Soft-Switching DC-DC Converters Based on A Phase Shift Controlled
Active Boost Rectifier Using Fuzzy Controller

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Abstract—High efficiency can be achieved with dc-dc transformer by working all the switches at fixed 50% duty cycle. But, the output voltage of the dc-dc transformer cannot be regulated. Operating at high frequency increases the switching losses which is a form of power loss. When the proposed circuit works in soft switching continuous conduction mode, zero voltage switching (ZVS) performs for all the primary and secondary side switches can be achieved. In this project active boost rectifiers (ABRs) concept is introduced. ABR is made up of traditional diode rectifier and bidirectional switch. By adopting phase shift control between primary and secondary side switches the output voltage can be regulated and reduces the diode reverse recovery problem by utilizing the ABR and phase shift control plan. As a result proposed circuit can be reduces the switching losses and diode reverse recovery problem. Closed loop simulation study is made with the help of the simulation tool MATLAB/SIMULINK/FLC to predict the performance of the proposed scheme.

Index Terms—Active boost rectifier (ABR), DC-DC converter, full bridge converters (FBC), soft switching, voltage doubler (VD), Fuzzy Logic Controller (FLC).

I. INTRODUCTION

DC-DC converters are important in most of the portable electronic devices and are employed in variety of applications including supply for personal computers, office equipment, spacecraft power systems, laptops, telecommunication equipment’s as well as DC motor drives which are very much useful to people. With rapid developments of renewable energy, smart grid, and electric vehicles, isolated dc–dc converters have been widely used in a number of applications to meet the requirements of galvanic isolation and/or voltage conversion ratio. For further improvements on performance of efficiency, power density, and electromagnetic noise, many soft-switching dc–dc converters have been proposed for various applications to overcome the disadvantages in hard-switching dc–dc converters. Among them, the phase-shift full bridge converter (FBC) is more attractive because it can achieve zero voltage switching (ZVS) for all the active switches by adopting phase-shift modulation. However, untilnow, it still suffers from high voltage ringing and reverse recovery on the secondary-side rectifier diodes, limited ZVS range, circulating current-related power loss, and duty cycle loss. The reverse recovery problem of the rectifier diodes becomes even more serious in high-output voltage and high-power applications. Various improvements have been proposed to solve these problems. Generally, some additional components are introduced to suppress the circulating currents and alleviate the reverse-recovery problem. For instance, an auxiliary inductor, a transformer, or a winding is introduced to recycle the energy. Recently, the dual active bridge topology attracts great interest because it can realize ZVS for all the power switches. But the limited ZVS range and high circulating currents at light load make this converter unsuitable for wide voltage/load range applications. Another attractive solution for the isolated dc–dc power conversion is the LLC resonant converter. By designing and selecting a proper operation region, soft switching of all the active switches and rectifier diodes over a wide load range can be achieved with the LLC resonant converter. However, frequency modulation makes the accurate modeling of the LLC converter difficult to achieve, and also complicates the design of magnetic components. Besides, the resonant tank in the LLC converter should be designed carefully as well to achieve high efficiency, which remains a challenge for this type of converter. As a result, soft switching of all the power switches can be always achieved by utilizing the leakage or magnetizing inductance. Therefore, high efficiency and high power density can be easily achieved. However, the output voltage/power of a dc–dc transformer cannot be regulated. If the output voltage of a dc–dc transformer can be regulated, high efficiency may be easily achieved. To achieve the goal mentioned previously, this paper proposes the active-boost-rectifier (ABR) concept with fuzzy based controller. The ABR circuit is introduced to the dc–dc transformer topology to implement output voltage/power regulation.

II. RELATED WORKS

X. Pan and A. K. Rathore presented a novel interleaved soft-switching bidirectional snubberless current-fed full-bridge voltage doubler (dc/dc converter) for an energy storage system in fuel cell electric vehicles. A novel secondary modulation technique was also proposed to clamp the voltage across the primary-side switches naturally with zero-current commutation. It, therefore,
eliminates the necessity for an external active-clamped circuit or passive snubbers to absorb the switch turn-off voltage spike, a major challenge in current-fed converters. Zero-current switching of primary-side devices and zero-voltage switching of secondary-side devices are achieved, which significantly reduce switching losses. An interleaved design is adopted over a single cell to increase the power handling capacity obtaining merits of lower input current ripple, reduction of passive components’ size, reduced device voltage and current ratings, reduced conduction losses due to current sharing, and better thermal distribution. Primary device voltage was clamped at rather low-reflect output voltage, which enables the use of low-voltage semiconductor devices having low on-state resistance. Considering input current was shared between interleaved cells, conduction loss of the primary side, a considerable part of total loss, was significantly reduced and higher efficiency can be achieved to obtain a compact and higher power density system. Steady-state operation, analysis, and design of the proposed topology have been presented [1].

W. Yu, J. S. Lai, W. H. Lai, and H. Wan, A novel soft-switching converter combining resonant half-bridge and phase-shifted pulse width modulation (PWM) full-bridge configuration was proposed by them to ensure the switches in the leading-leg operating at zero-voltage switching from true zero-load to full-load, and the switches in the lagging leg working at zero-current switching with minimum duty cycle loss and circulating conduction loss by significantly reducing leakage or series inductance. The hybrid resonant and PWM converter was attractive for electrical vehicle battery charger application [2].

D. S. Gautam and A. K. S. Bhat, A dc-to-dc converter was required to couple the electrolyzer to the system dc bus. They presented the design of three soft-switched high-frequency transformer isolated dc-to-dc converters for this application based on the given specifications. It was shown that LCL-type series resonant converter (SRC) with capacitive output filter is suitable for Electrolyzer application. Due to the wide variation in input voltage and load current, no converter can maintain zero-voltage switching (ZVS) for the complete operating range. Therefore, a two-stage converter (ZVT boost converter followed by LCL SRC with capacitive output filter) was found suitable for Electrolyzer application [3].

Y. S. Shin, C. S. Kim, and S. Y. Han, The conventional Zero Voltage Switching (ZVS) Phase Shift Full Bridge converter (PSFB) has large circulating energy during freewheeling interval caused by the small duty cycle, which could increase the primary side conduction losses, turn off switching losses of lagging leg switches and current ripple through the output inductor. To overcome these problems they proposed a new pulse frequency modulated full bridge DC-DC converter with series boost capacitor. The proposed converter controls the output voltage by varying the voltage across the series boost capacitor according to switching frequency and has no freewheeling interval due to 50% fixed duty operation. As a result, since its freewheeling current is eliminated, the conduction losses can be considerably reduced compared with those of the conventional ZVS PSFB. Moreover, ZVS of all power switches can not only be ensured along wide load ranges but current ripple through the output inductor can also be significantly reduced. Therefore, it has very desirable merits such as a high efficiency, small output inductor and improved heat generation [4].

B. Gu, C. Y. Lin, B. Chen, J. Dominic presented a zero-voltage-switching (ZVS) full-bridge dc-dc converter combing resonant and pulse-width-modulation (PWM) power conversions for electric vehicle battery chargers. In the proposed converter, a half-bridge LLC resonant circuit shares the lagging leg with a phase-shift full-bridge (PSFB) dc-dc circuit to guarantee ZVS of the lagging-leg switches from zero to full load. A secondary-side hybrid-switching circuit, which was formed by the leakage inductance, output inductor of the PSFB dc-dc circuit, a small additional resonant capacitor, and two additional diodes, was integrated at the secondary side of the PSFB dc-dc circuit. With the clamp path of a hybrid-switching circuit, the voltage overshoots that arise during the turn off of the rectifier diodes are eliminated and the voltage of bridge rectifier was clamped to the minimal achievable value, which was equal to secondary-reflected input voltage of the transformer. The sum of the output voltage of LLC resonant circuit and the resonant capacitor voltage of the hybrid-switching circuit was applied between the bridge rectifier and the output inductor of the PSFB dc-dc circuit during the freewheeling phases. As a result, the primary-side circulating current of the PSFB dc-dc circuit is instantly reset to zero, achieving minimised circulating losses [5].

III. PROPOSED SYSTEM:

![Block Diagram of Proposed full-bridge converter with voltage-doubler active boost rectifier](image)

The proposed system block diagram is shown in figure1. In the proposed system we have used the fuzzy logic controlling technique to improve the efficiency of the system. The system circuit diagram and operation of the proposed system is discussed below.

THE FBC WITH VOLTAGE-DOUBLER ABR:
The FBC-VD-ABR is redrawn in Fig. 2, where all the switches on the primary and secondary sides have a constant duty cycle of 0.5. S1 and S4 are always turned-on/off simultaneously, and the same with S2 and S3. A phase-shift angle between the primary- and secondary-side active switches is employed to regulate the output power and voltage. Lf stands for the total of the transformer leakage inductance and external inductor. The output series capacitors C1 and C2 have the same capacitance and are large enough to clamp the voltage stresses of the secondary-side switches and diodes to half of the output voltage. uDS1, uDS4, and uDS6 are the drain to source voltages of S1, S4, and S6, respectively. uP and uS are the voltages on the primary side and secondary side of the transformer. And iLf is the primary current flowing through the transformer with the positive direction shown in Fig.2. A proper dead time is necessary for the primary-side switches to achieve ZVS and avoid shoot-through of the switching bridges. To simplify the analysis, the parasitic capacitance of MOSFET is ignored and the transformer is assumed to be ideal.

![Fig2. Proposed system.](image)

The normalized voltage gain G is defined as

$$ G = \frac{NU_0}{2U_{in}} \quad \text{(1)} $$

Where $U_{in}$, $U_o$ and N are the input voltage, output voltage, and transformer turns ratio $n_p/n_s$, respectively. The phase shift $\phi$ is defined as the phase difference between $S_1$ gate signal and $S_6$ gate signal. Because this phase shift serves the same function as duty cycle in a PWM converter, we define duty cycle $D$

$$ D = \frac{\phi}{\Pi} \quad \text{(2)} $$

According to the waveforms of the primary-side current, the converter has three operation modes, namely secondary side soft-switching continuous-conduction mode (SS-CCM), secondary-side hard-switching continuous-conduction mode (HS-CCM), and discontinuous conduction mode (DCM), respectively.

SS-CCM Operation: In SS-CCM, the converter can work in Boost mode (G>1). The theoretical waveforms of the proposed circuit operating in SS-CCM are shown in Fig 3 where $D_3$ is defined as the equivalent duty cycle during which the primary current returns to zero after the primary-side switches turn OFF, and $T_3$ is the switching period. There are eight modes in one switching period.

Mode 1: $[t_0,t_1]$ Fig. 2.a. Before $t_0$, $S_2$, $S_3$, $S_4$, and $D_2$ are on. But no current flows through $S_4$ since body diode of $S_4$ is reverse biased. At $t_0$, $S_2$ & $S_3$ turn off. Body diode of $S_1$ & $S_4$ begin to conduct due to the energy stored $L_f$, which in ZVS of $S_2$ & $S_3$. Due to the negative voltage of the inductor, the current $i_{L_f}$ decreases rapidly.

$$ i_{L_f(t)} = i_{L_f(t_0)} + \frac{NU_0}{2LF} \left( \frac{1}{G} + 1 \right) (t - t_0) \quad \text{(3)} $$

Mode 2: $[t_1,t_2]$ Fig. 2.b. At $t_1$, $S_1$, and $S_4$ are turned ON with ZVS. This stage ends when $i_{L_f}$ returns to zero, and $D_2$ is OFF naturally without reverse recovery.

Mode 3: $[t_2,t_3]$ Fig. 2.c. At $t_2$, $i_{L_f}$ returns to zero, the inductor $L_{ds}$ charged by the input voltage.

$$ i_{L_f(t)} = i_{L_f(t_3)} + \frac{NU_0}{2GLF} (t - t_2) \quad \text{(4)} $$

Mode 4: $[t_3,t_4]$ Fig. 2.d. At $t_3$, $S_5$ turns OFF and $S_6$ is ON, but no current flows through $S_6$. Diode $D_4$ begins to conduct. The power is transferred to the load during this mode.

$$ i_{L_f(t)} = i_{L_f(t_3)} + \frac{NU_0}{2LF} \left( \frac{1}{G} - 1 \right) (t - t_3) \quad \text{(5)} $$

At the end of this mode, $i_{L_f}$ has the same absolute value but reverse direction as that the beginning of mode 1, which is expressed as

$$ i_{L_f(t)} = -i_{L_f(t_0)} \quad \text{(6)} $$

A similar operation works in the rest modes of a switching.

![Fig3. Key waveforms of the proposed converter in SS-CCM.](image)

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Fig4. Equivalent circuits for each operation stage of SS-CCM: (a) Stage 1 [t0, t1], (b) Stage 2 [t1, t2 ], (c) Stage 3 [t2, t3 ], and (d) Stage 4 [t3, t4 ].

IV. FUZZY CONTROLLER

 Basically, Fuzzy Logic (FL) is a multivalued logic that allows intermediate values to be defined between conventional evaluations like true/false, yes/no, high/low, etc. Notions like rather tall or very fast can be formulated mathematically and processed by computers, in order to apply a more human-like way of thinking in the programming of computers.

The internal structure of the fuzzy controller is shown in Figure 9. The error e and change of error (ce) are used numerical variables from the real system. To convert these numerical variables into linguistic variables, the following seven fuzzy levels or sets are chosen as: NB (negative big), NM (negative medium), NS (negative small), ZE (zero), PS (positive small), PM (positive medium), and PB (positive big) as shown in table 1.

The fuzzy controller is characterized as follows:

(i) Seven fuzzy sets for each input and output.
(ii) Fuzzification using continuous universe of discourse.
(iii) Implication using Mamdani’s ‘min’ operator.
(iv) Defuzzification using the ‘bisector’ method.

The elements of rule base table are determined based on the theory that in the transient state, large errors need coarse control, which requires coarse input/output variables; in the steady state, small errors need fine control, which requires fine input/output variables. Based on this the elements of the rule table are obtained as shown in Table 1, with error and change in error as inputs.

The fuzzy inference operation is implemented by using the 49 rules. Some of these rules are:

1. If error (E) is NB and change in error (CE) is NB then output is NB.
2. If error (E) is NB and change in error (CE) is NM then output is NB.
3. If error (E) is NB and change in error (CE) is NS then output is NB.
4. If error (E) is NB and change in error (CE) is ZE then output is NB.

Likewise 49 rules are defined.

Table 1 Control rule base

V. SIMULATION RESULT

Full-Bridge Converter With Voltage-Doubler Active Boost Rectifier

Fig6. Proposed full-bridge converter with voltage-doubler active boost rectifier.
The simulation of full-bridge converter with voltage doubler active boost rectifier is shown in figure10. As shown in the simulation DC source is the input source to full-bridge converter. 110V DC is the input voltage to the proposed system.

In the proposed system we have included the advantages of fuzzy logic controller to maintain the system stability and efficiency.

The full bridge converter output waveform in primary side is shown below figure11 X axis 1 div=0.0005s, Y axis 1 div=50V.

The secondary side of the transformer output voltage waveform is shown below figure11 X axis 1 div=0.0005s, Y axis 1 div=50V.

The output DC voltage waveform of the voltage doubler is shown below figure12 X axis 1 div=0.1, Y axis 1 div=50V.

The ZVS of primary and secondary voltage waveform is shown below figure10 (a) & (b).

Simulation specifications are listed in the table II below

TABEL II : SPECIFICATIONS OF SIMULATION PARAMETERS

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input voltage</td>
<td>110V</td>
</tr>
<tr>
<td>capacitor C1,C2</td>
<td>330µF</td>
</tr>
<tr>
<td>Inductor</td>
<td>16µH</td>
</tr>
<tr>
<td>Output Voltage</td>
<td>320V</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>80KHz</td>
</tr>
</tbody>
</table>

VI. CONCLUSION

In this paper, a soft-switching dc–dc converters has been presented for high-efficiency applications based on the proposed fuzzy controlled ABRs. The optimization of problems is achieved using fuzzy logic technique, the output voltage regulation is achieved by adopting phase shift control between the primary and secondary-side switches. ZVS performance has been achieved for both the primary- and secondary-side switches in a wide voltage and load range. Furthermore, the reverse-recovery problems associated with the rectifier diodes are alleviated. Therefore, the switching losses of the proposed converters can be reduced, which is important for high-frequency, high-efficiency, and high-power density applications. Moreover, the leakage inductance of the transformer has been utilized as the energy transfer inductor, and all the devices voltages are clamped to the input or output voltage. Thus, the voltage overshoots on the devices are effectively suppressed.
REFERENCE


