PWM Contol of High Gain Sepic Boost Converter With Coupled Inductor and Charge Pump Capacitor

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Abstract— ***The demand for Electrical energy is increasing with the advancement of Technology. The distributed generation based system with renewable energy resources have rapidly developed in recent years. These distributed generation systems are powered by sources such as fuel cell, photovoltaic (PV) systems and batteries. This consists of two conversion stages, in the first stage the low level voltage from the PV cell is converted to high level voltage by using a dc-dc converter. In the second stage the high level dc voltage is converted into AC voltage by using inverter. To attain the high energy demand requirements the efficiency of the systems must be increased. The energy demand requirements can be achieved by increasing the gain of the converter. The paper introduces a high gain boost converter which is derived from basic the single-ended primary-inductor converter (SEPIC) topology. The proposed converter achieves high gain by using coupled inductor and charge pump capacitor. The regenerative snubber helps to attain zero voltage and zero current switching (zvs and zcs) conditions, which improve the converter efficiency. The proposed converter also inherits the SEPIC advantage of continuous input current.***

Keywords— *boost conveter, coupled inductor, regenerative snubber, soft switching (zvs and zcs).*

1. INTRODUCTION

The energy shortage and atmospheric pollution led to more researches on the renewable energy sources such as the solar arrays (PV cells) and fuel cells. Renewable energy systems generate low voltage output; thus, high step-up dc-dc converters are widely employed in many renewable energy applications. Among renewable energy systems, photovoltaic systems are expected to play an important role in future energy production. Such systems transform light energy into electrical energy, and convert low voltage into high voltage via a step-up converter, which can convert energy into electricity using a grid-by-grid inverter [1]. The high step up converter performs importantly among the system because the system requires a sufficiently high step-up conversion. Classical converters with magnetic coupling as flyback or current-fed push-pull converters easily achieve high step-up voltage. But the disadvantages of the isolated dc-dc converters are large size, high switching losses and large electro-magnetic interference. Therefore non-isolated converters are widely used in many applications.

Conventional boost converters can be used for this purpose, but to enhance the output voltage of PV systems to such a higher value the duty cycle of the converter must be very high i.e around 0.9. This is not feasible due to the reverse recovery problem of the diode. To overcome this drawback number of topologies has been proposed. Voltage multiplier technique is applied to a classical non-isolated dc-dc converter in order to obtain high step-up gain [6]. The basic structure of the single phase voltage multiplier cell is composed of diodes, capacitors and a resonant inductor. It is possible to add more multiplier cells in order to achieve higher step-up ratios. The voltage multiplier cell increases the static gain of the classical boost by a factor of (M+1). Where M is the number of multiplier cells. The main disadvantage of this technique is usage of large number of components that increases the losses.

Switched capacitor and switched inductor structures are proposed for obtaining transformer less hybrid dc-dc PWM converters [7]. These switched structures are introduced in classical converters in order to achieve high conversion ratio. When the active switch of the converter is on, the inductors in the inductor switching blocks are charged in parallel or capacitors in the capacitor switching blocks are discharged in series. When the switch is turned off, the inductor in the L-switching blocks are discharged series or capacitors in C –switching blocks are charged parallel. Main disadvantages of this technique is increased the component count, cost and control complexity.

Voltage lift technique has been proposed in sepic converters [8]. Voltage lift technique is different from switched capacitor technique. In voltage technique both inductors and capacitors plays important role. The advantages of this converter compared to other converters are small ripple and high efficiency in simple structures.

The cascade boost converter is derived from the elementary boost converter by adding the parts (L–D–C). In this technique, the output voltage increase in a simple geometric progression. Main disadvantage is high conduction loss that decreases the overall converter efficiency.

A new trend for increasing DC voltage gain in boost converter is use of coupled inductor/tapped inductor [11]. High gain is achieved by increasing the turns ratio of the coupled inductor. By using coupled inductor, two advantages can be achieved. First, it helps to reduce the input ripple and second, it makes the total inductor size low because of using only one core and bobbin. But the converter efficiency is degraded by the losses associated with the leakage inductance.

Active clamp coupled inductor based converter is proposed [17]. In this converter, the passive lossless clamp circuit is replaced by active clamp circuit. Therefore both main and auxiliary switches are turned on at zero voltage switching. The main disadvantage of this converter is the voltage stress of the output diode is higher than its output voltage. The resonance between the leakage inductance and stray capacitor of the output diode that causes electromagnetic interference problems. , and create further increase in the output diode voltage stress.

In [18], different types of high step-up tapped inductor sepic converters are proposed. Sepic converter is a type of dc-dc converter. The sepic converter is a boost converter followed by a buck-boost converter. The output has the same voltage polarity as the input.

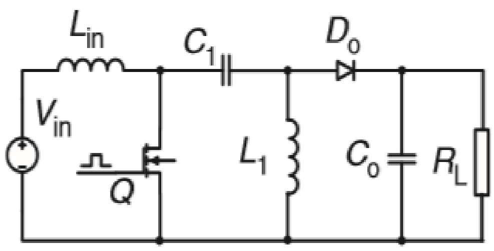


Fig 1: Traditional sepic converter

The traditional sepic converter shown in fig 1. Coupled inductor or tapped inductor introduced in traditional sepic converter to achieve high gain i.e L_1 of the traditional sepic converter is replaced by a coupled inductor or tapped inductor shown in fig 2. Therefore gain of the converter is increased by increasing the turns ratio of the coupled inductor.

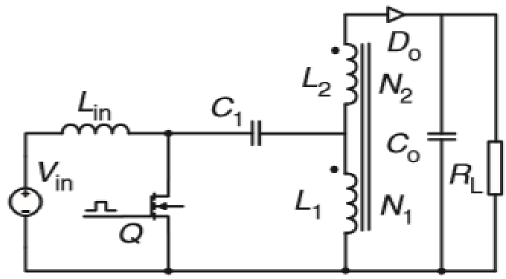


Fig 2: Sepic converter with coupled inductor

Coupled inductor sepic converter scheme for maximum power point tracking is proposed. In photovoltaic cells, the pulsating input current periodically shift the operating point. Therefore, tracking of maximum power point (MPP) is difficult. The main feature of the sepic converter is that pulsating current of the coupled inductor does not flow at the input port. Due to this property of sepic converter they are mostly used in PV applications. The main advantages of the converter compared to the classical converter are low array current ripple, load voltage has the same polarity as that of supply voltage, low ripple amplitude of SCA current that reduces electro-magnetic interference. The main disadvantage is it requires additional capacitor and inductor compared to that of classical converter.

High step-up gain dc-dc converter is proposed for microgrid system [21]. In this converter, the capacitors charges in parallel and discharges in series manner with the coupled inductor in order to achieve high output voltage. The converter has low conduction losses but the leakage inductor in the coupled inductor causes power losses and high voltage spikes. Therefore passive clamp circuit is required for recycle the leakage inductor energy of the coupled inductor.

Coupled inductor sepic converter with reduced voltage stress is proposed [22]. The splitting of the secondary inductor into two windings that reduces the voltage stresses on the diodes and switches. The voltage stress on the diodes and switches is less than that of the output voltage. Soft switching can be achieved.

Nonisolated high step-up boost converter integrated with sepic converter topology introduced in [23]. In this topology, the classical boost converter combines with the isolated converter. The converter provides additional gain with the help of the isolated converter. The main advantages of the converter are high boosting capability and distributed voltage stress.

RC-RCD clamp circuit is proposed for reducing ringing losses in flyback converter [24]. RCD clamp circuits are normally used to limit the voltage spikes, which is caused by the primary leakage inductance. The proposed clamp circuit improves the power ratio of the flyback converter.

The regenerative snubber for transformer isolated converters is proposed. Different snubber circuits are RCD snubber, Zener diode snubber and non-dissipative LCD snubber. RCD snubber allows the discharging of leakage inductance energy to the snubber capacitor and then trapped energy in the snubber capacitor is dissipated through the snubber resistor. The advantage of Zener diode over the RCD snubber is that the switch voltage stress is independent of load or duty cycle. In the case of lossless LCD snubber, when switch is turned off the primary leakage inductance is discharged into the snubber capacitor. As the switch is turned on the trapped energy is partially forward to the output side and partially feedback to the supply side. The analysis of regenerative snubber using graphical stste- plane technique presented in [26]. This technique gives a clear idea of the design procedure for minimum voltage stress.

The first approach developed to control SMPS applications is "Voltage control Mode". In Voltage mode, the actual output voltage is compared to the desired output voltage and the error signal is used to adjust the PWM duty cycle to control the voltage across the inductor. Later, Current-Mode control was developed to correct some issues known with voltage mode. Current-mode uses the error between the desired and actual output voltages to control the peak current through the inductor. Voltage mode control, where the output voltage is the control endpoint, is conceptually easier to understand than current mode control and sensing voltages is easy. The voltage mode control only needs to monitor the output voltage so only one feedback path is required, thus simplifying the design of the converter. Therefore PWM control technique is adopted to regulate the output voltage.

This paper is organized as follows. Section 2 and 3 describes high gain sepic converter and its operation. MATLAB simulation along with results is explained in Section 4. Finally, the conclusion is stated in Section 5.

2. HIGH GAIN SEPIC CONVERTER

The paper introduces a high gain dc-dc boost converter for renewable energy systems. The basic configuration of proposed boost converter shown in fig.3. The converter is derived from a traditional sepic converter. The high gain boost converter comprised of input inductor L_{in}, coupled inductor T1, charge pump cell, buffer capacitor, regenerative snubber, output capacitor and load resistor R_L. The charge pump cell consists of C_2, D_1, and D_o. The regenerative snubber can provide zero-voltage and zero-current switching and recycles the captured leakage energy to the capacitor C_1, which improves the efficiency of the converter.

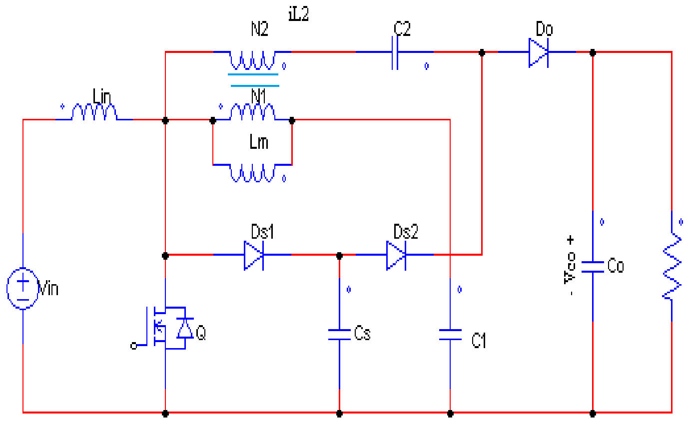


Fig .3: circuit diagram of the high step up converter.

2. OPERATION OF THE CONVERTER

The switch Q is turned ON, the supply voltage V_{in} is applied across the inductor L_{in} and the input current starts increasing. The secondary leakage inductance keeps discharging through the diode D_o to the output and the secondary current decays to zero and the diode D_o has entered cut off. Therefore snubber diode D_{s2} starts conduct and allows the C_s to resonant with the secondary leakage inductance and dumps the captured energy in the snubber capacitor into charge pump capacitor C_2. During this time secondary current i_{L2} reverses. When the snubber capacitor voltage drops to zero, D_{s1} starts to conduct and snubber capacitor clamps to ground. The charge pump capacitor attain fully charged condition, the secondary current decays to zero, the diodes D_{s1} and D_{s2} cut off at zero current. Therefore input inductor and magnetizing inductance of coupled inductor keeps charging. When the switch is turned off, at this instant voltage across the snubber capacitor is zero. Therefore zero voltage switching is achieved. During this interval snubber capacitor keeps charging and at the same time secondary current builds up through the charge pump capacitor and output diode. When the snubber capacitor voltage reaches its peak voltage and diode D_{s1} cut off and both input inductor and magnetizing inductance of coupled inductor discharges to the output. Therefore the output voltage equals to the charge pump capacitor, buffer capacitor and (1+n) times of the magnetizing inductance voltage.

3. SIMULATION RESULTS

The simulation of high gain converter with coupled inductor and charge pump capacitor has been carried out. An input voltage of 12V and switching frequency of 60 kHz is chosen and an output of 130V is obtained. The duty ratio of the switch is equal to 0.53 and the corresponding parameters are listed in Table I. Fig 4 shows the simulation waveforms of the converter (a) the input voltage, output voltage and current waveforms. (b) Voltage and current across the switch. Zero voltage and zero current switching is achieved. (c) Input inductor current, primary and secondary current of the coupled inductor. (d) Output diode voltage and current waveform. Fig 5, fig 6 shows the waveform of line and load regulation respectively.

TABLE I. SIMULATION PARAMETERS

Parameters	value
Input voltage Vs	12V
Output voltage Vo	130V
Output power Po	15W
Switching frequency fs	60kHz
Turns ratio	4
Magnetizing inductance	257.4μ H
Output filter capacitor Co	0.796μF
Charge pump capacitor C2	0.798μF
buffer capacitor C1	12.77μF
Snubber capacitor	7.68nF

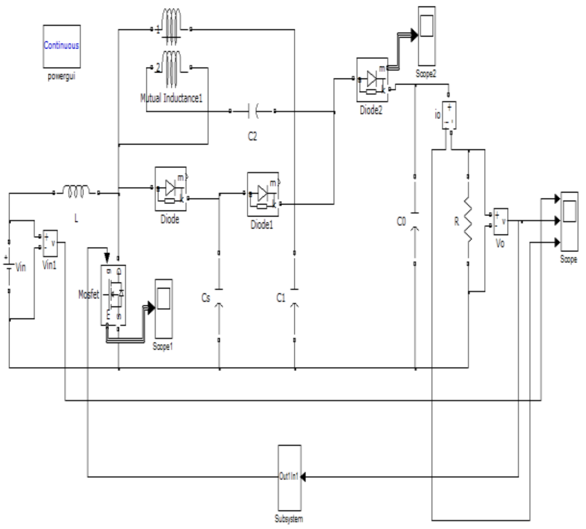
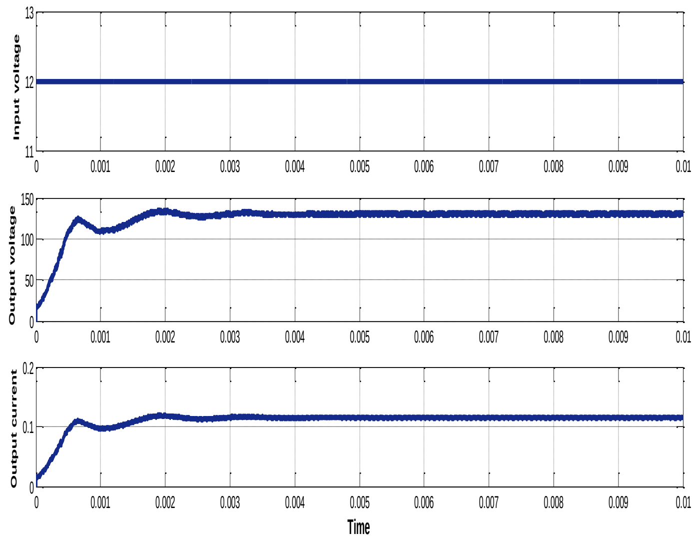
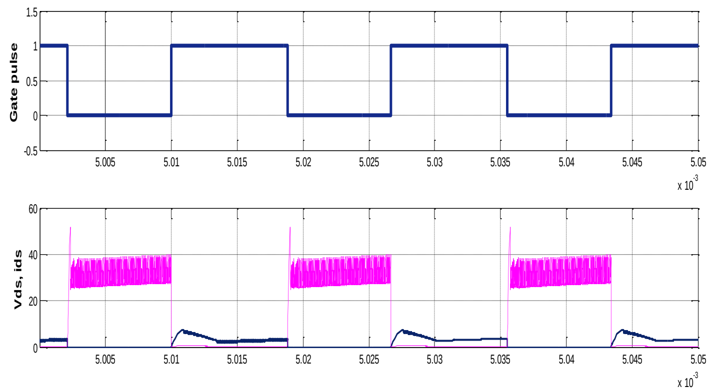


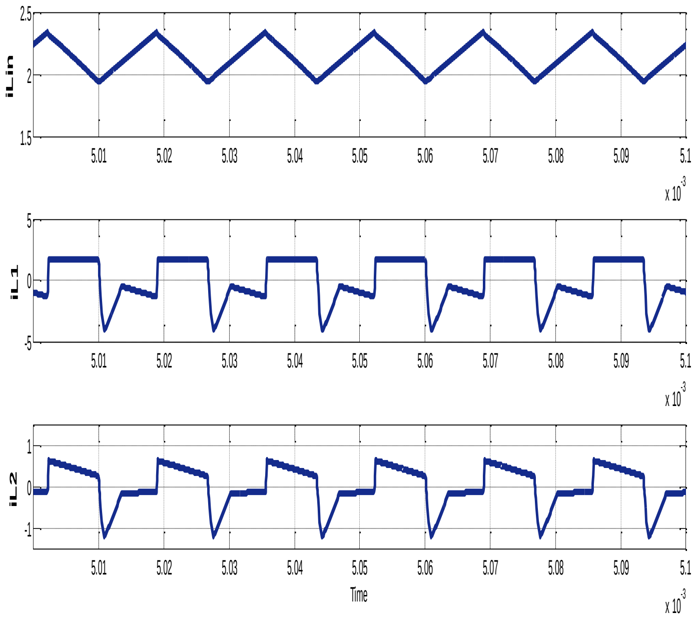
Fig 4: Simulink model of the converter



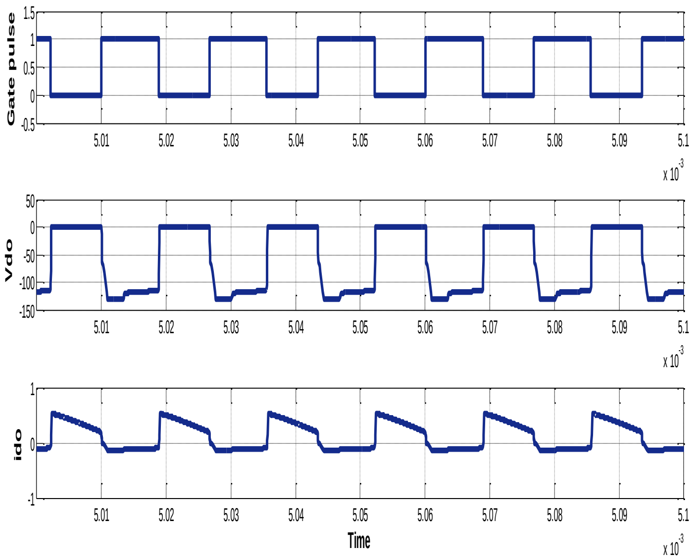
(a) Input and output voltage, output current



(b) Switch voltage Vds and switch current ids



(c) Input inductor current i_{lin}, primary and secondary currents of coupled inductor i_{L1} and i_{L2},



(d) Output diode voltage V_{Do} and output diode current i_{Do}

Fig 4: simulation results: **(a)** input and output voltage, output current, **(b)** switch voltage V_{ds} and switch current ids, **(c)** input inductor current i_{lin}, primary and secondary currents of coupled inductor i_{L1} and i_{L2}, **(d)** output diode voltage V_{Do} and output diode current i_{Do}

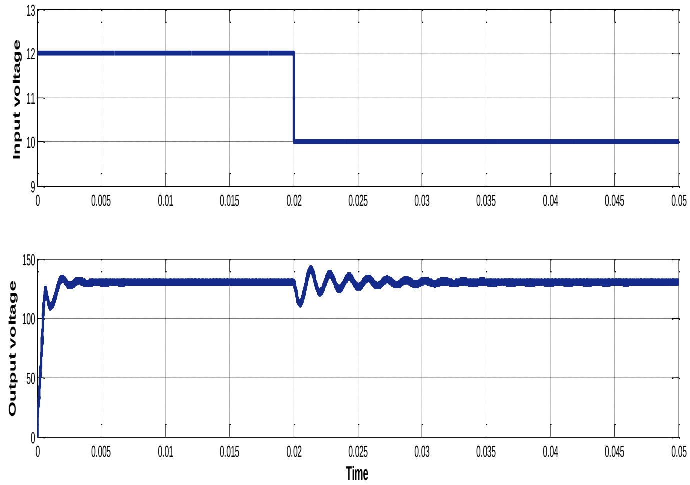


Fig5: Line regulation of the converter

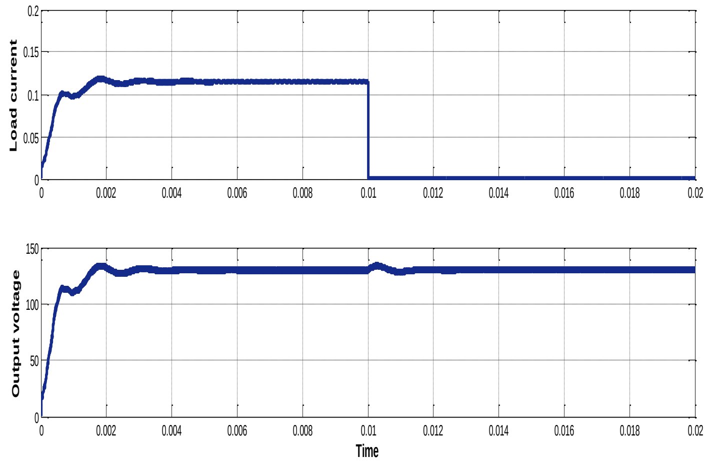


Fig 6: load regulation of the converter

4. CONCLUSIONS

The paper introduces a PWM control of high gain sepic boost converter. High gain is achieved by using coupled inductor and charge pump capacitor cell without extreme value of duty cycle. Inductorless passive regenerative snubber helps the converter to attain zero-voltage and zero-current switching, which improves converter efficiency. The validity is tested by using the MATLAB software and obtained the required output.

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