

Optimization and Closed Loop Control of Soft Switched Boost Converter with Flyback Snubber

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ABSTRACT

This paper presents a boost converter with flyback snubber which makes use of soft switching features, such as Zero Voltage Switching and Zero Current Switching. Initially, a conventional boost converter has been simulated and its output is compared with that of the proposed converter. It has been found that the switching loss of the boost converter with flyback snubber is much reduced in comparison to that of the conventional converter due to the implementation of soft switching features. Generally, closed loop control system is an important section in many process control stations. But the use of conventional converters gives poor performance in terms of peak overshoot, rise time and settling time. For a closed loop system having a PI controller and the proposed converter, the response obtained has less settling time and rise time but contains peak overshoot. So, to reduce the peak overshoot the gain values of the PI controller are first optimized using genetic algorithm.

General Terms

Boost converter, soft switching, closed loop control, optimization

Keywords

Flyback Snubber, Zero Voltage Switching, Zero Current Switching, PI Controller, Genetic Algorithm

1. INTRODUCTION

Renewable energy sources are the best choice in the current scenario where there is shortage of power and the need to generate clean and pollution free energy. The energy obtained from these sources must be stepped up to meet the load demand. Boost converter is the most commonly used dc-dc converter to achieve this purpose. This converter is used in various applications such as hybrid electric vehicles and lighting systems. But conventional boost converters have many limitations that include high switching losses, component stress, less reliability and high electromagnetic interference. Hence soft switching technique has been implemented in this thesis. Soft switching feature includes Zero Voltage Switching and Zero Current Switching. ZVS and ZCS can be attained by using snubber circuits. There are two types of snubber circuits active and passive.

Passive snubber circuit is used in most of the boost converter applications because it does not require many components and can achieve soft switching features without complex control. This circuit mainly includes resistors, inductors capacitors and diodes. The passive lossless snubber cell and its dual structure used for reducing the switching loss described in [2] provides zero current switching and zero voltage switching conditions for turning on and off, respectively, for the switch over a wide load range. It does not introduce extra voltage stress on the

switch. By taking the ripple current through the switch into account, the peak switch current during the snubber resonance period is designed to be less than the designed switch current without the snubber. Hence, this snubber does not introduce extra current stress on the switch but it induces extra voltage stress on the main switch at turn off transition which would increase switching loss. Thus, a snubber capacitor is required to absorb the energy stored in the snubber inductor and to clamp the switch voltage. However, for saving component count, the energy stored in the snubber capacitor is recycled through the main switch, resulting in high current stress which would deteriorate converter reliability and life span.

A new active snubber cell to contrive a new family of pulse width modulated (PWM) converters has been described in [3]. This snubber cell provides zero voltage transition (ZVT) turn on and zero current transition (ZCT) turn off together for the main switch of a converter. Also, the snubber cell has been implemented by using only one quasi resonant circuit without an important increase in the cost and complexity of the converter. However, in the active snubber, its auxiliary switch needs to sustain at least the same current rating as that of the main switch because the input inductor current flows through the auxiliary switch during the main switch turn off transition, reducing efficiency and reliability. It can improve high turn off loss and achieve near ZCS turn off and ZVS turn on soft-switching features for the main switch. But, its input and resonant currents will flow through the active snubber, resulting in high current stress on the auxiliary switch.

Because of the disadvantages of active and passive snubbers, flyback snubber is used. This snubber helps in reducing the switching losses by turning on the main switch at zero voltage and turning it off at zero current. When employed in a closed loop having a PI controller, the response has peak overshoot. In order to reduce the peak overshoot the gain values of PI controller must be optimized. For this purpose genetic algorithm has been implemented. The response obtained by using the optimized values has very low peak overshoot, settling time and rise time.

2. CONVENTIONAL BOOST CONVERTER

The conventional boost converter is given in figure 1. Due to the reverse recovery current of diode D, high current stress will occur when the main switch is turned on. On the other hand, when the switch is turned off, high voltage stress will be imposed on the main switch caused by input voltage V_s , finite forward recovery time of D, and the ringing between parasitic devices. These will result in turn-ON and turn-OFF switching losses, as shown in areas A and B of figure 2, respectively, and deterioration in conversion efficiency and reliability.

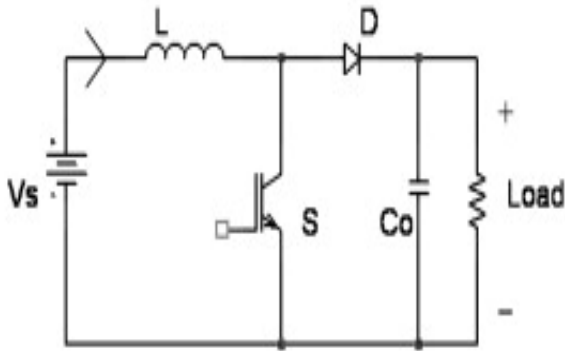


Fig 1: Conventional Boost Converter

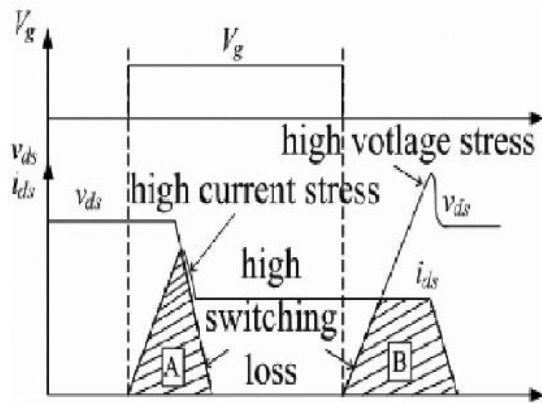


Fig 2: Gate Signal, Voltage and Current Waveforms

The disadvantages of using conventional converters are high component stresses, high switching loss across the main switch, electromagnetic interference due to high di/dt and dv/dt of the switch and low reliability. Higher switching frequency is used in most of the application for the following reasons:-

- By using Pulse Width Modulation (PWM), the waveform will be close to the expected waveform.
- Harmonics can be filtered out easily.
- The volume and weight of the circuit is reduced.
- It gives faster response.

But there are various limitations for higher switching frequency

- It leads to higher power loss on semiconductor devices since power loss is equal to the product of frequency and energy loss at each switching.
- It produces severe Electromagnetic Interference (EMI).

So, in order to avoid the above mentioned problems, soft switching is used. Soft switching can be achieved by using snubber circuits. Snubbers enhance the performance of the switching circuits and result in higher reliability, higher efficiency, higher switching frequency, smaller size, lower weight, and lower EMI. The snubber circuit discussed in this paper is the flyback snubber.

Flyback topologies operate by storing energy in the transformer during the power switch on-time and transferring this energy to the output during the off-time. The flyback circuit used in this thesis produces a short time interval for zero voltage and zero current transition during which the main switch is turned on and turned off respectively, thus reducing the switching losses. The flyback snubber consists of snubber

capacitor C_s , buffer capacitor C_b , four diodes, transformer T_f , inductor L_{mf} and auxiliary switch S_a . Due to the resonance produced by the inductor and capacitors, ZVS and ZCS can be attained.

3. PROPOSED BOOST CONVERTER WITH FLYBACK SNUBBER

The boost converter with flyback snubber mainly consists of main switch S_m , transformer, an auxiliary switch, inductors L_m and L_s and snubber circuit [1]. This snubber can also be used for other dc-dc converters. Figures 3 shows the boost converter with flyback snubber.

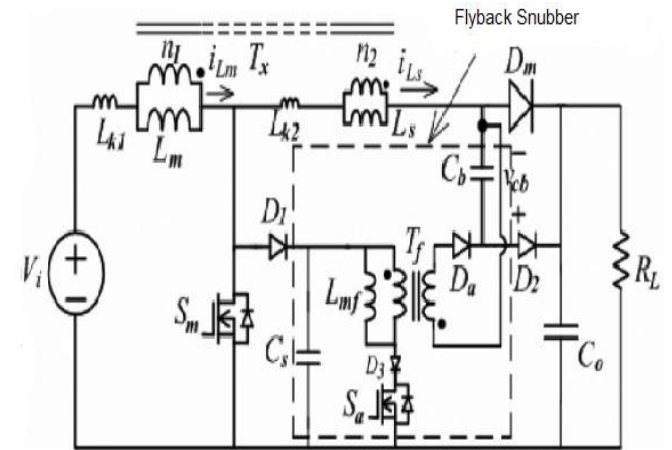


Fig 3: Proposed boost converter with flyback snubber

ZCS for the main switch can be achieved using the diode D_1 and capacitor C_s . The energy stored in capacitor C_s does not circulate through main switch S_m but it is transferred to C_b through the flyback snubber, which is operated in discontinuous conduction mode (DCM) to reduce switching loss and voltage stress. Buffer capacitor C_b stores the energy from C_s and the stored energy is released to the output through diode D_2 . The capacitor C_b not only buffers the energy transferred from C_s , but also reduces the voltage stress on S_m at turn off transition.

The operation of the proposed converter can be divided into 9 modes from t_0 - t_9 [1]. At the instant t_0 , both the main switch and the auxiliary switch are turned on. Now, the capacitor C_s and inductor L_{mf} form the resonant circuit. Current $I_{cs}(t)$ and voltage $V_{cs}(t)$ can be expressed as follows:

$$I_{cs}(t) = \frac{V_{cs}(t_0)}{Z_o} \sin \omega_0 (t - t_0) \quad \dots (1)$$

$$V_{cs}(t) = V_{cs}(t_0) \cos \omega_0 (t - t_0) \quad \dots (2)$$

where the resonant frequency and the characteristic impedance are expressed as follows:

$$\omega_0 = \frac{1}{\sqrt{L_{mf} * C_s}} \quad \dots (3)$$

$$Z_o = \sqrt{\frac{L_{mf}}{C_s}} \quad \dots (4)$$

The reverse recovery current of the diode D_m is limited by the leakage inductance of the snubber inductor L_s during the time t_1 to t_2 . When auxiliary switch S_a is turned off at t_3 , the energy stored in inductance L_{mf} starts to transfer to buffer capacitor C_b through D_a . During the interval t_3 to t_4 , both magnetizing inductance L_{mf} and buffer capacitor C_b are in resonant manner. Current $I_{cb}(t)$ and voltage $V_{cb}(t)$ can be derived as follows:

$$I_{cb}(t) = I_{lmf}(t_3) \cos(\omega_3 - t_3) + \frac{V_{lmf}}{Z_3} \sin\omega_3(t - t_3) \quad \dots (5)$$

$$V_{cb}(t) = Z_3 I_{lmf}(t_3) \sin\omega_3(t - t_3) - V_{lmf} \cos\omega_3(t - t_3) \quad \dots (6)$$

where $I_{lmf}(t_3)$ is the initial current of magnetizing inductance L_{mf} at t_3 . The energy stored in magnetizing inductance L_{mf} is completely transferred to capacitor C_b at t_4 .

When mode t_5 - t_6 begins the main switch S_m is turned off, and the snubber capacitor C_s is charged until its voltage is satisfied with the relationship shown by the following equation:

$$V_{cs}(t_6) + V_{cb}(t_6) = V_o \quad \dots (7)$$

At time t_7 , current I_{Ls} is equal to current I_{Lm} . Meanwhile, the voltage of the main switch S_m and capacitor C_s will reach the maximum value simultaneously. A near ZCS feature is therefore attained during t_5 - t_7 . In this mode, snubber capacitor C_s , equivalent inductance L_x , and buffer capacitor C_b are in resonance.

Before t_8 , the energy stored in buffer capacitor C_b was not completely drained out; thus, the capacitor will not stop discharging until its voltage drops to zero. The energy stored in capacitor C_s is given by:

$$W_{cs} = \frac{1}{2} C_s V_{cs}^2(t_7) \quad \dots (8)$$

Based on the energy stored in capacitor C_s , the power rating P_f of the flyback snubber can be determined as follows:

$$P_f = W_{cs} * f_s \quad \dots (9)$$

where, f_s is the switching frequency.

When the energy stored in C_b has been completely released to the output at t_8 , diode D_m will conduct. In this interval, the voltage across the main switch will drop back to around output voltage V_o . The switching cycle will end at t_9 . The key current and voltage waveforms are shown in figure 4.

To analyze the boost converter with a flyback active snubber, the following assumptions based on one switching cycle of the steady-state operation are made.

- 1) Both input voltage V_i and output voltage V_o are constant over one switching cycle.
- 2) Initial value of snubber inductor L_s and capacitor C_s are equal to zero.
- 3) Capacitance of C_s is much greater than parasitic capacitance of the main switch; thus, parasitic capacitance can be ignored.
- 4) The efficiency of the flyback active snubber is 100%.

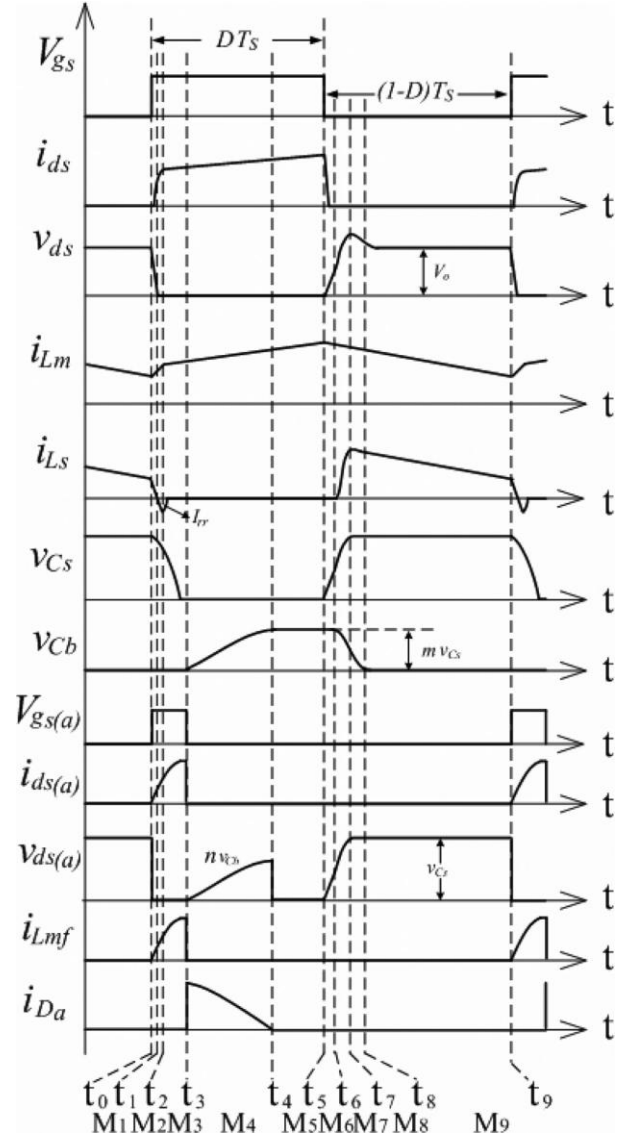


Fig 4: Key current and voltage waveforms of the proposed converter

3.1 Closed Loop Control Using Conventional PI Controller

The PI controller enhances the performance of the soft switched boost converters. The duty cycle of the boost converter is controlled by PI controller. The conventional PI controllers for such converters are designed under the worst case condition of maximum load and minimum line condition. As power electronic converters are nonlinear, and also are prone to variations in its operating states over a wide range, the conventional PI controllers are to be designed to provide optimal performance as the operating point changes. To provide optimal performance at all operating conditions of the system PI controller is developed to control the duty cycle of the boost converter. The block diagram of closed loop system is given in figure 5. For obtaining better control performance fuzzy gain scheduling can also be used to adjust the gain values. The block diagram can be modified accordingly.

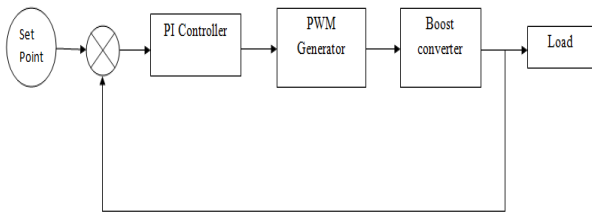


Fig 5: Block diagram of closed loop control for boost converter with flyback snubber

The output of the boost converter with flyback snubber is compared with the set point and the error calculated is given as input to the PI controller. This controller produces the error voltage based on the following equation:

$$V_e = K_p e + K_i \int e dt \quad \dots (10)$$

The control signal produced by the PI controller is used to generate the pulses of varying width so as to obtain the desired output voltage. Even though there might be changes in load requirement, the closed loop control has the ability to attain the set point value due to the controlling action of the PI controller.

3.2 Optimization of Gain Values of PI Controller Using Genetic Algorithm

Genetic Algorithm [8] provides an adaptive searching mechanism inspired on Darwin's principle of reproduction and survival of the fittest. The individuals (solutions) in a population are represented by chromosomes; each of them is associated to a fitness value (problem evaluation). The chromosomes are subjected to an evolutionary process which takes several cycles. Basic operations are selection, reproduction, crossover and mutation. Parent selection gives more reproductive chances to the fittest individuals. During crossover some reproduced individuals cross and exchange their genetic characteristics. Mutations may occur in a small percentage and cause a random change in the genetic material, thus contributing to introduce variety in the population. The evolution process guides the genetic algorithm through more promising regions in the search space. Some of the advantages of using genetic algorithms are: it is a global search technique, can be applied to the optimization of ill-structured problems and do not require a precise mathematical formulation for the problem. Besides, genetic algorithms are robust, applicable to a number of problems and efficient, in the sense that either a suboptimal or optimal solution may be found within reasonable time.

The genetic algorithm starts with no knowledge of the correct solution and depends entirely on responses from its environment and evolution operators (i.e. reproduction, crossover and mutation) to arrive at the best solution [9]. By starting at several independent points and searching in parallel, the algorithm avoids local minima and converging to sub optimal. A genetic algorithm is typically initialized with a random population consisting of between 20-100 individuals. This population (mating pool) is usually represented by a real-valued number or a binary string called a chromosome. How well an individual performs a task is measured as assessed by the objective function. The objective function assigns each individual a corresponding number called its fitness. The

fitness of each chromosome is assessed and a survival of the fittest strategy is applied.

Since the objective is to minimize the error between the set point (desired output) and the plant output (actual output), the fitness function used here can be defined as:

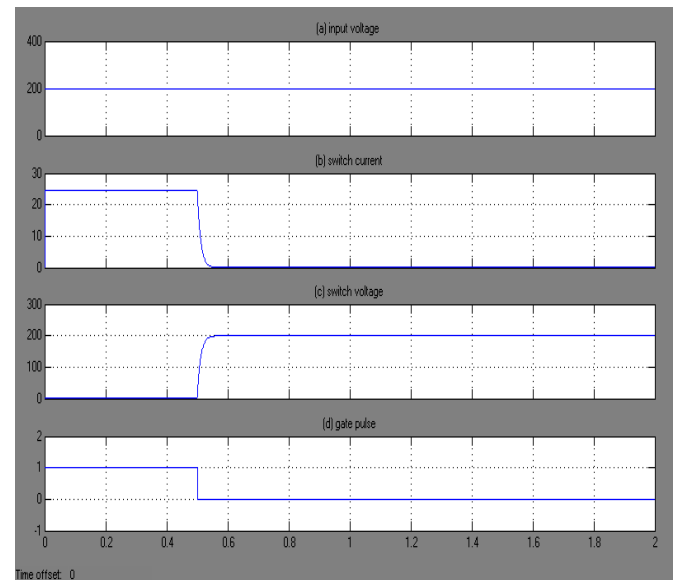
$$\text{Fitness} = \sum (\text{Desired Output} - \text{Actual Output})^2 \quad \dots (11)$$

The observation interval is divided into n points, or samples; the error for each sample is calculated and entered into (11), which gives the sum of all errors squared as a result. The minimization of (11), performed by the Genetic Algorithm by adjusting the PI gains, will ensure that the actual output is as close as possible to the desired one. The optimized values of k_p and k_i obtained through this method can then be used to generate the control signal. The final response obtained has reduced peak overshoot.

4. SIMULATION RESULTS AND DISCUSSION

The conventional and proposed boost converter models have been simulated using MATLAB 7.10.0 (R2010a). With the help of the waveforms obtained through simulation, the switching loss for both conventional and proposed converter has been compared. Moreover, the closed loop control for boost converter with flyback snubber has also been designed and simulated.

Figure 6 gives the voltage across the main switch and the current flowing through the main switch of conventional boost converter. It can be seen that during turn off time the current decreases and voltage increases gradually, which gives rise to the switching loss.



**Fig 6: (a) Input voltage
(b) Current through the switch
(c) Voltage across the switch
(d) Gate pulse**

Figure 7 shows the simulink model of boost converter with flyback snubber. It mainly consists of the main switch S_m , transformer, flyback snubber and snubber inductor L_s .

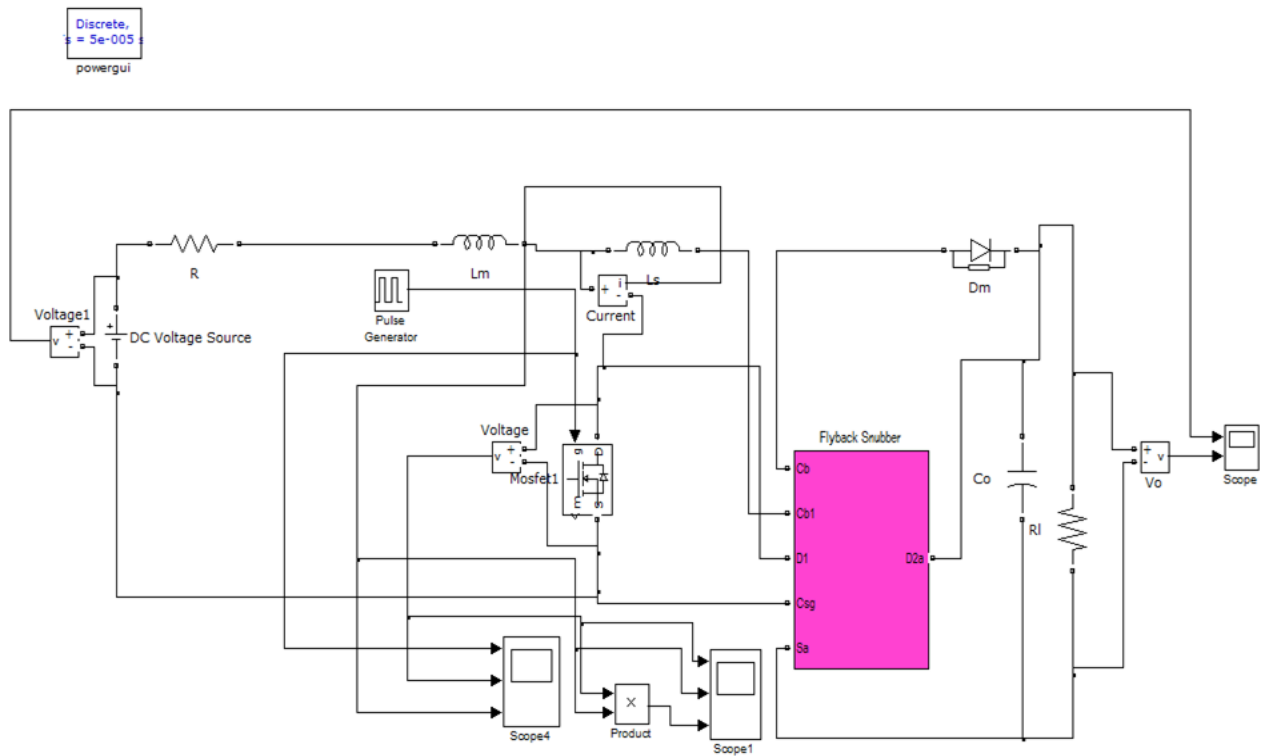


Figure 7 Simulink model of Proposed Boost Converter with Flyback Snubber

Figure 8 shows the subsystem model. The flyback snubber consists of an auxiliary switch, diodes, capacitors, an inductor and a transformer which help to achieve ZVS and ZCS. The transformer stores energy when the main switch is on and delivers the stored energy to the output when the main switch is off. Pulse is given to the auxiliary switch such that it has turn off time lesser than that of the main switch. When the auxiliary switch is turned off, the energy stored in the inductor is transferred to the buffer capacitor. The energy stored in the buffer capacitor is later transferred to the output.

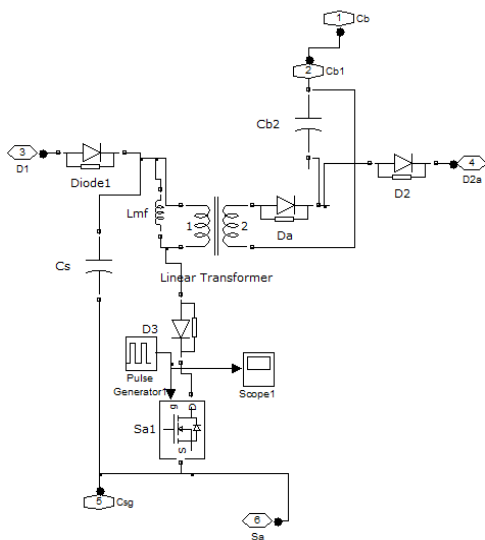


Fig 8: Subsystem - Flyback Snubber

The input voltage given to the proposed converter is 200 V, for which it gives an output voltage of 360 V. The input and output voltage waveform for the proposed converter is shown in figure 9.

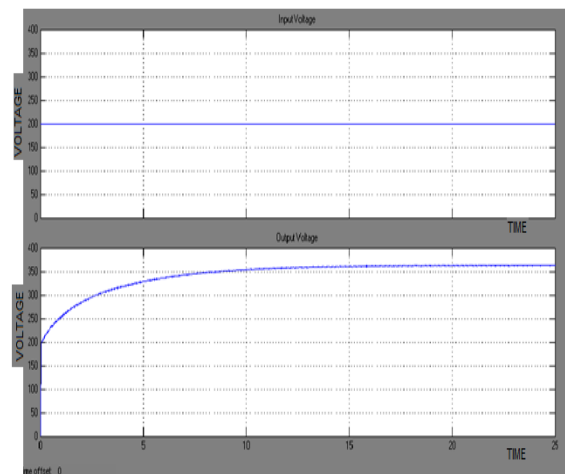


Fig 9: Input and output voltage for proposed converter

For open loop system, the output voltage has the following characteristics:-

- Rise time, $t_r = 4$ seconds
- Settling time, $t_s = 15$ seconds

The specifications for different elements used in simulation is given in the following table:

Table 1. Specifications

Parameter	Values
Input voltage, V_i	200 V
Input Current, I	25 A
Main Inductor, L_m	1.2 mH
Capacitor, C_o	470 μ F
Snubber Inductance, L_s	2.5 μ H
Inductance, L_{mf}	1 mH
Snubber Capacitance, C_s	22 nF
Buffer Capacitor, C_b	47 nF
Switching frequency, f_s	20 KHz

Due to the ZVS and ZCS, during turn on and turn off the voltage decreases and current increases instantaneously as shown in figure 10. The current through the main switch is nearly 23 V. Similarly, during turn off the voltage increases and current decreases instantaneously. Due to these features the switching loss has been much reduced in the proposed converter

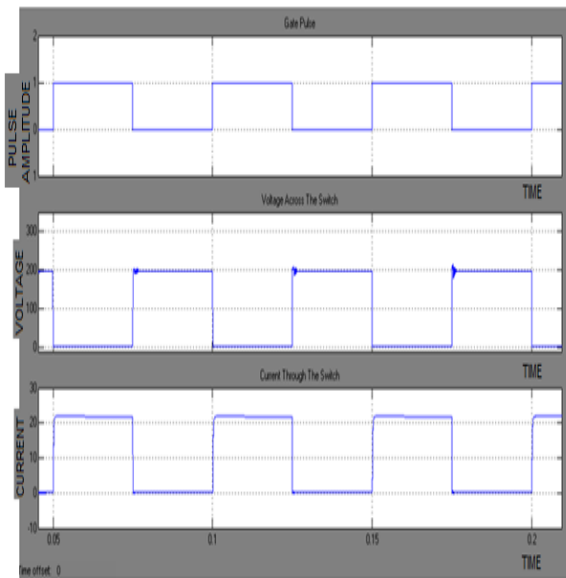


Fig 10: Current and voltage across the switch during T_{on} and T_{off}

4.1 Switching Loss In Conventional And Proposed Converter

Figures 11 and 12 show the switching loss in conventional and proposed converters respectively.

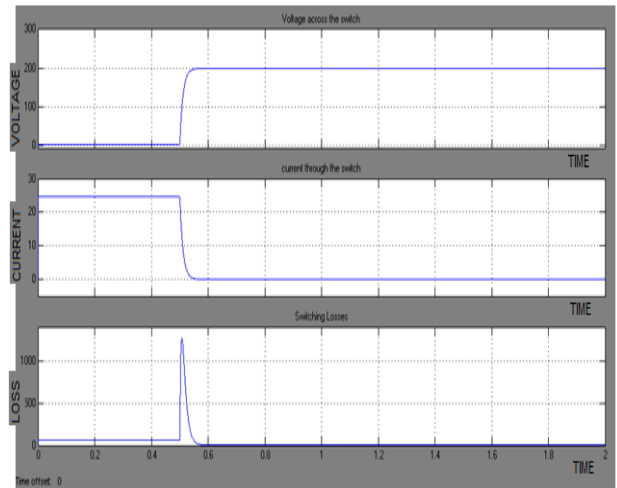


Fig 11: Switching loss in conventional converter

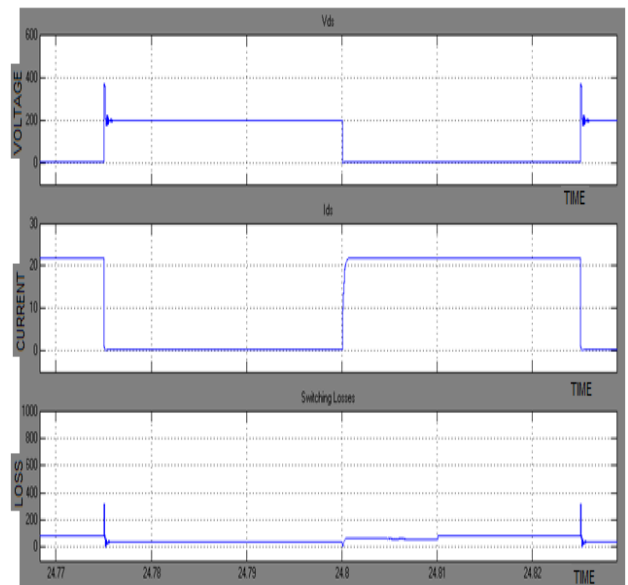


Fig 12: Switching loss in proposed converter

It can be seen from figure 11 that the switching loss for conventional converter at time $t = 0.5$ seconds is 1300 W, while from figure 12, the switching loss for boost converter with flyback snubber at $t = 24.775$ seconds is 300 W. Thus the efficiency of the proposed converter is improved due to the reduction of switching loss due to which, it can be used for high power applications.

4.2 Closed Loop Control For Boost Converter With Flyback Snubber

In order to reduce the settling time, rise time and to obtain an output voltage without oscillations, closed loop control for the proposed converter has been implemented. The controller used here is the PI controller. The output of the proposed converter is compared with that of the reference value which is set at 360 V. The error computed is given to the PI controller and it produces the control signal. Using PWM technique the pulse is generated and given to the main switch

of the proposed converter. For closed loop control, the same specification is used as given in table 1. The value for K_p is taken as 3 and the value for K_i is taken as 4 through trial and error method. The output response is shown in figure 13.

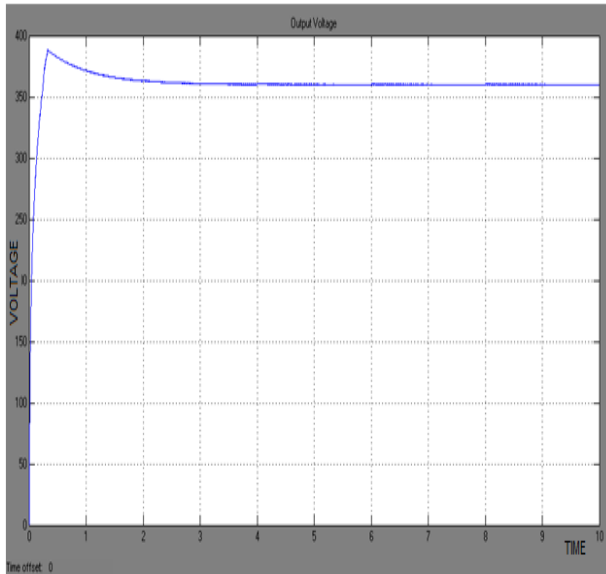


Fig 13: Output Voltage of Proposed Converter with Closed Loop Control

The final response obtained after implementation of closed loop control contains reduced rise time and settling time but has a peak overshoot of 25 V. In order to reduce this, the gain values of PI controller must be optimized. Genetic Algorithm is used as the optimization technique here.

4.3 Closed Loop Control With Optimized Gain Values Of PI Controller using GA

By setting the population size as 20, the generation as 5, population range from 0.01 to 12, mutation rate as 0.6% the process output obtained is shown in figure 14.

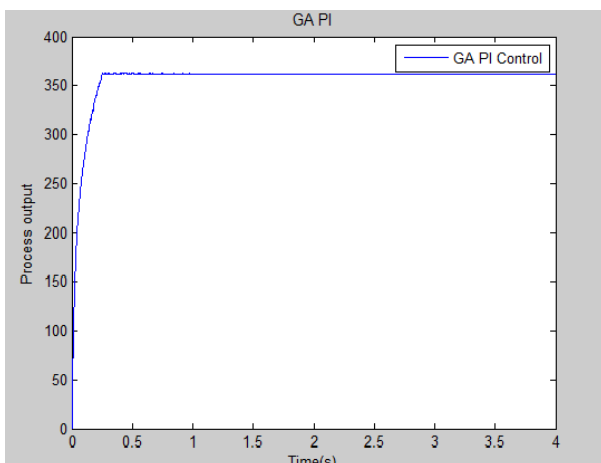


Fig 14: Output voltage of proposed converter using optimized values of K_p , K_i in closed loop control

By the use of optimized values for PI controller, it is found

that the peak overshoot has been much reduced and is nearly equal to zero. $K_p=10.8$ and $K_i=1.17$

5. CONCLUSION

In this paper, the boost converter with flyback snubber has been simulated and it is found that the switching loss for the proposed converter is much reduced by the use of soft switching techniques such as ZVS and ZCS, when compared to conventional boost converter. Moreover, the implementation of closed loop control with optimized gain values of PI controller yields an output voltage without oscillations, low peak overshoot and rise time. The boost converter with the flyback snubber is relatively suitable for high power applications and it can be integrated with other PWM converters to achieve soft-switching feature and low component stress. In order to obtain better control performance and attain an output with reduced peak overshoot, high set point tracking performance, fuzzy gain scheduling technique for PI controller can be incorporated in the closed loop system.

6. ACKNOWLEDGMENT

It gives me immense pleasure in expressing my sincere and deep sense of gratitude to **Dr. V. LAKSHMI PRABHA, M.E., Ph.D.**, Principal, Government College of Technology for the facility made available for the progress and completion of my thesis.

I am thankful to **Dr. M. RAJARAM, M.E., Ph.D.**, Professor and Head, Department of Electrical Engineering, for the permission and encouragement accorded to carry out this thesis work.

I would specially like to express my deep sense of gratitude and sincere thanks to my guide, **Prof. K. YASODA, M.E.**, Assistant Professor, Department of Electrical Engineering for her constant support, encouragement and motivation over the entire period of my thesis. Her suggestions and discussions helped me a lot more than anything, because of which the thesis has become a success.

I am also indebted to my parents for their encouragement, love and concern. Above all, I thank the almighty God for His gracious blessings for the completion of my thesis.

7. REFERENCES

- [1] Tsai-Fu Wu, Yong-Dong Chang, Chih-Hao Chang, and Jeng-Gung Yang, 2012 "Soft-Switching Boost Converter With a Flyback Snubber for High Power Application", IEEE Transactions On Power Electronics, VOL. 27, NO. 3.
- [2] Li, R.T.H., Chung, H.S.H., 2010, "A passive lossless snubber cell with minimum stress and wide soft-switching range," IEEE Trans. Power Electron., 25, No. 7, pp. 1725–1738
- [3] Aksoy, I., Bodur, H., Bakan, A.F. 2010, "A new ZVT-ZCT-PWM DC-DC converter", IEEE Trans. Power Electron., 25, No. 8, pp. 2093–2105.
- [4] Oliveira Stein, C. M., Hey, H. L., 2000, "A true ZCZVT commutation cell for PWM converters," IEEE Trans. Power Electron., 15, No. 1, pp. 185–193.
- [5] Das, P., Moschopoulos, G., 2007, "A comparative study of zero-current transition PWM converters," IEEE Trans. Ind. Electron., 54, No. 3, pp.1319–1328.
- [6] Oliveira Stein, C. M., Grundling, H. A., Pinheiro, H., Pinheiro, J. R., Hey, H. L., 2004, "Zero Current and

Zero-Voltage soft-transition commutation cell for PWM inverters," IEEE Trans. Power Electron., 19, No. 2, pp. 396–403.

- [7] Wu, T.F., Chen, Y.C., Yang, J.G., Kuo, C.L., 2010, "Isolated bidirectional full-bridge DC–DC converter with a flyback snubber," IEEE Trans. Power Electron., 25, No. 7, pp. 1915–1922
- [8] Davis L., Handbook of Genetic Algorithms, VNR Comp. Library, 1990
- [9] Tulafeh R.J., 2010 "Genetic Algorithms based optimization design of tuning a PID controller" Al-Qadisiya Journal For Engineering Sciences, Vol. 3 No. 3

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