A BI-DIRECTIONAL SWITCHED CAPACITOR DC/DC CONVERTER WITH COUPLED INDUCTOR FOR PHOTOVOLTAIC APPLICATIONS

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ABSTRACT

In this paper, a bi-directional high step-up dc/dc converter is proposed for renewable energy applications. The proposed topology consists of a coupled inductor and two voltage multiplier cells, in order to obtain high step-up voltage gain. In addition, two capacitors are charged during the switch-off period, using the energy stored in the coupled inductor which increases the voltage transfer gain. The energy stored in the leakage inductance is recycled with the use of a passive clamp circuit. The voltage stress on the main power switch is also reduced in the proposed topology using ZVS and ZCS technique. Therefore, a main power switch with low resistance $R_{DS}(ON)$ can be used to reduce the conduction losses. The operation principle and the steady-state analyses are discussed thoroughly. The results are analyzed using MATLAB/Simulink software for theoretical analyses of proposed high step-up converter.

Keyword: - *DC-DC Converter, ZVS, ZCS, Mosfet, Solar PV*

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1. INTRODUCTION

Now a days there is a lot of demand for clean and sustainable energy sources has dramatically increased during the past few years with growing population and industrial development. For a long time, fossil fuels have been used as the major source of generating electrical energy. Environmental consequences of these resources have made it necessary to benefit from clean energy sources such as wind and solar. Therefore, distributed generation (DG) systems based on renewable energy sources have attracted the researchers' attention. The DG systems include photovoltaic (PV) cells, fuel cells and wind power [1]–[3]. However, the output voltages of these sources are not large enough for connecting to ac utility voltage. PV cells can be connected in series in order to obtain a large dc voltage. However, it is difficult to ignore the shadow effect in the PV panels [4]–[6]. High step-up converters are a suitable solution for the aforementioned problem. Each PV panel can be connected to a particular high step-up converter. Therefore, each panel can be controlled independently. These converters boost the low-input voltages (24–40 V) to a high-voltage level (300–400 V) [7]. The main features of high step-up converters are their large conversion ratio, high efficiency, and small size [8]–[10]. Theoretically, conventional boost converters can achieve high-voltage gain with an extremely high duty ratio [11]. However, the performance of the system will be deteriorated with a high duty cycle due to several problems such as low conversion efficiency, reverse-recovery, and electromagnetic interference problems [12].

Some transformer-based converters like forward, push–pull or flyback converters can achieve high step-up voltage gain by adjusting the turn ratio of the transformer. However, the leakage inductor of the transformer will cause serious problems such as voltage spike on the main switch and high power dissipation. In order to improve the conversion efficiency and obtain high step-up voltage gain, many converter structures have been presented. Switched capacitor and voltage lift techniques have been used widely to achieve high step-up voltage gain. However, in these structures, high charging currents will flow through the main switch and increase the conduction losses.

Coupled-inductor-based converters can also achieve high step-up voltage gain by adjusting the turn ratios. However, the energy stored in the leakage inductor causes a voltage spike on the main switch and deteriorates the conversion efficiency. To overcome this problem, coupled-inductor-based converters with an active-clamp circuit have been presented. Some high step-up converters with two-switch and single-switch are introduced in the recent published literatures. However, the conversion ratio is not large enough.

This paper presents a novel high step-up dc/dc converter for renewable energy applications. The suggested structure consists of a coupled inductor and two voltage multiplier cells in order to obtain high-step-up voltage gain. In addition, a capacitor is charged during the switch-off period using the energy stored in the coupled inductor, which increases the voltage transfer gain. The energy stored in the leakage inductance is recycled with the use of a passive clamp circuit. The voltage stress on the main power switch is also reduced in the proposed topology. Therefore, a main power switch with low resistance R_{DS} (ON) can be used to reduce the conduction losses. The operation principle and the steady-state analyses are discussed thoroughly

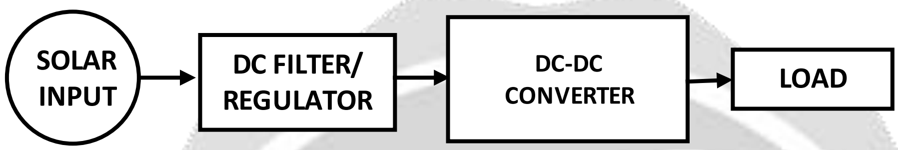

Fig-1: Block diagram of proposed system

2. PROPOSED TECHNIQUE

This chapter presents a novel high step-up dc/dc converter for renewable energy applications. The suggested structure consists of a coupled inductor and two voltage multiplier cells in order to obtain high-step-up voltage gain. In addition, a capacitor is charged during the switch-off period using the energy stored in the coupled inductor, which increases the voltage transfer gain.

2.1 OPERATING PRINCIPLE OF THE PROPOSED CONVERTER

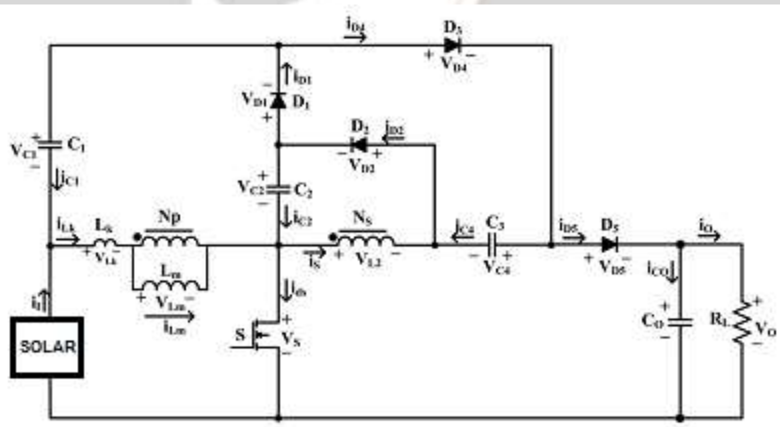

Fig-2: Circuit configuration of the presented high-step-up converter

The circuit configuration of the proposed converter is shown in Fig. 2. The proposed converter comprises a dc input voltage (*VI*), active power switch (S), coupled inductor, four diodes, and four capacitors. Capacitor *C*1 and diode *D*1 are employed as clamp circuit respectively. The capacitor *C*3 is employed as the capacitor of the extended voltage multiplier cell. The capacitor *C*2 and diode *D*2 are the circuit elements of the voltage multiplier which increase the voltage of clamping capacitor *C*1. The coupled inductor is modeled as an ideal transformer with a turn ratio *N* (*N*P/*N*S), a magnetizing inductor *Lm* and leakage inductor *Lk* .

In order to simplify the circuit analysis of the converter, some assumptions are considered as follows:

1) All Capacitors are sufficiently large; therefore *VC*1, *VC*2, *VC*3, and *VO* are considered to be constant during one switching period;

2) All components are ideal but the leakage inductance of the coupled inductor is considered.

According to the aforementioned assumptions, the continuous conduction mode (CCM) operation of the proposed converter includes five intervals in one switching period. The current-flow path of the proposed converter for each stage is depicted in Fig. 5.2. Some typical waveforms under CCM operation are illustrated in Fig. 5.3. The operating stages are explained as follows.

1) Stage I *[$t0 < t < t1$ see Fig. 5.2(a)]:* In this stage, switch S is turned ON. Also, diodes $D2$ and $D4$ are turned ON and diodes $D1$ and $D3$ are turned OFF. The dc source (VI) magnetizes Lm through S. The secondary-side of the coupled inductor is in parallel with capacitor $C2$ using diode $D2$. As the current of the leakage inductor Lk increases linearly, the secondary side current of the coupled inductor (iS) decreases linearly. The required energy of load (RL) is supplied by the output capacitor CO. This interval ends when the secondary-side current of the coupled inductor becomes zero at $t = t1$.

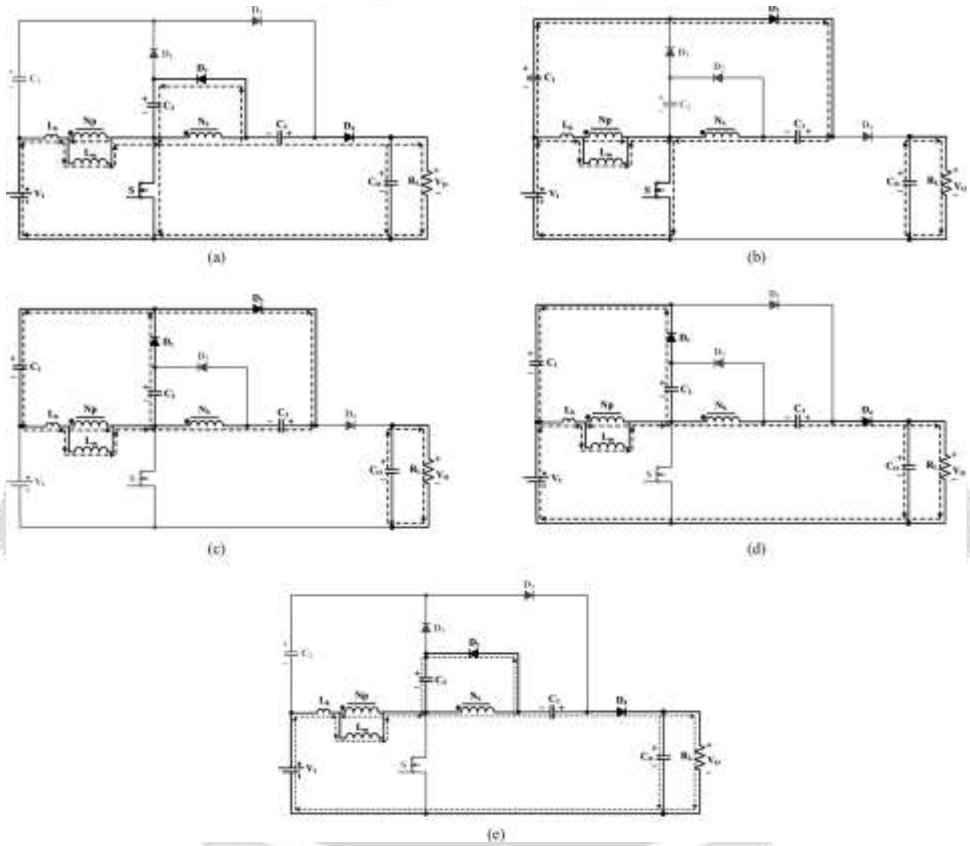

Fig-3: Current-flow path of operating modes during one switching period at CCM operation. (a) Mode I. (b) Mode II. (c) Mode III. (d) Mode IV. (e) Mode V.

2) *Stage II [$t1 < t < t2$ see Fig. 5.2(b)]:* In this stage, switch S and diode $D3$ are turned ON and diodes $D1$, $D2$, and $D4$ are turned OFF. The dc source VI magnetizes Lm through switch S. So, the current of the leakage inductor Lk and magnetizing inductor Lm increase linearly. The capacitor $C3$ is charged by dc source VI, clamp capacitor and the secondary-side of the coupled inductor. Output capacitor CO supplies the demanded energy of the load RL. This interval ends when switch (S) is turned OFF at $t = t2$.

3) *Stage III [$t2 < t < t3$ see Fig. 5.2(c)]:* In this stage, switch S is turned OFF. Diodes $D1$ and $D3$ are turned ON and diodes $D2$ and $D4$ are turned OFF. The clamp capacitor $C1$ is charged by the stored energy in capacitor $C2$ and the energies of leakage inductor Lk and magnetizing inductor Lm. The currents of the secondary-side of the coupled inductor (iS) and the leakage inductor are increased and decreased, respectively. The capacitor $C3$ is still charged through $D3$. Output capacitor CO supplies the energy to load RL. This interval ends when iLk is equal to iLm at $t = t3$.

4) *Stage IV [t3 < t < t4 see Fig. 5.2(d)]:* In this stage, S is turned OFF. Diodes *D*1 and *D*4 are turned ON and diodes *D*2 and *D*3 are turned OFF. The clamp capacitor *C*1 is charged by the capacitor *C*2 and the energies of leakage inductor *Lk* and magnetizing inductor *Lm*. The currents of the leakage inductor *Lk* and magnetizing inductor *Lm* decrease linearly. Also, a part of the energy stored in *Lm* is transferred to the secondary side of the coupled inductor. The dc source *VI,* capacitor *C*3 and both sides of the coupled inductor charge output capacitor and provide energy to the load *RL*. This interval ends when diode *D*1 is turned OFF at *t* = *t*4.

5) *Stage V [t4 < t < t5 see Fig. 2(e)]:* In this stage, S is turned OFF. Diodes *D*2 and *D*4 are turned ON and diodes *D*1 and *D*3 are turned OFF. The currents of the leakage inductor *Lk* and magnetizing inductor *Lm* decrease linearly. Apart of stored energy in *Lm* is transferred to the secondary side of the coupled inductor in order to charge the capacitor *C*2 through diode *D*2 . In this interval the dc input voltage *VI* and stored energy in the capacitor *C*3 and inductances of both sides of the coupled inductor charge the output capacitor *C*o and provide the demand energy of the load *RL*. This interval ends when switch S is turned ON at *t* = *t*5.

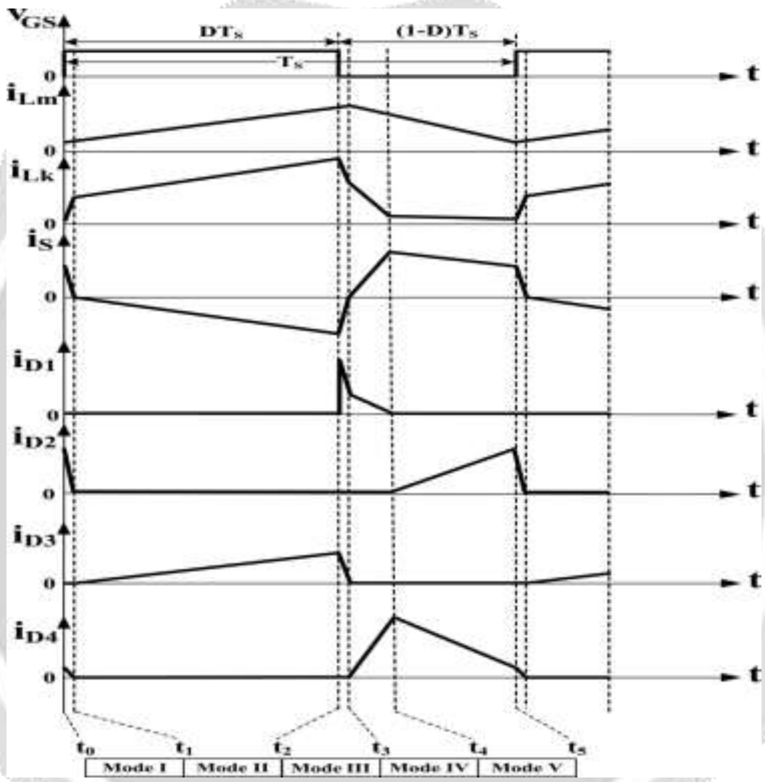

Fig-4: Some typical waveforms of the proposed converter at CCM operation.

4 SIMULATION RESULTS

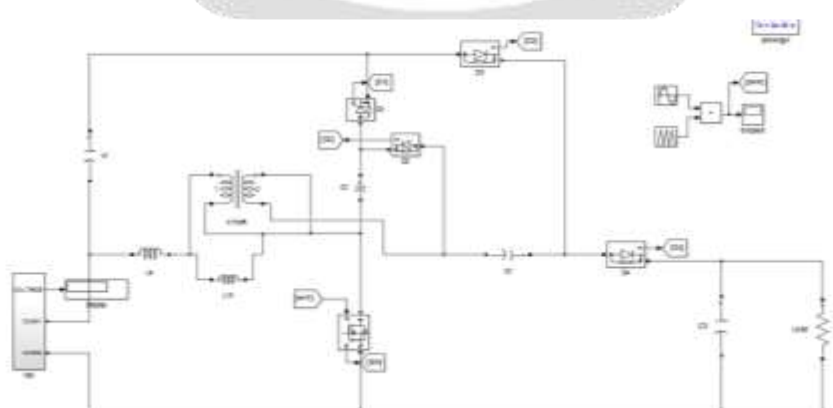

Fig-5 : simulation circuit of the proposed system

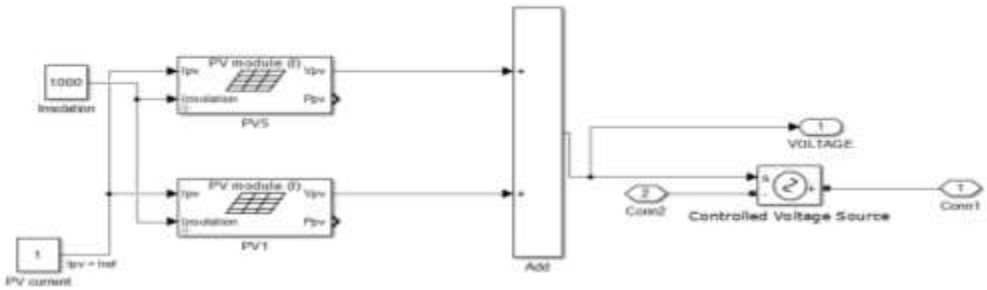

Fig-6: solar PV internal design

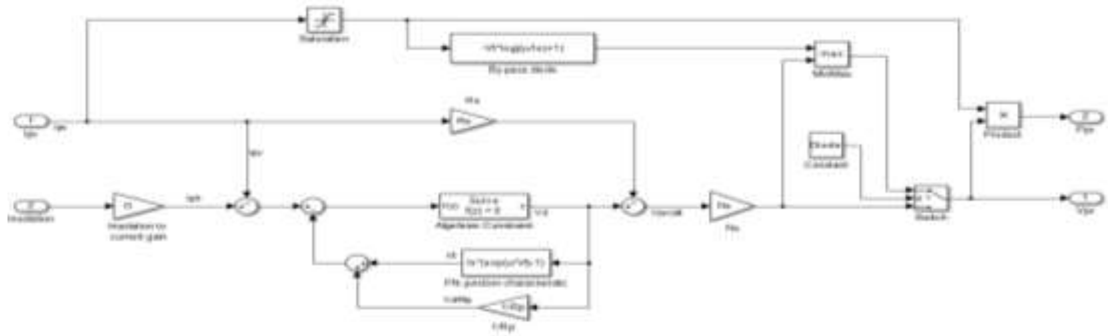

Fig-7: equivalent circuit of solar cell

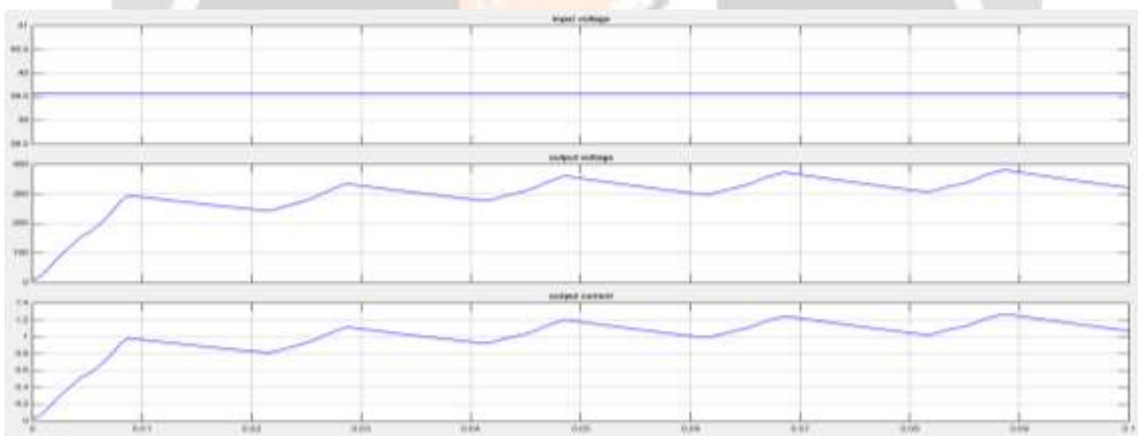

Fig-8: input voltage, output voltage and current waveform

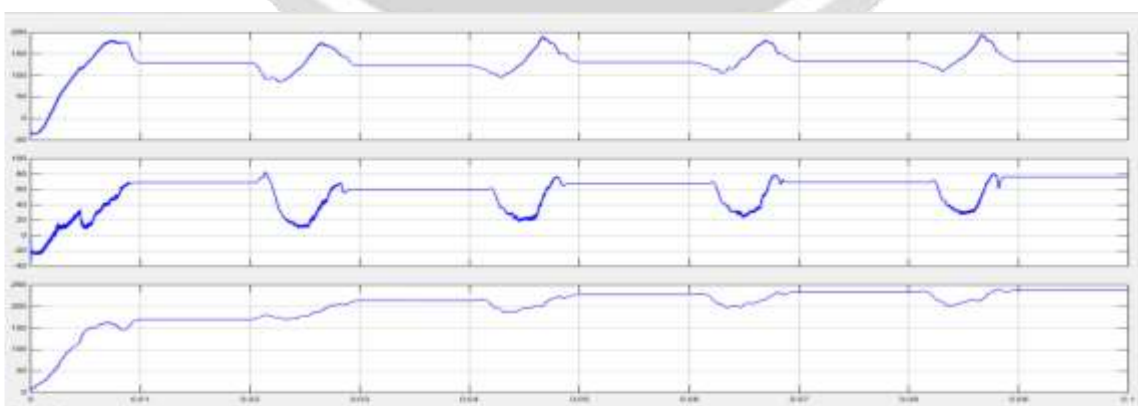

Fig-9: voltage across the capacitors C1, C2, and C3

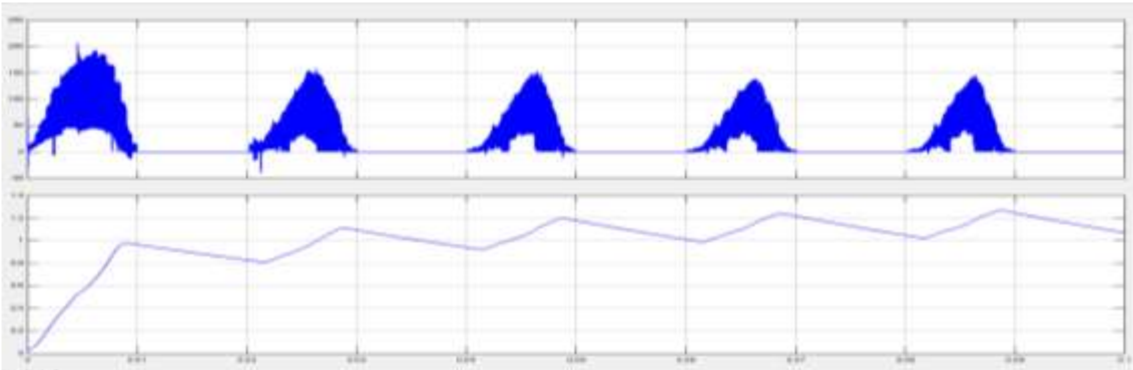

Fig-10: leakage and load currents

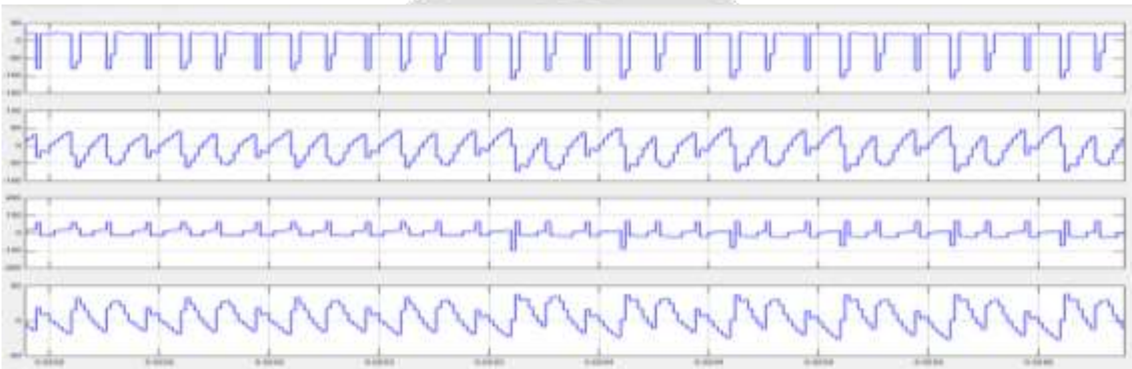

Fig-11:voltage and current through transformer

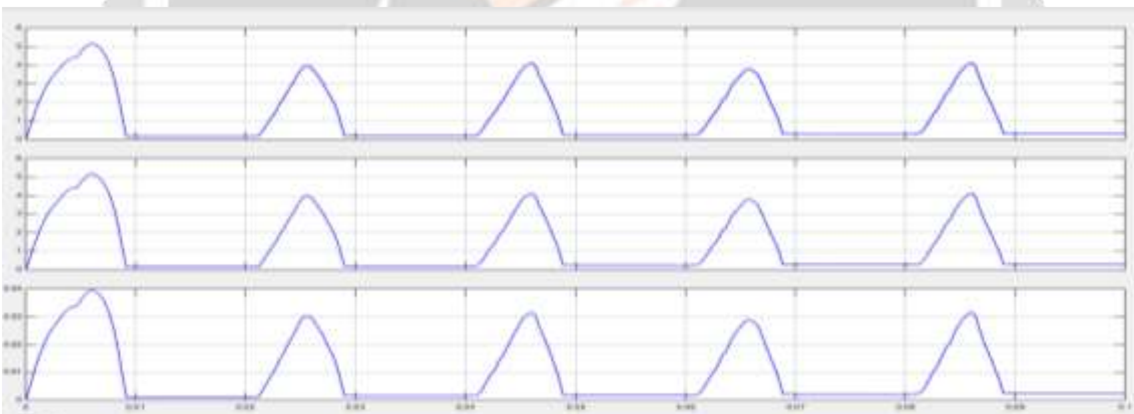

Fig-12: Voltage of capacitance

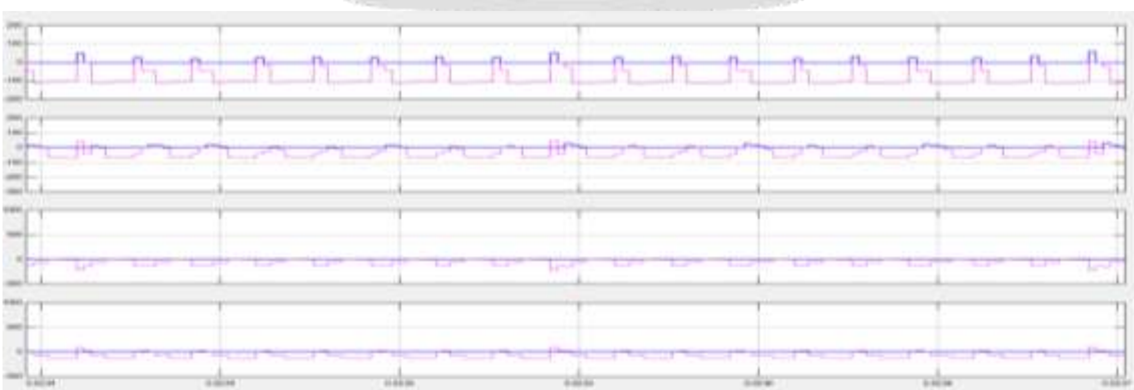

Fig-13: Voltage and current of diodes

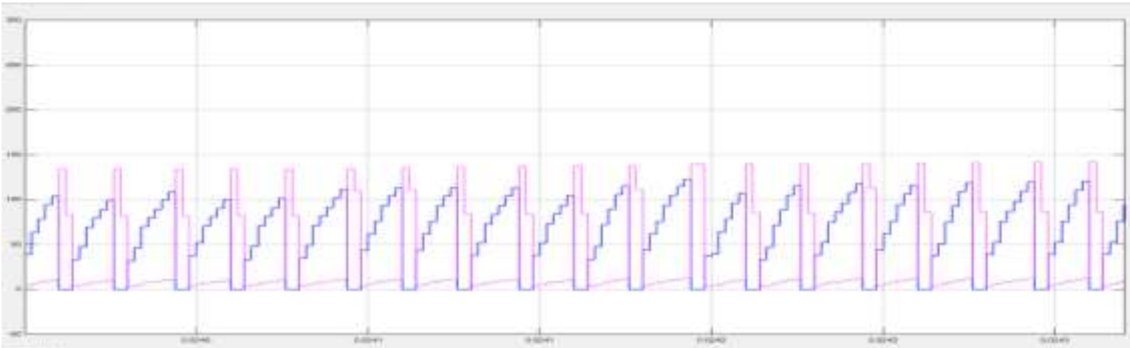

Fig-14: Voltage and current of switch S1

5. CONCLUSIONS

This paper presents a new high-step-up dc/dc converter for renewable energy applications. The proposed converter is suitable for DG systems based on renewable energy sources, which require high-step-up voltage transfer gain. The energy stored in the leakage inductance is recycled to improve the performance of the presented converter. Furthermore, voltage stress on the main power switch is reduced. Therefore, a switch with a low on-state resistance can be chosen. The steady-state operation of the converter has been analyzed in detail. Also, the boundary condition has been obtained. To analyze the proposed converter, MATLAB software has used with 40-V input voltage into 400-V output voltage. The results prove the feasibility of the presented converter.

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6. REFERENCES

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