LARGE SIGNAL AVERAGE SWITCH MODELING FOR PWM AND ZCS – QR CONVERTERS

Dr. Mustafa M. Ibrahim
University of IBB -College of Engineering
And Architecture_Electronic Department

Abstract:

The average switch modeling presented in this paper is a simple and new modeling approach. Such approach can be used to study the transient and steady-state behavior of (ZCS-QR) and PWM converters. Simulation results show that this new approach has less computation time and consists in its results with other modeling approaches.

1- Introduction:

Much attention has been paid to the analysis of periodically switched networks in recent years since their wide application in a number of practical circuits such as switching DC-DC converters. Zero-current switched (ZCS) quasi-resonant converters (QRC's) have been kinds of popular topologies for DC-DC power conversion due to their inherent soft-switching characteristics and circuits simplicity(Jianping Xu, and C. Q. Lee(1998)). However, the design of regulated switch-mode power supplies based on ZCS-QRC's are difficult to realize without a good model of the open-loop converter. Still, due to its nonlinearities and complicated operating characteristics, ZCS-QRC's are hard to model.

Steady-state analyses of QRC's were carried out, and relationships between their static voltage conversion ratios and the switching frequencies were reported. This information is useful in getting and understanding of the operation of the QRC in steady-state, but cannot be used to predict the transient behavior.

In this paper, a modeling approach for ZCS-QRC's is proposed. The model is constructed by replacing the active and passive switches in the converter by an equivalent three-terminals network known as average switch. Such a model is used to simulate the transient and steady-state response of the ZCS-QR and PWM DC-DC converters.

Simulation results have proved that the model is accurate and a very short time is required to execute the simulation programs using a common pc computer.

An interesting feature is the possibility that the method presented can be used generally to ZCS-QRC's and PWM DC-DC converters.

2-The Proposed Model

It is known that the switch average parameters in PWM converter is the duty cycle (D)(Arthur F. Witulski, and Robert W. Erickson (1990)) and in ZCS-QRC's it is the normalized switching frequency (μ) (Kwang-Hwa Liu, Ramersh Oruganti, and Fred C. Y. Lee(1987)) therefore; the normalized switching frequency in ZCS-QRC's play the same rule as the duty cycle in PWM converters: buck, boost, buck-boost, and cuk converter. These converters have one active switch and one passive switch performing the switching action in the converter. The active switch is directly controlled by an external control signal. It is usually implemented with a bipolar transistor or a MOSFET.The passive switch is directly controlled by the state of the active switch and the circuit condition. It is usually implemented by a diode. As shown in Fig. 1, these two switches can be combined into one network with three terminals a, p, and c which stands for active, passive, and common respectively. The three terminals network is called the average-switch and since all other elements of the converters are supposed to be linear, the average switch is the only nonlinear element and therefore responsible for the nonlinear behavior of the converters.

Fig. 2 shows the presentation of the average switch operation in the continuos conduction mode with the terminal currents and voltages. During the time interval (μT_S) the passive switch is off and the active switch is on, and the active terminal is connected to the common terminal. During the time interval ($\bar{\mu} T_S$) the active switch is off and the passive switch is on, and the passive terminal is connected to the common terminal, where (T_S) is the switching period of the active switch, (μ) is the switch average parameter as the ratio of the on-time of the active switch to the switching period and ($\bar{\mu} = 1 - \mu$) for the continuos conduction mode. The relations between the instantaneous terminal currents are found as:

$$i_a(t) = \begin{cases} i_c(t) & \text{during } \mu T_s \\ 0 & \text{during } \bar{\mu} T_s \end{cases} \quad (1)$$

$$i_b(t) = \begin{cases} 0 & \text{during } \mu T_s \\ i_c(t) & \text{during } \bar{\mu} T_s \end{cases} \quad (2)$$

The same applies for the instantaneous terminal voltages:

$$V_{cp}(t) = \begin{cases} V_{ap}(t) & \text{during } \mu T_s \\ 0 & \text{during } \bar{\mu} T_s \end{cases} \quad (3)$$

$$V_{ac}(t) = \begin{cases} 0 & \text{during } \mu T_s \\ V_{ap}(t) & \text{during } \bar{\mu} T_s \end{cases} \quad (4)$$

It is sufficient to inspect the averaged behavior of the average-switch to analyze the averaged behavior of a converter. So the instantinuos terminal waveform are time-averaged over one cycle T_s.

Thus, the averaged terminal currents are found using eqns. (1) and (2) as:

$$\langle i_a \rangle = \mu \langle i_c \rangle \qquad (5)$$

$$\langle i_p \rangle = \bar{\mu} \langle i_c \rangle \qquad (6)$$

Also, the average terminal voltages are found from eqns. (3) and (4):

$$\langle V_{cp} \rangle = \mu \langle V_{ap} \rangle \qquad (7)$$

$$\langle V_{ac} \rangle = \bar{\mu} \langle V_{ap} \rangle \qquad (8)$$

Fig. (4.3) shows a model applying a controlled voltage source and a controlled current source using eqns. (5) and (7). It is clear that eqns. (6) and (8) are also satisfied. The model for the average-switch always satisfies either eqn. (5) or eqn. (6) and eqn. (7) or Eqn. (8).

3-Application of the Average-Switch Model

As an application for average-switch model, we shall take a boost converter as shown in Fig. 4 while Fig. 5 presents the boost converter, where the average-switch is replaced by the model shown in Fig. 3. We can easily recognize from Fig. 4 that:

$$i_C = -i_L$$
$$V_{CP} = -V_C \qquad (9)$$

For boost converter we can easily recover the state equations from Fig. 5:

$$L\frac{di_L}{dt} = -(1-\mu)v_{co} + V_i \qquad (10)$$

$$C\frac{dv_{co}}{dt} = (1-\mu)i_L - \frac{v_{co}}{R_o} \qquad (11)$$

When f_S =300 kHz then

$\mu = 0.6 = f_s / f_r$ (for both buck and boost converters)

$=(300\times10^3) / (1/2\pi\sqrt{L_r C_r})$

The same steps are used for buck converter as in Figs. 6 and 7. The differential equations describing the buck converter model are

$$L\frac{di_L}{dt} = \mu V_i + Vco \qquad (12)$$

$$C\frac{dv_{co}}{dt} = i_L - \frac{v_{co}}{R_o} \qquad (13)$$

By solving the four differential equations (10-13) with the component values as shown in table-1 , we can get the response v_o (t) for the ZCS-QR boost and buck converters as shown in Figs. 8 and 9, respectively.

4-CONCLUSION

The average-switch modeling method is a simple method to model ZCS and PWM DC-DC converters operating in the continuous mode. This model gives the same results (shown in Fig.

10) as the method given by L. K. Wong, Frank H. Leung, and peter K.S. Tam (1997) and circuit simulator method. It is simple and fast method to obtain the model.

Another advantage of this model is that the model directly corresponds to the original converter circuit, only the switches are replaced by their model. All branch currents and node voltages of the converter are directly available from the model as averaged quantities.

	ZCS Buck	ZCS Boost
V_i	15V	15V
L_r	1.6μH	0.16μH
C_r	0.064μF	0. 64μF
L	100μH	100μH
C	1μF	10μF
R_o	10Ω	20Ω

Table –1: Component Values of Test Circuit.

5-REFERENCES:-

Arthur F. Witulski, and Robert W. Erickson 1990, “Extension of state-space Average to Resonant Switches and Beyond,” IEEE Trans. Power Elecronic. Vol. 5, No. 1,PP.98-109.

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Kwang-Hwa Liu, Ramersh Oruganti, and Fred C.Y. Lee (1987),”Quasi-Resonant Converters-Topologies and Characteristics,” IEEE Trans. Power elecronic. Vol. PE-2, No. 1, PP.62-71.

L.K. wong, Frank H.Leung, and Peter K.S. Tam , “Asimple Large Signal nonlinear(1997) modelling Approach for Fast Simulation of Zero-Current-Switch Quasi-Resonant Converter’s,” IEEE Trans. Power Elecronic. Vol. 12, No. 3.

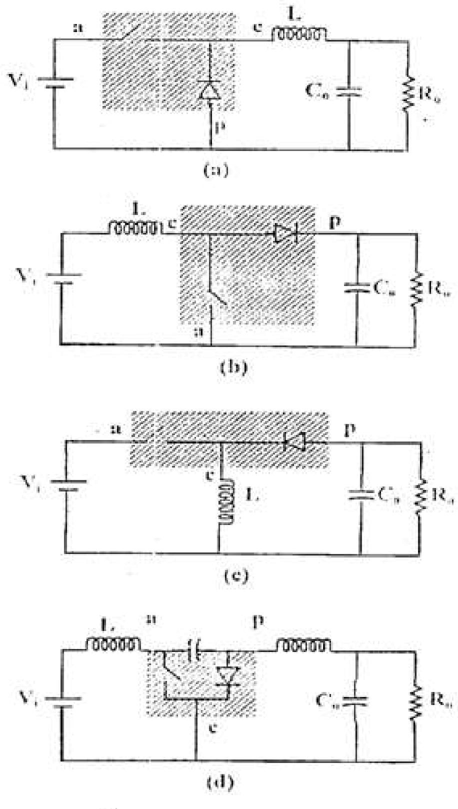


Fig. 1 Four basic DC-DC converters.
(a) Buck (b) Boost (c) Buck-Boost (d) Cuk

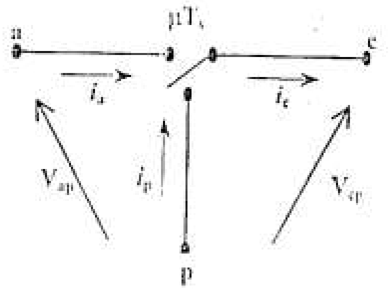


Fig. 2 Average Switch

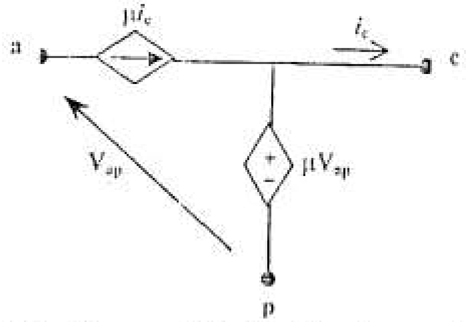


Fig. 3 Averaged Model of the Average Switch

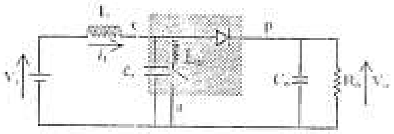


Fig. 4 The ZCS-QR boost converter

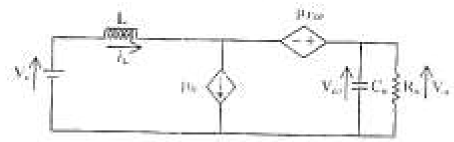


Fig. 5 The ZCS-QR boost converter with Average Switch replaced by the model shown in Fig. 3

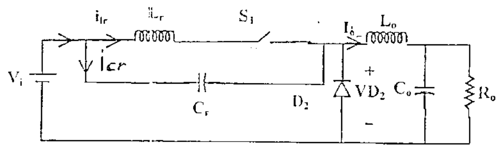
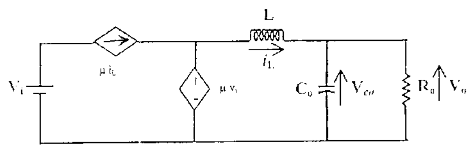


Fig. 6 The ZCS-QR Buck converter



(b)

Fig. 7 The ZCS-QR Buck converter with Average Switch replaced by the model shown in Fig. 3

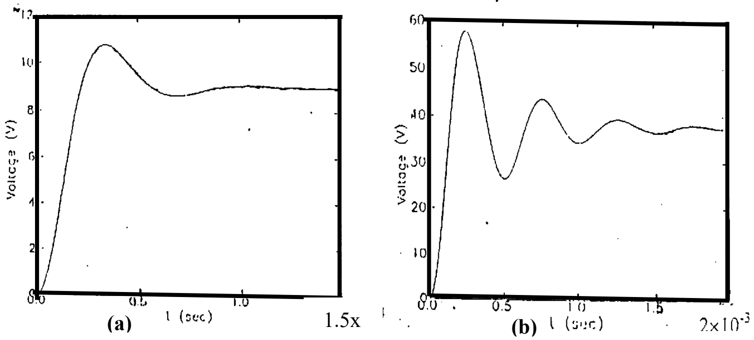


Fig.8 The transient reponse obtained on the proposed moduling approach
(a) buck converter (b) boost converter

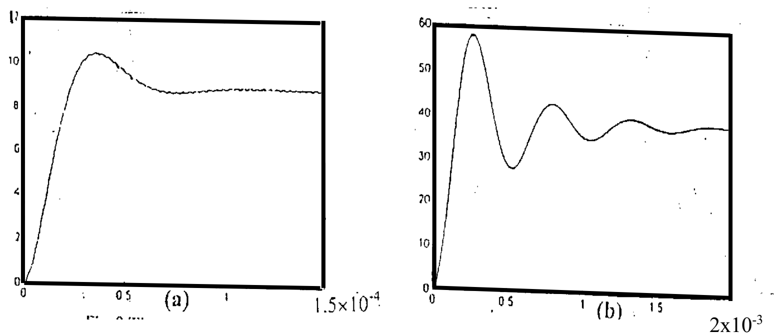


Fig.9 The transient response obtained based on the circuit simulator method.
(a) buck converter (b) boost converter

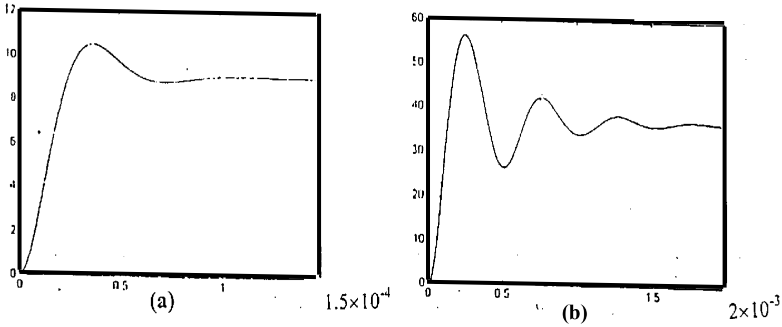


Fig.10 The transient response obtained based on the method proposed in [4]
(a) buck converter (b) boost converter