BIDIRECTIONAL DC-DC CONVERTER WITH FUZZY CONTROLLER FOR BATTERY HYBRID POWER GENERATORS

Sonali M. Deshmukhd[1], Prof.R. A. Metri[2]
Rajarambapu Institute of Technology, Rajaramnagar, Islampur, Sangli (MS),
Email: sonalideshmukh090693@gmail.com[1], rajanikant.metri@ritindia.edu[2]

Abstract
In this paper a bidirectional resonant dc-dc converter is introduced for battery hybrid power generators. The bidirectional dc-dc converter consists of two stage, one is series resonant converter and another is non isolated half bridge dc-dc converter. The zero current switching is applied to series resonant converter so switching losses are reduced. Due to the zero current switching of the MOSFET's with high frequency, this converter topology have important features like low size, low weight and low cost. The combination of PI and Fuzzy controller is used for non-isolated converter. The high side voltage and low side voltage are regulated efficiently due to PI-Fuzzy controller. The application of two stage bidirectional dc-dc converter is in uninterrupted power system to provide additional power to critical ac loads. The MATLAB simulation of step-up and step-down mode of bidirectional dc-dc converter are provided to validate performance of proposed two stage bidirectional dc-dc converter.
Keywords: Bidirectional DC-DC Converter (BDC), series resonant converter (SRC), zero current switching (ZCS), hybrid power generators, PI controlle, Fuzzy controller, MATLAB/SIMULINK.

NOMENCLATURE

L_r	Resonant Inductance
C_r	Resonant Capacitance
f_r	Resonant Frequency
D_d	On-Time duty cycle of SRC
T_s	
f_{s1}	Switching frequency of the SRC
f_{s2}	Switching frequency of non-isolated converter
V_H	High Side Voltage of BDC
V_L	Low side Voltage of BDC
I_{Lm}	Magnetizing current of SRC
I_L	Low side current of SRC
I_{Lr}	Resonant current of the SRC
I_{SL}	Low side current of SRC
V_{SH}	High Side voltage of SRC
V_{SL}	Low side voltage of SRC
L_{KP}	Primary side leakage inductor current of SRC
L_{KS}	Secondary side Leakage Inductor Current of SRC

I. INTRODUCTION

Nowadays demand of power has increased in various sectors such as IT companies, banks, hospitals, residential buildings etc. The continuous power supply is required in these facilities, so use of uninterruptible power supply system, standby or emergency generator is increased. In utility power failure condition these standby or generators are used for backup power supply [1]. In the event of loss of utility power these standby or diesel generator system fails to supply loads when power generated by generator is less than power required by loads. The generator systems are unable to counter sudden changes in loads so he power balancing between generator and load is required and for this purpose energy stored battery systems are required[3][4]. The bidirectional dc-dc transfer required to exchange power between battery system and rest of system. The bidirectional dc-dc converter has ability to reverse the direction of current flow and there by power, so the use of bidirectional dc-dc converter has increased. There are different application of BDC such as in renewable energy systems, hybrid vehicles, hybrid power generators and uninterruptible power supplies.

The one of the application of BDC is in hybrid power generators. The block diagram of battery hybrid power generator system is shown in fig. 1. The BDC is placed between high voltage dc bus and low voltage bus. When generator power is less than load then bidirectional dc-dc converter should transfer power to balance the ac load through battery discharging. When the generator balances the load and the battery voltage is less than rated voltage then BDC should charges the battery.

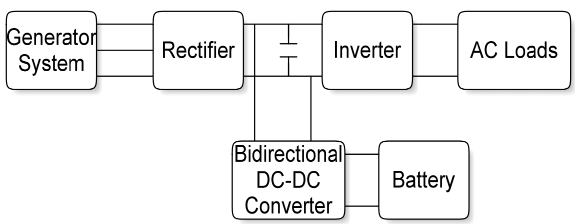


Fig.1 Battery Hybrid Power Generator System

There are main two type of dc-dc converter, isolated and non-isolated converter. The non-isolated converter has more advantages than isolated converter such as high efficiency and compactness. The different topologies of BDC consists of half bridge, full bridge, and push-pull pulse width modulation (PWM) converter [10],[11],dual active bridge (DAB) converters[12],[13][14], and two stage converters [15],[16].A drawback of PWM converter is high turn off switching losses [17]. The dual active bridge converter is problematic in low power application due to high ripple current [13].The drawback of conventional dc-dc converters are high switching losses, complex control technique, complex switching method, high cost large size. So to overcome such drawback bidirectional dc-dc converter with ZCS and PI-fuzzy controller is proposed.

In this paper a two stage bidirectional dc-dc converter is introduced with ZCS and combined PI-fuzzy controller. The BDC consists of half bridge dc-dc converter and series resonant converter. The ZCS reduces switching losses in converter. The zero current switching is used to control series resonant converter. The PI-fuzzy control is used to control non-isolated converter.

The remaining paper is organized as: section II describes the proposed two stage BDC. The next section III deals with modes of operation of SRC. The section IV consists of control strategy of BDC. The section V represents simulation results of BDC in both step down and step up condition. The section VI includes conclusion.

II. PROPOSED TWO STAGE BDC

The two stage bidirectional dc-dc converter consist of non-isolated converter and series loaded resonant converter. In this the high side voltage is connected at non-isolated converter. This non-isolated converter is used for controlling either high-side voltage or low side voltage. The series resonant converter is operated at fixed frequency. In first stage, non-isolated converter converts DC-DC voltage. The obtained DC voltage is then converted to AC voltage by half bridge converter circuit. This ac voltage is step-downed using transformer with turn’s ratio 8:1. The converted AC voltage is then converted into DC voltage using full bridge rectifier circuit. The zero current soft switching technique is used for series resonant converter regardless of change in voltage or load. The combined PI-fuzzy controller is used to control non-isolated converter to regulate either high side voltage or low side voltage.

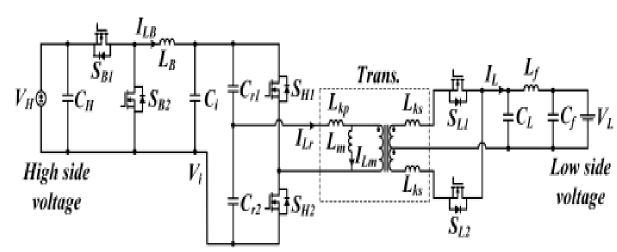


Fig.2 Two stage bidirectional dc-dc converter

III. MODES OF OPERATION OF SRC

The operation of SRC is based on fixed frequency and fixed duty with minimum current and voltage rating. The zero current switching technique is used for controlling of SRC. The ZCS causes to reduce switching losses. There are two modes of operation of SRC. Modes of operation and key-waveforms of series loaded resonant converter are shown in fig.3, 4 and fig.5 respectively. The expression of angular resonant frequency of SRC can determined by,

$$\omega_r = 2\pi f_r = \frac{1}{\sqrt{L_r . C_r}} \quad (1)$$

The expression of resonant inductance can be determined by,

$$L_r = L_{kp} + \frac{L_m . n^2 L_{ks}}{L_m + n^2 L_{ks}} \quad (2)$$

The expression of resonant capacitance can be determined by,

$$C_r = C_{r1} + C_{r2} \quad (3)$$

A. *Mode I (t_o-t_1)*

In this mode switch S_{H1} and switch S_{L2} are on. The on time duty cycle should be selected as $D_dT_s = 0.5/f_r$.

The low side current can be expressed as

$$i_L(t) = \frac{\pi I_{L,dc}}{2} \sin \omega_r t \quad (4)$$

The voltage across L_m can be determined by

$$i_{Lm}(t) = \frac{n\pi V_L}{2\omega_r L_m} - \frac{nV_L}{L_m} t + \left(\frac{n\pi L_{ks} I_{L,dc}}{2L_m} \right) \sin \omega_r t \quad (5)$$

Therefore from (4) and (5) can be determined by

$$i_{Lr}(t) = \frac{n\pi V_L}{2\omega_r L_m} - \frac{nV_L}{L_m} t + \left(\frac{n\pi L_{ks} I_{L,dc}}{2L_m} - \frac{\pi I_{L,dc}}{2n} \right) \sin \omega_r t \quad (6)$$

The resonant current can then be obtained using (4) and (6) by

$$v_{SL1}(t) = 2V_L + L_{ks} \frac{di_L}{dt} \quad (7)$$

Neglecting voltage oscillation after turning ON of S_{L2}, the voltage across low side switch S_{L1} at Mode I ($t_0 - t_1$) is expressed as,

$$V_{SL,off} = 2V_L + \frac{\pi \omega_r L_{ks} I_{L,dc}}{2} \quad (8)$$

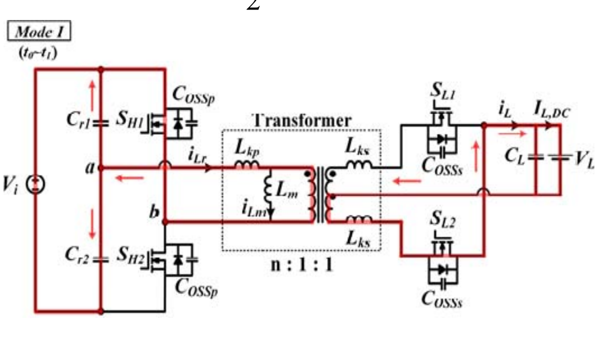


Fig. 3 Mode I of SRC

The turn-off voltage of low side switch can be obtained by,

$$v_{SL,off}(t) = 2V_L - \frac{\pi \omega_r L_{ks} I_{L,dc}}{2} \quad (9)$$

It should be noted that $V_{SL,off}$ should be greater than zero for the proposed operation. Therefore, from (4) and (9) the secondary side leakage inductance should be limited such as

$$L_{ks} < \frac{4V_L}{\pi \omega_r I_{L,dc}} \quad (10)$$

B. *Mode II (t_1-t_2)*

In operating mode II of SRC all switches are in off condition. The dead time is given to switches to avoid short circuit. As L_m is chosen large so $I_{Lm,pk}$ is very small so there is less switching losses. The output capacitors of S_{H1} and S_{H2} are charged and discharged, respectively by $I_{Lm,pk}$, as shown in Fig. 3. The charging and discharging operation may not be completed at the end of Mode II if $I_{Lm,pk}$ is not sufficiently large, which may lead to a nonzero turn-on voltage of high and low side switches. The turn-on voltages of the high and low side, switches can be determined respectively by

$$V_{SH,on} = v_{SH2}(t) = V_i - \frac{n^2 I_{Lm,pk} D_d T_s}{2n^2 C_{OSSp} + 2C_{OSSs}} \quad (11)$$

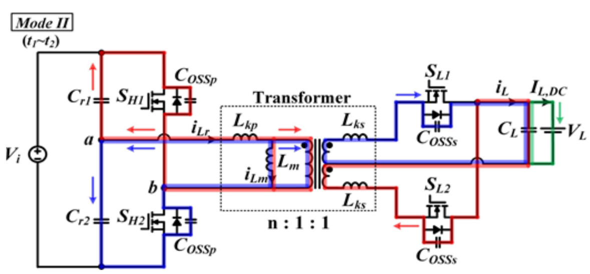


Fig.4 Mode II of SRC

$$V_{SL,on} = \frac{4V_L + \pi \omega_r L_{ks} I_{L,dc}}{2}{}_i - \frac{n \; I_{Lm,pk} D_d T_s}{2 \; C_{OSSp} + 2C_{OSSs}}$$

(12)

Fig.5 shows the key-waveform of SRC. The switches S_{H2} and S_{L1} are turned ON with ZCS, but there exists turn-on losses of high- and low side switches associated with energy stored in MOSFET's output capacitances as follows [18], [19].

$$P_{SH,Loss(on)} = 0.5C_{OSS\ p}V^2{}_{SH,on}\, f_S \tag{13}$$

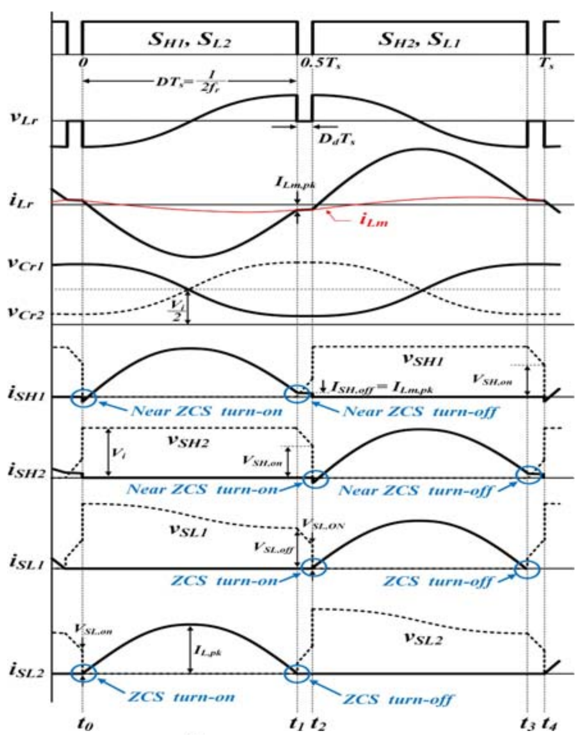
$$P_{SL,Loss(on)} = 0.5C_{OSS\ p}V^2{}_{SL,on}\, f_S \tag{14}$$

IV. CONTOL SCHEME FOR PROPOSED SYSTEM

A. *Control of non-isolated converter*

The non-isolated half bridge converter is controlled by Combination of PI-Fuzzy controller. The high and low voltage side of converter are controlled by non-isolated converter. The reference voltage (VH*) for controlling high voltage side is taken as 400V.The reference voltage (VL*) for controlling low voltage side is taken as 28V.

Fig.5 Key-waveform off SRC



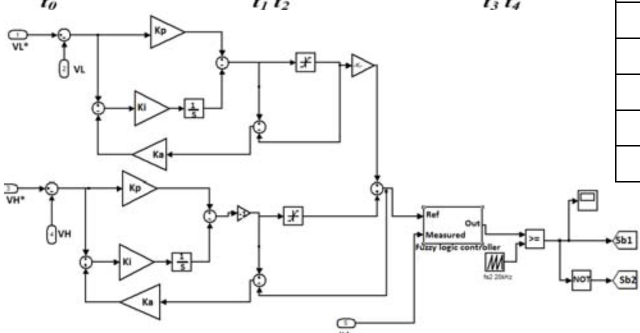


Fig.6 PI+Fuzzy Controller of Non-isolated controller

The fuzzy logic controller consists of simple linguistic variables, use fuzzy membership functions and linguistic rules to determine the appropriate process input. The advantages of fuzzy logic controller are faster and simple program development of system controller, more accurate response. The rules of fuzzy logic controller are shown in table I

TABLE I

RULSE OF FUZZY LOGIC CONTROLLER

e/Δe	NB	NS	ZE	PS	PB
NB	NB	NB	NB	NS	ZE
NS	NB	NB	NS	ZE	PS
ZE	NB	NS	ZE	PS	PB
PS	NS	ZE	PS	PB	PB
PB	ZE	PS	PB	PB	PB

B. *Control of series loaded resonant converter*

The zero current switching method is used for controlling series resonant converter. The switching frequency of SRC is taken as 50 kHz. The dead time is given to avoid short circuit of switches.

V. SIMULATION RESULT

The simulation of proposed BDC is carried out in SIMULINK/MATLAB software. Simulation parameter of proposed bidirectional dc-dc converter are shown in Table II.

TABLE II

PARAMETERS OF THE PROPOSED BDC

Parameter	Value	Parameter	Value
V_H	340-440 V	L_f	0.42µH
V_L	24-32 V	L_r	5.8µH
f_{s1}	50 KHz	C_f	110µH
f_{s2}	20 KHz	C_H	45mH
N_p:N_s	8:1	C_i	100µF
D_dT_s	600 ns	C_L	380µF
L_B	1 mH	C_{r1}= C_{r2}	0.94µF

Simulation waveforms of step down and step up mode of bidirectional dc-dc converter are shown as follows. The fig.7 input voltage of high side of BDC in step down mode.The fig. 8 shows gate pulses of switch SH1, SL2 and SH2, SL1. The fig.9 shows waveform of current I_{Lr}, I_{Lm}. The fig.10 shows waceforms of I_{SH1},I_{SL2} and fig.11 shows waveforms of I_{SH2},I_{SL2} respectively. The fig.12 shows the waveform of voltage Vcr1 and Vcr2. The fig.13 shows waveform of output voltage of low side BDC in step down mode. The fig.14 shows waveform of input voltage of low side of BDC in step up mode. The fig.15 shows waveform of output voltage of high side of BDC in step up mode.

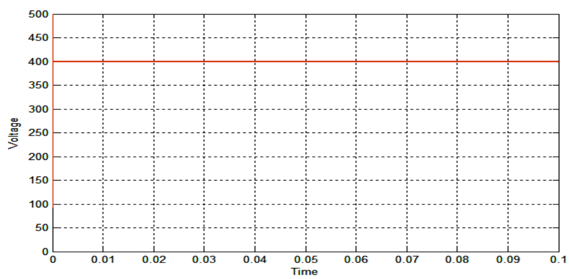


Fig.7 Input of high side of BDC (Step down mode)

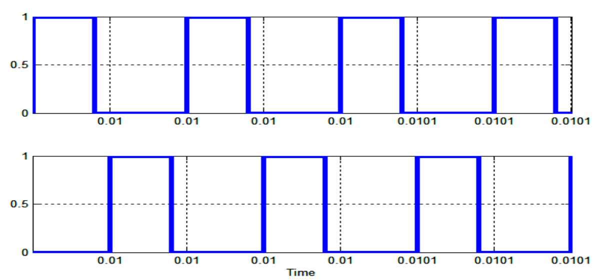


Fig.8 Gate pulses for SH1, SL2 and SH2, SL1

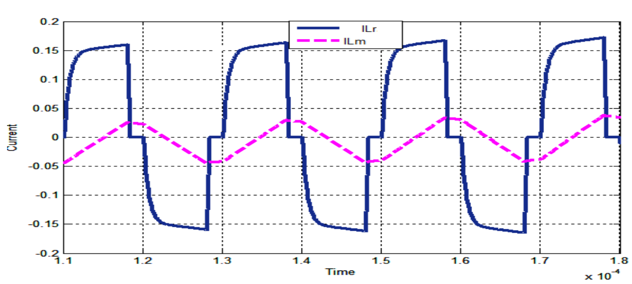


Fig.9 Waveforms of I_{Lr} and I_{Lm}

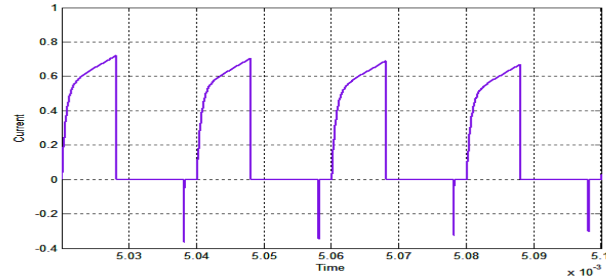


Fig.10 Waveform of I_{SH1} and I_{SL2}

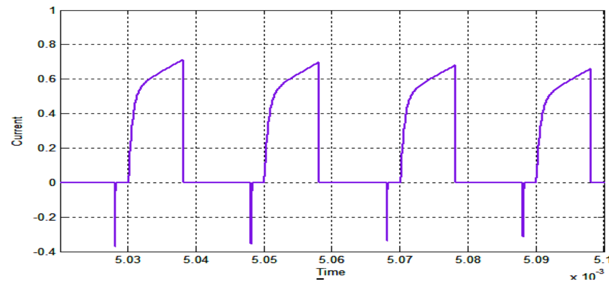


Fig.11 Waveform of I_{SL1} and I_{SH2}

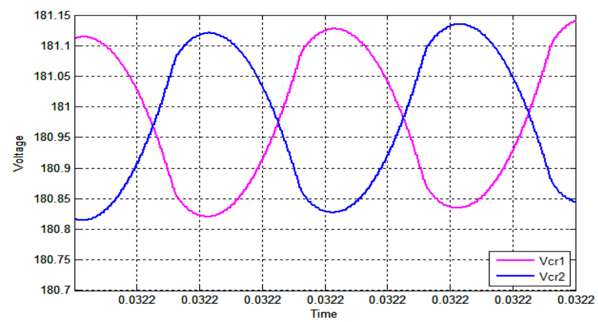


Fig. 12 Waveform of V_{cr1} and V_{cr2}

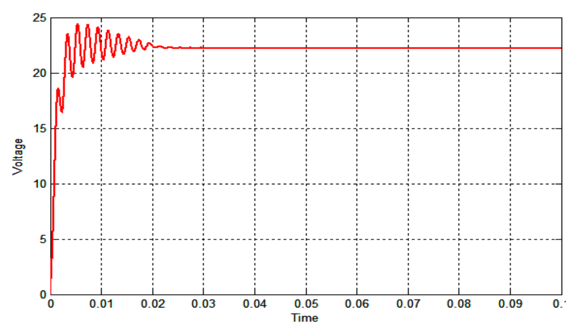


Fig. 13 Output of low side of BDC (Step down mode)

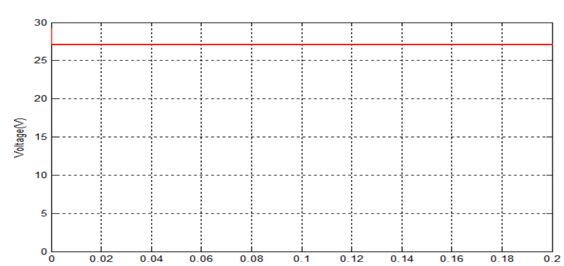


Fig. 14 Input of low side of BDC (Step up mode)

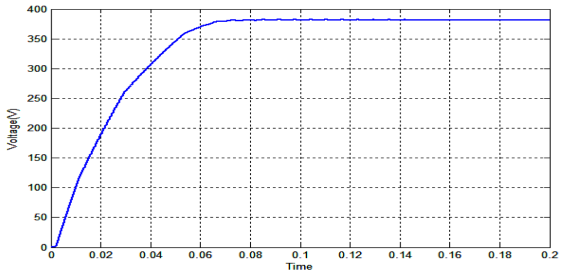


Fig. 15 Output of high side of BDC (step up mode)

VI. CONCLUSION

This paper presents a two stage bidirectional dc-dc converter. The advantages of two stage converter are simple switching technology, reduced component rating of isolated converter and simple combined PI-fuzzy controller. The series resonant converter operates at zero current switching technique so reduces switching losses. Due to the zero current switching of the MOSFET's with high frequency, this converter topology have important features like low component rating, low size, low weight and low cost The combination of PI and fuzzy controller improves performance of bidirectional dc-converter. This bidirectional converter used for stepping up and down voltage.

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