Rectified AC Input Connected Fully Directional Universal Converter with LC Series Soft-Switching Circuit for EV, HEV & PHEV Applications

Neenu C Robin[1], Joju Mohan[2]

[1]M.E Power Electronics and Drives, Department of Electrical and Electronics
CSI College of Engineering, Ketti

[2]M. Tech Embedded System, Vidya academy of Science and Technology, Thrissur, Kerala

Abstract: ***This paper focuses on the study of rectified ac input connected fully directional universal converter with LC series soft-switching circuit for electric vehicles(EV),hybrid electric vehicles(HEV) and plug-in hybrid electric vehicles(PHEV).In the applications mentioned above, the proposed converter interfaces the energy storage device with motor drive. In this paper battery is used as energy storage device. Charging and discharging action of battery, during acceleration and regenerative braking of motor take place through this bidirectional dc to dc converter. That is bucking and boosting action will take place in one direction with no inverted output voltage. Rectified ac input voltage is used here for V_{dc} to $V_{battery}$ bucking and boosting action.LC series resonant circuit is added with proposed bidirectional dc to dc converter for soft-switching action and closed loop PI controller is used for controlling purpose. Four modes of operation of proposed converter is described and simulations work are done in MATLAB simulink.***

Keywords: Fully directional universal converter, Rectifier circuit, I controller, LC series circuit, EV, HEV and PHEV

1. Introduction

For the requirements of reducing emissions, pollution and getting better performance, electrification in transportation industry is very essential. It also has so many advantages like electric motors are simple in construction and it also has greatest degree of energy resilience. The energy efficiency of EVs is higher than that of internal combustion engine. EVs can be plugged into the grid when not in use, that is stabilization of grid is possible. So automotive companies are interesting to develop electric vehicles, hybrid electric vehicle and plug-in hybrid electric vehicle. Power electronics concept is the enabling technology for the development of these vehicles. The proposed bidirectional dc to dc converter is used for transferring energy between different voltage levels. Electric vehicle use one or more electric motor for traction purpose, HEV use electric motor and other source for energy, but PHEV use external charger for traction purpose. The figure 1.1 shows the roll of bidirectional dc to dc converter in PHEV.

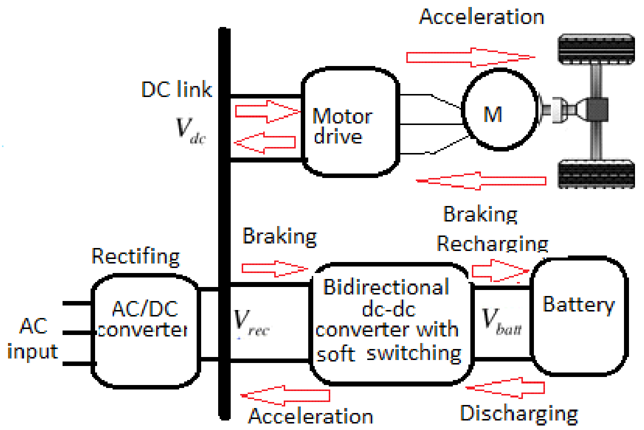

Figure 1.1: Bidirectional dc to dc converter in PHEV

It has two modes of operations, driving mode and grid connected mode. In driving mode two cases are possible, V_{dc}>V_{batt} and V_{dc}<V_{batt}. In V_{dc}>V_{batt}, the bidirectional dc to dc converter stepped up during acceleration and stepped down during braking. And in V_{dc} <V_{batt}, the proposed converter stepped down during acceleration and stepped up during braking. Similarly in grid connected mode V_{rec} >V_{batt} and V_{rec}<V_{batt} are possible. In this case, V_{rec} >V_{batt}, the converter stepped up in discharging and stepped down in charging. Similarly in V_{rec}<V_{batt} the proposed converter stepped up in charging and stepped down in discharging.12 pulse rectifier is used for the rectification action. Soft switching action is done through series LC circuit.

2. Bidirectional DC to DC Converter and Operating Modes

The figure 2.1 shows the schematic of the proposed bidirectional dc to dc converter. It has five power switches and five power diodes, which are properly connected to get bucking and boosting mode of operations. V_{dc} represents the dc link voltage and V_{batt} denotes battery terminal voltage.

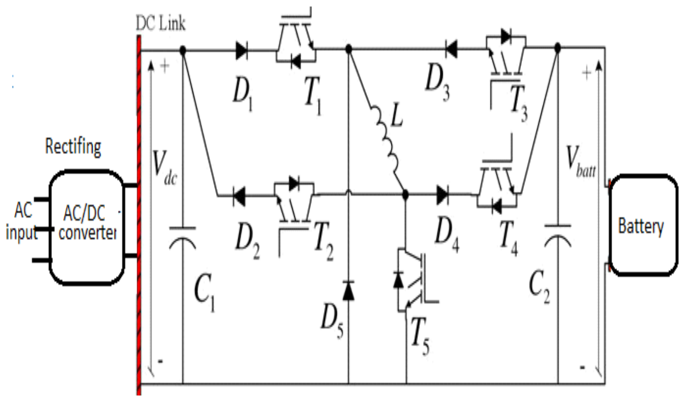

Figure.2.1: Proposed bidirectional dc to dc converter

IGBT is used as power switches. The proposed converter is capable of operating V_{dc} to V_{batt} bucking, V_{dc} to Vbatt boosting, V_{bat}t to Vdc bucking and V_{batt} to V_{dc} boosting by proper connection with positive output voltage. Operating modes are described in the table2.1.

Table 2.1: Modes of operation

Direction	Mode	T_1	T_2	T_3	T_4	T_5
$V_{dc} \rightarrow V_{batt}$	BOOST	ON	OFF	OFF	ON	PWM
$V_{dc} \rightarrow V_{batt}$	BUCK	PWM	OFF	OFF	ON	OFF
$V_{batt} \rightarrow V_{dc}$	BOOST	OFF	ON	ON	OFF	PWM
$V_{batt} \rightarrow V_{dc}$	BUCK	OFF	ON	PWM	OFF	OFF

Here four modes of operations are possible. In each operating mode any one of the switches is operating in PWM mode and other switches are act as simple on or off. It require only one high current inductor.

V_{DC} TO V_{BATT} BOOST MODE OF OPERATION

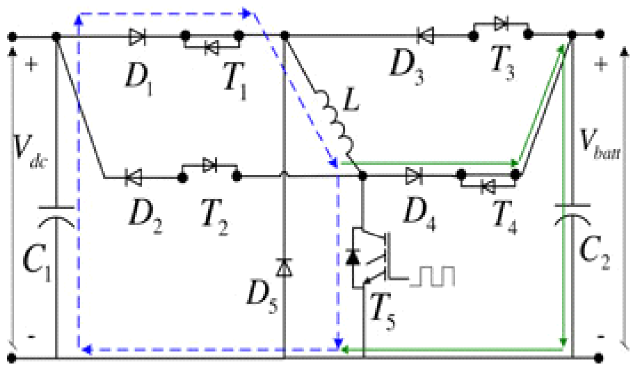

Figure 2.2: Vdc to Vbatt boost mode

Here T_5 is operated in PWM switching mode and T_2 and T_3remain in off state. At the same time T_1 and T_4 remain on all the time. Then boost converter is formed by D_1-T_1-L-T_5-D_4-T_4. When T_5 is ON, the current from V_{dc} passes through D_1,T_1,L and T_5. When T_5 is OFF, both the source and inductor currents flow to the battery side through D_4 and T_4.

V_{DC} TO V_{BATT} BUCK MODE OF OPERATION

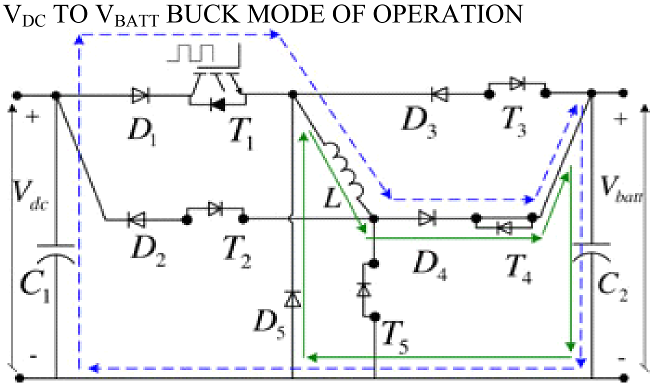

Figure 2.3: V_{dc} TO V_{batt} buck mode

Here T_1 is operated in PWM switching mode and T_2 ,T_3 and T_5 remain in OFF state.T_4 remain ON all the time. Then buck converter is formed by D_1-T_1- D_5-L-D_4 and T_4. When T_1 is ON,the current from V_{dc} passes through D_1,T_1,L, D_4 and T_4. When T_1 is OFF, the output current is recovered by freewheeling diode D_5.

V_{BATT} TO V_{DC} BOOST MODE OF OPERATION

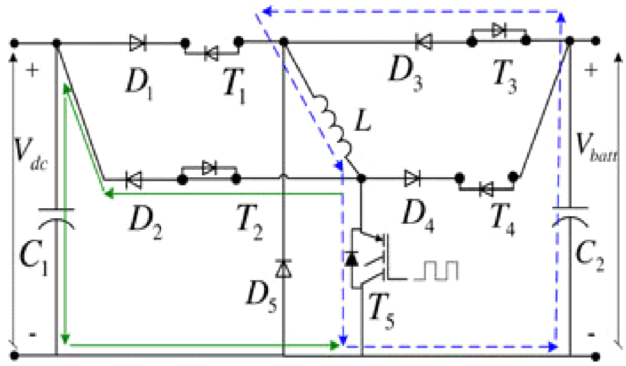

Figure 2.4: V_{batt} TO V_{dc} boost mode

T_5 is operated in PWM switching mode. And T_1 and T_4 remain OFF state. Then T_2 and T_3 remain ON all the time. Boost converter is formed by T_3-D_3-L-T_5-$T_2$and D_2. When T_5 is on, the current from V_{batt} passes through T_3, D3, L and T_5.When T_5 is off, both inductor and source current pass through T_2 and D_2.

V_{BATT} TO V_{DC} BUCK MODE OF OPERATION

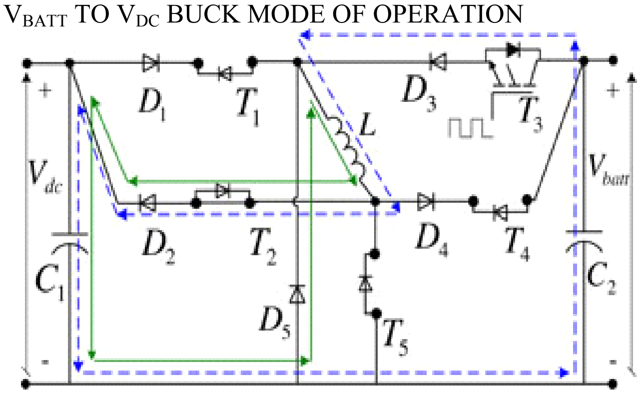

Figure 2.5: V_{batt} TO V_{dc} buck mode

T_3 is operated in PWM switching mode. and T_1, T_4 and T_5 remain OFF. Then T_2 remain ON all the time. Therefore Buck converter is formed by T_3-D_3-D_5-L-$T_2$and D_2. When T_3 is on, the current from V_{batt} passes through T_3, D3, L T_2 and D_2.When T_3 is off, the output current is freewheeled through the D_5, T2 and D_2.

3. Soft Switching Series LC Circuit

The schematic circuit of soft switching LC resonant circuit is shown in figure 3.1.

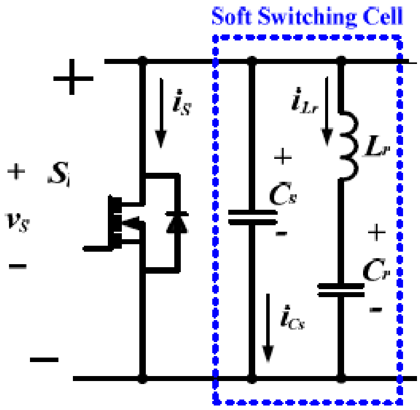

Figure 3.1: LC circuit

This LC resonant circuit used for avoiding transformer in bidirectional dc to dc converter and reduce the losses during turn on and turn off time of the switches. Here C_s is the snubber capacitance, L_r is the resonance inductor and C_r is the resonance capacitor.

4. AC TO DC Rectifier

The schematic of 12 pulse converter is shown. Twelve pulse rectifiers are formed by the cascaded connection of two 6 pulse converter. Primary of the transformer is star connected and one of the secondary is star connected and other one is delta connected.

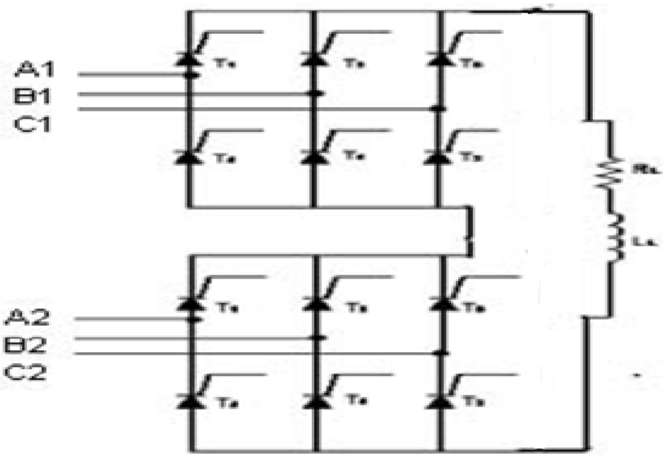

Figure 4.1: Pulse Converter

5. PI Controller

The key feature of this control is the existence of a feedback loop. Figure 5.1 shows the control system.

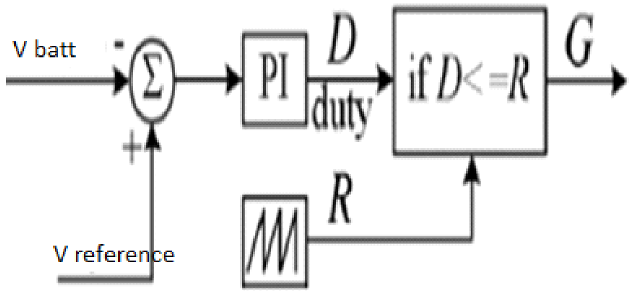

Figure 5.1: PI controller

Furthermore, in this control scheme, the difference between the output voltages Vbatt, (dc), and a reference signal, Vref, is processed by a compensation network which generates a error signal, Verror. This error signal tells how the duty cycle has to be changed in order to give the best transient dynamics for the desired output. This errorl signal is given as input to the PI controller .The output of PI controller is compared with a periodic ramp signal, Vramp(t), to generate a pulse width modulated signal which drives the switch

6. MATLAB Simulations and Results

Simulations of four modes of operations of bidirectional dc to dc converter with soft switching LC resonant circuit is done by using MATLAB Simulink. V_{dc} to V_{batt} boosting, V_{dc} to V_{batt} bucking, V_{batt} to V_{dc} boosting and V_{bat}t to V_{dc} boosting circuits are shown below. Figure 6.1 represents V_{dc} to V_{batt} boosting, here V_{dc} is 24V and V_{batt} is 42V.Boost mode simulation circuit result is shown in figure 6.2.Figure6.3 shows V_{dc} to V_{batt} bucking simulation circuit, with V_{dc} 42V and V_{batt} 24V.Figure 6.4 shows buck mode simulation circuit result. Figure 6.5 represents V_{bat}t toV_{dc} boost mode simulation circuit with V_{batt} 24V and V_{dc} 42V.Figure 6.6 represents boost mode simulation circuit result. Figure 6.7 represents V_{batt} to V_{dc} buck simulation circuit with V_{batt} 53V and V_{dc} 24V.Figure 6.8 represents buck mode simulation circuit result. First channel represents input voltage and second channel represents output voltage.

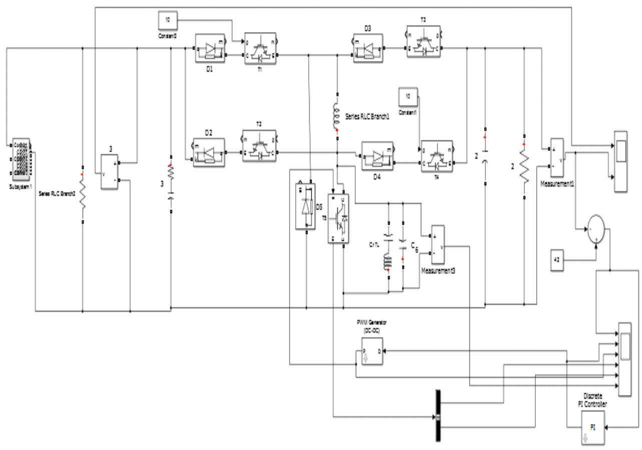

Figure 6.1: V_{dc} To V_{batt} boost mode simulation circuit

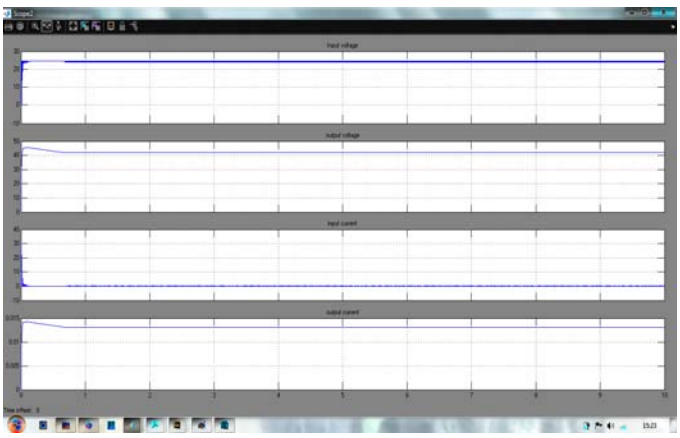

Figure 6.2: V_{dc} To V_{batt} boost mode simulation circuit result

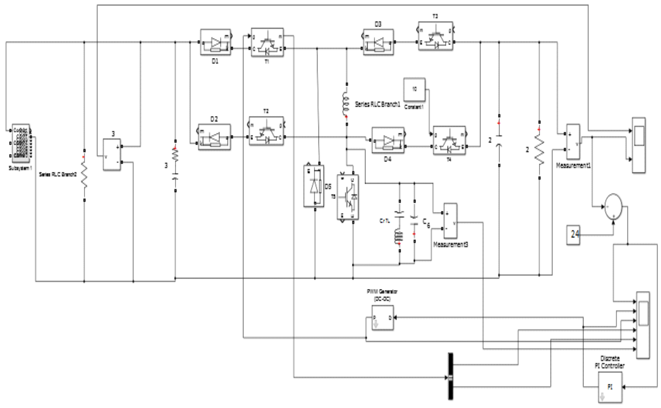

Figure 6.3: V_{dc} To V_{batt} buck mode simulation circuit

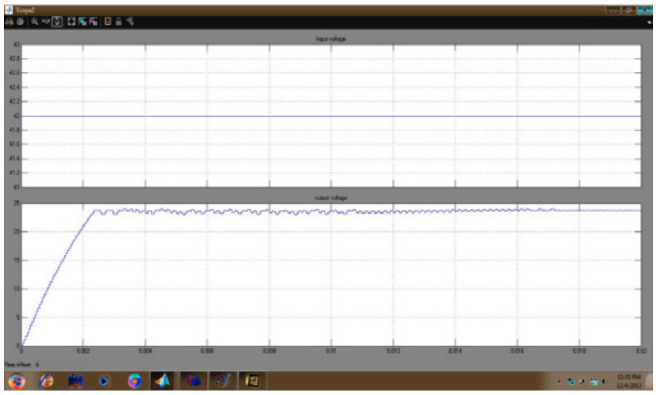

Figure 6.4: V_{dc} To V_{batt} buck mode simulation circuit result

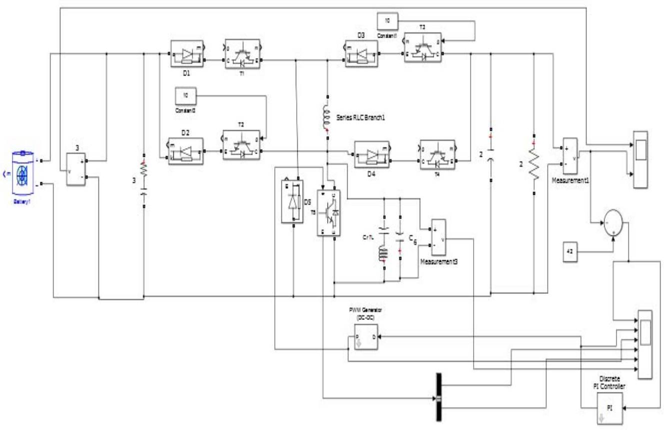

Figure 6.5: V_{batt} To V_{dc} boost mode simulation circuit

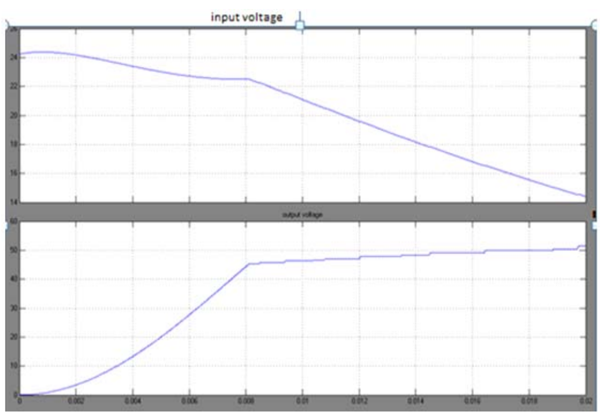

Figure 6.6: V_{batt} To V_{dc} boost mode simulation circuit result

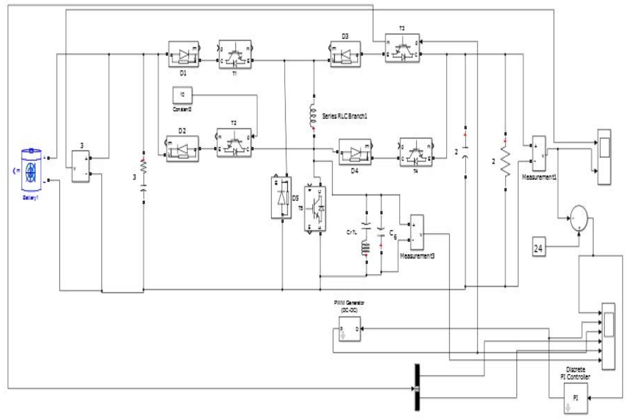

Figure 6.7: V_{batt} To V_{dc} buck mode simulation circuit

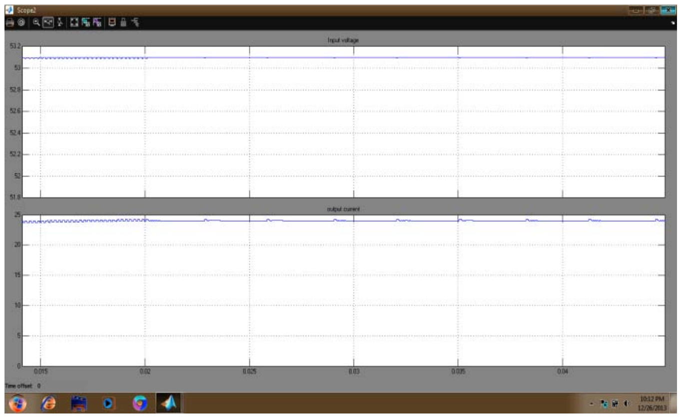

Figure 6.8: V_{batt} To V_{dc} buck mode simulation circuit result

7. Conclusion

This study presents a novel dc/dc converter structure that is suitable for both industrial needs and the electric vehicle conversion approaches for all EV, HEV, and PHEVs applications. Rectified AC in put connected bidirectional dc to dc converter with LC circuit soft switching is designed and simulated by using MATLAB simulik and the output of four modes of operations are recorded. This circuit works, bucking and boosting action in one direction.LC resonant soft switching circuit reduce the switching losses. These circuits are designed by using IGBT.

References

[1] B. W. Williams, “Basic DC-to-DC converters,” IEEE Trans. Power Electron., vol. 23, no. 1, pp. 387–401, Jan. 2008

[2] B. Sahu and G. A. Rincon-Mora, “A low voltage, dynamic, noninverting, synchronous buck-boost converter for portable applications,” IEEE Trans. Power Electron, vol. 19, no. 2, pp. 443–452, Mar. 2004.

[3] P. C. Huang, W. Q. Wu, H. H. Ho, and K. H. Chen, “Hybrid buck-boost feed forward and reduced average inductor current techniques in fast line transients and high-efficiency buck-boost converter,” IEEE Trans. Power Electron., vol. 25, no. 3, pp. 719–730, Mar. 2010.

[4] S. Waffler and J. W. Kolar, “A novel low-loss modulation strategy for high-power bidirectional buck + boost converters,” IEEE Trans. Power Electron., vol. 24, no. 6, pp. 1589–1599, Jun. 2009.

[5] M. B. Camara, H. Gualous, F. Gustin, A. Berthon, and B. Dakyo, "DC/DC converter design for supercapacitor and battery power management in hybrid vehicle applications—Polynomial control strategy," IEEE Trans. Ind. Electron., vol. 57, no. 2, pp. 587–597, Feb. 2010.
[6] F. Krismer, J. Biela, and J. W. Kolar, "A comparative evaluation of isolated bi-directional DC/DC converters with wide input output voltage range," in Proc. IEEE Ind. Appl. Conf., Kowloon, Hong Kong, Oct. 2005,vol. 1, pp. 599–606.
[7] P. Midya, K. Haddad, and M. Miller, "Buck or boost tracking power controller," IEEE Trans. Power Electron., vol. 2, no. 4, pp. 131–134, Dec. 2004.
[8] L. Ni, D. J. Patterson, and J. L. Hudgins, "High power current sensorless bidirectional 16-phase interleaved DC-DC converter for hybrid vehicle application,"IEEE Trans. Power Electron., vol. 27, no. 3, pp. 1141–1151, Mar. 2012.
[9] M. Gabriault and A. Notman, "A high efficiency, non-inverting, buckboost DC-DC converter," in Proc. IEEE 19th Annu. Appl. Power Electron. Conf. Expo., Anaheim, CA, Feb. 2004, vol. 3, pp. 1411– 1415.
[10] D.-Y. Jung, S.-H. Hwang, Y.-H. Ji, J.-H. Lee, Y.-C. Jung, and C.-Y. Won, Soft-switching bi-directional DC/DC converter with a LC series resonant circuit," IEEE Trans. Power Electron, vol. 28, no. 4, pp. 1680–1690, Apr. 2013.
[11] Z. Zhang, Z. Ouyang, O. C. Thomsen, and M. A. E. Andersen, "Analysis and design of a bidirectional isolated DC-DC converter for fuel cells and supercapacitors hybrid system," *IEEE Trans. Power Electron.*, vol. 27,no. 2, pp. 848–859, Feb. 2012.
[12] B. Zhao, Q. Song, andW. Liu, "Efficiency characterization and optimization of isolated bidirectional DC-DC converter based on dual-phase-shift control for DC distribution application," *IEEE Trans. Power Electron*, vol. 28, no. 4, pp. 1711–1727, Apr. 2013.
[13] B. Zhao, Q. Yu, and W. Sun, "Extended-phase-shift control of isolated bidirectional DC-DC converter for power distribution inmicrogrid," *IEEE Trans. Power Electron.*, vol. 27, no. 11, pp. 4667–4680, Nov. 2012.
[14] R. T. Naayagi, A. J. Forsyth, and R. Shuttleworth, "High-power DCDC converter for aerospace applications," *IEEE Trans. Power Electron.*,vol. 27, no. 11, pp. 4366–4379, Nov. 2012.
[15] L. Roggia, L. Schuch, J. E. Baggio, C. Rech, and J. R. Pinheiro, "Integrated full-bridge-forward DC-DC converter for a residential microgrid application," *IEEE Trans. Power Electron*, vol. 28, no. 4, pp. 1728–1740, Apr. 2013.
[16] L. Corradini, D. Seltzer, D. Bloomquist, R. Zane, D. Maksimovic, and B. Jacobson, "Minimum current operation of bidirectional dual-bridge series resonant DC/DC converters," *IEEE Trans. Power Electron.*, vol. 27, no. 7, pp. 3266–3276, Jul. 2012.
[17] N. M. L. Tan, T. Abe, and H. Akagi, "Design and performance of a bidirectional isolated DC-DC converter for a battery energy storage system,"*IEEE Trans. Power Electron.*, vol. 27, no. 3, pp. 1237–1248, Mar. 2012.

Author Profile

Neenu C Robin received the B-Tech degree in Electrical and Electronics Engineering from Vimal Jyothi Engineering Collage under Kannur University in 2012 and M.E degree in Power Electronics and Drives in Electrical Engineering from CSI collage of Engineering, Ketti, under Anna University Chennai in 2014.