International Journal of Advances in Engineering and Management (IJAEM)
Volume 2, Issue 3, pp: 176-179 www.ijaem.net ISSN: 2395-5252

# Cascaded Multiport Converter for SRM-Based Hybrid Electrical Vehicle Applications

Nikita U. Dhake[1], Kalpesh M. Mahajan[2]
*PG Student [EPS], Dept. of EE, KCES' S College Engineering and IT, Jalgaon, Maharashtra, India1*
*HOD, Dept. of EE, KCES' S College Engineering and IT, Jalgaon, Maharashtra, India2.*
*Corresponding author: Nikita U. Dhake*

Date of Submission: 15-07-2020 Date of Acceptance: 31-07-2020

**ABSTRACT:-** This paper proposes a cascaded multiport switched reluctance motor (SRM) drive for hybrid electric vehicle (HEV) applications, which not only allows flexible energy conversion among the generator/ac grid, the battery bank, and the motor, but also achieves battery management (BM) function for state-of-charge (SOC) balance control and bus voltage regulation. By integrating the battery packs into the AHB converter, the cascaded BM modules are designed to configure multilevel bus voltage and current capacity for SRM drive, which can accelerate the excitation and demagnetization processes during the commutation region, extend the speed range, reduce the voltage stress on the switches, and improve the torque capability and system efficiency. According to the different operation requirements, the multiple driving modes, regenerative braking modes, and charging modes are equipped in the proposed converter. Moreover, with the proposed BM strategy, each battery pack can be separately connected or disconnected from the power supply, which will greatly enhance the fault-tolerance ability and easily avoid the overcharge and overdischarge issues during the motor operation. The feasibility and effectiveness of the proposed cascaded multiport SRM drive are verified by the experiments on a three-phase 12/8 SRM.

**KEYWORDS:** Cascaded multiport converter, battery management (BM), state-of-charge (SOC) balance, switched reluctance motor (SRM), hybrid electric vehicles (HEVs).

## I. INTRODUCTION

With the growing concerns of fossil fuel crisis and environmental issue, the electric vehicles (EVs) and hybrid electric vehicles (HEVs) have drawn increasing attention due to their reduced fuel consumption and enhanced energy efficiency [1]-[4]. For the powertrain systems in the EV and HEV applications, permanent magnet synchronous motors (PMSMs) have always be dominated due to their superior torque and power densities [5]-[7]. However, with the rapid depletion and increased cost of rare-earth magnet source, the rare-earth-less and rare-earth-free motors are attracting more attention [8], [9]. As one rare-earth-free motor, switched reluctance motors (SRMs) are becoming a promising alternative due to their simple structure, low cost, exceptional robustness, high reliability, and strong applicability for harsh environments [10]-[13].

## II. LITERATURE SURVEY

Manuscript received June 29, 2018; revised October 14, 2018 and January 15, 2019; accepted March 19, 2019. (Corresponding author: Jianhua Wu.) Q. Sun is with the State Key Laboratory of Reliability and Intelligence of Electrical Equipment, School of Electrical Engineering, Hebei University of Technology, Tianjin 300130, China, and also with the College of Electrical Engineering, Zhejiang University, Hangzhou 310027, China (e-mail: lwsunqg@163.com). J. Wu, and J. Guo are with the College of Electrical Engineering, Zhejiang University, Hangzhou 310027, China (e-mail: hzjhwu@163.com; gif@zju.edu.cn). C. Gan is with the State Key Laboratory of Advanced Electromagnetic Engineering and Technology, School of Electrical and Electronic Engineering, Huazhong University of Science and Technology, Wuhan 430074, China (e-mail: chungan@hust.edu.cn). Jikai Si is with the School of Electric Engineering, Zheng Zhou University, Henan, Zheng Zhou 450001, China (e-mail: sijikai527@126.com) Y. Hu is with the Department of Electronic and Electrical Engineering, University of Liverpool, Liverpool L693BX, U.K.

## III.PROPOSED METHODOLOGY AND DISCUSSION

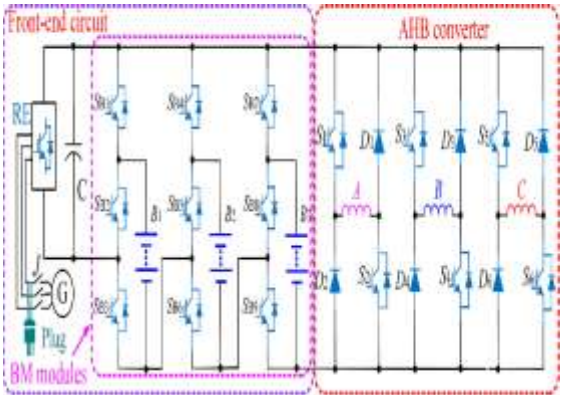


**Fig. 1.** Proposed cascaded multiport converter for a three-phase SRM

To achieve the high-efficiency energy conversion among the generator/ac grid, the battery bank, and the SRM for HEV applications, a highly integrated multiport converter is proposed with BM function, as shown in Fig. 1, where a relay J is used to connect the generator and the rectifier; a plug is used to connect the ac grid, and three BM modules are presented for function description. It can be seen that the generator/ac plug, the ac/dc rectifier, the BM modules, and the AHB converter are orderly connected in series. Hence, the proposed converter canbe considered as the combination of a front-end circuit and an AHB converter. The generator can not only act as a starter motor, but also be used to charge the battery bank and power the SRM [33]. The battery bank can also be charged by the SRM and the ac grid. The SRM can be powered by the generator and battery bank respectively or simultaneously. To enhance the flexibility and reliability of the battery packs, more BM modules can be designed, which are separately managed and composed of a battery pack and three power switches with anti-parallel diode. By employing the proposed topology, multiple driving modes, regenerative braking modes, and charging modes are achieved to satisfy different operation conditions**.**

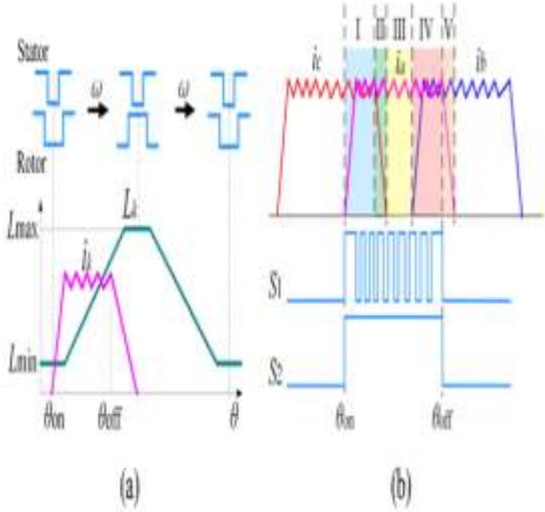


**Fig.2. Driving Operation condition (a) phase current and phase inductance. (b) phase currents and drive signals.**

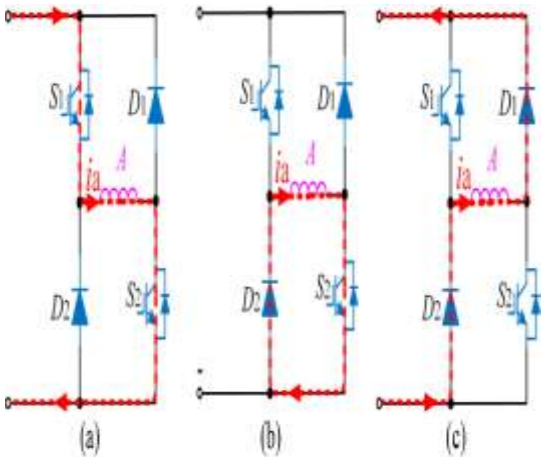


**Fig. 3. Operation states of AHB converter (a) E xcitation states (b) Freewheeling states .(c) Demagnetization states.**

When the SRM is under driving modes, the relationship between phase current and phase inductance is presented in Fig. 2(a), where θ is the rotor position angle; θon and θoff are the turn-on and turn-off angles, respectively, and ik and Lk are the kth phase current and phase inductance, respectively. According to the SRM characteristic, the phase winding should be conducted during the positive torque region, where the phase inductance is increasing. Fig. 2(b) shows three phase currents and the phase A signals under driving modes, where S1 and S2 are the corresponding switching signals. As illustrated in the figure, the whole conduction range of phase A can be divided into five regions. In Region I, the phases C and A are simultaneously conducting. In Region II, the phase

C is turned off and its current starts to decrease. In Region III, the phase C current reduces to zero and only phase A is conducting. In Region V the phase A is turned off. There are two switching states in the first four regions for phase A, including excitation state and zero-voltage freewheeling state. When the upper- and lower-switch of phase A (i.e., S1 and S2) are both turned on, the positive dc voltage is supplied to the phase winding, which is the excitation state, as shown in Fig. 3(a). With the upper switch S1 off and the lower switch S2 on, the voltage of phase winding is zero, which is the zero-voltage freewheeling state, as shown in Fig. 3(b). In Region V, the phase A winding is in the demagnetization state, as shown in Fig. 3(c), where the switches are both turned off, and the energy stored in the phase winding is fed back to the power supply through diodes D1 and D2. 2) Driving Modes by the Generator.

## III. CONTROLTECHNIQUE

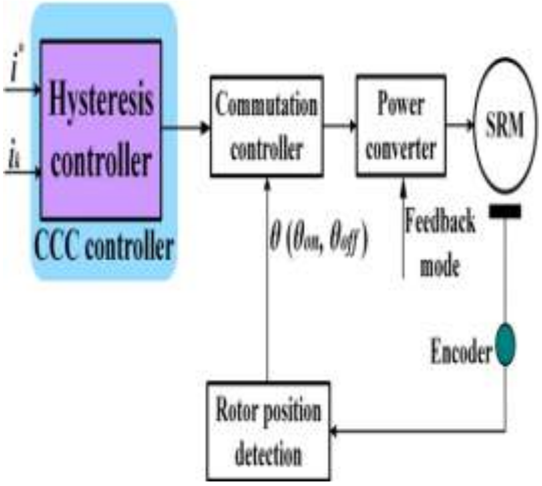


**Fig.4. control strstegy under regenerative braking modes.**

When the motor is under the regenerative braking mode, the SRM control system is illustrated in Fig. 12. The regenerative braking mode is used for braking with energy feedback, which can be considered to be independent from the driving mode. To avoid the overcurrent damage and implement the pulsed charging process [38]-[40], the CCC is employed to regulate the phase current. According to braking operation, the different braking current can be set for the inertial braking, slow braking, and quick braking. Meanwhile, the energy stored in the phase windings can be used to charge the battery packs.

## IV. CONCLUSION

In this project, a BMS including two different battery types and an isolated bidirectional Cuk converter for EVs was proposed. Li-ion battery is dominant type of battery in EVs due to its advantages, while other types like lead-acid can be employed in this application. Here, reducing fast charging stresses on the main battery was achieved by utilizing a lead acid battery as an auxiliary battery. An isolated Cuk converter was utilized to manage contribution of the batteries and enhance battery lifetime by achieving low voltage ripple and continues current. Three possible scenarios were considered to evaluate the performance of the proposed topology and control algorithm. The results confirm that the proposed converter is able to handle different functions in various conditions, desirably.

## REFERENCES

[1]. S. Kimura, Y. Itoh, W. Martinez, M. Yamamoto, and J. Imaoka, “Downsizing effects of integrated magnetic components in high power density DC/DC converters for EV and HEV applications,” IEEETrans. Ind. Appl., vol. 52, no. 4, pp. 3294-3305, 2016.

[2]. D. Moon, J. Park, and S. Choi, “New interleaved current-fed resonant converter with significantly reduced high current side output filter for EV and HEV applications,” IEEE Trans. Power Electron., vol. 30, no. 8, pp. 4264-4271, Aug. 2015.

[3]. A. Kulvanitchaiyanunt, V. C. P. Chen, J. Rosenberger, P. Sarikprueck, and W. J. Lee, “A linear program for system-level control of regional PHEV charging Stations,” IEEE Trans. Ind. Appl., vol. 52, no. 3, pp. 2046-2052, May./Jun. 2016.

[4]. L. Herrera, E. Inoa, F. Guo, J. Wang, and H. N. Tang, “Small-signal modeling and networked control of a PHEV charging facility,” IEEE Trans. Ind. Appl., vol. 50, no. 2, pp. 1121-1130, Mar./Apr. 2014.

[5]. D. Li, R. Qu, J. Li, L. Xiao, L. Wu, and W. Xu, “Analysis of torque capability and quality in vernier permanent-magnet machines,” IEEE Trans. Ind. Appl., vol. 52, pp. 125-135, Jan./Feb. 2016.

[6]. J. J. Justo, F. Mwasilu, E. K. Kim, J. Kim, H. H. Choi, and J. W. Jung, “Fuzzy model predictive direct torque control of IPMSMs for electric vehicle applications,” IEEE/ASME Trans. Mechatronics, vol. 22, no. 4, pp. 1542-1553, 2017.

[7]. T. A. Huynh and M. F. Hsieh, “Comparative study of PM-assisted SynRM and IPMSM on constant power speed range for EV

applications," IEEE Trans. Magn., vol. 53, no. 11, Nov. 2017.

[8]. I. Boldea, L. N. Tutelea, L. Parsa, and D. Dorrell, "Automotive electric propulsion systems with reduced or no permanent magnets: an overview," IEEE Trans. Ind. Electron., vol. 61, no. 10, pp. 5696–5711, Oct. 2014.

[9]. Z. Yang, F. Shang, I. P. Brown, and M. Krishnamurthy, "Comparative study of interior permanent magnet, induction, and switched reluctance motor drives for EV and HEV applications," IEEE Transactions on Transportation Electrification, vol. 1, no. 3, pp. 245-254, Oct. 2015. [10] A. Chiba, K. Kiyota, N. Hoshi, M. Takemoto, and S. Ogasawara, "Development of a rare-earth-free sr motor with high torque density for hybrid vehicles," IEEE Trans. Energy Convers., vol. 30, no. 1, pp. 175-182, Mar. 2015.

[10]. K. Kiyota, and A. Chiba, "Design of switched reluctance motor competitive to 60-kW IPMSM in third-generation hybrid electric vehicle," IEEE Trans. Ind. Appl., vol. 48, no. 6, pp. 2303-2309, Nov./Dec. 2012.

[11]. F. L. M. d. Santos, J. Anthonis, F. Naclerio, J. J. C. Gyselinck, H. V. d. Auweraer, and L. C. S. Góes, "Multiphysics NVH modeling: simulation of a switched reluctance motor for an electric vehicle," IEEE Trans. Ind. Electron., vol. 61, no. 1, pp. 469-476, Jan. 2014.

[12]. Q. Sun, J. Wu, C. Gan, Y. Hu, N. Jin, and J. Guo, "A new phase current reconstruction scheme for four-phase SRM drives using improved converter topology without voltage penalty," IEEE Trans. Ind. Electron., vol. 65, no. 1, pp. 133-144, Jan. 2018.

[13]. L. Dong-Hee and A. Jin-Woo, "A Novel four-level converter and instantaneous switching angle detector for high speed SRM drive," IEEE Trans. Power Electron, vol. 22, no. 5, pp. 2034-2041, 2007.

[14]. K. Tomczewski and K. Wrobel, "Quasi-three-level converter for switched reluctance motor drives reducing current rising and falling times," IET Power Electron., vol. 5, no. 7, pp. 1049-1057, 2012.