



# **Development of Buck Switch Mode Rectifier Charger for Battery Powered Switched Reluctance Motor Drive**

S.Dhatchayani<sup>1</sup>, B.Barathy<sup>2</sup>, A.Kavitha<sup>3</sup>.

PG student, Dept of EEE, College of Engineering, Anna University, Guindy, Chennai<sup>1</sup>

Research scholar, Dept of EEE, College of Engineering, Anna University, Guindy, Chennai<sup>2</sup>

Assistant Professor, Dept of EEE, College of Engineering, Anna University, Guindy, Chennai<sup>3</sup>

**ABSTRACT:** This paper presents the development of a compact battery-powered switched-reluctance motor (SRM) drive for an electric vehicle application. In motoring mode, the proposed front-end converter can be operated as a DC/DC boost converter to establish well-regulated and boosted DC-link voltage for SRM drive from battery. In idle charging mode, the proposed front-end converter is arranged to act as a buck-type switch-mode rectifier (SMR) for charging the battery with good line power quality. Four diodes embedded in the SRM converter and the two motor phase winding inductances are employed to form the necessary constituted components of the SMR.

**KEYWORDS:** Switched Reluctance Motor(SRM),Front end converter, Buck type switch mode rectifier, Battery.

## **I.INTRODUCTION**

Switched Reluctance Motor (SRM) possesses many advantages [1] and [2], such as simplicity and robustness in motor structure and converter circuit, high power density, high acceleration capability, and suitability for high-speed operation. Hence, SRM is very suited in many specific applications, wherein the automotive is a typical example. However, SRM suffers from the drawbacks of having high torque ripple, high vibration and acoustic noise and nonlinear torque dynamics. As generally recognized, electric vehicles (EVs) possess many advantages, such as high fossil fuel for driving energy conversion efficiency, motor-regenerative braking capability, fewer local exhaust emissions, and less acoustic noise and vibration. . A drive with a reluctance motor (SRM and converter) has higher efficiency than one realized using an induction motor with converter. It is of basic importance to minimize the amount of energy consumption by vehicles with electric drive. There have been some existing specific front end converters [3]-[6] for SRMs. In [3], a front-end single-ended primary inductance converter (SEPIC) is developed to achieve dc-link voltage boosting and obtain high ac line drawn power factor. As for the front-end converters with dc power sources [4]-[6], a buck type converter and its switching control were presented in [4]. It can only provide variable dc-link voltage below the input voltage, and the reduced demagnetization voltage leads to longer winding tail current and thus reduced average torque.

Switch-Mode Rectifier (SMR)[7]-[9], has been increasingly utilized to replace the conventional rectifiers as the front-end converter for many power equipments. Through proper control, the input line drawn current of a SMR can be controlled to have satisfactory power quality and provide adjustable and well-regulated DC output voltage.

# International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Special Issue 2, April 2014

## II.FRONT END CONVERTER FED WITH SRM DRIVE

The front-end converter is employed to regulate and/or boost the dc-link voltage of the SRM drive in motor driving mode. In idle mode, the proposed front-end converter is arranged as a switch-mode rectifier (SMR) to charge the battery from mains. Four diodes of the motor converter are utilized to form the rectifier of the SMR, and the inductances of two motor windings are used as the input filter components during each half ac cycle. Good charging performance with satisfactory line drawn power quality is obtained

Fig.1 shows the front end converter fed with SRM drive.  $S_{f1}$ ,  $D_{f1}$ ,  $S_{f2}$  and  $D_{f2}$  in Fig. 1 construct a two-quadrant front end converter. The circuit schematics during two operation modes are arranged as:

- 1) Battery discharging mode
- 2) Battery charging mode

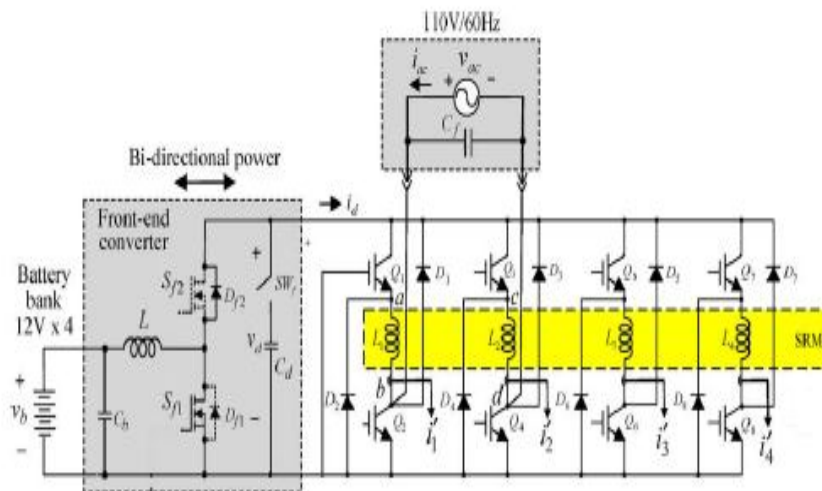


Fig 1.Front End Converter fed with SRM Drive

### 1) Battery discharging mode

- ❖  $S_{Wf}$ : closed;  $S_{f2}$ ,  $D_{f1}$ : permanently off.
- ❖  $S_{f1}$ ,  $D_{f2}$  : construct a dc–dc boost converter to let the dc-link voltage be regulated and boosted.

### 2) Battery charging mode

- ❖  $S_{Wf}$ : opened;  $S_{f1}$ ,  $D_{f2}$ : permanently off.
- ❖  $S_{f2}$ ,  $D_{f1}$  and  $D_1 \sim D_4$ ,  $L_1, L_2$  (embedded components of SRM and its converter): construct a buck-type SMR for charging the battery from utility. The imbedded four power diodes  $D_1 \sim D_4$  and the winding inductances  $L_1, L_2$  are employed to form the rectifier and the input filter components of the SMR.

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## Battery powered SRM drive in battery discharging mode

In battery discharging mode, front end dc-dc converter act as a boost converter. Battery is a source which give supply to SRM drive. Therefore battery get discharged. When switch  $S_{f1}$  is opened, battery voltage is given to the motor. Otherwise energy get stored in inductor L.

Fig 2.shows the battery powered SRM drive in discharging mode. The dc-dc boost front-end converter is formed using L, $S_{f1}$  and  $D_{f2}$  in the proposed front end converter.

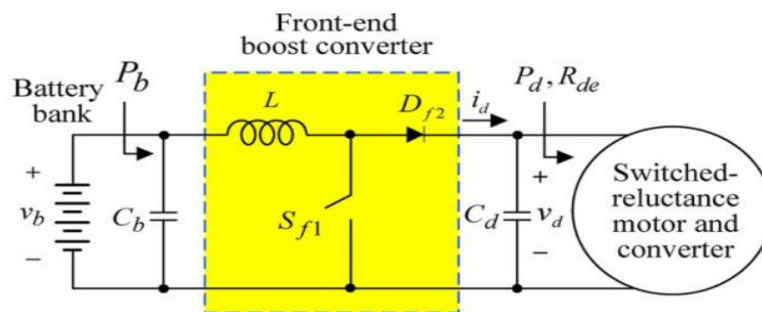


Fig 2.Circuit diagram of battery powered SRM drive in discharging mode.

## Design of converter parameter

Using Faraday's law for the boost converter

$$V_{in}DT_s = (V_0 - V_{in})(1 - D)T_s$$

from which the dc voltage transfer function turns out to be

$$\frac{V_0}{V_{in}} = \frac{1}{1-D}$$

The peak – peak current ripple can be calculated by

$$\Delta i_L = \frac{1}{L}V_{in}(DT_s) = \frac{1}{L}(V_0 - V_{in})(1 - D)T_s$$

The filter capacitor must provide the output dc current to the load when the diode D is off. The minimum value of the filter capacitance that results in the voltage ripple  $V_r$  is given by

$$C = \frac{DV_0}{V_r R_f}$$

By using these, the values of L & C for front end converter are calculated.

$$L=19.73e-6H$$

$$C=4700e-6F$$

## III.BATTERY POWERED SRM DRIVE IN BATTERY CHARGING MODE

In idle battery charging mode, vehicle is plugged into ac mains. AC voltage is rectified to DC by Switch Mode Rectifier (SMR). Four diodes of the motor converter are utilised to form the bridge rectifier of the SMR and two windings of motor are used the buck SMR input filter inductors during each half ac cycle. Then the rectified DC

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voltage is the input of front end converter. In charging mode front end converter act as a buck converter. Rectified DC voltage is stepped down and charges the battery.

Fig 3.shows the Circuit diagram of battery powered SRM drive in charging mode. The dc-dc buck front-end converter is formed using  $L, S_{f2}$  and  $D_{f1}$  in the proposed front end converter.

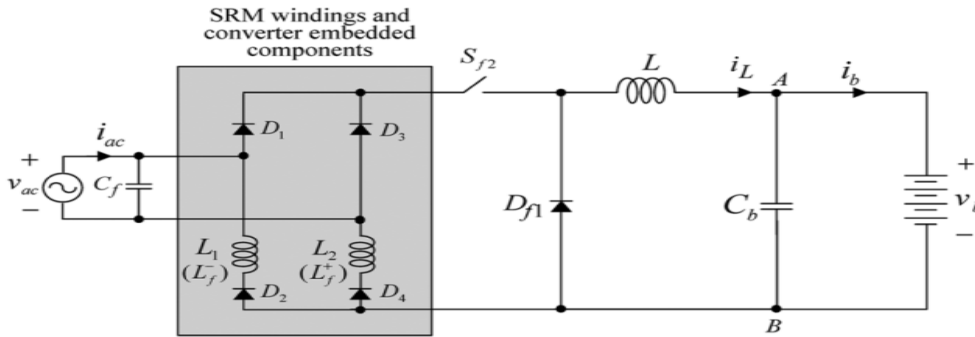


Fig 3. Circuit diagram of battery powered SRM drive in charging mode

## A. Open Loop Control Scheme

Fig 4. shows the open loop circuit configuration of battery powered SRM drive in charging mode. In this case, the switch  $S_{f2}$  and the diode  $D_{f1}$  in Fig 4 are arranged to be the active devices.

AC voltage,  $V_{ac}$  from mains is rectified to DC voltage,  $V_d$ , by switch mode rectifier. Then the rectified dc voltage is given as a input to the buck converter. Switch  $S_{f2}$  and Diode  $D_{f1}$  are employed to step down the rectified voltage  $V_d$  to battery voltage  $V_b$  and then the battery get charges.

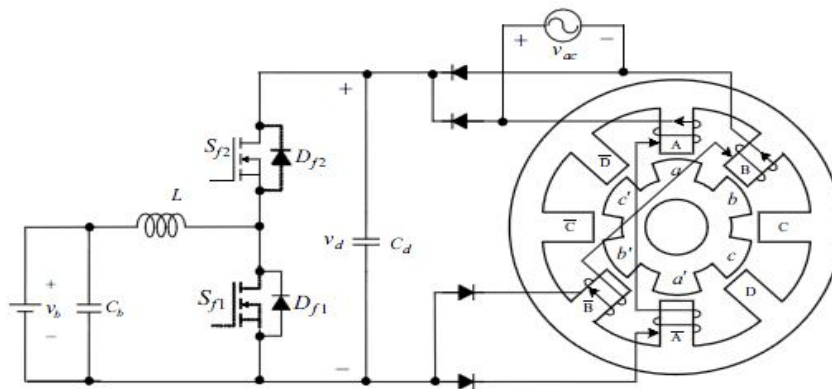


Fig 4. Open loop Circuit configuration of battery powered SRM in charging mode

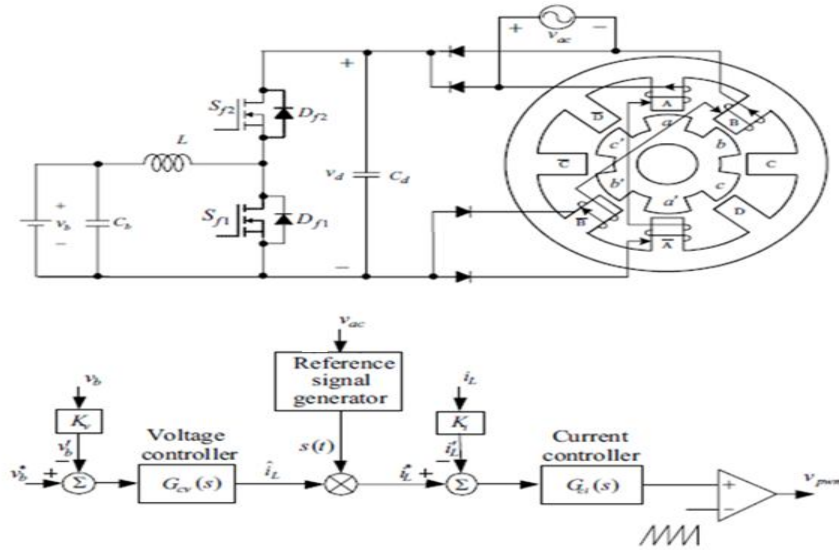
## B. Closed Loop Control Scheme

Fig 5. shows the close loop circuit configuration of battery powered SRM in charging mode. In this case, the switch  $S_{f2}$  and the diode  $D_{f1}$  in Fig 5. are arranged to be the active devices.

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**Fig 5. Closed loop circuit configuration of battery powered SRM in charging mode**

In closed loop control scheme, the actual battery voltage is multiplied with voltage gain,  $K_V$  and then it is compared with the reference voltage. The error is given to the voltage controller (PI)  $G_{CV}(S)$ . The output of voltage controller is multiplied with reference sine wave which is generated by a reference signal generator. The actual inductor current is multiplied with current gain,  $K_I$  and then compared with reference current. The error is given to the current controller (PI),  $G_{CI}(S)$ . The output of the current controller is compared with ramp signal, the pulse will be generated. This generated pulse is given as a switching pulse to the switch  $S_{f2}$  in closed loop circuit.

1) Current Controller: The feedback charging controller is chosen as:

$$G_{cic}(s) = K_{Pic} + \frac{K_{fic}}{s} = 6.7 + \frac{1000}{s}$$

and the current sensing scaling factor  $K_i = 0.12V/A$  is set.

2) Voltage Controller: Since the response speed of a battery floating voltage charging controller is not a critical concerned issue, for simplicity the following PI controller is chosen:

$$G_{cv}(s) = K_{pv} + \frac{K_{iv}}{s} = 0.173 + \frac{58}{s}$$

## IV.SIMULATION RESULTS AND CONCLUSION

This paper presents simulation for 2.3kW, 8/6 SRM. Table 1 gives the specifications of Motor and Front end converter used for MATLAB simulation.

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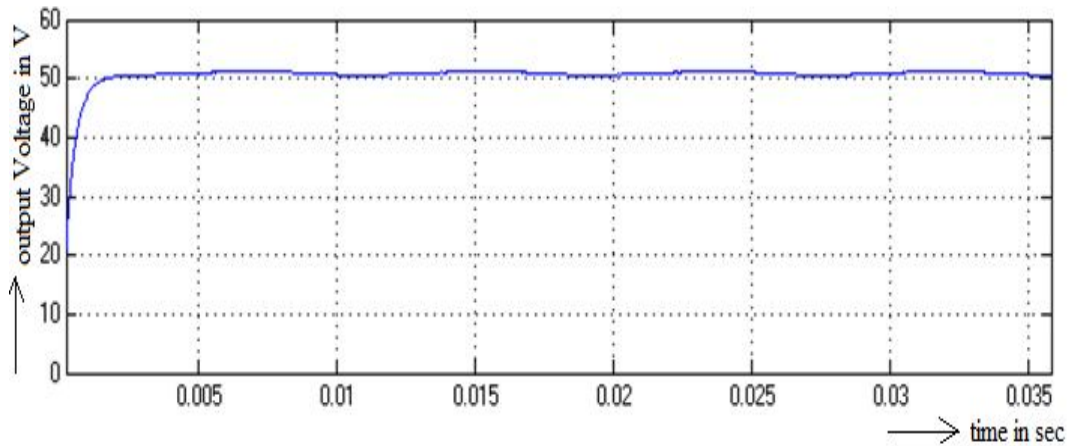
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**Table 1. Specifications**

<i>Power</i>	2.3kW
<i>Number of stator poles</i>	8
<i>Number of rotor poles</i>	6
<i>Phase</i>	4
<i>Speed</i>	6000RPM
<i>Aligned inductance</i>	23.6e-3H
<i>Unaligned inductance</i>	0.67e-3H
<i>V<sub>ac</sub></i>	110V/60Hz
<i>Battery charging current</i>	20A
<i>Nominal Battery voltage</i>	48V
<i>Rated capacity of Battery</i>	6.5Ah
<i>Switching Frequency</i>	12.5kHz

Fig 6 and 7 shows the waveform of open loop output voltage and close loop output voltage of the battery powered SRM drive in charging mode respectively.



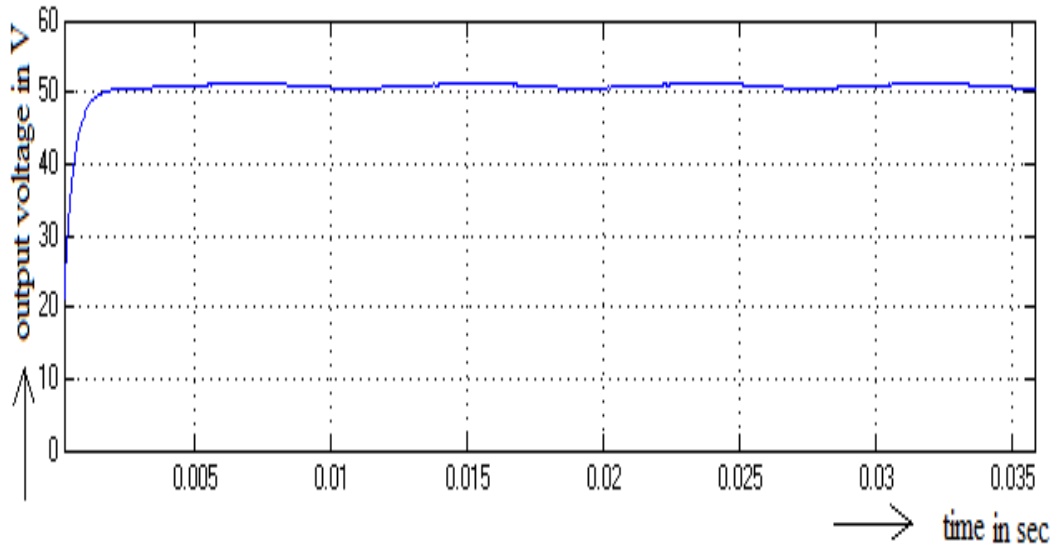
**Fig 6. open loop output voltage**

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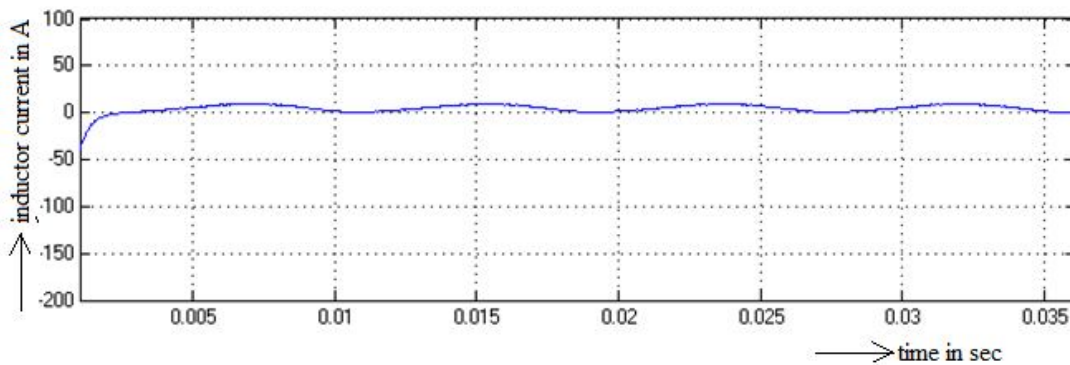
Obtained open loop Output voltage is 51V.



**Fig 7. close loop output voltage**

Obtained close loop Output voltage is 48V. The output voltage is well regulated in closed loop control scheme.

Fig 8 and 9 shows the open loop inductor current and the closed loop inductor current of battery powered SRM drive in charging mode.



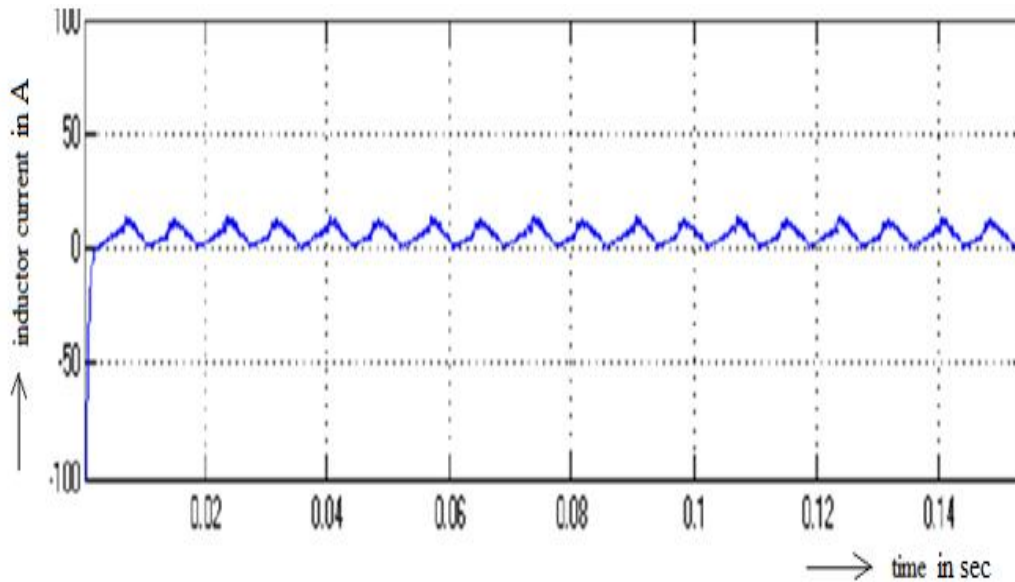
**Fig 8. Open loop inductor current**

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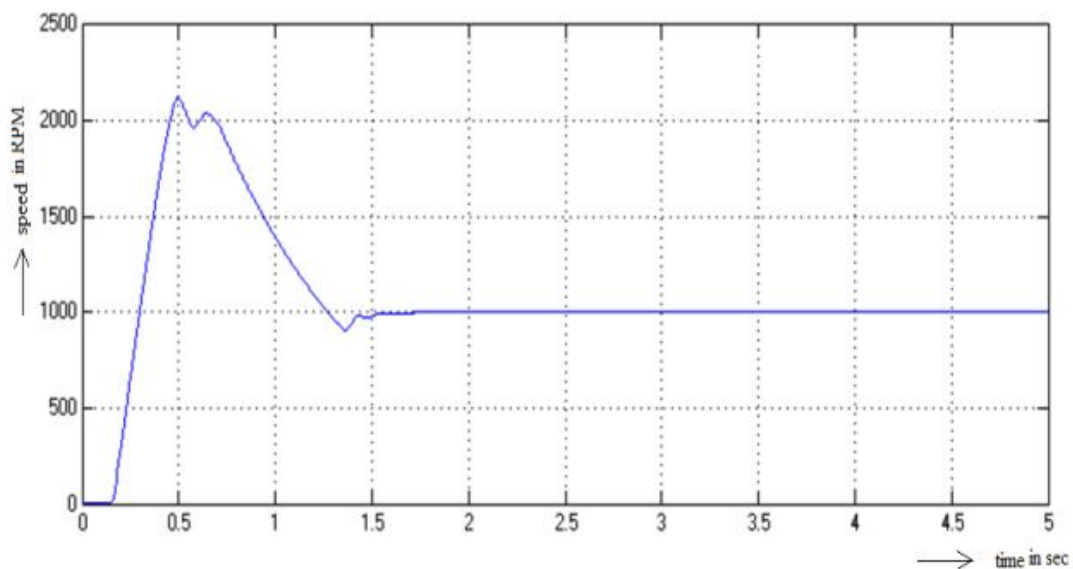
The value of obtained open loop inductor current is 10A.



**Fig 9. Closed loop inductor current**

The value of obtained closed loop inductor current is 12A.

Fig 10. shows the speed characteristics of SRM drive in discharging mode. The speed settles at 1000 RPM.



**Fig 10. speed characteristics of SRM drive**

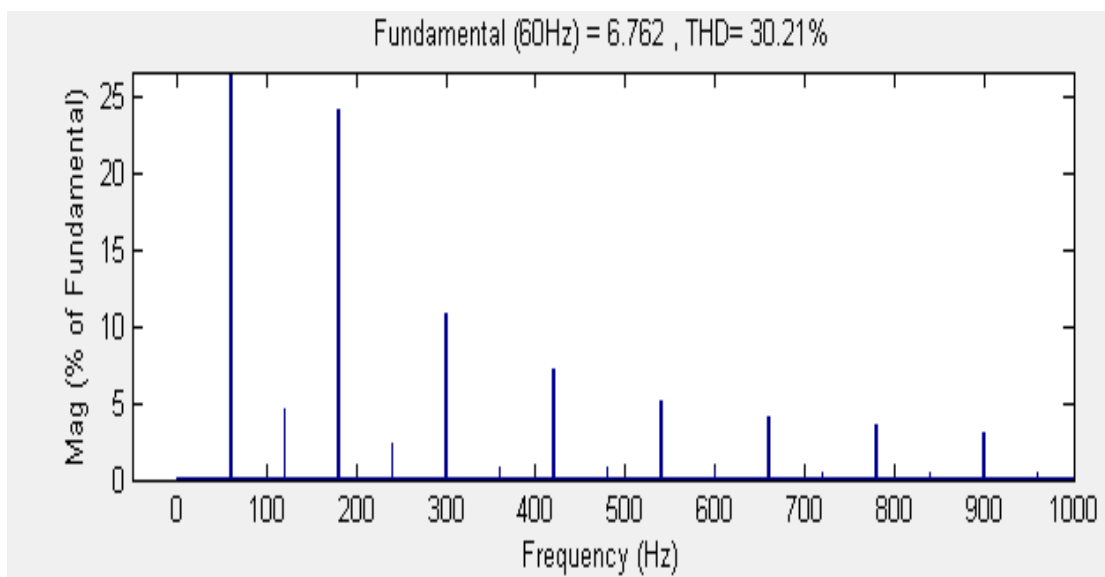


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Fig 11. Shows the THD of source current( $I_{ac}$ ). The measured Total Harmonic Distortion (THD) for source current ( $i_{ac}$ ) = 30.21%



**Fig 11. THD of source current( $I_{ac}$ ).**

## V.CONCLUSION

In this paper, a battery powered SRM drive equipped with a two-quadrant front-end converter has been presented. In charging mode, the proposed front-end converter is arranged to serve as a buck-type SMR to charge the battery with good line power quality. The distinct feature of the developed circuit is that four diodes of the motor converter and the inductances of two motor windings are efficiently used to form the rectifier and the input filter of SMR, respectively. The simulation results of open loop and close loop scheme for battery powered SRM in charging mode using MATLAB/SIMULINK are presented. Output voltage is well regulated in close loop control scheme than open loop control scheme.

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