IJEASM International Journal of Engineering Applied Science and Management
ISSN (Online): 2582-6948
Vol. 7 Issue 5, May 2026

Single-phase AC input, dual LLC bridge resonant converter for HEV battery charging application

Radharaman Jee [1] Durgesh Vishwakarma[2]
M. Tech Scholar, Department of Electrical &Electronics Engg. REC Bhopal (India)[1]
Assistant Professor, Department of Electrical &Electronics Engg.REC Bhopal (India) [2]

Abstract**—***In this paper a dual active bridge LLC resonant converter is proposed with variable input voltage sources and applied for battery charging of electric vehicle. As there is increase in demand for electric vehicles in present day and may increase more in near future better possible charging circuit needs to be developed. The constant DC voltage output is used to charge the battery of an electric vehicle which has very high capacity. The input can be hybrid which can also charge from electrical utility grid. The PWM technique used in the converter is fixed frequency PWM scheme which generates higher voltages for even low voltage inputs. The complete operation and control of the proposed topology is explained in detail with graphical representation of the model and characteristics of the module. The complete model is developed in MATLAB Simulink environment with graphs plotted with respect to time.*

Keywords**—** *Dual Bridge (DB) LLC Resonant converter, fixed frequency, LLC, PI controller voltage range, PWM.*

1. Introduction

In numerous applications, power transformation circuits are required to work with a wide info voltage range. For instance, the yield voltage scope of module and battery electric vehicle (EV) on-board chargers is wide (e.g., 200– 450 V), which implies the input-voltage scope of on-board dc/dc converters that condition power between the high-and low-voltage batteries is wide too [1]. Along these lines, building up a dc/dc converter with high efficiency over a wide voltage run is fundamental. LLC resonant converter, which is fit for acknowledging delicate changes from zero to full loads and accomplishing high efficiency what's more, as well as high power density, has turned into an exploration hotspot as of late. Regularly, ordinary half-and full-connect LLC converters work with variable frequency control. The working recurrence run must be expanded or the inductor proportion must be diminished so as to get a wide info voltage run [13], [14], which is trying to plan and streamline attractive segments [15]. This may cause numerous undesired issues, for example, low power density and high conduction losses. In this manner, the customary LLC converter isn't appropriate for wide info applications [14]. Consolidating the three-level circuit with a LLC resonant tank, numerous kinds of three-level LLC (TL LLC) full converters. A straightforward TL LLC resonant dc/dc converter with just a single attractive segment is proposed in [16], which can accomplish a wide information/yield go inside a tight recurrence go on account of the two-arrange reverberation. Not quite the same as the TL LLC resonant converters with one resonant tank, the topology talked about in [17] is a TL LLC full converter comprising of two half-connect (HB) LLC arrangement full converters in arrangement, yet, having the equivalent resonant inductor and transformer. As an augmentation of [17], another TL LLC converter with one resonant tank is proposed in [18], where the full recurrence is twice as high as the switching frequency, diminishing the measure of resonant parts and expanding the power density. Be that as it may, the recurrence varieties of these previously mentioned converters are still generally enormous, e.g., 88– 150 kHz in [16], which is trying for the streamlining of attractive parts. By utilizing the new modulation systems, a TL confined FB LLC converter that can work at a fixed recurrence is introduced in [19], which can work in whole two-level or three-level modes depending on the voltage run. In any case, various changes must be utilized and the structure is intricate. Jin and Ruan [20] proposed a cross-breed FB TL LLC converter equipped for working under both three-level and two-level modes. In spite of the fact that this converter can understand a wide voltage gain extend with the fixed-recurrence control, two working modes suggest progressively refined control and not every one of the switches persevere through portion of the info voltage under the three-level mode. A fixed-recurrence TL LLC converter with helper switches and windings on the auxiliary side is introduced in [21]. Be that as it may, extra windings are included the optional side of the transformer and the auxiliary assistant switches can't understand ZVS turn-on.

IJEASM International Journal of Engineering Applied Science and Management
ISSN (Online): 2582-6948
Vol. 7 Issue 5, May 2026

2. Design of Photo Voltaic Array

For effective boundless power age PVA is connected to make control from sunshine essentially based gentle. since the heap solicitation is growing gradually the quality age furthermore ought to be expanded, anyway on account of the regular strategy for power age is causing an unnatural climate change, due to this the capability of the PVA should be raised through alongside silicon surface the board and in addition, use the MPPT procedures to follow most extreme serious quality in the midst of any light and cools. The blueprint of PVA is finished in MATLAB with Simulink.

Voltage of PVA thoroughly depends on sunlight based orientated enlightenment (Sx) and encompassing temperature (Tx). PVA (picture voltaic grandstand) is a blend of affiliation and parallel solar cells arranged in a group to deliver the ideal voltage and contemporaryThe DC-DC converter used as a piece of the MPPT can be either a Cuk converter or a buck boost converter. The voltage yield of the PVA both should be quickened or blurred with respect to the delivered intensity of the PVA. The converter makes the voltage consistently with the alteration inside the temperature or the light. The control structure can give a commitment cycle regard which is appeared differently in relation to the triangular waveform and heartbeat is created encouraged to the exchange gave. The duty cycle is made by method for using the underneath computation. Photovoltaic cells and boards alternate over the sun powered power into coordinate modern (DC) power. The association of the sun-oriented boards in a solitary photovoltaic showcase is identical as that of the PV cells in a solitary board. The boards in an exhibit may be electrically related collectively in both an arrangement, a parallel, or a blend of the 2, but for the maximum element an arrangement affiliation is given an elevated yield voltage. as an example, whilst solar-based totally forums are stressed out collectively in arrangement, their voltage is doubled even as the present day maintains as earlier than.

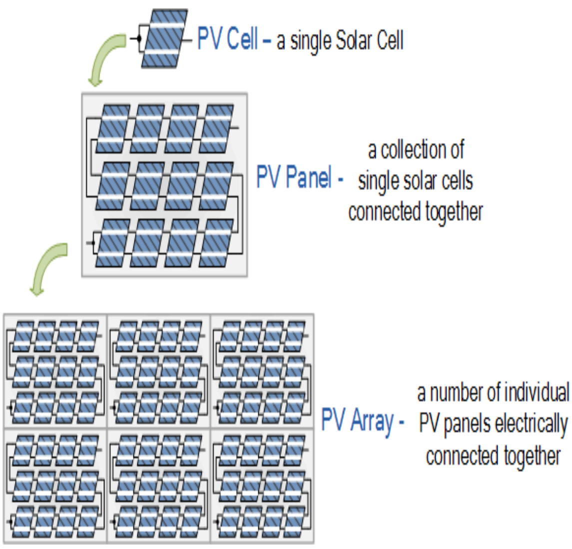

Fig. 1: A Photovoltaic PV Array

3. Resonant converter:

The growing call for better strength density and occasional profile in power converter designs has pressured designers to growth switching frequencies. Operation at better frequencies drastically reduces the scale of passive components which include transformers and filters. But, switching losses were an obstacle to excessive frequency operation. For you to lessen switching losses, permitting excessive frequency operation and resonant switching strategies had been advanced. These techniques procedure electricity in a sinusoidal manner and the switching gadgets are softly commutated. Consequently, the switching losses and noise can be dramatically decreased. Conventional resonant converters use an inductor in collection with a capacitor as a resonant network. Two primary configurations are viable for the burden connection; series connection and parallel connections. For the series resonant converter (SRC), the rectifier-load community is placed in series with the L-C resonant network as depicted in Fig.1. From this configuration, the resonant community and the weight act as a voltage divider. By using changing the frequency of driving voltage V_d, the impedance of the resonant network modifications. The enter voltage will be split among this impedance and the reflected load. On the grounds that it is a voltage divider, the DC advantage of an SRC is continually lower than 1. At mild load condition, the impedance of the load could be very large in comparison to the impedance of the resonant network; all the input voltage can be imposed on the load. This makes it tough to regulate the output at mild load. Theoretically, frequency should be countless to regulate the output at no load. For parallel resonant converter, the rectifier-load community is placed in parallel with the resonant capacitor as depicted in Fig.2 For the reason that load is attached in parallel with the resonant network, there necessarily exists big amount of circulating modern-day. This makes it tough to use parallel resonant topologies in high power packages.

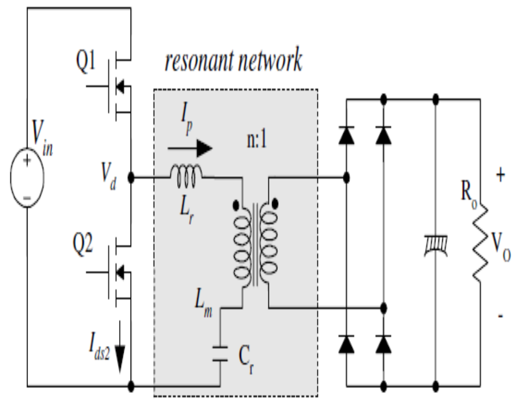

Fig 2 Half-bridge series resonant (SR) converter

With a view to clear up the restrictions of the conventional resonant converters, the LLC resonant converter has been proposed. The LLC-type resonant converter has many blessings over traditional resonant converters. First, it could alter the output over extensive line and cargo variations with a

IJEASM International Journal of Engineering Applied Science and Management
ISSN (Online): 2582-6948
Vol. 7 Issue 5, May 2026

fairly small variant of switching frequency. 2nd, it may achieve zero voltage switching (ZVS) over the entire working range. Eventually, all critical parasitic factors, including junction capacitances of all semiconductor gadgets and the leakage inductance and magnetizing inductance of the transformer, are utilized to achieve ZVS. This paper offers an evaluation and design considerations for a half of-bridge LLC resonant converter. The use of the essential approximation, the voltage and modern waveforms are analyzed and the gain equations are received. A layout for DC/DC converter with 120W/24V output has been selected as an ordinary example for describing the layout system. [3]

4.Proposed Methodology

Proposed fixed frequency a fixed frequency DBLLC converter with pi controller are used for hybrid electric vehicles and it is used for wide input voltage range application. The proposed system can be seen as combination of AC grid, DBR HB LLC converter FBLLC converter battery DC motor drive, PI controller and PWM Generator. The output voltage is regulated by controlling the percentage of operating time of FB and HB during a switching circle. This converter employs the fixed frequency PWM control, and the switching frequency equals to the resonant frequency, which facilitates the design of magnetic elements Unlike traditional PFM-controlled LLC resonant converters, the voltage gain range is independent of the quality factor Q. Moreover, the magnetizing inductor has little influence on the voltage gain, which means that the parameter design process can be simplified, and the magnetizing inductor can be designed as large as possible to reduce the conduction loss. In addition, all main switches and rectifier diodes are softly switched over the full load range, which significantly decreases the switching loss and the reverse recovery loss

The proposed circuit topology is updated with input as PVA source which is switched to utility grid during low voltage level. The low voltage level in PVA is generated because of low solar irradiation. Two switches are connected to grid and PVA individually which operate complimentarily. The charging of battery is done through either grid or PVA depending on the switching of the switches. The updated circuit is shown in fig. 4.1

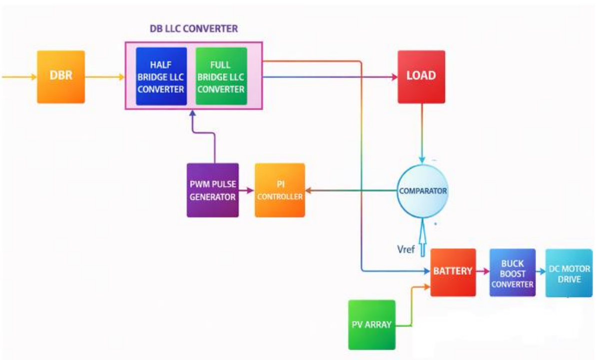

Fig. 3: proposed system of Single-phase AC input Dual LLC bride resonant converter

4.1 PWM GENERATOR

The figure below shows the process of pulse width modulation. It is commonly known as an indirect method of PWM generation. The message signal and the carrier waveform is fed to a modulator which generates PAM signal. This pulse amplitude modulated signal is fed to the non-inverting terminal of the comparator. A ramp signal generated by the saw tooth generator is fed to the inverting terminal of the comparator. These two signals are added and compared with the reference voltage of the comparator circuit. The level of the comparator is so adjusted to have the intersection of the reference with the slope of the waveform.

The PWM pulse begins with the leading edge of the ramp signal and the width of the pulse is determined by the comparator circuit. The width of the PWM signal is proportional to the omitted portion of the ramp signal by the comparator level. The shown in fig. will help you to understand in a better way how PWM signal is generated by the comparator:

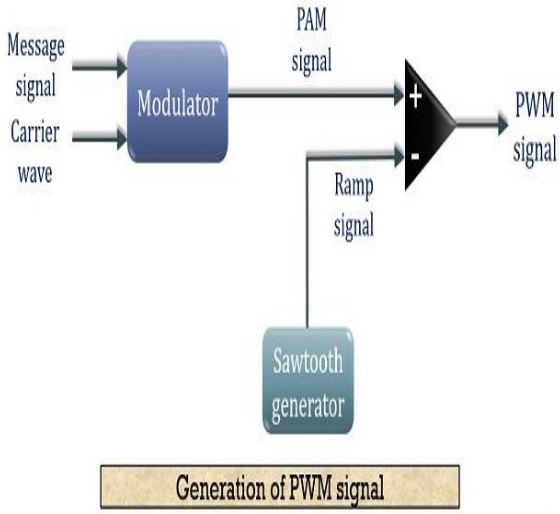

Fig.4 Generation of PWM signal

5.Simulation Result & Discussion

Proposed MATLAB Simulation DBLLC Model with feedback loop control

The model is updated with a battery connected at the load side with a feedback controller connected for control of the output voltage. Below is the updated Dual LLC resonant converter with a battery connected at the load side. The battery is further connected to a DC motor representing an electric vehicle. Figure 516 shows the MATLAB Simulink model of the proposed Dual-Bridge LLC (DB-LLC) resonant converter with closed-loop feedback control. The model includes the AC–DC rectification stage, the DB-LLC resonant power stage, the output rectifier, and the control circuit. The output voltage is sensed and compared with a reference voltage, and the resulting error is processed through a PI controller. The PI controller output generates PWM signals that control the switching of the DB-LLC converter. This closed-loop arrangement ensures constant output DC voltage, stable

IJEASM International Journal of Engineering Applied Science and Management
ISSN (Online): 2582-6948
Vol. 7 Issue 5, May 2026

operation under input and load variations, and improved dynamic response. The model validates the effectiveness of the proposed control strategy for efficient and reliable EV battery charging applications.

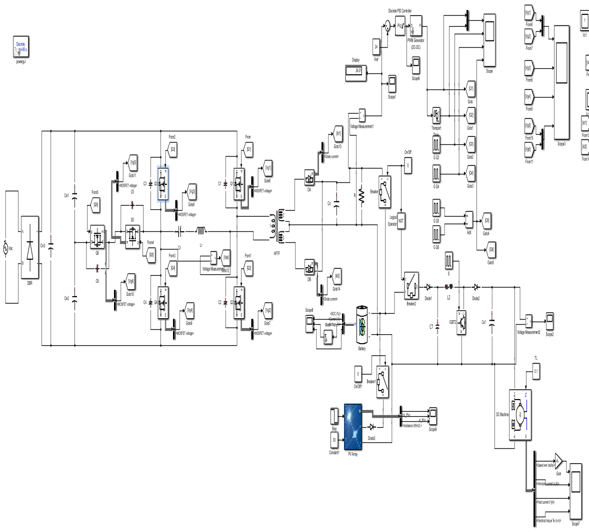

Fig 5 Matlab Simulink DBLLC model with feedback loop control

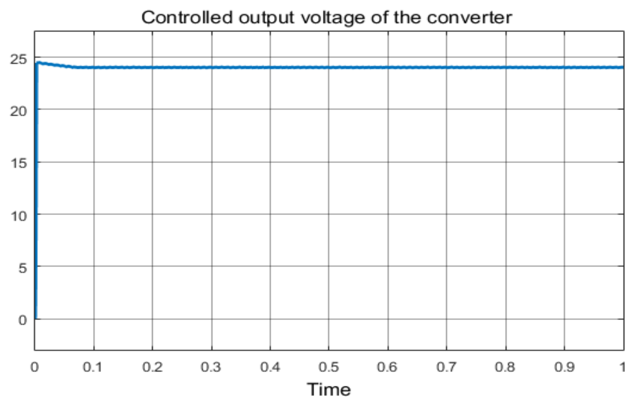

Fig. 6 Controlled output voltage of the converter

5.2 MODE OF OPERATION:

5.2.1 Battery Discharging

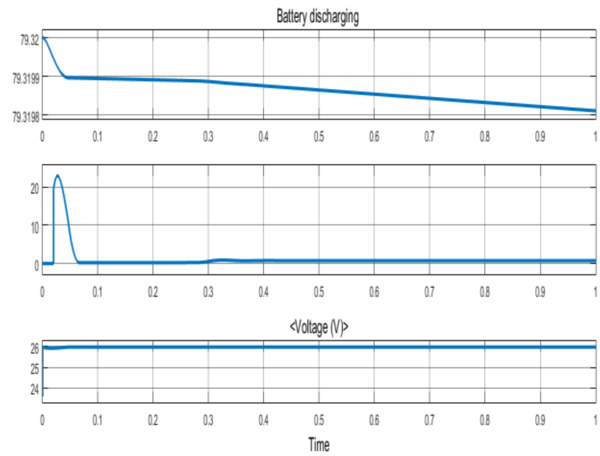

Fig 7: Battery discharging through HEV

The above is the battery discharging mode, where the state of charge is dropping. The power from the battery is consumed by the DC motor load. In the above graphs, the current is in positive as the current is discharged from the battery.

5.2.2 Battery Charging through PV Array

The state of charge of the battery is raising from 79% as the battery is charged from the proposed converter. The current is in negative direction as the battery consumes current from the circuit output.

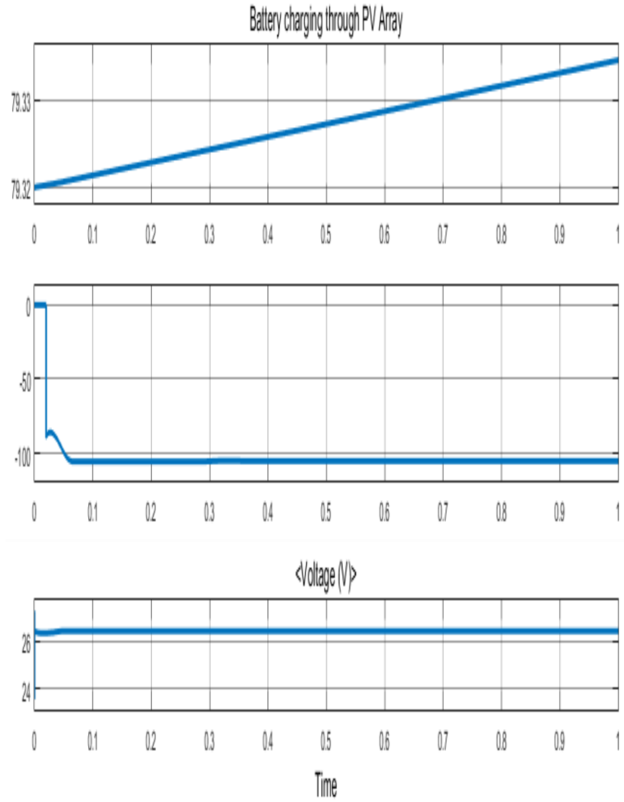

Fig 8 Battery charging through PV Array

6. Conclusion

In this paper, a Dual-Bridge (DB) LLC resonant converter–based hybrid battery charging system for HEV/EV applications is presented, capable of operating with multiple input sources, namely a single-phase AC utility grid and a photovoltaic (PV) array. The proposed topology was developed to address the challenges of wide input voltage variation, fast battery charging, and high efficiency operation, which are critical requirements in modern electric vehicle charging systems. The proposed DB LLC resonant converter integrates half-bridge and full-bridge LLC configurations and operates with a fixed-frequency PWM control strategy. This approach eliminates the drawbacks of conventional variable-frequency LLC converters and simplifies the design of magnetic components. The resonant tank enables soft-switching operation, achieving Zero Voltage Switching (ZVS) for the primary switches and Zero Current Switching (ZCS) for the secondary diodes, thereby reducing switching losses and improving overall system efficiency. A closed-loop feedback control using a PI controller was implemented to regulate the output DC voltage. The MATLAB Simulink model of the proposed system was developed and simulated under different operating conditions. The simulation results demonstrate that the output voltage closely follows the reference value with minimal ripple, confirming stable operation, fast dynamic response, and effective voltage regulation. The regulated DC output was successfully used for HEV battery charging, and a buck-boost converter was employed to supply a DC motor drive, validating the applicability of the system for practical EV applications.

References

[1] M. M. Jovanovi´c and B. T. Irving, "On-the-fly topology-morphing control-efficiency optimization method for LLC resonant converters operating in wide input- and/or output-voltage range," IEEE Trans. Power Electron., vol. 31, no. 3, pp. 2596–2608, Mar. 2020.

[2] J. Deng, C. C. Mi, R. Ma, and S. Li, "Design of LLC resonant converters based on operation-mode analysis for level two PHEV battery chargers," IEEE Trans. Mechatronics, vol. 20, no. 4, pp. 1595–1606, Aug. 2018.

[3] 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, Jun. 2018.

[4] F. Musavi, M. Craciun, D. S. Gautam, and W. Eberle, "Control strategies for wide output voltage range LLC resonant DC–DC converters in battery chargers," IEEE Trans. Veh. Technol., vol. 63, no. 3, pp. 1117–1125, Jun. 2016.

[5] C. W. Tsang, M. P. Foster, D. A. Stone, and D. T. Gladwin, "Analysis and design of LLC resonant converters with capacitor-diode clamp current limiting," IEEE Trans. Power Electron., vol. 30, no. 3, pp. 1345–1355, Mar. 2017.

[6] B. Yang, F. C. Lee, A. J. Zhang, and G. Huang, "LLC resonant converter for front end DC/DC conversion," in Proc. IEEE APEC Expo., 2002, vol. 2, pp. 1108–1112.

[7] H. Wang, S. Dusmez, and A. Khaligh, "Maximum efficiency point tracking technique for LLC-based PEV chargers through variable DC link control," IEEE Trans. Ind. Electron., vol. 61, no. 11, pp. 6041–6049, Nov. 2015.

[8] Z. Hu, Y. Qiu, Y. F. Liu, and P. C. Sen, "A control strategy and design method for interleaved LLC converters operating at variable switching frequency," IEEE Trans. Power Electron., vol. 29, no. 8, pp. 4426–4437, Aug. 2016.

[9] K. H. Yi and G. W. Moon, "Novel two-phase interleaved LLC series-resonant converter using a phase of the resonant capacitor," IEEE Trans. Ind. Electron., vol. 56, no. 5, pp. 1815–1819, May 2010.

[10] W. Feng, F. C. Lee, and P. Mattavelli, "Simplified optimal trajectory control (SOTC) for LLC resonant converters," IEEE Trans. Power Electron., vol. 28, no. 5, pp. 2415–2426, May 2016.

[11] G. Yang, D. Patrick, and D. Sadarnac, "Double-phase high-efficiency, wide load rang high-voltage/low-voltage LLC DC/DC converter for electric/hybrid vehicles," IEEE Trans. Power Electron., vol. 30, no. 4, pp. 1876–1886, Apr. 2017.

[12] Z. Guo, D. Sha, and X. Liao, "Hybrid phase-shift-controlled three-level and LLC DC–DC converter with active connection at the secondary side," IEEE Trans. Power Electron., vol. 30, no. 6, pp. 2985–2996, Jun. 2016.

[13] X. Sun, Y. Shen, Y. Zhu, and X. Guo, "Interleaved boost-integrated LLC resonant converter with fixed-frequency PWM control for renewable energy generation applications," IEEE Trans. Power Electron., vol. 30, no. 8, pp. 4312–4326, Aug. 2018.

[14] Singh et al. "Energy management systems using artificial intelligence: Future trends, challenges and solutions:, Power System Management , CRC Press 2025.