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Closed Loop Control of Non isolated Bidirectional ZVS-PWM Active Clamped DC–DC Converter

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Abstract—This paper presents closed loop control of Non-Isolated Bidirectional ZVS-PWM Active Clamped DC-DC Converter .The converter can operate with soft-switching, a continuous inductor current, fixed switching frequency, and the switch stresses of a conventional PWM converter regardless of the direction of power flow. In Hysteresis control strategy try to control the current of inductor on an appropriate level and then using this current we control the output voltage by hysteresis method. Controllers were first designed using the frequency response techniques based on the small signal models of the DC-DC converters, then transformed into digital controllers using the backward integration method. A performance index (P.I) has been minimized by PSO implemented in MATLAB.

***Index Terms*— Non isolation, bidirectional dc-dc converter ,zero voltage switching (zvs),active clamp circuit.**

I. INTRODUCTION

Bidirectional dc-dc converters are mainly two type, isolated and non-isolated depending on the application. Bidirectional DC-DC converter have widely studied for many industrial application such as auxiliary power supplies, hybrid electric vehicles, fuel cell based DC-DC converter ,and battery charged/discharged DC converters in UPS system. The batteries are connected to the buses with non isolated bidirectional dc-dc converters that allow them to discharge or to be charged necessary. The converter able to step up the voltage from batteries when they providing energy to dc voltage bus and they must able to step down the voltage when the bus is charging the battery. The standard non isolated dc –dc converter has no auxiliary circuit to enhance the operation of inductor current. The auxiliary circuit gives continuous inductor current with constant switching frequency and the switch stresses. It is not difficult to implement soft-switching in isolated bidirectional dc-dc converters as they tend to be based on conventional half-bridge and full-bridge structures that can use inductive energy stored in the main power transformer to discharge the capacitance across the converter switches. It is more challenging to do so for non-isolated converters as there is no such transformer.

II. CONVERTER OPERATION

The fig. 1 shows the equivalent circuit diagram of non isolated bidirectional ZVS-PWM Active Clamped DC-DC Converter. When energy is transferred from the low-side source V_{lo} to the high-side source V_{hi} ,S_1 operates like a boost switch S_2 operates as a boost diode When energy is transferred from V_{hi} to V_{lo}, S1operates like a buck diode and S_2 like a buck switch. In this converter auxiliary switch Sa, capacitor Cr and inductors Lr1and Lr2 have been added. These four components make up a simple active clamp circuit. It can be used to ensure that the main power switches, S1and S2, operate with zero voltage switching (ZVS) regardless of whether the converter is operating in a boost mode or buck mode.

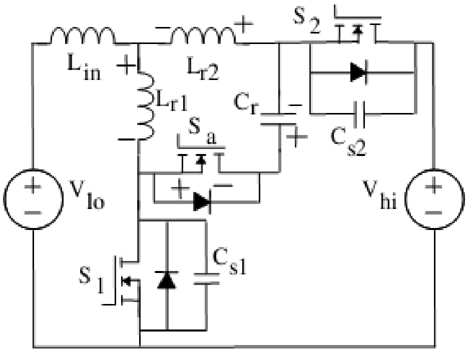

Fig:1 Non-Isolated Bidirectional ZVS-PWM Active Clamped DC-DC Converter

A. Mode of operation

Boost mode Mode 0 ($t < t_0$): Initially, before time $t=t_0$, switch S1on converter operate as a standard PWM boost converter. The current I_{Lin} through Lin is rising. At this time there is no current in the auxiliary circuit . Mode 1 ($t_0 < t < t_1$): At time $t = t_0$, switch S_1 is turned off and the rise in voltage across it is limited by Cs1. The current through L_{r1}charges up $C_{s1}$and begins to flow through Cr. In this mode, input current begins to be diverted to $L_{r2}$and the capacitance across S_2, C_{s2}, begins to be discharged. Mode 2 ($t_1 < t < t_2$): It is a continuation of mode 1 except that C_S is completely discharged at time $t=t_1$. The current flows through the anti parallel diode across S_2. Mode3 ($t_2 < t < t_3$):At time t = t2, the current stops flowing through the auxiliary active clamp circuit. The converter operates as a standard PWM boost converter. The current through L_{in} decreases and a negative voltage is impressed across L_{in} Mode 4 ($t_3 < t < t_4$): Some time before switch S_1 is to be turned on, at time $t = t_3$, switch Sa is turned on with zero current switching (ZCS).Capacitor Cr begins to discharge through L_{r1} and L_{r2}, as I_{Lin} continues to decrease. It will continue until current has been completely transferred to S_1 and it enters mode 0 at $t=t_7$ Mode 5 ($t_4 < t < t_5$): In this mode Switch Sa is turned off at $t = t_4$. The current in L_{r1} is flowing through the output capacitor of switch S_1.The current flowing through S_1 discharges capacitor C_{S1}.

Mode 6 ($t_5 < t < t_7$): At time $t=t_5$ capacitor C_{S1} has been completely discharged .The anti-parallel diode across S1begins to conduct. S_1can be turned on with ZVS while this diode is conducting. Mode 7 ($t_6 < t < t_7$): Some time after S_1has been turned on, at $t = t_6$, the current through L_{r1} will begin to reverse direction .The transfer of current from $L_{r2}$to S_1will begin. In this mode of operation will continue until current has been completely transferred to S1and the converter enters Mode 0 at $t = t_7$.

BUCK MODE

Mode 0 (t < t0): Initially, before time $t = t_0$, switch S_2 on the converter operates as a standard PWM buck converter . The current through Lin, I_{Lin}, rising.

Mode 1 ($t_0 < t < t_1$):At time $t = t_0$, switch S_2 is turned off and the rise in voltage across it is limited by C_{s2} . The current through Lr2charges up Cs1and begins to flow through Cr. Input current begins to be diverted to Lr1and the capacitance across S_1, C_{s1}, begins to be discharged.

Mode 2 ($t_1 < t < t_2$):This is a continuation of Mode 1 except that Cs2 is completely charged at $t = t_1$. In some time during this mode, Cs1 may be completely discharged and/or current may stop flowing through Cr.

Mode 3 ($t_2 < t < t_3$):At time $t = t_2$, current stops flowing through the auxiliary active clamp circuit. The converter operates as a standard PWM buck converter. The current through L_{in} decreases. In this mode as the converter is in a freewheeling mode of operation.

Mode 4 ($t_3 < t < t_4$):Some time before switch S_2 is to be turned on, at $t = t_3$, switch Sa is turned on with zero crossing switching (ZCS). Capacitor Cr begins to discharge through $L_{r1}$and L_{r2}, as I_{Lin} continues to decrease.

Mode 5 ($t_4 < t < t_5$): At $t = t_4$ Switch Sa is turned off. The current in $L_{r2}$is used to discharge C_{s2}

Mode 6 ($t_5 < t < t_6$):At time $t = t_5$, capacitor C_{s2} has been completely discharged. The anti-parallel diode across S_2 begins to conduct. Switch S_2can be turned on while this diode is conducting.

Mode 7 ($t_6 < t < t_7$) : Some time after S_2 has been turned on, at $t = t_6$. The current through L_{r2} will begin to reverse direction .The current transfer from L_{r1} to S_2will begin. This mode of operation will continue until current has been completely transferred to S_2. and the converter enters Mode 0 at time $t = t_7$. [1]

III. CLOSED LOOP CONTROL

In Hysteresis control strategy we try to control the current of inductor on an appropriate level and then using this current we control the output voltage by hysteresis method. Since inductor current can be increased to increased robustness margins against fluctuations in input voltage and load changes, there is two reference quantities:Output voltage, Ratio of inductor current to minimum inductor current. In this control method, controller increase and decrease the inductor current reference according to output voltage error.Voltage control loop works independently to control output voltage. Voltage control unit considers inductor as a current source, since it can use hysteresis control method for voltage

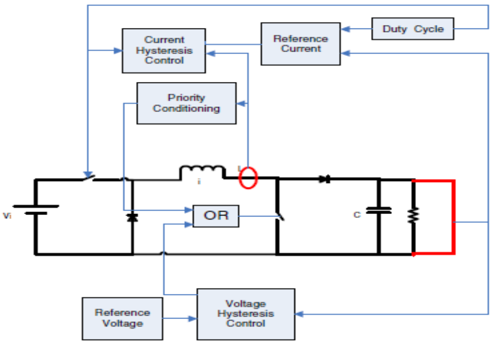

Fig.2 schematic diagram of controller

Controllers were first designed using the frequency response techniques based on the small signal models of the DC-DC converters, then transformed into digital controllers using the backward integration method. The z-domain transfer function of a digital PID controller is shown as,

$$G_C(z) = K_P + \frac{K_1 T_z}{z-1} + \frac{K_D(z-1)}{T_z} \qquad (1)$$

and the z-domain transfer function of a digital PI controller is shown as,

$$G_C(z) = K_P + \frac{K_1 T_Z}{z-1} \qquad (2)$$

The difference equation to calculate a new duty cycle for the digital PID controller is written as,

$$u[k] = K_P e[k] + K_I T \sum_{i=0}^{k} \{e[k] - e[k-1]\} \qquad (3)$$

And the difference equation to calculate a new duty cycle for the digital PI controller is given as,

$$u[k] = K_P e[k] + K_I T \sum_{i=0}^{k} e[i] \qquad (4\_)$$

In the difference equation, u[k] is the controller output for the kth sample, and e[k] is the error of the kth sample. The error e[k] is calculated as e[k] = Ref-ADC[k], where ADC[k] is the converted digital value of the kth sample of the output voltage, and Ref is the digital value corresponding to the desired output voltage. $\sum_{i=0}^{k} e[i]$ is the sum of the errors and {e[k]-e[k-1]} is the difference between the error of the k^{th} sample and the error of the $(k-1)^{th}$ sample.

Application of Self-Tuning PI Controller :The optimal values of these gains are found out from the integral time square error (ITSE) criterion. A performance index (P.I) given by,

$$P.I. = \int_0^t z^2 (\Delta I_{dc}(z)) dz \qquad (5)$$

has been minimized by PSO implemented in MATLAB. Where, ΔIdc is the error signal.

IV. OUTPUT AND RESULT

A. simulink model

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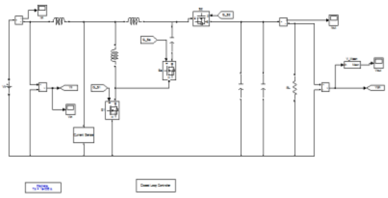

Fig.3 Boost mode operation

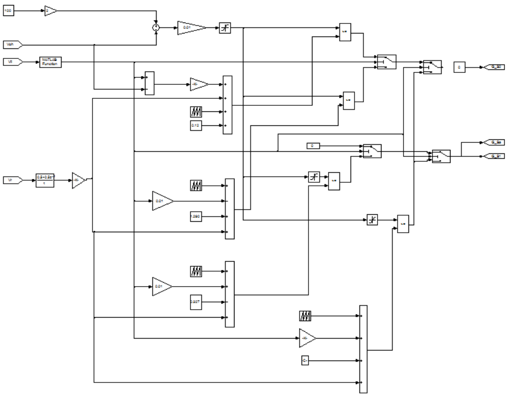

Fig.4 Closed loop controller

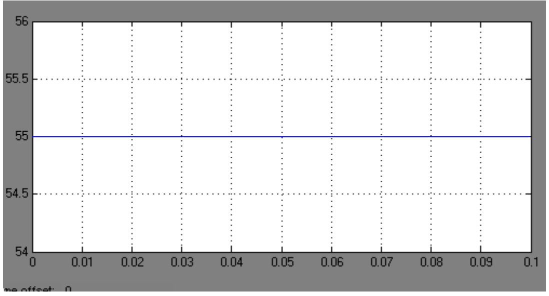

Fig.5 Input voltage waveform

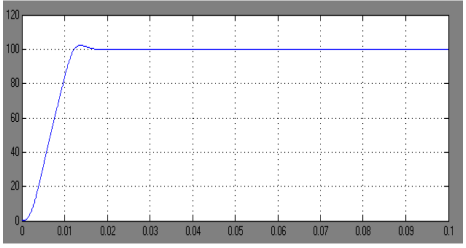

Fig.6 Output voltage waveform

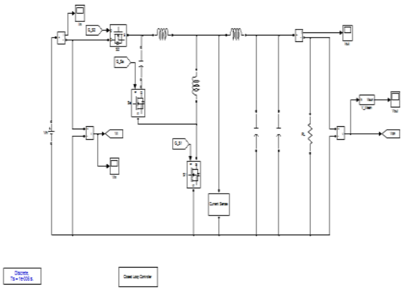

Fig.7 Buck mode operation

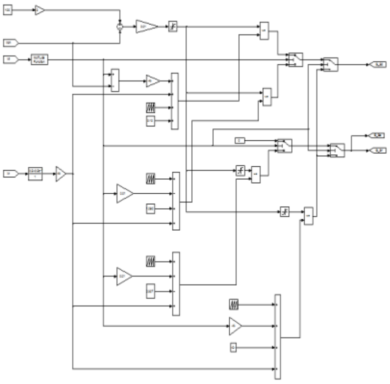

Fig .8 Closed loop controller

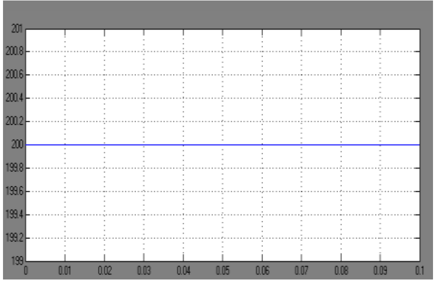

Fig 9 Input voltage wave form

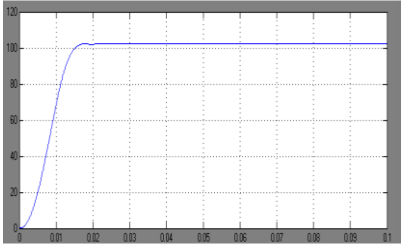

Fig .10 Output voltage waveform

V. CONCLUSION

The closed loop control of non isolated ZVS-PWM active clamped DC-DC converter is simulated and output waveforms are obtained. The converter can operate with continuous inductor current and fixed frequency .Closed loop control is an effective technique, and improve the overall performance of the converter.

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