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A Novel DC-DC Boost Converter with Coupled Inductors for High Gain and Smooth Switching

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ABSTRACT

This work deals with a novel high step-up isolated DC-DC boost converter proposed with the help of a couple of inductors. At present, eco-friendly vehicles like Electric-Vehicles (EVs), Hybrid Electric Vehicles (HEVs), and Plug-In Electric Vehicles (PEVs) are effectively used as a feasible solution for achieving high efficiency over fossil-fuel operated vehicles, releases low emissions, global warming, noise-less, low maintenance, so on. In general, the vehicles like Internal Combustion Vehicles (ICE) are propelled by using fossil fuels like petrol, diesel, gasoline, and so on. But the efficiency is very low in this system because of the usage of hydraulic and mechanical components which requires more maintenance, high fuel consumption, toxic emissions, and so on. To overcome these challenges a novel Isolated DC-DC converter has been proposed adopted from Zeta converter with slight modifications. The proposed isolated DC-DC boost converters are used in many applications, due to high step-up gains, low duty ratios, high efficiency, low EMI loss, and low switch stress, so on. It has high power capacity, greater reliable features, and a modular, compact size best suitable for vehicular applications. Employing the high turns ratio of coupled inductor attains high voltage step-up gain as well as the secondary winding is in series with a switched capacitor for obtaining increased voltage level. Following is a detailed description of the proposed Isolated DC-DC converter: (a) The energy in connected inductor leaky inductors may be recycled, increasing overall system efficiency and reducing voltage spikes. (b) Using linked capacitor and switched capacitor methods maximizes the conversion gain ratio. (c) Creates an isolation channel while the solar PV arrays are not working, preventing electric risks to humans. The performance of the system is studied in the simulation environment.

1.Introduction

In recent years DC-DC converters in energy storage systems play a vital role in electric vehicles to transfer power from low input voltage to high output voltage and vice-versa. Initially, there are

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different topologies like boost, buck, and buck-boost DC-DC converters in energy storage systems (Fuel cells, Super capacitors) were introduced by many researchers [1-3], which are operated with hard-switching conditions under various circumstances input, output, etc. However, these converters have more conduction losses, switching losses, and poor efficiencies.

To enhance converter effectiveness, the literature focuses on soft-switching versions of zero voltage/zero current. Non-isolated converter [4] has developed a new nonlinear inductor based on magneto-rheological fluid (MR) to improve efficiency for light and intermediate loads.The proposed coupled inductor can be utilised as a transformer in non-isolated high-voltage gain converters. By choosing appropriate turns – the ratio of coupled inductors, the voltage gain of the converter is increased. The leakage energy of the coupled inductors can be retrieved which leads to increase the overall system efficiency. These converters have small current ripple that leads to reducing EMI[5].High-voltage and efficient power converter topologies equipped with the simple and practical controller circuits are necessary, especially for integration between the low-power and low-voltage renewable energy sources (RESs) like the photovoltaic (PV) arrays and the grid. [6]

The bidirectional converter can operate in discontinuous conduction mode, reducing inductor size and achieving a lossless snubber capacitor for zero-voltage turn-on and turn-off. Similarly, by utilizing the passive lossless snubber capacitor and a single resonant inductor with a conventional non-isolated BDC [7], the zero voltage switching turn-on operations are obtained with 97% efficiency at 3kW output power. Then the research also focused on auxiliary edge resonant cells (passive plus active) incorporated with conventional converters [7] obtained lossless 97% efficiency by the ZVS turn-on technique. [8] proposed structure can ensure an enhancement in voltage gain by eight times for duty cycle of 50% that is much more effective than a conventional boost converter that can gain the input voltage to two times at the output of the converter. The higher amounts of the DC voltage gain are possible by adding the novel and efficient switched capacitor (SC) blocks. To achieve high output power from the converter, the design can be multiple numbers of phase's i.e. parallel connection of converter modules. For battery charging applications in hybrid vehicles, a hard-switched isolated dual half bridge [9,10] is interleaved to obtain 1.5 kW output power at 60 kHz. Non-isolated multi-phase bidirectional converters [11] are interleaved to attain 30kW as the output power, which is operated under hard-switching conditions. Similarly, a dual-phase interleaved converter [12] topology is implemented on hard-switching with modal predictive control (MPC) to reduce the switching transition between charging/discharging and to balance the two inductor currents. A switched-capacitor-based quadratic single-switch power boost converter to obtain the high voltage gains and low voltage stresses across the power components and decrease the complexity of the controller designs was explained in [13].

There is a significant demand in the current research scenario for soft switching ZVS or ZCS converters to power storage applications, most notably effective use of sources switching from batteries, fuel cells, and super capacitors, but also an efficient application of energy storage resources [14,15].This research focuses on soft turn-on-based two-phase interleaved bidirectional converter to limit the currents of inductors, and ripple produced by the batteries and increase the life cycle. An auxiliary resonant cell [16-23] was used in a boost converter to minimize switching stresses and reduce size and cost. Battery storage systems in DC traction vehicles consist of stacked super-capacitors, with each battery supplying 125V to the non-isolated converter. The output voltage from the converter is used as input to the isolated FB converter, which generates the source voltage for the inverter controlling the drive-in electric vehicle. [24] explains switched capacitor (SC)-based single-switch DC–DC boost converter structure operating under the high voltage gain and the low duty ratio is proposed using the PI control technique. With the proposed converter, an output voltage of 10 times greater rather than the input voltage is obtained at 0.57 of the duty cycle.

2. Methodology
2.1 Proposed System Description and Principle of Operation

The Isolated DC-DC converter proposed in Figure 1 is based on a Zeta converter, but the input inductor is replaced with a coupled transformer or coupled inductor. The high turns ratio of the coupled inductor achieves a high voltage step-up gain, and the secondary winding is in series with a switched-capacitor for obtaining an increased voltage level. The coupled inductor is configured with a MOSFET switch Sa1 and the N1, N2 are the primary and secondary windings of the coupled inductor. The coupled inductor N1 consisted of magnetizing inductor Lam and the primary leakage inductor is LKa1 and the secondary leakage inductor is L_{Ka2}, the diode $D_{a1,}$ and capacitor C_{a1}act as recycling energy storage elements from N1. The N_2 secondary winding is integrated with another set of diodes D_{a2} and capacitor C_{a2}, all these are in series formation with N_1. The load-side rectifier diode D_{a3} interconnects to load side capacitor C_{a3} and load R_L. The operating features of the proposed Isolated DC-DC converter are clearly described below:

1) The energy in leakage inductors of a coupled inductor can be recycled, increasing overall system efficiency and preventing voltage spikes.
2) The conversion gain ratio can be maximized by using either the coupled capacitor or the switched capacitor techniques.
3) The switch creates the isolation path when the solar-PV arrays are in non-operating situations, preventing any electric hazards to human beings. The proposed Isolated DC-DC converter is working in CCM operating mode and steady-state analysis is presented in the following sections.

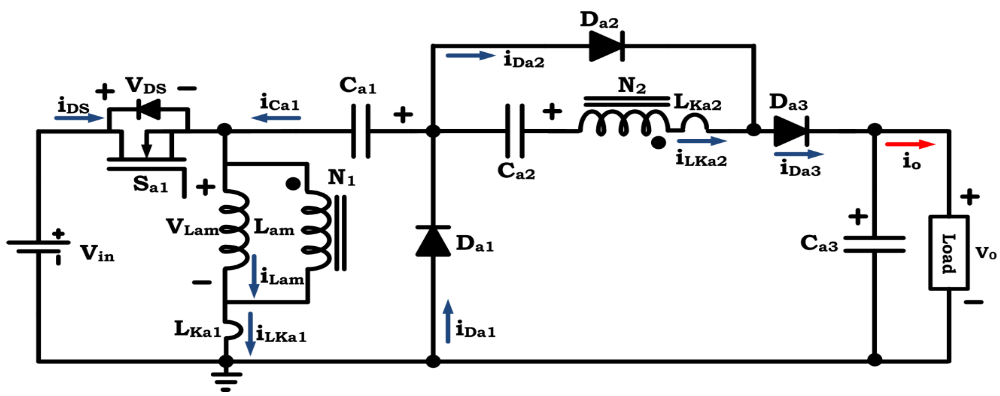


Fig. 1. Schematic configuration of proposed isolated DC-DC converter

The individual operations of this converter are explained with the help of Figure 2(a-e). The theoretical voltage and current waveforms are shown in Figure 3. According to Figure 3, there are five modes in each Ts. The following are the details of these modes:

Mode-A: (t_0, t_1)

In this Mode-A, switch S_{a1} is Switched-On, and diode D_{a2} is in forward bias, then the secondary side leakage inductor L_{Ka2} is predominantly supporting energy to C_{a2} capacitor. The current of magnetizing inductor i_{Lam} is decreasing due to the input voltage V_{in} applied on L_{am} magnetizing inductor and L_{Ka1} leakage inductor. Meantime, L_{am} is supporting energy to the secondary winding of coupled inductor charging the capacitor C_{a2}concerning decreasing the charged current in D_{a2} diode I_{Da2} and capacitor current i_{C2}. The secondary side leakage inductor's current i_{LK2} is diminishing the with accorded to turns ratio as i_{Lam}/n. Once the increased current i_{LKa1} equals the decreasing current i_{Lam} at transition t=t_1, this mode-A completes. The working mode-A is depicted in Figure 2 (a).

$$i_{LKa2}(t) = \frac{i_{Lam}(t) - i_{LKa1}}{n} \tag{1}$$

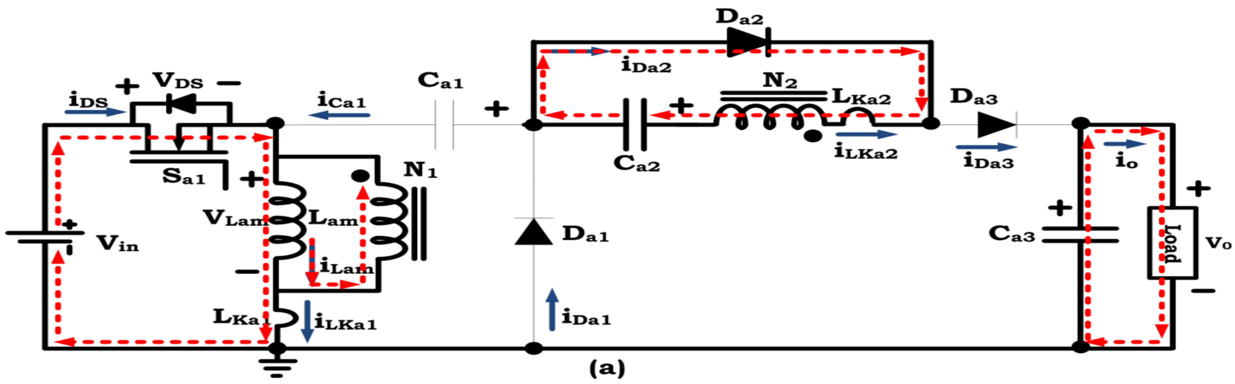
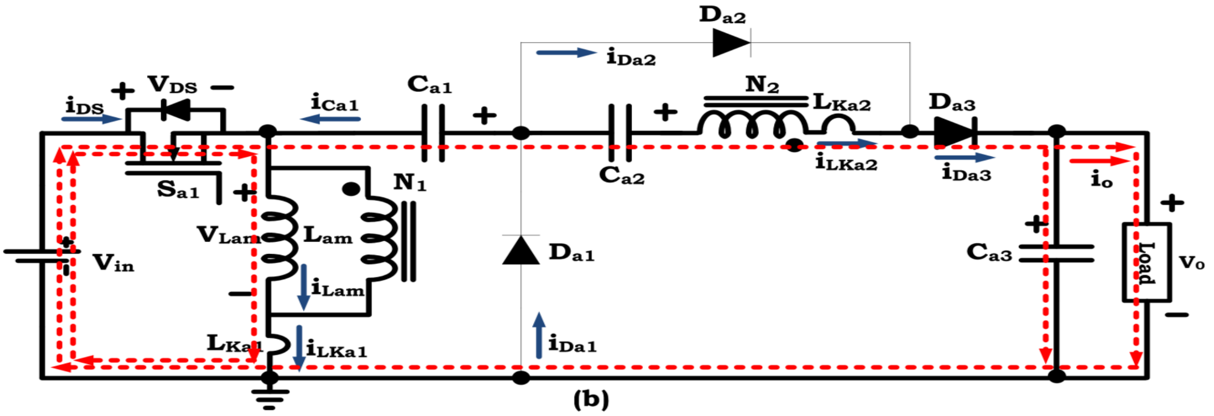


Fig. 2. (a) Current directions in proposed isolated converter working mode-A in CCM operation

Mode-B: (t_1, t_2)

In this Mode-B from Figure 2 (b), switch S_{a1} is Switched-On and diode D_{a3} is in forward-bias, the input voltage V_{in} is in series with capacitors C_{a1}, C_{a2}, leakage inductor L_{Ka2} and secondary winding N_2 is used to charge the load-side capacitor C_{a3} and achieves load voltage as constant, meantime the magnetized inductor L_{am} is also energizing from input voltage V_{in}. The current i_{Lam}, i_{LKa1} and i_{Da3} are linearly increased due to V_{in} is crossed over the inductors L_{Ka1} and L_{am} and also primary winding N_1, then the inductors L_{Ka1} and L_{am} storing energy from input voltage V_{in}. Meantime, V_{in} is in series with secondary winding N_2 of coupled inductor and C_{a1}, C_{a2} capacitors are ready to discharge energy to load-side capacitor C_{a3} and R_L-load, leads to increasing the current in i_{LKa1}, i_{Lam}, i_{Da3} and i_{DS}. This mode-B completes when the switch S_{a1} is switched-OFF at t-t_2.

$$\frac{di_{LKa2}(t)}{dt} = \frac{di_{Da3}(t)}{dt} = \frac{(1+n)V_{in} + V_{Ca1} + V_{Ca2}}{L_{Ka2}} \tag{2}$$



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ig. 2. (b) Current directions in proposed isolated converter working mode B in CCM operation

Mode-C: (t_2, t_3)

In this Mode-C from Figure 2 (c), switch S_{a1} is Switched-OFF and diode D_{a1}, D_{a3} is conducted in forward-bias, the secondary leakage inductor L_{Ka2} is supported to charge C_{a3} during switch S_{a1} is in OFF-state. The stored energy in leakage inductor L_{Ka1} flows towards the diode D_{a1} supports charging the C_{a1} capacitor instantly during switch S_{a1} is in OFF-state. Meantime, the leakage inductor L_{Ka2}furnishes current path towards the previous mode and it is in-series with capacitor C_{a2} to support load side capacitor C_{a3} charging and achieves the R_L load. The voltage across switch S_{a1} is added with V_{in}, V_{Lam}, V_{LKa1}, then the currents i_{LKa2} and i_{LKa1} suddenly decreasing due to current in $L_{am}$is received from L_{Ka2}. Once the current in leakage inductori_{LKa2} attains to 0, then this mode-C completes at t-t_3.

$$i_{in}(t) = 0 \tag{3}$$

$$\frac{di_{LKa2}(t)}{dt} = \frac{di_{Da3}(t)}{dt} = \frac{nV_{Lam} + V_{Ca2} + V_0}{L_{Ka2}} \tag{4}$$

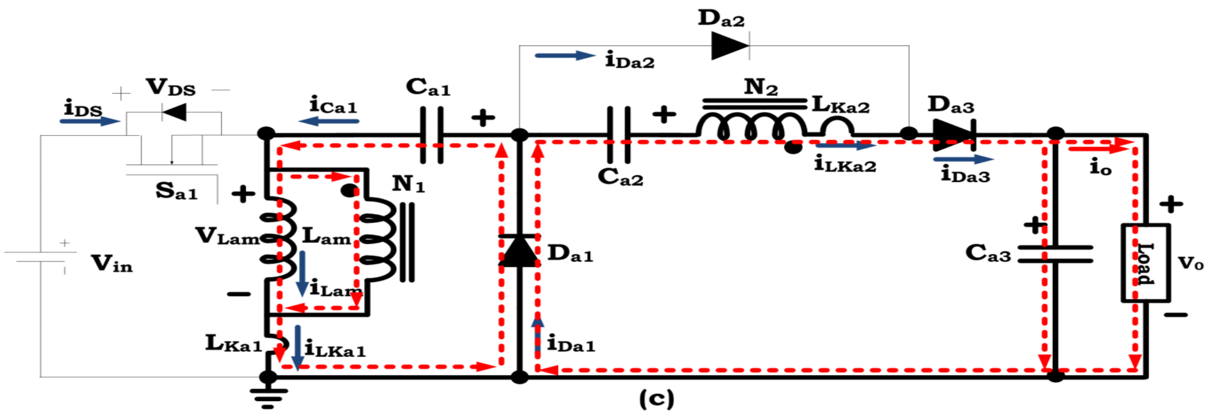


Fig. 2. (c) Current directions in proposed isolated converter working mode C in CCM operation

Mode-D: (t_3, t_4)

In this Mode-D from Figure 2 (d), switch S_{a1} is Switched-OFF, and diode D_{a1}, D_{a2} is conducted in forward-bias, the stored energy in magnetizing inductor L_{am} simultaneously supporting to charge capacitors C_{a2} and C_{a1}. The currents in i_{LKa1} and i_{Da1} are slowly decreased due to the current in the leakage inductor travels towards diode D_{a1} and continuously charging the capacitor C_{a1}. The magnetizing inductor L_{am} is discharging its energy through N_1 and D_{a2} charges the capacitor C_{a2}. Then the stored energy in C_{a3} is discharges to R_L-load constantly. The voltage across switch S_{a1} is same as previous mode-C, the currents i_{LKa1} and i_{Lam} are slowly decreasing but the current i_{Da2} is increased, then this mode-D completes when the current in i_{LKa1} comes to zero at t-t_4.

$$i_{Lam}(t) = i_{LKa1}(t) - n i_{LKa2}(t) \tag{5}$$

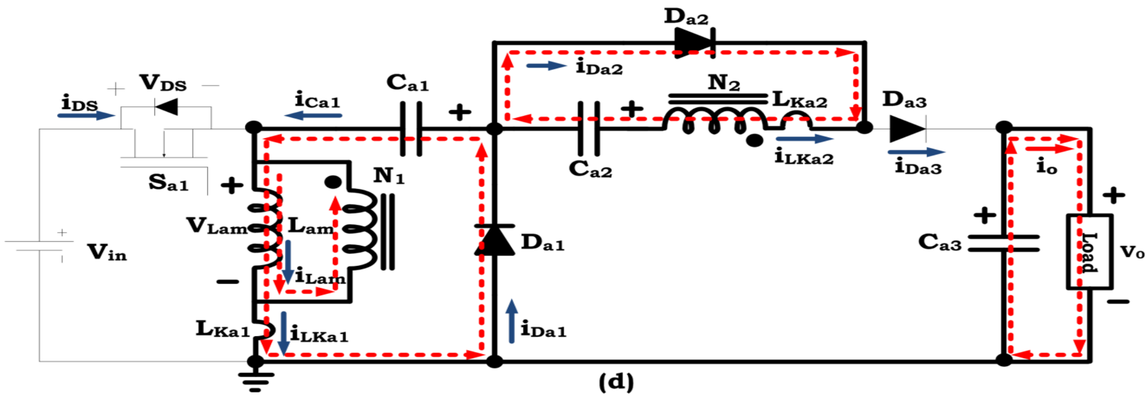


Fig. 2. (d) Current directions in proposed isolated converter working mode D in CCM operation

Mode-E: (t_4, t_5)

In this Mode-E from Figure 2 (e), switch S_{a1} is Switched-OFF, and diode D_{a2} is conducted in forward bias, the magnetizing inductor Lam is constantly supporting energy to capacitor C_{a2}. The current in magnetizing inductor i_{Lam} is slowly decreased due to energy flows continuously through coupled inductors N_1 to N_2 and D_{a2} to charge the capacitor C_{a2}. The stored energy in capacitor C_{a3} is constantly and slowly delivering to R_L-load. Then the voltage across switch S_{a1} is the addition of both V_{Lam} and V_{in}. This completes when switch Sa1 is switched-on at starting of the next transition period.

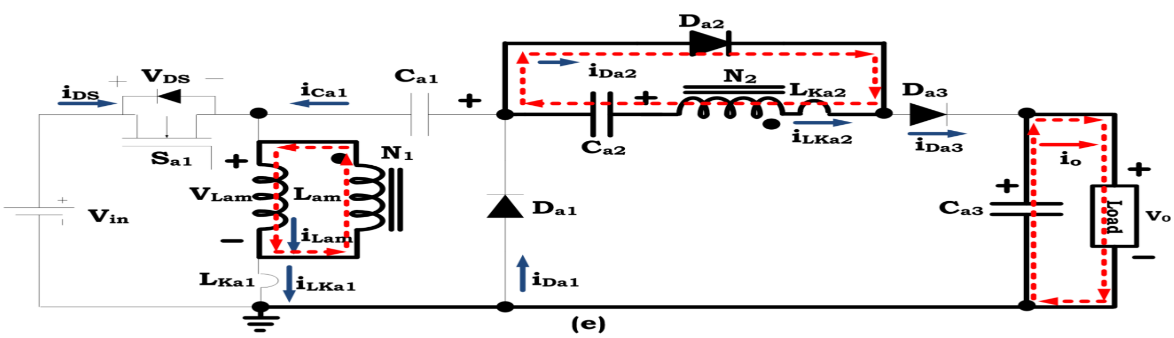


Fig. 2. (e) Current directions in proposed isolated converter working mode E in CCM operation

$$i_{LKa1}(t) = 0 \tag{6}$$

$$\frac{di_{LKa2}(t)}{dt} = \frac{nV_{Lam} + V_{Ca2}}{L_{Ka2}} \tag{7}$$

The steady state analysis of proposed Isolated DC-DC converter for EV system considering the mode-B and mode-D for CCM operation, ignoring the primary, secondary windings, leakage inductances, the respective equations is written from Figure 2 (b),

$$V_{Lam} = V_{in} \tag{8}$$

$$V_{N2} = nV_{in} \tag{9}$$

During mode-D, the respective equations can be written as seen below;

$$V_{Lam} = V_{Ca1} \tag{10}$$

$$-V_{N2} = nV_{Ca2} \tag{11}$$

Applying the voltage-second balance principle on magnetizing inductors L_{am} yields,

$$\int_{0}^{DT_s} V_{in}dt + \int_{DTs}^{T_s} -V_{Ca1}dt = 0 \tag{12}$$

$$\int_{0}^{DT_s} nV_{in}dt + \int_{DTs}^{T_s} -V_{Ca2}dt = 0 \tag{13}$$

Then the voltage across the capacitors C_{a1} and C_{a2} are attained as follows;

$$V_{Ca1} = \frac{D}{1-D}V_{in} \tag{14}$$

$$V_{Ca2} = \frac{nD}{1-D}V_{in} \tag{15}$$

During mode-B, the voltage across load is $V_o = V_{in} + V_{Ca1} + V_{N2} +$' as depicted as,

$$V_0 = V_{in} + \frac{D}{1-D}V_{in} + nV_{in} + \frac{nD}{1-D}V_{in} = \frac{1+n}{1-D}V_{in} \tag{16}$$

The output voltage gain M of proposed Isolated DC-DC converter can be represented as follows,

$$M_{CCM} = \frac{V_0}{V_{in}} = \frac{1+n}{1-D} \tag{17}$$

The main time waveforms of the proposed converter in CCM operation is shown in Figure 3

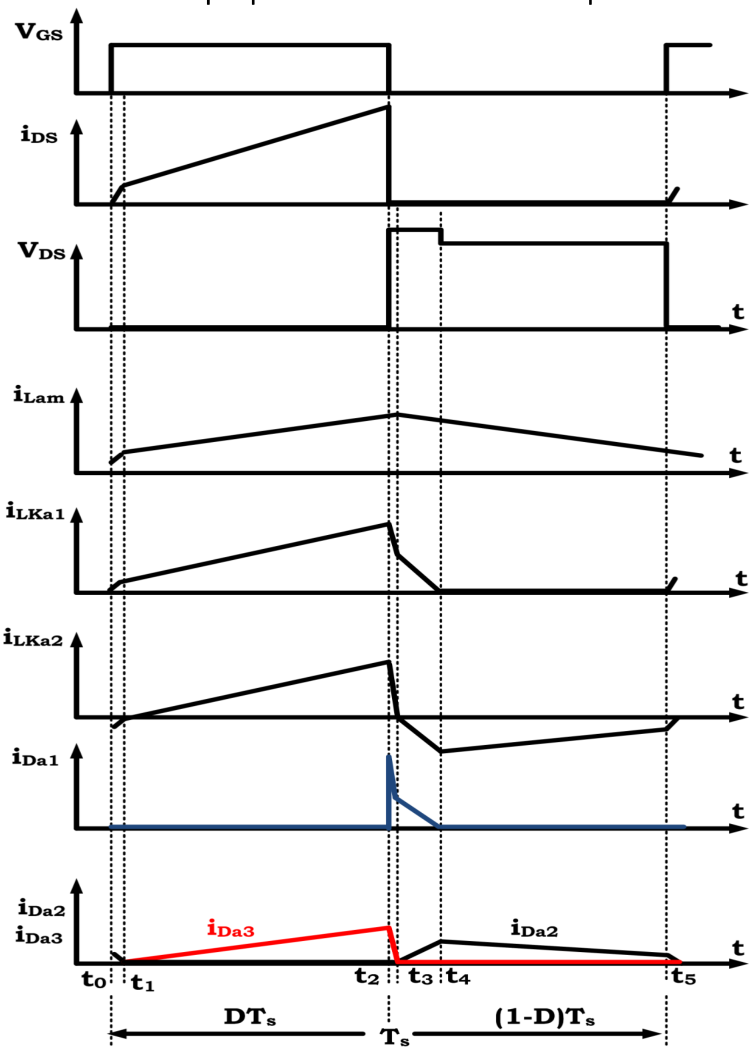


Fig.3. Typical waveforms of proposed isolated DC-DC converter in CCM operation

Efficiency calculation:

To calculate the efficiency of the presented converter, the parasitic resistances of components are expressed as follows:

- ON-state resistance of power switch (P1)
- ESR of inductors L_{am}, L_{ka1}, L_{ka2} (P2)
- ESR of capacitors C_{a1}, C_{a2}, C_{a3} (P3)
- Forward voltages of diodes D_{a1}, D_{a2}, D_{a3} (P4)

The efficiency of the proposed converter can be calculated as follows:

$$\eta_{cov} = \frac{P_0}{P_0 + \Delta P} * 100\% \quad (18)$$

where ΔP = P1+P2+P3+P4

3. Results

3.1 Simulation Analysis

The performance of the Proposed Isolated DC-DC boost converter powered by Solar-PV system is evaluated under different irradiance conditions by using Matlab/Simulink tool with the help of system parameters illustrated in Table 1. Figure 4(a) shows Solar-PV Output Voltage, and Figure 4(b) DC Output Voltage. The Solar-PV array generates the 40V as input voltage to proposed isolated DC-DC converter; it converts input 40V into required 400V output voltage as a step gain of 10%.

Table 1
Operating parameters

Parameter	Value
PV input voltage	V_{pv}-40 V, P_{PV}-8KW
Proposed isolated DC-DC converter	V_{in}-40 V
	V_o-400V
	F_s-50 KHz
	C_{a1}= C_{a2}-47µF,
	C_{a3}- 1000 µF

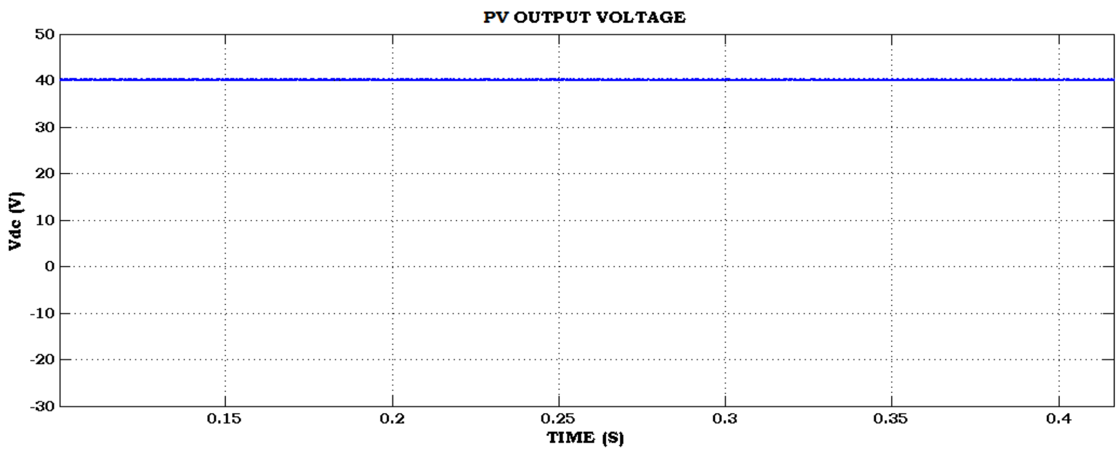


Fig. 4. (a) Solar-PV output voltage

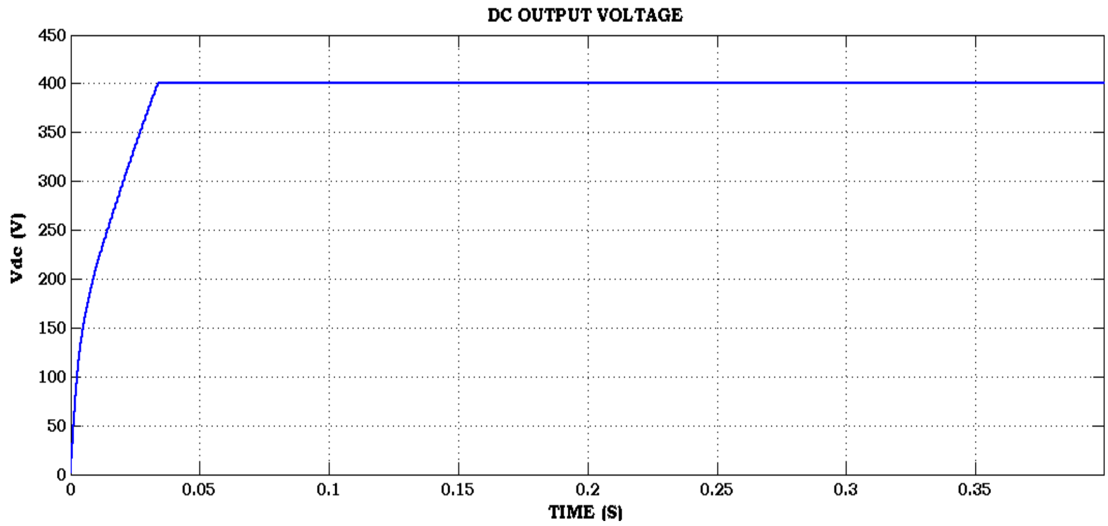


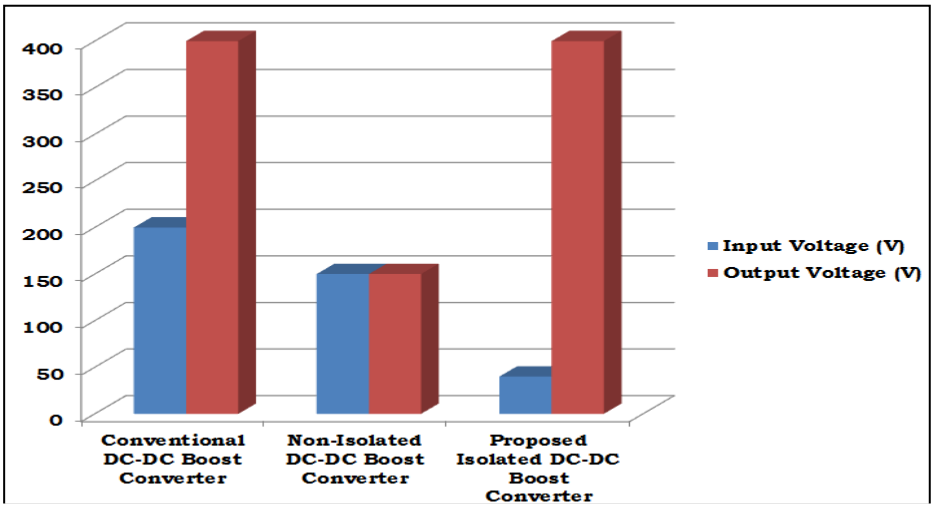
Fig. 4. (b) DC output voltage

3.2 Comparative Analysis

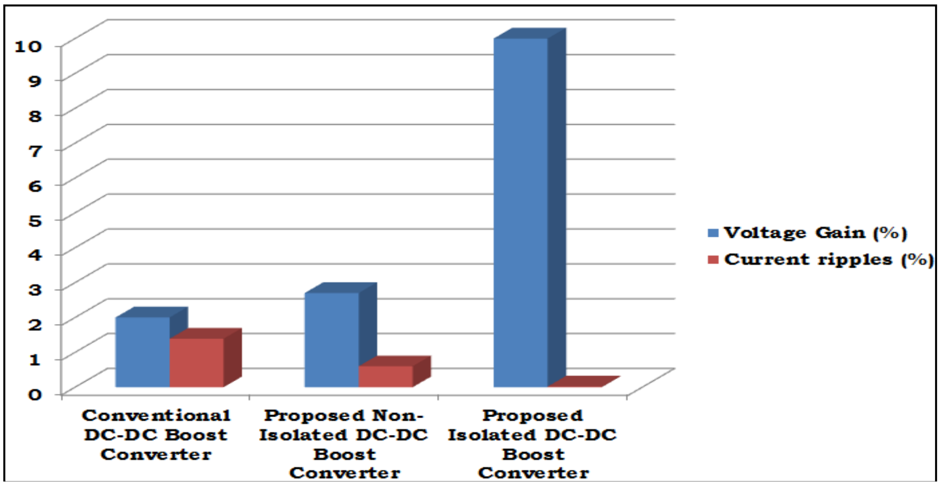
The comparative analysis of conventional DC-DC boost converter, classical non-isolated, and proposed isolated DC-DC converter is illustrated in Table 2. In that, the conventional DC-DC converter requires high input voltage furnishes by solar-PV arrays as 200V produces a DC output voltage of 400V with a voltage gain is 2%. It requires high space requirement for placing solar-PV arrays and highly complex circuitry, high cost, etc. The classical Non-Isolated DC-DC converter requires medium input voltage furnishes by solar-PV arrays as 150V produces a DC output voltage of 400V with a voltage gain is 2.7%. It requires moderate space requirement for placing solar-PV arrays and highly complex circuitry, medium cost, etc. As well as the proposed Isolated DC-DC converter requires very low input voltage furnishes by solar-PV arrays as 40V and produces a DC output voltage of 400V with a voltage gain is 10%. It requires low space requirements for placing solar-PV arrays and low complex circuitry, low cost, etc. The current ripples of the conventional DC-DC boost converter is 1.39% and classical Non-isolated DC-DC converter is 0.6%, and the current ripples of the proposed Isolated DC-DC boost converter attain low ripple content in current is 0.02%. The proposed Isolated DC-DC boost converter has better features over the conventional and classical non-isolated DC-DC boost converter on various factors. The graphical view of performance analysis on conventional, classical non-isolated DC-DC boost converters and proposed Isolated DC-DC boost converters are depicted in Figure 5.

Table 2
Comparison of conventional, non-isolated, and proposed DC-DC boost converters

Parameter	Conventional DC-DC boost converter	Non-isolated DC-DC boost converter	Proposed isolated DC-DC boost converter
Input voltage	V_{in}-200V	V_{in}-150V	V_{in}-40V
Output voltage	V_o-400V	V_o-400V	V_o-400V
Voltage gain (%)	2%	2.7%	10%
Ripple current	1.39%	0.6%	0.02%
Switch stress	High	Moderate	Low
Efficiency	Low	Moderate	High



(a)



(b)

Fig.5. Graphical view of performance analysis of conventional DC-DC boost converter, non-isolated and proposed isolated DC-DC boost converters, (a) Input and output voltages, (b) Voltage gain and current ripples

Table 3 shows the performance of the proposed converter with number of components, voltage stress on the switches and voltage gain is compared with other similar converters.

The proposed converter has high voltage gain and low voltage stress on the active switches when compared with other similar converters. The voltage stress on the diodes for the proposed converter is less among the compared converters when the turns ration less than 2.

Table 3
Comparison of proposed converter with similar converters

Parameter	Converter[21]	Converter[22]	Proposed converter
No. of switches	2	2	1
No. of diodes	6	4	2
No. of cores	2	3	1
Voltage stress	$\frac{V_0}{2+ND(1-D)}$	$\frac{V_0}{2(1+N)}$	$\frac{V_0}{2(1+N)}$

Voltage gain	$ND+(\frac{2}{1-D})$	$\frac{2}{1-D}[1+N]$	$\frac{1+N}{1-D}$

4. Conclusions

The performance of the isolated DC-DC boost converter driven by solar PV was examined under changing irradiance circumstances. The proposed isolated DC-DC boost converter converts the solar-PV voltage of 40V into a high step-up voltage of 400V with a step-up gain of 10%, and it is operated in a closed-loop control system to provide constant and precise output parameters. To stimulate performance evaluation of the suggested system, good operational statistics over the standard DC-DC converter, classical Non-isolated DC-DC boost converter, and data obtained by utilizing the Matlab/Simulink tool have been compiled and presented in detail. The suggested technology is appropriate for an EV system since, in an electric vehicle, space is a critical consideration, and the isolated DC-DC converter requires a minimal number of solar-PV arrays. It also achieves high output voltage at low duty ratios, which reduces dv/dt switch stress. It also has minimal current ripples, low switching losses, and high efficiency, among other characteristics.

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References

[1] Wester, Gene Ward, and Richard D. Middlebrook. "Low-frequency characterization of switched dc-dc converters." *IEEE Transactions on Aerospace and electronic Systems* 3 (1973): 376-385.https://doi.org/10.1109/TAES.1973.309723

[2] Zhiguo, Kong, Zhu Chunbo, Yang Shiyan, and Cheng Shukang. "Study of bidirectional DC-DC converter for power management in electric bus with supercapacitors." In *2006 IEEE Vehicle Power and Propulsion Conference*, pp. 1-5. IEEE, 2006.https://doi.org/10.1109/VPPC.2006.364376

[3] Kohno, M., and K. Kuwabara. "Single-ended dc-to-dc converter with two individually controlled outputs." In *INTELEC-1978 International Telephone Energy Conference*, pp. 191-198. IEEE, 1978.https://doi.org/10.1109/INTLEC.1978.4793546

[4] Sathish, T., Ümit Ağbulut, Vinod Kumari, G. Rathinasabapathi, K. Karthikumar, N. Rama Jyothi, Sumanth Ratna Kandavalli, T. Vijay Muni, and R. Saravanan. "Energy recovery from waste animal fats and detailed testing on combustion, performance, and emission analysis of IC engine fueled with their blends enriched with metal oxide nanoparticles." *Energy* 284 (2023): 129287.https://doi.org/10.1016/j.energy.2023.129287

[5] Kishore, D. Ravi, T. Vijay Muni, B. Srinivas Raja, Mukesh Pushkarna, B. Srikanth Goud, Kareem M. AboRas, and Sadam Alphonse. "Grid-Connected Solar PV System with Maximum Power Point Tracking and Battery Energy Storage Integrated with Sophisticated Three-Level NPC Inverter." *International Transactions on Electrical Energy Systems* 2023 (2023).https://doi.org/10.1155/2023/3209485

[6] Ahmed, Furqan, Su-Han Kim, Honnyong Cha, Dong-Hun Kim, and Heung-Geun Kim. "Intermediate and light load efficiency improvement of a high-power density bidirectional DC-DC converter in hybrid electric vehicles with MR fluid gap inductor." In *2014 International Power Electronics Conference (IPEC-Hiroshima 2014-ECCE ASIA)*, pp. 790-795. IEEE, 2014.https://doi.org/10.1109/IPEC.2014.6869677

[7] Zhang, Junhong, Jih-Sheng Lai, Rae-Young Kim, and Wensong Yu. "High-power density design of a soft-switching high-power bidirectional dc–dc converter." *IEEE Transactions on power electronics* 22, no. 4 (2007): 1145-1153.https://doi.org/10.1109/TPEL.2007.900462

[8] Tekin, Hakan, Kübra Bulut, and Davut Ertekin. "A novel switched-capacitor and fuzzy logic-based quadratic boost converter with mitigated voltage stress, applicable for DC micro-grid." *Electrical Engineering* 104, no. 6 (2022): 4391-4413. https://doi.org/10.1007/s00202-022-01631-3

[9] Prakash, R. B. R., P. Srinivasa Varma, Chinthaginjala Ravikumar, T. Vijay Muni, Asadi Srinivasulu, Kalapraveen Bagadi, A. Rajesh, and K. Sathish. "Intelligent Energy Management for Distributed Power Plants and Battery

Storage." *International Transactions on Electrical Energy Systems* 2023 (2023).https://doi.org/10.1155/2023/6490026

[10] Bayrak, Gökay, and Davood Ghaderi. "An improved step-up converter with a developed real-time fuzzy-based MPPT controller for PV-based residential applications." *International Transactions on Electrical Energy Systems* 29, no. 12 (2019): e12140.https://doi.org/10.1002/2050-7038.12140

[11] Anantha Krishnan, V., A. Jeba Sheela, B. Muthuraj, U. Senthil Kumaran, T. Vijay Muni, Tirukoti Sudha Rani, Ramesh NSVSC Sripada, Manzoor Hiu Siddique, and Raja Raju. "An IOT Innovation of Smart Solar Energy Consumption Analysis and Control in Micro Grid." *International Journal of Photoenergy* 2022 (2022).https://doi.org/10.1155/2022/7506237

[12] Ganthia, Bibhu Prasad, R. Dharmaprakash, Tushar Choudhary, T. Vijay Muni, Essam A. Al-Ammar, A. H. Seikh, M. H. Siddique, and Abdi Diriba. "Simulation Model of PV System Function in Stand-Alone Mode for Grid Blackout Area." *International Journal of Photoenergy* 2022 (2022).https://doi.org/10.1155/2022/6202802

[13] Qi, Qun, Davood Ghaderi, and Josep M. Guerrero. "Sliding mode controller-based switched-capacitor-based high DC gain and low voltage stress DC-DC boost converter for photovoltaic applications." *International Journal of Electrical Power & Energy Systems* 125 (2021): 106496.https://doi.org/10.1016/j.ijepes.2020.106496

[14] Sai, P. Swapna, G. G. Rajasekhar, T. Vijay Muni, and M. Sai Chand. "Power quality and custom power improvement using UPQC." *International Journal of Engineering & Technology* 7, no. 2.20 (2018): 41-43.https://doi.org/10.14419/ijet.v7i2.20.11742

[15] Muni, T. Vijay, and S. V. N. L. Lalitha. "Implementation of control strategies for optimum utilization of solar photovoltaic systems with energy storage systems." *International Journal of Renewable Energy Research* 10, no. 2 (2020).https://doi.org/10.20508/ijrer.v10i2.10565.g7943.

[16] Zhang, Zhe, and Michael AE Andersen. "Interleaved boost-half-bridge dual-input DC-DC converter with a PWM plus phase-shift control for fuel cell applications." In *IECON 2013-39th Annual Conference of the IEEE Industrial Electronics Society*, pp. 1679-1684. IEEE, 2013.https://doi.org/10.1109/IECON.2013.6699385

[17] Omara, Ahmed M., and M. Sleptsov. "Bidirectional interleaved DC/DC converter for electric vehicle application." In *2016 11th International Forum on Strategic Technology (IFOST)*, pp. 100-104. IEEE, 2016.https://doi.org/10.1109/IFOST.2016.7884201

[18] Garcia, Oscar, Pablo Zumel, Angel de Castro, Pedro Alou, and JosÉ A. Cobos. "Current self-balance mechanism in multiphase buck converter." *IEEE Transactions on Power Electronics* 24, no. 6 (2009): 1600-1606.https://doi.org/10.1109/TPEL.2009.2013859

[19] Bahrami, Hamid, Ehsan Adib, Shahrokh Farhangi, Hossein Iman-Eini, and Rahmat Golmohammadi. "ZCS-PWM interleaved boost converter using resonance-clamp auxiliary circuit." *IET Power Electronics* 10, no. 3 (2017): 405-412.https://doi.org/10.1049/iet-pel.2016.0267

[20] Das, Moumita, Monidipa Pal, and Vivek Agarwal. "Novel high gain, high efficiency dc–dc converter suitable for solar PV module integration with three-phase grid tied inverters." *IEEE journal of photovoltaics* 9, no. 2 (2019): 528-537.https://doi.org/10.1109/JPHOTOV.2018.2877006

[21] Ardi, Hossein, Ali Ajami, and Mehran Sabahi. "A novel high step-up DC–DC converter with continuous input current integrating coupled inductor for renewable energy applications." *IEEE transactions on industrial electronics* 65, no. 2 (2017): 1306-1315.https://doi.org/10.1109/TIE.2017.2733476

[22] Sathyan, Shelas, Hiralal Murlidhar Suryawanshi, Bhim Singh, Chandan Chakraborty, Vishal Verma, and Makarand Sudhakar Ballal. "ZVS–ZCS high voltage gain integrated boost converter for DC microgrid." *IEEE Transactions on Industrial Electronics* 63, no. 11 (2016): 6898-6908.https://doi.org/10.1109/TIE.2016.2582460

[23] Li, Wuhua, and Xiangning He. "Review of nonisolated high-step-up DC/DC converters in photovoltaic grid-connected applications." *IEEE Transactions on industrial electronics* 58, no. 4 (2010): 1239-1250.https://doi.org/10.1109/TIE.2010.2049715

[24] Ertekin, Davut, Kübra Bulut, Hakan Tekin, and Gerry Moschopoulos. "A design for switched capacitor and single-switch DC–DC boost converter by a small signal-based PI controller." *International Journal of Circuit Theory and Applications* 50, no. 5 (2022): 1620-1651.http://dx.doi.org/10.1002/cta.3213