International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 11 Issue: 06 | Jun 2024 www.irjet.net p-ISSN: 2395-0072

# SIMULATION AND MODELLING OF NONISOLATED BIDIRECTIONAL ZERO-VOLTAGE-SWITCHING DC–DC CONVERTER

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**Abstract** - *A new nonisolated zero voltage switching(ZVS)bidirectional dc-dc converter is proposed in this paper. Bidirectional converters have been widely used in various industrial applications such as uninterruptible power supplies, fuel cell vehicle, and satellite applications. A bidirectional converter controls the power flow between the dc bus and the low voltage sources such as back-up batteries, fuel cell, and super capacitors. The proposed converter utilizes a very simple auxiliary circuit that consist of an additional winding to the main inductor and an auxiliary inductor to provide ZVS of the power switches and a ripple free inductor current. A comparative study between the conventional nonisolated bidirectional dc–dc converter and the proposed nonisolated bidirectional ZVS dc–dc converter is analyzed and simulation is done in MATLAB software and the practical implementation of the proposed converter is done.*

***Key Words***: **Zero Voltage Switching (ZVS), Zero Current Switching (ZCS), Bidirectional DC-DC convertor (BDC), PWM generators, Coupled inductor.**

## 1. INTRODUCTION

Bidirectional dc–dc converters have been widely used in various industrial applications such as renewable energy systems, hybrid electric vehicle, fuel cell vehicle, uninterruptible power supplies, and satellite. In such applications, bidirectional dc–dc converters control the power flow between the dc bus and the low-voltage sources such as back-up batteries, fuel cells, and super capacitors. Bidirectional dc–dc converters are classified into isolated and nonisolated versions.

In conventional nonisolated bidirectional dc–dc converter, it operates in continuous conduction mode (CCM). The CCM provides a low ripple current. However, the switching loss of the power switches is large and there exists the reverse recovery phenomenon of the antiparallel body diode of the power switch. With a smaller inductance, the conventional converter operates with an inductor current that flows in both directions during each switching period. Then ZVS operation of the power switches is achieved. However, large inductor current ripple causes large voltage ripple and shortens lifetime of low-voltage sources. However, to avoid reverse recovery phenomenon, to achieve ripple free inductor current, to reduce voltage ripple a new nonisolated bidirectional converter is proposed in this paper.

### 1.1 Proposed Bi-directional DC-DC converter:

The proposed bidirectional dc–dc converter is shown in Fig-1. It is very similar to the conventional converter except that an additional winding $N_s$ to the main inductor and auxiliary inductor Ls are added and the filter capacitor $C_f$ is split into $C_{f1}$ and $C_{f2}$. This auxiliary circuit provides ZVS function and cancels out the ripple component of the main inductor current regardless of the direction of power flow. The equivalent circuit of the proposed converter is shown in Fig-2.

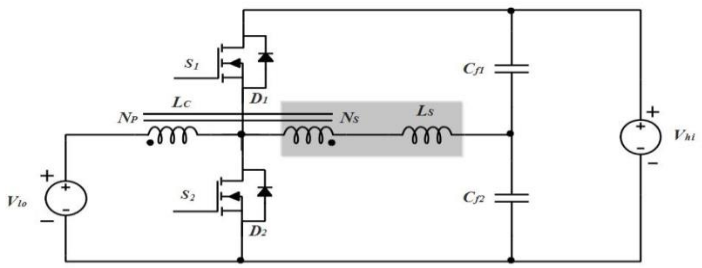


**Fig – 1: Proposed bidirectional dc-dc converter**

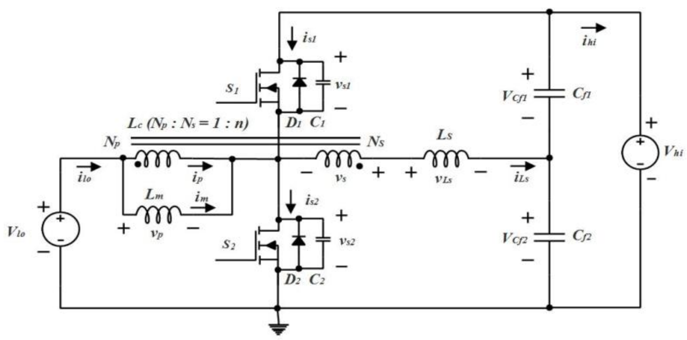


**Fig -**Error! No text of specified style in document.**:**
**Equivalent circuit of the proposed converter**

The coupled inductor $L_c$ is modeled as a magnetizing inductance $L_m$ and an ideal transformer that has a turn ratio of $N_p$:$N_s$ = 1:n. The leakage inductance of the coupled inductor $L_c$ is included in the auxiliary inductor $L_s$. The diodes $D_1$ and $D_2$ represent the intrinsic body diodes of $S_1$ and $S_2$ . The capacitors $C_1$ and $C_2$ are the parasitic output capacitances of $S_1$ and $S_2$. Since the capacitances of $C_{f1}$ and $C_{f2}$ are large enough, $C_{f1}$ and $C_{f2}$ can be considered as voltage sources $V_{Cf1}$ and $V_{Cf2}$ during a switching period. Since the average of the voltage across the inductor should be zero at steady-state according to volt-second balance law, the average values of filter capacitors voltages $V_{Cf1}$ and $V_{Cf2}$ are equal to voltages ($V_{hi}$ - $V_{lo}$) and $V_{lo}$ respectively.

## 2. DESIGN OF BDC

Specification $V_{io}$ = 12V (Input voltage), $V_{hi}$ = 24V (Output voltage)

$$P_o = 100W, f = 10kHz, \frac{\Delta V_o}{V_o} \leq 10\%$$

**Table 1: Design values of BDC**

| Sl. No | Specification | Design Value | |
|---|---|---|---|
| | | Boost mode | Buck mode |
| 1 | Duty ratio (D) | 0.5 | 0.5 |
| 2 | Resistance (R) | 5.76Ω | 1.44 Ω |
| 3 | Inductance(L) | 45µH | 45µH |
| 4 | Capacitance(C) | 86.805µF | 138.88 µF |
| 5 | Full load current ($I_O$) | 4.166 A | 8.33 A |

### 2.1 DESIGN OF COUPLED INDUCTOR

**Specifications:**
Input Voltage $V_i$ = 24V, Output Voltage $V_o$ = 12V at 8.33A, Switching Frequency $f_s$ = 10kHz, Magnetizing current ripple $\Delta i_m$ = 20% $I_m$ (demagnetizing current = 12A) Duty cycle D = 0.5, Turns ratio $N_s$/ $N_p$ = 0.3, Assume copper loss $P_{cu}$ = 1.5W, Wire resistivity $\rho = 1.724 * 10^{-6}\,\Omega cm$, Core cross sectional area $A_c$ = 1.09 cm², Winding fill factor $K_u$ = 0.3, Core Maximum flux density $B_{max}$ = 0.25T, Core window area $A_W$ = 0.256 cm²

**Components of magnetizing current referred to primary: -**

$$Im = (Ns/Np) * (1/D') * (V/R)$$

$Im$ = 0.3 * (1/1-0.5) *(24/1.2) = 12A ,$\Delta i_m$ = 20% of $I_m$ = 2.4A

$$Immax = Im + \Delta im$$

$$Immax = 14.4A$$

**Table -2: Design values of coupled inductor**

| Sl. No | Specifications | Design value |
|---|---|---|
| 1 | Magnetizing inductance ($L_m$) | 250 µH |
| 2 | Winding current (I) | 17.07 A |
| 3 | Primary number of turns ($N_P$) | 13 Turns |
| 4 | Secondary number of turns ($N_s$) | 4 Turns |
| 5 | Wire guage | 19 AWG |
| 6 | Power loss density (ΔB) | 0.04 W/cm³ |
| 7 | Core loss ($P_{fe}$) | 0.25 W |

## 3. SIMULATION RESULTS

### 3.1 Conventional bidirectional DC-DC converter

Fig-3 shows the simulink model of conventional bidirectional DC-DC converter, Fig-4 shows the subsystem to generate trigger pulses for switches $S_1$ and $S_2$, The simulation waveforms are in Fig-5, which gives the input voltage and output voltage waveforms.

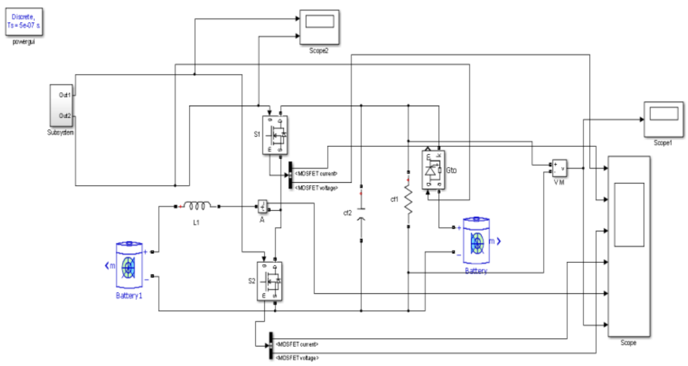

**Fig –3: Conventional bidirectional DC-DC converter**

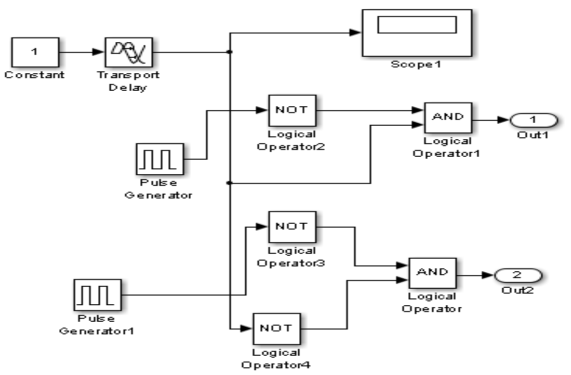


**Fig –4: Subsystem: MOSFET switches S1 and S2 PWM generator**

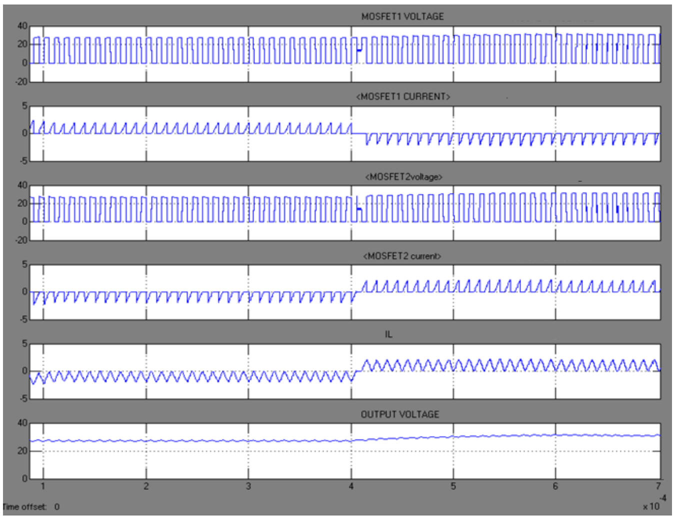


**Fig –5: Conventional bidirectional DC-DC converter simulation waveforms**

### 3.2 fuzzy PI controlled BDC

In Fig-6 proposed BDC boost mode line regulation is obtained by fuzzy, PI control. Fig-7 which gives the combination of PI and fuzzy PI output waveform of proposed boost mode for line regulation. In fuzzy control the output voltage settles faster than PI control.

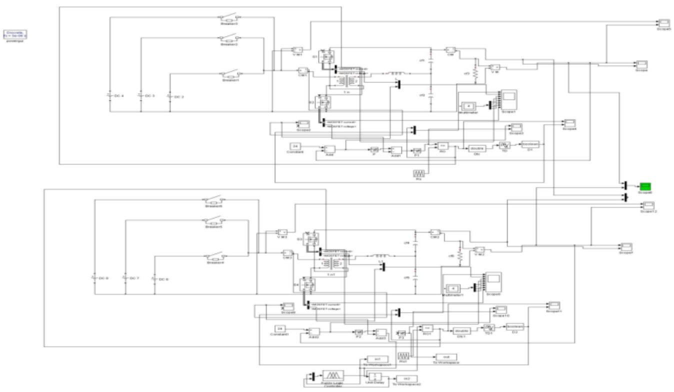

**Fig –6: Proposed Boost line PI and FUZZY**

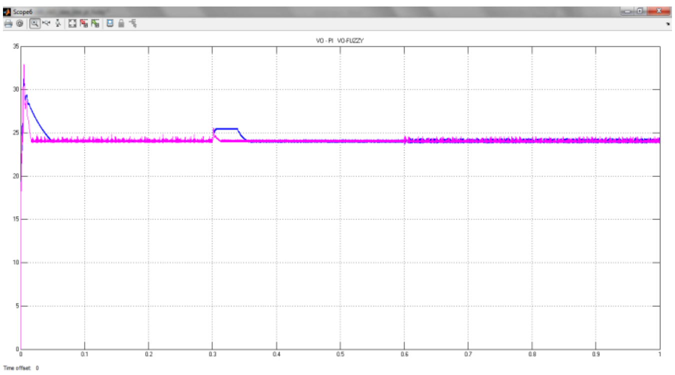

**Fig –7: Comparison of PI and fuzzy PI waveform in proposed BDC boost mode line regulation**

In Fig-8 proposed BDC buck mode line regulation is obtained by fuzzy, PI control. Fig-7 which gives the combination of PI and fuzzy PI output waveform of proposed buck mode for line regulation. In fuzzy control the output voltage settles faster than PI control.

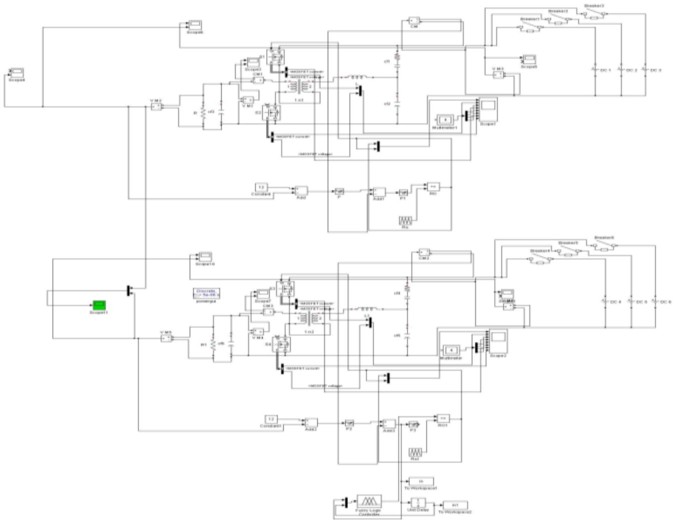

**Fig –8: Proposed Buck line PI and FUZZY**

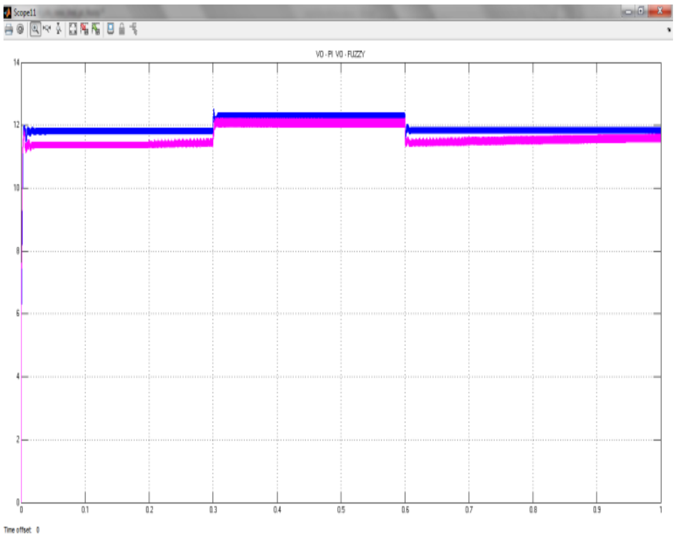

**Fig –9: Comparison of PI and fuzzy PI waveform in proposed BDC buck mode line regulation**

## 4. HARDWARE IMPLEMENTATION

Figure-10 shows the hardware implementation of proposed BDC using FPGA. Figure-11 shows an output voltage waveform of 12V in buck mode operation when input of 24V supply is given. Figure - 12 shows an output voltage waveform of 24V in boost mode operation when input of 12V supply is given.

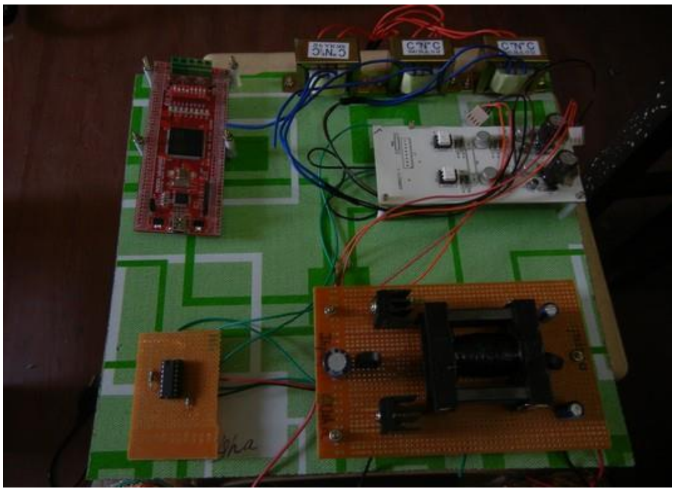

**Fig - 10: BDC circuit using FPGA**

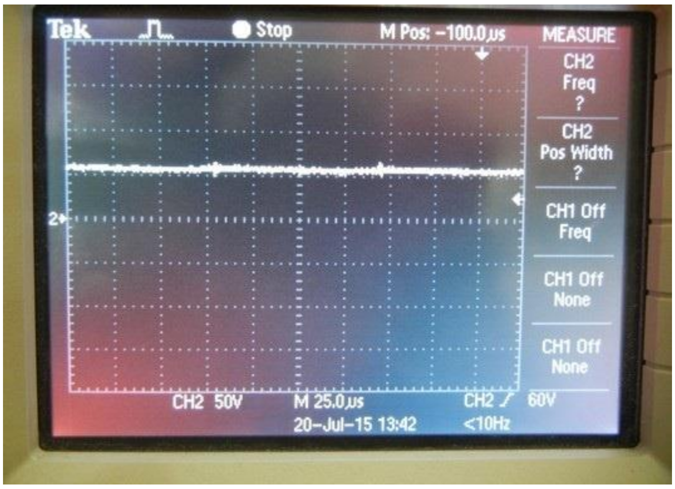


**Fig – 11: Output Voltage waveform of Buck mode operation**

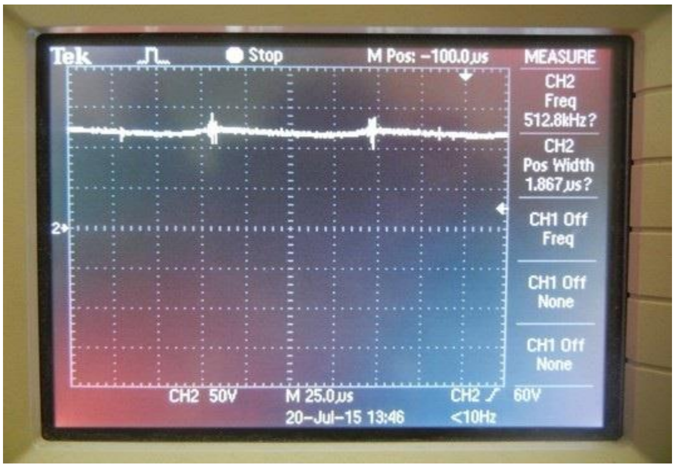


**Fig – 12: Output Voltage waveform of Boost mode operation**

## CONCLUSION

Simulation for conventional BDC and proposed BDC is simulated in open loop and closed loop control with input given as 12V and output obtained as 24V in boost mode and input given as 24V and output obtained as 12V in buck mode.In simulation for closed loop(PI and fuzzy PI) control, line regulation is obtained by varying input voltages and output voltage is obtained approximately constant as 24V in boost mode and 12V in buck mode operation. Compared to fuzzzy and PI control the rise time and settling time is reduced in fuzzy.Hardware Implementation for proposed BDC is done using FPGA.In hardware implementation of boost mode operation an input of 12V is supplied and output of 24V is obtained and in buck mode operation an input of 24V is supplied and output of 12V is obtained.

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