ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

# A Hybrid Cascaded Multilevel Converter for Battery Energy Management Applied in Electric Vehicles

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## ABSTRACT

***In electric vehicle (EV) energy storage systems, a large number of battery cells are usually connected in series to enhance the output voltage for motor driving. The difference in electrochemical characters will cause state-of-charge (SOC) and terminal voltage imbalance between different cells. In this paper, a hybrid cascaded multilevel converter which involves both battery energy management and motor drives is proposed for EV. In the proposed topology, each battery cell can be controlled to be connected into the circuit or to be bypassed by a half-bridge converter. All half bridges are cascaded to output a staircase shape dc voltage. Then, an H-bridge converter is used to change the direction of the dc bus voltages to make up ac voltages. The outputs of the converter are multilevel voltages with less harmonics and lower dv/dt, which is helpful to improve the performance of the motor drives. By separate control according to the SOCof each cell, the energy utilization ratio of the batteries can be improved. The imbalance of terminal voltage and SOC can also be avoided, fault-tolerant can be easily realized by modular cascaded circuit, so the life of the battery stack will be extended. Simulation and experiments are implemented to verify the performance of the proposed converter.***

## INTRODUCTION

An energy storage system plays an important role in electric vehicles (EV). Batteries, such as lead-acid or lithium batteries, are the most popular units because of their appropriate energy density and cost. Since the voltages of these kinds of battery cells are relatively low, a large number of battery cells need to be connected in series to meet the voltage requirement of the motor drive. Because of the manufacturing variability, cell architecture and degradation with use, the characters such as volume and resistance will be different between these cascaded battery cells. In a traditional method, all the battery cells are directly connected in series and are charged or discharged by the same current, the terminal voltage and state-of-charge (SOC) will be different because of the electrochemical characteristic differences between the battery cells. The charge and discharge have to be stopped even though only one of the cells reaches its cut-off voltage. Moreover, when any cell is fatally damaged, the whole battery stack cannot be used anymore. So the battery cell screening must be processed to reduce these differences, and voltage or SOC equalization circuit is often needed in practical applications to protect the battery cells from overcharging or over discharging.

Generally, there are two kinds of equalization circuits. The first one consumes the redundant energy on parallel resistance to keep the terminal voltage of all cells equal. For example, in charging course, if one cell arrives at its cut-off voltage, the available energy in other cells must be consumed in their parallel-connected resistances. So the energy utilization ratio is very low. Another kind of equalization circuit is composed of a group of inductances or transformers and converters, which can realize energy transfer between battery cells. The energy in the cells with higher terminal voltage or SOC can be transferred to others to realize the voltage and SOC equalization. Since the voltage balance is realized by energy exchange between cells, the energy utilization ratio is improved. The disadvantage is that a lot of inductances or isolated multiwinding transformers are required in these topologies, and the control of the converters is also complex. Some studies have been implemented to simplify the circuit and improve the balance speed by multistage equalization. Some zero voltage and zero current switching techniques are also used to reduce the loss of the equalization circuit. Multilevel converters are widely used in medium or high voltage motor drives. If their flying capacitors or isolated dc sources are replaced by the battery cells, the battery cells can be cascaded in series combining with the converters instead of connection in series directly. In, the cascaded Hbridge converters are used for the voltage balance of the battery cells. Each H-bridge cell is used to control one battery cell; then the voltage balance can be realized by the separate control of charging and discharging. The output voltage of the converter is multilevel which is suitable for the motor drives. When used for power grid, the filter inductance can be greatly reduced. The cascaded topology has better fault-tolerant ability by its modular design, and has no limitation on the number of cascaded cells, so it is very suitable to produce a higher voltage output using these low-voltage battery cells, especially for the application in power grid. Similar to the voltage balance method in traditional multilevel converters, especially to the STATCOM using flying capacitors, the voltage balance control of the battery cells can

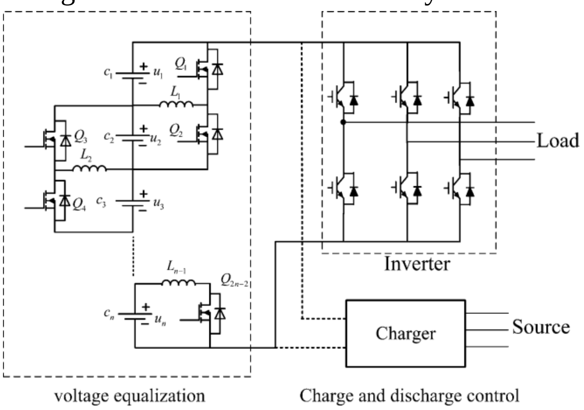


Fig. 1.Traditional power storage system with voltage equalization circuit andinverter.

also be realized by the adjustment of the modulation ratio of each H-bridge Compared to the traditional voltage balance circuit, the multilevel converters are very suitable for the balance of battery cells. Besides the cascaded H-bridge circuit, some other hybrid cascaded topologies are proposed in which use fewer devices to realize the same output. Because of the power density limitation of batteries, some ultracapacitors are used to improve the power density. Some converters must be used for the battery and ultracapacitor combination. Multilevel converters with battery cells are also very convenient for the combination of battery and ultracapacitors. A hybrid cascaded multilevel converter is proposed in this paper which can realize the terminal voltage or SOC balance between the battery cells. The converter can also realize the charge and discharge control of the battery cells. A desired ac voltage can be output at the H-bridge sides to drive the electric motor, or to connect to the power grid. So additional battery chargers or motor drive inverters are not necessary any more under this situation. The ac output of the converter is multilevel voltage, while the number of voltage levels is proportional to the number of cascaded battery cells. So in the applications of EV or power grid with a larger number of battery cells, the output ac voltage is approximately ideal sine waves. The harmonics and dv/dtcan be greatly reduced than the traditional two-level converters. The proposed converter with modular design can realize the fault redundancy and high reliability easily. Simulation and experimental results are proposed to verify the performance of the proposed hybrid cascaded multilevel converter in this paper.

## AC-DC CONVERTER:

A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), current that flows in only one direction, a process known as rectification. Rectifiers have many uses including as components of power supplies and as detectors of radio signals. Rectifiers may be made of solid state diodes, vacuum tube diodes, mercury arc valves, and other components.

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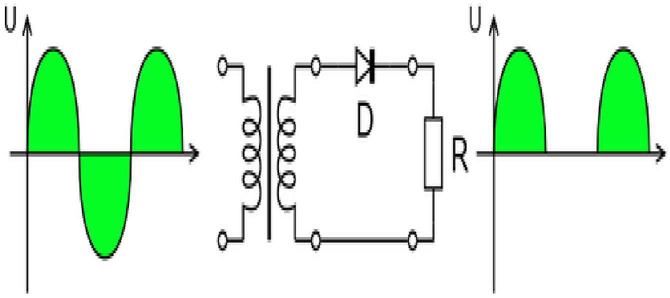
A device which performs the opposite function (converting DC to AC) is known as an inverter. When only one diode is used to rectify AC (by blocking the negative or positive portion of the waveform), the difference between the term diode and the term rectifier is merely one of usage, i.e., the term rectifier describes a diode that is being used to convert AC to DC. Almost all rectifiers comprise a number of diodes in a specific arrangement for more efficiently converting AC to DC than is possible with only one diode. Before the development of silicon semiconductor rectifiers, vacuum tube diodes and copper(I) oxide or selenium rectifier stacks were used.

## HALF-WAVE RECTIFIER

In half wave rectification, either the positive or negative half of the AC wave is passed, while the other half is blocked. Because only one half of the input waveform reaches the output, it is very inefficient if used for power transfer. Half-wave rectification can be achieved with a single diode in a one-phase supply, or with three diodes in a three-phase supply.



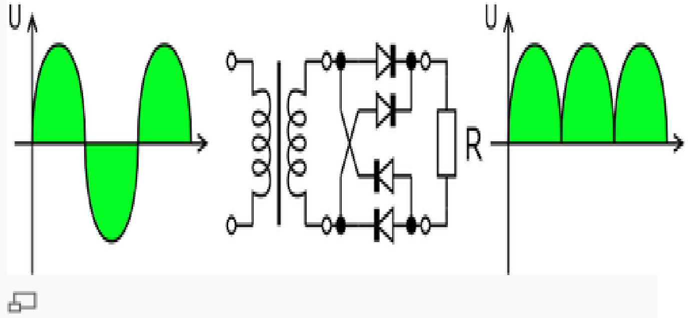

The output DC voltage of a half wave rectifier can be calculated with the following two ideal equations:

$$V_{rms} = \frac{V_{peak}}{2}$$

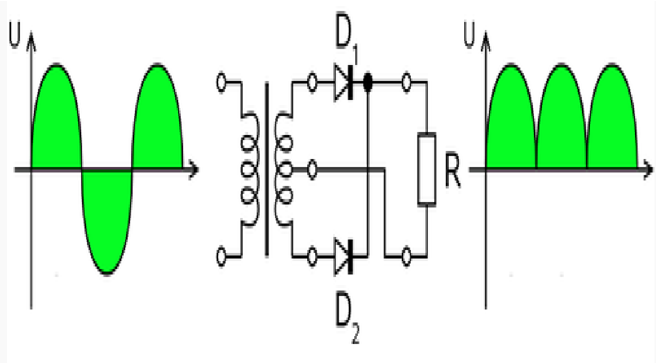
$$V_{dc} = \frac{V_{peak}}{\pi}$$

## FULL-WAVE RECTIFIER

A full-wave rectifier converts the whole of the input waveform to one of constant polarity (positive or negative) at its output. Full-wave rectification converts both polarities of the input waveform to DC (direct current), and is more efficient. However, in a circuit with a non-center tapped transformer, four diodes are required instead of the one needed for half-wave rectification. Four diodes arranged this way are called a diode bridge or bridge rectifier:




For single-phase AC, if the transformer is center-tapped, then two diodes back-to-back (i.e. anodes-to-anode or cathode-to-cathode) can form a full-wave rectifier. Twice as many windings are required on the transformer secondary to obtain the same output voltage compared to the bridge rectifier above.




A very common vacuum tube rectifier configuration contained one cathode and twin anodes inside a single envelope; in this way, the two diodes required only one vacuum tube. The 5U4 and 5Y3 were popular examples of this configuration.

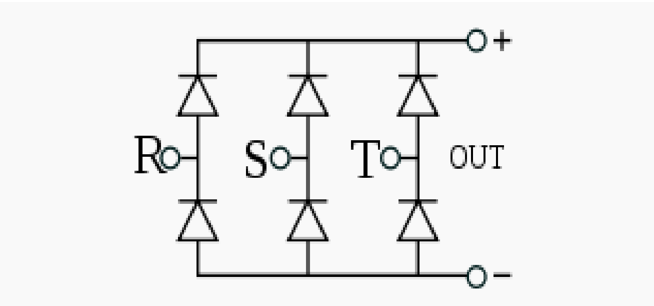



Fig. A three-phase bridge rectifier.

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International Journal & Magazine of Engineering, Technology, Management and Research
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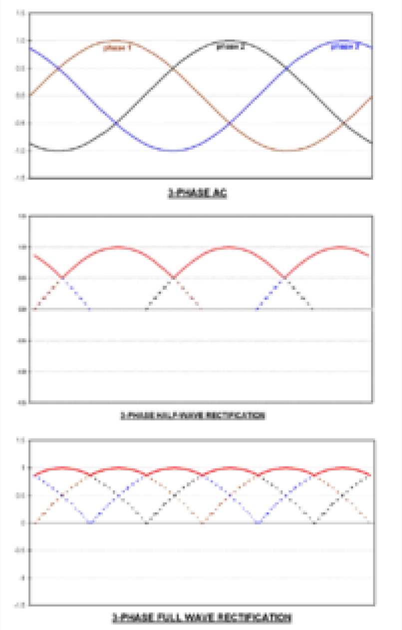


Fig. 3-phase AC input, half & full wave rectified DC output waveforms

For three-phase AC, six diodes are used. Typically there are three pairs of diodes, each pair, though, is not the same kind of double diode that would be used for a full wave single-phase rectifier. Instead the pairs are in series (anode to cathode). Typically, commercially available double diodes have four terminals so the user can configure them as single-phase split supply use, for half a bridge, or for three-phase u

Most devices that generate alternating current (such devices are called alternators) generate three-phase AC. For example, an automobile alternator has six diodes inside it to function as a full-wave rectifier for battery charging applications.

The average and root-mean-square output voltages of an ideal single phase full wave rectifier can be calculated as:

$$V_{dc} = V_{av} = \frac{2V_p}{\pi}$$

$$V_{rms} = \frac{V_p}{\sqrt{2}}$$

Where:

**$V_{dc}$,$V_{av}$** - the average or DC output voltage,

**$V_p$** - the peak value of half wave,

**$V_{rms}$** - the root-mean-square value of output voltage.

***π*** = ~ 3.14159

## EXPERIMENTAL RESULTS

To verify the performance of the proposed topology and the control method, a three-phase four-cell cascaded circuit is erected at lab. The lead-acid battery modules of 5 Ah and 12 V are used. The battery modules are monitored by the LEM Sentinel which can measure the voltage, temperature, and resistance of the battery modules. The measured information is transferred to the DSP controller byRS-232 communication. The voltages and currents are measured and recorded by YOKOGAWA Scope order DL750. Since the SOC of the battery cells are difficult to be estimated, the terminal voltages are used for the PWM carrier-wave arrangement

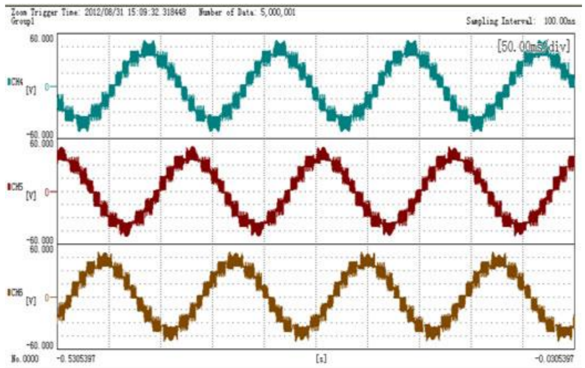

Fig. 2.Triphase output voltage of multilevel.

then the terminal voltage balance is realized instead of the SOC balance which can still verify the effects of the converter.

The cascaded half-bridges are designed with MOSFETIPP045N10N3 (Infineon) whose on-resistance is only 4.2 mΩand the rated current is 100 A. Even if the discharge or charge current is 50 A, the conduction loss on the MOSFET of each half-bridge is only

*P* = *I2R* = 10.5W.

Then, the efficiency drop caused by the conduction loss of the MOSFET in the whole phase is

$\Delta\eta$= *I2R · n/U · I · n*= 1.75%.

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So the conduction loss added by the equalization circuit is very small compared to the output power of the whole converter.

Another device of MOSFET IPB22N03S4L-15 (Infineon) of30 V, 22 A, and 14.6 mΩ will be used in our platform. The efficiency drop caused by the conduction loss $\Delta\eta$= 1.38% when the output current is 11 A. The three-phase output voltage is shown in Fig. 2. There are nine levels at each phase. So it approaches more to the ideal sinusoidal wave than the traditional two-level inverters. Ina steady state, the FFT analysis result of the output ac phase voltage is shown in Fig. 3. It shows that the harmonics is little compared to the base-frequency component.

An induction motor (IM) was driven with the variable voltage–variable-frequency (VVVF) control method. The parameters of the motor are shown in Table II.The dc bus voltage; ac output voltage, output current, and dc bus current are shown in Figs. 4 and 5, which indicate the whole process from start-up to the stable state of the relative IM. From Fig. 4, it is obvious that the output voltage levels keep increasing according to the acceleration of the motor speed. The stator current of the motor shown in Fig. 5 are of improved sinusoidal shape which can reflect the control performance of the motor. The dc bus current is also shown in Fig. 5. As the lag between the voltage and current phase, when the phase voltage change direction, the H-bridge will change its switching state too. But the phase ac current will change its direction after a

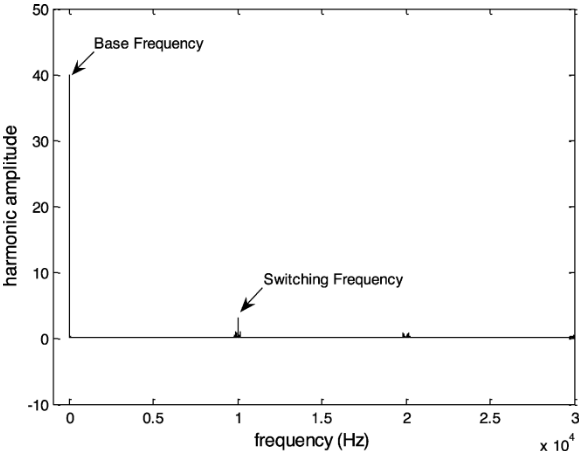


Fig. 3.FFT analysis of the output ac voltage.

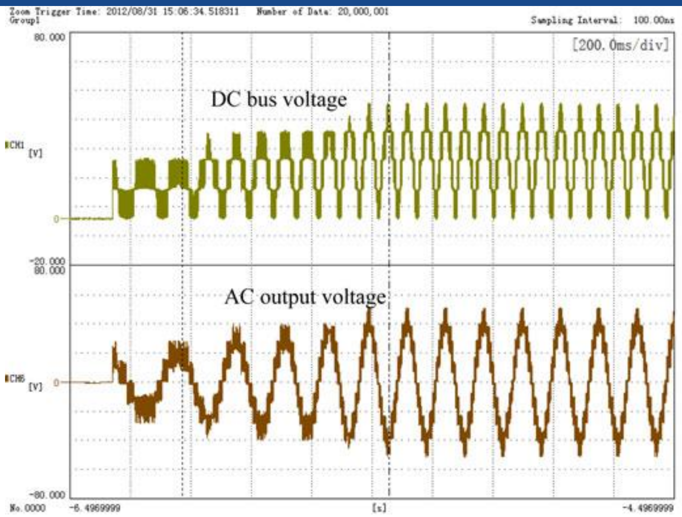


Fig. 4. DC and ac output voltage during motor acceleration.

period of time, so the direction of the dc bus current is reversed when the directions of phase voltage and current are different. The reversed dc bus current also reflects the reactive power of the load. As the induction motor is of nearly no load, the phase current is nearly $\pi/2$ lag with the phase voltage and the average dc current is almost zero in steady state. But in starting course,

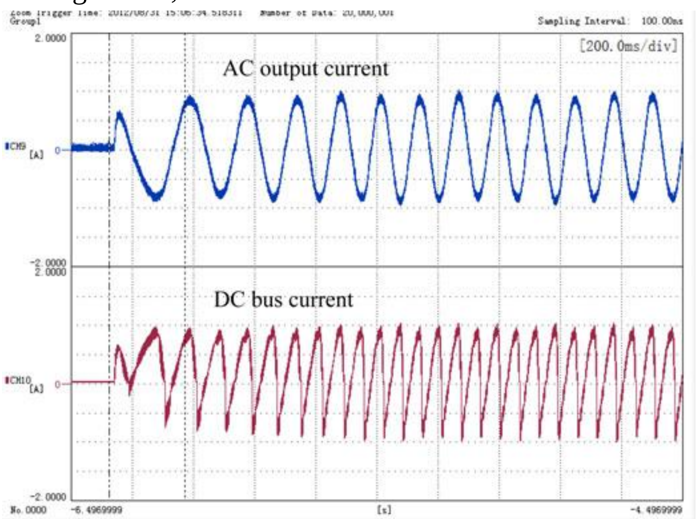


Fig. 5.Output ac and dc current during motor acceleration.

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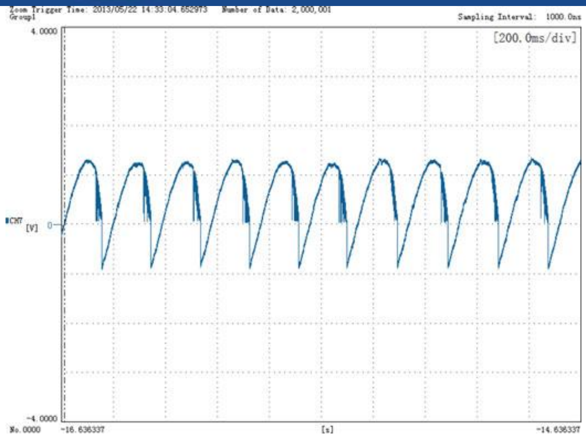


Fig. 6.DC bus current with some loads.

the average dc bus voltage is positive which stands for the active power flow from the battery to the electric motor.

## CONCLUSION

The hybrid-cascaded multilevel converter proposed in this paper can actualize the charging and discharging of the battery cells while the terminal voltage or SOC balance control can be realized at the same time. The proposed converter with modular structure can reach any number of cascaded levels and is suitable for the energy storage system control with low-voltage battery cells or battery modules. The fault module can be bypassed without affecting the running of the other ones, so the converter has a good fault-tolerant character which can significantly improve the system reliability. The PWM method with low switching loss for both discharging and charging control is proposed considering the balance control at the same time. The output of the circuit is multilevel ac voltages where the number of levels is proportional to the number of battery cells. So the output ac voltage is nearly the ideal sinusoidal wave which can improve the control performance of the motor control in EVs. Adc bus current control method for battery charging with external dc or ac source is also studied where the constant-current control can be realized and the additional charger is not needed anymore. Experiments are implemented and the proposed circuit and control method are verified.

## REFERENCES

[1] S. M. Lukic, J. Cao, R. C. Bansal, F. Rodriguez, and A. Emadi, “Energystorage systems for automotive applications,” *IEEE Trans. Ind. Electron.*,vol. 55, no. 6, pp. 2258–2267, Jul. 2008.

[2] H. M. Zhang and S. P. Ding, “Application of synergic electric power supplyin HEV,” in *Proc. 8th World Congr. Intelligent Control Autom.*, 2010,pp. 4097–4100.

[3] A. Emadi, Y. J. Lee, and K. Rajashekara, “Power electronics and motor
drives in electric, hybrid electric, and plug-in hybrid electric vehicles,”*IEEE Trans. Ind. Electron.*, vol. 55, no. 6, pp. 2237–2245, Jun. 2008.

[4] K. Jonghoon, S. Jongwon, C. Changyoon, and B. H. Cho, “Stable configurationof a Li-Ion series battery pack based on a screening process forimproved voltage/SOC balancing,” *IEEE Trans. Power Electron.*, vol. 27,no. 1, pp. 411–424, Jan. 2012.

[5] L. Yuang-Shung, T. Cheng-En, K. Yi-Pin, and C. Ming-Wang, “Chargeequalization using quasi-resonant converters in battery string for medicalpower operated vehicle application,” in *Proc. Int. Power Electron. Conf.*,2010, pp. 2722–2728.

[6] Y. C. Hsieh, C. S. Moo, and W. Y. Ou-Yang, “A bi-directional chargeequalization circuit for series-connected batteries,” in *Proc. IEEE PowerElectron. Drives Syst.*, 2005, pp. 1578–1583.

[7] S.Yarlagadda, T. T.Hartley, and I.Husain, “Abatterymanagement systemusing an active charge equalization technique based on a DC/DC convertertopology,” in *Proc. Energy Convers. Congr.Expo.*, 2011, pp. 1188–1195.

[8] K. Chol-Ho, K. Young-Do, and M. Gun-Woo, “Individual cell voltageequalizer using selective two current paths for series connected Li-ionbattery strings,” in *Proc. Energy Convers. Congr.Expo.*, 2009, pp. 1812–1817.

[9] H. Shen, W. Zhu, and W. Chen, "Charge equalization using multiplewinding magnetic model for lithium-ion battery string," in *Proc. Asia-Pacific Power Energy Eng. Conf.*, 2010, pp. 1–4.

[10] P. Sang-Hyun, P. Ki-Bum, K. Hyoung-Suk, M. Gun-Woo, and Y. Myung-Joong, "Single-magnetic cell-to-cell charge equalization converter withreduced number of transformer windings," *IEEE Trans. Power Electron.*,vol. 27, no. 6, pp. 2900–2911, Jun. 2012.

[11] K. Chol-Ho, K. Moon-Young, P. Hong-Sun, and M. Gun-Woo, "A modularizedtwo-stage charge equalizer with cell selection switches for seriesconnectedlithium-ion battery string in an HEV," *IEEE Trans. PowerElectron.*, vol. 27, no. 8, pp. 3764–3774, Aug. 2012.

[12] K. Chol-Ho, K. Moon-Young, and M. Gun-Woo, "A modularized chargeequalizer using a batterymonitoring IC for series-connected Li-Ion batterystrings in electric vehicles," *IEEE Trans. Power Electron.*, vol. 28, no. 8,pp. 3779–3787, Aug. 2013.

[13] Y. Ye, K. W. E. Cheng, and Y. P. B. Yeung, "Zero-current switchingswitched-capacitor zero-voltage-gap automatic equalization system for seriesbattery string," *IEEE Trans. Power Electron.*, vol. 27, no. 7, pp. 3234–3242, Jul. 2012.

[14] L. M. Tolbert, Z. P. Fang, and T. G. Habetler, "Multilevel converters forlarge electric drives," *IEEE Trans. Ind. Appl.*, vol. 35, no. 1, pp. 36–44,Jan. 1999.

[15] J. Rodriguez, S. Bernet, B. Wu, J. O. Pontt, and S. Kouro, "Multilevelvoltage-source-converter topologies for industrial medium-voltagedrives," *IEEE Trans. Ind. Electron.*, vol. 54, no. 6, pp. 2930–2945, Dec.2007.