

CONTROL SYSTEM GUI PROGRAM FOR ZVS BUCK RESONANT CONVERTER

by
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Abstract. This paper presents proposes a critical conduction analyze of buck resonant DC-to-DC power converter. The proposed cell consists of a main switch, with ZVS switching characteristics. The power converter control is realized by the PWM technique, with constant switching frequency operation. The complete operation principles, theoretical analysis, relevant equations, theoretical analysis, simulation results for the buck converter are presented because both the active switch and the diode have soft switching operation by the resonance between the switch parasitic capacitors and the filter inductor. And, the turn-off switching loss of the active switch is reduced by the decrease of the turn-off current. In addition, tapped-inductor changes the conduction operation, which makes some advantageous conditions that diminish the conduction loss and device stresses

Key Words. Buck, resonant, analyze, simulation

1. Modelation of buck converter

In this circuit the transistor is modeled by the ideal switch K, diode D1 and capacitor Cr in parallel and the inductance Lr. The diode D1 is turning on only voltage across capacitor Cr is negative. For a good understanding of model the differentials equations that describe circuit are grouped in four cases. Those cases are implemented in MathLab. Variable are currents through inductor and voltage across capacitors. GUI interface was made in two cases, with D1 in parallel and without D1. First case is selected by a button called half-wave mode in this interface. Second case is calculated if we select full-wave mode. All calculations were made in steady-state and transient mode by resolving differential equations attached. In figure 1 is presented a schematic buck resonant converter.

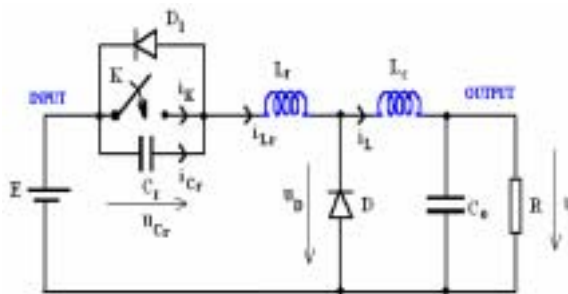


Fig. 1: Buck resonant converter

For a good understanding stage in simulation in one period are four stages characterized by transistor and diode D. The stages are similar with a simple observation. In absence of diode D1 (full wave – mode) voltage across capacitor Cr have negative values. Transistor is substituted with the switch K and the stages are shown below: a. Switch K ON diode D OFF b. Switch K OFF diode D OFF c. Switch K OFF diode D ON d. Switch K ON diode D ON

A. Switch K ON diode D OFF. To analyze the voltages of this circuit let us consider the switch K ON and diode D is turned OFF. Equivalent circuit is shown below

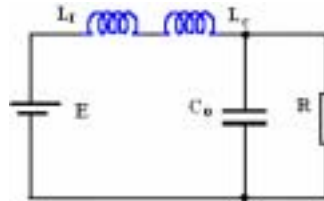


Fig. 2: Buck resonant converter with switch K ON and diode D OFF

For steady state operation at the start, the current through inductances L_r and L_c is zero and to get a simple relation between voltages we assume no voltage drop across capacitors.

$$u_{Cr} = u = 0 \quad i_{Lr} = i_L = 0 \quad (11)$$

The differentials equations in this case are

$$\frac{du_{Cr}}{dt} = 0 \quad (12) \quad \frac{di_{Lr}}{dt} = \frac{E - u}{L_r + L_c} \quad (13)$$

$$\frac{di_L}{dt} = \frac{E - u}{L_r + L_c} \quad (14) \quad \frac{du}{dt} = \frac{1}{C_o} \left(i_L - \frac{u}{R} \right) \quad (15)$$

From (15) after derivation and substitute $\frac{di_L}{dt}$ from (14) result a second order differential equation:

$$C_o(L_r + L_c) \frac{d^2 u}{dt^2} + \frac{(L_r + L_c)}{R} \frac{du}{dt} + u = E \quad (16)$$

Similar from (14) after derivation and substitute $\frac{du}{dt}$ from (15) and combined with (13) result a second order differential equation:

$$C_o(L_r + L_c) \frac{d^2 i_r}{dt^2} + \frac{(L_r + L_c)}{R} \frac{di_L}{dt} + i_L = \frac{E}{R} \quad (17)$$

B. Switch K OFF diode D OFF. To analyze the voltages of this circuit let us consider the switch K OFF and diode D is turned OFF. Equivalent circuit is shown below:

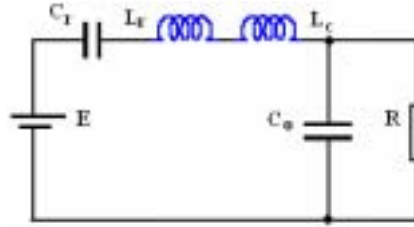


Fig. 3: Buck resonant converter with switch K OFF and diode D OFF

For steady state operation at the start, the current through inductances L_r and L_c is equal and to get a simple relation between voltages we assume no voltage drop across capacitor C_r .

$$u_{C_r} = 0; \quad i_{L_r} = i_L = \frac{E}{L_r + L_c} t \quad \text{same type like (11)}$$

The differentials equations in this case are:

$$\frac{du_{C_r}}{dt} = \frac{di_L}{dt} \quad (18) \quad \frac{di_{L_r}}{dt} = \frac{E - u_{C_r} - u}{L_r + L_c} \quad (19)$$

$$\frac{di_{L_r}}{dt} = \frac{E - u_{Cr} - u}{L_r + L_c} \quad (20) \qquad \frac{du}{dt} = \frac{1}{C_o} \left(i_{L_r} - \frac{u}{R} \right) \quad (21)$$

To get a relation between voltages and diode voltage we assume no voltage drop across capacitor Cr and diode while ON and a perfect switch change. The voltage across diode D

$$u_d = \frac{EL_c - u_{Cr}L_c + uL_r}{L_r + L_c} = \frac{(E - u_{Cr})L_c + uL_r}{L_r + L_c} \quad (22)$$

After a time this voltage fall to zero and diode is turn on. Because value of Lr is negligable compared with Lc we assume that product $u \cdot L_r$ is zero. Time after diode turn on are approximate from (22) when $u_d > 0$.

$$u_d = \frac{(E - u_{Cr})L_c + uL_r}{L_r + L_c} \approx \frac{(E - u_{Cr})L_c}{L_r + L_c} > 0 \quad \text{result} \quad u_{Cr} > E \quad (23)$$

C. Switch K OFF diode D ON. To analyze the voltages of this circuit let us consider the switch K OFF and diode D is turned ON. Equivalent circuit is shown below:

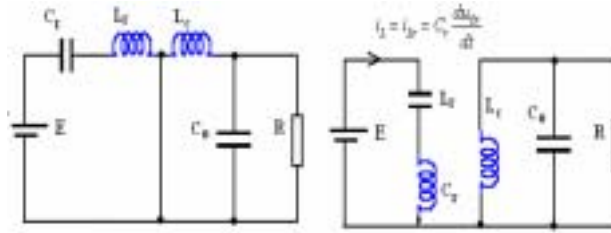


Fig. 4: Buck resonant converter with switch K OFF and diode D ON

For steady state operation at the start, the current through inductance Lr is equal with current across Lc and to get a simple relation between voltages we assume no voltage drop across diode D. After diode D is ON current across Lr is different like current across Lc. At the moment when D is ON voltage across Cr is very close to E. Initial condition at this state

$$u_d = 0 \qquad i_{L_r} = i_L \qquad u_{Cr} \approx E \qquad \text{The differentials equations in this case are}$$

$$\frac{du_{Cr}}{dt} = \frac{i_L}{C_r} \quad (24) \quad \frac{di_{Lr}}{dt} = \frac{E - u_{Cr}}{L_r + L_c} \quad (25)$$

$$\frac{di_L}{dt} = \frac{-u}{L_c} \quad (26) \quad \frac{du}{dt} = \frac{1}{C_o} \left(i_L - \frac{u}{R} \right) \quad (27)$$

Form (24) and (25) after derivate and substitute we obtain next equations:

$$L_r C_r \frac{d^2 i_{Lr}}{dt^2} + i_{Lr} = 0 \quad (28)$$

$$L_r C_r \frac{d^2 u_{Cr}}{dt^2} + u_{Cr} = E \quad (29)$$

Form (26) and (27) after derivate and substitute we obtain next equations:

$$L_c C_c \frac{d^2 u}{dt^2} + \frac{L_c}{R} \frac{du}{dt} + u = 0 \quad (30)$$

$$L_c C_c \frac{d^2 i_L}{dt^2} + \frac{L_c}{R} \frac{di_L}{dt} + i_L = 0 \quad (31)$$

LrCr is a resonant circuit. Lc with capacitor Co is a resonant circuit amortized by resistor R. Voltage uCr is positive only, because diode D1 is turning ON and in this situation switch K can be turned ON. Discussion in this case is about value of voltage uCr. Voltage fall to zero and in this point diode D1 turn ON, that made possible to turn switch ON. This situation is shown in next figure. Voltage across inductance Lr is E, that means slope current in this circuit is E/Lr.

To analyze the voltages of this circuit let us consider the switch K ON and diode D is turned ON. Equivalent circuit is shown below

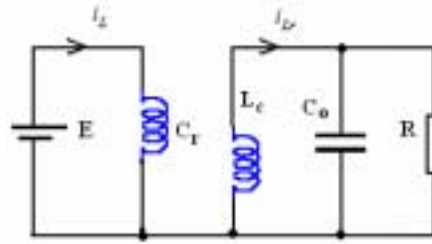


Fig. 5: Buck resonant converter with switch K ON and diode D ON

For steady state operation at the start, the current through inductance L_r is greater than zero. We assume no voltage drop across switch K and output voltage u is also greater than zero. Initial condition at this state

$$u_{C_r} = 0; \quad i_{L_r} > 0; \quad u > 0$$

The differentials equations in this case are

$$\frac{du_{C_r}}{dt} = 0 \quad (24) \quad \frac{di_{L_r}}{dt} = \frac{E}{L_r} \quad (25)$$

$$\frac{di_L}{dt} = \frac{-u}{L_c} \quad (26) \quad \frac{du}{dt} = \frac{1}{C_o} \left(i_L - \frac{u}{R} \right) \quad (27)$$

The current through inductor L_r grow linear with slope E/L_r . Also current through diode D is decrease linear with $-u / L_c$ factor. This phase is over after current across diode D fall to zero.

2. Interface of buck converter simulator

The following Graphical User Interface MathLab programs have been developed for the computational aids in resonant converter. These GUI programs with point-and-click features are designed for ease of use. These programs together with the traditional hand-written problems can help students to develop a stronger intuition and deeper understanding in this topic. The following graphics

window is displayed. The user can specify the plant and the values of components functions and select permanent or steady-state analyses. All four systems of equations are represented with different colors.

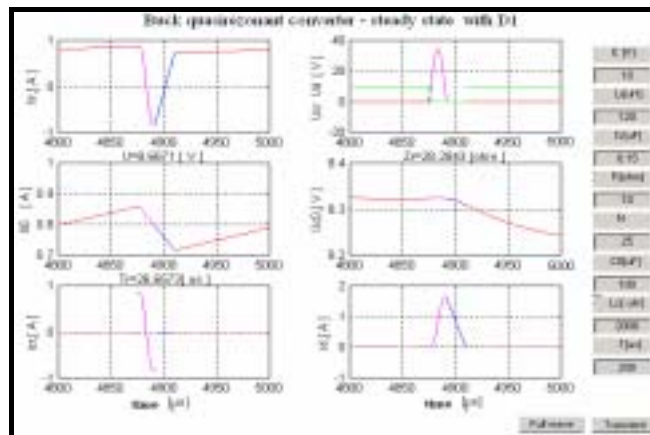


Fig. 6: GUI interface for Buck resonant converter in steady state for half wave mode (with D1)

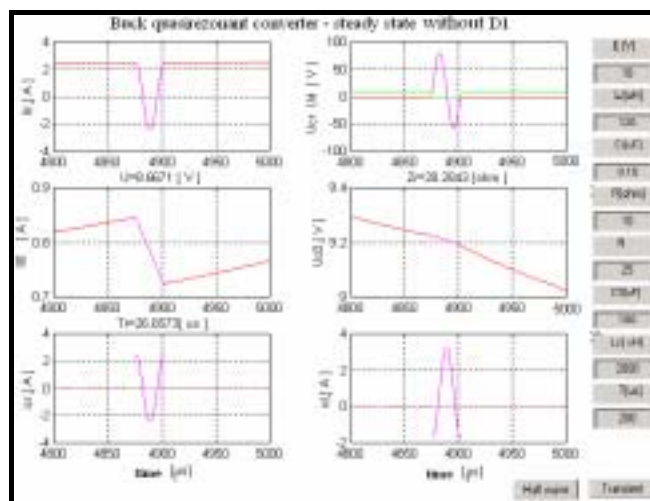


Fig. 7: GUI interface for Buck resonant converter in steady state for full wave mode (without D1)

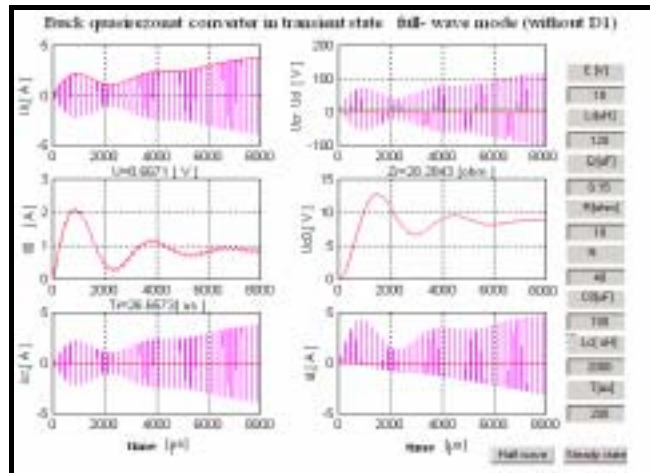


Fig. 8: GUI interface for Buck resonant converter in transient state full wave mode (without D1)

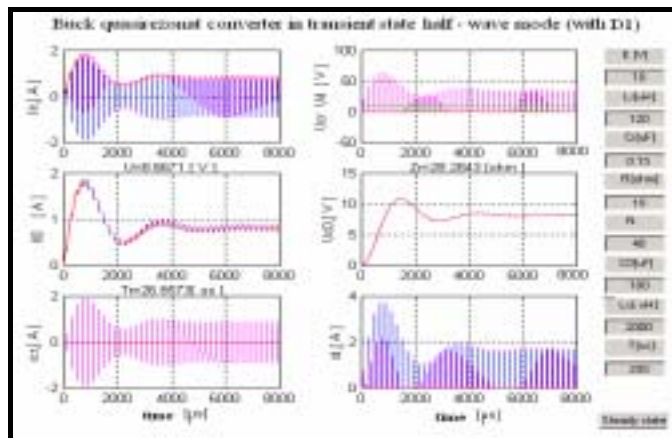


Fig. 9: GUI interface for Buck converter in transient state half-wave mode (with D1)

Upon initial selection of values, the user is prompted to enter the desired values. Among the important aspects in the steady-state analysis the variation of current, power, losses associated with various operating conditions. In the program the parameters of the equivalent circuit can be entered on the circuit diagram. The program calculates the Thevenin's equivalent circuit. Performance characteristics are then obtained for the specified is plotted on the screen. The analysis can be repeated for different value of components. be entered on the circuit diagram.

Very important in practice is the above figure. This performance characteristics are then obtained for the specified and plotted on the screen. The analysis can be

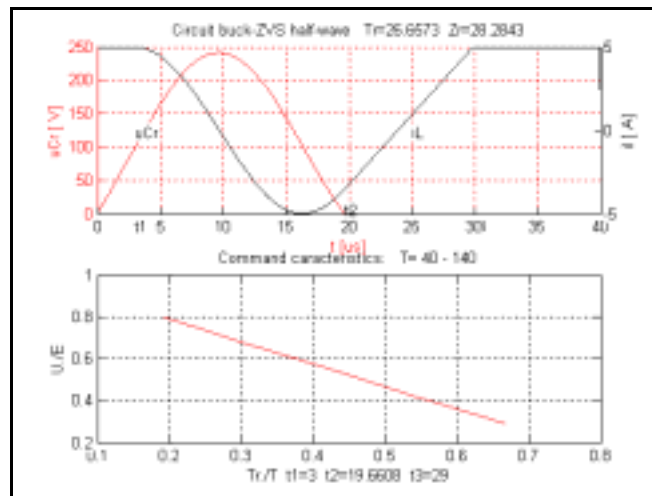


Fig. 10: GUI interface for Buck converter. Command characteristic

3. CONCLUSION

A unified analysis method for families of soft-switching dc–dc converters was developed in this paper. This leads to several advantages such as improving the computer-aided analysis and design, simplified mathematical modeling, and gives more insight into the converter-cell operation. The unified equations for each stages can be easily used in the analysis of any new converter that uses the same switching cell. This is done by finding the generalized parameters for the new converter and then substituting in the unified equations. Hence, the decrease of the total switching loss in the buck resonant scheme is achieved. In addition to the improvement of the switching loss, the increase of operating duty cycle at the same low voltage conversion as the conventional version reduces the conduction loss, as well. In this paper, the operation principle of the converter and the parameter analysis about the efficiency and device stress are included.

References

- [1] E. J. Miller, "Resonant switching power conversion," in *Proc. IEEE PESC'76*, 1976, pp. 206–211.

- [2] K. Liu, R. Oruganti, and F. C. Lee, "Resonant switches—Topologies and characteristics," *IEEE Trans. Power Electron.*, vol. PE-2, pp. 62–74, Jan.1987.
 - [3] V. Vorpe'rian, "Quasisquare-wave converters: Topologies and analysis," *IEEE Trans. Power Electron.*, vol. 3, pp. 183–191, Mar. 1998.
 - [4] T. Mizoguchi, T. Ohgai, and T. Ninomiya, "A family of single-switch ZVS-CV DC-DC converters," in *Proc. IEEE APEC'94*, vol. 2, 1994, pp. 1392–1398.
 - [5] E. Ismail and A. Sebzali, "A new class of quazi-square wave resonant converters with ZCS," in *Proc. IEEE APEC'97*, 1997, pp. 1381–1387.
 - [6] G. Hua, C. Leu, and F. C. Lee, "Novel zero-voltage-transition PWM converters," in *Proc. IEEE PESC'92*, 1992, pp. 55–61.
 - [7] G. Hua, E. X. Yang, Y. Jiang, and F. C. Lee, "Novel zero-current-transition PWM converters," *IEEE Trans. Power Electron.*, vol. 9, pp. 601–606, Nov. 1994.
 - [8] G. Hua and F. Lee, "Evaluation of switched-mode power conversion topologies," in *Proc. 1st Int. Power Electronics Motion Control Conf. (IPEMC)*, vol. 1, 1994, pp. 12–26.
 - [9] A. B. Carlson, *Circuits*. Pacific Grove, CA: Brooks/Cole-Thomson Learning, 2000.
 - [10] C. Tseng and C. Chen, "Zero-voltage-transition topologies for Cuk converters," in *Proc. IEEE PESC'98*, vol. 2, 1998, pp. 930–935.
 - [11] , "On the ZVT-PWM Cuk converter," *IEEE Trans. Ind. Electron.*, vol. 45, pp. 674–677, Aug. 1998.
 - [12] D. C. Martins and G. N. de Abreu, "Application of the ZETA converter in switch-mode power supplies," in *Proc. IEEE APEC'93*, 1993, pp.214–220.
 - [13] C. H. G. Treviso, O. C. De Freitas, and V. J. Farias, "A ZVS-ZCS-PWM self-resonant dc-dc sepic converter," *Ind. Electron., Control Instrum.*, vol. 1, pp. 176–181, 1994.
 - [14] J. Abu-Qahouq, "Generalized analysis of soft-switching dc-dc converter families," Tech. Rep., Univ. Central Florida, Orlando, 2000.
 - [15] J. Abu-Qahouq and I. Batarseh, "Generalized analysis of soft-switching DC-DC converters," in *Proc. IEEE PESC'00*, vol. 1, 2000, pp. 185–192.
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