Interleaved Boost Converter For Photovoltaic Power-Generation System

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Abstract: *in this paper, an interleaved boost converter (IBC) for a photovoltaic (PV) power-generation system is proposed. The topology used raises the efficiency of the DC/DC converter of the PV power conditioning system (PVPCS), and it minimizes switching losses by adopting a resonant soft-switching method. A detailed mode analysis of the proposed topology is presented. Consequently, it is confirmed that the overall efficiency is increased by about 1.5% compared with the conventional hard switching interleaved boost converter.*

Index Terms: *Boost converter, interleaved, maximum power point tracking (MPPT), photovoltaic (PV) power-generation systems,resonant converter, soft-switching.*

I. Introduction

RECENTLY, photovoltaic (PV) energy has attracted interest as a next generation energy source capable of solving the problems of global warming and energy exhaustion caused by increasing energy consumption. PV energy avoids unnecessary fuel expenses and there is no air pollution or waste. Also, there are no mechanical vibrations or noises because the components of power generation based on PV energy use semiconductors. The life cycle of the solar cell is more than 20 years, and it can minimize maintenance and management expenses. The output power of the solar cell is easily changed by the surrounding conditions such as irradiation and temperature, and also its efficiency is low. This high efficiency is required for the power conditioning system (PCS), which transmits power from the PV array to the load. In general, a single-phase PV PCS consists of two conversions Stages (i.e., DC/DC conversion stage and DC/AC conversion stage). The DC/DC converter is the first stage and it performs maximum power-point tracking (MPPT) andGuarantees the DC-link voltage under low irradiance conditions[1], [2].This paper proposes a high efficiency DC/DC boost converter toIncrease the overall efficiency of the PV power conditioning system (PVPCS) [3]–[8]. We studied a 2-phase interleaved boost converter integrated with a single-switch type soft-switching boost converter. The proposed single-switch type soft-switching boost converter can minimize switching losses by adopting a resonant soft-switching method. And, no additional switches are needed for soft switching [9] –[15]. However, the drawback of this converter is that the voltage across the switch is very high during the resonance mode. The voltage across the switch depends on the parameters of the resonant components (i.e., resonant inductance and resonant capacitance) and the resonant inductor current. In this paper, the optimal design of the resonant components and the interleaved method is applied for resonant current reduction. Since the interleaved method distributes the input current according to each phase, it can decrease the current rating of the switching device. Also, it can reduce the input current ripple, output voltage ripple, and size of the passive components [16] –[18]. The proposed soft-switching interleaved boost converter can not only exploit the interleaved converter, but also reduce switching losses through the soft-switching technique. Therefore, the output power of the PV array can be boosted with high efficiency. This paper presents the operational principle of the converter, for simulated.

II. Proposed Topology

A. Proposed Soft-Switching Boost Converter

The interleaved boost converter consists of two single-phase Boost converters connected in parallel. The two PWM signal The difference is 180◦ when each switch is controlled by the interleaving method. Because each inductor current magnitude is decreased according to one per phase, we can reduce the inductor size and inductance when the input current flows through two boost inductors. The input current ripple is decreased because the input current is the sum of each current of inductor L1 and L2 .Fig. 1(a) shows the proposed single-switch type soft switching boost converter [19]. One resonant inductor, two capacitors, and two diodes are added to a conventional boost converter for soft switching using resonance. Fig. 1(b) shows the interleaved soft-switching boost converter (ISSBC) proposed in This paper. Two single-phase soft-switching boost converters are connected in parallel and then to a single output capacitor.
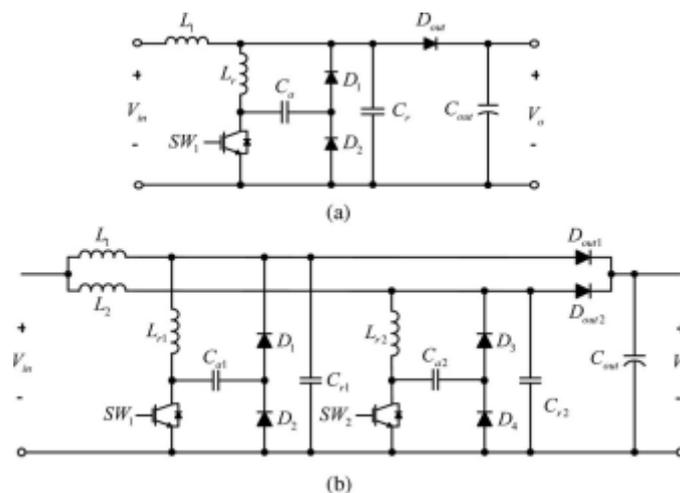
Fig. 1 Proposed soft-switching boost converter. (a) Proposed single-switch soft-switching boost converter.(b) ISSBC
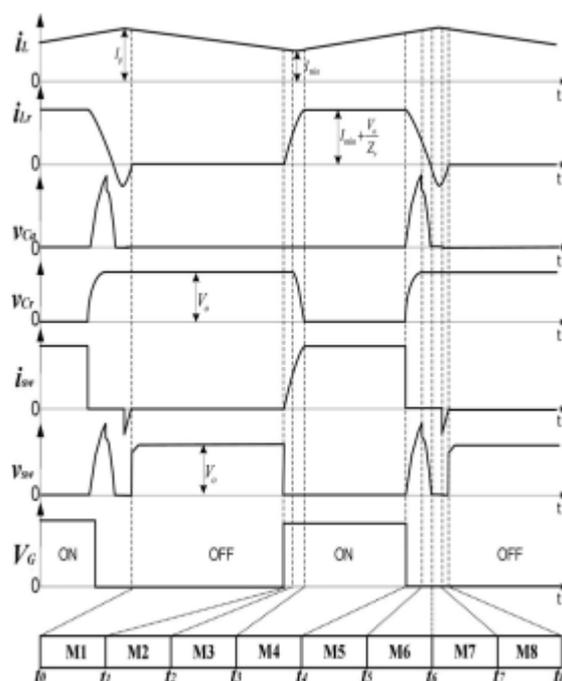
Fig. 2. Key waveforms of proposed converter.

B. Mode Analysis of the Proposed Converter

       Each mode is presented during one switching cycle of steady state operation of the proposed converter. For illustrating the soft-switching operation using resonance, we describe the operation modes of a single-phase soft switching boost converter [see Fig. 1(a)], which consists of the proposed ISSBC. The key waveforms associated with the operation stages are shown in Fig. 2. There are operation modes shown in Fig. 3, and the duty ratio is assumed to be 0.5 in order tosimplify theAnalysis. The operation can be analyzed in terms of eight modes according to the operating conditions defined in the following paragraphs.

1) All switching devices and passive elements are ideal.
2) The parasitic components of all switching devices and
    Elements are ignored.
3)It is assumed that the initial value of each operation   mode Is equal to zero.

Mode 1 (t0 ≤ t <t1): The switch is in the off state and the DC Output of the solar cell array is transmitted directly to the load Through L and Dout. In this mode, the main inductor voltage Becomes (Vo – Vin). Thus, the main inductor current decreases linearly

$$iL(t) = iL(to) - \frac{Vo-Vin}{L}t \qquad (1)$$

$$iLr(t) = 0, \quad vCr(t) = Vo, \quad vCa(t) = 0 \qquad (2)$$

$$iL(t1) = I_1 \qquad (3)$$

Mode 2 (t1 ≤t<t2): In mode 2, the switch is turned on under Zero-current switching (ZCS) because of the resonant inductor Lr.In this case, as the output voltage is supplied to the resonant inductor Lr, the current increases linearly. When the resonant current iLrbecomes equal to the main inductor current IL, the current of the output side diode Dout becomes zero

$$iL = I_1 - \frac{Vo-Vin}{L} \qquad (4)$$

$$iLr(t) = \frac{Vo}{Lr}t, \quad vCr(t) = Vo, \quad Vca(t) = 0 \qquad (5) \qquad\qquad iL(t_2) = Imin, \; iLr(\text{t2}) = Imin \qquad (6)$$

Mode 3 (t2 ≤ t <t 3): When the output current iDout becomes zero, the mode starts. In this mode, the resonant inductor Lrand the resonant capacitor Cr resonate and the voltage of Cr decreases from the output voltage VO to zero. In this case, the main inductor current IL flows through Lrand the switch

$$iL(t) = Imin \qquad (7)$$

$$V_{ca}(t) = 0 \qquad (8)$$

$$iL_r(t) = I_{min} + \frac{Vo}{Zr} \qquad (9)$$

$$VC_r(t) = V_0 \cos \omega rt \qquad (10)$$

$$iL_r(t_3) = I_2, vrC_R(t_3) = 0 \qquad (11)$$

$$\omega r = \frac{1}{\sqrt{LrCr}}, Zr = \sqrt{Lr}Cr \qquad (12)$$

Mode 4 (t3 ≤t<t4): When the resonant capacitor voltage VCr Becomes zero, the two auxiliary diodesD1 andD2 are turned on and the mode starts. In this mode, the resonant inductor current is separated into two parts. One is the main inductor current iL and the other is the current turning through the two auxiliary diodes. The main inductor current iLincreases linearly

$$L(t) = I_{min} + \frac{Vin}{L}t \qquad (13)$$

$$iL_r(t) \approx I2 \qquad (14)$$

$$VC_r(t) = 0, VC_a(t) = 0 \qquad (15)$$

$$iL(t4) = I3, iL_r(t4) = I2 \qquad (16)$$

Mode 5 (t4 ≤ t <t5): In mode 5, the switch turns off under The zero-voltage condition because of the auxiliary resonantcapacitor Ca. There are two current loops. One is the L-Cr - Vinloop for which the voltage of the resonant capacitor Cr Increases linearly from zero to the output voltage Vo.The other is the Lr–Ca–D1 loop for which the second resonance occurs. The energy stored in Lris transferred to Ca. The resonant current iLrdecreases linearly and the voltage across Cabecomes maximum.

$$iL(t) \approx I_3 = I_{ma} \qquad (17)$$

$$iL_r(t) = I_2 \qquad (18)$$

$$VC_a(t) = Zr \, I_2 \sin \omega a \, t, VC_r(t) = I_3/C_a \qquad (19)$$

$$\omega a = 1/\sqrt{LrCa} \qquad (20)$$

$$Za = \sqrt{Lr/Ca}. \qquad (21)$$

Mode 6 (t5 ≤ t < t6): When the resonant capacitor voltage vCr is equal to the output voltage Vo, the mode starts. In this mode, the energy flow from Lr to Ca is completed and the resonant current iLr becomes zero

$$iL(t) = I_3 - \frac{Vo-Vin}{L} \qquad (22)$$

$$iLr(t) = I_2 \cos\omega a \, t \qquad (23)$$

$$vCa(t) = Zr \; I2 \sin \omega a \; t, \; vCr(t) = VO \qquad (24)$$

$$vCa(t6) = Za I_3. \qquad (25)$$

Mode 7 (t6 ≤ t < t7): In mode 7, the voltage of Cadecreases, continuously resonates on the D2–Ca–Lr–Dout–Co loop and the energy is transferred from Cato Lr. When the Cavoltage becomes zero, the resonant current iLris the reverse of the current direction of mode 6. When the voltage of Cabecomes zero, the anti-parallel diode of the switch turns on and it transitions conditions..

$$iL(t) = I_3 - \frac{Vo - Vin}{L}t, \text{ iLr (t6)} = I_4 \qquad (26)$$

$$iLr(t) = \left(\frac{Vo}{Za} - I_2\right)\text{Sin } \omega a \text{ t, iLr (t)} = I_5 \qquad (27)$$

vCr (t) = Vos   (28)

vCa (t) = Vo − (Vo − ZaI_2) cosωa t = V_2 (29)

Mode 8 (t7 ≤ t < t8): There are two current loops. The main inductor current iL transmits energy to the output through Dout and decreases linearly. The resonant inductor current iLr also transmits energy to the load through Dout and flows through the antiparallel diode of the switch. When the resonant inductor current iLr becomes zero, mode 8 ends

$$iL(t) = I_4 + \frac{Vo - Vin}{L}t, \text{iLr}(t_8) = I_6 \qquad (30)$$

$$iLr(t) = I_5 - \frac{Vo}{Lr}t, \text{ iLr }(t_8) = 0 \qquad (31)$$

vCr (t) = Vo   (32)

vCa (t) = 0   (33)

TABLE I
Experimental Parameters

Parameter	Symbol	value	unit
Input voltage	V_{in}	180-200	V
Output voltage	V_O	400	V
Rated power	P_O	1.2	KW
Switching frequency	f_{sw}	30	KH_Z
Main inductor	L_1, L_2	1	mH
Resonant inductor	L_{r1}, L_{r2}	50.6	µH
Resonant capacitor	C_{r1}, C_{r2}	100	nF
Auxiliary capacitor	C_{a1}, C_{a2}	10	nF
Output capacitor	C_{OUT}	15	µF

III. Design Procedures Of The Proposed Converter

A. Switch Peak Voltage Analysis and Parameter Design

In mode 5, the current that flows through the Lr–Ca–D1 loopthe next mode Should be large enough for resonance. As described by (18),the voltage across the auxiliary resonant capacitor Cais as high asI2 during this resonant period. Voltage across the auxiliary resonant capacitor Cais as high as I2 during this resonant period

vSW(t) = vCa(t) + vCr(t)

The amplitude of the switch voltage is determined by the resonant devices and the resonant current. To minimize the peak voltage of the switch, designs for optimal parameters of resonant components are included and the interleaved method is adopted. Because the interleaved method distributes the input current according to each phase, it can decrease the current rating of the switching device. Thus, it can reduce the peak voltage across the switch, input current ripple, output voltage ripple and size of passive components.

B. Selection of Resonant Inductor and Capacitor

The ZVS condition of the switch is affected by the auxiliary
Resonant capacitor Ca. In mode 5, the current that flows through the Lr–Ca–D1 loop should be large enough for resonance. In general, the snubbed capacitance has to be more than ten times the parasitic capacitance. The resonant capacitance Cahas to be more than 20 times the output capacitance of the switch ,because the Cais charged by the resonant inductor current (it is about 2 times the main inductor current) during the switch turn-off period, represented as follows:
Ca>20Coes.

In mode 3, the resonant inductor current is represented by (8).The period of resonance between resonant inductance LrandResonant capacitance Cr is about a quarter of the entire resonant period. In general, the rising time of the resonant inductor current is 10% of the minimum on-time of the switch. However r, for satisfaction of the ZVS condition, the rising time of the resonant inductor current is 50% of the minimum on-time in this paper, as represented by

$$T3 - T1 = \frac{Lr}{Vo}Imin + \frac{Tr}{4} < 0.5DminT \qquad (34)$$

Where

$$Tr = \frac{1}{fs} = 2\pi\sqrt{LrCr}$$

$$Tr = \frac{1}{fsw}$$

And $Dmin = (Vo - Vin\ min)/Vo$.

From (18) and (25), the resonant capacitance Cr can be defined as

$$Cr > \frac{D^{2min}}{\pi^2 Lr f^2 sw} + \frac{I^2\ min\ Lr}{\pi^2 VO^2} - \frac{2IminDmin}{\pi^2 Vo fsw^2} \qquad (35)$$

Since $(2IminDmin)/(\pi 2Vof2SW) \approx 0$ in (36), this equation can be rewritten as follows:

$$Cr > \frac{D^{2min}}{\pi^2\ Lr f^2 sw} + \frac{I^2\ min\ Lr}{\pi^2 VO^2}$$

$$Lr = \{Vo|(I2 - Imin)\}2\ Cr$$

Where $I2 - Imin = Vo/Zr = Vo\sqrt{Cr}\ /\sqrt{Lr}$
.

From (37) and (38), Cr can be defined as

$$Cr > \frac{D^{2min}(I2-Imin)}{\pi^2 Lr f^2 sw} / \sqrt{I - I^2 min / \pi^2 (I_2 - Imin)^2} \qquad (36)$$

From (38), the resonant inductor parameter is expressed as

$$Lr < \left\{ 2 \times 0.85 \frac{C_S}{C_a} - Vo\left|(\frac{I_P}{C_r + C_a} \pi\sqrt{C_a})\right\}^2 \right.$$

Where

$$C_{s=C_r} C_{S/(C_r + C_a)},\ Vo - V_2 \approx 0.85 V_O$$

C. Design Example

In this section, the design procedure of the proposed converter Is based on the derived equations. Table I shows the Design parameters of the proposed boost converter. And, the Design guidelines herein provides a proper tool to help choose resonant components and ensure the appropriate operation of the resonance converter.
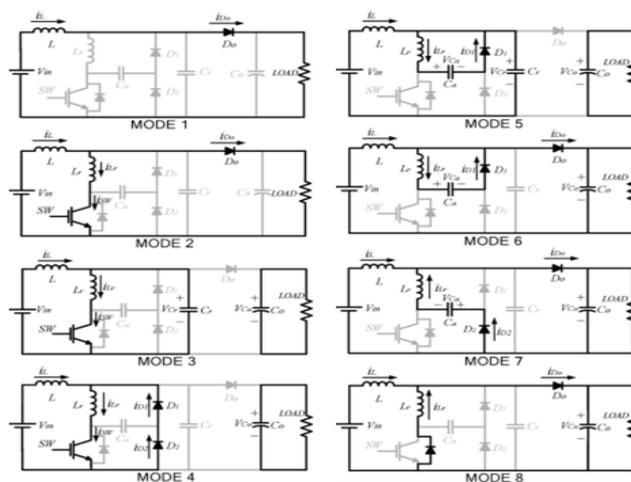
IV. Simulation Results

A. Simulation diagram for Interleaved Boost Converter
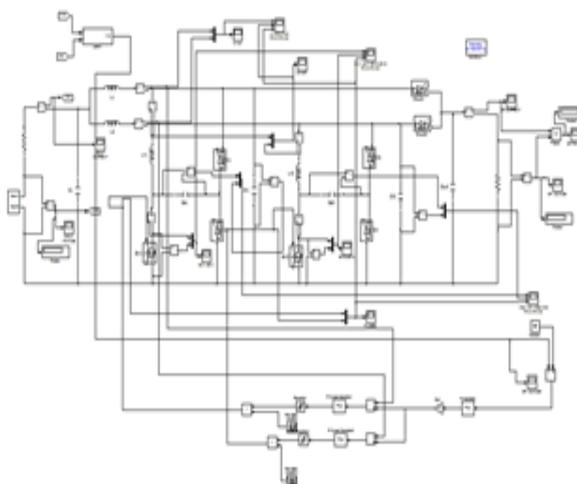
Fig 1 Simulation diagram of Interleaved Boost Converter

B. MPPT Controller: P&O MPPT Algorithm

The MPPT algorithm used in the simulations is a hill climbingP&O technique. The boost converter duty ratio is changed andThe resulting change in power is observed. The duty ratio isthen changed again based on the previous sample such thatthe new duty ratio is closer to the MPP. In this simulation, theboost converter duty ratio and the average power generatedby the PV are measured and compared to the value duringthe previous sample. The sample rate is 100Hz. The change induty ratio and change in average power are multiplied togetherand then compared to zero. If the product is positive, the dutyratio is incremented by 1%. If the product is negative, theduty ratio is decremented by 1%. If the product is zero, thecontrol toggles between incrementing and decremented theduty ratio by 1%. This prevents the simulation from gettingstuck at one duty ratio, and does not appear to add additionaloscillation around the equilibrium point. The duty ratio islimited between 0 and 90% to keep the boost converter in asuitable operating range.
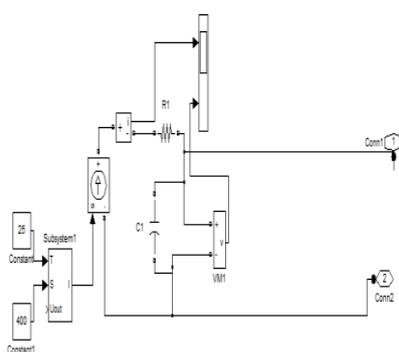
Fig .2Simulation model of PV array
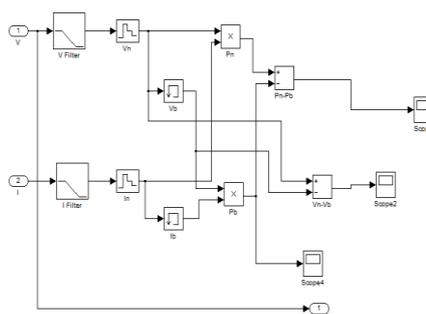
Fig .3 Simulink model of P&O MPPT converter control
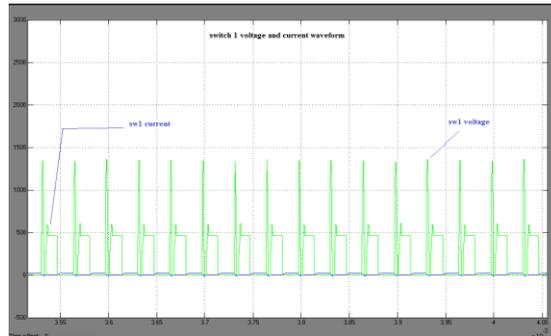
Fig.4 Simulation result for sw1 current and voltage
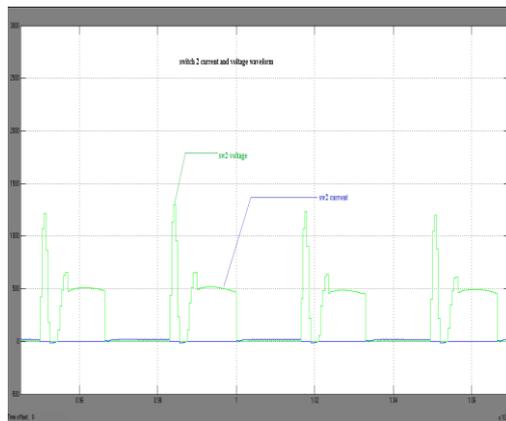
Fig.5Simulation result for sw2 current and voltage
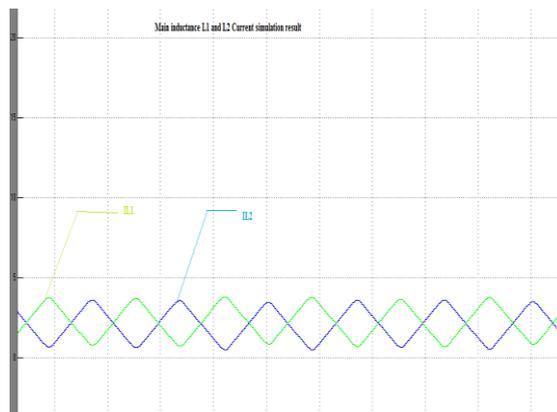
Fig.6 Simulation result for main inductance current
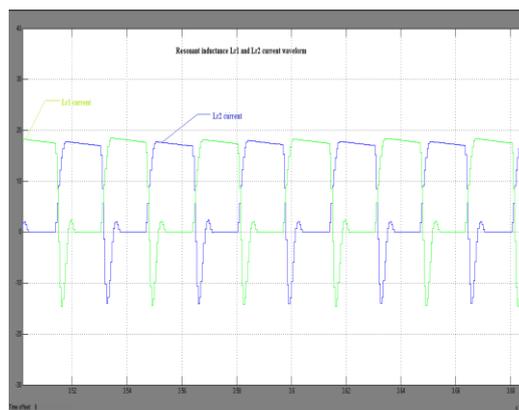
Fig. 7 Simulation result for resonant inductance current

Fig.6&7 shows the current waveforms of the resonant inductor Lr1,Lr2 , and gate signals. The current through Lr1 and Lr2 aremore than twice the main inductor L1 and L2 current
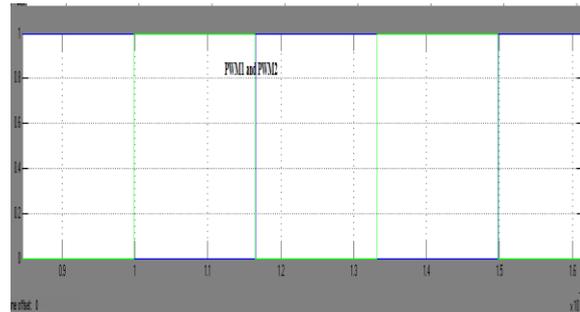
Fig.8 Simulation result for PWM 1 and PWM 2

Fig. 9Simulation result for MPPT pulses

Fig.9 shows the MPPT Pulses of the system the constant level of the pulses given to the system the perfect output is produced.
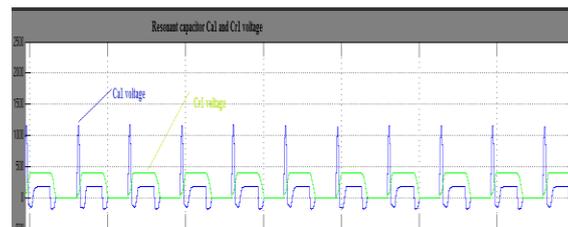
Fig.10 Simulation result for resonant capacitor Ca1 and Cr1 voltage

Fig.10 shows the Ca1 and Ca2 ofresonant
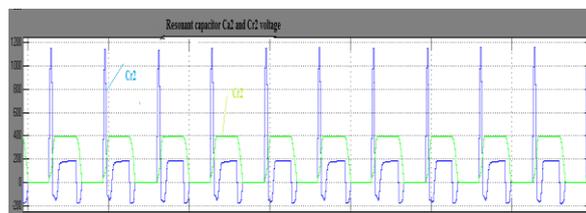
Fig.11Simulation result for resonant capacitor Ca2 and Cr2 voltage
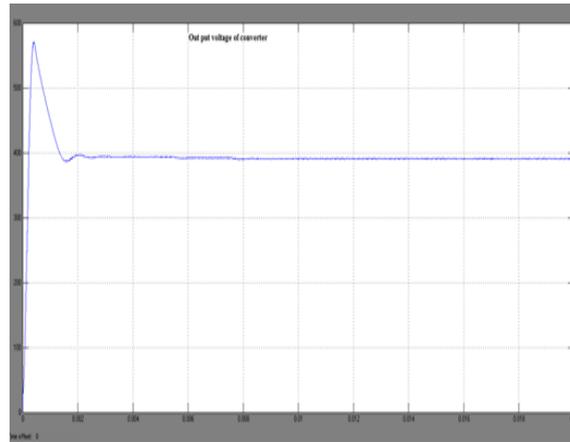
Fig.12simulation result for converter output voltage

Fig. 12 shows the output voltage waveform of the converter to produce twice amount of voltages produced.
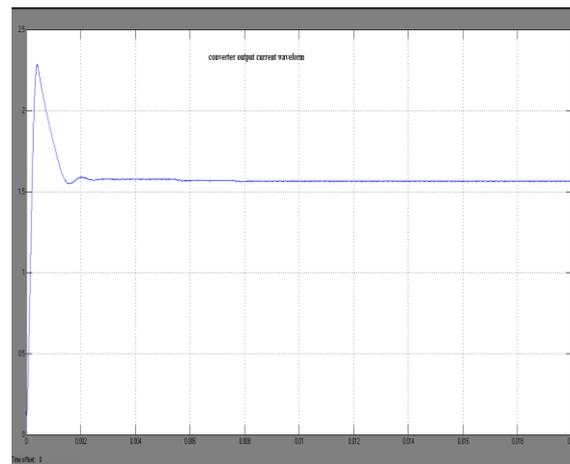
Fig.13Simulation result for converter output current

Fig. 13 shows the output current of the converter to produced constant current of the system.
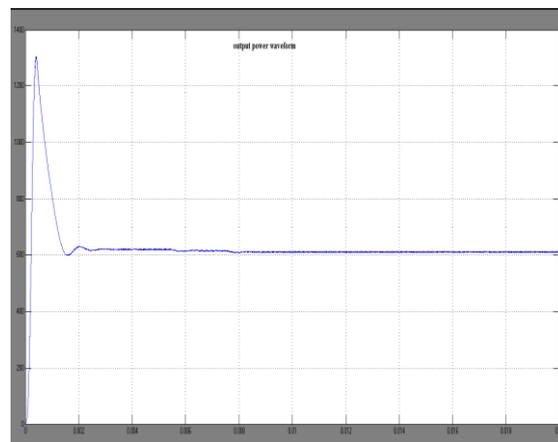
Fig. 14 Simulation result for converter output power

Fig. 14 shows the output power of the converter multiple product of the voltage and current the power is developed so constant amount of power is obtained.

The MATLAB simulation software was used to analyse theOperational characteristics of the proposed soft-switching interleaved boost converter. The design parameters for the simulationare shown in Table I.Fig.4&5 shows the current waveforms of the main inductor and resonant inductor, and the gate signals (SW1

and SW2) of the proposed soft-switching interleaved boost converter. The main inductor currents (iL1 and iL1) increase and decrease linearly according to the gate signals. The phase difference of each waveform is 180◦.Also, the resonant inductors store and release energy according to the gate signals. Fig. 6 shows the voltage waveforms of the resonant capacitor and auxiliary resonant capacitor, and gate signals (SW1 and SW2). The peak voltage of VCais higher than that of the resonant capacitor voltage VCr.When the switch turns off, the auxiliary resonant capacitor voltage VCaincreases and then decreases to the zero level, satisfying he ZVS condition represented by (36).Fig. 7 shows the voltage and current waveforms of the switches and gate signals. The switches SW1 and SW2 are turned on under ZCS and turned off under ZVS.

V.   Conclusion

The interleaved boost and converter with both zerovoltage Switching and zero-current-switching functions andA closed loop control system has been designed for themZCS Interleaved boost converter in continuous time domainUsing thePID controller. The simulation results thusobtained using MATLAB/Simulink. is proposed in this paper. Theduty cycle of this topology can be more or less than 30%areused each switches.
1) The main switches Sw1and Sw2can achieve both ZVS and
ZCS.
2) The voltage stress of all switches are reduced by using soft switching techniques.
3) It uses the resonant inductor Lr, resonant capacitor Cr ,
Parasitic capacitors Ca1and Ca2,
4) The driving circuit can automatically detect whether the
Driving signals of the main switches are more than 50%
or not and get the driving signal of the auxiliary switch.
5) The users can only apply the ZVS or ZCS function just
By the adjustment of the driving circuit
6) The efficiency is 97.6% with output voltageis400 and
input voltage of 150Vto 200Vand it is 97.6%with output power is obtained.

References

[1]. Interleaved Soft-Switching Boost Converter for PhotovoltaicPower-GenerationSystemDoo-Yong Jung, Young-HyokJi, Sang-Hoon Park, Yong-Chae Jung,   and Chung-YuenWon,Senior Member,IEEE
[2]. J.-P. Lee, B.-D.Min,T.-J. Kim, D.-W.Yoo, and J.-Y.Yoo,"Design and controlof novel topology for photovoltaic dc/dc converter with high efficiencyunder wide load ranges," J.Power Electron., vol. 9, no. 2, pp. 300–307,Mar. 2009.
[3]. B.-D. Min, J.-P.Lee, and J.-H. Kim, "A novel grid-connected PV PCSwith new high efficiency converter," J. Power Electron., vol. 8, no. 4,pp. 309–316, Oct. 2008.
[4]. G. Hua, C.-S.Leu, Y. Jiang, and F. C. Y. Lee, "Novel zero-voltagetransitionPWM converters," IEEE Trans. Power Electron., vol. 9, no. 2,pp. 213–219, Mar. 1994.
[5]. G. Hua, E. X. Yang, Y. Jiang, and F. C. Y. Lee, "Novel zero-currenttransitionPWM converters," IEEE Trans. Power Electron., vol. 9, no. 6,pp. 601–606, Nov. 1994.
[6]. H. Bodur and A. F. Bakan, "A new ZVT-ZCT-PWM DC-DC converter,"IEEE Trans. Power Electron., vol. 19, no. 3, pp. 676–684, May 2004.
[7]. H. Bodur and A. F. Bakan, "A new ZVT-PWM DC- DCconverter," IEEETrans. Power Electron., vol. 17, no. 1, pp. 40–47, Jan. 2002.
[8]. N. Jain, P. K. Jain, and G. Joos, "A zero voltage transition boost converteremploying a soft switching auxiliary circuit with reduced conductionlosses," IEEE Trans. PowerElectron., vol. 19, no. 1, pp. 130–139,Jan. 2004.
[9]. S. K. Kwon and K. F. A. Sayed, "Boost-half bridge single power stagePWM DC-DC converters for PEM-fuel cellstacks," J. Power Electron.,vol. 8, no. 3, pp.239– 247, Jul. 2008.
[10].X. Kong and A. M. Khambadkone, "Analysis and implementation of ahigh efficiency, interleaved current— Fed full bridge converter for fuel cellsystem," IEEE Trans. Power Electron., vol. 22, no. 2, pp. 543–   550, Mar.2007.
[11].H. M. Suryawanshi, M. R. Ramteke, K. L. Thakre, and V. B. Borghate,"Unity-power-factor operation of three-phase ac–dc soft switched converterbased on boost active clamp topology in modular approach," IEEE Trans. Power Electron., vol. 23, no. 1, pp. 229–236, Jan.2008.
[12].H. Mao, O. Abdel Rahman, and I.Batarseh,"Zero voltage-switching   dc-dc   converterswithsynchronou rectifiers," IEEE Trans. PowerElectron.,vol. 23, no. 1,   pp. 369–378, Jan. 2008.
[13].H.Tao, A.Kotsopoulos, J.L.Duarte,andM.A.M.Hendrix,"Transformercoupledmultiport ZVS bidirectional dc–dc   converter with wide inputrange," IEEE Trans. Power Electron., vol. 2, pp. 771–781, Mar. 2008.

[14]. H. Xiao and S.Xie, "A ZVS bidirectional dc–dc converter with phase-shiftplus PWM control scheme," IEEE Trans.Power Electron., vol. 23, no. 2,pp. 813–823, Mar. 2008.

[15]. D. V. Ghodke, K. Chatterjee, and B. G. Fernandes, "Three-Phase threelevel, soft switched, phase shifted PWdc-dc converter for high powerapplications," IEEE Trans. Power Electron., vol. 23, no. 3, pp. 1214–1227,May 2008.

[16]. M. Borage, S. Tiwari, S. Bhardwaj, and S. Kotaiah, "A full-bridge dc–dcconverter with zero-voltage-switching over the entire conversion range,"IEEE Trans. Power Electron., vol. 23, no. 4, pp. 1743–1750, Jul. 2008.

[17]. S. Y. Tseng, J. Z. Shiang, H. H. Chang, W. S. Jwo, and C. T. Hsieh, "Anovel turn-on/off snubber for interleaved boost converter," Proc. IEEE38th Annu. Power Electron.Specialists Conf. (PESC 2007), 2718–2724.

[18]. X. Wu, J. Zhang, X. Ye, and Z. Qian, "Analysis andderivations for afamily ZVS converter based on a new active clamp ZVS cell," IEEETrans. Ind. Electron., vol. 55, no. 2, pp. 773–781, Feb. 2008.

[19]. P.-W.Lee,Y.-S.Lee, D. K.W. Cheng, and X.-C. Liu,"Steady-state analysisof an interleaved boost converter with couples inductors," IEEE Trans.Ind.Electron., vol. 47, no. 4, Aug. 2000.

[20]. D.-Y. Jung,Y.-H. Ji, J.-H.Kim, C.-Y.Won,andY.-C. Jung,"Soft is switchingboost converter for photovoltaic power generation system," Proc. 13th