Closed Loop Control of Synchronous Buck Converter with PID Controller for Low Voltage-High Current Applications

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Abstract : In this paper a closed loop control of synchronous buck converter with zero voltage transition (ZVT) and zero current transition (ZCT) is proposed using pulse with modulation technique. This converter is best suited for low voltage and high current applications. In this the switching is done by zero voltage switching and an auxiliary circuit is proposed to reduce the stress and improves the efficiency by reducing the conduction and switching losses of the converter. The switching frequency is increased due to the low values of resonant components used in this multiphase synchronous buck converter. The output voltage and current of the proposed converter are verified with MATLAB/SIMULINK and the experimental results have been obtained.

IndexTerms **- Synchronous buck converter, zero current transition (ZCT) and zero voltage transition (ZVT).**

I. INTRODUCTION

In the present scenario the reduction of switching and conduction losses can be reduced by zero voltage transition (ZVT)–zero current transition (ZCT) technique which are applied to synchronous buck converter. The ZVT–ZCT concept extending to multiphase SBC has emerged as a leading technique for meeting the power requirement of the portable electronic systems. To get high performance the switching frequency of the converter can be increased with the introduction of multiphase high current synchronous buck converter. Due to the hard switching PWM converters the switching losses are not reduced but are limited to some extent. The concept of ZVT was also extended to full-bridge PWM converters. A new family of ZVT PWM converters was presented and is widely used in the industry. In these converters, the zero voltage switching (ZVS) condition, which is bestowed by an auxiliary circuit for wide line and load ranges, provides minimum voltage and current stresses on devices.

Another way to achieve high-performance and high power-density converters is adopting the multiphase conversion technique. With the interleaved operation, small size inductors can be used to keep low-current ripple at the input and output capacitor filters, and high dynamic performance can be achieved since the operating frequency of input and output filter capacitors is increased by n times for n-phase converters. Higher dynamic performance and higher power-density power conversion can be achieved if both ZVT–ZCT and multiphase conversion techniques are combined.

As the switching frequency is equal to the inductor current ripple frequency so the switching frequency is limited between 300 and 500 kHz. The inductor current ripple is increase with the slight increase of the inductor value for improvement in transient response. It also increases the inductor winding losses. This conflict limits the average inductor current in each channel. Moreover, there is a tradeoff between transient response and efficiency. As a result, these technical conflicts not only increase the cost and sacrifice the power density, but also it is difficult to meet the power requirements of future equipments. So the efficiency of the high current multi phase buck converter can be increased by reducing the switching losses. The auxiliary switch activates just before the main switch and commutates after it .The converters proposed either provide ZVT or ZCT soft-switching condition, making some switches in the converter to operate with hard switching that increases switching loss which affects the overall performance of the converter. The industry standard voltage regulator topology used to deliver high current and low voltage is the multiphase SBC.

In this paper, the ZVT–ZCT multiphase SBC is presented with the directive to improve its performance and alleviate the issues of the conventional multiphase SBC. In contrast to the contemporary topologies the proposed novel topology resolves the issues of unbalanced distribution of current, the high amount of losses in the converter, reduces the problem of EMI of the converter and operates with both soft-switching conditions that enhance the performance of the converter. Here the proposed multiphase ZVT–ZCT PWM SBC is associated with active auxiliary circuit rather than passive auxiliary circuit because at the high load current passive auxiliary circuit will give high conduction losses.

II. SYNCHRONOUS BUCK CONVERTER

A regulated DC output voltage can be obtained by the use of synchronous buck converter which can deliver a high currents with minimum power losses.Figure 1 shows that the synchronous buck converter consists of a filtering circuit with a combination of inductor and capacitor and two power MOSFETs for switching purpose. There is a synchronised control operation for the regulated output voltage in order to prevent the switching on and switching off of two MOSFETs at the same time..

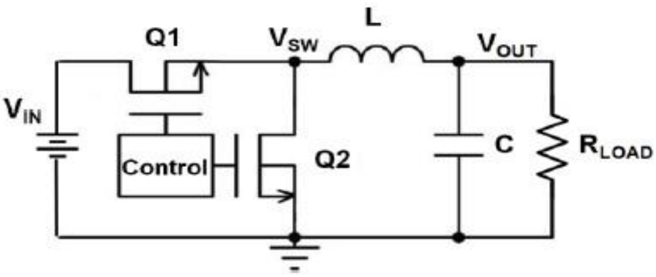


Figure 1.Basic Synchronous Buck Converter

The input voltage of the circuit is connected directly to Q1. When this Q1 is switched on, current is supplied through the high side MOSFET to the load. The current in the inductor increases when Q2 is off which charges the LC filter. When Q1 turns off, Q2 turns on and current is supplied to the load through the low side MOSFET. The current through the inductor decreases, discharging the LC filter when Q1 is turned off and Q2 is turned on. The switch node voltage is clamped by the low side MOSFET which is an additional function when both MOSFETs are off which is done through the body diode to prevent VSW from going too far negative when the high side transistor first turns off.

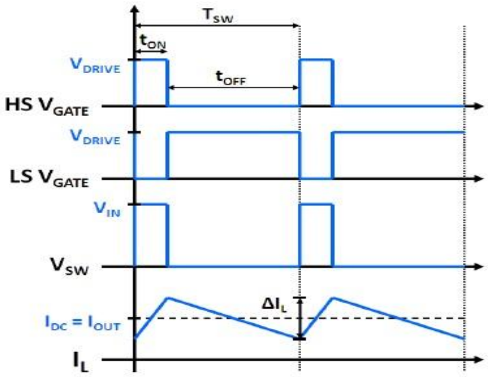


Figure 2. Wave form of Synchronous Buck Converter

The basic wave forms in the continuous conduction mode of the Synchronous buck converter are shown in Figure 2. The peak−to−peak inductor current is the total change in the inductor current, _I_L. the LC output filter smoothed the node voltage for the better regulated DC output voltage. The shoot through is controlled by the synchronized switching of the MOSFETs. When both the switches are switched on then there is chance of direct short circuit to ground which produces high currents.

III. PROPOSED TOPOLOGY

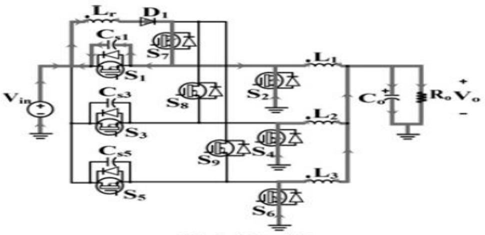
Configuration of proposed circuit and conditions that are assumed to simplify the analysis The proposed ZVT–ZCT multiphase SBC is shown in Fig. 3. It is a combination of the conventional multiphase SBC along with an active auxiliary circuit that facilitates reduction of switching losses. The auxiliary circuit consists of inductor Lr, diode D1, and MOSFET switches S7, S8, and S9. The number of auxiliary MOSFET switches depends on the number of phases. The ZVS is provided by the main switches S1,S2 and S3. To analyse the steady-state operations of the proposed circuit, the following assumptions are made during one switching cycle:

i. The input voltage Vin is constant.
ii. The average output current Io is constant.
iii. The filter inductors L1, L2, L3 are much larger than the resonant circuit inductor Lr.
iv. The resonant circuits are ideal.
v. The reverse recovery (RR) time of the diode is ignored.

Modes of operation

On the basis of these assumptions, circuit operations in one switching cycle can be divided into 15 stages. The key waveforms of these stages are illustrated in Fig. 2 and the equivalent circuit schemes of the operating stages are given in Fig. 3. The detailed analysis of every stage is presented below:

Mode 1 (t0–t1): Prior to t = t0, the body diode of switch S2 was conducting, while the main switch S1 is off. The equations are iS1 = 0, iD4 = I0/3, iLr = 0 are valid at the beginning of this stage. At t = t0, the auxiliary switch S7 is turned on, which realises zero-current turn-on as it is in series with the resonant inductor Lr. During this stage, iLr rises and current iDS2 through the body diode of switch S1 falls simultaneously at the same rate. The resonance occurs between Lr and CS1. This mode ends at t = t1, when iLr reaches I0/3, and iDS2 becomes zero. The body diode of switch S2 is turned off with ZCS.



Mode 1 (t0—t1)

Figure 3. Mode I of SBC

Mode 2(t1–t2): Since the inductor current iLr is increasing continuously beyond one third of load current, the exceeding current makes the diode DS1 to conduct. At t = t1, iS7 = iLr = I0/3. After reaching the peak current ILrmax, the inductor current starts decreasing. This mode comes to an end when iLr becomes again equal to Io/3. At this moment, the main switch is triggered to turn ON under ZVS.

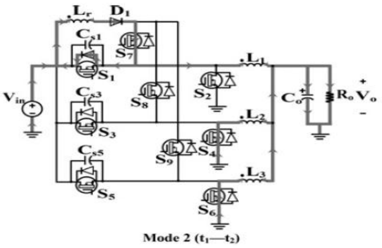


Figure 4. Mode II of SBC

Mode 3(t2–t3): At t = t2, the main switch is turned on while the auxiliary switch is still in the ON state. Now the stored energy in inductor Lr will be transferred to the load at the same rate as the current increase through the main switch S1. At t = t2, iLr = I0/3. This mode comes to an end when the total energy of the resonant inductor will be transferred to the load. The auxiliary switch S7 will turn off under ZCS.

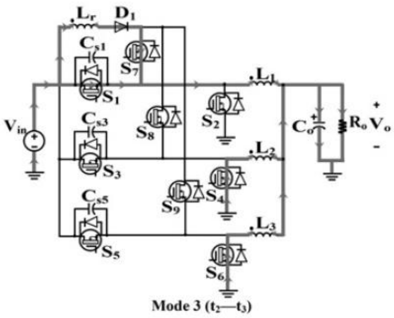


Figure 5. Mode III of SBC

Mode 4(t3–t4): In this mode, the converter behaves as a conventional PWM converter. For the required output voltage, the turn on period of the main switch is decided. At the end of this mode, the main switch S1 is turned off under ZCS due to the existent of capacitor CS1 across it.

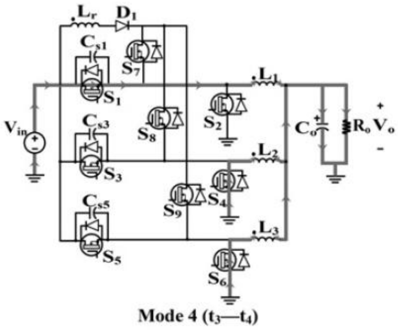


Figure 6. Mode IV of SBC

Mode 5(t4–t5): At t = t4, the synchronous switch is turned on to provide a constant load current. At the end of this mode, the complete operation for one phase converter is completed and the second auxiliary switch S8 is turned on with a phase difference of 360/n, where n is the number of phases, here n = 3. The same five modes will be repeated for each phase. So there are 15 modes for this proposed multiphase converter.

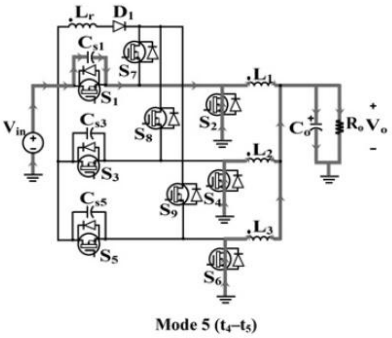


Figure 7. Mode V of SBC

IV. EXPERIMENT AND RESULTS

The simulation is done in Matlab 2010A and the outputs currents for the different sets and the total currents of the output are observed. The output currents are in synchronism with each other. The output voltage is achieved to be as 1.5 Volts. Figure 8 is the simulation circuit. Figure 9 is the control circuit of one phase. Figure 10 is the three currents produced in each phase, Figure 11 gives the synchronized currents. Figure 12 is the output voltage across the load.

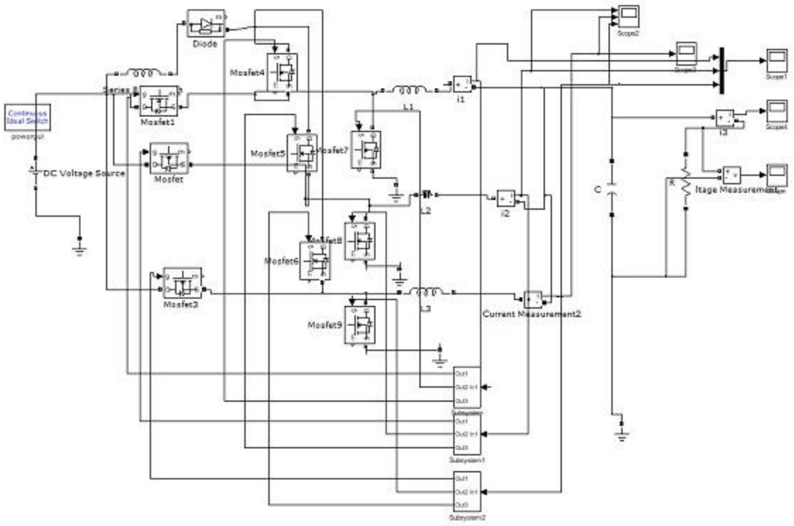


Figure 8 Simulation circuit

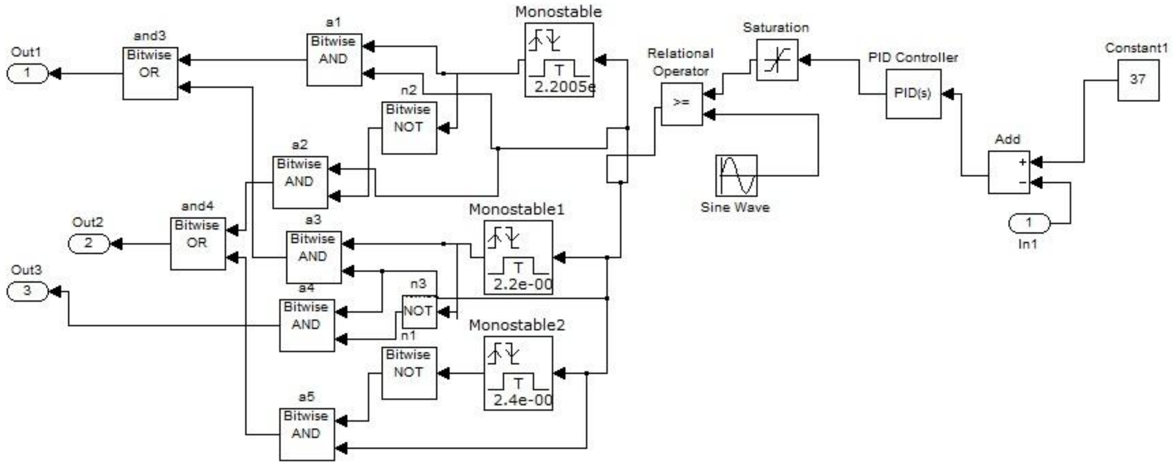


Figure 9 Control Circuit of one phase

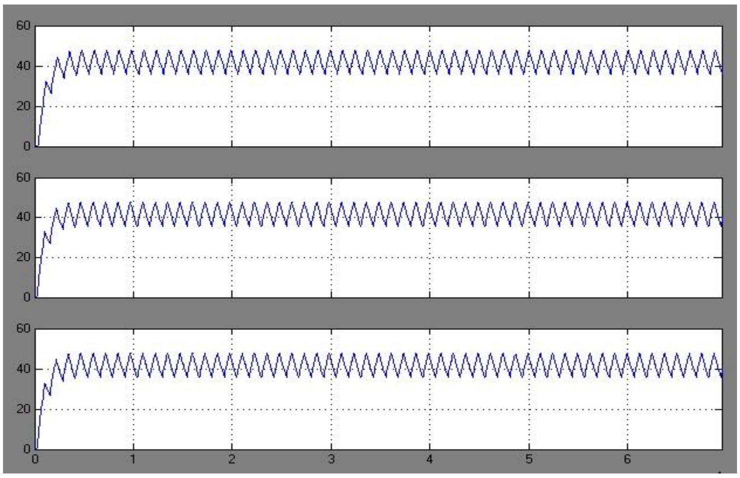


Figure 10 Currents in three Phases

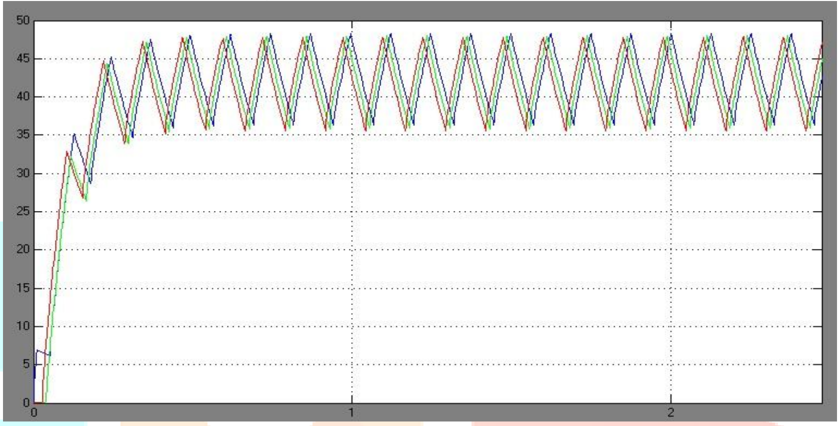


Figure 11 Synchronized currents

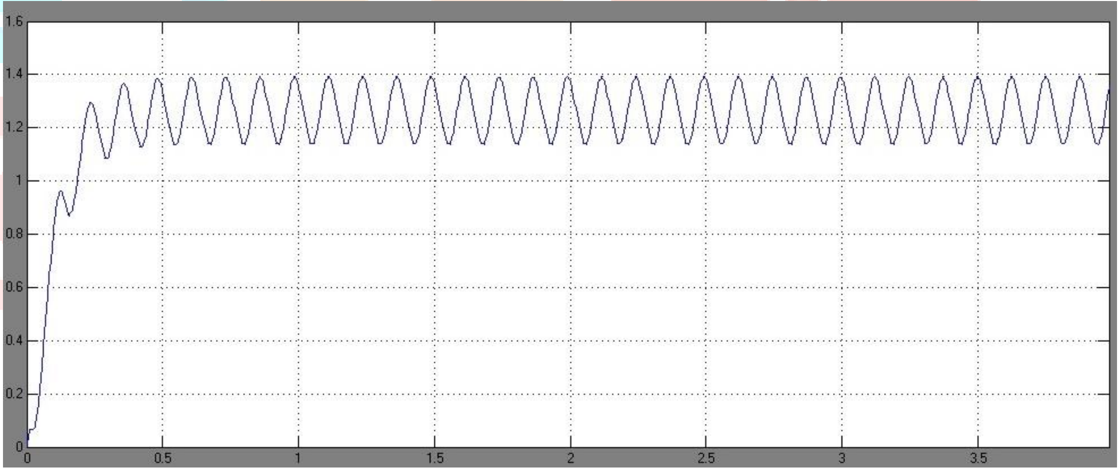


Figure 12 Output voltage

IV. CONCLUSION

In this paper, the concept of ZVT–ZCT is implemented in multiphase SBC with closed loop control and it is shown that the switching losses in SBC are eliminated. The turn on and turn off of the main switch and the synchronous switches done by ZVS and ZCS, respectively. The turn on and turn off of the auxiliary switches are also done by ZVS and ZCS with tolerable voltage stresses across the switch. Hence, switching losses are reduced and the proposed multiphase SBC is highly efficient than the conventional converter. In this paper the PID controller used to generate the pulses using the pulse width modulation. The output is achieved near to the reference value and the outputs are achieved.

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