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TWO STAGE BIDIRECTIONAL DC-DC CONVERTER FOR BATTERY HYBRID POWER GENERATORS

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Abstract— In this paper a two stage 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 that magnetic components and EMI filters can be optimized. The PI controller is used for non-isolated converter. The high side voltage and low side voltage are regulated efficiently due PI controller. The application 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 is provided validate performance of proposed two stage bidirectional dc-dc converter.

Keywords—Biditrctional dc-dc converter (BDC) ,Hybrid power genertors, series resonant converter (SRC), Zero current switching (ZCS), PI.

NOMENCLATURE

L_r	: Resonant Inductance
C_r	: Resonant Capacitance
f_r	: Resonant Frequency
$D_d\, T_s$	: On-Time duty cycle of SRC
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 BD
I_{Lm}	:Magnetizing current of SRC
IL	: Low side current of SRC
ILr	:Resonant current of the SRC
ISL	: Low side current of SRC
VSH	: High Side voltage of SRC
VSL	: Low side voltage of SRC
LKP	: Primary side leakage inductor current of SRC
LKS	: Secondary side Leakage Inductor Current of SRC

I. INTRODUCTION

In recent years, the rate of power consumption in industrial loads, residential load and different activities in IT companies, banks, hospitals etc. has increased. 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 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 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.

As 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 transfer power to balance the ac load through battery discharging. When the generator balances the load the BDC charges the battery.

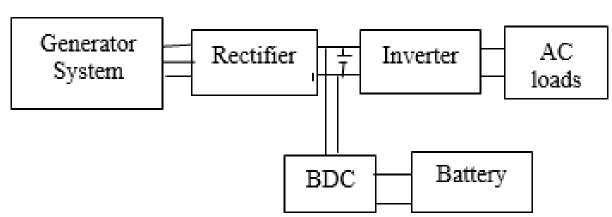

Fig.1 Battery Hybrid Power Generator System

The BDC should provide a galvanic isolation and a high step up/down voltage conversion ratio in the application where the low-voltage battery is used. Typical topology candidates with these requirements include half-bridge, full-bridge, and push-pull pulse width modulation (PWM) converters [10], [11] ,

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dual active bridge (DAB) converters [12], [13], and two-stage converters [14], [15]. The PWM converters usually necessitate passive or active clamping on the low-voltage side to clamp the surge voltage generated by the leakage inductance of the transformer. The active clamping technique makes the converter not only clamp the surge voltage, but achieve zero-voltage switching (ZVS) turn-on of all the switches. A drawback of the active clamped PWM converter is high turn-off switching losses [16]. The DAB has a modular and symmetric structure and can achieve ZVS turn-on without auxiliary components. However, the DAB has limited ZVS range and high-circulating currents for applications requiring wide voltage variation. The ripple current of the DAB converters is high and especially problematic in the low-voltage applications [17]. Two-stage converters consist of a non-isolated stage and an isolated stage. Since the non-isolated stage is operated to regulate the voltage and power flow, the isolated stage can be designed with minimum components' rating. Even though the power is passing through two conversion stages, the two-stage converter could achieve a higher efficiency especially in a wide voltage range application [14], [15].

In this paper a two stage bidirectional dc-dc converter is introduced with ZCS and PI 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 control is used to control non-isolated converter.

The section II describes the proposed two stage BDC. The next section III describes modes of operation of SRC. The section IV describes control strategy of BDC. In section V simulation results are presented

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 5:1. 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 PI controller is used to control non-isolated converter to regulate either high side voltage or low side voltage.

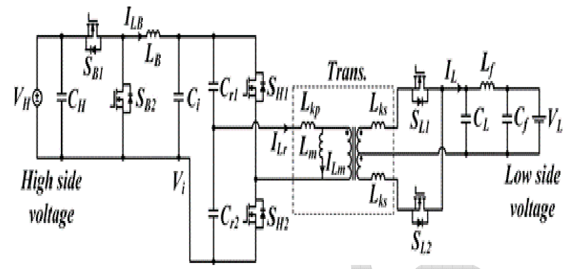

Fig.2 Two stage bidirectional dc-dc converter

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 ZCS is applied to SRC to improve EMI filter. Modes of operation and key-waveforms of series loaded resonant converter are shown in fig.3, 4 and fig.5. The expression of angular resonant frequency of SRC can determined by,

$$w_r = 2\pi f_r = \frac{1}{\sqrt{(L_r C_r)}} \qquad (1)$$

The expression of resonant inductance can be determined by,

$$Lr - Lkp + \frac{Lm + n^2 Lks}{Lm + n^2 Lks} \qquad (2)$$

The expression of resonant capacitance can be determined by,

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

A. Mode I (t_o-t_1)

In this mode switch S_{H1} and switch S_{L2} are on. The on time duty cycle is selected in such way so the low side current becomes purely sinusoidal. The on time duty cycle should be selected as $D_d T_s = 0.5/f_r$.

The low side current can be expressed as

$$i_{L(t)} = \frac{\pi I_{L,dc}}{2} \sin w_r t \qquad (4)$$

The voltage across L_m can be determined by

$$v_{Lm}(t) = -n\left(V_L + L_{ks}\frac{di_L}{dt}\right) \qquad (5)$$

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

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

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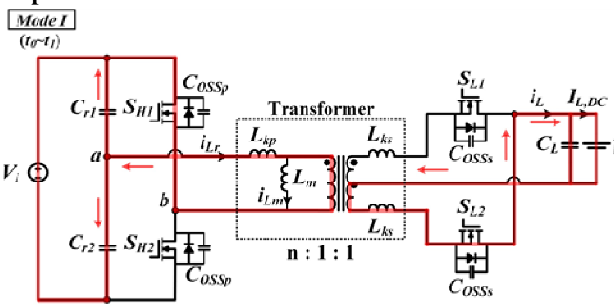

Fig. 3 Mode I of SRC

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

$$i_{Lr}(t) = \frac{\pi n V_L}{2w_r L_m} - \frac{nV_L}{L_m} + \left(\frac{\pi n L_{ks} I_{L,dc}}{2L_m} - \frac{n I_{L,dc}}{2n}\right)\sin w_r t \qquad (7)$$

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,

$$v_{SL1}(t) = 2V_L + L_{ks}\frac{di_L}{dt} \qquad (8)$$

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

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

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,

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

B. Mode II (t_1-t_2)

In Mode II, Switch S_{H1} is turned OFF at t_1, and turn-off current of the high side switch, $I_{SH,off}$, becomes equal to the peak magnetizing current $I_{Lm,pk}$. Since L_m is made very large in the proposed SRC, I Lm,pk is very small, resulting in negligible switch turn-off 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

$$V_{SH,on} = v_{SH2}(t2) = V_i - \frac{n^2 I_{Lm,pk} D_d T_s}{2n^2 Coss_p + 2Coss_s} \qquad (11)$$

$$V_{SL,on} = \frac{4V_L + \pi w_r L_{ks} I_{L,dc}}{2} - \frac{n I_{LM,pk} D_d T_s}{2Coss_p + 2Coss_s} \qquad (12)$$

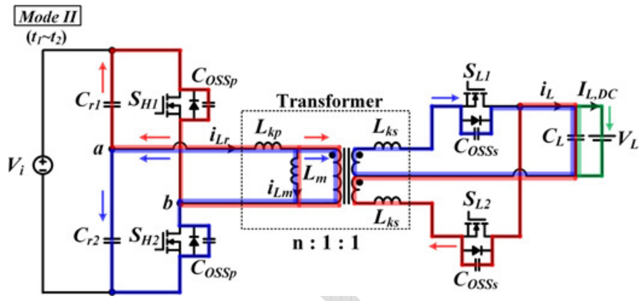

Fig.4 Mode II of SRC

Note that 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].

IV Control Strategy

The PI controller is used for controlling non-isolated converter for regulating high voltage side and low voltage side. The reference voltage for controlling high voltage side is taken as 400V.The reference voltage for controlling low voltage side is taken as 28V.

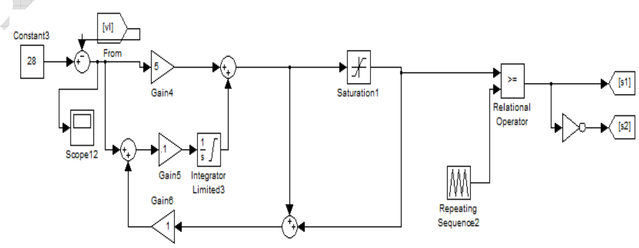

Fig. 5 Control strategy for low side voltage

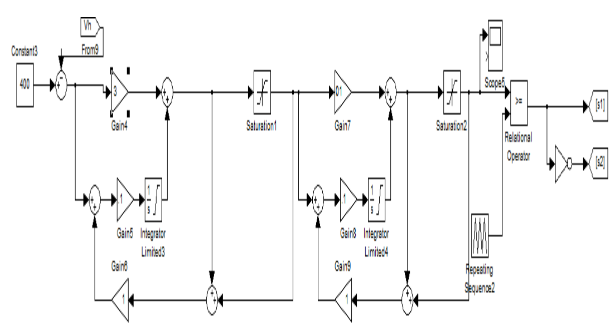

Fig. 6 Control strategy for high side voltage

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V Simulation Result

Simulation parameter of proposed bidirectional dc-dc converter are shown in Table I.

TABLE I

PARAMETERS OF THE PROPOSED BDC

Parameter	Value	Parameter	Value
P_o	5 KW	L_f	0.42μH
V_H	340-440 V	L_r	5.8μH
V_L	24-32 V	C_f	110μH
f_{s1}	48 KHz	C_H	45μH
f_{s2}	20 KHz	C_i	100μF
N_p:N_s	5:1	C_L	380μF
D_dT_s	600 ns	C_{r1}	0.94μF
L_B	1 mH	C_{r2}	0.94μF

Simulation waveforms of high and low voltage side control are shown as follows, The Fig.7 shows gate pulses of switch SH1, SH2, SL1, SL2.Fig.8 and fig.9 shows waveform of current IL$_r$, I$_{Lm.}$ and ISH, ISH2 respectively. The fig.10 shows the waveform of voltage Vcr1 andVcr2. Fig.11 shows output waveform of low side voltage control. Fig.12 shows output voltage of high side voltage.

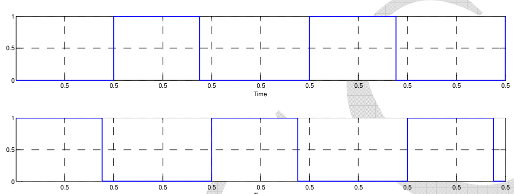

Fig.7 Gate pulse for SH1, SH2, SL1 and SL2

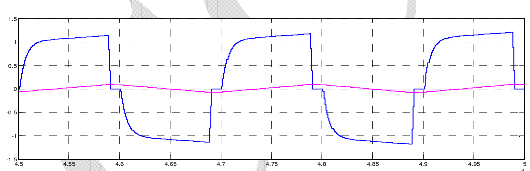

Fig.8 I$_{L}$r and I$_{Lm}$

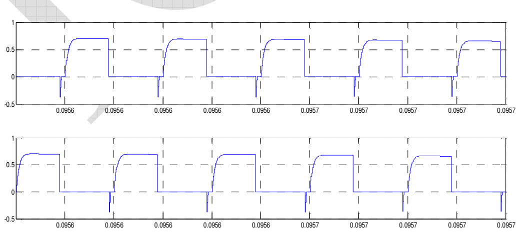

Fig.9 ISH1 and ISH2

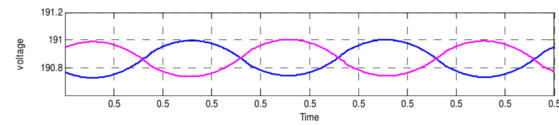

Fig. 10 Vcr1 and Vcr2

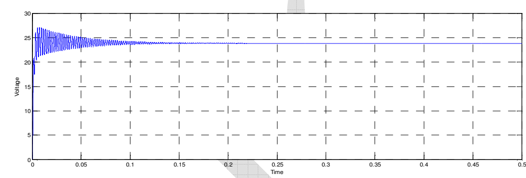

Fig.11 Output waveform of low side voltage control

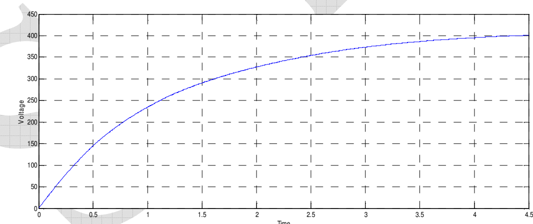

Fig.12 Output waveform of high side voltage control

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. The series resonant converter operates at zero current switching technique so reduces switching losses and improves performance of converter. This bidirectional converter used for stepping up and down voltage.

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