Solar Energy 171 (2018) 466–477

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

A novel single switch dc-dc converter with high voltage gain capability for solar PV based power generation systems

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ARTICLE INFO

Keywords:
Solar PV
Non-isolated
dc-dc converter
High voltage gain

ABSTRACT

This paper presents a single switch non-isolated DC-DC converter with high voltage gain capability for solar photovoltaic (PV) applications. The proposed converter is synthesized from passive switched inductor (SI) and switched capacitor (SC) topologies and integrated with an additional voltage boost capacitor to enhance the voltage gain. Due to the converter structure and adopted gain extension technique, the voltage stress on the switch and three diodes is 50% of the output voltage, while the remaining diodes experience a voltage stress of only 25% of the output voltage. Experimental results obtained from a 34 V/380 V, 200 W prototype converter validate the proposed concept, adopted design procedure and illustrates the fact that the proposed converter operates at a full load efficiency of 93%. Further, the proposed converter provides better component utilization compared to some existing converters.

1. Introduction

In recent years, distributed power generation using renewable energy sources has received greater attention due to the rapid exhaustion of fossil fuels and increased emission of greenhouse gases (Jacobson and Delucchi, 2011). Solar energy is one of the promising and clean renewable energy resources for electric power generation (Bennett et al., 2012). However, the output from solar panel is low and many panels have to be connected in series-parallel combination (Singh and Banerjee, 2015). The voltage available from the different series-parallel combination of solar PV cell is of the order of 20–60 V (Rajesh and Carolin Mabel, 2015). Hence, a suitable power converter is required to interface the PV panels with the load (Shuhui et al., 2011). In many applications like solar based generation system, comparatively high voltage is achieved by dc-dc boost derived converter (Forouzesh et al., 2017; Li and He, 2011) as shown in Fig. 1.

Isolated dc-dc converters are not preferable solution for high voltage gain applications like, solar based power generation system due the problems like saturation in high frequency transformer core, low efficiency, bulk in size etc (Gonzalez et al., 2007; Fathabadi, 2016; Kima et al., 2010). However, conventional non-isolated dc-dc boost converter suffers from the problem of high voltage stresses on switch and reverse recovery problem of diodes during high duty ratio operations in order to achieve high voltage gain. The problems of isolated converter topologies can easily be overcome in non-isolated topologies (Meneses et al., 2013; Sivakumar et al., 2016; Li and He, 2011). Many non-isolated high gain dc-dc converter topologies which use different combinations of voltage lifting techniques for PV application are discussed (Revathi and Prabhakar, 2016; Taghvaee et al., 2013). One of the simple methods to achieve high voltage gain is cascaded technology. But cascaded boost converter suffers from the problems of high voltage stress on second stage switch and diode, reverse recovery issue and instability (Vighetti et al., 2012).

Quadratic boost converters and their derivatives also provide higher voltage gain at the expense of extreme duty ratios ($D > 0.8$), diode reverse recovery problems and associated higher power losses (Divya Navamani et al., 2017; Zhang et al., 2015).

The concept using multilevel is introduced to achieve high voltage gain (Zhang et al., 2013). No of levels in multilevel boost converter is limited due to high switching loss, poor voltage regulation, high voltage and high current stress on switch. Voltage multiplier cell technology offers high voltage gain (Al-Saffar and Ismail, 2015; Nouri et al., 2013). Unfortunately, the power handling capability reduces when voltage gain is more than 10 (Tseng et al., 2013; Tseng and Huang, 2014).

Coupled inductor based topologies also offer high voltage gain (Chen et al., 2012; He and Liao, 2015). However, leakage inductance causes serious problems like resonance and EMI in the power circuit. At times, voltage lifting techniques like, voltage multiplier cells, switched

Abbreviations: PV, photovoltaic; SI, switched inductor; SC, switched capacitor; MPPT, maximum power point tracking; CCM, continuous conduction mode; DCM, discontinuous conduction mode

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https://doi.org/10.1016/j.solener.2018.06.081
Received 17 January 2018; Received in revised form 1 June 2018; Accepted 20 June 2018
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Nomenclature

Symbols used

S	switch
L_1, L_2	switched inductors
C_1, C_2	switched capacitors
C_B	boost capacitor
C_0	output capacitor
D_1, D_2	passive switched inductor diodes
D_{C1}, D_{C2}	switched capacitor diodes
D_0	output diode
R_0	load resistance
V_{in}, V_0	input voltage and output voltage
V_{L1}, V_{L2}	voltage across L_1 and L_2
V_{C1}, V_{C2}, V_{CB}, V_{C0}	voltage across C_1, C_2, C_{CB} and C_0
V_{D1}, V_{D2}, V_{DC1}, V_{DC2}, V_{D0}	voltage across D_1, D_2, D_{C1}, D_{C2} and D_0
V_S	voltage across switch S
I_{L1}, I_{L2}	current through L_1, L_2
I_{CB}, I_{C1}, I_{C2}	current through C_B, C_1, C_2
D	duty cycle of the switch S
T_{ON}	ON time period of switch S
G_{CCM}, G_{DCM}	voltage gain during CCM and DCM
T_S	switching time period
f_S	switching frequency
τ, τ'	normalized inductor time constant and boundary normalized inductor time constant
ΔI_L	ripple current of inductor
ΔV_{C1}, ΔV_{C2}, ΔV_{CB}, ΔV_{C0}	ripple voltage of C_1, C_2, C_B and C_0

capacitor cells etc. are also integrated with coupled inductor based topologies to achieve high voltage gain (Ye et al., 2017).

Switched capacitor based boost converters can provide high voltage gain at reduced voltage stress on switch by charging the capacitors in parallel and discharging in series. But the voltage regulation of these types of converter is poor (Axelrod et al., 2008; Wu et al., 2015). Zeta derived converters integrated with SC cells also provide high voltage gain (Ismail et al., 2008). But the discontinuous input current makes it inappropriate for solar PV applications. Switched inductor based boost converters are simple and enhance the voltage gain with high component count by charging the inductors in parallel and discharging in series (Axelrod et al., 2008; Yang and Liang, 2009). In passive switched inductor based converters, the entire switched inductor cell is connected in series with the single active switch (Axelrod et al., 2008) while in active switched inductor network, each inductor is connected with an individual active switch to reduce the voltage stress on active switches at the cost of high component count (Yang and Liang, 2009). Combined active and passive SI cells can also deliver high gain but at the expense of large no of active switches as well as large no of total component counts leading to high switching and conduction losses (Maheri et al., 2017).

This paper presents a novel single switch non-isolated dc-dc converter with high voltage gain capability. The proposed converter is a combination of switched inductor and switched capacitor technology integrated with an additional boost capacitor. Combination of passive switched inductor and switched capacitor cells provides high voltage gain. Incorporation of an additional boost capacitor instead of diode in the discharging path of switched inductor cell ensures additional voltage gain with reduced voltage stress on switch and diodes. Low voltage

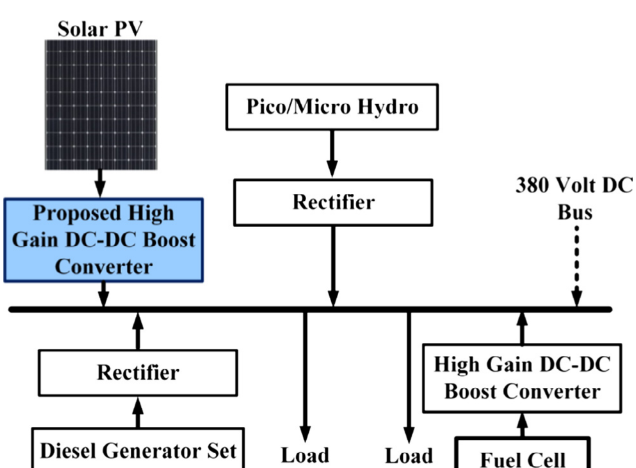

Fig. 1. Block diagram of solar PV integrated standalone DC Micro grid.

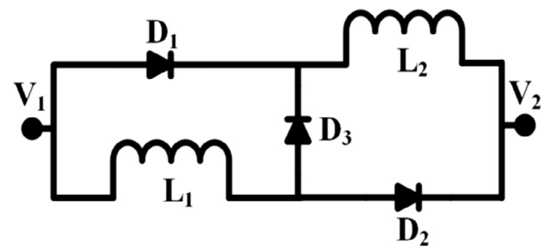

Fig. 2. Passive switched inductor cell.

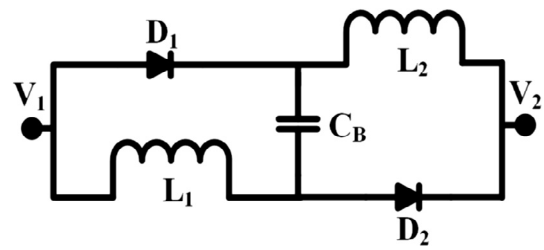

Fig. 3. Proposed modified switched inductor cell.

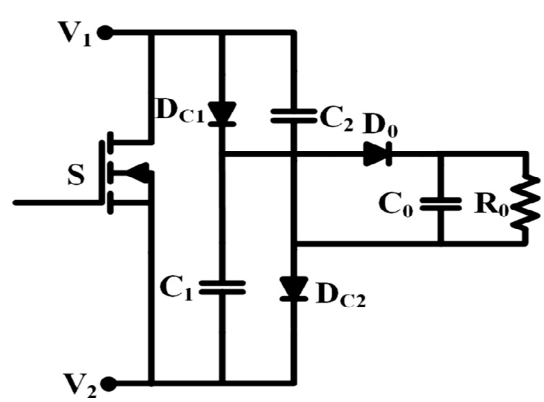

Fig. 4. Switched capacitor cell.

stress on diodes helps to eliminate the problem of reverse recovery in the proposed converter. It also supports for further reduction of conduction and switching losses of the diodes leading to improved efficiency of the converter. As the proposed converter is a hybrid combination of SI and SC technology, it overcomes the problem of poor voltage regulation of conventional SC based converter. The paper also includes an extensive comparative study with similar types of high gain converters which ensures the high voltage gain and better component utilization capability of the proposed converter than the other

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