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Closed Loop Control of PWM Based Soft Switched Non Isolated DC-DC Boost Converter

Aravind. G. S, P. Ebby Darney
PG Scholars, Associate Prof,
EEE Department
SCAD College of Engineering and Technology Cheranmahadevi,
Tirunelveli District, Tamilnadu,India

Abstract— **The conventional boost converter need high duty cycle to obtain high output voltage as well as high power. In order to obtain high voltage and power, the size and rating of the power semiconductor used should be increased. This semiconductor switch will increase conduction loss of the system and also reverse recovery problem is present. To reduce these problems nonisolated non isolated high step up DC-DC converter with soft switching technique is used. But PWM based this technique has high turn off switching losses. To reduce the turn off switching losses a new method called resonant PWM (RPWM) based soft switching nonisolated high step up DC-DC converter is used. The RPWM is performed by utilizing Lr–Cr resonance in the auxiliary circuit; the capacitance is significantly reduced compared to the pulse width modulation method. Because of reduced switching losses, diode reverses recovery problems and increased step up ratio. A PWM based closed loop control is employed to this converter to enhance the load regulation and reliability of the control. The characteristics of Fuzzy Logic based closed loop control system is studied and the transient parameters are obtained. The Fuzzy Logic controller gives better performance on control the voltage under transient conduction.**

I. INTRODUCTION

The use of non-isolated high step-up dc–dc converters has been increasing with the use of renewable energy sources like photo voltage system and wind energy systems and also used for the development of dc backup energy storage. Large input current and high output voltage are the two main factors related to the efficiency of the system The large input current results from low input voltage; therefore, low voltage rated devices with low on state resistance are necessary in order to reduce the conduction loss. The boost and buck–boost converters are the simplest nonisolated topologies. The non-isolated converters can provide high step-up voltage gain without incurring extreme duty ratios. A coupled inductor high step-up dc–dc converter utilizes a voltage doubler and adjusts the turn ratios of the coupled inductor. This converter has been highly efficient because it recycles the energy stored in the leakage inductor of the coupled inductor, but stress across the switches is high and large inductor leakage current may damage the switches.

Most of the coupled-inductor and switched-capacitor converters are hard switched. The hard-switched CCM boost converter suffers from severe diode reverse-recovery problem in high-current high-power applications. That is, when the main switch is turned on, a shoot through of the output capacitor to ground due to the diode reverse recovery causes a large current spike through the diode and main switch. This not only incurs significant turn-off loss of the diode and turn-on loss of the main switch, but also causes severe electromagnetic interference (EMI) emission. The effect of the reverse-recovery-related problems becomes more significant for high switching frequency at high power level. Therefore, the hard-switched CCM boost converter is not capable to achieve high efficiency and high power density at high power level. Therefore, they are not suitable for high efficiency and high-power applications.

Some soft-switched interleaved high step-up converter topologies have been proposed to achieve high efficiency at desired level of volume and power level. Among them, the soft-switched continuous conduction mode (CCM) boost converter demonstrated reduced voltage stresses of switches and diodes and zero-voltage switching (ZVS) turn-on of the switches in CCM and zero-current switching (ZCS) turn-off of the diodes. However, a drawback of this pulse width modulation (PWM) converter is high turn-off switch losses. In this project, an improved switching method, called resonant PWM (RPWM) is proposed for the soft-switched CCM boost converter in order to reduce the turn-off switching losses.

II. OPERATING PRINCIPLES OF THE PROPOSED CONVERTER

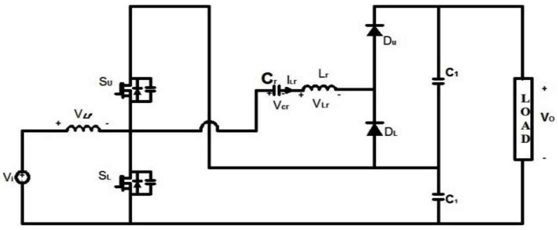


Fig.1.Proposed ZVZCS RPWM DC-DC converter.

PWM method and Resonant PWM method has same circuit topology. Main boost converter and an auxiliary circuit are the two main part of the proposed converter. The resonant capacitor C_r, resonant inductor L_r and two diodes D_L and D_U are the two main part of the auxiliary circuit. The two switches S_1 and S_2 regulated the output voltage of the system. This is a CCM mode converter. The turning of the converter is happen due to the high value of peak current. . But in the resonant PWM (RPWM) converter, the switches are turned off with resonance attained by the resonant capacitor Cr and inductor Lr of the system. The current through the resonant circuit decides which switch is turned on and off.

When closed loop system is introduced, response of the system is increased and also the steady state of the system is reduced. The resonant PWM (RPWM) converter reduces the conduction losses of the system. It also reduced the reverse recovery problems of the switching diode. This will help to reduce the size of the system. The closed loop control to regulate the output voltage is introduced which is based on PWM based control.

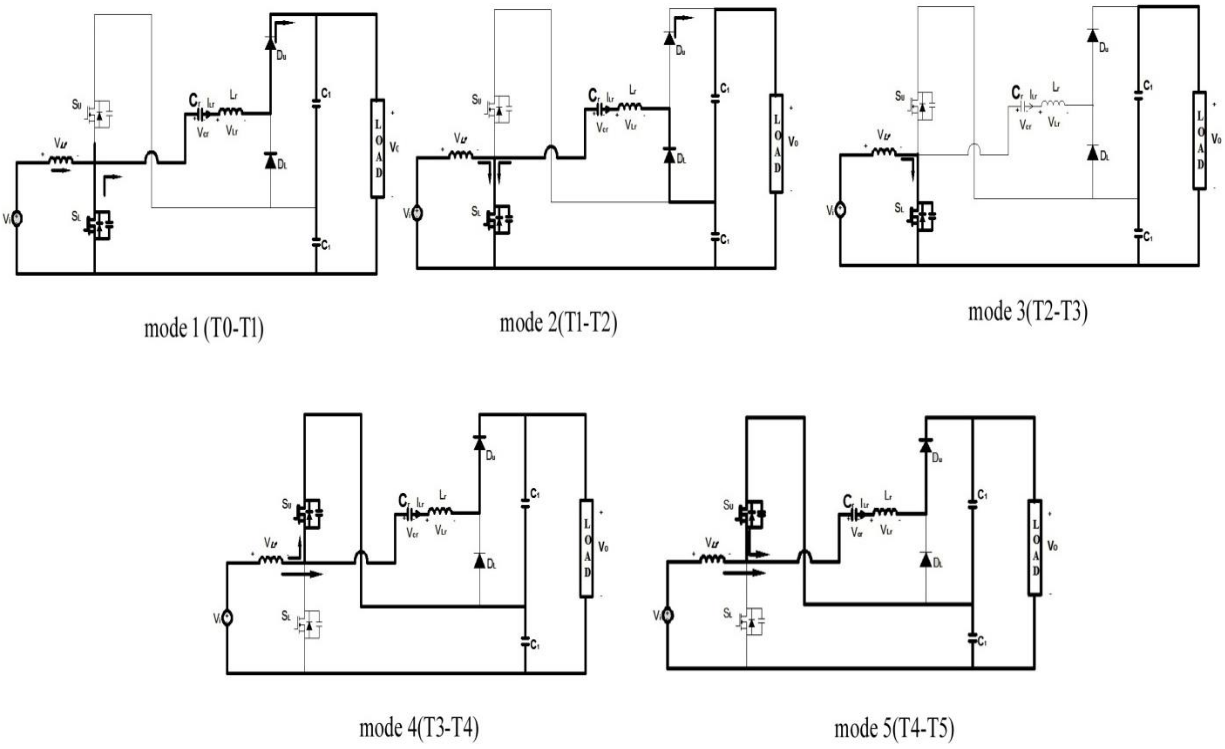
III. MODES OF OPERATION

The operating modes and the key wave of the proposed converter are shown in figs.

Mode 1(T_o-T_1): This mode begins when upper switch S_u which was carrying the current of difference between i_{Lf} is turned OFF.S_L can be turned ON with ZVS if signal for S_L is applied before the current direction reversed. Filter inductor current i_{Lf} and auxiliary current i_{Lr} starts to linearly increase and decrease, respectively, as follows.

$$\frac{di_{Lf}}{dt} = \frac{V_i}{L_1} \qquad (1)$$

$$\frac{di_{Lr}}{dt} = \frac{V_{c1}-V_{c2}-V_{c3}}{L_2} \qquad (2)$$


mode 1 (T0-T1)

mode 2(T1-T2)

mode 3(T2-T3)

mode 4(T3-T4)

mode 5(T4-T5)

Fig 2 : Mode of operating of the proposed RPWM converter.

Mode 2(T_1-T_2): In the beginning of this mode the L_r and C_r, auxiliary inductor and capacitor of the auxiliary circuit are resonant with each other. Current i_{Lf} is still linearly increasing. The voltage and current of resonant components are determined, respectively, as follows:

$$\frac{di_{L1}}{dt} = \frac{V_i}{L_1} \qquad (3)$$

$$\frac{di_{L2}}{dt} = \frac{V_{c1}-V_{c3}}{L_2} \qquad (4)$$

The resonance mode ends when i_{Lr} reaches to zero. Note that D_L is turned OFF under ZCS condition.

Mode 3(T_2-T_3): There is no current path through the auxiliary circuit during this mode. Output capacitors supply the load. At the end of this mode the turn-off signal of S_L is applied. It is noted that the turn-off current of S_L, I_{SL} is limited to filter inductor current at $T3$, I_{Lf} which is much smaller than that of PWM method.

$$\frac{di_{L1}}{dt} = \frac{V_i}{L_1} \qquad (5)$$

Mode 4(T_3–T_4): This mode begins when lower switch S_L is turned OFF. S_U can be turned ON with ZVS if gate signal for S_U is applied before the current direction of S_U is reversed. Filter inductor current i_{Lf} starts to linearly decrease since voltage v_{Lf} becomes negative.

$$\frac{di_{L1}}{dt} = \frac{V_{i}\text{-}V_{c3}}{L_1} \tag{6}$$

$$\frac{di_{L2}}{dt} = \frac{V_{c1}\text{-}V_{c2}}{L_2} \tag{7}$$

In this mode the other L_r–C_r resonance of auxiliary circuit is started, and D_U starts conducting as same as Mode 2. At the end of this mode the current i_{Lr} is equal to i_{Lf}.

Mode 5(T_4-T_3): This mode begins when the currents i_{Lr} equals i_{Lf} , the direction of the upper switch i_{SU} changes, then this mode begins. At the end of this mode, turn-off signal of S_U is applied and this mode ends. The modes of operation of the system are shown in fig.2

IV. CONTROL CIRCUIT OF PROPOSED CONVERTER.

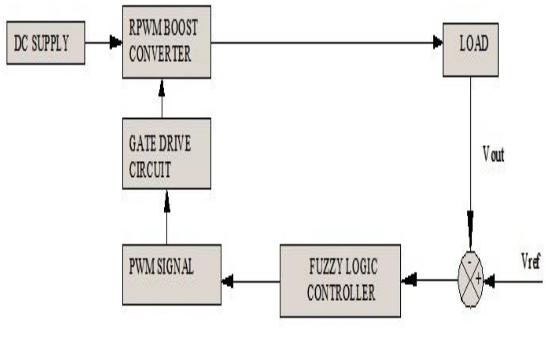


Fig.3 Closed loop control of the proposed converter

The closed loop control of the proposed converter is as shown in fig.3. The closed loop control will help to maintain the system stability under transient condition. The closed loop control of the proposed converter is done with the help of a FUZZY Logic controller. The function of the FUZZY Logic controller is to maintain the system stability under transient conditions. This is done by comparing a part of the output voltage with a reference voltage V_{ref}. The output of the error signal is given into a FUZZY Logic controller. The FUZZY Logic controller produce corresponding error signal and it is then given into a PWM converter. The PWM converter produces the corresponding PWM signals and is then given to gates of the switches. The switches will turned on and off with respect to the gate signal given to the system.

DESIGN OF THE PROPOSED CONVERTER

The load regulation of the converter is taken as 2kW. Although the design is developed for 2kW rating, the control circuit remains more or less the same for output ranging from 50 W to 5kW.

1. Specifications:

Determinations of the operating requirements for the hardware design are

P_{out} (max):2kW
V_{input} range: 70V
Line frequency f_L: 50 kHz
Output voltage V_{out}: 380 VDC

2. Selection of switching frequency (f_s):

The switching frequency of the system must be high enough to minimize the size of power circuit and reduce distortion. On the other hand it should be less for greater efficiency. Compromising between the two factors the value is selected as 50 KHz.

3. Selection of resonant frequency (f_r):

The resonant frequency must be designed to reduce the total switching loss of the systems. In the below resonant condition both switch turn-off current and diode *di/dt* are smaller. Therefore, the resonant frequency can be determined by

$f_r \geq f_s /2D_{eff}$
$f_r = 50x10^3/(2x0.63) = 39.68$ kHz = 40 kHz

A. Input current.

$P_{input} = P_{out}$ (max)
$I_{pk} = P/ V_{input}= 2x10^3/70=28.571$ A

B. Ripple current.

Ripple current is usually assumed to about 30% of the peak inductor current.
$I' = 0.3 \text{ x } I_{pk}= 0.3x28.57=8.57$ A peak to peak

C. Determination of the duty cycle of the system

$V_o = (2V_{in} / (1\text{-}D))\text{-}\Delta V_o$
ΔV_o=5% of the output voltage
$D=1\text{-}(2V_{input}/ (V_o+\Delta V_o))$
$= 1\text{-}(2x70/ (380+19))=0.649$

D. To determine the effective duty ratio of the system

$V_o = (2V_{in} / (1\text{-}D_{eff}))$
$D_{eff} = 1\text{-}(2 V_{in} / V_o)=1\text{-}(2x70/380)=0.63$

E. To determine the output current

$I_o=P_{out}/V_o= 2000/380=5.263A$

5. To determine the **input inductor**
$L_f=DxV_{in}/2\Delta I_{in} f_s=(0.64x70)/(2x8.571x50x10^3)$
$=52.27\mu H =50\mu H$
In the practical case input inductor is chosen as 50μH.

6. To determine the value of **auxiliary resonant inductor and auxiliary resonant capacitor.** Auxiliary inductor is assumed to be $L_r \geq 6\mu H$. Resonant frequency $f_r =1/2\pi\sqrt{L_r x C_r}$
Auxiliary capacitor $C_r =1/4\pi^2 x(40x10^3)^2 x6x10^{-6}$
$=2.64x10^{-6}=2.7\mu F$.

7. Selection of **output resistor** with output current value, and output voltage. $R = (P_{out}/ Io^2) = (2000/5.263^2) = 72.2\Omega$

8. PARAMETERS FOR SIMULATION

Parameters	**Design values**
Input voltage	70V
Output voltage	380V
Switching frequency	50KHz
Input inductance	50µH
Auxiliary capacitance	2.7µF
Auxiliary resonant inductor	6µH
Output current	5.45A
Power	2 kW
Output Resistance	72Ω

Table 1 Parameters for circuit design

8. FUZZY LOGIC CONTROLLER DESIGN

The block diagram of fuzzy logic controller (FLC) is shown in fig.4. It consists of three main blocks: fuzzification, inference engine and defuzzification. The two FLC input variables are the error e and change in error e*. Depending on membership functions and the rules FLC operates.

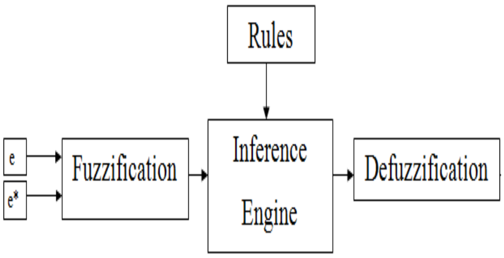


Fig 4:Block Diagram of Fuzzy logic controller

A. Fuzzification

The membership function values are assigned to the linguistic variables using seventeen fuzzy subsets. Table-2 shows the rules of FLC. E and E* are input variables, where E is the error between the reference and actual voltage of the system, E* is the change in error in the sampling interval.

E* E	NE	ZE	PE
NE	NE	NE	NE
ZE	NE	ZE	PE
PE	PE	PE	PE

TABLE 2: RULE TABLE FOR FLC

B. Inference Engine

Mamdani method is used with Max-Min operation fuzzy combination. Fuzzy inference is based on fuzzy rules. Rules are framed in inference engine block. The output membership function of each rule is given by MIN (Minimum) operator and MAX (Maximum) operator.

C. Defuzzification

The output of fuzzy controller is a fuzzy subset. As the actual system requires a non fuzzy value of Control, defuzzication is required. Defuzzifier is used to convert the linguistic fuzzy sets back into actual value

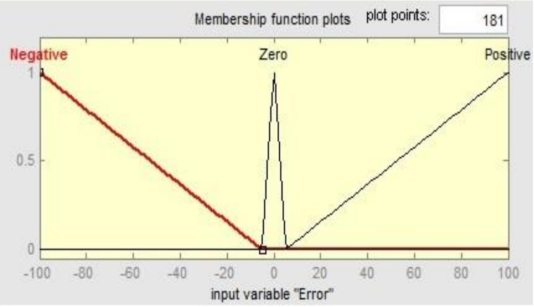


Fig:5 Membership Functions of Error (e)

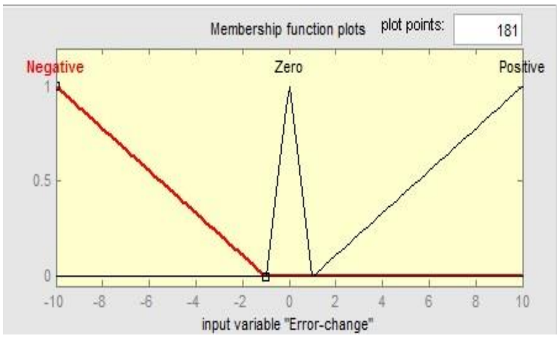


Fig:6 Membership Functions of Change in Error(e*)

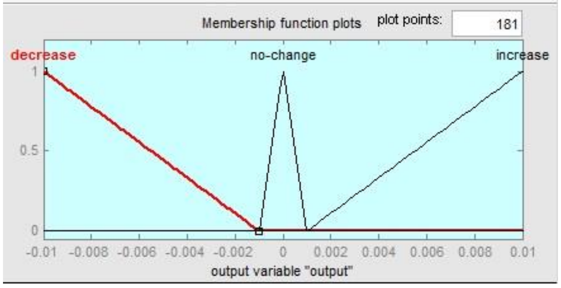


Fig:7: Membership Function of Duty Cycle

V.SIMULATION RESULTS

The simulation result of the system is as shown below.

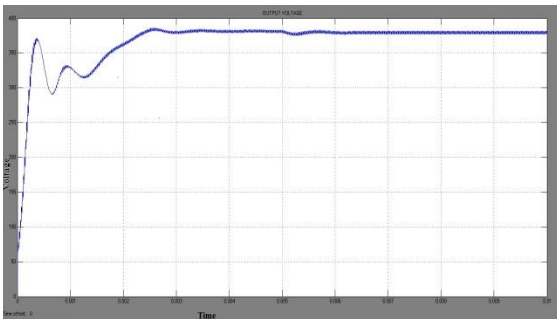


Fig:8 Output voltage wave form of the existing system

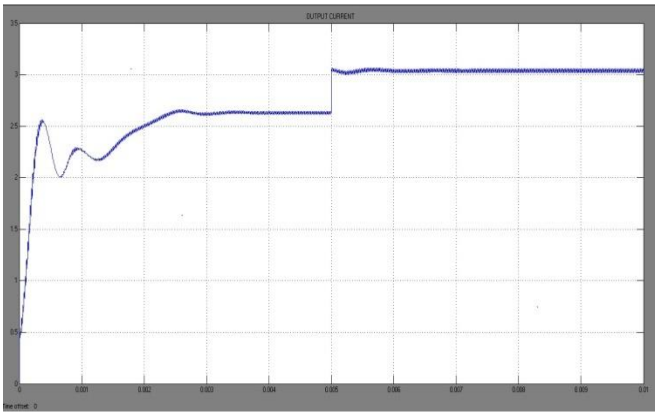


Fig:8 Output current wave form of the existing system

VI. CONCUSION

A DC-DC converter for high step up and high power applications is proposed. From the simulation results it is observed that ZVS turn on and ZCS turn off of all the switches is obtained. The voltage stress across the switches is much lesser. The Capacitor size and inductor size are reduced in the proposed topology by adapting proper switching scheme. The output voltage ripple can be reduced to 5%. The closed loop control adjusted the duty ratio of the system. The closed loop control limits the output voltage disturbances in particular limits.

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