BIDIRECTIONAL FULL-BRIDGE DC-DC CONVERTER WITH FLYBACK SNUBBER FOR PHOTOVOLTAIC APPLICATIONS

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ABSTRACT

Application of a bidirectional full bridge DC-DC converter with flyback snubber for photovoltaic cell is proposed in this paper. Bidirectional converters are important to interface an energy storage device to renewable energy sources like fuel cell, solar cell etc. Bridge-type bidirectional converters are important for high power applications. In this paper, a bridge-type bidirectional dc-dc converter with an isolation transformer is used. A snubber circuit is used to clamp the voltage spike caused by the current difference between the current-fed inductor and leakage inductance of isolation transformer. It reduces the current flowing through the active switches at the current-fed side. Operational principle of the proposed converter is described for step up and step down mode. A PV cell is connected in the low voltage side to get a boosted output that is used to charge a battery. Simulation is done by using MATLAB.

Keywords: Bidirectional Full Bridge Dc-Dc Converter;Flyback Snubber;PV Cell,Step-Down Mode,Step-Up Mode

1. INTRODUCTION

The importance of bidirectional converters are increasing day by day. They are the main part of a system to interface an energy storage device and renewable energy sources like solar cell. Bridge-type bidirectional converters are used for high power applications. A dual full-bridge configuration is used for increasing the power level with step-up circuit in low voltage side and step-down circuit in high voltage side. A bridge type bidirectional dc-dc converter is used in this paper to step-up voltage from a solar cell and charge a battery.

Isolated bidirectional dual-active-bridge dc-dc converters have many advantages like electrical isolation, high reliability, bidirectional energy flow etc[1]. Bidirectional dc-dc converters find applications in battery chargers and dischargers, uninterruptible power supply, hybrid electric vehicles etc[2]

The main interests of this study includes decreasing switching loss and reduction of current stress. To reduce the voltage spike caused due to the difference between the currents in the inductor and leakage inductance of transformer, passive and active clamping circuits have been proposed[3][4]. A fly back snubber circuit can be used to clamp the voltage to a required level [5]. This reduces the current stress on the switches.

2. ISOLATED BIDIRECTIONAL DC-DC CONVERTER WITH FLYBACK SNUBBER

Fig.1 shows an isolated bidirectional dc-dc converter with a flyback snubber. The converter is operated in two modes: step-up mode and step-down mode. Fig.1 includes a current fed switch bridge and flyback snubber at low voltage side and voltage fed bridge at high voltage side. Clamping capacitor Cc and diode Dc absorb the current difference between inductor Lmi and leakage inductance of isolation transformer.
Voltage stress switches $M_1-M_4$ can be limited since the flyback snubber can regulate $V_C$ to a desired value higher than $V_{AB}$. No spike current circulates through the switches and the voltages across them are clamped. As a result, reliability of the system is improved.

Assumptions made for the steady state analysis:
1. All components are ideal.
2. Inductor $L_m$ can keep current $i_L$ constant for a switching interval.
3. Clamping capacitor $C_c$ is higher than parasitic capacitance of the switches.

![Fig.1: isolated bidirectional dc-dc converter with flyback snubber](image)

**2.1 Step Up Mode**
In this mode, switches $M_1-M_4$ are operated and the body diodes of switches $M_5-M_8$ conducts for transferring power to $V_{HV}$. When switch pair ($M_1, M_4$) or ($M_2, M_3$) operates, the current difference $i_C = i_L - i_P$ will charge $C_C$ to raise $i_P$ to $i_L$. The average power $P_C$ transferred to $C_C$ is given as:

$$P_C = \frac{1}{2} C_c \left[ (i_L^2 - i_o^2) + 2 i_L i_o V_C(R) \right] f_s \quad (1)$$

where:

$$i_o = \sqrt{\frac{P_C}{C_c f_s}} \quad (2)$$

$$L_{eq} = L_{in} + L_{in} \frac{N_2^2}{N_1^2} \quad (3)$$

$V_{C(R)}$ is regulated $V_C$ which is nearly equal to $V_{HV} (N_1 / N_2)$, $f_s$ denotes switching frequency and $L_{eq}$ is much greater than $L_{eq}$. Power is transferred to the high voltage side through the fly back snubber. The snubber circuit will regulate the clamping capacitor to $V_{C(R)}$ within one cycle. The peak voltage $V_{C(P)}$ of the clamping capacitor that is imposed on the low voltage side switches is determined as:
where \( i_{\text{LM}} \) is the maximum inductor current. The operation wave forms of step up mode is shown in Fig 2.

\[
V_{C}(\theta) = L_{L}(\theta)I_{L} + V_{KE} \frac{N_{E}}{N_{G}} \tag{4}
\]

The different modes of half cycle operation are described below:

**Mode 1** \([t_0 \leq t < t_1]\): All the switches from M1-M4 are turned on to charge inductor Lm. Inductor current increases linearly. Equivalent circuit is shown in Fig.3(a).

**Mode 2** \([t_1 \leq t < t_2]\): At \( t_1 \), M1 and M4 remain on but M2 and M3 are turned off. Diode \( D_c \) conducts till the difference between \( i_L \) and \( i_p \) at \( t=t_2 \) becomes zero. The body diodes of switches M3 and M5 conduct to transfer power. In this interval, the current difference flows into \( C_c \). Fig.3(b) shows the equivalent circuit.

**Mode 3** \([t_2 \leq t < t_3]\): At \( t_2 \), \( D_c \) stops conducting the current difference and the snubber circuit starts its operation. Now the clamping capacitor \( C_c \) discharges and the flyback inductor stores energy. The equivalent circuit is given in Fig.3(c).

**Mode 4** \([t_3 \leq t < t_4]\): At \( t_3 \), energy from the flyback inductor is transferred to the high voltage side. In this interval, \( V_c \) is regulated to \( V_{COR} \). Power transfer continues from low voltage side to high voltage side. Fig. 3(d) shows the equivalent circuit.

**Mode 5** \([t_4 \leq t < t_5]\): At \( t_4 \), the capacitor voltage is regulated and snubber remains idle. Power is still transferred which stops at \( t_5 \). The equivalent circuit is shown in Fig. 3(e).
2.2 Step Down Mode

In this mode, switches M₁-M₈ are operated. The switch pairs (M₅, M₈) and (M₆, M₇) are turned on alternately to transfer power from high voltage side to low voltage side. The different modes of operation are explained below.
Mode 1 \[ t_0 \leq t < t_1 \]: In this mode, switches \( M_5 \) and \( M_8 \) are turned on. The high voltage is imposed on the transformer which increases the current linearly. The switches \( M_1 \) and \( M_4 \) conduct to transfer power and a stepped down voltage is obtained in the current-fed side. Fig. 5(a) shows the equivalent circuit.

Mode 2 \[ t_1 \leq t < t_2 \]: At \( t_1 \), switch \( M_5 \) is turned off while \( M_8 \) is conducting. The body diode of \( M_6 \) starts conducting the freewheeling leakage current. The equivalent circuit is shown in Fig. 5(b).

Mode 3 \[ t_2 \leq t < t_3 \]: At \( t_2 \), switch \( M_6 \) is turned on by zero voltage switching. The equivalent circuit is shown in Fig. 5(c).

Mode 4 \[ t_3 \leq t < t_4 \]: Switch \( M_6 \) is turned off and \( M_8 \) is still conducting. The freewheeling leakage current is conducted by the body diode of switch \( M_7 \). Fig. 5(d) shows the equivalent circuit.

Mode 5 \[ t_4 \leq t < t_5 \]: Using zero voltage switching, switch \( M_7 \) is turned on. Switches \( M_2 \) and \( M_3 \) become active. Equivalent circuit is shown in Fig. 5(e).

Fig. 5: Modes Of Operation Of Step Down Mode. (A) Mode 1, (B) Mode 2, (C) Mode 3, (D) Mode 4, (E) Mode 5

3. PROPOSED SYSTEM

The proposed system includes a photovoltaic cell and a battery in the circuit of bidirectional DC-DC converter with fly back snubber. The low output voltage from a photovoltaic cell is given to the input of the bidirectional converter. The low voltage is stepped up and used to charge a battery. The Simulink model of the proposed system is shown in Fig. 6.
Ten solar cells of 0.6V each were connected together to give an output of 6V. This 6V input was given to the battery and the battery was fully charged at 15.79V.

4. SIMULATION RESULTS

The simulation of the circuit of bidirectional DC-DC converter with fly back snubber for step up and step down modes were done using MATLAB. For the simulation of the step up mode 48V was given at input side. It was stepped up to 174.8V. For the simulation of the step down mode 360V was given at input side. It was stepped down to 48.91V. For simulating the proposed system, ten solar cells of 0.6V each were connected together to give an output of 6V. This 6V input was given to the battery and the battery was fully charged at 15.79V.
5. CONCLUSION

A Bidirectional DC-DC converter with fly back snubber connected to a photovoltaic cell at the input to charge a battery has been designed and simulated using MATLAB SIMULINK software. The circuit is used for high power applications. A fly back snubber is used to cancel the voltage spike and thus reduce the stress on the switches and the system reliability is increased. Bidirectional DC-DC converters find wide applications in fuel cell systems, hybrid vehicles etc.

REFERENCES


