A BI-DIRECTIONAL DC-DC CONVERTER TOPOLOGY FOR LOW POWER APPLICATION

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Abstract :- This paper presents a bi-directional dc-dc converter for use in low power application. Application that require exchange of power from the source to load and vice-versa. So a bi-directional dc-dc converter, capable of bilateral power flow, provides the functionality of two unidirectional converters in single converter unit. The topology is based on a half-bridge on the primary side and a current-fed push-pull on the secondary side of a high frequency isolation transformer. The dc mains, when presented, powers the downstream load converter and bi-directional converter will operates in the buck mode for charging battery to its nominal value. On failure of the dc mains, the converter operations is comparable to that of a boost and battery discharges. The dc power based application like telecommunication, computer system and battery charge/discharge.

Key words - Bi-directional power flow, current-fed push-pull, dc UPS, isolated transformer.

I. INTRODUCTION

Power electronic circuits supply energy from a source to match the energy required by the load, by using semiconductor devices to control the voltage and current. Bi-directional dc-dc converter is used to transfer power between two dc sources, in either direction with the ability to reverse the direction of flow of current and also power. The converter maintain the voltage polarity at both end unchanged. They are being used in number of application like motor drives, battery charger-discharger, uninterruptible power supply, telecommunication and computer power system.

Bi-directional topology for medium and high power applications are also possible along with few topology presented for low power applications. Implementation of bi-directional converters using resonant, soft switching and hard switching PWM has been consider. But, these topology lead to increase in component ratings, conduction losses in resonant mode, circuit complexity, output current ripple and lack of galvanic isolation in integrated topologies.

This paper present a Bi-directional dc-dc converter topology for application as battery charger/discharger circuit. The converter is combination of two well known converter topology such as half bridge and push-pull, as Fig. 1. The converter provides the required bi-directional flow of power for battery charging and discharging using only one isolated transformer.

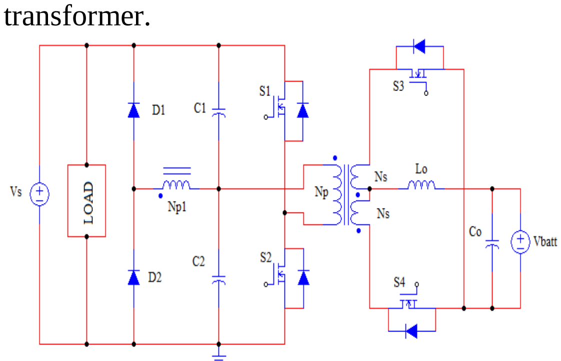


Fig. 1 Basic power topology for Bi-directional dc-dc converter

MOSFET's are considered for Bi-directional transfer of power. Other advantages of topology are (a) reduction in number of path as same components are used for power flow in both direction, (b) galvanic isolation, (c) low stress on switches, (d) less number of active switches, (e) fast switchover on failure and reappearance on dc mains, and, (f) low ripple in battery charging current.

II. POWER TOPOLOGY

The basic power circuit is shown in Fig. 1. The galvanic isolation is provide between dc mains and battery using transformer. The primary side of the converter is a half bridge and is connected to the dc mains. The secondary side, connected to the battery, forms a current-fed push-pull. The converter has two modes of operation. In the forward/charging mode the energy from the dc mains charges the battery over aspecified input voltage range while powering the downstream load converters. In this mode of operation only the switches S_1 and S_2 are gated and the body diode of the switches S_3 and S_4 provide battery side rectification. On failure of the dc mains, reversal of power flow occurs resulting from a switch-over to the battery. Now, the battery supplies the load power at the dc bus voltage. In this backup/current-fed mode, the switches S_3 and S_4 are gated and the body diodes of the switches S_1 and S_2 provide rectification at the load side.

The use of the half-bridge and current-fed topologies over other possible configurations can be justified as follows. Switches in the off state in half and full-bridge topologies are subject to a voltage stress equal to the dc input voltage and not twice that as in the push-pull and single ended forward converters. In low power applications the two-switch half-bridge is preferred over the four-switch full-bridge topology. A two-switch double ended forward with voltage stress across the switches equal to the dc input voltage, provides a half wave output at its secondary, compared to a full wave in the half-bridge converter. Thus, the square wave frequency in the half-bridge secondary winding is twice that in the forward, thereby allowing a smaller output LC filter. The primary winding of the transformer in a half-bridge sustains half the supply voltage compared to the full dc voltage for the forward converter, implying half the number of turns on the primary. This allows full copper utilization of the half-bridge transformer, low number of primary winding turns, and reduction in its size and cost. For the secondary side converter, the current-fed push-pull is the most suitable topology that utilizes the presence of the output filter inductor of the half-bridge converter. Equal division of inductor current between switches during their overlap period reduces the average and rms values of the current flowing through them and also the rms current in the transformer secondary. A current-fed push-pull reduces the possibility of flux imbalance. It allows a wider range of input voltages.

III. MODES OF OPERATION AND CONTROL PRINCIPLE

(a) Description of operating modes

Forward/Charging Mode : In this mode, Fig. 2, the dc mains, V_S, powering the load converters, provides the battery charging current, i_{Lo}. This charges the battery of the bidirectional converter at the nominal voltage. The switches S_1 and S_2 on the primary side are gated at duty ratios less than 0.5, while S_3 and S_4 are not switched at all. Operation of the bidirectional converter during this mode is comparable to that of a buck converter. Intervals t_0 to t_4, in the idealized waveforms of Fig. 3, describe the various stages of operation during one switching time period, T_S. The converter operation is repetitive in the switching cycle.

Fig. 2 shows a balancing winding N_{P1} and two catching diodes D_1 and D_2 on the primary side of the half bridge. They maintain the center-point voltage at the junction of C_1 and C_2 to one half of the input voltage, V_S. and prevent a 'runaway' condition of staircase saturation of the transformer core. Such a condition may occur in current mode control when different amounts of charge are removed from the capacitors, C_1 and

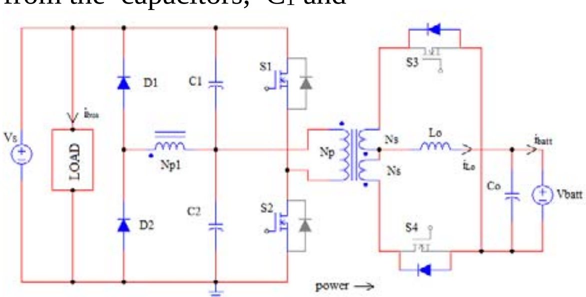


Fig. 2 Forward/charging mode

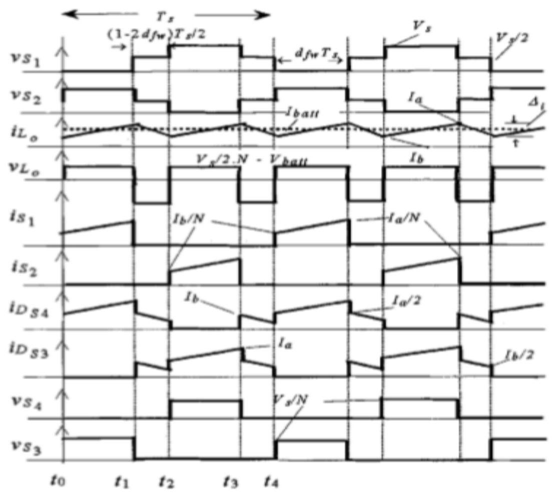


Fig. 3 Idealized waveforms during the forward/charging mode

C_2, due to mismatches between the MOSFET's S_1 and S_2. Should the midpoint of C_1 and C_2 begin to drift, a small current, in mA, flows through N_{P1} and D_1 and D_2 to compensate for the drift, has the same number of turns as the winding N_P and is phased in series with it through the ON time of S_1 and S_2.

Interval t_0-t_1 : Switch S_2 is OFF and S_1 is turned ON at time t_0. A voltage $V_S/2$ appears across the primary winding. The body diode of switch S_4, D_{S4}, is forward biased and provides rectification on the secondary side. It also carries the battery charging current, i_{batt}. The primary current, i_{S1}, builds up as it consists of the linearly increasing inductor current, i_{Lo}, reflected from the secondary, and the transformer primary magnetizing current.

Interval t_1-t_2 : Switch S_1 is turned OFF at t_1 while S_2 continues to remain OFF. During this dead time interval there is zero voltage across the primary, and also on secondary windings, and no power is transferred to the secondary side. The energy stored in L_o results in the freewheeling of the current i_{Lo}, equally through the body diodes D_{S3} and D_{S4} to charge the battery. Only half the supply voltage, V_S, appears across each switch S_1 and S_2 during this interval.

Interval t_2-t_3 : Switch S_2 is turned ON at t_2 while S_1 continues to be in the OFF state. The operation is similar to that during interval t_0-t_1 , but now the body diode of switch S_3, D_{S3}, conducts and provides secondary side rectification. Inductor current, i_{Lo}, rises linearly again as the voltage across the inductor, v_{Lo}, increases. The switch body diode, D_{S3}, carries the total battery charging current.

Interval t_3-t_4 : The converter operation during this interval is similar to that in the interval t_1-t_2 . No primary side switch is conducting and the battery charging current, is provided by the energy stored in the inductor. The body diodes of both the switches on the secondary side, D_{S3} and D_{S4}, conduct simultaneously and equally.

<u>Backup/Current-fed Mode</u> : The converter operates in this mode, Fig. 4, on failure of the dc mains. The battery discharges to supply the load power. The switches S_3 and S_4 of the current-fed push-pull topology are driven at duty ratios greater than 0.5. The converter operation during this mode is described with reference to the waveforms in Fig. 5. As in the charging mode, inductor current is assumed to be continuous. The time intervals between t_0 to t_4 describe the converter operation, which is repetitive over a switching cycle, T_S.

Interval t_0-t_1 : Switch S_3 is turned ON at time t_0 while S_4 remains in the ON state from the previous interval. The transformer secondary, N_S, is subject to an effective short circuit, which causes the inductor, L_o, to store energy as the total battery voltage appears across it. The inductor current, i_{Lo}, ramps up linearly and is shared equally by both S_3 and S_4. During this interval, the bulk capacitors, C_1 and C_2 provide the output load power load.

Interval t_1-t_2 : S_4 is turned OFF at instant t_1 while S_3 continues to remain ON. The energy stored in the inductor, L_o, during the previous interval is now transferred to the load through the body diode D_{S2} and the diode D_1. Voltage across the auxiliary winding N_{P1} and the primary winding N_P is identical due to their series phasing and equal number of turns. This allows simultaneous and equal charging of both C_1 and C_2 through D_1 and D_{S2}, respectively.

Interval t_2-t_3 : This interval is similar to interval t_0-t_1 . Switch S_3 remains ON and S_4 is also turned ON at time t_2. The duty ratio for S3 is therefore greater than 0.5. With both S_3 and S_4 turned ON, the transformer secondary is effectively shorted and the inductor stores energy, resulting in a linear rise in its current, i_{Lo}. Voltage across both N_P and N_{P1} is zero, so load power is supplied by the discharge of the bulk capacitors.

Interval t_3-t_4 : Converter operation during this interval resembles that during the interval t_1-t_2. S_4 remains ON and S_3 is turned OFF at t_3. The stored energy of L_o is transferred to the primary side of the converter through the switch conducting on the secondary side, S_4, and the primary diodes D_{S1} and D_2. The conduction of D_{S1} and D_2 again results in equal charging of C_1 and Ç2, respectively.

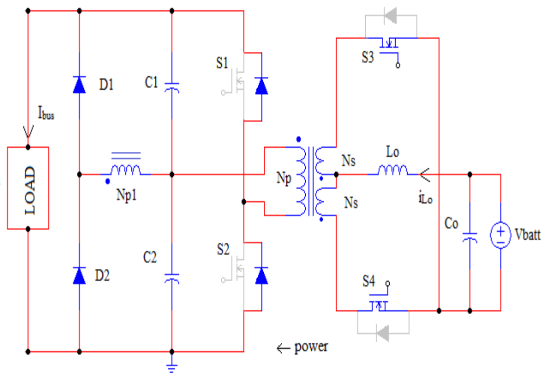


Fig. 4 Backup/discharging mode

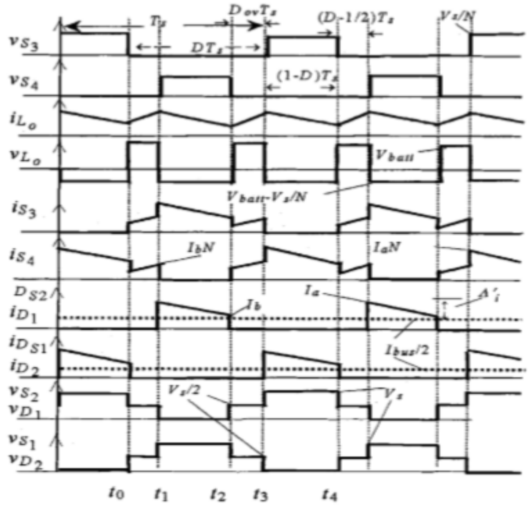


Fig. 5 Idealized waveforms during backup/current-fed mode

(b) Control Principle

Current mode control is used for both modes of converter operation. This allows

1. a pulse by pulse monitoring and limiting of current, thus avoiding flux imbalance in the transformer,
2. fast regulation to input voltage variation,
3. enhanced load regulation due to greater error amplifier bandwidth,
4. minimal external parts.

IV. SIMULATION PARAMETERS AND RESULTS

(a) Simulation Parameters

The values of the power components used in the topology, chosen after considering converter operation in both modes, are given in Table I.

The specifications for converter operation are as follows :

Forward/ChargingMode

Input voltage range = 300 V (V_{smin}) – 400 V (V_{smax})

Output Power = 100 W

Backup/Current-fedMode

Output power (on dc mains bus) = 300 W

Output voltage (on dc mains bus) = 320 V

Table I Components used in simulations

Parameters	***Values***	***Parameters***	***Values***
V_S	300 - 400 V	V_{batt}	48 V
C_1, C_2	150 µF	f_S	1 KHz
L_P, L_{P1}	2 mH	N_P	19
L_S, L_o	360 µH	N_S	8
C_o	470 µF	S_1 to S_4	MOSFET's
R_L	1225	D_1, D_2	Diodes

(b) Simulation Results

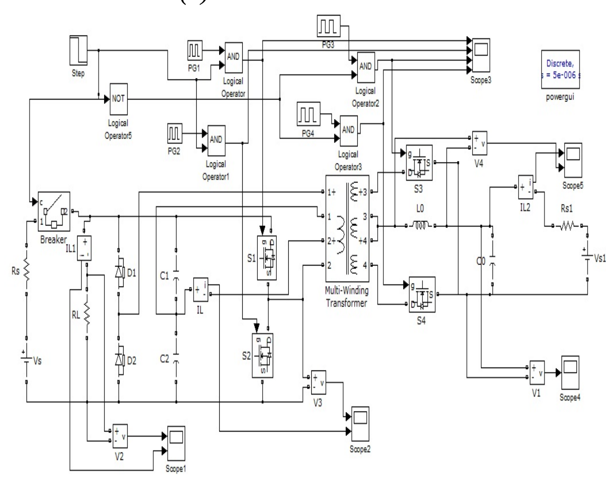
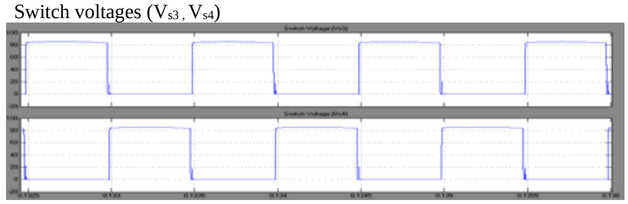


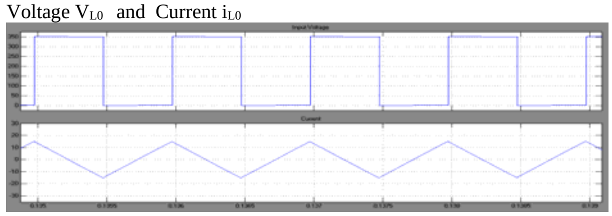
Fig. 6 Simulation of Forward and Backup mode converter Waveforms

(i) For Forward mode converter

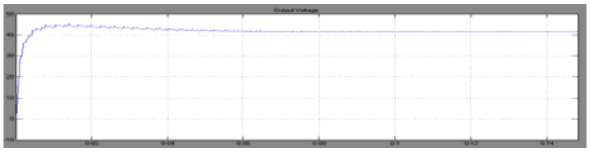
Switch voltages (V_{s3}, V_{s4})



Voltage V_{L0} and Current i_{L0}

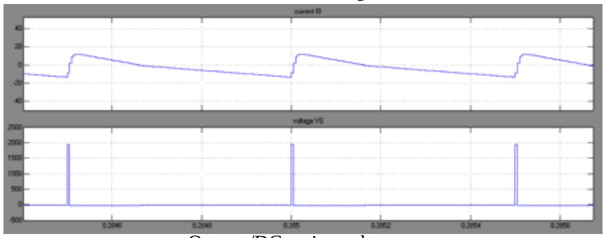


OUTPUT VOLTAGE

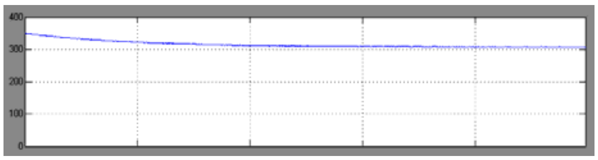


(ii) For Backup mode converter

Current i_{L0} and Voltage v_{L0}

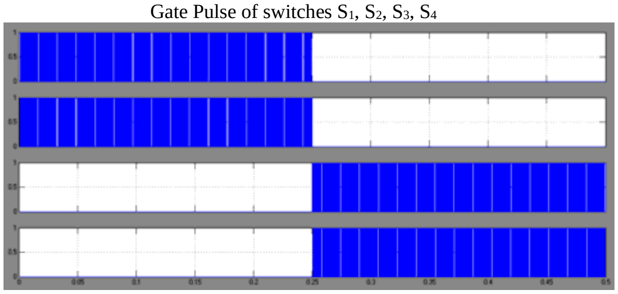


Output /DC mains voltage

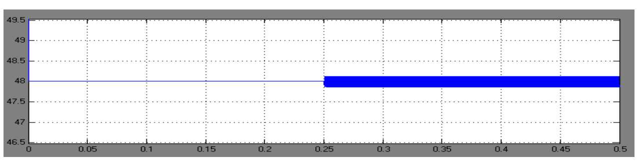


(iii) For both Forward and Backup mode converter

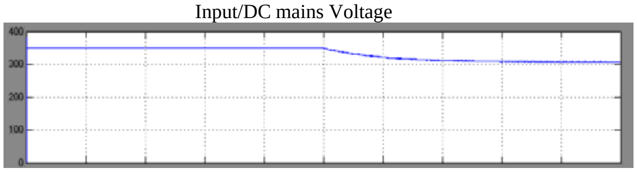
Gate Pulse of switches S_1, S_2, S_3, S_4



Output/Battery Voltage



Input/DC mains Voltage



V. CONCULSION

A single bidirectional converter topology has been implemented instead of two unidirectional converter. The bi-directional dc-dc converter has been evaluated and provides the desired reversible flow of power in a battery charger-discharger circuit for a DC UPS. The topological advantages include combining two simple converter topologies in a single power processing stage, enabling its operation in either mode. This integrated unit has only one high frequency transformer that provides galvanic isolation for the low voltage battery from the high voltage supply end and the load. The converter exhibits high steady state efficiency for both operating modes. The proposed bi-directional converter is an industrially viable converter topology that offers substantial improvement in simplicity, efficiency, less size, and low component count over the conventional battery charger-discharger circuits.

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