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High Step up Switched Capacitor Inductor DC-DC Converter for PV Array

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ABSTRACT*:* In this paper a high step-up switched capacitor inductor dc-dc converter for PV array is proposed. The high step-up voltage is obtained by integrating a switched inductor with a switched capacitor in parallel-series configuration.A small resonant inductor is used in this converter to limit the current peak caused by switched capacitor.This Switched Capacitor Inductor (SCI) converter circuit can meet the high efficiency requirement and it has simple structure. This converter can achieve a very high dc conversion ratio. In order to verify the proposed SCI DC-DC converter modelling and simulation was carried out by MATLAB

KEYWORDS*:* Switched capacitor, Switched inductor, high voltage gain

I. INTRODUCTION

A DC-DC converter with high step up value is indeed a much needed one. The future is looking towards alternative power sources for clean energy. To make this possible, a highly efficient low cost product will have to be designed. Among all the different converter designs only a few are capable of providing high power with high efficiency. The basic switched-mode dc–dc converters including buck, boost, buck-boost, cuk, zeta, and sepic have been used in various electronic applications due to their numerous advantages such as simple structure, good performance, high efficiency, easy design, and simple control circuit [1]. The resonant converters such as single-ended and bridge type are also very popular in the last decade [2], [3]. The basic switched-capacitor (SC) converters also have wide application as their advantages of nonmagnetic components employed and small size and high power density [4],[5]. All the converter are composed of the same number of electronic components include two energy transfer components, i.e., one Switched Capacitor $C1$ and one switched inductor $L1$, a small resonant inductor Lrthat is employed to limit the current peak caused by SC, three active or passive switches and one output filter capacitor. The greatest feature of these converters is that energy flowing from input power sources is directly transferred to the two energy transfer components ($C1$ and $L1$) and then directly released to output terminal, i.e., these converters are actually single-stage dc–dc converters rather than like aforementioned converters obtained high voltage gain by using different cascading methods. When the two energy transfer components operate in parallel manner during a charging process and then in series manner during a discharging period, the higher output level can be produced. Similarly, this principle is not only suitable for deriving single-input converters, but can also be extended to dual-input dc-dc converters that are popularly used in dual-level dc distributional and renewable energy system. The proposed switched capacitor inductor (SCI) converter has high efficiency.

II.PROPOSED SYSTEM

PV array output is given to SCI converter and the DC output is given to SPWM inverter. This SPWM inverter output can be directly connected to the load or stepped up with an transformer and can be integrated to an grid. The SCI converter is connected to a filter capacitor for smoothening of DC voltage. This proposed system block diagram is as given below.

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Fig. 1. Block diagram of Proposed System

III. PV ARRAY

PV arrays are built up with combined series/parallel combinations of PV solar cells, which are usually represented by a simplified equivalent circuit model in the following figure.

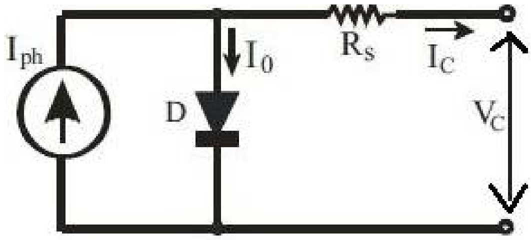

Fig. 2. Equivalent circuit of PV model

The PV cell output voltage is a function of the photocurrent that mainly determined by load current depending on the solar irradiation level during the operation.

$$V_c = \frac{AKT_c}{e} \ln\left(\frac{I_{ph} + I_0 - I_c}{I_0}\right) - R_s I_c \quad (1)$$

Where the symbols are defined as follows:
e: electron charge (1.602 × 10-19 C).
k: Boltzmann constant (1.38 × 10-23 J/oK).
Ic: cell output current, A.
Iph: photocurrent, function of irradiation level and junction temperature (5 A).
I0: reverse saturation current of diode (0.0002 A).
Rs: series resistance of cell (0.001 Ω).
Tc: Reference cell operating temperature (20°C).
Vc: cell output voltage, V.

IV. SCI DC-DC CONVERTER

The proposed SCI DC-DC converter circuit is shown in figure. The circuit uses only one active switch *Q* and a very small resonant inductor *Lr*which is employed to limit the current peak caused by capacitor *C*1 when the switch *Q* is turned ON. The two energy storage components *C*1 and *L*1 are alternately connected in parallel and series according to different switching states.

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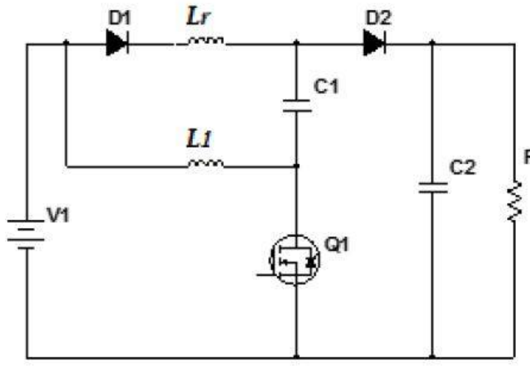

Fig. 3. SCI converter

The voltage transfer relationship can be derived and expressed as follows,

$$V_0 = \frac{2-d}{1-d}V_{in}$$

There are two inductors employed in the new SCI converter, the energy transfer inductor *L*1 and the resonant inductor *Lr*. The function of *L*1 is to transfer ener (2) le *Lr*is just used to limit the current peak caused by the capacitor *C*1 when the switch *Q* is turned ON. Specific hen switch *Q* is turned ON, the capacitor *C*1 begins to be charged or to discharge, the charging or discharging current will soar to a very high peak at the moment of *Q* being ON if there are not any measures to limit it. For this reason, a small inductor *Lr*is added and connected in series with *C*1 to form a resonant tank with the resonant frequency, $=1/2\pi\sqrt{LC}$during the switching ON period. With the resonant inductor, the charging or discharging current of *C*1 gradually increases from zero when switch *Q* is turned ON. In c (3) ensure that the current changes back to zero before switch *Q* is turned OFF, the switch conduction time `d be longer than half of a period of the resonant frequency, i.e., *d TS*>*π* (where *TS* and *d* are the switching cycle period and duty ratio, respectively).

The SCI Step-up converter oscillation amplitudes of capacitor voltage and current are related to the parameters of the resonant tank and the output current and the switching cycle period. When the switch *Q* is turned ON, the charges flow into the capacitor *C*1 from power source *V*1 causing a gradual increase in capacitor voltage *VC*1. And then, the switch *Q* is turned OFF and the charge stored in *C*1 during the charging process flows out of capacitor *C*1 to output filter capacitor *C*2 and the load causes the capacitor voltage *VC*1 gradually decreases from its maximum to its minimum. The amount of charge flowing into capacitor *C*1 during the charging process should be equal to the amount of charge flowing out of *C*1 during the discharging process, and the amount also should be equal to the amount of charge flowing though the load during one switching cycle, i.e.,

$$(V_{C1_{max}} - V_{C1_{min}})C_1 = I_0T_s$$

Where*I*0 is the average output current. The charging current *IC*2 changes in a sinusoidal manner with the resonant frequency0 *f* =1/2*πL C*1 *r***; hence, the amount of charges flow into *C*1 during the charging process can also be expressed as

$$(V_{C1_{max}} - V_{C1_{min}})C_1 = 2I_{C1}L_rC_1$$

The oscillation amplitude of resonant current *IC*1 can therefore be derived from [3] and [4]

$$I_{C1} = \frac{I_0T_S}{2\sqrt{L_rC_1}}$$

And the voltage oscillation amplitude can be (6) d from [3] and expressed as

$$\Delta V_{C1} = V_{C1\_max} - V_{C1\_min} = \frac{I_0T_S}{C_1} \qquad (5)$$

For the inductor *L*1, the amount of charge flowing though it during the discharging process is also equal to the amount of charge flowing out the capacitor *C*1. Its average current *IL*1 can therefore be expressed as

$$I_{L1} = \frac{I_0}{1-d}$$

And the ripple current Δ*IL*1 is related to the input voltage *V*2, the switching cycle *TS*, and the duty ratio, i.e.

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$$\Delta I_{L1} = \frac{V_2}{L_1} dT_s$$

When the switch *Q* is turned OFF, the voltage across it is the difference between the output voltage *V*0 and the capacitor voltage *VC*1, and a voltage (*V*1−*V*0) is developed across the diode *D*1. The current flowing though the diode *D*2 is the same as the inductor current *IL*1 during the OFF state. Its average and maximum transient values therefore can be expressed as *IL*1/(1–*d*) and (*IL*1+Δ*IL*1/2) respectively. When *Q* is turned ON, the voltage across *D*2 is the difference between the input voltage *V*1 and the output voltage *V*0. The current flowing though the diode*D*1 is the same as the capacitor current *IC*1 and the current flowing though the switch *Q* is the sum of the capacitor current and the inductor current, i.e., (*IC*1+*IL*1). Their average values can be derived from [4.4], and [4.6] and expressed as *I*0 for *D*1 and (*I*0+*IL*1/*d*) for *Q*, respectively. The maximum current flowing though *D*1 is the same as *IC*1 and the maximum value of the current flowing though *Q* is the value of [*IC*1+*IL*1−Δ*IL*1/2+*V*2/(2*ωOL*1)]. The switches stress therefore can be expressed as

$V_{ds\_Q} = V_0 - V_{C1} \approx V_0 - V_1$

$V_{R\_D1} = V_0 - V_1$

$V_{E\_D2} = V_0 - V_2$

Based on the previous analysis, the oscillation amplitudes of resonant current and voltage can be calculated by the values of *C*1 and *Lr*. In turn, the values of *C*1 and *Lr*can be determined by the design requirements of the resonant current and voltage, and the value of *L*1 can be determined by the design requirements of its current ripple.

The design process therefore can be divided into the following steps:

1) Determine the minimum and maximum values of the duty ratio and the switching frequency (usually, the switching frequency is higher than 50kHz), and then calculate the resonant frequency according to the condition that the switch conduction time should be longer than half of a period of resonant frequency, i.e.

$$f_0 = \frac{1}{2\pi\sqrt{L_r C_1}}$$

2) The value of the capacitor *C*1 can be calculated by [6], i.e.

$$C_1 = \frac{I_{0\,max} T_s}{\Delta V_{C1}} \qquad (9)$$

Where Δ*VC*1 is the design requirement of t[illegible] oscillation amplitude and *I*omax is the maximum output current.

3) The resonant inductor *Lr*hence can be de[illegible] (12) [illegible] the value of *C*1 and the resonant frequency, i.e.

$$L_r = \frac{1}{4\pi^2 f_0{}^2 C_1} \qquad (10)$$

4) The value of inductor *L*1 can be determined by [8], i.e.

$$L_1 = \frac{V_2}{\Delta I_{L1}} d_{max} T_s \qquad (13)$$

Where Δ*IL*1 is the current flowing though *L*1 and *d*max is the maximum values of the duty ratio.

V. SPWM INVERTER

Pulse Width Modulation technology is used in Inverters to give a steady output voltage of 230 or 110 V AC irrespective of the load. The Inverters based on the PWM technology are more superior to the conventional inverters. The use of IGBT's in the output stage and the PWM technology makes these inverters ideal for all types of loads. In addition to the pulse width modulation, the PWM Inverters have additional circuits for protection and voltage control.The PWM Inverter is as Follows

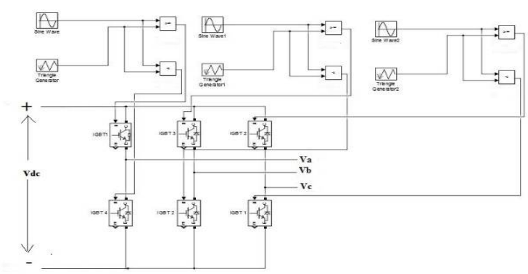

Fig. 4. SPWM Inverter

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The sinusoidal pulse-width modulation (SPWM) technique produces a sinusoidal waveform by filtering an output pulse waveform with varying width. A high switching frequency leads to a better filtered sinusoidal output waveform. The desired output voltage is achieved by varying the frequency and amplitude of a reference or modulating voltage. The variations in the amplitude and frequency of the reference voltage change the pulse-width patterns of the output voltage but keep the sinusoidal modulation [6]-[10]. A low-frequency sinusoidal modulating signal is compared with a high frequency triangular signal, which is called the carrier signal. The switching state is changed when the sine waveform intersects the triangular waveform[11]-[13]. The crossing positions determine the variable switching times between states. The duty cycle of the one of the inverter switches is called the amplitude modulation ratio.

VI. SIMULATION PARAMETERS

Theproposed SCI converter is simulated with an SPWM inverter connected to it. PV array Output voltage is 104v. The SCI converter conversion ratio is 3. Hence the output obtained from the SCI converter is 312v. This 312v is given as input to the SPWM inverter to obtain required ac voltage and current.
The simulation parameters of an SCI converter is given in the following table.

Table .1. Simulation parameters

Parameter	Value
Input Voltage	104V
Switching Frequency	20KHZ
Capacitor C1	4.7µF
Capacitor C2	100µF
Inductor L1	95µH
Resonant Inductor Lr	0.3 µH

In the SCI converter the switching frequency given to the switch is 20KHZ with a duty cycle ratio of 0.2 and the load connected is an RLC load.

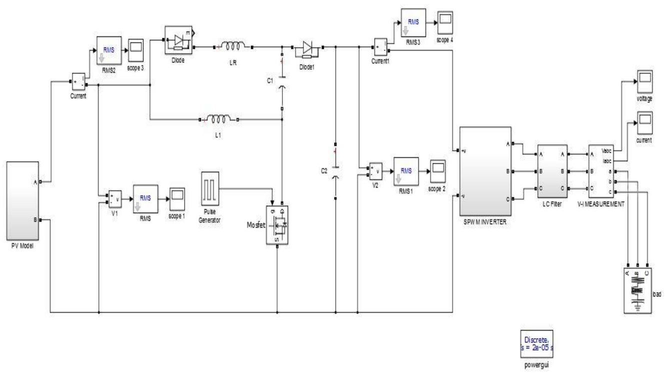

Fig.5. Simulink circuit of High Step up Switched Capacitor Inductor Dc-Dc Converter for Renewable Energy Source

An LC filter is used to reduce the harmonics in the required Ac voltage and Current. The value of Inductor used in the Filter is 150mH and Capacitive reactive power of value 5KVAR is connected in parallel with the inductor.

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VII. SIMULATION RESULTS

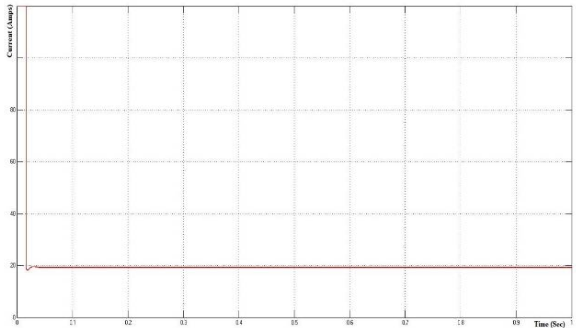

Fig.6. Output voltage of SCI converter

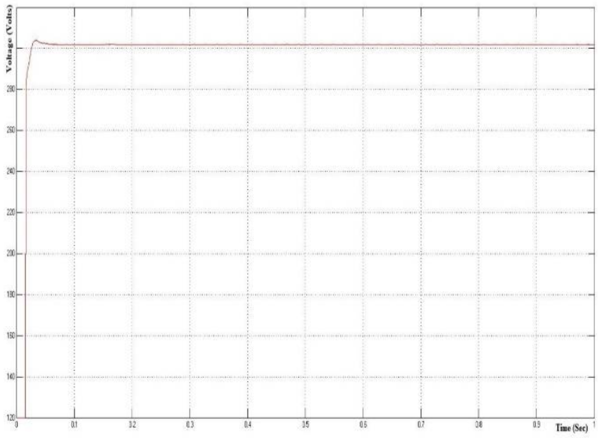

Fig.7. Output current of SCI converter

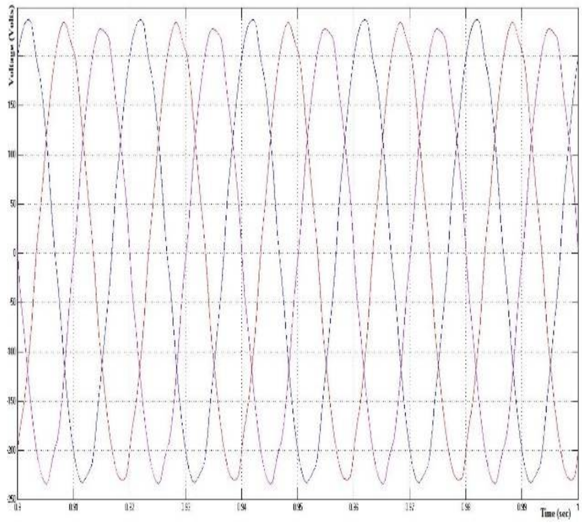

Fig.8. Output voltage at load

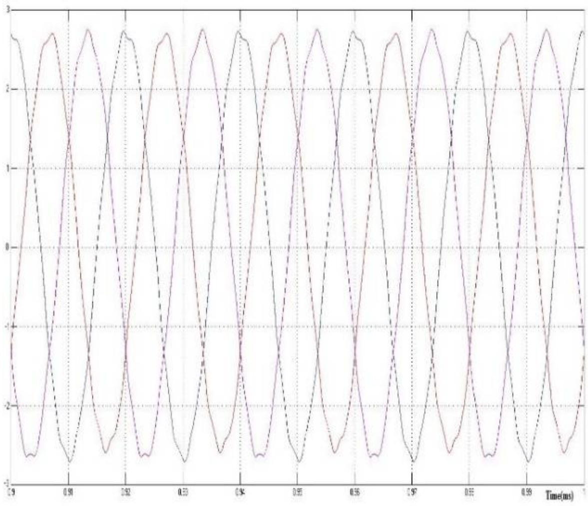

Fig.9. Output Current at load

VIII. CONCLUSION

The SCI DC-DC converter gives high step up voltage and efficiency compared with conventional converters. The energy stored in the two components both directly come from input power sources and then directly been released to output terminal. This design can meet the high efficiency requirement with a simple structure. A resonance method is used in this project to limit the current peak caused by the SC. The proposed converters can provide higher voltage gains and the switch stress is lower. In SCI converter the voltage stress on the converter is less. The renewable energy sources can give more efficient power by using SCI DC-DC converter.

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BIOGRAPHY

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