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A Novel High Step-Up DC-DC Converter based on Integrating Coupled Inductor with Open Loop and Closed Loop Control Strategies

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ABSTRACT: A novel high step up dc-dc converter based on integrating coupled inductor and switched capacitor techniques for renewable energy application is proposed in. The output is verified for both open loop and closed loop control strategies. The converter consists of a coupled inductor and two voltage multiplier cells, in order to obtain a high voltage gain. The capacitors which are charged using the energy stored in the coupled inductor increases the voltage transfer gain. The voltage stress across the main switch is reduced and hence the use of low resistance $R_{DC(on)}$reduces the conduction losses. The operation principle and steady state analyses are presented along with the comparison of the output voltage for open loop and closed loop control strategies. Simulation results are presented to demonstrate the effectiveness of the converter.

KEYWORDS: Coupled inductor, high step up DC-DC converter switched capacitors, PI controller.

I.INTRODUCTION

Dramatic increase in the demand for clean and sustainable energy resources have paved the way for the development of power converters .In order to avoid the environmental consequences caused due the use of fossil fuels for electrical energy, distributed generation systems(DG) based on renewable energy resources have attracted researchers attention. However, output voltages of the DG systems (PV cells, fuel cells, wind power etc) are not large enough for connecting to ac utility voltage. Series connected PV panels can provide a large DC voltage but it is difficult to avoid the shadow effect in the PV panels. High step up converters are suitable solutions for the aforementioned problem. Each PV panel can be connected to particular high step up converter. These converters boost the low input voltages (24-40V) to a high voltage level (300-400V).The main features of high step up converters are their large conversion ratio, high efficiency and small size.

This paper presents a novel high step up dc-dc converter renewable energy applications. The proposed circuit consist of a coupled inductor and two voltage multiplier cells in order to obtain high voltage step up .In addition a capacitor is charged using the energy stored in the coupled inductor, which increases the voltage transfer gain. The energy used in the leakage inductance is recycled with the use of active clamp circuit. In this proposed topology the voltage stress across the switch is reduced. Therefore a main power switch with low resistance $R_{DC(on)}$can be used to reduce the conduction losses. Comparison of the proposed converter with open loop and closed loop control is presented. The closed loop control is achieved by using Proportional Integral (PI) controller. First, a literature survey is carried out which necessitates the need for a new topology. The circuit topology and operation principle are given in Section III. The corresponding steady state analysis is made in Section IV. The comparison of two control schemes in the novel converter presented in Section V Simulation model and its results are presented in section VI. Finally conclusion is presented in last section.

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II.LITERATURE REVIEW

A conventional boost converter can achieve high voltage gain only with a higher duty ratio.[1].At high duty cycle low conversion efficiency, reverse recovery and EMI problems[2] occur resulting in the deterioration of the performance of the system. Some transformer based converters can achieve high voltage gain by adjusting the turns ratio of the transformer .However, the leakage inductance of the transformer will cause serious problems such as voltage spikes on the main switch and high power dissipation [3].switched capacitors and voltage lift techniques [4] have been used to achieve high voltage gain. High charging current through the switches increases conduction losses in these structures. Coupled inductors based converters can achieve high step up voltage gain by adjusting the turns ratios. However, the energy stored in the leakage inductor causes voltage spikes in the main switches and deteriorates the conversion efficiency[5],[6].As a solution for this problems coupled inductor with active clamp circuit was presented[7],[8].However ,the conversion ratio was not large enough .As a solution for the above mentioned problems this paper presents a new topology.

III.OPERATING PRINCIPLE

The circuit configuration of the proposed converter is shown in Fig. 1. 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 modelled as an ideal transformer with a turn ratio N (N_P/N_S), a magnetizing inductor L_m and leakage inductor L_k.

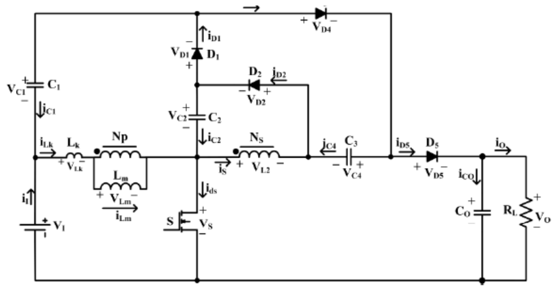

Fig .3.1.Circuit configuration of proposed converter

Assumptions considered are:

- All capacitors are large ;therefore V_{C1},V_{C2},V_{C3} and V_o are considered to be constant during the switching period
- All components are ideal but the leakage inductance of the coupled inductor is considered.

According to the above mentioned assumptions, the Continuous Conduction Mode (CCM) operation of the proposed converter is presented below. It includes five stages of operation in one switching period. Conducting elements in each stages is shown in the corresponding explanation.

1) Stage I: [Fig. 3.2(a)]: In this stage, switch S is turned on. Also, diodes D_2 and D_4 are turned on and diodes D_1, D_3 are turned off. The DC source (V i) magnetizes L_m through S. The secondary-side of the coupled inductor is in parallel with capacitor C_2 using diode D_2. As the current of the leakage inductor L_k increases linearly, the secondary-side current of the coupled inductor (i_S) decreases linearly. The required energy of load (R_L) is supplied by the output capacitor C_O. This interval ends when the secondary-side current of the coupled inductor becomes zero.

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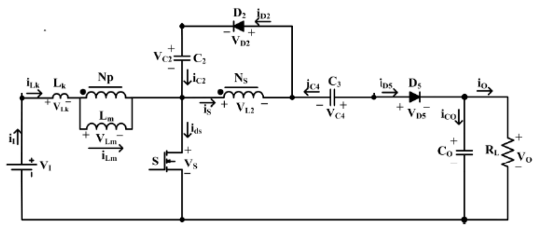

Fig.3.2 (a).Stage I

2) Stage II [Fig. 3.2(b)]: In this stage, switch S and diode D_3 are turned on and diodes D_1, D_2 and D_4 are turned off. The DC source V_i magnetizes L_m through switch S. So, the current of the leakage inductor L_k and magnetizing inductor L m increase linearly. The capacitor C_3 is charged by dc source V I, clamp capacitor and the secondary-side of the coupled inductor. Output capacitor C_O supplies the demanded energy of the load R_L. This interval ends when switch (S) is turned off.

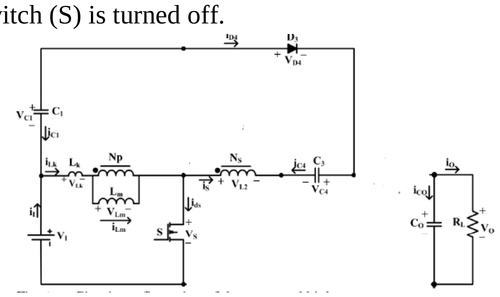

Fig.3.2 (b).Stage II

3) Stage III [Fig. 3.2(c)]: In this stage, switch S is turned off. Diodes D_1 and D_3 are turned on and diodes D_2 and D_4 are turned off. The clamp capacitor C_1 is charged by the stored energy in capacitor C_2 and the energies of leakage inductor L_k and magnetizing inductor L_m. The currents of the secondary-side of the coupled inductor (i_S) and the leakage inductor are increased and decreased respectively. The capacitor C 3 is still charged through D 3. Output capacitor C O supplies the energy to load R L. This interval ends when i_{Lk} is equal to i_{Lm}.

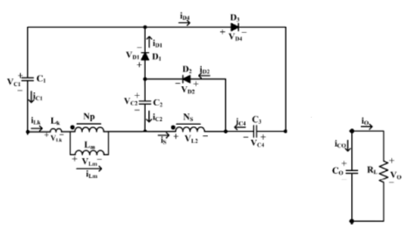

Fig.3.2(c).Stage III

4) Stage IV [Fig. 3.2(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 L_k and magnetizing inductor L_m. The currents of the leakage inductor L_k and magnetizing inductor L_m decrease linearly. Also, a part of the energy stored in L_m is transferred to the secondary side of the coupled inductor. The dc source V_I, capacitor C_3 and both sides of the coupled inductor charge output capacitor and provide energy to the load R_L. This interval ends when diode D_1 is turned off.

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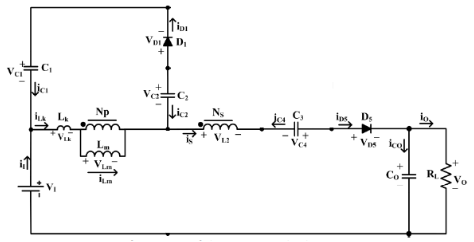

Fig.3.2 (d).Stage IV

5) Stage V [Fig. 3.2(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 L_k and magnetizing inductor L_m decrease linearly. Apart of stored energy in L_m 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 V_I 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 R_L. This interval ends when switch S is turned on.

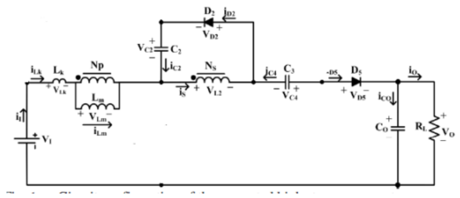

Fig.3.2 (e).Stage V

IV.STEADY STATE ANALYSIS

Continuous Conduction Mode (CCM)of operation

To simplify the steady state analysis, only stages II, IV and V are considered since these stages are sufficiently large in comparison with stages I and III. During stage II, L_k and L_m is charged by dc source V_i. Therefore, the following equation can be written according to Fig. 3.2(b):

$$V_{Lm} = kV_i \qquad (4.1)$$

Where k is the coupling coefficient of coupled inductor which equals to $L_m/(L_m+L_k)$. Capacitor C_3 is charged by clamp capacitor C_1, dc source (V i) and the secondary-side of the coupled inductor. The voltage across the capacitor C_3 can be expressed by:

$$V_{C3} = V_{C1}+(kn+1)V_i \qquad (4.2)$$

Where n is the turn ratio of coupled inductor which is equal to N_S/N_P. As shown in Fig. 2(d), during stage IV, L_k and L_m demagnetize to the clamp capacitor C_1 with the help of capacitor C_2. Hence, the voltage across L_m can be written as:

$$V_{Lm}=k(V_{C2}-V_{C1}) \qquad (4.3)$$

Also, the output voltage can be formulated based on Fig.3.2 (d)

$$V_o=V_i+V_{C3}+(kn+1)(V_{C1}-V_{C2}) \qquad (4.4)$$

According to Fig. 3.2(e), in the time interval of stage V, the voltage across L_m can be expressed by:

$$V_{Lm}= \frac{-Vc2}{n} \qquad (4.5)$$

Moreover, the output voltage is derived as:

$$V_o = V_i + V_{C3} + (\frac{1}{kn}+1)\, V_{C2} \qquad (4.6)$$

According to aforementioned assumption, the output capacitor voltage is constant during one switching period. Therefore, by equalization of (4.4) and (4.6), the following equation is derived as:

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$$V_{C1} = \frac{kn+1}{kn} V_{C2} \quad (4.7)$$

Using the volt-second balance principle on L equations (1), (3), (5) and (7), the voltages across capacitors C1 and C 2 is obtained as:

$$V_{C1} = \frac{(kn+1)D}{1-D} V_i \quad (4.8)$$

$$V_{C2} = \frac{knD}{1-D} V_i \quad (4.9)$$

Substituting (4.8) into (4.2), yields:

$$V_{C3} = \frac{(kn+1)}{1-D} V_i \quad (4.10)$$

Substituting (4.9) and (4.10) into (4.6), the voltage gain is achieved as:

$$G_{CCM} = \frac{2+kn+knD}{1-D} V_i \quad (4.11)$$

When k equals 1, the ideal voltage gain is obtained as

$$G_{CCM} = \frac{2+n+nD}{1-D} V_i \quad (4.12)$$

Based on the description of the operating modes, the voltage stresses on the active switch S and diodes D_1, D2, D3 and D_4 are expressed as:

$$V_S = V_{D1} = \frac{1}{1-D} V_i = \frac{1}{2+2n} (V_o + nV_i) \quad (4.13)$$

$$V_{D2} = \frac{n}{1-D} V_i = \frac{n}{2+2n} (V_o + nV_i) \quad (4.14)$$

$$V_{D3} = V_{D4} = \frac{1+n}{1-D} V_i = ½ (V_o + nV_i) \quad (4.15)$$

V.CONTROL SCHEME

Two control schemes are used in this proposed converter. Open loop control is simpler in their layout. Due to its simpler layout they are easier to construct. Since these systems do not have a feedback mechanism, they are very inaccurate in terms of result output and hence they are unreliable too. Due to the absence of a feedback mechanism, they are unable to remove the disturbances occurring from external sources.Closed loop control schemes are more accurate than open loop system due to their complex construction. They are equally accurate and are not disturbed in the presence of non-linearities. Since they are composed of a feedback mechanism, so they clear out the errors between input and output signals, and hence remain unaffected to the external noise sources.

The closed loop PI controller is used in the proposed converter to achieve the desired output voltage. The PI controller continuously calculates an error value as the difference between a measured process variable and a desired set point. The controller attempts to minimize error over time by adjustment of a control variable. PI controllers are fairly common, since derivative action is sensitive to measurement noise.

PI controller is implemented here due to its several advantages. Steady state error resulting from P controller is easily overcome by the use of PI controller. However, the controller possess negative effect in terms of overall stability of the system, it has a negative impact. This controller is mostly employed in areas where speed of the system is not a matter of significance. It also serves the purpose of the converter by achieving voltage regulation. Even though closed loop scheme poses the above advantages it may create oscillatory response of the system and it also reduces the overall gain of the system. It is less stable than open loop system but this disadvantage can be striked off since we can make the sensitivity of the system very small so as to make the system as stable as possible.

VI.SIMULATON MODEL AND RESULT

The proposed converter is simulated using open loop and closed loop control strategies .Comparison of the output voltages for the control strategies is shown in the figure6.6.The figure 6.1 shows the simulation model of an open loop controlled converter. An input of 40voltage is given to the system. For that same input voltage closed loop control is provided for the converter in figure 6.2.This converter is designed to produce an output of 400volts.

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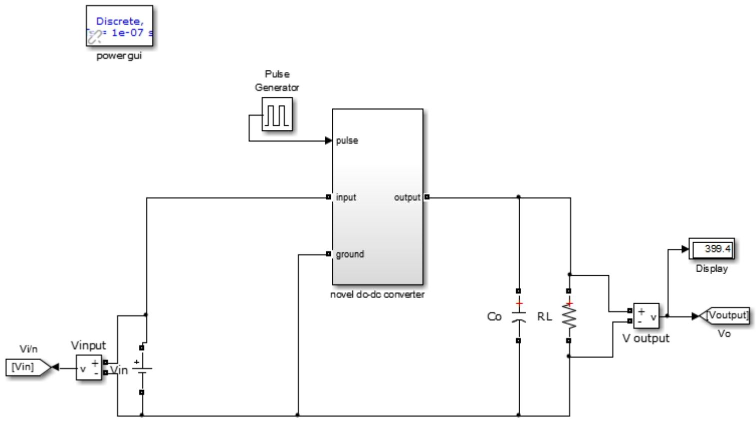

Fig.6.1.Open loop controlled converter

Open loop control strategy is adopted to obtain the output voltage in the above circuitry. Pulse generator is used to produce the required gate pulse.

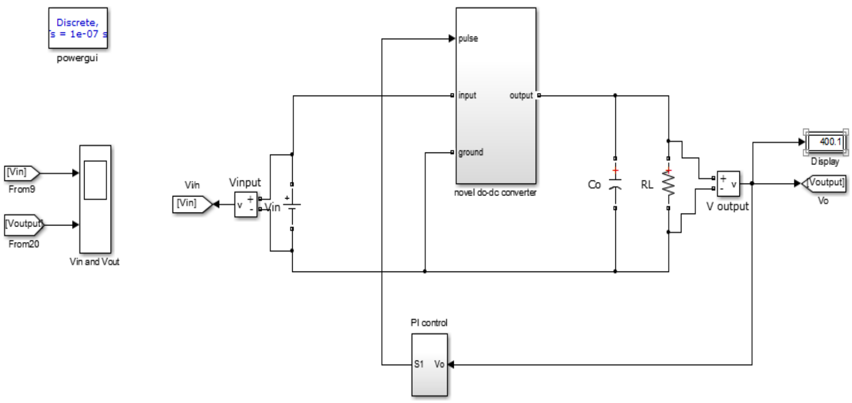

Fig.6.2Closed loop controlled converter

PI control is used as the closed loop controller. The closed loop control circuitry for the proposed converter is shown in the above figure.

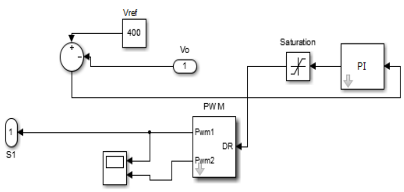

Fig.6.3. Simulated PI control

Proportional integral (PI) controller circuit, error calculation and its simulated model is shown in the above figure.

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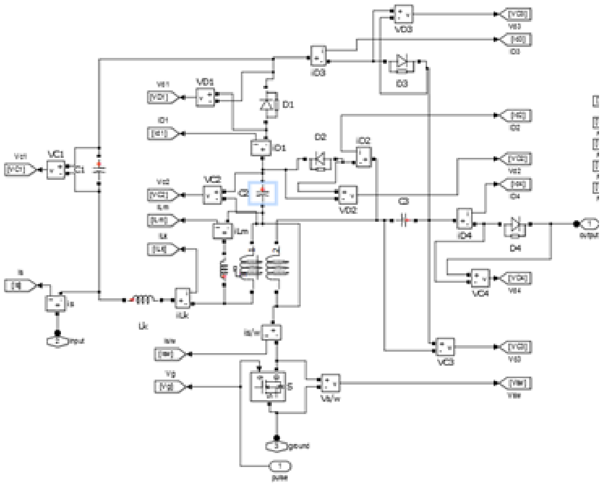

Fig.6.4.Simulated model of the proposed converter

The above figure shows the simulated model of the proposed converter section alone. The proposed DC-DC converter is designed to operate at 40V, input. and produce an output of 400V. The above mentioned control strategies are used for this proposed converter section.

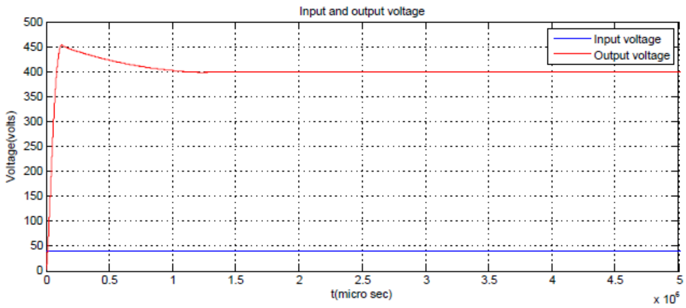

Fig.6.5. .Simulated Input and output voltage of the proposed converter

An output voltage of 400V is obtained for 40V input, the corresponding voltage s with respect to time is shown in the above figure.

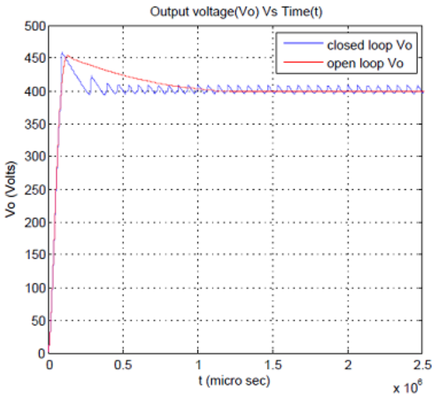

Fig.6.6.Comparison of the output voltages of the open loop and closed loop controlled converter

The above figure shows the comparison of the voltages produced by the two control strategies and it also shows effect of closed loop control and open loop control in generating the output voltage w.r.t time. Both control strategies provide output voltage within a short period .Hence no external disturbances is applied the open loop control is more stable. Even though closed loop control is more accurate due to its feedback mechanism it creates an oscillatory response

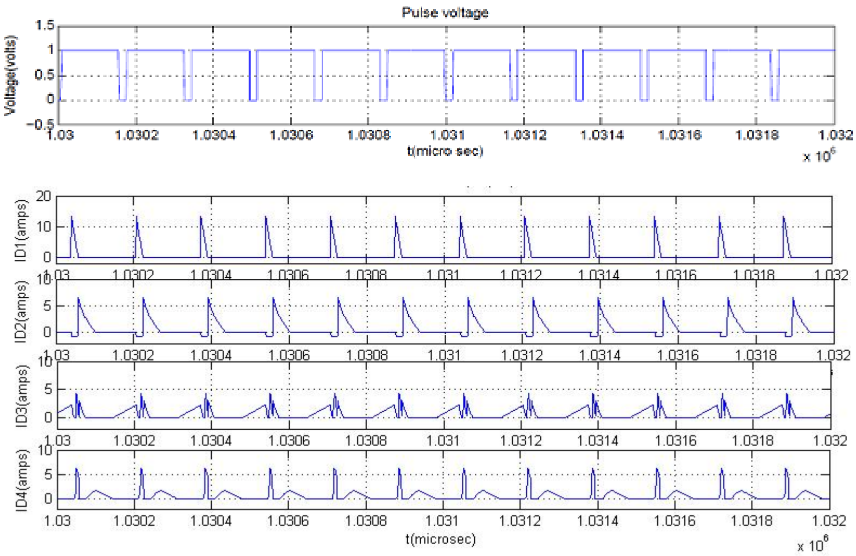

Fig.6.7.Current through diodes D1,D2,D3,D4

The above figure shows the diode current waveforms .On analysing it is found that at least two diodes is conducting in each stages of operation

VII.CONCLUSION

The novel dc –dc converter proposed in this paper is suitable for DG systems based on renewable energy sources which require high voltage transfer gain. The voltage stress on the main power switch is reduced therefore a switch with low on state resistance can be chosen. The energy stored in the leakage inductance is recycled to improve the performance of the converter. The proposed converter is simulated for both open loop and closed loop control and their corresponding output voltages are presented. The steady state operation of the converter in the Continuous Conduction Mode has been analysed.

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