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Design and Implementation of CUK Hybrid Converter with PV Cell and Fuel Cell

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***Abstract*— A bidirectional DC-DC JAYA CONVERTER is used for dc-dc power conversion applications. The power converter includes two full bridge converter where one serving as inverter and other as rectifier. This Bidirectional dc–dc converter is good for electrical vehicle applications. The topology proposed system has advantages of simple circuit topology with soft switching implementation without additional devices, high efficiency and simple control. Proposed system is a three-port system interfacing a PV, an ESS unit (Fuel Cell) and a DC load.**

The Fuel Cell serves as an energy buffer, which means it can be charged or discharged to balance the power flow in the PV/battery hybrid power system.

The phase-shift full-bridge DC-DC converter interfacing the PV and the load shares power switches with the integrated bidirectional buck/boost converter.

Fuel cell is used to convert the AC to DC source.

The converter used for medium and high power applications especially for auxiliary power supply in fuel cell vehicles and power generation where they are high power density, low cost, lightweight and high reliability power converters are needed.

Generating pulses are implementing PWM technique for making MOSFETS devices are controlled and operated by PIC Micro controller. The harmonic in the circuit is reduced by PWM techniques.

INDEX TERMS: DC-DC Jaya Converter, Fuel cell, Photo voltaic cell, Inverter, PIC Micro Controller, MOSFET devices.

1. INTRODUCTION

In Recent years, more energy efficient are growing concerns about environmental issues demanded in nonpolluting vehicles. The fuel cell technology and power electronics have enabled the significant developments in fuel cell are used to powered the electric vehicles. The fuel cells have numerous advantages such as high density current output ability, clean electricity generation, and high efficiency operation. However, the traditional chemical-powered battery are characteristics from the fuel cell. The fuel cell output voltage drops are quick, when the fuel cell are first connected with a load and gradually decreases as the output current rises.

The fuel cell also lacks energy storage capability. Therefore, in electric vehicle applications, an auxiliary energy storage device (i.e., lead-acid battery) is always needed for a cold start and to absorb the regenerated energy fed back by the electric machine. In addition, a dc–dc converter is also needed to draw power from the auxiliary battery to boost the high-voltage bus during vehicle starting.

Until the fuel cell voltage raises to a level high enough to hold the high-voltage bus, the excess load from the battery will be released. The regenerated braking energy can also be fed back and stored in the battery using the dc–dc converter.

A full-bridge isolated bidirectional dc–dc converter is considered one of the best choices for these applications.

DC-DC JAYA CONVERTERs are devices which change one level of direct current voltage to another (either higher or lower) level. They are primarily of use in battery-powered appliances and machines which possess numerous sub circuits, each requiring different levels of voltage. A DC-DC JAYA CONVERTER enables such equipment to be powered by batteries of a single level of voltage, preventing the need to use numerous batteries with varying voltages to power each individual component.

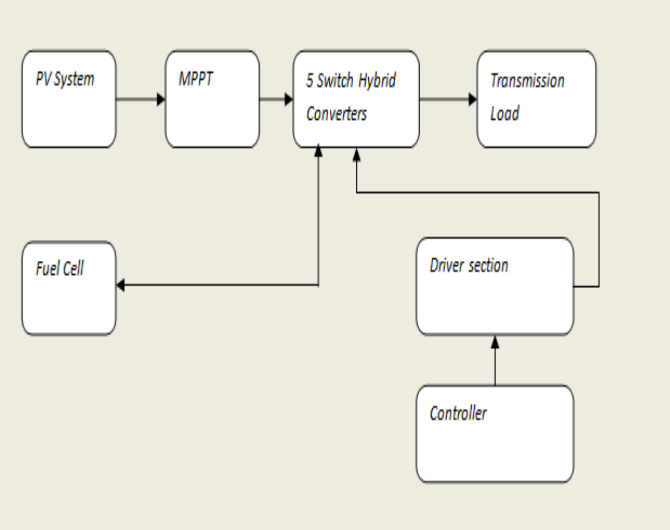

Figure: Block Diagram of DC-DC Jaya converter

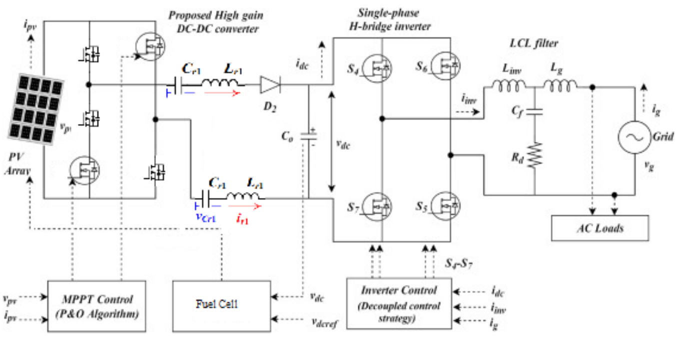

Figure: Circuit Diagram

1.1 BUCK CONVERTER STEP-DOWN CONVERTER

In this circuit the transistor turning ON will put voltage Vin on one end of the inductor. This voltage will tend to cause the inductor current to rise. When the transistor is OFF, the current will continue flowing through the inductor but now flowing through the diode. We initially assume that the current through the inductor does not reach zero, thus the voltage at Vx will now be only the voltage across the conducting diode during the full OFF time. The average voltage at Vx will depend on the average ON time of the transistor provided the inductor current is continuous.

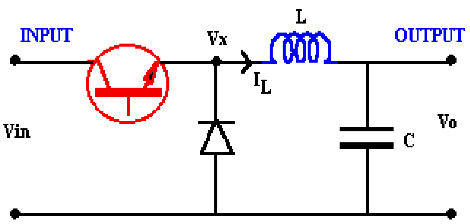

Fig. 1: Buck Converter

To analyse the voltages of this circuit let us consider the changes in the inductor current over one cycle. From the relation

Vx – Vo = L (di/dt)

the change of current satisfies

$$di = \int_{ON} (V_x - V_o)\,dt + \int_{OFF} (V_x - V_o)\,dt$$

For steady state operation the current at the start and end of a period T will not change. To get a simple relation between voltages we assume no voltage drop across transistor or diode while ON and a perfect switch change. Thus during the ON time $V_x = V_{in}$ and in the OFF $V_x=0$. Thus

$$0 = di = \int_0^{t_{on}} (V_{in} - V_o)\,dt + \int_{t_{on}}^{t_{on}+t_{off}} (-V_o)\,dt$$

Which simplifies to

$$(V_{in} - V_o)\,t_{on} - V_o\,t_{off} = 0$$

Or

$$\frac{V_o}{V_{in}} = \frac{t_{on}}{T}$$

and defining "duty ratio" as

$$D = \frac{t_{on}}{T}$$

the voltage relationship becomes Vo=D Vin Since the circuit is lossless and the input and output powers must match on the average $V_o * I_o = V_{in} * I_{in}$. Thus the average input and output current must satisfy $I_{in} = D\, I_o$ These relations are based on the assumption that the inductor current does not reach zero.

1.2 TRANSITION BETWEEN CONTINUOUS AND DISCONTINUOUS

When the current in the inductor L remains always positive then either the transistor T1 or the diode D1 must be conducting. For continuous conduction the voltage V_x is either V_{in} or 0. If the inductor current ever goes to zero then the output voltage will not be forced to either of these conditions. At this transition point the current just reaches zero as seen in Figure 3. During the ON time V_{in}-V_{out} is across the inductor thus

$$I_{L(peak)} = (V_{in} - V_{out})\frac{t_{on}}{L} \qquad (1)$$

The average current which must match the output current satisfies

$$I_{L(average\ at\ transition)} = \frac{I_{L(peak)}}{2} = (V_{in} - V_{out})\frac{dT}{2L} = I_{out(transition)} \qquad (2)$$

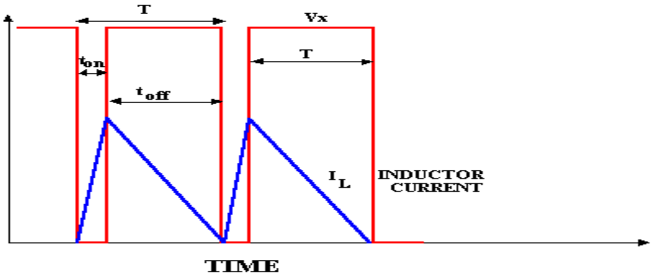

Fig. 3: Buck Converter at Boundary

If the input voltage is constant the output current at the transition point satisfies

$$I_{out(transition)} = V_{in}\frac{(1-d)d}{2L}T \qquad (3)$$

1.3 VOLTAGE RATIO OF BUCK CONVERTER (DISCONTINUOUS MODE)

As for the continuous conduction analysis we use the fact that the integral of voltage across the inductor is zero over a cycle of switching T. The transistor OFF time is now divided into segments of diode conduction $d_d T$ and zero conduction $d_o T$. The inductor average voltage thus gives

$$(V_{in} - V_o)\, DT + (-V_o)\, □_d T = 0 \qquad (4)$$

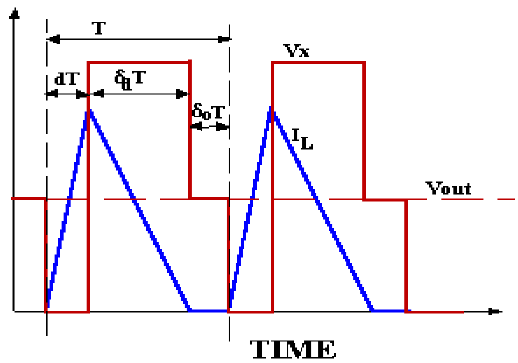

Fig. 4: Buck Converter - Discontinuous Conduction □$_d$

$$\therefore \frac{V_{out}}{V_{in}} = \frac{d}{d+\delta_d} \qquad (5)$$

for the case $d+\delta_d<1$. To resolve the value of δ_d consider the output current which is half the peak when averaged over the conduction times $d+\delta_d$

$$I_{out} = \frac{I_{I(peak)}}{2}\, d+\delta_d \qquad (6)$$

Considering the change of current during the diode conduction time

$$I_{I(peak)} = \frac{V_o(\delta_d T)}{L} \qquad (7)$$

Thus from (6) and (7) we can get

$$I_{out} = \frac{V_o\,\delta_d T(d+\delta_d)}{2L} \qquad (8)$$

using the relationship in (5)

$$I_{out} = \frac{V_{in}\, d\, \delta_d T}{2L} \qquad (9)$$

and solving for the diode conduction

$$\delta_d = \frac{2L\, I_{out}}{V_{in}\, d\, T} \qquad (10)$$

The output voltage is thus given as

$$\frac{V_{out}}{V_{in}} = \frac{d^2}{d^2 + \left(\frac{2L\, I_{out}}{V_{in}\, T}\right)} \qquad (11)$$

defining $k^* = 2L/\ (V_{in}\ T)$, we can see the effect of discontinuous current on the voltage ratio of the converter.

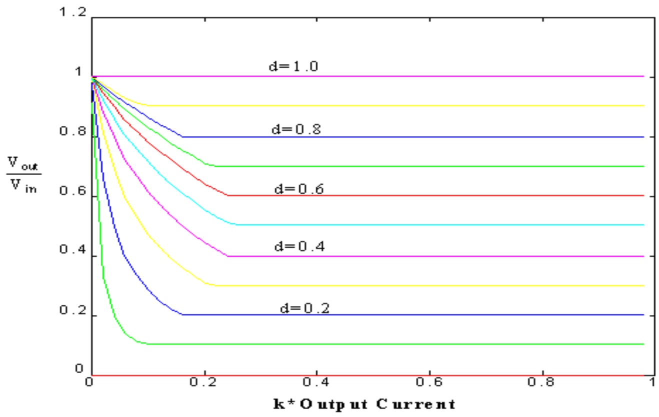

Fig. 5: Output Voltage vs Current

As seen in the figure, once the output current is high enough, the voltage ratio depends only on the duty ratio "d". At low currents the discontinuous operation tends to increase the output voltage of the converter towards V_{in}.

1.4 BOOST CONVERTER STEP-UP CONVERTER

The schematic in Fig. 6 shows the basic boost converter. This circuit is used when a higher output voltage than input is required.

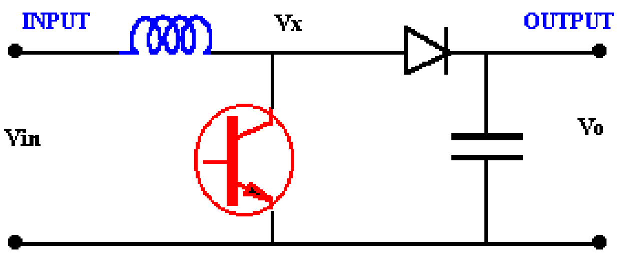

Fig. 6: Boost Converter Circuit

While the transistor is ON $V_x = V_{in}$, and the OFF state the inductor current flows through the diode giving $V_x = V_o$. For this analysis it is assumed that the inductor current always remains flowing (continuous conduction). The voltage across the inductor is shown in Fig. 7 and the average must be zero for the average current to remain in steady state

Vin ton + (Vin - Vo) toff =0

This can be rearranged as

$$\frac{V_o}{V_{in}} = \frac{T}{t_{off}} = \frac{1}{(1-D)}$$

and for a lossless circuit the power balance ensures

$$\frac{I_o}{I_{in}} = (1-D)$$

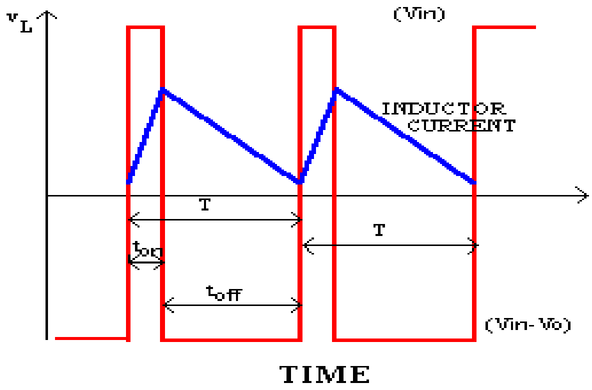

Fig. 7: Voltage and current waveforms (Boost Converter)

Since the duty ratio "D" is between 0 and 1 the output voltage must always be higher than the input voltage in magnitude. The negative sign indicates a reversal of sense of the output voltage.

1.5 BUCK-BOOST CONVERTER

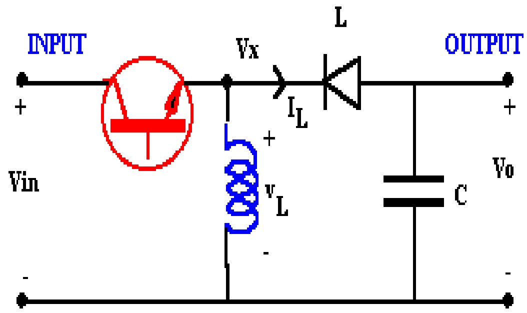

Fig. 8: schematic for buck-boost converter

With continuous conduction for the Buck-Boost converter $V_x = V_{in}$ when the transistor is ON and $V_x = V_o$ when the transistor is OFF. For zero net current change over a period the average voltage across the inductor is zero

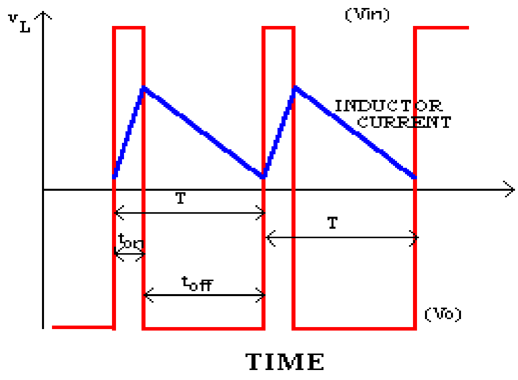

Fig. 9: Waveforms for buck-boost converter

Vin ton + Vo toff = 0

which gives the voltage ratio

$$\frac{V_o}{V_{in}} = -\frac{D}{(1-D)}$$

and the corresponding current

$$\frac{I_o}{I_{in}} = -\frac{(1-D)}{D}$$

Since the duty ratio "D" is between 0 and 1 the output voltage can vary between lower or higher than the input voltage in magnitude. The negative sign indicates a reversal of sense of the output voltage.

1.7 CONVERTER COMPARISON

The voltage ratios achievable by the DC-DC JAYA CONVERTERs is summarised in Fig. 10. Notice that only the buck converter shows a linear relationship between the control (duty ratio) and output voltage. The buck-boost can reduce or increase the voltage ratio with unit gain for a duty ratio of 50%.

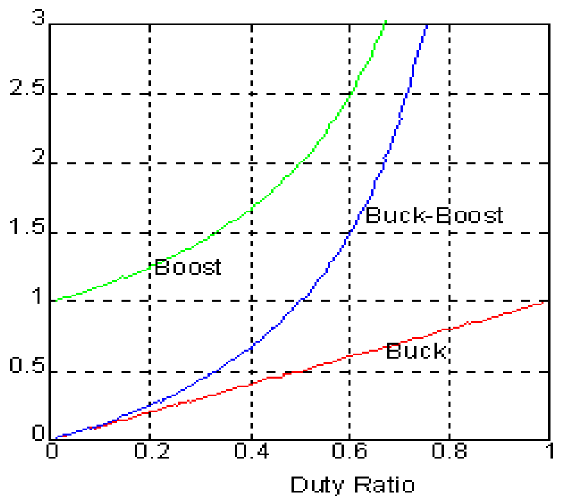

Fig. 10: Comparison of Voltage ratio

1.6 JAYA CONVERTER

The buck, boost and buck-boost converters all transferred energy between input and output using the inductor, analysis is based on voltage balance across the inductor. The JAYA converter uses capacitive energy transfer and analysis is based on current balance of the capacitor. The circuit in Fig. 11 is derived from DUALITY principle on the buck-boost converter.

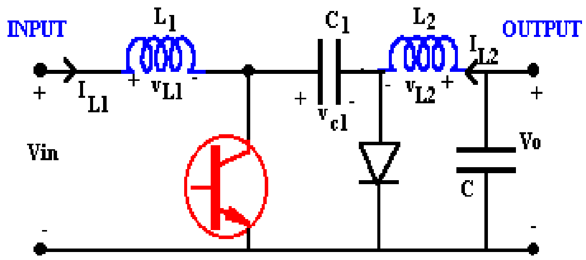

Fig. 11: JAYA Converter

If we assume that the current through the inductors is essentially ripple free we can examine the charge balance for the capacitor C1. For the transistor ON the circuit becomes

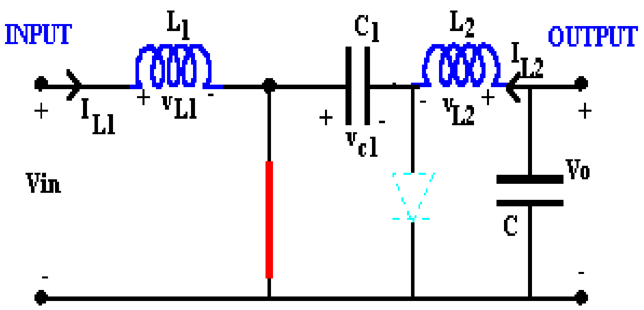

Fig. 12: JAYA "ON-STATE"

and the current in C1 is I_{L1}. When the transistor is OFF, the diode conducts and the current in C1 becomes I_{L2}.

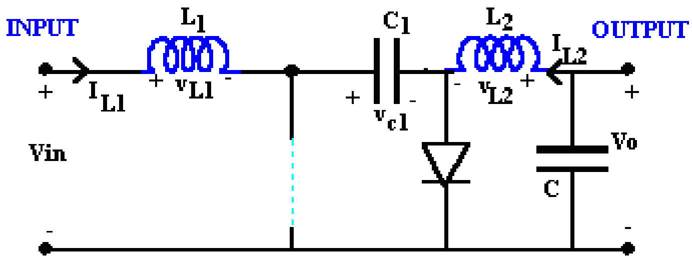

Fig. 13: JAYA "OFF-STATE"

Since the steady state assumes no net capacitor voltage rise, the net current is zero

IL1tON + (-IL2) tOFF = 0

which implies

$$\frac{I_{L_2}}{I_{L_1}} = \frac{(1\text{-}D)}{D}$$

The inductor currents match the input and output currents, thus using the power conservation rule

$$\frac{V_o}{V_{in}} = -\frac{D}{(1\text{-}D)}$$

Thus the voltage ratio is the same as the buck-boost converter. The advantage of the JAYA converter is that the input and output inductors create a smooth current at both sides of the converter while the buck, boost and buck-boost have at least one side with pulsed current.

1.9 ISOLATED DC-DC JAYA CONVERTERs

In many DC-DC applications, multiple outputs are required and output isolation may need to be implemented depending on the application. In addition, input to output isolation may be required to meet safety standards and / or provide impedance matching. The above discussed DC-DC topologies can be adapted to provide isolation between input and output.

1.8 FLY BACK CONVERTER

The fly back converter can be developed as an extension of the Buck-Boost converter. Fig 14a shows the basic converter; Fig 14b replaces the inductor by a transformer. The buck-boost converter works by storing energy in the inductor during the ON phase and releasing it to the output during the OFF phase. With the transformer the energy storage is in the magnetization of the transformer core. To increase the stored energy a gapped core is often used. In Fig 14c the isolated output is clarified by removal of the common reference of the input and output circuits.

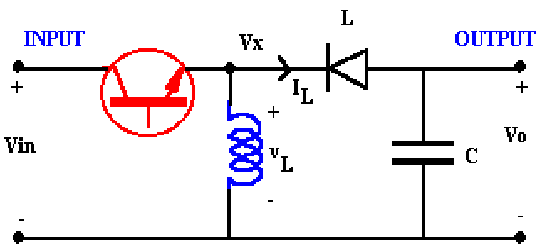

Fig. 14(a): Buck-Boost Converter

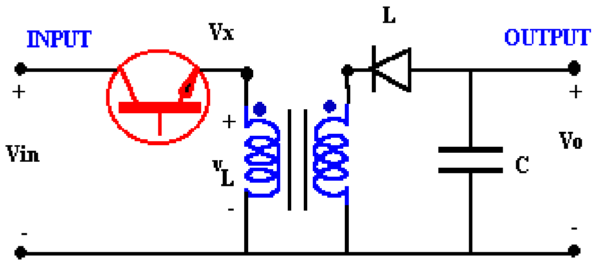

Fig. 14(b): Replacing inductor by transformer

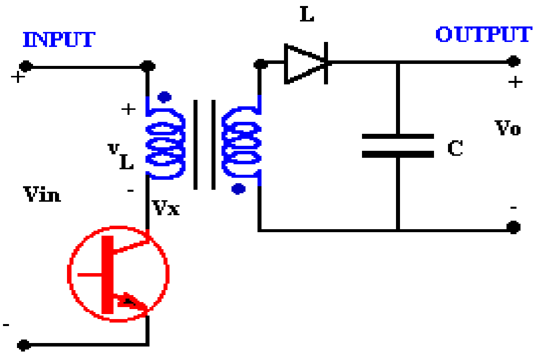

Fig. 14(c): Fly back converter re-configured

FORWARD CONVERTER

The concept behind the forward converter is that of the ideal transformer converting the input AC voltage to an isolated secondary output voltage. For the circuit in Fig. 15, when the transistor is ON, Vin appears across the primary and then generates

$$Vx = \frac{N_1}{N_2} Vin$$

The diode D1 on the secondary ensures that only positive voltages are applied to the output circuit while D2 provides a circulating path for inductor current if the transformer voltage is zero or negative.

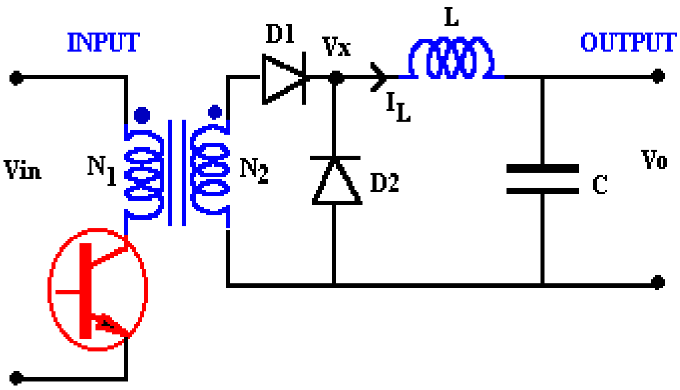

Fig. 15: Forward Converter

The problem with the operation of the circuit in Fig 15 is that only positive voltage is applied across the core, thus flux can only increase with the application of the supply. The flux will increase until the core saturates when the magnetizing current increases significantly and circuit failure occurs. The transformer can only sustain operation when there is no significant DC component to the input voltage. While the switch is ON there is positive voltage across the core and the flux increases. When the switch turns OFF we need to supply negative voltage to reset the core flux. The circuit in Fig. 16 shows a tertiary winding with a diode connection to permit reverse current. Note that the "dot" convention for the tertiary winding is opposite those of the other windings. When the switch turns OFF current was flowing in a "dot" terminal. The core inductance act to continue current in a dotted terminal, thus

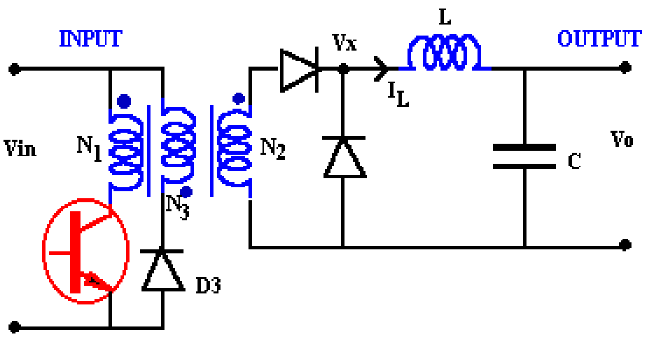

Fig. 16: Forward converter with tertiary winding

2.0 BI-DIRECTIONAL DC-TO-DC CONVERTER

A DC/DC converter which can be operated alternately as a step-up converter in a first direction of energy flow and as a step-down converter in a second direction of energy flow is disclosed. Potential isolation between the low-voltage side and the high-voltage side of the converter is achieved by a magnetic compound unit, which has not only a transformer function but also an energy store function. The converter operates as a push-pull converter in both directions of energy flow. The DC/DC converter can be used for example in motor vehicles with an electric drive fed by fuel cells.

A bi-directional converter for converting voltage bi-directionally between a high voltage bus and a low voltage bus, comprising a switching converter connected across the high voltage bus, the switching converter comprising first and second switching modules connected in series across the high voltage bus, a switched node disposed between the switching modules being coupled to an inductor, the inductor connected to a first capacitor, the connection between the inductor and the first capacitor comprising a mid-voltage bus, the first and second switching modules being controllable so that the switching converter can be operated as a buck converter or a boost converter depending upon the direction of conversion from the high voltage bus to the low voltage bus or vice versa; the mid-voltage bus being coupled to a first full bridge switching circuit comprising two pairs of series connected switches with switched nodes between each of the pairs of switches being connected across a first winding of a transformer having a preset turns ratio; and a second full bridge switching circuit comprising two pairs of series connected switches with switched nodes between each of the pairs of switches being connected across a second winding of the transformer, the second full bridge switching circuit being coupled to a second capacitor comprising a low voltage node.

2.1 USES OF DC-DC JAYA CONVERTER:

DC-DC JAYA CONVERTERs are used to fill the gaps left by the limitations of direct and alternating currents. Direct current (DC) is a steady flow of electric energy in the same direction, while alternating current (AC) is a flow of energy which frequently changes in direction and intensity. Alternating current is used for the vast majority of electric transmission, because it is far easier to harness and dispense, and because it can be easily stepped up or down in intensity by use of transformers, devices which produce higher or lower levels of voltage by transferring currents into windings of varying lengths. Because transformers work by means of time delays, they are unable to work with direct current, due to direct current's constant rate of flow.

Alternating current has thus become far more commonly used simply because it is far more flexible, and it is the preferred form of current for all forms of transmission save one: batteries, which are unable to alternate their electrical flow and thus work on direct current alone. For this reason, the DC-DC JAYA CONVERTER has become an important electrical component, acting as the direct current equivalent of a transformer for battery-operated devices, enhancing or reducing intensity as needed.

2.1 WORKING OF DC-DC JAYA CONVERTERs

In its simplest form, a DC-DC JAYA CONVERTER simply uses resistors as needed to break up the flow of incoming energy – this is called linear conversion. However, linear conversion is a wasteful process which unnecessarily dissipates energy and can lead to overheating. A more complex, but more efficient, manner of DC-DC conversion is switched-mode conversion, which operates by storing power, switching off the flow of current, and restoring it as needed to provide a steadily modulated flow of electricity corresponding to the circuit's requirements. This is far less wasteful than linear conversion, saving up to 95% of otherwise wasted energy.

2.2 BIDIRECTIONAL DC-DC JAYA CONVERTERS TOPOLOGIES

There are many circuit topologies for bidirectional DC-DC JAYA CONVERTER. Some of them are

I. ***Non isolated (Without transformer):***
- **a.** Full bridge bidirectional DC-DC JAYA CONVERTER (shown in fig)
- **b.** Half bridge bidirectional DC-DC JAYA CONVERTER

II. ***Isolated (with transformer):***
- **a.** Full bridge bidirectional DC-DC JAYA CONVERTER (shown in fig)
- **b.** Half bridge bidirectional DC-DC JAYA CONVERTER.

A. NON-ISOLATED BIDIRECTIONAL DC/DC CONVERTER:

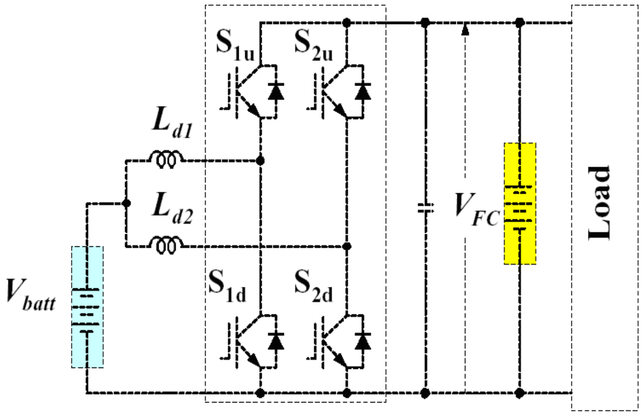

Fig17: Full bridge bidirectional DC-DC JAYA

CONVERTER

Interleaved operation for both boost and buck modes →
- Smaller passive components;
- Less battery ripple current.

B. ISOLATED BIDIRECTIONAL DC-DC JAYA CONVERTER (PROPOSED CONVERTER):

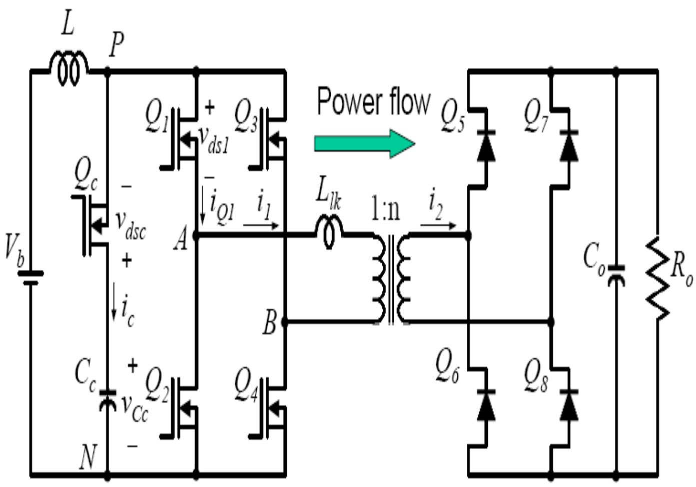

Fig18: lv-side "current source" and hv-side "voltage source"

The above converter has the following features

- Simple voltage clamp circuit implementation
- Simple transformer winding structure and low turns ratio
- High choke ripple frequency (2fs)
- start up problem will be present in this circuit.

III SIMULATION RESULT

To verify the theoretical operating principles, a 2-kW design example was simulated by using **MATLAB**. There is a good agreement between the simulation results and theoretical analysis. In this research, a 2-kW laboratory prototype was implemented and tested to evaluate the performance of the proposed bidirectional isolated dc–dc converter. Fig47, 48, 49 shows the waveforms in the boost mode operations for the laboratory prototype & Fig 49, 50, 51 shows the waveforms for buck mode operation. The gating signals for the LVS switches Q1, Q4, & Q2, Q3 and HVS switches Q5,Q8 & Q6, Q7 are shown in Fig. . The ripple cancellation between two inductor currents can be observed. This is desirable for a low-voltage battery. In Fig 48 and 50, the zero-voltage turn-on details of the LVS switch Q3 and HVS switch Q5 shown. For the full-bridge topology, the peak voltage across the LVS switches is around 45 V, allowing 75-V MOSFET to be used.

IV RESULTANT WAVE FORM:

BOOST OPERATION:

Input wave for waveform

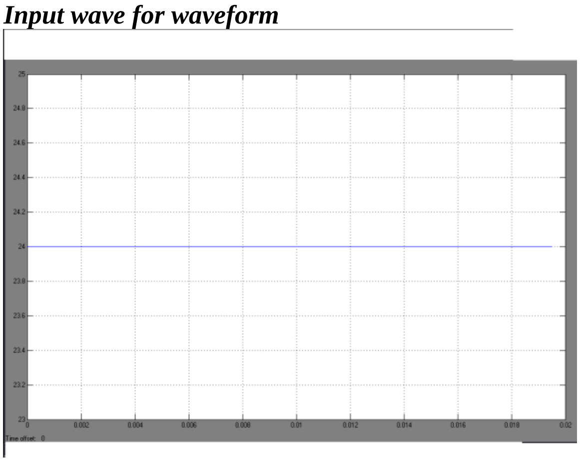

Fig 1 *Input wave form*

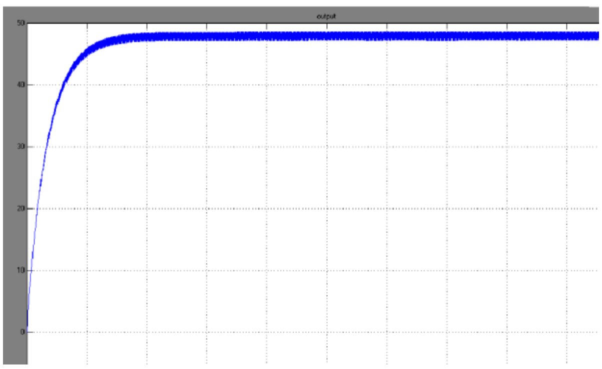

Fig 2 *Output waveform*

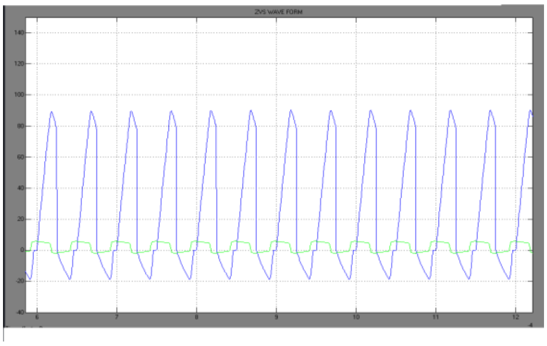

Fig 3. ZVS Wave Form:

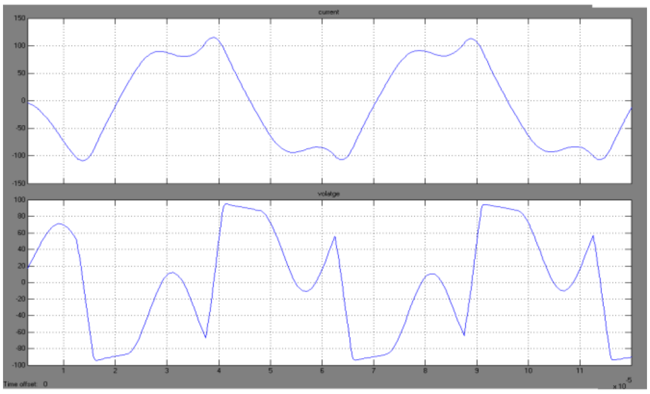

Fig 4

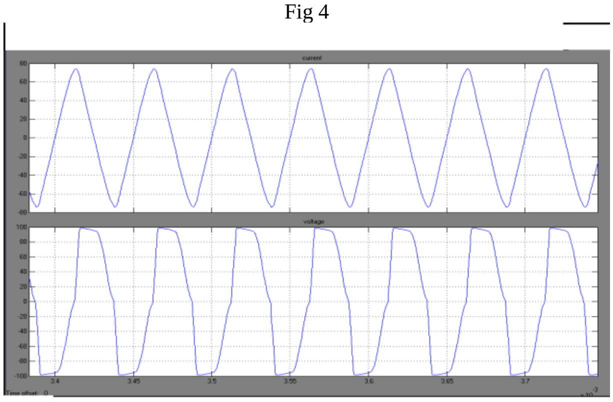

Fig5. Current & Voltage Waveform Of Primary Side Of Transformer:

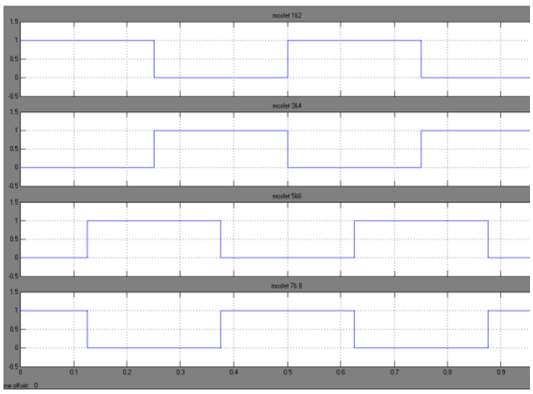

Fig 6. *Current & Voltage Wave Form of Primary Side Transformer:* Fig 4 *Input pulses to mosfet*

IV CONCLUSION:

In this project, a soft-switched isolated bidirectional dc–dc converter has been implemented. The operation, analysis, features and design consideration were evaluated. Simulation and experimental results for the 200W, 20 kHz prototype was proposed based on principle. Either direction of power flow is achieved with no lossy components, no additional active switch, no additional TDR exhibited in ZVS. The dual functions which has simultaneous boost conversion and inversion are provided by the low voltage side half bridge, current stresses on the switching devices and transformer are kept minimum. As results, the new circuit including ZVS with full load range, decreased device count, high efficiency measured more than 95% at rated power. The low cost as well as less control and accessory power needs, make the proposed converter better efficient for medium power applications with high power density.

FUTURE SCOPE

The several half bridge configurations is used for bidirectional DC-DC JAYA CONVERTER instead of full bridge isolated configuration can be made as half bridge isolated configuration. This half bridge will have less device count and simple circuit, therefore it is more economic and achieve high efficiency than full bridge configuration. This circuit will have better advantages than full bridge configuration.

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