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FPGA (Field Programmable Gate Array) controlled solar based zero voltage and zero current switching DC–DC converter for battery storage applications

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ABSTRACT

The objective of the paper is to develop a solar based soft switching isolated DC–DC converter for battery charging applications. The use of conventional boost converter is likely to decrease the efficiency because of hard switching, which generates loss during the switch on/off. But soft switching technique informs well with zero-current switching by the resonant inductor at turn-on, and zero-voltage switching by the resonant capacitor at turn-off. The major drawback of switched mode power converter operation is to produce EMI due to large dv/dt and di/dt during the time of switch mode operation. Therefore, to realize high switching frequencies in converters, the switching losses and EMI emission are reduced if each controlled switch in the converter is turn-on or turn-off only when current passing through and or voltage across the switch is zero. The FPGA (Field Programmable Gate Array) controlled DC–DC converter is used to provide zero voltage and zero current switching of all the main power devices. In this paper, the gate pulses are generated from FPGA (Field Programmable Gate Array) controller. This paper also describes the main operational modes of the converter as well as its simulation and Hardware results.

1. Introduction

The DC–DC converters are widely used for battery power supply in different electronic devices like mobile phones, MP3 players and laptops [1,2]. There is a scope for developing DC–DC converters to generate multiple dc output voltage from single dc power supply. These multiple output voltages are fed to different dc load applications. This scheme of developing multiple dc voltage levels from a single dc supply source can reduce the overall device area. The dc voltage provided by rectifier or battery contains more ripples and it is not a constant value and is not suitable for many electronic devices. To overcome this problem, the DC–DC voltage regulators are used to control the ripples when these are changes in the input voltage or load current.

The switching mode type DC–DC converter power supply is widely used because it uses a switch in the form of transistor type and less loss components such as transformers, inductors and capacitors for controlling the output voltage [1–12]. The switched mode power supply contains two different parts: control part and power part. The majority of the work is carried out by the control part for getting better control of output voltage. Generally the MOSFET is used as a control switch in Switched mode power supply for stabilizing the required output voltage. The MOSFET switches are not to be conducted continuously and they operate only under specific frequency interval only, hence these switches are useful for future and also provide less power loss converter circuit. The basic structure of Switched mode power supply is used for stepping up or stepping down of input DC voltage. The SMPS (Switched Mode Power Supply) circuit basically consists of a filter at the output side for removing the ripples due to switching.

With available devices and circuit technologies, PWM converters have been designed to operate generally at 30–50-kHz switching frequency [6–10]. In this frequency range, the equipment is deemed optimal in weight, size, efficiency, reliability and cost. In certain applications where high power density is of primary

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concern, the conversion frequency has been chosen as high as several hundred kilohertz. With the advent of power MOSFET devices, switching speed as high as tens of megahertz is possible. Accompanying the high switching frequency, however, are two major difficulties with the semiconductor devices, namely high switching stress and switching loss. For a given switching converter, the presence of leakage inductance in the transformer and junction capacitance in semiconductor devices cause the power devices to operate in inductive turn-off and capacitive turn-on. As the semiconductor device switches off an inductive load, voltage spikes are induced by the sharp di/dt across the leakage inductances. On the other hand, when the switch turns on at high voltage level, the energy stored in the device's output capacitances, 0.5 CV^2, is trapped and dissipated inside the device. Furthermore, turn-on high voltage levels induce a severe switching noise known as the Miller effect which is coupled with the drive circuit, leading to significant noise and instability.

The present paper presents a DC–DC converter that achieves soft switching for all the main switches, reduces the voltage stresses across each main switch, and controls the voltage on the secondary side of Full Bridge step-down converter. The simulation is done with the help of MATLAB/Simulink and controlling of power switches must be done with FPGA (Field Programmable Gate Array) controller. Fig. 1 shows the arrangement of photovoltaic electric power generation.

2. ZVZCS DC–DC converter

In order to improve the efficiency of energy conversion for a PV (photovoltaic) system, a soft-switching DC–DC converter using a simple auxiliary resonant circuit that consists of auxiliary switches, diodes, a resonant inductor, and a resonant capacitor is used as shown in Fig. 2. The use of conventional boost converter is likely to decrease the efficiency because of the hard switching, which generates losses during the switch on/off.

Figs. 2 and 3 show the circuit topology and the operational waveforms of the proposed converter. The simple control strategy is based on phase-shifted- pulse-width modulation with diagonal switches receiving the same control signals. Thus, S_1 and S_2, S_3 and S_4, S_5 and S_6, and S_7 and S_8 are each controlled in pairs.

The intermediate voltage stages typically are available in a 3L converter (i.e., ±Vdc/2) which allow a better approximation of a sinusoid, thus resulting in the reduction of harmonic levels for the inverter case, but this feature is not applicable to the DC–DC converter here since the output voltage V_{OUT} fixed at a constant dc level, is greater than the intermediate levels typical of DC–AC 3L converters. If the intermediate voltages were used, the voltage at the input of the diode-bridge rectifier would be less than V_{OUT} and the rectifier would not conduct, so no power would be delivered to the load.

Table 1 gives the proposed switching states and identifies the voltage levels V_S at the output of the transformer for each switching state. A "+" symbol indicates that the switch is ON during the switching state, while "−" symbol indicates that the switch is OFF. The switching frequency is fixed and each switch is ON for exactly half a switching cycle, but the timing of the turn-OFF and turn-ON of each controlled switch is controlled so that the dc-bus voltage is applied to the transformer for the desired time as with phase-shifted PWM. Using Table 1, it is recognized that the rectifier causes the voltage at the output filter to be positive regardless of the polarity of the transformer voltage. It can be realized that the system has the same general operating modes as a buck converter. The switching scheme, though it does not allow the intermediate voltage levels, does achieve soft switching for all the main devices. Furthermore, the loss of intermediate switching states is consistent with other 3L soft-switched designs. The rectifier diodes D_{rec1}–-D_{rec4} change the transformer voltage so that a positive voltage is applied to the output filter regardless of the polarity of the transformer voltage; thus, the converter's operation can be defined in terms of half cycles with the voltage and current seen by the output filter $L_f - C_o$ being the same for each half cycle. If the converter is in state 1 for duration $D \times Tsw/2$, where D represents the duty cycle and is a fraction between 0 and 1, then the average voltage at the rectifier will be

$$V_{out} = \frac{D^* V_{dc}}{n} \quad (1)$$

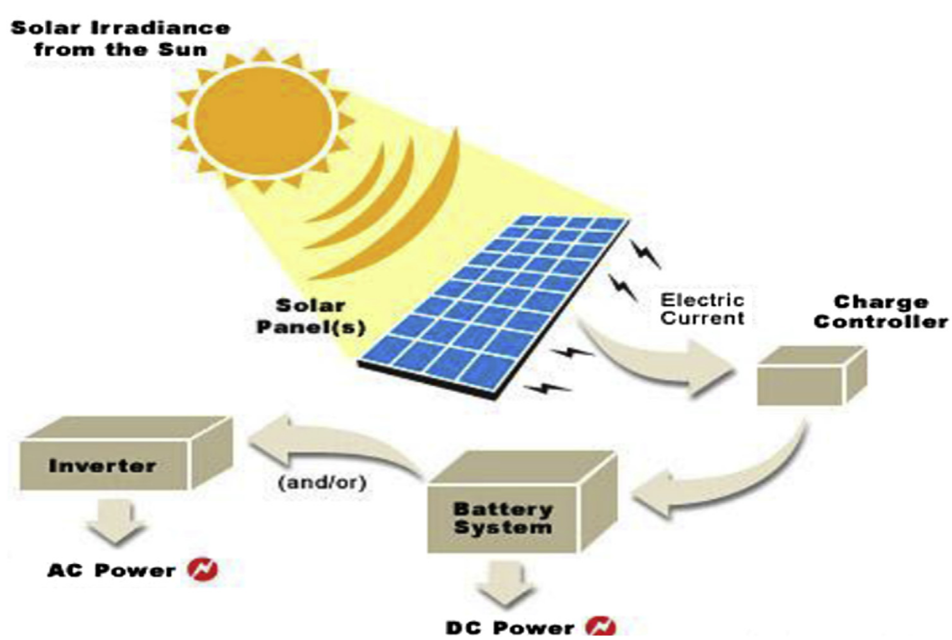

Fig. 1. Photovoltaic electric power generation.