Abstract - Integrated switched reluctance motor drive as an electric vehicle battery charger is presented in this paper. The SRM, which is used as the traction power in the driving mode, is used in the charge circuit to improve the power factor of charging system. The charging circuit can share the power switches of the asymmetric converter and phase windings of SRM to charge the battery, and can reduce the size and cost of the system in the plug-in system. To keep the rotor at standstill, zero torque control method is proposed. Since the inductances of the SRM windings are not same at any stop position, the charger controller controls the reference current to satisfy the total charging current with PFC and zero torque condition. A novel cubic equation method is proposed as a current reference distributor of the charging controller. Simulations are performed by MATLAB software and results satisfy the Effectiveness of proposed battery charging system.

1. Introduction

The switched reluctance motor(SRM) has become an attractive candidate for electric vehicle(EV) applications and is advancing rapidly due to inexpensive, high power switching devices. SRM has many distinguished merits, such as simple construction while the rotors have no windings or magnets, negligible mutual inductance, high reliability due to fault tolerant drive and low cost mass production[1-2].

To reduce cost, size, weight, and volume of battery charger with high reliability, improvement of power quality and low battery current ripple an integrated SR drive battery charger can be a good choice for EV systems[3]. Torque production is an important problem when an integrated electric motor drive is used as an EV battery charger. Torque can move the rotor because the flow of current in the motor phase windings during battery charging. There are some solutions to solve this problem. One solution is using a mechanical lock or brake [3-6]. Also an extra clutch can be used to let the rotor move during charging process.

In this paper, zero torque control with keeping rotor position is proposed based on cubic equation method in SRM Drives. Because of keeping the rotor at stand still is very important during battery charging, a new zero torque control method is proposed. Current references are calculated based on battery pack current required and zero torque constraint while power factor correction is achieved.

2. Integrated SRM Battery Charger

Total block diagram of the proposed battery charging system is shown in Fig. 1. Next, proposed charging system will be explained.

![Fig. 1] Total block diagram of proposed system.

2.1 SRM Model

Double salient structure and high saturation effect, makes its magnetic characteristics highly complex and nonlinear. In this regard, it is necessary to achieve a realistic SRM model for high performance torque control (such as torque sharing function method) or position sensor less applications. Torque and flux magnetic characteristics \((T - i \cdot \theta)\) and \((\lambda - i \cdot \theta)\) are modeled with several researchers[7]. Also in this work, zero-torque controller is proposed based on an accurate torque characteristic that has been presented in[7].

\[
T(i, \theta) = \sum_{p=1}^{P} \sum_{q=1}^{Q} a_{pq} \sin(p\theta) q_i^q
\]  

(1)

Where, \(k\) is one of the motor phases A, B, C or D and \(a_{pq}\) is the coefficient that obtained from curve fitting. Constants \(P\) and \(Q\) are the maximum order of functions that obtained according to the required accuracy. To obtain high degrees of interpretability and accuracy of torque profile of SRM with acceptable error range, \(P\) and \(Q\) are selected 7 and 3 respectively. This equation can be rewritten as a cubic equation.

2.2 Power Converter

In the Fig. 2, asymmetric SRM converter in driving mode is used. In the proposed system, conventional SRM power converter is used to integrate the charger of the battery in the EVs. The power devices of the asymmetric converter and winding inductance of SRM are used in the charging circuit. The total cost and size can be extremely reduced with high power factor implementation in the charging system. According to the input and output voltage, operation mode of battery charger will be selected(Fig. 2).

![Fig. 2] Proposed Integrated SRM drive battery charger.

![Fig. 3] Three Mode Operations according to the input and output conditions.
2.3 Control

In this battery charging system battery pack current reference is obtained from battery charger controller and then current phase commands are produced according to zero torque condition. To keep the rotor at stand still and control the rotor position precisely, a position control is added as an outer loop control and zero torque control is considered as an inner loop. Fig 4 shows four-phase SRM torque curves versus position for nominal current.

![Torque Characteristics of a Four-phase SRM with considering zero torque capability.](image)

Four regions are specified for one period of rotor position. In each region two phases have same torque direction while other two phases phase have opposite torque direction[6]. Therefore, it is possible to consider each two phases with opposite torque to produce zero torque control with this manner, a cubic equation is achieved that with solving of this equation yields current references. this procedure is called cubic equation method[8]. In this paper, position control is proposed for keeping position based on a sliding mode controller using scalar sign function [9]. To design position controller using sliding mode control position error is defined as:

\[ \Delta \theta = \theta_{ref} - \theta_{act} \]  

(2)

where \( \theta_{ref} \) represents the desired initial position as a reference value. A first order sliding surface or switching function is selected as follows:

\[ S = \Delta \theta - \lambda \omega \]  

(3)

where \( \omega \) (speed) is derivative of rotor position with respect to time. Also, \( \lambda \) is a positive constant and is introduced to reduce the chattering and disturbance.

3. Simulation Results

Simulation of the whole SRM drive based system is performed using MATLAB-Simulink. In this paper, the current control is achieved by a closed-loop control with hysteresis switching control of the converter. As rotor position is kept, switching frequency will be constant. Dynamic simulation results are obtained for the prototype 4 phase 8/6 SRM. Battery pack current is selected 5 A and initial rotor position is arbitrarily considered 10 degree. Fig 5 and 6 show the input current and THD spectrum with using of cubic equation method. Torque curve is presented in Fig 7 and rotor position is kept constant. This figure shows that the proposed method can keep the rotor stand still while battery charging is achieved for a command battery current. In order to show complying of the input current THD for proposed battery charger with IEC standard, its harmonics up to 39th are compared with EN61000-3-2 standard in Fig 6. In the cascaded buck-boost and buck mode operations, input current becomes discontinuous whereas input current in the boost mode operation becomes continuous. Therefore, THD in the case of boost mode is low. Unlike the previous case, THD for buck mode and buck-boost mode is high. However All harmonics for each case are well below IEC standard, which is required for EV battery chargers. As expected, Fig 5 shows input current and voltage with nearly perfectly sinusoidal shape for current waveform.

4. Conclusion

Since the inductances of the SRM windings are not same in the any step position, the charger controller controlled the reference current distribution to satisfy the total charging current. For the proper charging with SRM winding as inductance element of battery charger, a novel current sharing method is proposed as a current reference distributer of the charging controller. The proposed method makes the proper reference for each phase windings of SRM to satisfy the total charging current of the battery with zero torque condition and PFC achievement.

![Input voltage and current.](image)

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[References]


<Fig. 6> Proposed Input current harmonics at Vin = 220 V, (a) Boost Mode, (b) Cascaded Buck+Boost Mode, (c) Buck Mode

<Fig. 7> Zero Torque Control, (a) Boost Mode, (b) Cascaded Buck+Boost Mode, (c) Buck Mode