Soft-Switching Converter for Energy Applications

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Abstract— A new Zero-Voltage Transition based DC-DC converter sufficient to draw power from two distinct sources feeding a common dc-bus is presented in this paper. This converter belongs to higher-order family and behaves as buck converter for one dc source also it acts as both buck and boost converter with the other source. The significant feature of the proposed converter is that both the sources either singly or simultaneously supply power to the subsequent load at minimal ripple current. This feature is particularly attractive for photo-voltaic power processing applications. The main objective here is to realize the soft-switching by integrating the ZVT cell into the two input DC-DC converter enabling to improve the efficiency by reducing the switching losses in the converter.

Key words: Converter, Energy Application

I. INTRODUCTION

DC-DC converter is one of the most important and widely used devices of modern power applications. Power electronics field in the last decade has been the development of switching-mode converters with higher power density and low electromagnetic interference. Light weight, small size and high power density are also some of the key design parameters. Several different types of switch-mode dc-dcconverters belongs to buck, boost and buck-boost topologies, have been developed and reported in the literature to meet variety of applications [1]. Major concern in the recent dc distribution systems, such as in automotive and telecom power supply systems, is to meet the increased power demand and reducing the load on the primary energy source, i.e. built-in battery. This is possible by adding additional power sources in parallel to the existing battery source. The additional power sources can be: (i) renewable energy sources such as photovoltaic (PV) or wind, (ii) fuel cell storage power [2].

Integration of renewable energy sources to form a distributed generation system is another option for the hybrid vehicles, automotive industries and even in remote standalone power supply system. In order to efficiently and economically utilize renewable energy resources it is necessary to tap the energy as and when it is available and then store for subsequent utilization [3]-[5]. However, the power conversion efficiency and its control is major challenge for the power supply designer. The efficiency improvement with higher power density, from the steady-state point of view, of the distributed energy generation is one of the considerations for the designer. The other difficulty is while designing such system is to evolve simple and reliable power control strategy [6]-[8]. To address some of the above issues, multi-input converters, with different topology combinations, are evolving. Although several power conversion topology configurations can easily be developed, but an integrated converter with bucking, buck-boost feature is desired in most of these schemes [9]-[10].

To this affect, there is no sufficient literature covering the development of converter and control schemes for such applications. Further, literature including design aspects of digital controllers for such kinds of converters is also limited. In order to cover this gap, a new two-input dc-dc converter is proposed in this paper and then digital controllers have been designed to ensure dc-bus voltage regulation together with power distribution control of the input dc power sources. The aim of this paper is to realize the soft-switching by integrating the ZVT cell into the two input DC-DC converter enabling to improve the efficiency by reducing the switching losses in the converter, belonging to higher order family.

II. MODELING AND ANALYSIS OF THE CONVERTER

Assuming all switching devices, energy storage elements are considered to be ideal. The voltage source in series with input inductors (L_1) and (L_2) is considered to be an ideal current source (I_{g1}) and (I_{g2}). At Output side the presence of large Capacitor (C_3) in parallel with the load has been replaced with a constant voltage source with the magnitude of V_0.

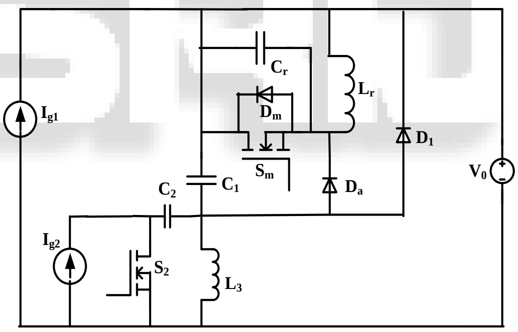

Fig. 1: Two Input ZVT DC-DC Converter

Mode-1: ($t_o<t<t_1$)

S_m-OFF, S_a-ON, S_2-OFF, D_m-OFF, D_a-OFF, D_1-ON

During Mode-1, the auxiliary switch turns on and diode D_1 is conducting. The current in the resonant inductor starts to build up through the auxiliary switch.

Initial conditions:

$$V_{cr}(t_0) = V_{g1}, i_{Lr}(t_0) = 0$$

The resonant capacitor is fully charged and inductor current linearly increases.This mode ends at $t = t_1$, when $i_{lr}\left(t_1\right) = I_o$

This gives the time duration for Mode-1 and at the end of this mode D_1 is turned off.

Mode-2: ($t_1<t<t_2$)

S_m-OFF, S_a-ON, S_2-OFF, D_m-OFF, D_a-OFF, D_1-OFF

During Mode-2, the resonant capacitor starts discharging through the resonant inductor. In this mode, resonance occurs in the ZVT cell.

Initial conditions:

$$V_{cr}(t_1) = V_{g1}\ ,\ i_{lr}(t_1) = I_o$$

Mode-3: (t_2<t<t_3)

S_m-OFF, S_a-ON, S_2-OFF, D_m-ON, D_a-OFF, D_1-OFF

During this mode the anti-parallel diode of the main switch starts conducting and the resonant inductor current remains constant since there is no change in the state of the resonant tank elements. In this mode the anti-parallel diode is conducting therefore negative current flows across main switch and the voltage across the main switch is zero.

Initial conditions:

$$V_{cr}(t_2) = 0\ ,\ i_{lr}(t_2) = I_o + \frac{V_{g1}}{Z_r}$$

In this mode there is no change in the state of the resonant tank elements

This mode ends when S_a is turned off.The main switch body diode is still on and in the next mode the second switch and the auxiliary diode is turned on.

Mode-4: (t_3<t<t_4)

S_m-OFF, S_a-OFF, S_2-ON, D_m-ON, D_a-ON, D_1-OFF

During Mode-4, the second switch, the anti-parallel diode of the main switch as well as the auxiliary diode starts conducting. The energy stored in the resonant inductor is released via the auxiliary diode.

Initial conditions:

$$V_{cr}(t_3) = 0\ ,\ i_{lr}(t_3) = I_o + \frac{V_{g1}}{Z_r}$$

This gives the timing for Mode-4 and at the end of this mode D_a turns off.

Mode-5: (t_4<t<t_5)

S_m-OFF, S_a-OFF, S_2-ON, D_m-ON, D_a-OFF, D_1-OFF

During this mode, the second switch and anti-parallel diode of the main switch are conducting.

Initial conditions:

$$V_{cr}(t_4) = 0\ , i_{lr}(t_4) = 0$$

No change in the resonant tank elements as they are disconnected from the circuit.

Mode ends when S_2 is turned off.

Mode-6: (t_5<t<t_6)

S_m-ON, S_a-OFF, S_2-OFF, D_m-OFF, D_a-OFF, D_1-OFF

During Mode-6, the main switch is turned on.

Initial conditions:

$$V_{cr}(t_5) = 0\ , i_{lr}(t_5) = 0$$

Also, $i_{lr}(t) = 0$, At the end of this mode, $I_{g1} = i_{c1}$, therefore $i_{sm} = 0$

Mode-7: (t_6<t<T_S)

S_m-OFF, S_a-OFF, S_2-OFF, D_m-OFF, D_a-OFF, D_1-ON

During Mode-7, diode D_1 starts conducting.

Initial conditions:

$$V_{cr}(t_6) = V_{g1}\ , i_{lr}(t_6) = 0$$

This mode is identical to the freewheeling stage of the conventional converter and at $t = T_S$, this mode ends when S_a is on and a new switching cycle begins.

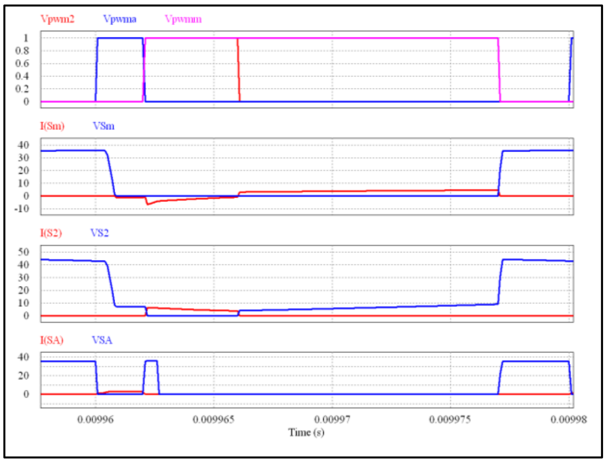

Fig. 2: PWM gating signals and ZVT operating conditions of switches

III. DESIGN OF DIGITAL CONTROLLER

Although the conventional DC-DC converter is capable of stepping-up of voltages, but the load side requires a huge capacitance to filter-out the switching frequency harmonics. However, use of larger capacitance lead to higher starting inrush current and sometimes this may be more than the overload capacity of the given converter and hence single stage filter may not be recommended for the reasons mentioned above. Adding LC low-pass filter on the output stage is one of the feasible solutions. However, addition of LC-filter on load increases the system order and hence its controller design is an important aspect to the power supply designer.

Digital control of the power supply systems is coming-up in recent days due to the advancement of the technology in the area of micro-controller and digital signal processors. In general, the digital control offers several advantages, over the analog control, but few of them are as follows: (i) less susceptible to ageing and environment variations, (ii) less sensitive to noise, (iii) provide improved sensitivity to parameter variations, etc. There are several different ways to realize the digital controllers for the power supplies. However, there are two different control schemes, widely used in the power supply industries, which are: (i) voltage-mode control, (ii) current-mode control. Among these two control strategies, the voltage-mode scheme is quite attractive and efficient. Further, there are no unstable issues, arising due to adding current-loop, and dynamic response time is almost close to the cascade control. Hence, in this paper a digital voltage-mode controller is employed for the zero-voltage transition two input DC-DC converter.

IV. SIMULATION RESULTS

The simulation is carried out with the aim to study the voltage and current waveforms of the circuit components. The voltage and current waveforms of all the switching devices are recorded in order to obtain their switching performance. The main, second and auxiliary switches undergo soft transition during turn-on whereas the power circuit diode and the auxiliary diode undergo soft transitions during turn-off as per the mode analysis done.

The PWM gate signals for main, second and auxiliary switches used in the simulation process are shown in Fig.2. Here, the rising edge of the main switch gate signal and rising edge of the second switch gate signal should be synchronized each other.The voltage-mode controller transfer functions that are designed

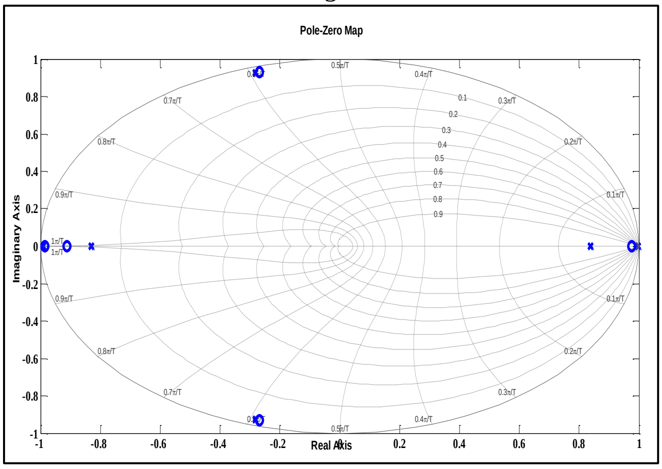

Fig. 3: Pole-zero plot of the converter transfer function $G_{p1}(z)$.

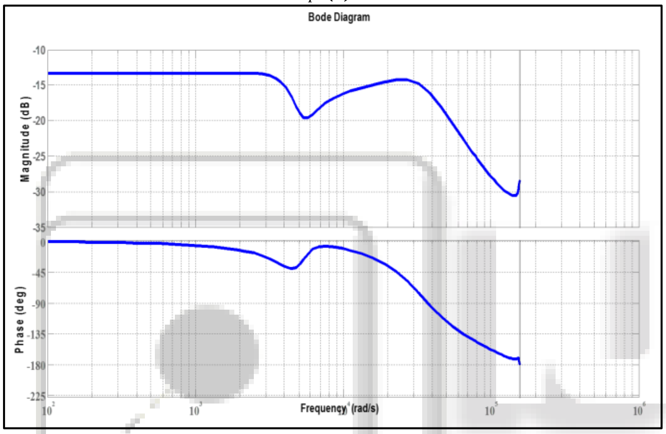

Fig. 4: Frequency response characteristics of the converter transfer function $G_{p2}(z)$.

The effectiveness of the designed controller has been verified in simulation for load side and source side disturbances. A load disturbance of load resistance from 100 to 70 Ω has been created after 15*ms*and the controller action made the converter to regulate the voltage and found the controller action to be satisfactory which made thetransients to die down.

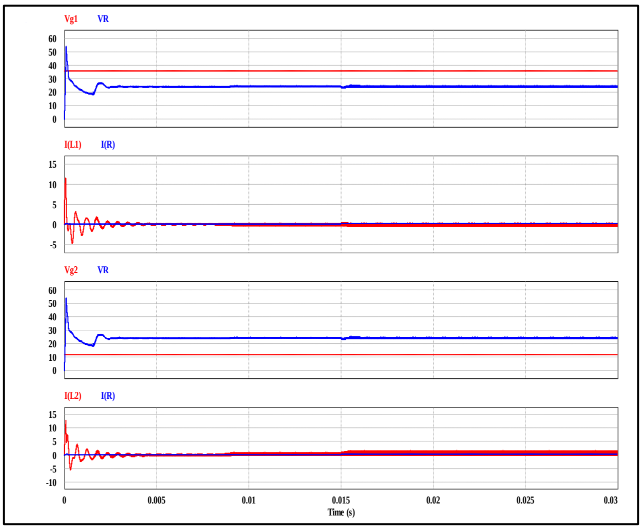

Fig. 5: Start up Response of the converter(R= 100 → 70Ω).

V. Conclusion

In this paper of soft switching DC-DC converter using an auxiliary resonant circuit is proposed which offered significant advantages over conventional converters. This higher order converter provides higher voltage level at lower duty ratios and the ripple at input and output is also reduced. The zero-voltage transition cell was also incorporated into the circuit providing further advantages in terms of reduction of switching losses for nearly all the switching devices.The ZVT operation of the main switch and the soft-switching for all other switching devices was achieved in the simulationwhen employed with the proper gating sequence for the main, second and auxiliary switches.

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