DESIGN OF DIGITAL CONTROLLER FOR SOFT SWITCHED BOOST CONVERTER

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ABSTRACT

In this paper, a new digital controller is designed for soft switched high voltage gain boost converter. This high voltage gain boost converter utilize the L_r –C_r resonance in the auxiliary circuit to achieve soft switching technique. The soft switched technique allows the ZVS turn on of active switch and ZCS turn off of diodes.
Further, control-to-output z domain transfer function is formulated using system identification toolbox of MATLAB. Next, loop gain is also defined according to which designing of digital controller is done. Pole-zero placement technique is used to find out the required digital controller.

Keywords-soft switching, control-to-output transfer function, digital controller, high voltage gain boost converter.

1. INTRODUCTION

In the field of power electronics, main concern is to deal with the processing of the electrical power using electronic devices. The switching converter is the key element in power electronics. In a DC-DC converter, the dc input voltage is converter to a dc output voltage which might have smaller or larger magnitude, may have opposite polarity or with isolation of the input and output ground references[1].

In the switched mode DC-DC converters there exists a class of power circuits which are used to regulate the input signals and meet the load demand. They are classified into
(i) buck, (ii) boost and (iii) buck boost topologies,etc. Due to their features in terms of size, efficiency and reliable operation, they have find a wide range of applications such as battery charging, DC motor drive, personal computers, telecommunication industry, automotive industry, welding machine and power supply applications.

DC-DC boost converter is one of the most popular converter for delivering large output voltage at load from a low voltage source [2]. Although, the conventional boost converter is capable enough of stepping up of voltages and meeting the load demands. But due to higher switching losses, the full load efficiency of conventional boost converter is low.

A continuous conduction mode is chosen for boost converter with a continuous input current. The advantage of continuous current is that it simplifies the input filter stage. Generally, conventional boost converter functions at high duty cycle to generate high output voltage resulting in electromagnetic problems and high switching losses. Soft switching technique are introduced in literature to reduce excessive switching losses in order to realize higher efficiencies for the dc-dc converters. Such soft switching technique is reported in the literature[3]-[4]. In recent times, high frequency switching converter applications are in major demands. The significant advantages of high frequency switching converter is to reduce switching losses, high voltage conversion ratio, high power density, reducing electromagnetic interference high efficiency and to reduce the size and weight of the electronic components.

Traditionally, the output voltage of DC-DC converter can be regulated through the use of analog controller with the help of analog circuits [5]. By the use of hardware modification controller gains or algorithms can be changed in an analog controller. This technique is time consuming and expensive. Also the implementation is nearly impossible in analog circuits [6]. On the other hand, digital controller has many advantages over analog controller. The digital controller is implemented using digital processor. The various advantages over analog controller include reduced susceptibility to environment changes, ability to implement complicated control algorithms and adaptability and etc. In switching mode power converter, the main work of controller established is to drive the main switching devices like IGBT and MOSFET with a duty cycle, the ratio on time/switching period, such that dc component of the output voltage is equal to is reference [5]. In recent times, there has been a strong desire to establish digital controllers for high frequency conversion systems and dc –dc converters. Digital controllers are established through recent advances in microcontrollers/digital signal processors implementing complex control strategies [7].

2. BASIC IDEA OF SOFT SWITCHING

A semiconductor device is said to be soft switched when the circuit topology is able to establish the zero difference in the voltage potential across a switch and zero current flow through a switch before and during the instant of a switch on/off.

Resonant and quasi-resonant converters incorporate switches which turn on and/or off during zero-voltage and/or zero current condition resulting in soft switching.

Many soft switching techniques have been published to minimize the switching losses.

3. ANALYSIS OF SOFT SWITCHED BOOST CONVERTER

The circuit consists of a main circuit and an auxiliary circuit. The boost converter is the main circuit. In the conventional boost converter the rectifier diode is replaced by the upper switch S_2. The output is regulated by the asymmetrical complementary switching operation of the lower switch S_1 and the upper switch S_2. The inductor L_2 , two diodes D_1 and D_2 and two capacitor C_1 and C_2 form the auxiliary circuit. The output voltage of the converter is formed by the combination of the C_2 connected on the top of the output capacitor C_3. The function of the auxiliary circuit is to enhance the output voltage of the converter. Also it helps to achieve the ZVS turn on of active switches S_1 and S_2. The auxiliary circuit resonance reduces the turn off current of switches, unlike the PWM method in which there exists high peak current during turning off switches.

The soft switched boost converter undergoes six operating modes in one PWM cycle and the conducting device in each mode operates as follows: (a) mode-I : D-ON, (b) mode-II : $S_{1,}$ S_2 and D are in ON state, (c) mode-III : S_1 and S_2 are in ON state with L_r-C_r are resonating, (d) mode-IV : $S_{1\,,}$ $S_{2\,,}$ D_1 and D_2 are in ON state, (e) D_1 and D_2 are in ON state with L_r-C_r are resonating, (f) D_1, D_2 and D are in ON state. Due to these, operating mode the key waveforms for soft switched boost converter obtained is as follows:

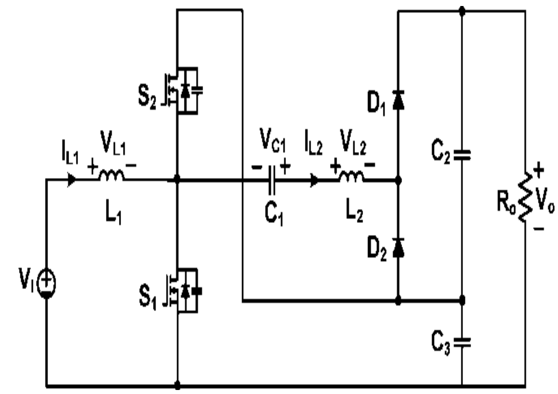

Fig 1: Soft switched boost converter

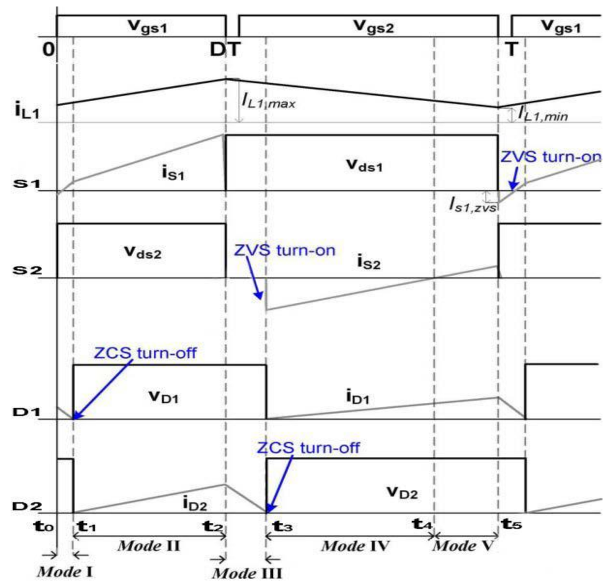

Fig 2: Key waveforms for soft switched boost converter

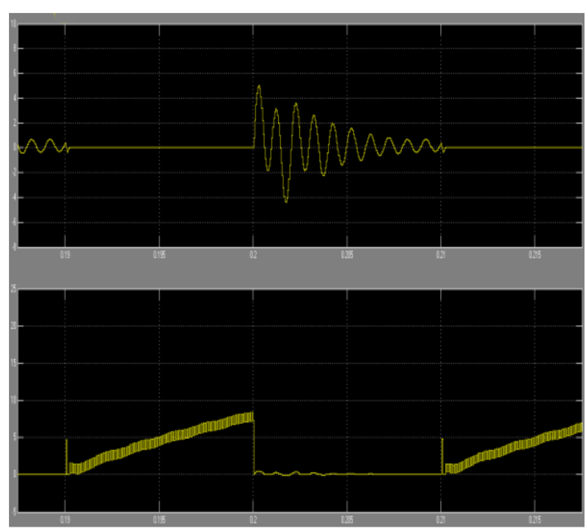
Fig 3: voltage and current waveform

The waveform shows the steady state behavior/operation of soft switching boost converter. The first graph shows the voltage with respect to time. The second graph shows the current with respect to time.

4. MODELING OF SOFT SWITCHED BOOST CONVERTER

For modeling soft switched boost converter system identification techniques are introduced in various previous studies which are utilized for modeling switched mode dc-dc converters[8]. Earlier, techniques utilizes Generalized state space averaging (GSSA) for modeling soft switched PWM DC-DC converters [9]. There are certain limitations associated with generalized state space averaging (GSSA). The resulting model has a very low accuracy, reason being that it assumes the variables of the resonant tank as variables of input control, instead of variables of state. In order to overcome the disadvantage of the GSSA, large number of harmonics are added. Due to this, the order of the model increases. The resultant model is tough to be mathematically analyzed.

The system identification has an edge over GSSA technique. The various advantages of system identification technique is as follows : (i)As long as, we are getting the satisfactory information about the data of a system, we need not to bother about the internal architecture of the circuit. (ii)This approach is very helpful in places where reduced order model are needed for complex power system. (iii)The most important application of this technique is at places where a circuit has many operating modes. This technique helps to find the duty cycle with respect to the each operating modes.

For modeling soft switched boost converter various system identification techniques tools are available. In this paper Box- Jenkins methodology [10] is utilized for generation of the discrete transfer function. The functioning of the box –jenkins methodology is explained has below. Firstly, the converter parameters are selected according to the design requirement. Then, using simulink platform soft switched boost converter is formulated. Further, for the given range of the perturbation of the predefined parameter, the response of the desired parameter is generated. The final transfer function generated is checked for its accuracy by the means of perturbation range, duty cycle and perturbing signal's sampling frequency. Controlled duty ratio range is the most important parameter for the converter discrete transfer function generation. For the given values of the source voltage and load resistance as given in the table below, a range for perturbation duty ratio control signal is selected. Next, this range is selected as a boundary limits. These limits are equally spaced with intermediate points having its step time equal to the sampling time are generated. This signal generate an equivalent duty ratio when compared with the triangular ramp. The generated equivalent duty ratio is used to control the switching devices of converter. Next, samples of current or voltage and the perturbation signal are used to generate the discrete transfer function through the system identification toolbox of MATLAB. The structure of compensator depends upon the order of the converter system. The selection of the compensator is important in order to provide sufficient gain margin (G.M) and phase margin (P.M).

5. COMPENSATOR DESIGN RULES

For the design of digital compensator is carried out in the similar way as that of the conventional controller design. Following are the design rules.

(i) Using the open loop transfer function to plot frequency response
(ii) According to the transient response calculate the phase shift and gain at cutoff frequency.
(iii) Depending on the maximum allowable overshoot requirement maximum allowable overshoot requirement
(iv) Next the type of the compensator is analyzed and its pole zero configuration is determined.
(v) Pole and zero are placed such that the loop gain frequency response meets the required PM, GM and bandwidth.
(vi) Finally, through pole zero location, transfer function of compensator is determined.
(vii) As a result of the above steps digital equivalent compensator is designed.

6. SIMULATION

$G_{vd}(z)$ is the control-to-output transfer function. It is obtained through system identification using parameters of circuit.

$$G_{vd} = \frac{0.031z^2+0.0715z-0.007}{z^3-1.948z^2-0.956}$$

Using this transfer function the loop gain is defined as:

$$TF(z) = Gvd(z)\,Gc(z)$$

$G_c(z)$ is the compensator which is to be designed. Here, a compensator with three pole and two zero is considered.

$$G_c = \frac{0.2847z^2 - 0.5968z + 0.2992}{z^3 - 1.418z^2 + 0.4619z - 0.04364}$$

The frequency response plots for converter $G_{vd}(z)$, compensator $G_c(z)$ and the loop gain $T_L(z)$ are shown in figure below.

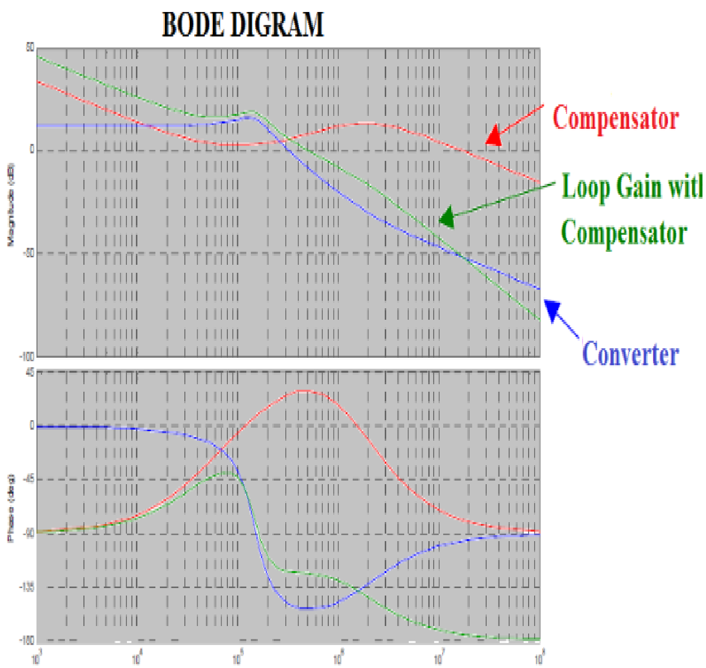

Fig 4: Bode plot of open loop(blue), compensator(red) and loop gain(green)

7. RESULTS

The result of the above bode plot shows that the gain margin of the loop gain plot is 55 dB and the phase margin is 48°. The cutoff frequency is chosen to be 110Hz. The peak overshoot chosen is 2% and settling time is 5msec. The analysis is done through MATLAB computer simulations for 24 to 100V, 200 Watt prototype converter system.

8. CONCLUSION

In this paper digital controller for soft switched boost converter is designed. The formation of discrete-time transfer is done using system identification tool. And then the digital compensator design steps are explained. PSIM is used to valid the digital compensator design. The pole zero location gives the required gain margin and phase margin.

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