A NOVEL SOFT SWITCHING CONVERTER WITH HIGH VOLTAGE GAIN AND AMPLIFIED EFFICIENCY FOR PHOTOVOLTAIC APPLICATIONS

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Abstract-This paper proposes a soft switching converter with high voltage gain for ac and dc photovoltaic applications. Day to day energy usage is snow balling significantly. Dc-Dc converters are the major consequence in renewable grid connected power applications because of the low voltage PV arrays. This shortcoming is overcome by using a novel soft switching dc-dc converter. This proposed concept is used to change the power efficiency by boosting voltage and also reduces the switching losses and efficiency. This problem is handled by using a high gain interleaved dc boost converter with capacitor and leakage inductor.A passive clamp network round the inductors affords the recapture of energy through leakage inductance leading to upgrading in the voltage gain and efficiency. The benefit of passive clamp network is that it condenses voltage stress on the switch. This proposed converter is designed and implemented by MATLAB/Simulation software and the results are results are validated.

Keywords: voltage gain, bi directional DC-DC converter, Inverter.

I. Introduction

In the last few decades, there has been a drastic increasein the demand for electricity. This has led to rapid use anddepletion of fossil fuels. These factors have led theresearchers to renewable energy sources such as wind,solar PV and fuel cell stack. Solar Photovoltaic (PV) andfuel cell energy sources play a prominent role among theexisting renewable sources poses major challenges such as optimal utilization of the source due to their non-linearcharacteristics (e.g. Maximum Power Point Tracking(MPPT) is required to track maximum available powerfrom a PV source. They are usually operated at low output voltage levels(typ. 25-50V) because of safety issues. This makes theirapplication to grid connected systems and even somestand-alone loads difficult because a large voltage boostingis required.A direct implication of points (a) and (b) is that the use ofa dc-dc converter [1, 2] is essential at the front end, rightacross the source as shown in Fig. 1.
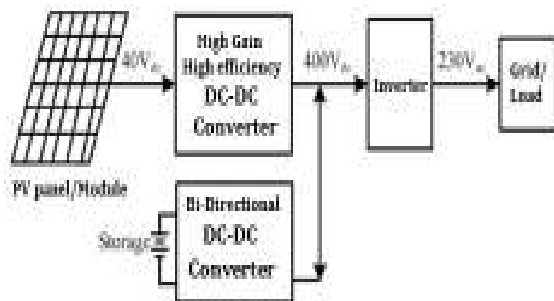

Fig. 1 Block diagram of a PV power conversion system

Use of conventionaldc-dc converters has the following disadvantages: 1. it causes large peak current to flow on the input side, which adversely affects the magnetic

components andresults in high losses. It causes large voltage to appear across the switch. Asthe on state resistance of a switch depends on its voltagerating [$R_{DS (on)}\alpha V_{DS}^2$], the conduction losses increase. Dueto large duty cycle, the losses in parasitic resistances ofinductance and capacitance also increase.Diode reverse recovery becomes a major concern.In view of the above, there is clearly a need to developand use special high gain, high efficiency dc-dc convertersto implement MPPT and to step up voltage level. Severalcircuit topologies have been proposed in the past [3-6] forthis application. They follow one or more of the followingphilosophies to achieve high voltage at the converteroutput.(a)Direct voltage step-up using high frequency transformer.(b) Use of coupled inductor to utilize the energy storagecapability of the magnetizing inductance of the core toincrease the voltage level using turns ratio of the coupledinductor.(c) Use of interleaved coupled inductor that facilitates useof smaller inductors, division of current and highereffective inductance for higher power applications.(d) Active and passive clamp circuits to recover leakageenergy in the coupled inductor based high gain convertersto reduce losses in leakage inductance.(e) Use of intermediate energy storage capacitors asadditional buffers to increase the voltage gain withoutincreasing duty cycle to high value.A brief overview of the high voltage gain topologiesreported in the literature is presented in the next section.
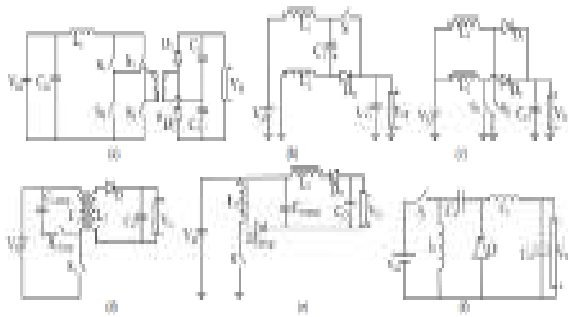
Fig. 2 Circuit diagrams of the high voltage gain dc-dc converters: (a) Isolated current-fed boost converter (b) Coupled inductor boost converter (c) Interleaved coupled inductor boost converter (d)Active clamp converter (e)Passive clamp converter (f) Intermediate Energy storage capacitor based converter

II.Overview of High Voltage Gain Dc-Dc

Converter Topologies

The converters shown in Fig. 2 depict some of the highvoltage gain topologies that are representative of theexisting configurations. Direct voltage step up using highfrequency transformer renders a simple and easilycontrollable converter providing high gain. Isolatedcurrent-fed dc-dc converters [Fig. 2(a), [7-9] are exampleof this category. However these topologies result in highvoltage spikes across the switch (due to leakage inductance)and large ripple in primary side transformer current as theturns ratio in the high frequency transformer increases. Theisolated systems are relatively costly, bulky and generallyless efficient [10] even though they offer more safety,eliminate issues such as ground leakage current and canprovide multiple outputs among other advantages.

Most of the non-isolated high voltage gain dc-dc powerconverters employ coupled inductor (to achieve highervoltage gain) [Fig. 2(b)] [11] in contrast to a highfrequency transformer used by the isolated versions [Fig.2(a)]. The coupled inductor based dc-dc converter hasadvantages over isolated transformer based dc-dc converterin minimizing current stress, using lower ratingcomponents and simple winding structure. Modelingprocedure of the coupled inductor is described in [12]. Forhigh power converter applications interleaved coupledinductor based boost converters [13-15] have also beenproposed [Fig. 2(c)].A demerit of coupled inductor based systems is that theyhave to deal with higher leakage inductance, which causesvoltage spikes across the main switch during turn-off timeand current spike during turn-on time, resulting in areduction of the overall circuit efficiency. The effects ofleakage inductance can be eliminated by using an activeclamp network shown in Fig. 2(d) [9,15], which providesan alternate path to recover leakage energy. But activeclamp network is not as efficient

as a passive clampbecause of conduction losses across the power switch ofthe active clamp [16] network. Active clamp networkconsists of a switch with passive components while passive clamp network [Fig. 2(e)] [4] consists of passive components such as diode, capacitor and resistor. The passive clamp circuit is more popular to reduce voltage stress across the converter switch by recycling leakage energy [17].

Voltage gain of the converter can be increased without increasing the duty cycle of the switch by connecting an intermediate capacitor in series with the inductor [Fig. 2(f)]. The intermediate energy storage capacitor with coupled inductor charges in parallel and discharges in series with the coupled inductor secondary. Various principles discussed in preceding paragraphs have also been used in combinations to achieve highvoltage gain and enhanced features. A coupledinductor type boost converter has been used in associationwith a passive clamp circuit to achieve high gain and increased efficiency. Converter configurations withcoupled inductor in association with a voltage multiplier circuit and/or intermediate capacitor have alsobeen reported to achieve high voltage gain. In recent times,use of coupled inductors along with intermediatecapacitors has also become popular.Keeping in mind the merits and demerits of the variousschemes described in preceding paragraphs, a noveltopology has been proposed in this paper that achieveshigh voltage through a coupled inductor connected ininterleaved manner that charges an intermediate buffercapacitor and a passive clamp network to recover theleakage energy. Coupled inductor leads to the incorporation of 'turn's ratio' into the gain expression that leads to high efficiency without increasing the duty ratio. As compared to existing high gain dc-dc converters, the number of passive components used in the proposed converter is less, which reduces the cost and improves the efficiency. Though the proposed converter is applicable to any low voltage source application (e.g. solar PV, Fuel cell stack, battery etc.), this paper focuses only on the solar PV source. All the details of this work are presented in the subsequent sections of the paper.

III. Description of the Proposed Converter

Energy conversion efficiency of solar PV is quite low (about 12–25%) [24]. Therefore, it is essential to use a highly efficient power conversion system to utilize the PV generated power to the maximum. The proposed high gain dc-dc converter configuration is shown in Fig. 3.
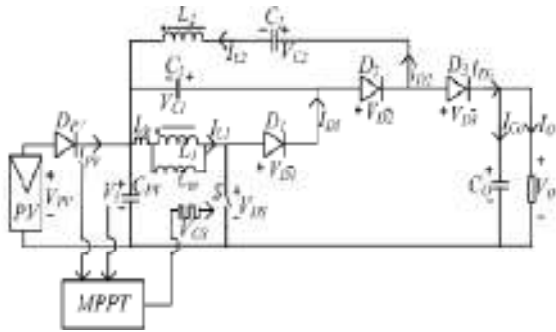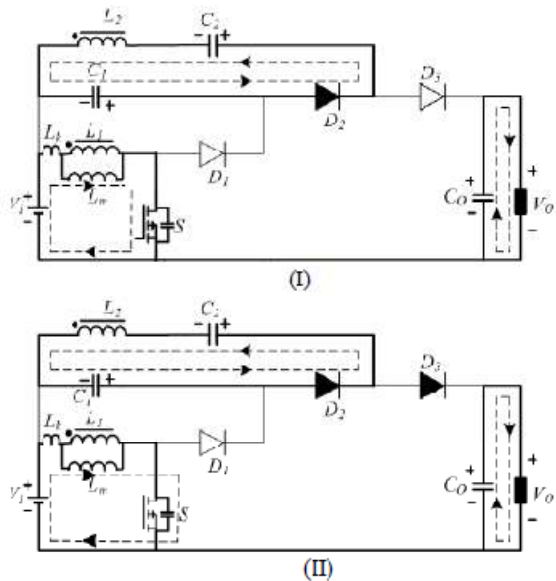
Fig. 3 Circuit diagram of proposed dc-dc converter

It consists of one passive clamp network, a coupled inductor (L1,L2) and an intermediate capacitor apart from other components.The symbol VPV represents the PV voltage applied to the circuit. S is the main switch of the proposed converter. The coupled inductor's primary and secondary inductors are denoted by L1 and L2. C1 and D1 represent the passive clamp network across L1. The capacitor CO is the output capacitor while D3 is the output diode. The voltage VO is the average (dc) output across the load. The intermediate energy storage capacitor, C2 and the feedback diode D2 are connected on the secondary side.

(I)

(II)

The gain ratio, n is given by:

$$n = \frac{V_{L2}}{V_{L1}}$$

Where, VL1 and VL2 represent the voltages across inductorsL1 and L2. The operating modes for continuous conductionmode (CCM) are shown in Fig. 4. Various operatingmodes are described below:

Mode 1[t0-t1]: The switch (S) is turned on at the start of the converter operation. The current flows through the switch and the primary side of the coupled inductor (L1),

energizing the magnetizing inductance (Lm) of the coupled inductor. The current path is as shown in Fig. 4(I).

Mode 2[t1-t2]: The two diodes, D1 and D3 are reverse biased, while D2 is forward biased during this mode. The intermediate capacitor, C2 is charged through D2 by L2 and capacitor, C1. If voltage across intermediate capacitor (C2) becomes equal to the summation of voltages across L2 and C1, diodeD2 turns off. The parasitic capacitance of the switch S is charged by the magnetizing current flowing through the inductor L1. The diode D2 remains forward biased and current continues to flow through this. Current path in this mode is shown in Fig. 4(II).
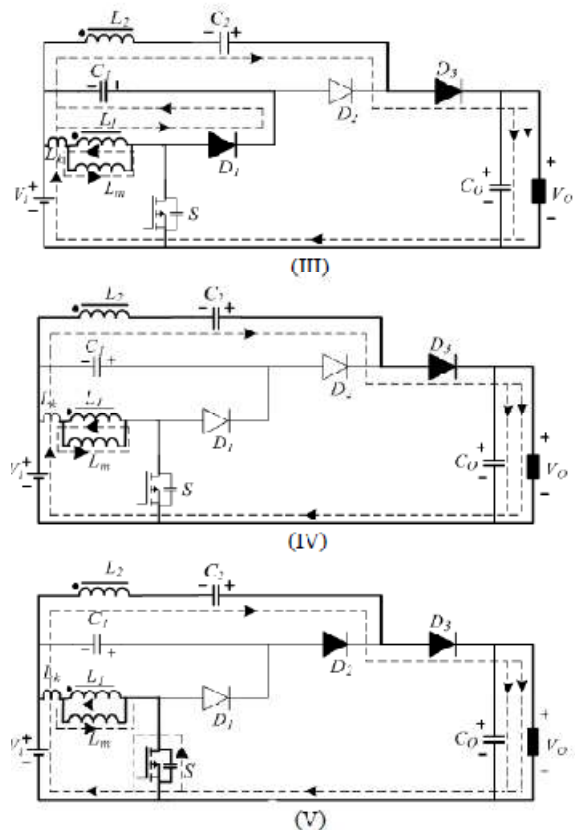

(III)

(IV)

(V)

Fig. 4 Various modes of opération during CCM: (I) Mode 1; (II) Mode 2;

(III) Mode 3; (IV) Mode 4 ; (V) Mode 5.

Mode 3[t2-t3]: In this mode, diodes D1 and D3 become forward biased. D2 is reverse biased and its current becomes zero in this mode. The leakage energy stored in the primary side of the coupled inductor (L1) is recovered and stored in the clamp capacitor (C1) through D1. Also, the energy is transferred from the input side to the output side through diode D3 as shown in Fig. 4(III).

Mode 4[t3-t4]: This mode begins after the completion ofrecovery of the leakage energy from inductor L1. The diodeD1 now becomes reverse biased while diode D3

remainsforward biased in this mode. The current flows from theinput side to the output side to supply the load as shown inFig. 4(IV).

Mode 5[t4-t0]: This mode begins by turning on switch S.The leakage inductor energizes quickly using the fullmagnetizing current while the parasitic capacitance acrossthe switch discharges in this mode. The two diodes D1 andD2 are in reverse biased condition. The current flow path inthis mode is shown in Fig. 4(V). This mode ends whendiode D3 becomes reverse biased and current flow throughinductor, L2 changes direction. Thevoltage (VDS) across the switch 'S' cannot changeinstantaneously and decreases slowly. Thus, there is little overlap of falling voltage and rising current and negligible switching loss at turn-on. Typical waveforms of the circuit are shown in Fig. 5.
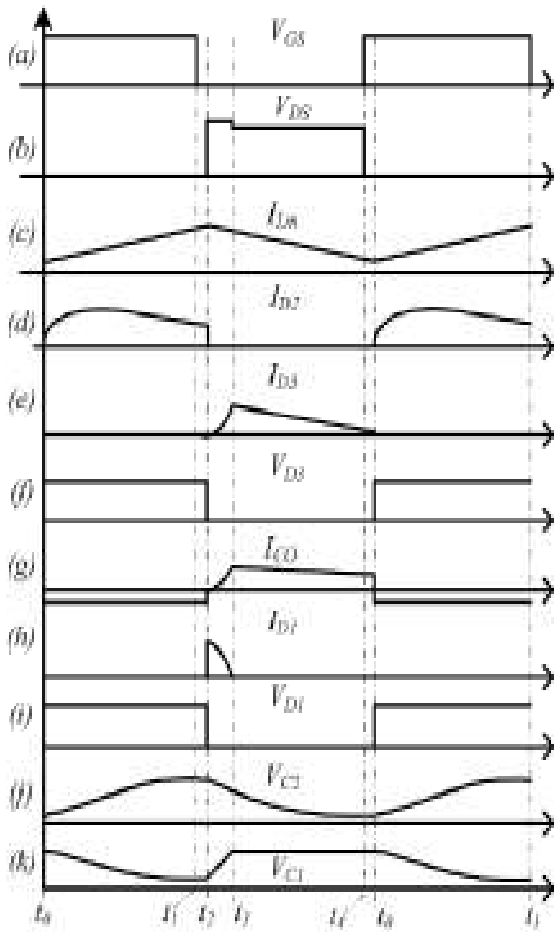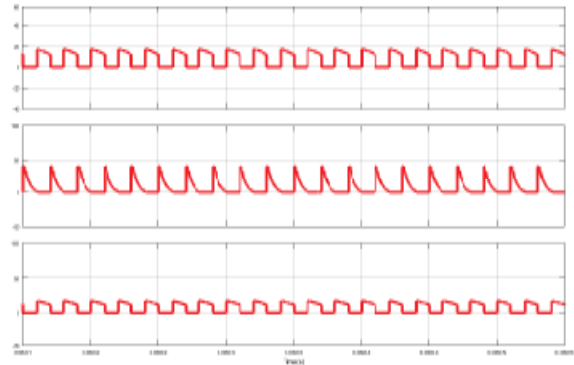

Fig.6. Current through diode d1, d2, d3.

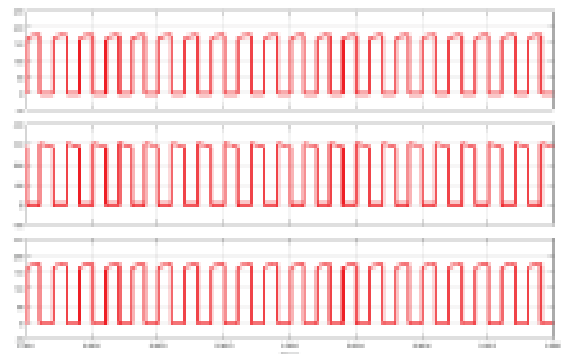

Fig.7. Voltage across diode d1, d2, d3.

Fig.8. Output voltage of the solar PV system

Fig. 5 Typical waveforms during CCM operation.

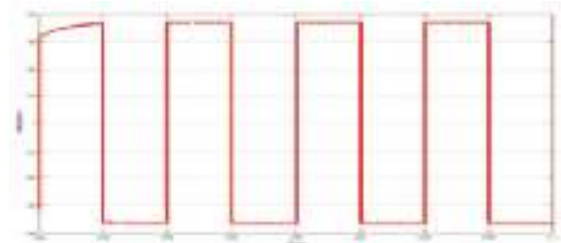**IV.Simulation Results**
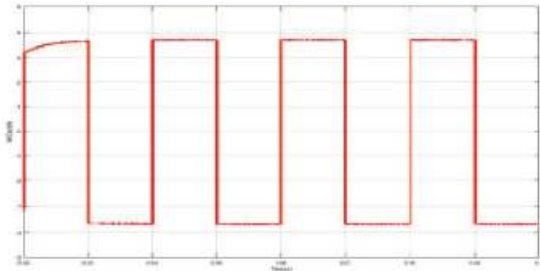
Fig.9. AC Output Current.
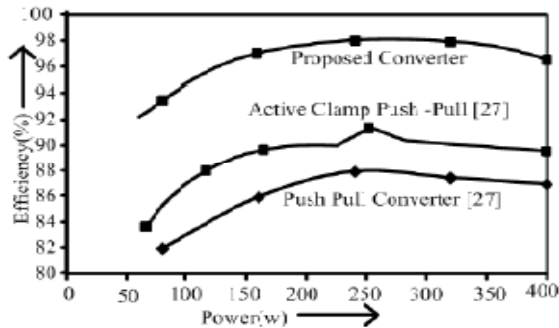
Fig.10. AC Output Current.

Fig.11. Efficiency versus load curve for the proposed dc-dc converter and comparison with existing versions;

Efficiency plot with respect to load variation of the proposed converter is shown in Fig. 8(i). The efficiency plot of the proposed converter is compared with conventional push-pull converter having identical inputoutput voltage ratings (Vi=40V; Vo=400V) and operating frequency (50kHz). Full load (400W) efficiency of the converter, obtained from experimentation, is 96% (maximum ≈ 97% at lighter load). A comparison is also shown with conventional, hard switched push pull converter (of identical rating, operating frequency and input/output voltage specifications) with and without active clamp across the main switch. The proposed system shows a higher efficiency under all load conditions.

V. Conclusion

The high gain, high frequency converter proposed in this paper is suitable for low output voltage sources such as solar PV, fuel cell stack and battery. The circuit efficiency can be achieved nearly 96%. The proposed converter has turns ratio of inductor around 4 or 5 and duty cycle may be 0 to 0.7. High voltage gain is achieved without extreme duty cycle. The reason for high efficiency is reduction in switching losses. Moreover high gain design is implemented to achieve higher value of output voltage. The major advantage of proposed converter is that it is applicable for both AC and DC loads.

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