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Simulation of Isolated High Step-Up DC-DC Converter with Low Voltage Stress

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ABSTRACT:Continuous input currents and high step-up ratios are desired from the DC-DC converters that work with renewable energy sources such as photovoltaic panels and fuel cells. Most DC-DC converters use transformers to have high step-up ratios. There are another types of converters that use coupled inductors, but they need to be operate at high duty cycles to increase the gain. These converters suffer from low efficiency values because of the leakage inductance values and long reverse recovery times of the diodes. A new DC-DC converter based on Z-source topology is presented in this study. It uses coupled inductors to increase the step-up ratio. Its main features are high step-up ratios, continuous input currents, high efficiency and galvanic isolation between input and output. Simulation results are given for a prototype converter that converts 6-100 V DC at 10 W. The model is simulated in MATLAB/Simulink environment.

KEYWORDS: Coupled-inductor, Z-source converters.

I. INTRODUCTION

The rapid increase in energy consumption overloads the distribution grids as well as the power stations. It also reduces power availability, security and quality of the system. One of the solutions for overcoming this is the Distributed Generation (DG) system [1]. Distributed generating units include Renewable energy sources such as solar photo voltaic (PV), fuel cells and wind generators are gaining importance in today's scenario because of depletion of fossil fuels and the growing energy demands. These sources produces DC voltages and they have to be converted to AC voltages through inverters for supplying power to the grid [2-4]. But the DC voltage output of solar PV panels is in too low to be directed converted to AC using the inverters. The voltage level can be increased by connecting the PV panels in series, but shading effects and voltage drops on wiring reduce the efficiency of the system. Also if the panels are connected in series, a fault in one of the panels will result in all the other series panels getting out of operation. The solution is to connect the PV panels in parallel and increase the DC voltage level using high gain DC-DC converters. This structure is less prone to shading problem and maximum power point tracking algorithms can be independently applied to each panel. DG systems have the advantage that the power is produced in close proximity to where it is consumed. The efficiency of commercial PV panels is around 15-20 percent Therefore, one of the major research area regarding PV systems is that how to transfer this available power to useful purposes without much losses in interfacing power electronic systems.

The DC-DC converter in boost converter configuration can be used to increase the DC voltage level. At the same time the boost converter steps-down the current as a natural result of the energy conservation principle. Gain of the conventional boost circuit is given by, $\frac{1}{1-D}$(D is the duty ratio). In theory if we increase the duty ratio to 0.95 we get the output voltage 20 times the input voltage according to the output voltage equation of boost converter. The major problem with this high duty cycle operation is that it will drastically reduce the efficiency of the circuit due to increased losses. Some limitations of conventional boost converter under high duty cycle operation are the current ripples of the switches and the output diodes are large. The switch voltage stress is equal to the output voltage, which is large in high output voltage applications. The switching losses and the output diode reverse-recovery losses are large due to the hard switching operation and high switch voltage stress.

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These limitations can be overcome by using coupled inductors to attain high gains in DC-DC converters. To attain high efficiency values, leakage inductance should not impose any voltage stress over switches and diodes. Z-source topology of DC-DC converters can provide a gain of $\frac{1}{1-2D}$as opposed to the gain of $\frac{1}{1-D}$in the conventional boost topology. Thus it can provide more gain and result in higher efficiency. A DC-DC converter with coupled inductor based on Z-source topology [5-6] is presented in this paper. Chapter 2 gives details of recent literature in this area. Chapter 3 gives the principle of operation of the converter. The simulation results are given in Chapter 4 and Chapter 5 gives the conclusion and future scope.

II.LITEARTURE SURVEY

Many modified boost converter topologies are designed to overcome the demerits of the Conventional boost converters. Some are Converters with Coupled Inductor, Converters with Switched Capacitors, and Converters with Voltage Multiplier Cell. One of the earliest topologies of high gain DC-DC converter is the high step up coveter with coupled inductor and clamp capacitor [7]. The leakage energy can be recycled using a clamp capacitor. High step-up fly-back boost converter with coupled inductor topology [8] and topology with coupled inductor adds with two pairs of additional capacitors and diodes [9] to achieve high step-up voltage gain. Low efficiency and high switch voltage stress are drawbacks. Switched capacitor [10] using only switches and capacitors, no use of inductors. It has less power loss due to the two symmetric short paths of charge pumps. It substantially reduces total capacitor voltage ratings.These converters need complex cascaded connections, it reduces the efficiency. The Cockcroft Walton multiplier, (CW) is a voltage multiplier that converts AC or pulsing DC electrical power from a low voltage level to a higher DC voltage level [11]. It is made up of a voltage multiplier ladder network of capacitors and diodes to generate high voltages. The complexity and cost of the proposed converter is high because an isolated circuit is necessary to drive the power semiconductor switches. It have reduced switch stresses, the switching losses, and EMI noise.

Z – Sourcehave been recently proposed as an alternative power conversion concept as they have both voltage buck and boost capabilities. It have a unique impedance network, coupled between the power source and converter circuitThe z-source converters overcome the conceptual and theoretical limitations of traditional V-source and I-source converters. The Z-source network provides a second-order filter, so it is more effective to supress voltage and current ripples than capacitor and inductor used alone. It have high voltage gain for same duty cycle ratio and also reverse recovery problem is lower than other topologies. Lower inrush current, lower harmonic injection, and improved reliability are the advantages of Z-source topology compared to conventional DC-DC converters.

III.PRINCIPLE OF OPERATION

The DC-DC converter circuit is shown in figure1.It has one coupled inductor with four windings. For the ease of understanding, it is shown in the figure as if there are two cores, T_1 and T_2. However, in real circuit, all coils are wound

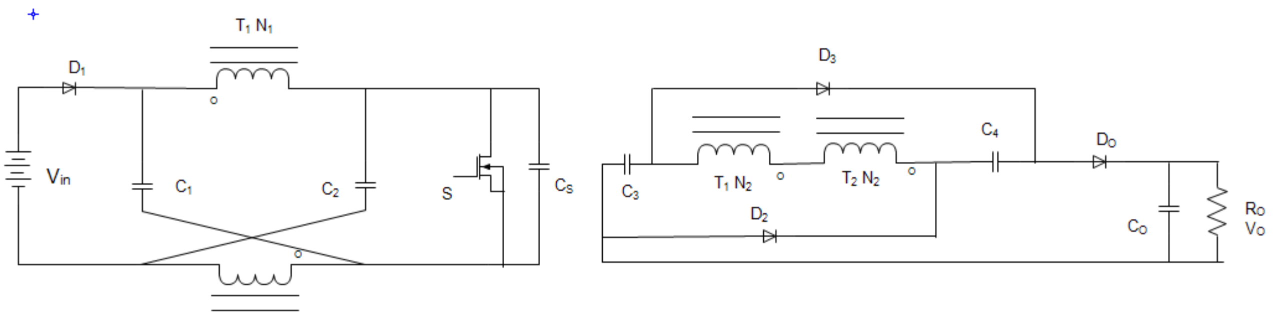

Figure 1

on the same core. Each coupled inductor has two windings, with turns $N_1$and N_2 respectively. Primary and secondary inductances of the coupled inductors are L_1 and L_2. The detailed representation of the converter is shown in figure2.The

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equivalent model of the coupled inductors includes the magnetizing inductors Lm, the primary leakage inductor Llk1, the summation secondary leakage inductor Llk2, and an ideal transformer.

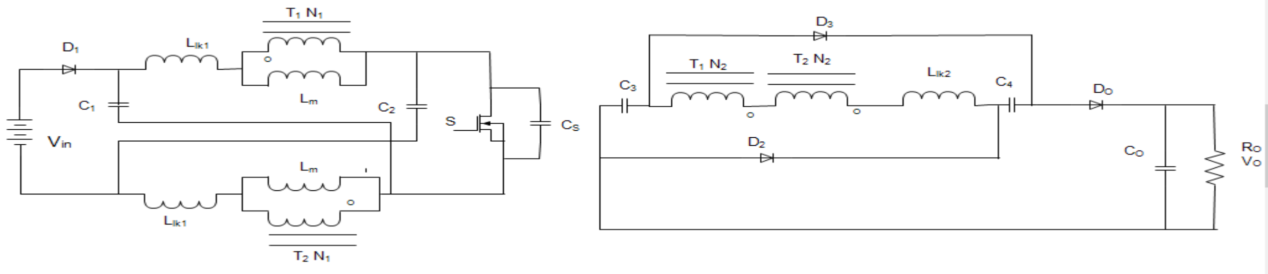

Figure 2

Each switching period can be divided in to seven subintervals in Continuous Conduction Mode operation.

Mode 1: shown in figure 3

- Short mode.
- Switch is conducting.
- The stray capacitor C_s quickly discharges.
- The capacitors C_1 and C_2 are discharged.
- The magnetizing and leakage inductors L_m and L_{lk1} are charged by VC voltage.
- The leakage inductor Ll_{k2} discharges its energy through parallel the capacitors C_3 and C_4.
- C_o is discharged through the load ends at $t = t_1$ when $i_{D2} = i_{D3} = 0$.

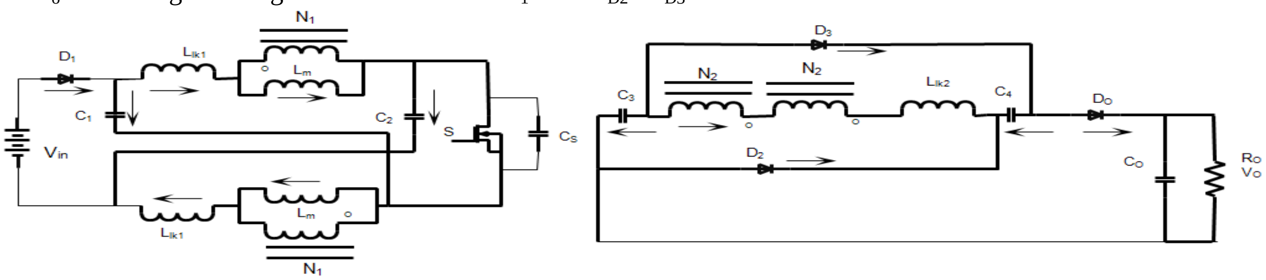

Figure 3

Mode 2: shown in figure 4

- Short mode.
- Switch is conducting.
- The diode D_0 conducts and the diodes D_1, D_2 and D_3 are OFF.
- The capacitors C_1 and C_2 are discharged.
- The inductors L_m and L_{lk1} as in mode 1.
- The capacitors C_3 and C_4 are in series and discharged through the load.
- The capacitor C_0 is charged.
- This mode ends when $v_{L2} = nv_{L1}$ at $t = t_2$.

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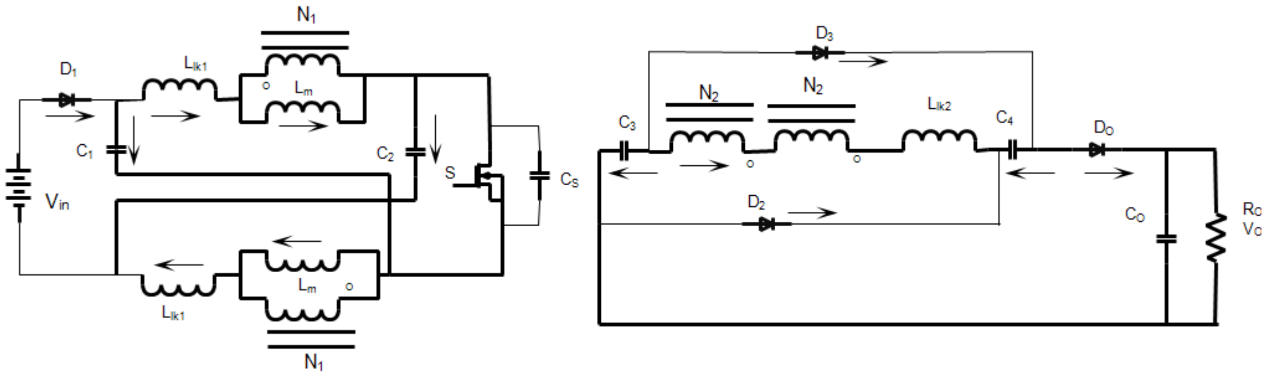

Figure 4

Mode 3: shown in figure 4

- The magnetizing inductor L_m transfers the stored energy to the secondary.
- The secondary side of the coupled inductors is in series with the capacitors C_3 and C_4.
- Charging C_3 and C_4 to a voltage level depending on the conversion ratio.
- This mode ends at $t = t_3$ when the switch is turned OFF.

Mode 4: shown in figure 5

- Short mode.
- Stray capacitor C_s starts to charge quickly.
- The diodes, capacitors, and inductors keep their states as in Mode 3.
- Mode ends when the diode D_1 starts conducting and the voltage on the switch is equal to $\frac{Vin}{1-2D}$ at $t = t_4$.

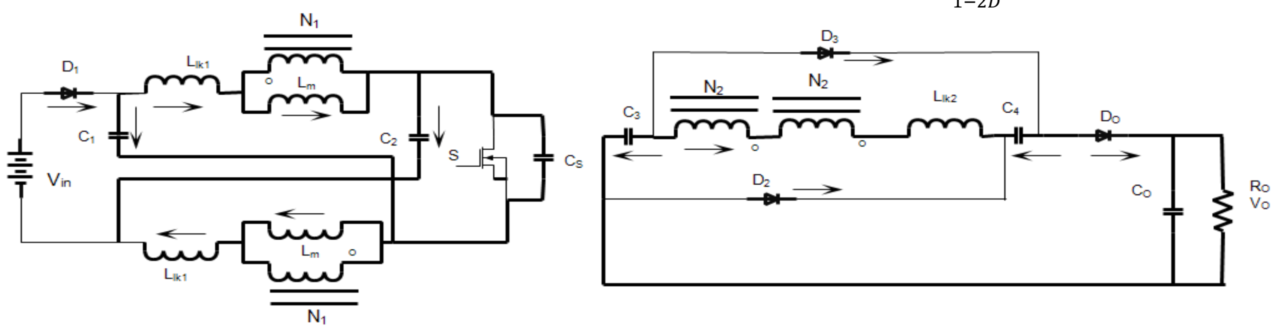

Figure 5

Mode 5: shown in figure 6

- Short mode.
- The switch is in OFF state.
- The diodes D_2 and D_3 are OFF and D_0 and D_1 conduct the current.
- The energy stored in L_m and L_{lk1} is discharged through C_1, C_2 and the source.
- The leakage inductor L_{lk2} discharges its energy through the series capacitors C_3 and C_4 and the load.
- The capacitor C_0 is charged.
- Mode ends when the diode $D_0$is OFF at $t = t_5$.

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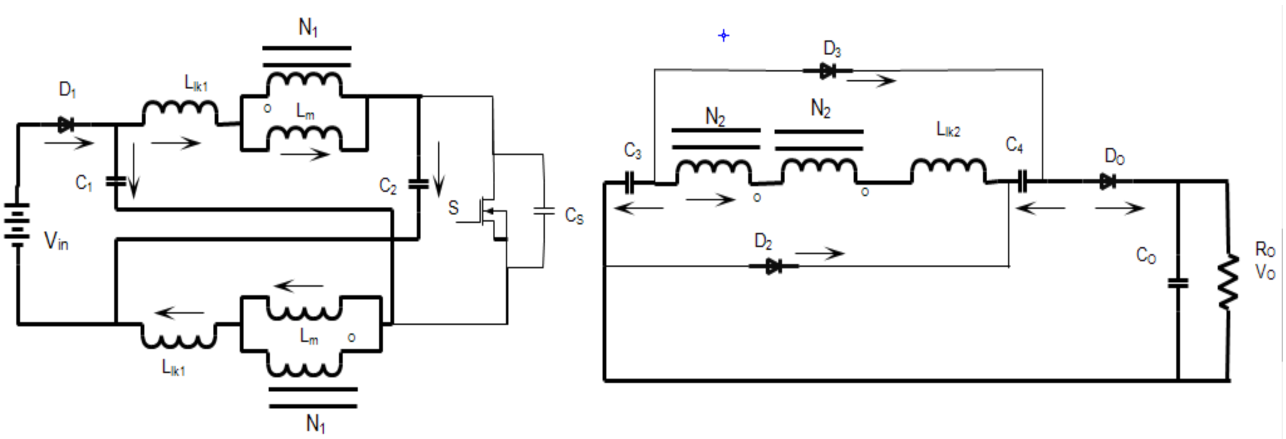

Figure 6

Mode 6: shown in figure 7

- Short mode.
- The diodes D_1, D_2, and D_3 conduct the current.
- Energy stored in L_m and L_{lk1} is discharged through the capacitors C_1 and C_2 and the source.
- The capacitors C_1, C_2, C_3, and C_4 are charged.
- The secondary current i_{L2} quickly increases.
- The load capacitor C_0 is discharged through the load.
- This mode ends when $v_{L2} = nv_{L1}$ at $t = t_6$.

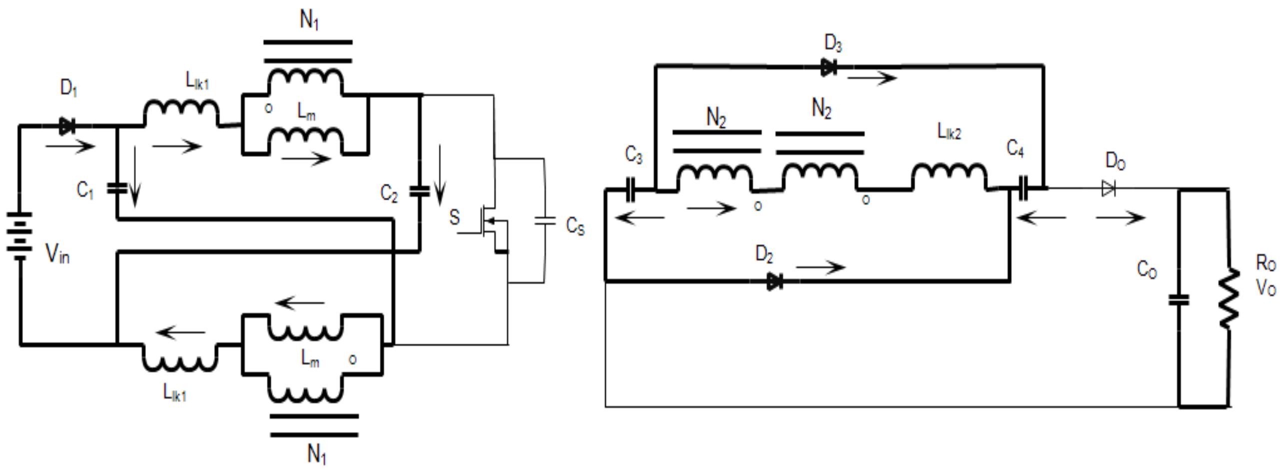

Figure 7

Mode 7: shown in figure 7

- The stored energy in L_m is transferred to the secondary side.
- The capacitors C_1 and C_2 was charged.
- The secondary of the coupled inductors is in parallel to the capacitors C_3 and C_4.
- Charging C_3 and C_4 to a voltagelevel depending on the conversion ratio.
- Mode ends when the switch is turned ON at $t = t_7$.

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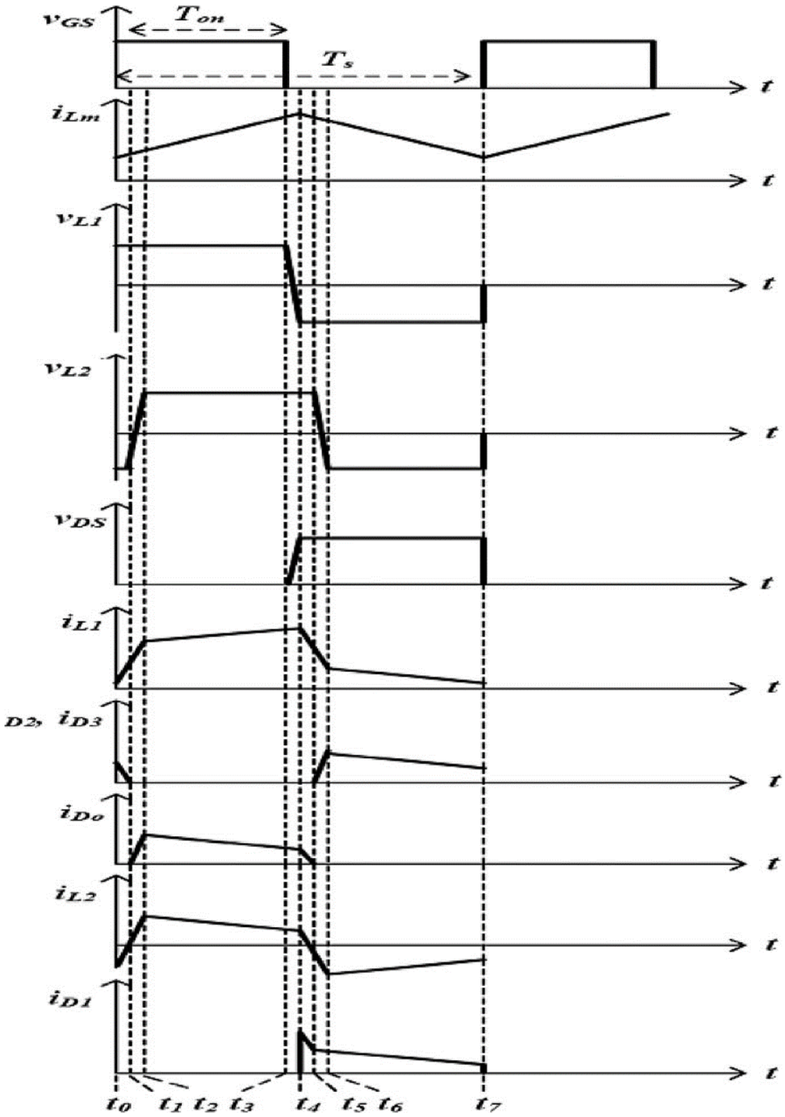

Figure 8

The waveforms describing the operation in these modes are given in figure 8. Mode 3 and mode 7 are the two main intervals during which the switch is ON or OFF for a long time. Other modes are very short and descries transitions. The current i_{Lm} never be zero in any modes of operation.

IV.SIMULATION

DC-DC boost converter with a 6-V input voltage and 100-V output voltage and maximum output power of 10-Wis simulated using MATLAB/Simulink. There is one coupled inductor with four windings in the real circuit. For ease of understanding it is taken as two coupled inductors T_1andT_2.Turns ratio of these windings areN_1andN_2.primary and secondary inductance of the coupled inductors are L_1andL_2.The primary and the secondary windings of the coupled inductor are 8 and 22 turns, respectively. DC-DC boost converter with a 6-V input voltage and 100-V output voltage and maximum output power of 10-W is simulated using MATLAB/Simulink. There is one coupled inductor with four windings in the real circuit. For ease of understanding itis taken as two coupled inductors T_1andT_2.Turns ratio of these

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- Input DC voltage (Vin) :6V
- Output DC voltage (Vo) :100V
- Maximum output power (Po) :10W
- Switching frequency (fs): 50 kHz
- Power switch: MOSFET
- Voltage Gain =16
- Duty cycle ratio (D) =0.28
- Turns ratio (n) =2.9
- Coupling coefficient (k)=1
- Resistor =1000

Closed loop simulation layout:

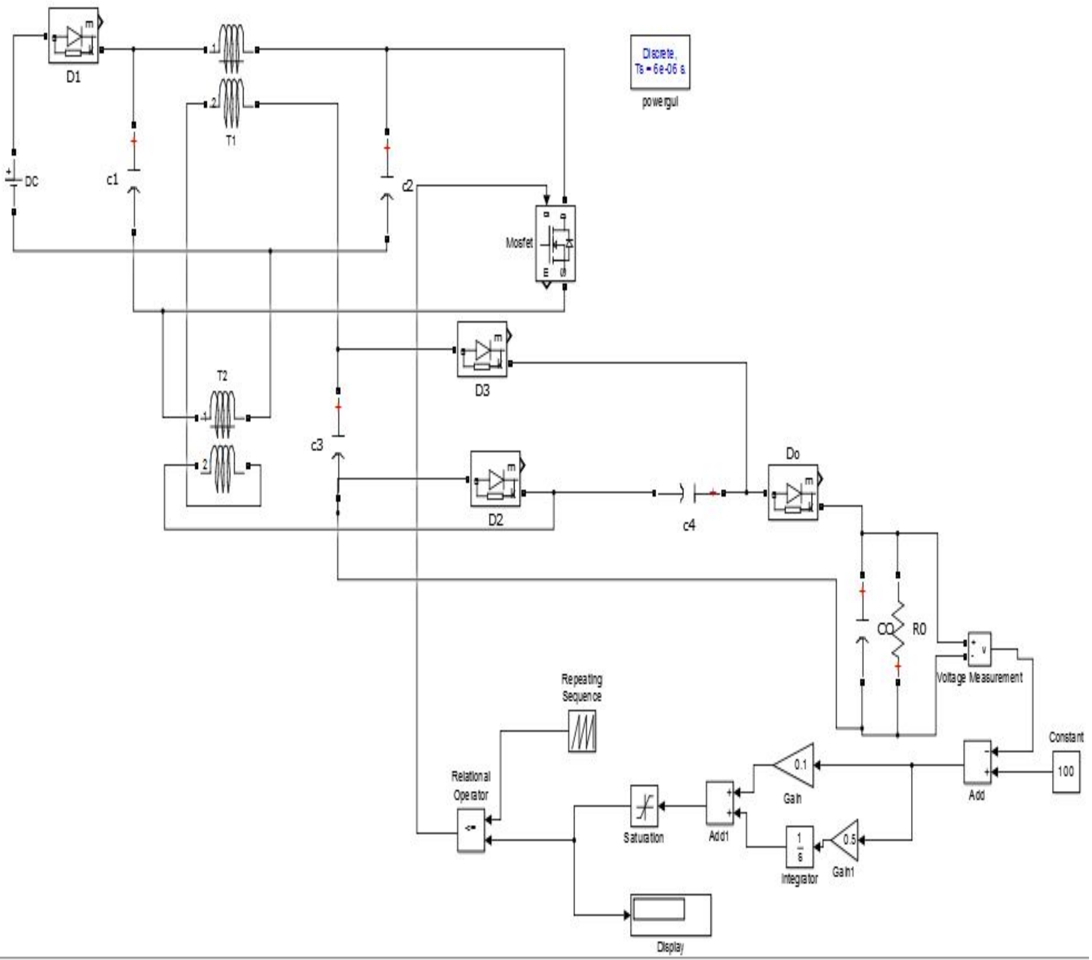

Figure 9

The figure 9 shows the closed loop simulation diagram of the DC-DC converter.

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V. RESULT AND DISCUSSION

1: Output voltage:

The output voltage across the load is around 100V for 6V input. The output voltage can be further improved by increasing the turns ratio of the coupled inductor. The output is shown in figure 10

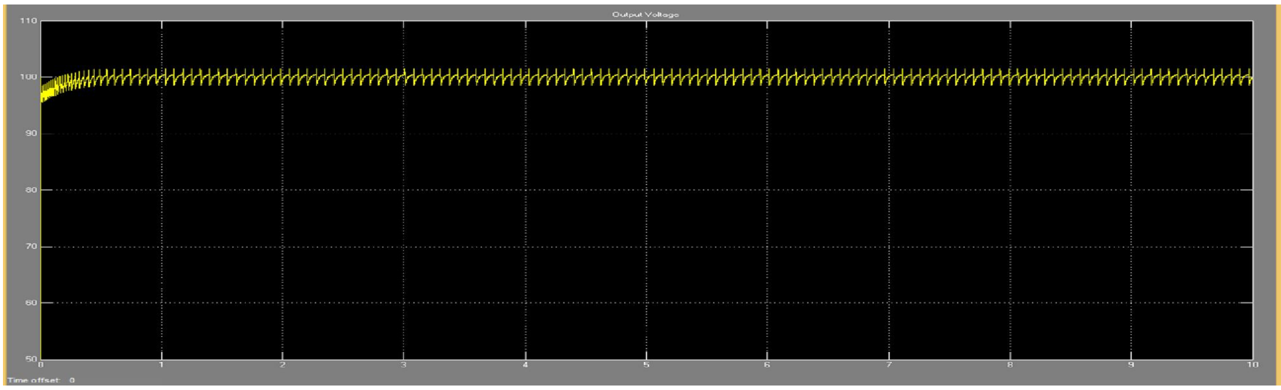

Figure 10

2: Voltage across switch:

The voltage stress on the switch is effectively clamped at about 15V without a snubber circuit and much lower than the output voltage when the switch is turned OFF. Voltage across switch is shown in figure11

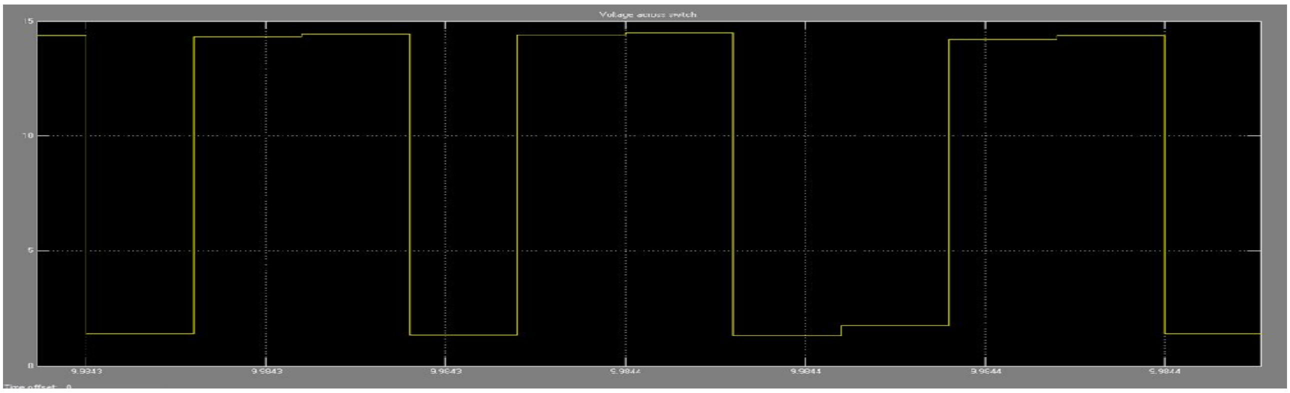

Figure 11

VI. CONCLUSION

This paper has presented the topological principles, steady state analysis, and experimental results for a cost effective dc-dc converter. The Z-source-based topology used in this study can boost the input voltage to desired levels with low duty ratios. The circuit is designed for an input voltage of 6V and output 100V at 10W output power. The circuit parameters were calculated for this requirement. Simulation has been done using MATLAB/Simulink environment for the designed parameters. Output voltage is maintained constant by a feedback loop using PI controller. The simulation results are found to be satisfactory. The voltage stresses over the power switches are restricted (15V) and are much lower than the output voltage (100V). Also, the converter has a galvanic isolation between source and load. This converter is extremely suitable for PV systems or other renewable energy applications that need high step-up high-

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power energy conversion. The next work is to build a hardware prototype of the converter for doing further testing of the topology.

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