ISSN 1975-8359(Print) / ISSN 2287-4364(Online)
The Transactions of the Korean Institute of Electrical Engineers Vol. 66, No. 2, pp. 328～338, 2017
http://doi.org/10.5370/KIEE.2017.66.2.328

충전기 겸용 스위치드 릴럭턴스 전동기의 제로토크제어

Zero Torque Control of Switched Reluctance Motor for Integral Charging

라쉬디* · 나마찌* · 세헤이안* · 이동희** · 안진우†
(A. Rashidi · M.M Namazi · S.M. Saghaian · D.H. Lee · J.W. Ahn)

Abstract - In this paper, a zero torque control scheme adopting current sharing function (CSF) used in integrated Switched Reluctance Motor (SRM) drive with DC battery charger is proposed. The proposed control scheme is able to achieve the keeping position (KP), zero torque (ZT) and power factor correction (PFC) at the same time with a simple novel current sharing function algorithm. The proposed CSF makes the proper reference for each phase windings of SRM to satisfy the total charging current of the battery with zero torque output to hold still position with power factor correction, and the copper loss minimization during of battery charging is also achieved during this process. Based on these, CSFs can be used without any recalculation of the optimal current at every sampling time. In this proposed integrated battery charger system, the cost effective, volume and weight reduction and power enlargement is realized by function multiplexing of the motor winding and asymmetric SR converter. By using the phase winding as large inductors for charging process, and taking the asymmetric SR converter as an interleaved converter with boost mode operation, the EV can be charged effectively and successfully with minimum integral system. In this integral system, there is a position sliding mode controller used to overcome any uncertainty such as mutual inductance or DC offset current sensor. Power factor correction and voltage adaption are obtained with three-phase buck type converter (or current source rectifier) that is cascaded with conventional SRM, one for wide input and output voltage range. The practicability is validated by the simulation and experimental results by using a laboratory 3-hp SRM setup based on TI TMS320F28335 platform.

Key Words : Switched Reluctance Motor (SRM), Zero torque control, Battery charging, Current sharing function

1. Introduction

An integrated battery charger was developed for the first time in 1985 [1], and many various integrated solutions have been reported until now. To have a high performance EV, one must have: (i) a converter-fed motor drive having good driving and regenerative braking performances; (ii) good battery discharging/charging characteristics; and (iii) on-board charger with good line drawn power quality from utility (G2V).

Switched reluctance motors (SRM) have been used since 1969 for variable speed applications. Due to the advent of inexpensive, high power switching devices and high speed microprocessors, SRM has been receiving attention from researchers and industrial companies. SRM structure is simple and its manufacturing cost is low. SRM advantages make it ideal for many industrial applications such as hybrid bus drive, aircraft and electric vehicle. Plug-in hybrid electric vehicle (PHEV) and electric vehicle (EV) applications for variable speed drives are cost sensitive while at least highly reliable, equally performing DC and induction motor drives are also demanded [2]. SRM drives are promising systems to meet these demands in certain high-volume applications; hence, the spurt of activity in this field. In EVs and PHEVs, batteries are used as the main power source; therefore battery charger is an important and technological part. Torque production is an important problem when an integrated electric motor drive is used as an EV battery charger. During battery charging, torque can move the rotor because the flow of current in the motor phase windings. There are some solutions to solve this problem. One solution is by using a mechanical lock or brake [4, 5]. Also an extra clutch can be used to let the rotor move during charging process. But these solutions make the system complex and are not cost effective. In [5] a special motor with an extra clutch is used as an isolated PFC integrated charger.

However, as the battery ground is generally floating with

---

† Corresponding Author : Dept. of Mechatronics Engineering, Kyungsung University, Korea
E-mail: jwahn@ks.ac.kr
* Dept. of Electrical and Computer Engineering, Isfahan University of Technology, Isfahan, Iran
** Dept. of Mechatronics Engineering, Kyungsung University, Korea

Received : October 20, 2016; Accepted : December 26, 2016

Copyright ⓒ The Korean Institute of Electrical Engineers
This is an Open-Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (http://creativecommons.org/licenses/by-nc/3.0/)which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

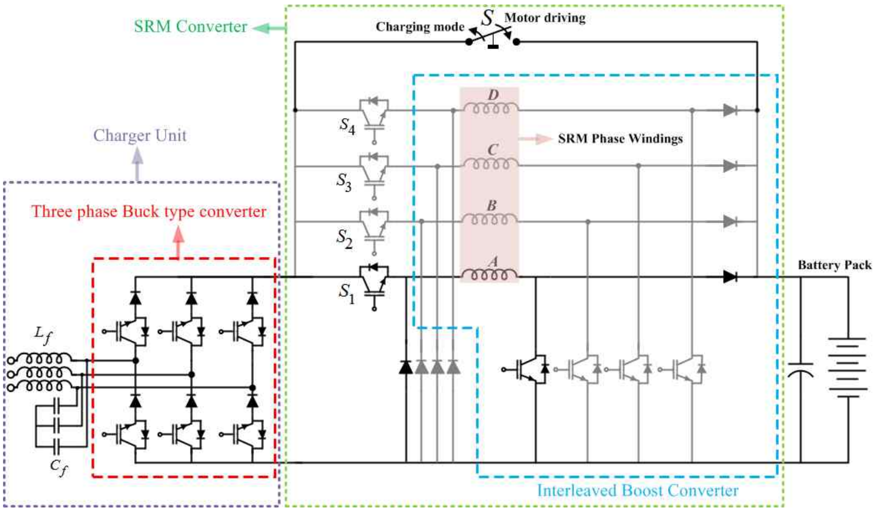


Fig. 1 Proposed integrated battery charger

the body ground of the vehicle, electrical isolation of battery from ac input power is not reasonable [6]. Also transformer stage can reduce efficiency of battery charger and manufacturing of this specially designed machine is complex. In [7], an integrated SRM battery charger with zero torque control is proposed. But phases cannot work in buck and buck-boost mode operations independently during battery charging in this converter. An alternative approach to single-phase charging using the inductances of the motor and inverter as three-phase interleaved PFC boost converter is proposed in [8]. In this system a mechanical contact is used to access the neutral point of the motor windings. Simple integrated battery charger without considering power factor correction and battery charging at standstill condition was reported in [9]. Zero torque control for SRM EV battery charging is presented before [10]. Single phase PFC converters are used usually for low charging power levels such as hybrid electric vehicles, whereas three-phase PFC topologies are used for high power applications such as EV battery charger stations [11]. An important aspect of the PFC battery charger is the capability to control the battery current and output voltage over different main input voltage, because DC bus voltage for different utility voltages is different for various regions [12]. On the other hand, chargers should be able to adapt to output voltage with different type of EVs [13]. In this regard, for EV application, due to different level of battery pack and utility voltage, only the boost converter topology is not appropriate and using a step-up DC-DC converter at the output of three-phase or single-phase buck type converter is necessary [14, 15]. Torque Sharing Function for ripple reduction is the best method for high performance SRM drives [16]. DC link capacitors increase cost while decreasing reliability of the system [17, 18]. Phase windings of SRM are used as large inductors for CSR. DC link inductor in CSR increases volume and cost of the system, so this system is cost and volume effective. Proposed integrated battery charger topology is so reliable because of the anti-shoot-through structure. In these systems, open-switch fault detection methods should be considered [19, 20]. In this paper, the novel current sharing function applied on the EV SRM battery charger, which in charging condition the power circuit is reconfigured to be a part of the integral charger, and its merits are fully verified with compact experimental results.

2. Proposed System

The proposed integrated battery charger is shown in Fig. 1. Input stage does not have bulky DC link capacitors while SRM windings are used as inductance elements of the PFC circuit. The integrated charger consists of SRM phase windings (four-phase, 8/6, 1200 r/min, 3-hp), SRM power converter and a charger unit (three phase buck type converter).

2.1 SRM Power Converter

Fig. 1 shows the proposed charging circuit of the EV with SRM traction power converter. The area with green dashed line contains the asymmetric converter for SRM in driving mode. As well-known, the asymmetric converter can supply three operating modes such as excitation, wheeling and demagnetization mode to produce output torque of SRM (Fig. 2). In the proposed integrated battery charger system, only one power switch is additionally added to integrate the charger of the battery in the EVs with simple interconnection. Also SRM drive has not been changed. The power devices of the asymmetric converter for driving of the SRM and winding inductance of SRM are used in the battery charger circuit for charging mode. From this, the total cost and size can be extremely reduced with high power factor implementation during the charging process from AC grid. This system simplifies interconnection issues between charger unit and SRM drive. Actually in this battery charger topology, integrated SRM power converter battery charger is an interleaved converter that according to the input and output conditions can operate like buck, cascaded buck+ boost or boost converter.

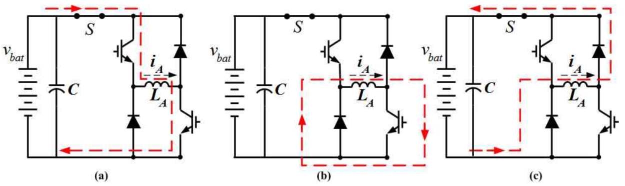
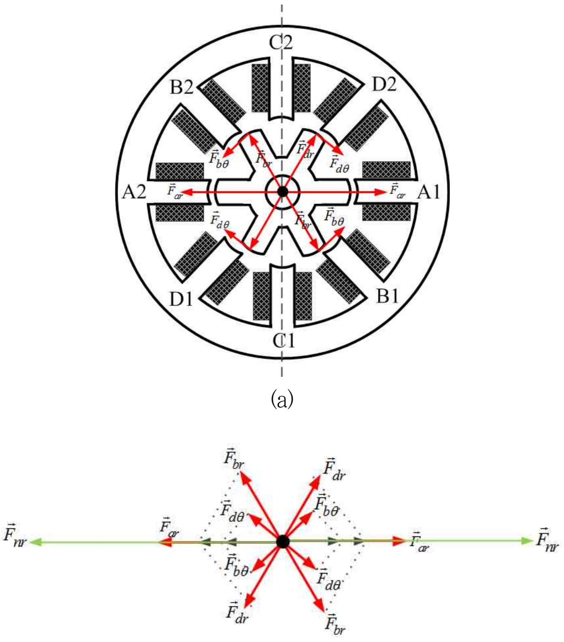


Fig. 2 Motor driving operation modes of SRM asymmetric converter: (a) Magnetization (b) Freewheeling (c) Demagnetization.



(a)

(b)

Fig. 3 Zero torque and force component at aligned and unaligned positions.

2.2 Zero Torque Capability in SR Motors

In order to achieve battery charging with zero torque condition, determination of zero torque operating area (ZTOA) considering current limitation for charging process is necessary. This means that current limitation must be met during battery charging with zero torque condition to achieve over current protection. Proposed area and zero torque condition are presented in [10]. As can be seen in Fig. 3, total torque (force) production can be zero at aligned position. Actually, this position is stable and is same for unaligned position. In other positions it should be examined for zero torque capability.

2.3 Zero Torque Operating Area in Even and Odd Number Phase SR Motors

Fig. 4 shows that in four-phase SRM there are six regions that in each region two phases have same torque direction and one phase has opposite torque direction. It is possible to consider such similar regions for multi-phase SR motors. These regions are selected based on zero crossing point of the torque profile. Other phases with zero torque regions are shown in this figure.

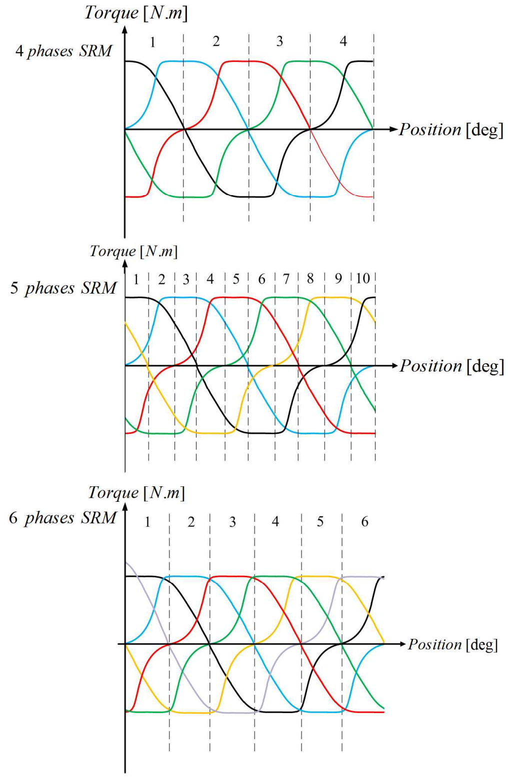


Fig. 4 Zero torque regions for multiphase SRM

Table 1 Regions and torque directions

SRM phase number	Zero torque regions	Phase number			
		CW(T >0)		CCW(T < 0)	
		Positive torque	Negative torque	Positive torque	Negative torque
4	4	2	2	2	2
5	10	2	3	3	2
6	6	3	3	3	3

2.4 Model based optimized simple current sharing functions

Rotor and stator in SR motors have salient-pole. Also, the length of the air gap between the stator and rotor is made as small as possible to increase the energy conversion ratio. Therefore, double salient structure and high saturation effect make 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 sensorless position applications. Torque and flux magnetic characteristics ($T-i-\theta$ and $\lambda-i-\theta$) are modeled with several researches [21]. In this work, zero-torque controller is proposed based on an accurate torque characteristic that has been presented in [22]. After zero torque condition determination, an optimization problem considering some constraints (zero torque condition and battery current demand with subject to copper loss minimization) is solved by Lagrange method. In [22], the SRM model is provided in detailed. The problem is as follow:

$$\begin{cases} I: & \sum T_k(i_k,\theta_{rm})=0,\ k=A,B,C,D \\ II: & (1-\overline{D})(i_A+i_B+i_C+i_D)=I^*_{chg} \\ Min: & \frac{1}{2}R(i_A^2+i_B^2+i_C^2+i_D^2) \end{cases} \tag{1}$$

Where, k is one of the motor phases A, B, C or D. Also θ_{rm} and I^*_{chg} are mechanical rotor position and the battery pack current demand, respectively. Many of the constrained optimization algorithms are based on iterative approach. In some cases with nonlinear constraints, starting from an initial feasible point is very important to find optimal values of the objective function. Solutions of this problem for all SRM phases are shown in Fig. 5. These data are used for curve fitting by MATLAB toolbox with acceptable accuracy. The final optimized simple current sharing function is:

$$i_k(I^*_{chg},\theta_{rm})=I^*_{chg}\sum_{j=1}^{3}A_j\sin(B_j\theta_{rm}+C_j) \tag{2}$$

Where A_j, B_j and C_j are coefficient that are obtained from curve fitting. Accuracy of these functions is 0.99 for 500 point data. Finally all of phase current sharing functions are obtained with curve fitting which coefficients are shown in [10].

2.5 Position Controller

This section presents a high-performance controller for outer loop control, acting as a keeping position regulation subsystem in the proposed KP-ZT cascaded control structure. The keeping position control scheme is designed and used to increase the reliability of overall EV control drive by the help of zero torque control subsystem to prevent any small mechanical movement. Removing some drawbacks of the conventional PI control design, some advanced control methods such as feedback linearization controller, artificial neural network and fuzzy controller, Lyapunov function based algorithms, back stepping and robust strategies and model predictive control have been developed to achieve a high performance position control in the literature. However, the sophisticated design of these methods is their disadvantage and appropriate simple robust control design is a must. Recently, designing controllers based on variable structure system and sliding-mode control (SMC) has been the developed by many researchers, thanks to its features such as simplicity, high-speed feedback control which could be easily used along with motor switching circuit and inherent robustness against nonlinear complex uncertain dynamic systems.

In this paper, position control for keeping position is constructed based on sliding-mode control approach using scalar sign function. The overview of the proposed sliding-mode based keeping position control block diagram is shown in Fig. 6. As a preliminary step to design position controller using sliding mode control, position error is defined as:

$$e=\Delta\theta^*_{rm}-\theta_{rm} \tag{3}$$

Where θ_{rm} is the actual rotor position and θ^*_{rm} represents the desired initial position as a reference value. To improve the system response, a first order sliding surface or switching function is selected as follows:

$$S=e+\lambda\dot{e}=\nabla\theta-\lambda\omega \tag{4}$$

where ω is the rotor speed, λ is the positive slope of the sliding line that reveals the gain of the speed dynamic used to reduce the chattering phenomena [23]. As can be seen from Fig. 6, for a pre-scribed rotor position error ϵ

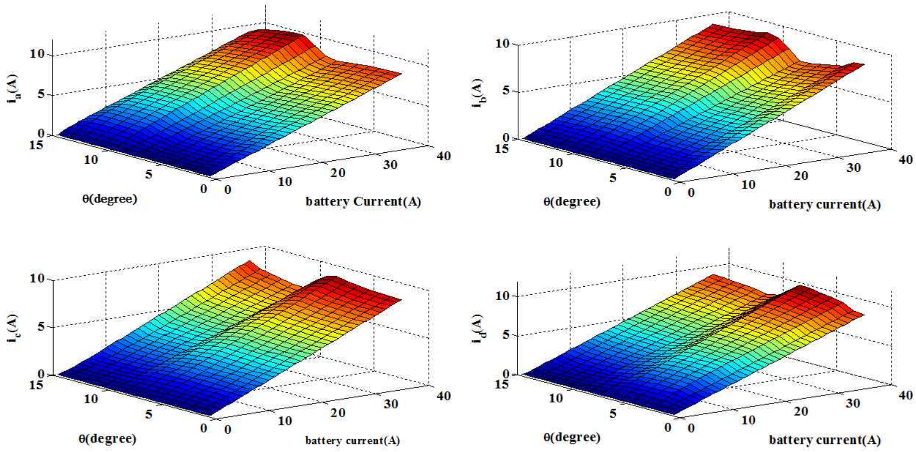


Fig. 5 Four-phase optimized SRM current

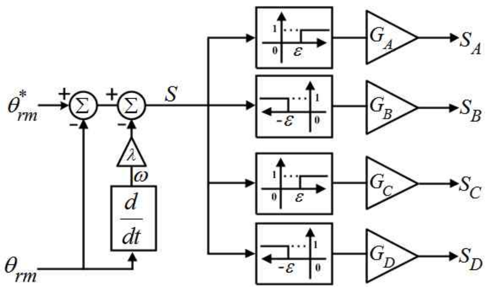


Fig. 6 Keeping position controller (KPC) block diagram

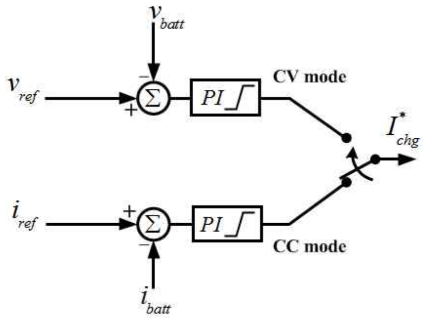


Fig. 7 Battery charger controller

the desired switching signals can be expressed as:

$$\begin{aligned} S_{A,C} &= G_{A,C}\, sgn[(S-\epsilon)] \\ S_{B,D} &= G_{B,D}\, sgn[-(S+\epsilon)] \end{aligned} \tag{5}$$

Where the $S_{A,C}$ and $S_{B,D}$ are surface error outputs defined as phase switching signals to control the rotor position precisely. The phases A and C produce positive torque and phases B and D produce negative torque. Moreover, the gains $G_{A,C}$ and $G_{B,D}$ are defined to improve the control precision via position disturbance rejection and control law time response enhancement, simultaneously.

2.6 Battery Charger Controller

Constant Current-Constant Voltage (CC-CV) method is the best effective method for battery charging. At first, in CC-mode, the voltage of battery is slowly increased by the constant current. When the voltage battery reaches the desired value, the charging mode is changed from CC-mode to CV-mode and the voltage is kept constant. The output of the battery charger controller is a current command that is used as an input of PFC-Zero torque controllers (Fig. 7).

2.7 Total Block Diagram

Total block diagram of the proposed charging system is shown in Fig. 8. The current references are produced by PFC-Zero torque and keeping position controllers. PFC-Zero torque controller produces current references based on an accurate SRM model to achieve zero torque condition and power factor correction. Keeping position controller prevents rotor from moving at the presence of any disturbance. In this section each part is explained.

3. Simulation Results

The current references are produced by PFC-Zero torque and keeping position controllers. PFC-Zero torque controller produces current references based on an accurate SRM model to achieve zero torque condition and power factor correction. Keeping position controller prevents rotor from

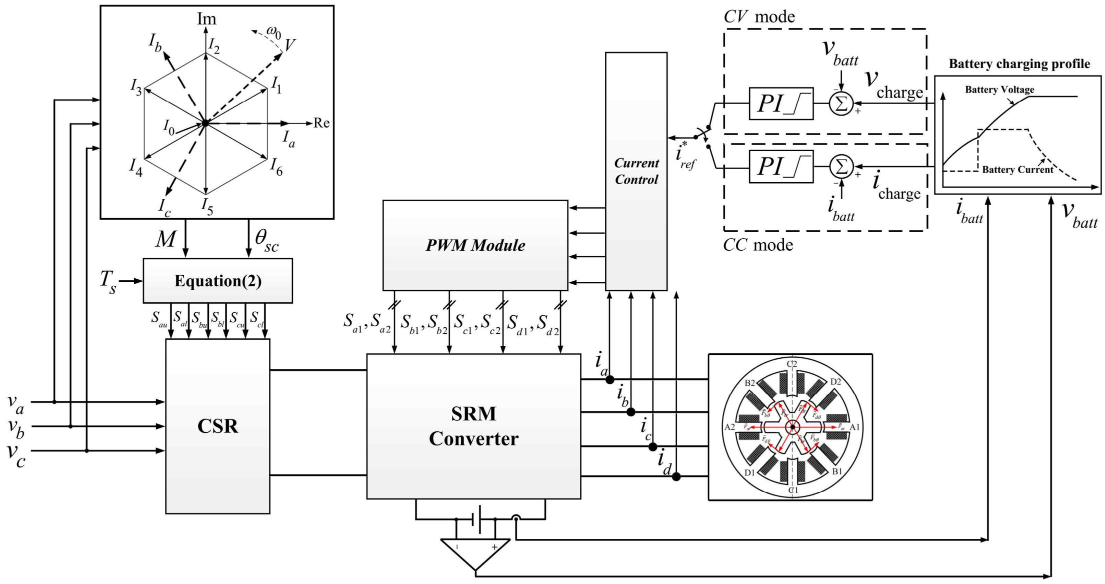


Fig. 8 Total block diagram of proposed controller and integrated SRM drive battery charger

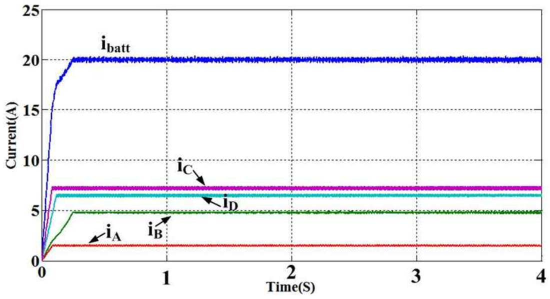


Fig. 9 Battery and phase current

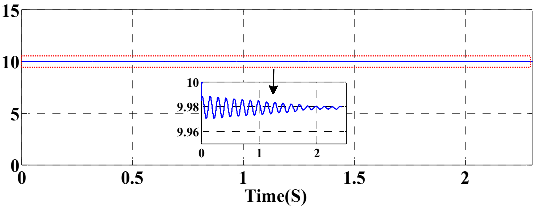


Fig. 10 Reference and actual rotor position

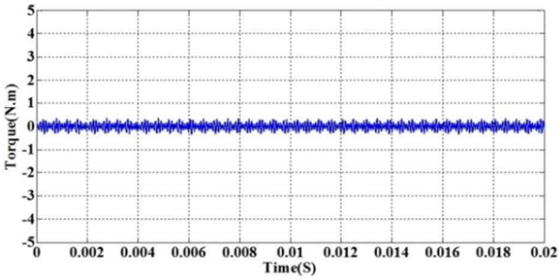


Fig. 11 Zero total torque production

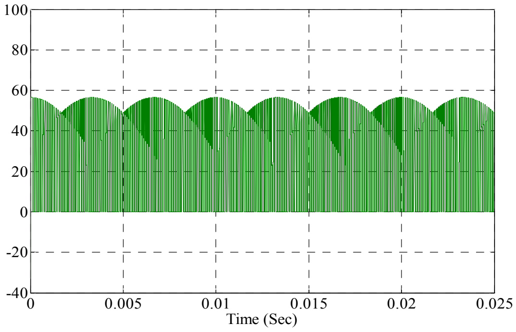


Fig. 12 Output voltage of CSR in simulation

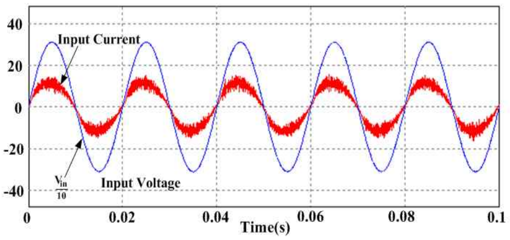


Fig. 13 Input voltage and current of battery with PFC

any movement at the presence of any disturbance and uncertainty. Fig. 9 shows battery and SRM phase current. Position and torque are presented in figures 10 and 11, respectively.

Figure 12 shows output voltage of three-phase buck type converter. Input current and voltage of input stage are illustrated in Fig. 13. The output of the battery charger

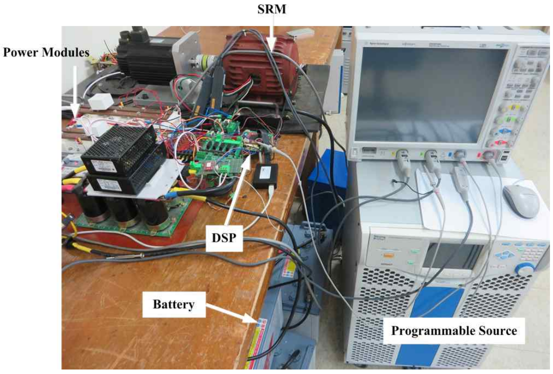


Fig. 14 SRM test setup for experiment

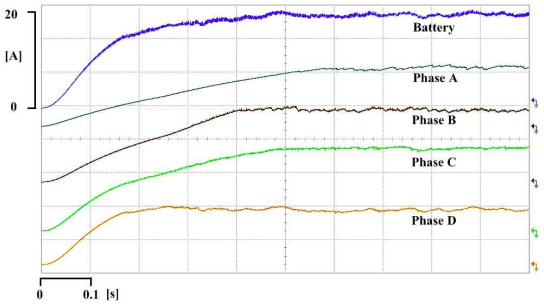


Fig. 15 Experimental battery and phase current at 10 degree rotor position

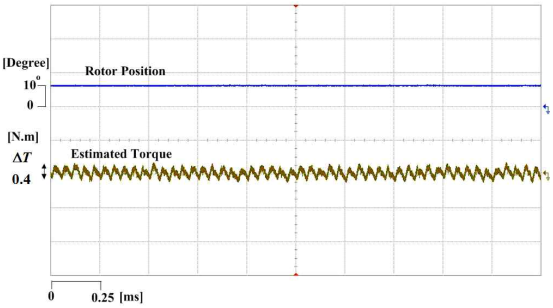


Fig. 16 Rotor position and estimated torque at 100 degree rotor position

controller is a current command that is used as an input of keeping position-Zero torque controller. In this method, as mentioned, phases with larger inductance have smaller current than the other ones. Therefore peak current in phases A and C is higher than other two phases to achieve a good current references tracking at the given position. It should be mentioned that phases with larger inductance are slower to track current reference than other ones. Unlike conventional sliding mode controllers (SMC) that act on the voltage, proposed KPC based on SMC acts on the current as a function of rotor position and speed to prevent rotor from any

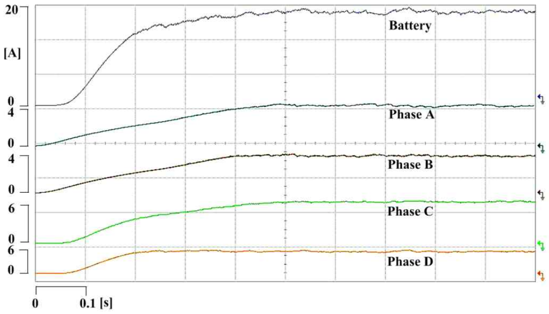


Fig. 17 Experimental battery and phase current at 15 degree rotor position

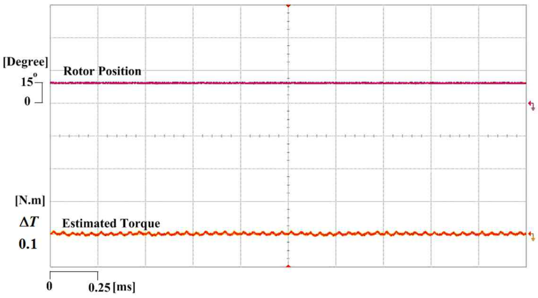


Fig. 18 Rotor position and estimated torque at 15 degree rotor position

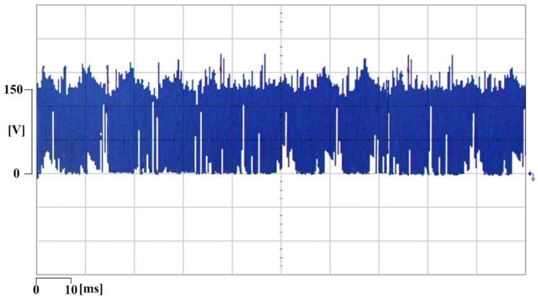


Fig. 19 Experimental output voltage of three-phase buck type converter

movement at any uncertainty.

4. Experimental Results

All of the experimental hardware used for evaluating the integrated 8/6 SRM drive battery charger is shown in Fig. 14. Table 1 in appendix shows SRM motor specifications. The proposed power converter and the chopper are mounted on a workbench, as shown in the picture. A floating point, TI DSP TMS320F28335 is used for implementing the control algorithm. Battery pack and phase current for two rotor

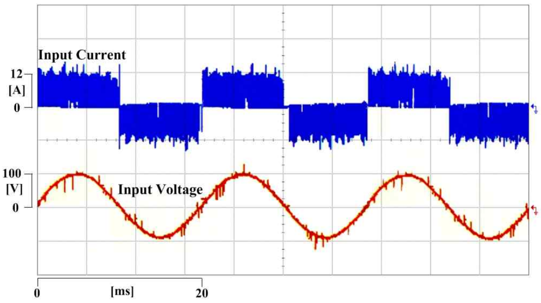


Fig. 20 Unfiltered input phase current and voltage of proposed system

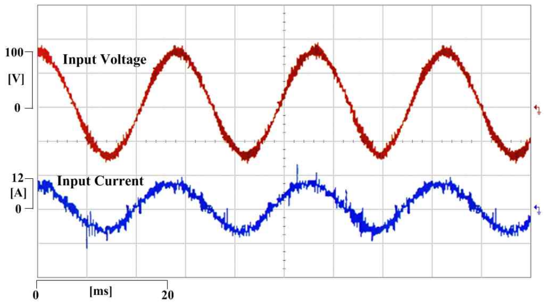


Fig. 21 Filtered input phase current and voltage of proposed system.

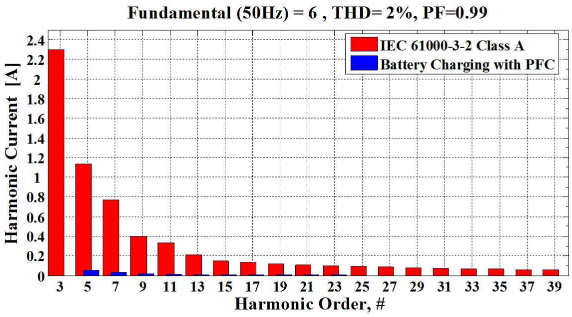


Fig. 22 Input current harmonic content of input stage

positions (10 and 15 degree) with rotor position and torque are shown in Figs 15 to 18. As can be seen in these figures, rotor position is kept constant and zero torque production is achieved.

Fig. 19 shows the first stage output voltage with frequency of 100 Hertz. Unfiltered input phase current and voltage of the proposed system is shown in Fig. 20. Because input current contains higher harmonic components, input filter is considered to reduce THD. Filtered input phase current and voltage of proposed system are illustrated in Fig. 21.

In order to show compliance of the input current THD for proposed battery charger with IEC standard, its harmonics up to 39th are compared with EN 61000-3-2 standard in Fig. 22.

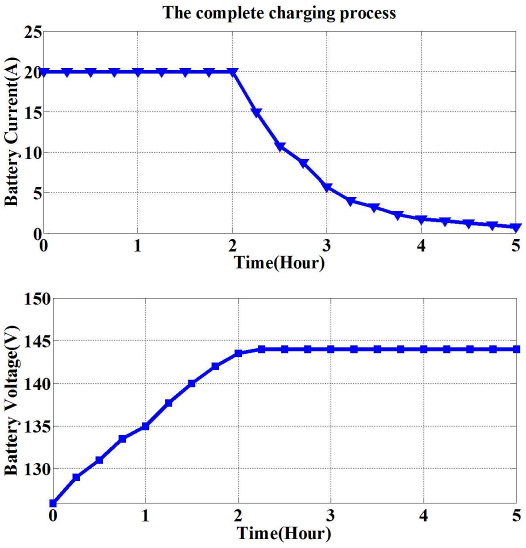


Fig. 23 Complete experimental battery charging process with CC and CV mode operation

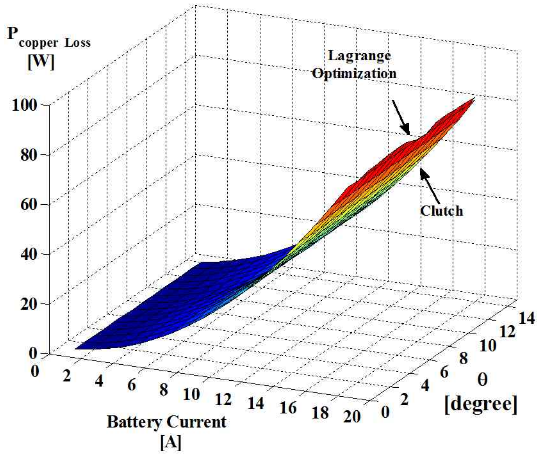


Fig. 24 Copper loss optimization comparison between the proposed method and clutch.

Constant Current-Constant Voltage (CC-CV) method is the best effective method for battery charging. At first, in CC-mode, the voltage of battery is slowly increased by the constant current. When the voltage battery reaches the desired value, the charging mode is changed from CC-mode to CV-mode and the voltage is kept constant. Fig. 23 shows this complete process. Battery charging with zero torque condition is necessary during DC charging while EV is plugged in. Slope of battery current reference curve should be lower than lowest phase current reference slope. In other words, all phases should be able to track current references with zero torque condition during the increasing of battery current from zero to reference value during the first moments of charging.

Another important parameter in battery charging process is copper loss minimization that presented in this paper. Current references are obtained with using of Lagrange optimization. With using of optimization method not only no needs to clutch but also copper loss can be minimized effectively. As can be seen from Fig. 24, copper loss can be decreased with proposed method like as a using clutch in the system.

5. Conclusion

Keeping position-zero torque control to avoid any movement of the rotor in EVs based on SR drives during battery charging is proposed. Simple optimized current sharing functions are proposed where during charging mode SRM model is not needed. Power factor correction is achieved with proposed integrated battery charger. In this integrated SRM drive battery charger, asymmetric SR converter and phase windings are used as an interleaved converter with boost mode operation. This reliable integrated battery charger topology is cost, volume and weight effective. Input current quality is in compliance with IEC standard. There is no need of clutch or brake during battery charging with proposed method. Results show that KP-ZT keeps the rotor still during charging. The worst case for rotor position without friction torque is considered. Results verify effectiveness of proposed system.

감사의 글

본 연구는 2016년도 산업통상자원부의 재원으로 한국에너지기술평가원(KETEP)의 에너지인력양성사업으로 지원받아 수행한 인력양성 성과입니다. (No. 20164010200940)

Appendix

Table 2 Motor specifications

Rated power	3 hp
RMS phase current	8 A
Rated speed	1200 rpm
Rated Voltage	280 V
Number of pole	8/6
Phase resistance	0.7 Ω
Inertia (J)	0.002 $N.ms^2$
Friction Constant(B)	0.00013 Nms

References

[1] J.M. Slicker, “Pulse width modulation inverter with battery charger,” US Patent 4,491,768, 1985.

[2] T. J. E. Miller, ed., Electronic Control of Switched Reluctance Machines, New York: Newnes, 2001.

[3] K. M. Rahman, B. Fahimi, G. Suresh, A. V. Rajarathnam, and M. Ehsani, “Advantages of switched reluctance motor applications to EV and HEV: Design and control issues,” IEEE Trans. Ind. Appl., vol. 36, no. 1, pp. 111–121, Jan./Feb. 2000.

[4] Yilmaz M., Krein P. “Review of battery charger topologies, charging power levels, and infrastructure for plug-in electric and hybrid vehicles’, IEEE Trans. Power Electron. 2013, 28, (5), pp. 2151–2169.

[5] S. Haghbin, S. Lundmark, M. Alakula, and O. Carlson, “An isolated high power integrated charger in electrified-vehicle applications,” IEEE Trans. Veh. Technol., vol. 60, no. 9, pp. 4115–4126, Nov. 2011.

[5] S. Haghbin, S. Lundmark, M. Alakula, and O. Carlson, “An isolated high power integrated charger in electrified-vehicle applications,” IEEE Trans. Veh. Technol., vol. 60, no. 9, pp. 4115–4126, Nov. 2011.

[6] Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charger Coupler, SAE Recommended Practice. J1772, Jan. 2010.

[7] Jianing Liang; Guoqing Xu; Linni Jian and Ming Chang, “Analysis Parking Position of Integrated Switched Reluctance Motor Drive System with On-board Charger for EV”, the 8th IEEE Vehicle Power and Propulsion Conference (VPPC 2012), 9-12th, Oct. 2012, pp: 1-6.

[8] G. Pellegrino, E. Armando, and P. Guglielmi, “An integral battery charger with power factor correction for electric scooter,” IEEE Trans. Power Electron., vol. 25, no. 3, pp. 751–759, Mar. 2010.

[9] W. K. Thong and C. Pollock, “Low-cost battery-powered switched reluctance drives with integral battery-charging capability,” IEEE Trans. Ind. Appl., vol. 36, no. 6, pp. 1676–1681, Nov./Dec. 2000.

[10] A. Rashidi, M. M. Namazi, S. M. Saghaian-nezhad, D. H Lee, J. WAhn, “Zero torque control of switched reluctance motors for charging reactor of electric vehicles”, Advanced Intelligent Mechatronics (AIM) IEEE International Conference on, pp. 990–995, 2015.

[11] D. H. Lee, Z. G. Lee, J. Liang, J. Ahn, “Single-phase SRM drive with torque ripple reduction and power factor correction,” IEEE Trans. On Industry Applications, Vol. 43, No. 6, pp. 1578-1587, Nov./Dec. 2007.

[12] J. W. Kolar and T. Friedli, “The essence of three-phase

PFC rectifier systems–Part I," IEEE Trans. Power Electron., vol. 28, pp. 176–198, Jan. 2013.

[13] T. Soeiro, T. Friedli, and J. W. Kolar, "Three-phase high power factor mains interface concepts for electric vehicle battery charging systems," in Proc. 27th Annu. IEEE Appl. Power Electron. Conf. Expo., Feb., 2012, pp. 2603–2610.

[14] M. A. Khan, I. Husain and Y. Sozer, "Integrated electric motor drive and power electronics for bidirectional power flow between the electric vehicle and DC or AC grid," IEEE Trans. Power Electron., vol. 28, no. 12, pp. 5774-5783, 2013.

[15] H.-C. Chang and C.-M. Liaw, "Development of a compact switched reluctance motor drive for EV propulsion with voltage-boosting and PFC charging capabilities," *IEEE Trans. Veh. Technol.*, vol. 58, no. 7, pp. 3198–3215, Sep. 2009.

[16] D.-H. Lee, Z.-G. Lee, J. Liang, and J.-W. Ahn, "A Simple Nonlinear Logical Torque Sharing Function for Low-Torque Ripple SR Drive," *IEEE Trans. Ind. Electron.,* vol. 56, no. 8, pp. 3021, 3028, August 2009.

[17] Thanh Hai Nguyen, Dong-Choon Lee, "Deterioration monitoring of DC-link capacitors in AC machine drives by current injection," IEEE Trans. Power Electron., vol. 30, no. 3, pp. 1126–1130, March 2015.

[18] H. S. Jung, S. J. Chee, S. K. Sul, Y. J. Park, H. S. Park, and W. K. Kim, "Control of three phase inverter for AC motor drive with small DC-link capacitor fed by single phase AC source," IEEE Trans. Ind. Appl., vol. 50, no. 2, pp. 1074–1081, Mar./Apr. 2014.

[19] W. S. Im, J. M. Kim, D. C. Lee, and K. B. Lee, "Diagnosis and fault tolerant control of 3-phase AC-DC PWM converter systems," IEEE Trans. Ind. Appl., vol. 49, no. 4, pp. 1539–1547, Jul./Aug. 2013.

[20] J. S. Lee and K. B. Lee, "An open-switch fault detection method and tolerance controls based on SVM in a grid-connected T-type rectifier with unity power factor," *IEEE Trans. Ind. Electron.*, vol. 61, no. 12, pp. 7092–7104, Dec. 2014.

[21] Ye, J. Bilgin, B., Emadi, A."An Extended-Speed Low-Ripple Torque Control of Switched Reluctance Motor Drives", IEEE Trans. on Power Electron., vol. 30, no. 3, pp. 1457-1470, 2015.

[22] P. L. Chapman, S. D. Sudhof, "Design and Precise Realization of Optimized Current Waveforms for an 8/6 Switched Reluctance Drive," IEEE Trans. on Power Electron, vol. 17, pp. 76-83, 2002.

[23] J. J. Slotine, W. Li, Applied Nonlinear Control. Prentice Hall Englewood Cliffs, NJ, 1991.

라쉬디 (Amir Rashidi)

Amir Rashidi was born in Mashhad, Iran, in 1984. He received the B.Sc. degree from Sistan and Baluchestan University, Zahedan, Iran, in 2006 and the M.Sc. degree from Isfahan University of Technology, Isfahan, Iran, in 2009, where he is currently working toward the Ph.D. degree in the Department of Electrical and Computer Engineering. He was a visiting researcher in smart mechatronics lab in Kyungsung University, Busan, Korea from September 2014 to August 2015. His research interests include electric motor drives, power electronics and microprocessor-based control systems.

나마찌 (Mohammad Masoud Namazi)

Mohammad Masoud Namazi was born in Isfahan, Iran, in 1986. He received the B.Sc. degree from Shahed University, Tehran, Iran, in 2008 and the M.Sc. degree from Isfahan University of Technology, Isfahan, Iran, in 2011, where he is currently working toward the Ph.D. degree in the Department of Electrical and Computer Engineering. He was a visiting researcher in smart mechatronics lab in Kyungsung University, Busan, Korea from September 2014 to May 2015. His fields of research are control of electric machine drives, automotive applications and control of DC microgrids using renewable energy sources.

세헤이안(Sayed Morteza Saghaian-Nejad)

Sayed Morteza Saghaian-Nejad was born in Isfahan, Iran, in 1952. He received his B.S., M.S. and Ph.D. in Electrical Engineering from the University of Kentucky, USA in 1977, 1979 and 1989, respectively. Since 1979, he has been a faculty member of Isfahan University of Technology, where he is currently a Professor in electrical and computer engineering department. He is the author or coauthor of various journal and conference papers. His current research interests are in the areas of electrical machines, power electronics and advanced motor drive systems.

이 동 희 (Dong-Hee Lee)

Dong-Hee Lee was born on November 11, 1970. He received the B.S., M.S., and Ph.D. degrees in electrical engineering from Pusan National University, Busan, Korea, in 1996, 1998, and 2001, respectively. He was a Senior Researcher with the Servo R&D Team at OTIS-LG, from 2002 to 2005. He has been with Kyungsung University, Busan, Korea, as a Full-Time Lecturer in the Department of Electrical and Mechatronics Engineering, since 2005. His major research fields are servo systems and electrical motor drives with power electronics. Dr. Lee is a member of the Korean Institute of Electrical Engineers and Korean Institute of Power Electronics.

안 진 우 (Jin-Woo Ahn)

Jin-Woo Ahn was born in Busan, Korea, in 1958. He received the B.S., M.S., and Ph.D. degrees in electrical engineering from Pusan National University, Busan, Korea, in 1984, 1986, and 1992, respectively. Since 1992, he has been a Professor with the Department of Mechatronics Engineering, Kyungsung University, Busan. From July 1998 to July 1999, he was a Visiting Professor with the Department of Electrical and Computer Engineering and with WEMPEC at the University of Wisconsin, Madison, WI, USA, and also from July 2006 to June 2007, with the Department of Electrical and Computer Engineering, Virginia Polytechnic Institute and State University, Blacksburg, VA, USA. He is the Director of the Smart Mechatronics Advanced Research and Technology Institute. He is the author of five books and more than 200 papers, and has more than 30 patents. His current research interests include advanced motor drive systems and electric vehicle drives. Prof. Ahn has served as a Conference Chairman of the International Conference on Electric Machines and Systems 2013 (ICEMS2013), and of the International Conference on Industrial Technology 2014 (IEEE/ICIT2014). He is a Fellow of the Korean Institute of Electrical Engineers and a member of the Korean Institute of Power Electronics.