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Extended Switched-Inductor Quasi-Z-Source Inverter for Solar Power System

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Abstract

In single-phase photovoltaic (PV) system, there is double-frequency power mismatch existed between the dc input and ac output. The double-frequency ripple (DFR) energy needs to be buffered by passive network. Otherwise, the ripple energy will flow into the input side and adversely affect the PV energy harvest. In this paper, an Extended switched inductor quasi-Z-source inverter (ESL-qZSI) is proposed to buffer the DFR energy. In this ESL-qZS network, one inductor is replaced by an improved switched-inductor cell. Totally it consists of four inductors, four capacitors, four diodes and one switch. By controlling the maximum ripple at input the stability of the system is improved. The ESL-qZSI is a single stage power converter derived from the Z-source inverter topology, employing an impedance network which couples the source and the inverter to achieve voltage boost and inversion. The sinusoidal pulse width modulation (SPWM) strategy is used for the ESL-qZSI which gives a significantly high voltage gain compared to the other PWM techniques. This technique employs sine wave as reference signal and triangular wave as carrier signal, with which the simple boost control for the shoot-through states is integrated to obtain an output voltage boost. All the simulations are done using MATLAB

Index Terms - Switched capacitor, boost ability, quasi- Z-source inverter (qZSI), switched inductor.

1. Introduction

The importance of renewable energy resources is understood by the people all over the world. Because it is pollution free and we are having enormous amount of renewable energy sources in nature like Solar, Wind, and Tidal and so on. Solar energy is an important source of renewable energy. Solar energy is radiant light and heat from the Sun harnessed using a range of ever evolving technologies such as solar heating, photovoltaic and so on.

The conversion efficiency of solar energy into electrical energy is approximately 22%. We only get the dc as the output from the solar panel. But most of our industrial and domestic electrical devices need ac supply. So we need to convert the dc output from the PV panel into ac supply. The Z-source inverter and quasi Z-source inverter has been considered for photovoltaic (PV) application in recent years. These inverters feature single stage buck-boost and improved reliability due to shoot-through capability. It can be used for single phase and three phase applications. In three-phase applications, the Z-source network only needs to be designed to handle the high frequency ripples. But in single phase applications it also needs to handle the low frequency ripples.

In this paper an Extended switched –inductor quasi-Z-source inverter is proposed which has high conversion efficiency and ripple control comparing to the conventional method. In this ESL-qZS network, one inductor is replaced by an improved switched-inductor cell. Totally it consists of four inductors, four capacitors, four diodes and one switch. By controlling the maximum ripple at input the stability of the system is improved.

2. Existing System

The quasi Z-source inverter (qZSI) is used in the proposed system to convert the dc output of the solar panel in to ac. It is a single stage power converter derived from the Z-source inverter topology, employing a unique impedance network. The conventional VSI and CSI suffer from the limitation that triggering two switches in the same leg or phase leads to a source short and in addition, the maximum obtainable output voltage cannot exceed the dc input, since they are buck converters and can produce a voltage lower than the dc input voltage. Both ZSI and qZSI overcome these drawbacks; by utilizing several shoot-through zero states. A zero state is produced when the upper three or lower three switches are fired simultaneously to boost the output voltage. But the qZSI has some drawbacks like the voltage stress across the passive components are high. This will affect the passive components used in the system and reduce the life of the components. The conversion efficiency of this system is low and the startup inrush current is high which will destroy the device. The boosting ability of the system is also low and the ripple control also less in this method. So we need an alternative system which increases the conversion efficiency and to overcome all other drawbacks of this system. Then only we can improvise the performance of the solar power system. Because the Solar energy is the most important source of renewable energy. And the conversion efficiency of the solar panel is only 22%. So we need to improve the dc to ac conversion efficiency and need to suppress the unwanted fluctuations in the solar panel output.

3. Proposed System

To overcome the drawbacks of the QZSI and as well as to improve the performance of inverter, an extended switched inductor quasi-Z-source inverter (ESL-qZSI) is proposed in this paper. ESL-qZSI has high conversion efficiency and ripple control comparing to the conventional method. Comparing to the SL-qZS network in this ESL-qZS network, one inductor is replaced by an improved switched-inductor cell. Totally it consists of four inductors, four capacitors, four diodes and one switch. By controlling the maximum ripple at input the stability of the system is improved. Although a few components are added, the proposed topology possesses much higher boost ability with the same shoot-through duty ratio than the other topologies to improve the output voltage profile

The DC input from the PV panel is given to the ESL-qZI network. The ripple frequency presented in the input is suppressed by the ESL-qZI network. MOSFET is used in the inverter circuit. The inverter converts the DC input from the PV panel in to AC output and supplied to the load. The driver circuit is connected to the 12V DC power supply and the controller circuit is connected to the 5V DC power supply. The circuit diagram of the proposed method is shown in the figure 1

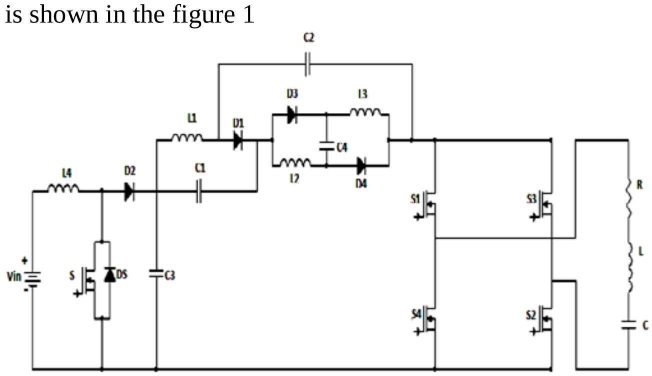

Fig 1.Circuit diagram of the proposed method

The purpose of the capacitor is to absorb the voltage ripple and maintain a fairly constant voltage. During shoot-through the capacitor charges the inductors and the current through the capacitor equals the current in the inductor. During traditional operation mode, the capacitor voltage is always equal to the input voltage. So there is no voltage across the inductor. During shoot through mode, the inductor current increases linearly and the voltage across the inductor is equal to the voltage across the capacitor. The maximum current occurs through the inductor when the maximum shoot-through happens, which causes maximum ripple current.

Sinusoidal pulse width modulation (sin PWM) is applied in the proposed inverter since it has various advantages over other techniques. Sinusoidal PWM inverters provide an easy way to control amplitude, frequency and harmonics contents of the output voltage. Through this method the maximum ripple is controlled comparing to the proposed system. The conversion efficiency and the boosting ability are also high in the proposed system.

4. Hardware Description

Current Rating of MOSFET and Diodes

Let the rms value of the line current of the load be IL . Therefore

IL =square root of (2/3)*I [1]

Irms MOSFET= Irms diode = 0.707 IL [2]

A. Voltage Rating of MOSFET

It is easily seen that the peak forward blocking as well as the peak reverse voltage on the MOSFET is equal to the maximum capacitor voltage. Hence the voltage rating of the thyristor is equal to Vco.

B. Voltage Rating of Diodes

The peak reverse voltage across a diode occurs just before the switch in the same leg is fired and is given by (Vco-IR/3). This could be taken as Vco itself for a safe design.

C. Inductor Design

During traditional operation mode, the capacitor voltage is always equal to the input voltage. So there is no voltage across the inductor. During shoot through mode, the inductor current increases linearly and the voltage across the inductor is equal to the voltage across the capacitor.

The average current through the inductor is given by,

IL = P/Vdc [3]

Where P is the total power and Vdc is the input voltage. The average current at 1kW and 150 V input is

IL (avg) = 1000/150 = 6.67A [4]

The maximum current occurs through the inductor when the maximum shoot-through happens, which causes maximum ripple current. In this design, 30% current ripple through the inductors during maximum power operation was chosen. Therefore the allowed ripple current was 4A and maximum current is 10.67A.

For a switching frequency of 10 kHz, the average capacitor voltage is

VC = (1-TO/T) * Vdc / (1-2TO/T) [5]

Substituting the values in the above equation 4.1.5

the average capacitor voltage is 300V. So the inductance must be no less than

L = 0.1 * 10 * 300 / 10.67 = 3mH [6]

D. Capacitor Design

The purpose of the capacitor is to absorb the voltage ripple and maintain a fairly constant voltage. During shoot-through the capacitor charges the inductors and the current through the capacitor equals the current in the inductor. Therefore the voltage ripple across the capacitor is

VC = IL(avg)TS/C [7]

The capacitor voltage ripple is 0.17%.

Substituting the above values in the equation the required capacitance was found to be

C=6.67*0.1*10(300*0.0017)=1000µF [8]

Hence the impedance network of the Quasi Z-Source inverter consists of a inductor of value 3mH and capacitor of 1000µF.

E. Driver Circuit

TLP250 is suitable for gate driving circuit of IGBT or power MOSFET.

- Input threshold current: IF=5mA(max.)
- Supply current (ICC): 11mA(max.)
- Supply voltage (VCC): 10−35V
- Output current (IO): ±1.5A (max.)
- Switching time (tpLH/tpHL): 1.5µs(max.)
- Isolation voltage: 2500Vrms(min.)
- UL recognized: UL1577, file No.E67349
- Option (D4) type
- VDE approved: DIN VDE0884/06.92,certificate No.76823
- Maximum operating insulation voltage: 630VPK
- Highest permissible over voltage: 4000VPK
- Creepage distance: 6.4mm(min.)
- Clearance: 6.4mm(min.)

5. Modes of Inverter Operation

The mode of inverter operation is mainly classified based on the thyristor conduction period as

180ºconduction

120ºconduction

Three phase inverters are normally used for high power applications. Three single phase half or full bridge inverters can be connected in parallel to form the configuration of a three phase inverter. The gating signals of single phase inverters should be advanced or delayed by 120º with respect to each other in order to obtain three phase balanced voltages.

The three phase output can be obtained from a configuration of six switches and six diodes. Two types of control signals can be applied to the switches: 180ºconduction or 120ºconduction.

6. Hardware and Simulation

MATLAB is a software package for computation in engineering, science, and applied mathematics. It offers a powerful programming language, excellent graphics, and a wide range of expert knowledge. MATLAB is published by and a trademark of The Math Works, Inc.

The focus in MATLAB is on computation, not mathematics: Symbolic expressions and manipulations are not possible (except through the optional Symbolic Toolbox, a clever interface to maple). All results are not only numerical but inexact, thanks to the rounding errors inherent in computer arithmetic. The limitation to numerical computation can be seen as a drawback, but it's a source of strength too: MATLAB is much preferred to Maple, Mathematical, and the like when it comes to numeric.

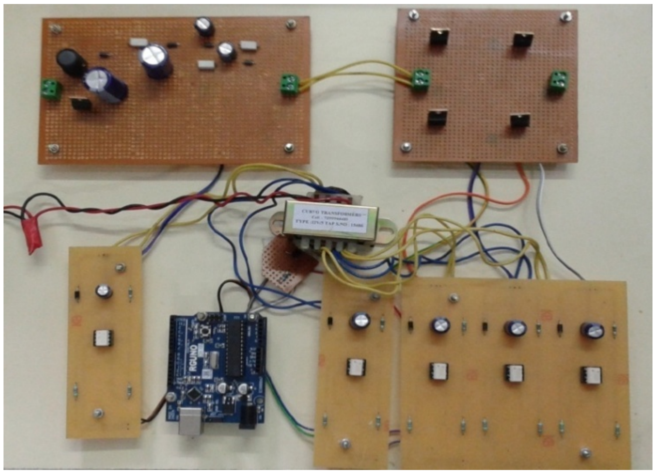

Fig.2 Hardware module of the proposed system

On the other hand, compared to other numerically oriented languages like C++ and FORTRAN, MATLAB is much easier to use and comes with a huge standard library.1 the unfavorable comparison here is a gap in execution speed. This gap is not always as dramatic as popular lore has it, and it can often be narrowed or closed with good MATLAB programming. Moreover, one can link other codes into MATLAB, or vice versa, and MATLAB now optionally supports parallel computing. Still, MATLAB is usually not the tool of choice for maximum-performance.

The effectiveness of the analysis for the proposed ESL-qZSI is verified by simulations. Through the simulation we can compare the performance and efficiency of the proposed system with the conventional system. And also we can easily know about the working of the proposed system. So the analysis of the system is become very easy.

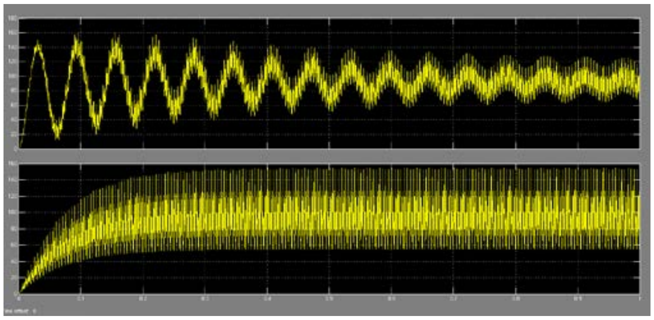

Fig 3.Result Input and Output Ripple Waveform

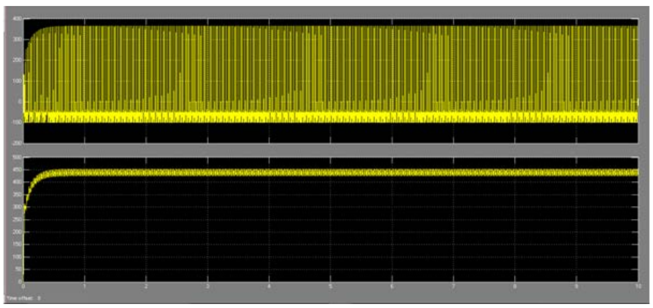

Fig 4.Input and Output Ripple Waveform

The simulation module of both existing system and the proposed system is done using MATLAB. The corresponding waveform for the existing system and the proposed system is compared. Through this comparison the performance ability of the existing system is known.

Fig.4 shows the input and output ripple waveform of the existing system and the Fig.4 shows the input and output ripple waveform of the proposed system. From the waveforms we can know that the ESL-qZSI is better than the qZSI in ripple control. So we can conclude that the output of the proposed system is having better boosting ability and ripple suppression control comparing to the existing system.

7. Conclusion

An ESL-qZSI is a combination of traditional SL-qZSI with boost converter as well as applying an improved SL cell. Compared with the original qZSI, the proposed ESL-qZSI has the following main characteristics: obtains high boost ability with continuous input current; offers lower voltage stress across capacitor, switching devices as well as diodes for the same input and output voltage.

Furthermore, the proposed topology will be able to achieve higher conversion efficiency. The effectiveness of the analysis for the proposed ESL-qZSI is verified by simulations. Hence we can conclude that the proposed ESL-qZSI is more applicable for the distributed generation applications with low voltage sources, such as fuel cells, photovoltaic and so on.

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