A Switched Inductor Capacitor Converter for Wind Solar Hybrid Standalone Applications

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Abstract: Now a days researchers focus more on renewable energy sources for power generation due to the increasing world energy demand and the depletion of fossil fuels. Renewable energy sources are more environmental friendly because it is pollution free. For cost efficiency and reliability, we need to interconnect two or more renewable energy sources together to make a hybrid energy system. This paper presents a Switched Capacitor Inductor Converter for integrating Wind and Solar Energy Sources. Operational analysis of the proposed system will be discussed in this paper. Simulation results are given to support the theoretical analysis.

Keywords: Hybrid energy system, Renewable, Switched Capacitor Inductor.

I. INTRODUCTION

In most developing countries electrifying rural households by extending the main grid is a major challenge due to economic and technical reasons. There is a need to find other methods of supplying electricity to rural households. Supply of electricity to rural communities will have significant impact on preventing problems associated with deforestation, environmental effects and contributing towards sustainable development. Small scale hybrid power systems offer a means to quickly electrify areas that have little chance of being connected to a centralized grid in the foreseeable future. Hybrid power systems combine two or more electricity generation methods, like diesel engines and solar panels, into a single plant to reduce long term generation costs. While it is possible to find governments or organizations to fund the capital cost of an electrification project, recurring costs over the life of the system can be as large as or larger than capital costs. Without a community being able to regularly generate funds to pay for salaries, fuel, and replacement parts, an electricity plant will quickly cease operating. The principle advantage of a hybrid plant is its ability to affordably extend reliable electricity access into remote communities.

The world energy demand is increasing day by day and the fossil fuels on earth are depleting. So now a days researchers focus more on renewable energy sources in order to reduce our dependence on non-renewable fossil fuels. So that the amount of greenhouse gas emission is also reduced. The major sources of renewable energy include wind energy, photovoltaic energy, hydrogen fuel cell energy, tidal energy, and geothermal energy. Most of these energy resources are utilized in the form of electric energy. The installations of renewable energy is growing dramatically around the world. In this project, a switched capacitor-inductor converter for wind solar integration is being proposed.

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. And the basic switched-capacitor (SC) converters also have wide application as their advantages of nonmagnetic components employed and small size and high power density. A small resonant inductor has been added in SC converters to eliminate the current peak and achieve soft switching in and, therefore, the SC converters have good performance and high efficiency as well. In recent years, many researchers are trying to take these types of converters aforementioned into a new type of combination converters to obtain high step-up/down voltage gains. Specifically, two step-up SC cells have been introduced to zeta, cuk, and sepic converters, respectively, to obtain high step-up voltage conversion ratios. Some step-up and step-down SC cells are presented and combined with boost and buck converters to achieve high step-up and step-down voltage gains. Even though these converters have different structures and can provide different voltage conversion ratios, they have a characteristic in common which is that all of them are multistage combination of switched-inductor cells and SC cells as shown in Fig. 1. Like other cascaded high step-up/down converters in which energy is transferred from one unit to next unit and gradually to output stage, their efficiency is therefore generally not promising and is equal to the product of efficiency of each unit.

Here a single stage switched-mode converter for wind solar integration is being proposed. It is composed of following electronic components: i.e., one Switched Capacitor $C_1$ and one switched inductor $L_1$, a small resonant inductor $L_r$ that is employed to limit the current peak caused by SC, three active or passive switches and
one output filter capacitor. The greatest feature of this converter is that energy flowing from input power sources is directly transferred to the two energy transfer components \(C_1\) and \(L_1\) and then directly released to output terminal, i.e., this converter is 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 and the step-up converter can therefore be derived.

The circuit uses only one active switch \(Q\) and a very small resonant inductor \(L_r\) 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.

For the dual input step up converter, there are three working states in one period of switching cycle. The following detailed analysis is based on the assumptions that: all components are ideal, i.e., there are no voltage drop and on resistance; the inductor \(L_1\) operates in continuous current mode; the output filter capacitor \(C_2\) is so large such that the output voltage ripple is ignorable

**A. Dual Input Step-Up Converter**

**Fig.1. Conventional SC/switched-inductor Converter**

The circuit diagram of voltage summer circuit

**Fig.3. The circuit diagram of voltage summer circuit**

There are two inductors employed in the dual input step up converter, the energy transfer inductor \(L_1\) and the resonant inductor \(L_r\). The function of \(L_1\) is to transfer energy while \(L_r\) is just used to limit the current peak caused by the capacitor \(C_1\) when the switch \(Q\) is turned ON. Specifically, when 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 \(L_r\) is added and connected in series with \(C_1\) to form a resonant tank with the resonant frequency \(f_0 = 1/2\pi\sqrt{L_rC_1}\) 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 order to ensure that the current changes back to zero before switch \(Q\) is turned OFF, the switch conduction time should be longer than half of a period of the resonant frequency, i.e., \(dTS > \pi\sqrt{L_rC_1}\) (where \(TS\) and \(d\) are the switching cycle period and duty ratio, respectively).

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**B. Solar And Wind Voltage Summer Circuit**

\[
V_o = V1 + \frac{1}{(1 - d)}V2
\]

where \(d\) is the duty ratio of the converter, \(V_1\) and \(V_2\) are input voltages, and \(V_o\) is the output voltage.

**III. DETAILED ANALYSIS**

**A. State Analysis For The Dual-Input Step-Up Converter**

\[
V_1, \text{ and the current flowing though } L_1 \text{ can be also regarded as constant. Based on volt–second balance across } L_1, \text{ the voltage level relationship of the output and inputs can be expressed as}
\]

\[
V_o = V1 + \frac{1}{(1 - d)}V2
\]

where \(d\) is the duty ratio of the converter, \(V_1\) and \(V_2\) are input voltages, and \(V_o\) is the output voltage.
and it can therefore be seemed as a constant voltage source $V_0$.

1) State I ($t_0$-$t_1$):

When the switch $Q$ is turned ON, diode $D_2$ is reversely biased. $D_1$ is forward biased and the resonant inductor $L_r$ is connected in series with $C_1$ to form a resonant tank. The input voltage $V_1$ is developed across the resonant tank that causes the resonant current $i_{C_1}$ gradually increases from zero in a sinusoidal manner; $C_1$ begins to be charged and its voltage increases from its minimum value. Meanwhile, another input voltage $V_2$ is developed across inductor $L_1$ causing a linear increase in current $i_{L_1}$. The state can be mathematically described as

$$i_{C_1} = I_{C_1} \sin \omega_o(t - t_0)$$

$$V_{C_1} = V_1 - \frac{\Delta V_{C_1}}{2} \cos \omega_o(t - t_0)$$

$$i_{L_1} = i_{L_1-min} + \frac{V_2}{L_1} (t - t_0)$$

where $\omega_o$ is resonant angular frequency and is equal to $\sqrt{L_rC_1}$; $I_{C_1}$ and $\Delta V_{C_1}$ are oscillation amplitudes of the current and voltage of capacitor $C_1$, respectively, and both are related to the output current; $i_{L_1-min}$ is the minimum value of the current flowing through $L_1$. After $L_r$ and $C_1$ resonate for half of a cycle, the resonant current $i_{C_1}$ falls back to zero and then diode $D_1$ is reversely biased. The resonance stops and the capacitor voltage reaches to its maximum value at time $t_1$, i.e., $V_{C1 \_max} = V_1 + \frac{\Delta V_{C1}}{2}$

2) State II ($t_1$-$t_2$):

After the resonance stops, the switch $Q$ continues to conduct and the inductor current $i_{L_1}$ continues to rise linearly as given by equation. There is no current flowing though $C_1$ and its voltage is maintained the maximum value. The state circuit is shown in Fig. 5. This state continues until the switch is turned OFF as shown in Fig. 3.4 time from $t_1$ to $t_2$, and then the inductor current $i_{L_1}$ rises to its maximum value, i.e.,

$$i_{L_1\_max} = I_{L_1} + \frac{V_2}{L_1} dT_s$$

3) State III ($t_2$-$t_3$):

After switch $Q$ is turned OFF, diode $D_2$ is forward biased and $D_1$ is reversely biased. The capacitor $C_1$, the inductor $L_1$, and input source $V_2$ are connected in series and discharge to $V_0$. The currents flowing though $C_1$ and $L_1$ are therefore the same and can be expressed as

$$i_{L_1} = -i_{C_1} = I_{L_1 \_max} \frac{V_0 - V_2 - V_{C_1}}{L_1} (t_1 - t_2)$$

IV. SIMULATION RESULTS

A simulation circuit with parasitic components of the dual input step-up converter has been built as shown in Fig 9. When the input powers $V_1$ and $V_2$ are 30 and 20 V, respectively, the load is a 45-Ω pure resistor, and the switch $Q$ is operated at 100-kHz switching frequency with duty ratio 0.62, the output voltage is 79.5 V and some simulation waveforms are shown in Fig. 10.
For Summer output = 17.4V; Duty Ratio=0.62, Switching frequency = 100kHz.

Fig 9. Simulation output for model in figure 8

V. CONCLUSION

A Switched capacitor inductor converter for wind solar integration is being proposed in this paper. The proposed converter employ two energy transfer components (one SC and one inductor) and do not use the cascade method like conventional SC/switched-inductor converter. 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 paper to limit the current peak caused by the SC. Compared with traditional switched-mode converters, the switch stress is lower. The simulation results of the converter members confirm their functionality and verify the theoretical analysis presented. The proposed step-up converter can also meet high efficiency and good voltage regulation.

VI. REFERENCES


