is that the supply current drawn has high content of harmonics with very low input power factor.The supply current can be made sinusoidal by circulating third harmonic current through ac side of the diode bridge rectifier. The third harmonic current is generated by modulating dc link current and feedback through ac side of diode bridge rectifier by current injection network. The proposed topology for SRM drive system is capable of improving the power factor ity with low Total Harmonic Distortion (THD) of supply current and keeps the dc link capacitor voltage almost constant[5].

Due to the advantages of high efficiency and high density of power the single-phase switch mode AC-DC converters are being used as front-end rectifiers for various applications. These conventional converters, gets non-sinusoidal input alternating currents which leads to low input power factors and harmonic injections into the lines [6]. Sceintific explorations in quality of power, utility interference has gained much importance due to good regulation in power quality and rigid limits on total harmonic distortion (THD) of current input. A well-defined linearized model around the steady-state operating point is possessed by AC-DC rectifiers presenting unity power factor as shown in Fig.1 which shows the diagram of power factor correction technique which is improved. The SRM has become an attractive campaigner for different applicationof speed drives and is encouraging due to low-cost, high power switching devices and having many advantages , like elementary construction, having no windings or magnets on rotor, negligible mutual coupling, high fault tolerant and robust structure [7]. Due to lacking in operating power factor, ripple in torque which causes undesirable vibration and acoustic noise causes severe problem in switched reluctance motor drive.Torque ripple can be reduced either by motor design or by suitable controlling methods. Distribution system losses would be a cause due to Low power factor. Therefore, improvement of power factor is essential to enhancing their competitiveness [8].

In order to properly control SRM, the stator excitation needs to be synchronized with the rotor position.Several Sensorless position detection techniques have been developed in the past few decades [9], to replace the expensive and unreliable physical position sensors. SRM drive has the crucial problem of large torque ripples due to lack of continuity in the generated torque. But this can be mitigated to a great extent by phase current overlapping. Therefore, the converters used for SRM drive requires separate control for each phase, so that the torque ripples can be reduced by phase current overlapping. Another reason for torque ripples is that the stator current falls behind the reference current during the commutation of each SRM phase current because of back EMF. This means that during commutation, the phase current reaches zero after the reference current which causes negative torque and more ripples in the torque produced by the motor. Thus, the converter used in the SRM drive must have the quick commutation ability of phase currents, which will reduce torque ripples considerably. This paper presents novel converter topologies of SRM drive for speed control. To obtain a better transient response, the overall proposed system is implemented in closed loop configuration with PI controller. Proposed two-stage power converter validation through significant reduction of the THD value of the supply current with the line drawn current quality and power factor improvement are evaluated by computer simulations using MATLAB/Simulink platform.

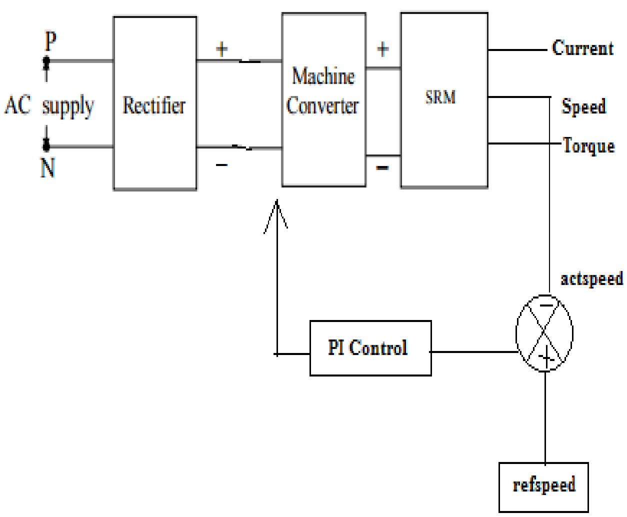

Fig.1. Proposed SRM drive with reactor circuit and Closed Loop Controller.

II. SYSTEM CONFIGURATION

For proposed rector circuit are the combination of a resistor, a transformer & an inductor. The proposed circuit is shown in fig.2. The input supply nature is 3-phase ac source, having ea, eb & ec are the concerned phase voltages & e_{ab}, e_{bc}&e_{ca} are the corresponding line voltages. This circuit topology uses both the voltage in such a manner that the 5th harmonic component of the output voltage will be decreased by a remarkable magnitude. The proposed reactor circuit will improve the power quality by the variation of the value of resistance connected in a proposed circuit.

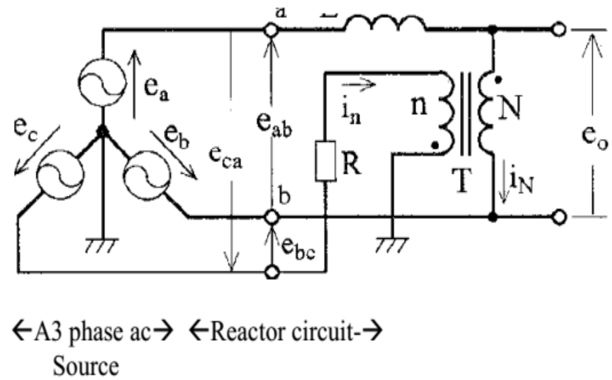

Fig.2. Basic structure of a proposed reactor circuit.

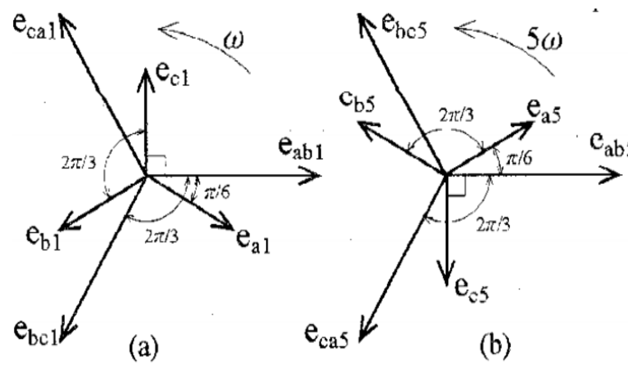

Fig. 3. Phasor diagrams of the fundamental and the 5th harmonic component of the voltage (a) is a phasor diagram of the fundamental voltages, and (b) is that of 5th harmonic voltages.

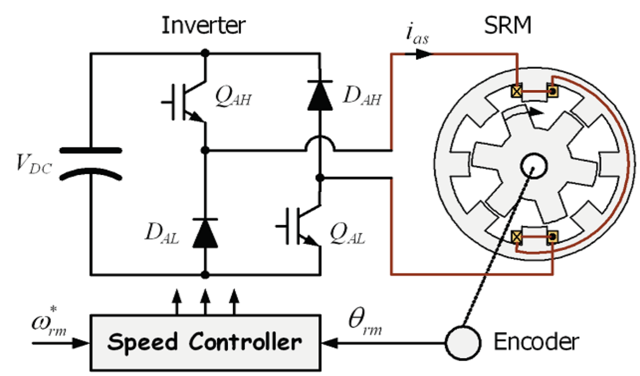

Fig.4. Basic structure for SRM drive with one phase excitation.

III. OPERATION PRINCIPLE OF A REACTOR CIRCUIT

The basic structure of the proposed reactor circuit is shown in fig 2. Which are going to introduced between 3-phase ac source & the Switched Reluctance Motor drive. The circuit includes a series connected inductor (L), a transformer (T) & resistor (R). The phase sequence of the 3-phase ac source is $e_ae_be_c$. The reactor circuit transformer has primary winding (N), which is connected across the line voltage e_{ab}& secondary winding (n) is connected to a phase e_c. The inductance is connected between phase-a & primary winding similarly the resistance is connected between the phase-c & secondary winding. The currents in the winding

N & n are i_N& in respectively. The output voltage E_0 will obtained across the output terminals as the phase voltages & line voltages of fundamental & 5th harmonic components are shown in Fig.3. In this diagram e_{a1}, e_{b1} and e_{c1} indicates the phase voltages, and e_{ab1},e_{bc1} and eca1 indicates the line voltages. Similarly the e_{a5}, e_{b5} and e_{c5} indicates the phase voltages, having the phase order of $e_{a5}e_{c5}e_{b5}$, and e_{ab5} , e_{bc5} and e_{ca5} indicates the line voltages. In the angular frequency of ω rad/sec in the direction of arrow with phase sequence of ea1eb1ec1 & fig.3(b) the angular frequency of 5 ω rad/sec in the s a m e direction with the phase sequence of ea5eb5ec5. By the analysis of fig.3 we can conclude that the phase angle between e_{cl} with e_{abl}& e_{c5} with e_{ab5} are π/2 rad but there is an difference the nature i.e. e_{cl} leads e_{abl}& e_{c5} lags e_{ab5} as shown in Fig.4. The voltage e_{ab} is the phasor sum of e_{abl} and e_{ab5} similarly e_c is the phasor sum of e_{cl} and e_{c5} When there is a 5th harmonic component induced voltage e_{c5} supplies a current i_N in series connected inductor, this will compensate the 5th harmonic component of e_0 because e_{ab5} is cancelled by the induced voltage of inductance L due to the current i_N as shown in Fig.5.

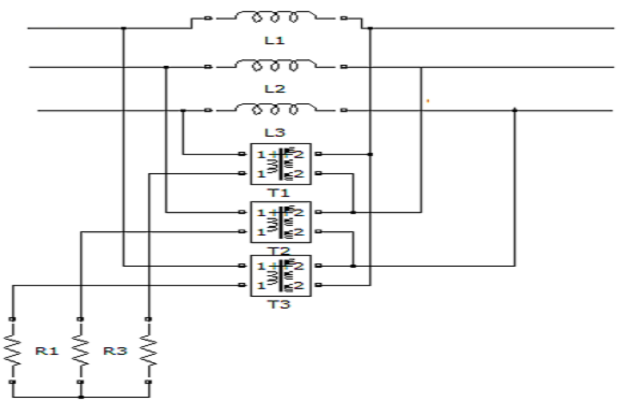

Fig.5.Circuit configuration of a filter circuit.

After applying the proposed configuration, if we consider that the amplitude of fundamental voltage of e_{ab} be E1 and 5th harmonic voltage of e_{ab} be E5 then as per the pharaoh diagram the equation of e_{ab}& e_c are as follows

$$e_{ab} = E_1 e^{jwt} + E_5 e^{j5wt} \quad (1)$$

$$e_c = j(E_1/\sqrt{3})e^{jwt} - j(E_5/\sqrt{3})e^{j5wt} \quad (2)$$

Furthermore, if we assume that the characteristics of the elements like transformer T and the inductance L are having ideal characteristics, then the next step equations are formulized in the circuit as

$$e_o = e_{ab} - L(di_N/dt) \quad (3)$$

$$e_c = Ri_n - (n/N)e_o \quad (4)$$

$$ni_n = Ni_N \quad (5)$$

By applying equation (3) to (5), and assume that there are two constants coefficients are K=n/N and τ= L/R. If we include them than the in next equations are as redefined as

$$K^2\tau(de_0/dt) + e_0 = e_{ab} - k\tau(de_{ab}/dt) \quad (6)$$

By solving equation (1), (2) and (6), the output voltage of reactor circuit e_o is as follows:

$$e_0 = [\{1 + (k\omega\tau/\sqrt{3})\}/(1 + K^2\omega\tau)\}]E_1 e^{j\omega t} + [\{1 - (5k\omega\tau/\sqrt{3})\}/(1 + j5K^2\omega\tau)]E_5 e^{j5\omega t} \quad (7)$$

After the analysis of equation (7), we can conclude that the magnitude of 5th harmonic voltage of eo are depends on the magnitude of coefficient τ & k. The 5th harmonic component of eo can be zero by using the proper values of the variables. So by using this specific feature we can remove the 5th harmonic voltages of 3-phase ac source.

IV. PROPOSED SYSTEM BLOCK DIAGRAM

The proposed scheme for the SRM drive fed by a new reactor circuit based PFC converter shown in Fig.6.The front end proposed reactor circuit suppress the 3rd & 5th harmonics from current drawn by the drive. An asymmetric machine converter is connected between universal DBR and Switched reluctance motor. A high frequency MOSFET of suitable rating is used in the machine converter for its high frequency operation whereas an IGBT's (Insulated Gate Bipolar Transistor) are used in the VSI for low frequency operation. The proposed scheme maintains high power factor and low THD of the AC source current while controlling rotor speed equal to the set reference speed.

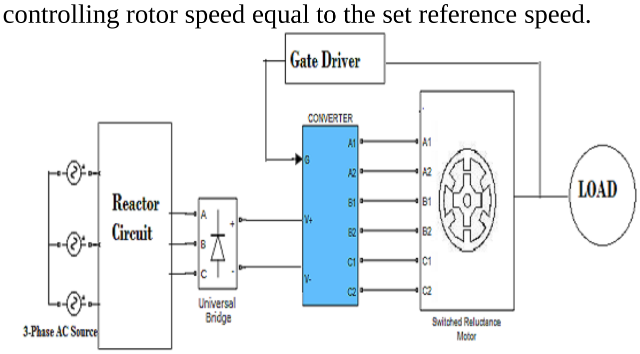

Fig.6. Proposed SRM drive with reactor circuit.

V. SIMULATIONS RESULTS

Simulations results of this paper is as shown in bellow Figs.7 to 14.

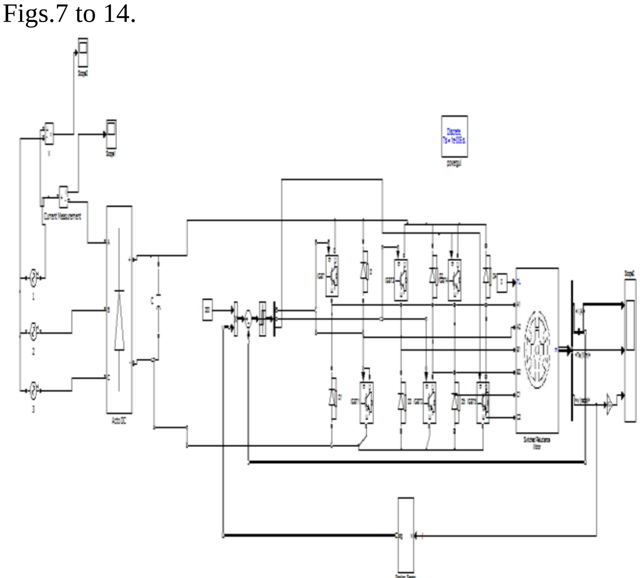

Fig.7. Matlab/Simulink circuit of conventional SRM drive without power factor.

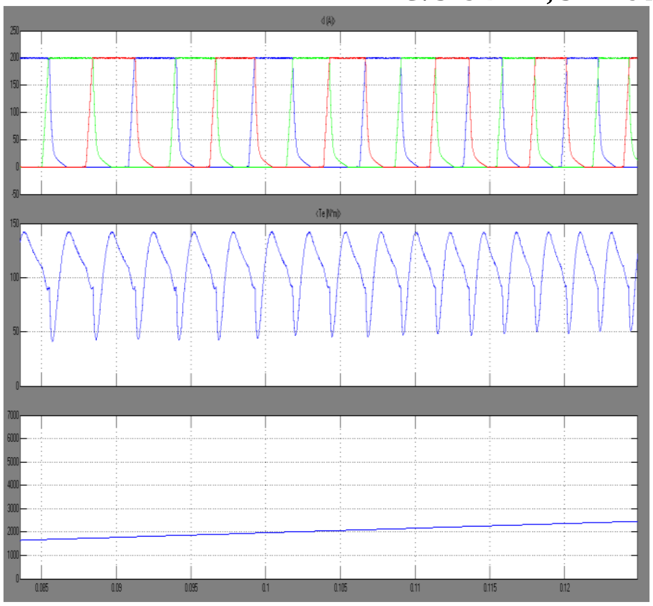

Fig.8. Matlab/Simulink wave form of current, torque and speed conventional SRM drive without PF.

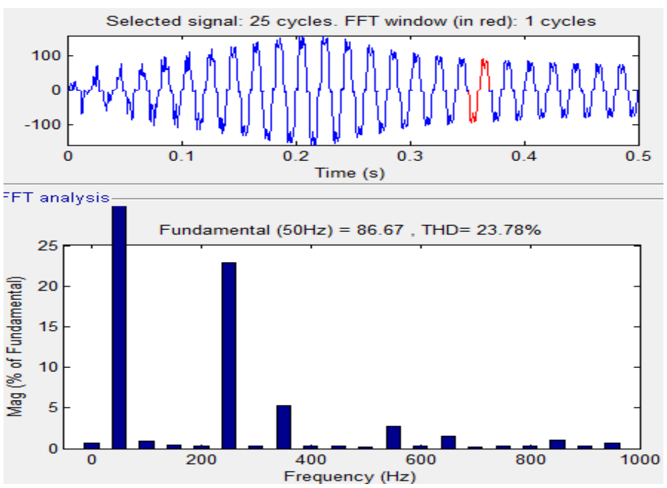

Fig.9. FFT Analysis SRM drive without Power Factor.

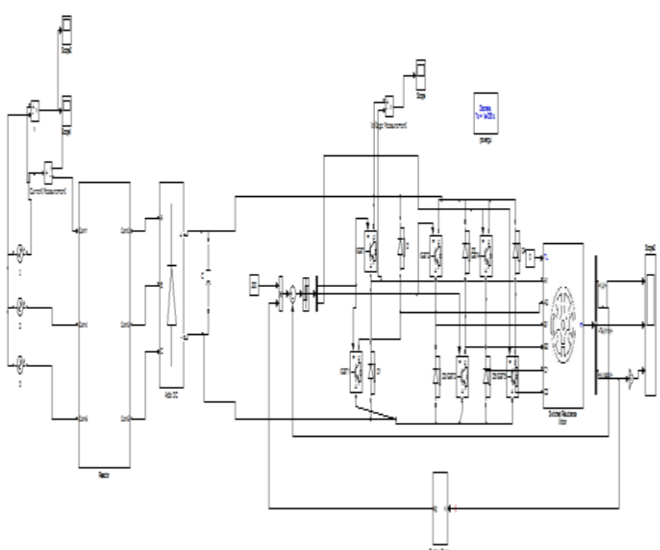

Fig.10. Matlab/Simulink circuit of conventional SRM drive with power factor.

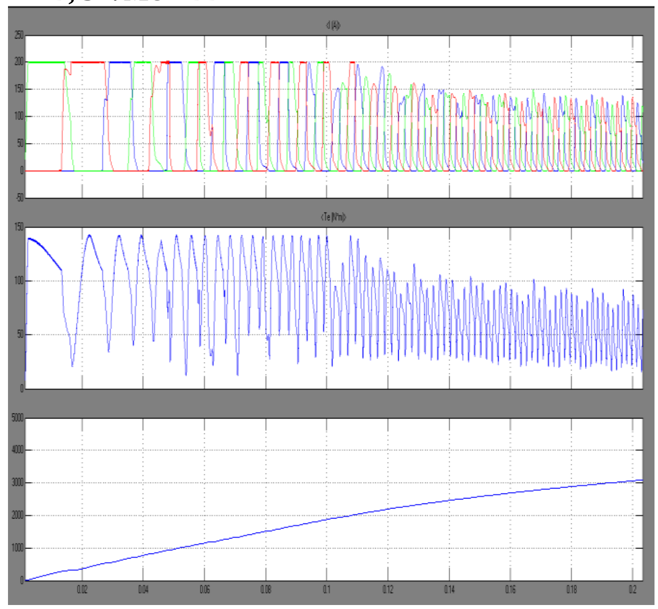

Fig.11.Matlab/Simulink circuit wave form of current, torque and speed conventional SRM drive with PF.

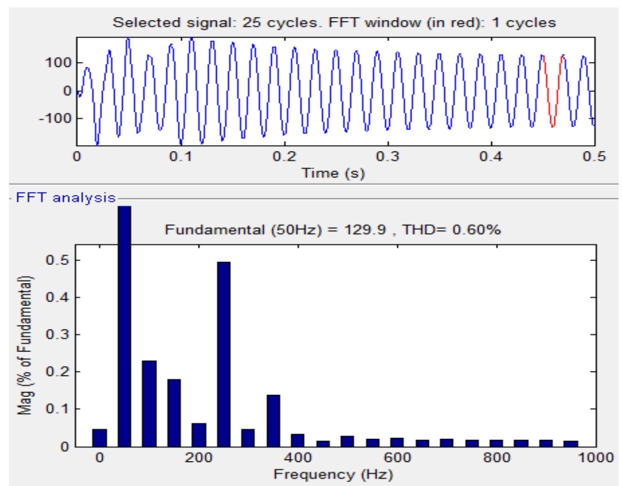

Fig.12. FFT Analysis SRM drive with power factor.

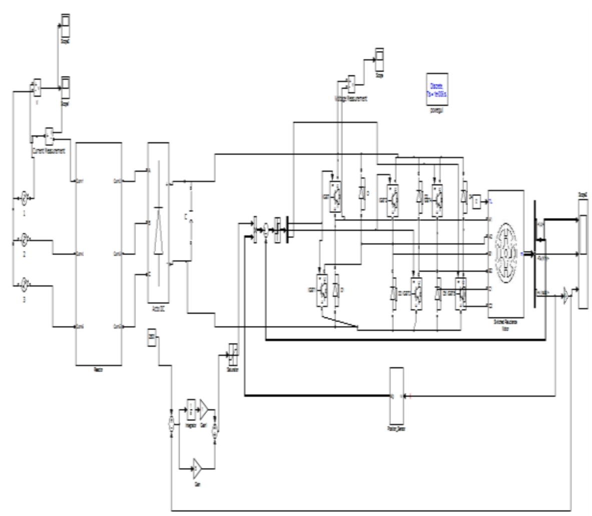

Fig.13.Matlab/Simulink circuit of proposed closed loop SRM drive with power factor.

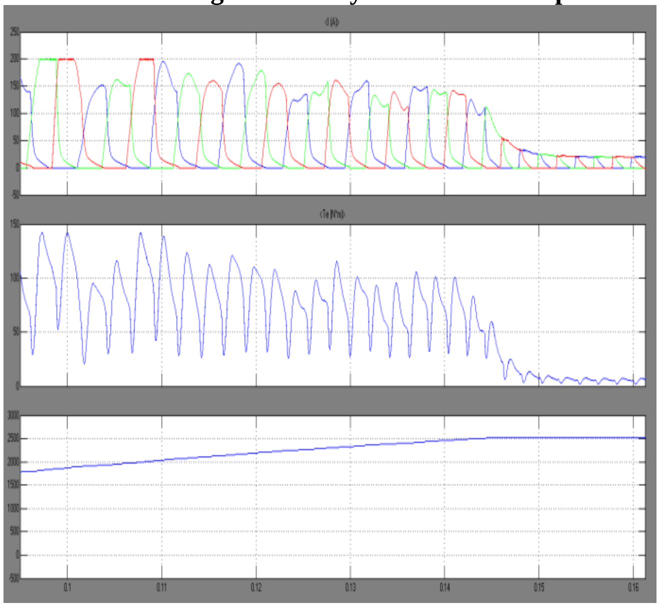

Fig.14.Matlab/Simulink circuit wave form of current, torque and speed conventional SRM drive with closed loop.

V. CONCLUSION

The proposed reactor circuit fed asymmetrical converter-based Switched reluctance motor drive has been designed and modeled in MATLAB/ Simulink environment. The performance of proposed reactor circuit fed SRM drive has been compared with the conventional DBR based SRM drive. The proposed circuit has reduced the THD of supply current to less than 5%. The ripples in dc link voltage have been found negligible and the voltages across the capacitors are observed to be almost constant which is needed for the proper operation of the SRM. The power factor at the front end side has been also near to unity for different value of the source voltages. The THD of ac supply current have been maintained within IEEE- 519 standard with a high power factor.The input phase current frequency spectra clearly illustrate current THD improvement as within IEEE/IEC standards through power factor correction.Closed loop control using a PI controller with Kp and Ki values are presented in this paper for achieving fast response, low steady state error and low torque ripples. Closed loop controller for an SRM drive with power factor correction is implemented in Matlab/Simulink environment.

VI. REFERENCES

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