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Modified Bidirectional Converter with Current Fed Inverter

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ABSTRACT

A bidirectional dc-dc converter with multiple outputs are concatenated with a high frequency current source parallel resonant push pull inverter is presented in this paper. The two outputs are added together and it is taken as the input source for the inverter. The current source parallel resonant push pull inverter implemented here with high frequency applications like induction heating, Fluorescent lighting, Digital signal processing sonar. This paper proposes a simple photovoltaic power system consists of a bidirectional converter and a current fed inverter for regulating the load variations. Solar power is used as the input source for the system. Simulation of the proposed system is carried out in PSIM software and experimentally verified the results.

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1. INTRODUCTION

The sun has provided solar power for billions of years and will do so for many billions more. It is computed that there is sufficient hydrogen still in the sun's core for 4.5billions more. One major advantage with the use of solar energy is that as it is renewable and also sustainable in nature, so it will never run out. Generally renewable energy resource needs very less maintenance than traditional generators. Solar modules are one of the main parts of a typical photovoltaic power system and also it includes interfacing circuits such as converter and an inverter with a control strategy [1-3]. This paper bring up with such a small system with simulation study as well as the experimental results. Converter used here with a high frequency transformer for reducing the size as well as the weight and it is a dc-dc type multi output bidirectional converter. Since the converter is a bidirectional one, rechargeable batteries are used in the output side for correct operation. Here bidirectional converter is designed for supplying the input source to the current fed inverter. Since rechargeable battery there in the converter side, the inverter operation will not be interrupted even if the solar energy is not available due to the climatic conditions. The current fed inverter selected her is for high frequency applications [4-5].

2. SYSTEM DESCRIPTION AND DESIGN

The circuit diagram without the control strategy is depicted in Figure 1. Dual output of the modified bidirectional converter is summed together and given as the input for the current fed inverter [6-10]. Since the bidirectional topology included in the system, the supply for the inverter will be there for all the time even if solar energy is not there also.

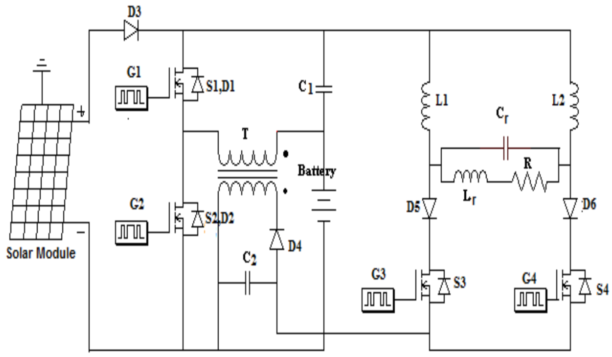

Figure 1. Proposed System

The inverter which is used here with two inductors, power switches with common grounds and resonant tank circuit connected in parallel. The advantages of this topology are no high side driver circuits needed and very less voltage stress on the power switches. The modes of operation of the modified bidirectional converter explained in [11]. The design equations of the system are given in (1)-(5). The specifications of the modified bidirectional converter are given below. Input Voltage, V_s = 30V, Battery Voltage, V_b = 24V, Switching Frequency = 5 kHz, Voltage Ripple V_{ripple} = 0.05, Duty Cycle = 72%, V_{01} = 29.3V, V_{02} = 10V, I_o = 0.3A.

2.1. Capacitor Design

Two output capacitors are there in converter. Both are separately designed according with the output voltages.

Magnetizing current, $I_m = \dfrac{P_o}{\eta V_b}$ (1)

Change in current, $\Delta I = 20\% I_m$ (2)

Change in capacitor voltage, $\Delta V_c = V_o \; V_{ripple}$ (3)

Output Capacitor, $C = \dfrac{DI_{cap}}{\Delta V_c F_s}$ (4)

Capacitor Current, $I_{cap} = I_c + \dfrac{\Delta I}{2}$ (5)

Capacitor, C_{01} is designed according with the output voltage V_{01} and Capacitor $C_{02}$is designed according with the output voltage V_{02}.The values obtained for C_{01} and C_{02} are 28*uF* and 47*uF* respectively.

2.2. Transformer Design

The design steps [12-14] for the transformer given in equations (6)-(20)
The specifications are given below
Utilization Factor, *K*=0.4, Current Density, J=3*10^{6}A/m^2, Conservative Efficiency, η =0.8, Flux Density, B_m = 0.2T.
Since the output voltage V_{02} only depends on the transformer. So only V_{02} considering for the transformer design. It is important to calculate the total load power P_o that the transformer has to withstand.

Power, $P_o = V_o \; I_o + V_D I_o + P_{L-CU} + P_{L-Core}$ (6)

$P_{L\text{-}CU}$ and $P_{L\text{-}Core}$ are copper loss and core loss respectively.

$$P_{L\text{-}CU} + P_{L\text{-}Core} = 10\%\ V_o\, I_o \tag{7}$$

Area product equation of half bridge converter is A_p,

$$A_c\, A_w = \frac{P_0[\sqrt{2} + (\,^{1}\!/_{\eta})]}{4K_W J B_m f_s} \tag{8}$$

From the calculated area product A_p, choose an suitable core that should has an area product greater than that calculated value. Primary number of turns can be given

$$N_p = \frac{V_{i\max}}{2f\Delta B_m A_c} \tag{9}$$

Where V_{imax} is the primary winding voltage

$$V_{imax} = V_i + 10\% V_i \tag{10}$$

$$N_s = \frac{e_s}{2fB_m A_c} \tag{11}$$

Where $e_s = \dfrac{V_o + V_D + 0.1V_o}{D_{\min}}$ (12)

$$D_{\min} = \frac{V_{i\min} * D_{\max}}{V_{i\max}} \tag{13}$$

$$V_{imin} = V_i - 10\% V_i \tag{14}$$

The turns ratio is given as n = $\dfrac{N_s}{N_p}$ (15)

The rms value of current flowing through primary winding is given as,

$$I_{s-rms} = I_o\sqrt{D_{\max}} \tag{16}$$

The rms value of current flowing through secondary winding is given as

$$I_{p-rms} = n * I_{s-rms} \tag{17}$$

The current through the demagnetizing winding is given as

$$I_{d-rms} = I_m\sqrt{(1 - D_{\max})/3} \tag{18}$$

Where $I_m = \dfrac{D_{\max} V_{i\min}}{fL_m}$ (19)

Where $L_m = \dfrac{{N_p}^2\ \mu_o \mu_r A_c}{l_m}$ (20)

The transformer parameters obtained from the above equations are summarized in the Table I.

Table1. Transformer Parameters

Parameters	Value
Load Power, P_o	38W
Area Product, A_p	18704.99mm^4
Core Selected	P66/22
Number of Primary Turns, N_p	50
Number of Secondary Turns, N_s	129
Primary Winding RMS Current, $I_{p\text{-}rms}$	2.3A
Secondary Winding RMS Current, $I_{s\text{-}rms}$	0.89A
Current in Demagnetizing Winding, $I_{d\text{-}rms}$	0.1A
Magnetizing Current, I_m	0.4A
Magnetizing Inductance, L_m	17.7mH

2.3. Resonant Tank Design

The design steps are given in equation (21)-(23).The specifications selected are given below.
Load Resistor, R=1200*ohm*, Quality Factor, Q=7.5, Damping Ratio, ξ =0.1, Resonant Inductor, L_r=130*uH.*

Q Factor, $Q = R\dfrac{\sqrt{L_r}}{\sqrt{C_r}}$ (21)

Natural frequency of the resonant tank, $\omega_n = \dfrac{1}{\sqrt{L_r Cr}}$ (22)

Resonant frequency, $\omega_r = \omega_n\sqrt{1-\xi^2}$ (23)

L_1 and L_2 are chosen as higher value than that of the L_r, 3mH each. The obtained values of natural frequency and resonant frequency are 1216 kHz and 121 kHz respectively

3. SIMULATION STUDY

3.1. Open Loop Simulation

Open loop simulation was carried out in PSIM software to verify the performance of the system. Charging mode and discharging mode of the bidirectional converter are separately verified by the simulation study. Charging mode get activated when the input source voltage become higher than that of the battery voltage and the switch S_1 and diode D_2 are take part in this mode. Input voltage is not enough to supply the converter and the battery voltage level is greater, then battery discharging gets activated. The switch and the diode operating in this mode are S_2 and D_1. The input voltage selected for the converter is 30V. The output voltages that are getting from the converter are 29.3V and 10V. The sum of these two outputs 39.3V is the input voltage for the current fed resonant inverter. In charging mode of operation, the converter output voltage waveforms and inverter output waveforms are depicted in Figure 2(a) to Figure 2(c).

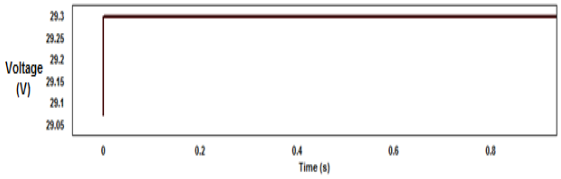

Figure 2(a). Converter Output Voltage 1

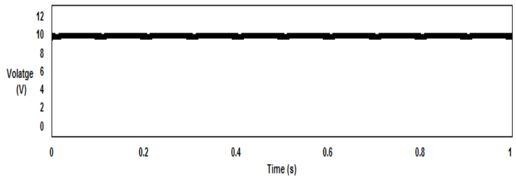

Figure 2(b). Converter Output Voltage 2

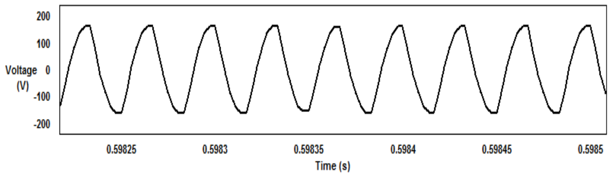

Figure 2(c). Inverter Output Voltage

The converter output voltages and inverter output voltages are depicted in Figure 3(a) to Figure 3(c) during the discharging mode of the converter.

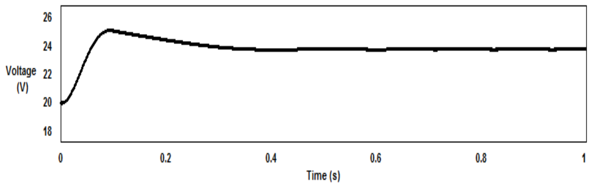

Figure 3(a). Converter Output Voltage 1

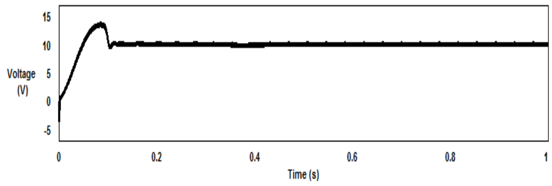

Figure 3(b). Converter Output Voltage 2

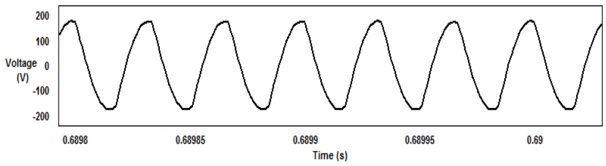

Figure 3(c). Inverter Output Voltage

3.2. Closed Loop Simulation

Closed loop simulation was carried out to verify the load variations. PSIM coupled with MATLAB simulink by using simcoupler. A simple PI controller is used and the load is regulated for 20% of load changes. The circuit that showing PSIM coupled with MATLAB is depicted in Figure 4(a) and Figure 4(b).

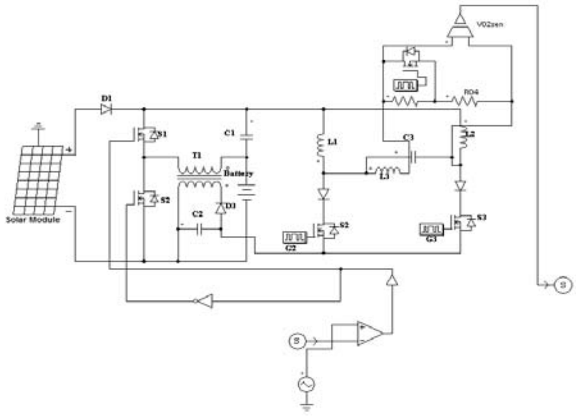

Figure 4(a). Closed Loop Circuit in PSIM

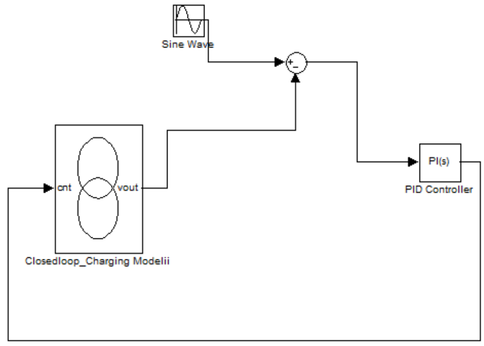

Figure 4(b). Controller Circuit in MATLAB Simulink

The output voltage and current of the current fed inverter in closed loop operation is shown as in Figure 5. Here up to 0.5s circuit runs at actual load and after 0.5s circuit runs at 20% of load change.

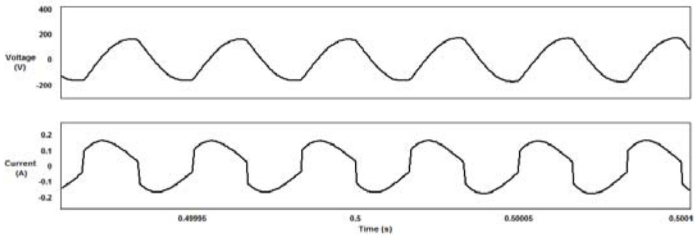

Figure 5. Inverter Output Voltage and Current during Load Change

4. HARDWARE IMPLEMENTATION

An experimental setup for the modified bidirectional converter with current fed inverter was implemented and verified the hardware results with simulation results. Power MOSFETs IRF 540 is used as converter switches and IRF840 is used as the inverter switches. The experimental setup of the power circuit is shown as in Figure 6. The gating pulses for converter and inverter are generated using TMS320 microcontroller. Complementary pulses are needed for both converter and inverter. Complementary pulses with 5 kHz frequency is generated for converter and complementary pulses with 30 kHz generated for inverter.

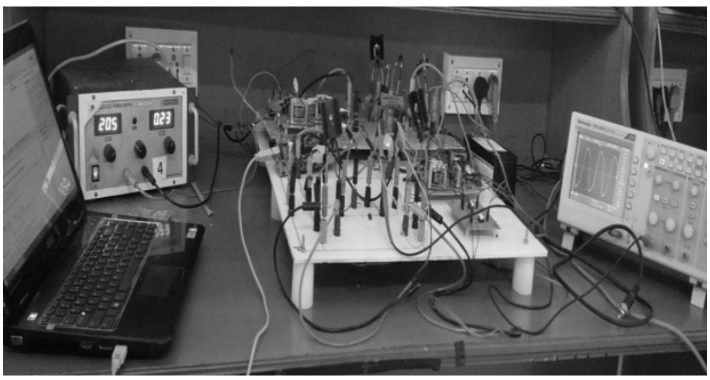

Figure 6. Hardware Setup

Pulses generated from TMS320 controller for converter and inverter are depicted in Figure 7(a) and Figure 7(b) respectively

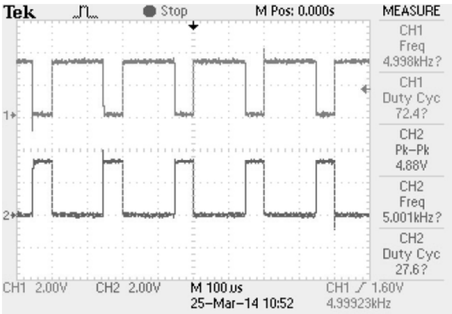

Figure 7(a). Gate Pulses for Converter

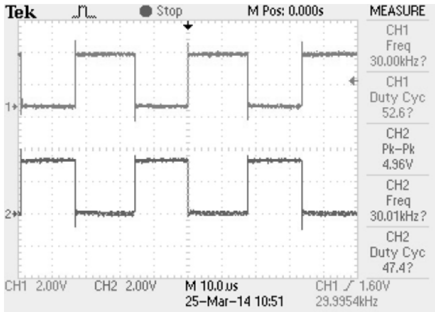

Figure 7(b). Gate Pulses for Inverter

The optocoupler IC TLP250 is used for amplifying magnitude of gate pulses generated from the TMS320 controller. The magnitude of gate pulses generated from the controller is not sufficient to trigger the power MOSFETs. Optocoupler ICs are used to increase the magnitude of the gate pulses. The amplified gate pulses generated from optocoupler IC is shown as in Figure 8(a) and Figure 8(b).

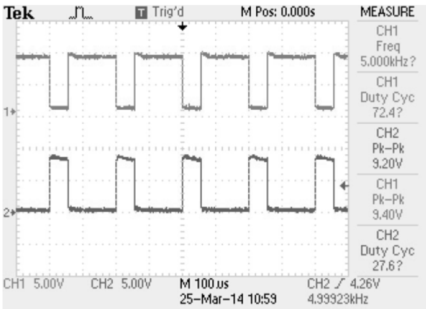

Figure 8(a). Pulses from IC TLP250 for Converter

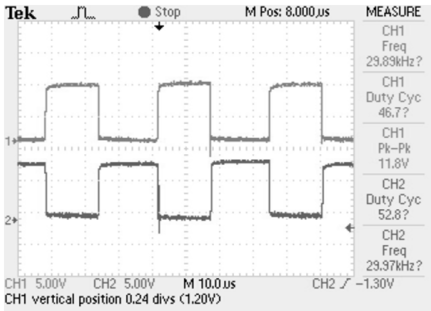

Figure 8(b). Pulses from IC TLP250 for Inverter

The two output voltages of modified converter with source voltage of 30V are 29.2V and 10.2V obtained practically depicted in Figure 9(a) and Figure 9(b) respectively.

Figure 9(a). Converter Output Voltage 1

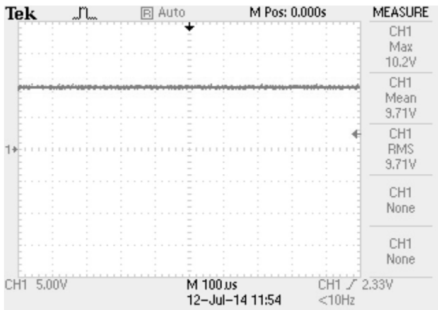

Figure 9(b). Converter Output Voltage 2

The two outputs obtained are added and it is given as the input voltage for inverter and inverter used here is dc-ac type. The input source for current fed inverter is shown as in Figure 10. The inverter implemented here with high frequency applications.Peak-peak voltage 298V with 30kHz frequency sinewave is practically obtained by designed values. The output voltage waveform is depicted in Figure 11.

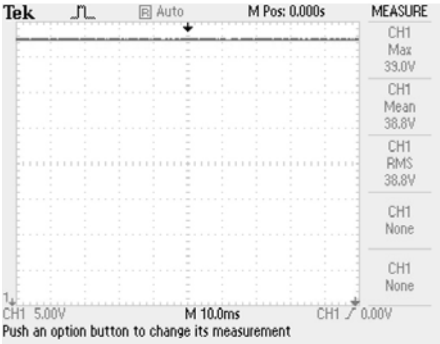

Figure 10. Inverter Input Voltage

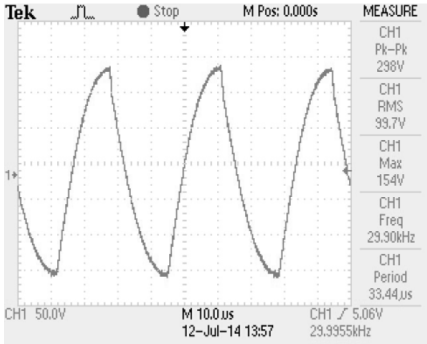

Figure 11. Inverter Output Voltage Waveform

5. CONCLUSION

In this paper, components design, simulation study in PSIM software, analysis of hardware results of modified bidirectional converter with current fed inverter were carried out. Using TMS320 controller, gate pulses for converter and inverter were obtained for hardware setup. Verified the hardware results by comparing the simulation results carried out in PSIM software. Increased the output voltages of the basic half bridge bidirectional converter due to modification included in the topology. Since high frequency is used in the system the size and weight of the components was reduced. Also due high frequency, the ripples in the output voltage of the inverter get reduced.

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