THE MULTI INPUT-MULTI OUTPUT STATE SPACE AVERAGE MODEL OF KY BUCK-BOOST CONVERTER INCLUDING ALL OF THE SYSTEM PARAMETERS

Mohammad Reza Modabbernia[1], Seyedeh Shiva Nejati[2] &
Fatemeh Kohani Khoshkbijari [3]
[1]Electrical Engineering Group, Technical and Vocational University, Rasht, Iran
[2]Electrical Engineering Group, Sardar Jangal Higher Education Institute, Rasht, Iran
[3]Sama Technical and Vocational Training College, Islamic Azad University, Rasht, Iran

ABSTRACT

In this paper a complete multi input-multi output state-space average model for the KY buck-boost converter is presented. The introduced model includes the most of the regulator's parameters and uncertainties. In modeling, the load current is assumed to be unknown, and it is assumed that the inductor, capacitor, diode and regulator active switches are non ideal and have a resistance in conduction condition. Some other non ideal effects look like voltage drop of conduction mode of the diode and active switches are also considered. After presenting the complete model, the KY buck-boost converter Benchmark circuit is simulated in PSpice and its results are compared with our model simulation results in MATLAB SIMULINK. The results show the merit of our model.

KEYWORDS: *KY buck-boost converter, average model, SMPS, SIMULINK, PSpice.*

I. INTRODUCTION

In many applications such as portable devices, personal computers, car equipments, etc., there is a main supply that must be converted to some other smaller or greater voltages. In these applications buck-boost converters are very efficient. Recently, a new circuit was introduced for buck-boost converter by Hwu based on the KY converter structure [1]. This regulator has a good transient response and its performance is look like buck converter without any right half plan zeros [2]. One of the other advantages of this converter is its continuous conduction mode (CCM) performance, which decreases the output voltage ripple [1-2].

The topology of DC-DC converters consists of two linear (resistor, inductor and capacitor) and nonlinear (diode and active switches) parts. Because of the switching properties of the power elements, the operation of these converters varies by time. Since these converters are nonlinear and time variant, to design a linear controller, we need to find a small signal model basis of linearization of the state space average model about an appropriate operating point of it. The small signal analysis and modeling in frequency domain for DC-DC converters are carried out by references [3-5].

A complete model with all of the converter parameters (such as turn-on resistance of the diode and active switches, resistance of inductor and capacitor, and unidentified load current that it can receive from the converter) is the main step in designing a non conservative robust controller for the regulators [6-7]. The essential of KY converters and their derivatives are introduced by Hwu in 2009 [8], but a model that consists of the aforementioned parameters was not presented yet.

The average model of KY buck-boost converter is presented in [1-2] without concerning the deviation of input capacitance (C). A model for KY and second-order-derived KY converter is presented in [8-9]. In [10], a model for KY Boost converter is introduced. Inverse KY converter and its model are demonstrated in [11]. The transfer function of negative-output KY buck converter and the steady state model of KY voltage-boosting converter with leakage inductance and without leakage inductance are

introduced in [12-13] respectively. In these references the model of converters were calculated by minimum parameters and all of the switches and diodes assumed are ideal. Their on state resistance and voltage drop are neglected and there are not any parasitic resistance for capacitances and inductors.
This paper is organized in seven parts. On the basis of state space average method [3], we first obtain the state space equations of a KY buck-boost regulator in turn on and turn off modes by considering all the system parameters such as an inductor with resistance, a capacitor with resistance, a diode and switches on mode resistance and voltage drop, a load resistance and unidentified load current in section II. Then in section III, the state equations are linearized around circuit operation point (input DC voltage and current versus output DC voltage) in section IV. The coefficients of state space equations will therefore be dependent on the DC operating point in addition to the circuit parameters. At the end the duty cycle parameter "d" (control input) is extracted from the coefficients and introduced as an input. This work was introduced for the Boost and Buck-boost converters in [14-15] respectively. The effects of parasitic resistances, on state voltage drop of switches and the deviation of load current can be studied with this completed model. In section V, by neglecting the parasitic resistances of the regulator's elements $(r_m = r_d = r_L = r_C = r_{Co} = 0)$, the steady state average model of KY buck-boost converter will be simplified. Anybody can use this simple model to design a linear controller for the converter and then utilize the complete model for analyzing the robustness of his or her controller [16-17].
In section VI, the KY buck-boost converter Benchmark circuit is simulated in PSpice and its results are compared with our complete model simulation results in MATLAB. The simulations were done in three scenarios. The results are so closed to each other. Finally, in Section VII, some suggestions are presented for future works.

II. KY BUCK-BOOST CONVERTER STATE EQUATIONS FOR ON-OFF TIME SWITCHING

In modeling of the state space, the state variable which principally are the elements that store the energy of circuit or system (capacitance voltage and inductor current) have significant importance. In an electronic circuit, the first step in modeling is converting the complicated circuit, into basic circuit in which the circuit lows can be established. In switching regulators, there are two regions; the on region and off region. The on time denoted by dT, and the off time is denoted by $d'T = (1-d)T$, in which T is the period of steady state output voltage. "Fig.1" shows a KY buck-boost converter. The switch is turned on (off) by a pulse with a period of T and its duty cycle is *d*. Therefore we can represent the equivalent circuit of the system in two on and off modes with dT and $d'T$ seconds respectively, by "Fig.2" and "Fig.3". By considering i_L, v_C and v_{Co} as our state variables ($x = [i_L \quad v_C \quad v_{Co}]'$) and writing the KVL for the loops of "Fig.2", we will have:

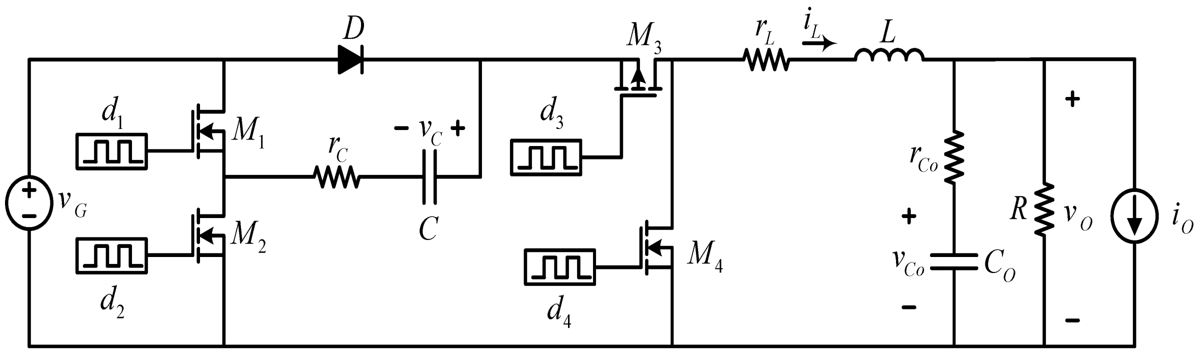

Figure 1. KY Buck-boost regulator circuit

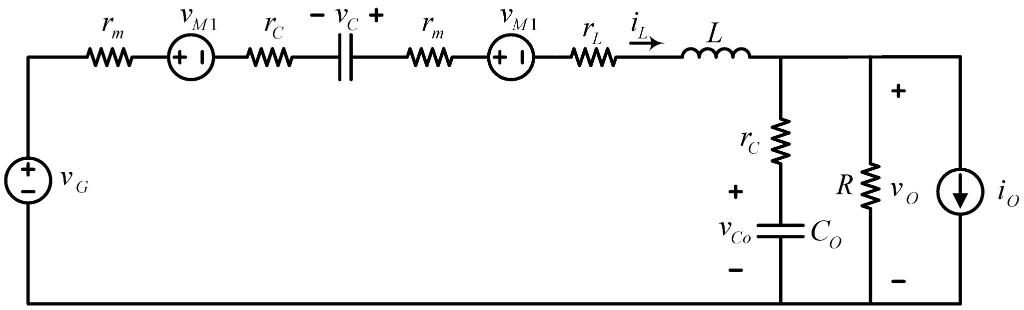

Figure 2. Equal circuit of KY Buck-boost regulator in on times

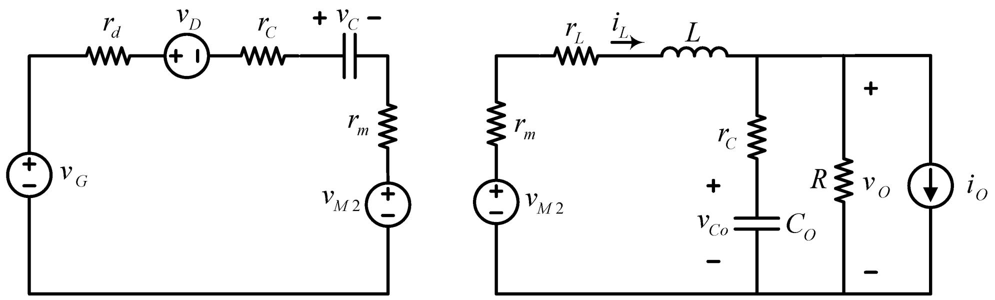

Figure 3. Equal circuit of KY Buck-boost regulator in off times

$$\begin{cases} \dot{x} = A_1\ x + B_1\ u \\ y = C_1\ x + D_1\ u \end{cases} \quad x = \begin{bmatrix} i_L \\ v_C \\ v_{Co} \end{bmatrix} \quad u = \begin{bmatrix} v_G \\ i_O \\ v_{M1} \\ v_{M2} \\ v_D \end{bmatrix} \quad y = \begin{bmatrix} i_L \\ v_O \end{bmatrix} \tag{1}$$

$$A_1 = \begin{bmatrix} \dfrac{-(r_L + 2r_m + r_C) - (R \| r_{Co})}{L} & \dfrac{1}{L} & \dfrac{-R}{(R + r_{Co})\, L} \\ \dfrac{-1}{C} & 0 & 0 \\ \dfrac{R}{(R + r_{Co})\, C_o} & 0 & \dfrac{-1}{(R + r_{Co})\, C_o} \end{bmatrix} \tag{2}$$

$$B_1 = \begin{bmatrix} \dfrac{1}{L} & \dfrac{R \| r_{Co}}{L} & \dfrac{-2}{L} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & \dfrac{-R}{(R + r_{Co})\, C_o} & 0 & 0 & 0 \end{bmatrix} \tag{3}$$

$$C_1 = \begin{bmatrix} 1 & 0 & 0 \\ (R \| r_{Co}) & 0 & \dfrac{R}{(R + r_{Co})} \end{bmatrix} \tag{4}$$

$$D_1 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & -(R \| r_{Co}) & 0 & 0 & 0 \end{bmatrix} \tag{5}$$

Also for off time or $d'\,T$ seconds the KVL equations from "Fig.3" are given by "(2)".

$$\begin{cases} \dot{x} = A_2\ x + B_2\ u \\ y = C_2\ x + D_2\ u \end{cases} \qquad x = \begin{bmatrix} i_L \\ v_C \\ v_{Co} \end{bmatrix} \qquad u = \begin{bmatrix} v_G \\ i_O \\ v_{M1} \\ v_{M2} \\ v_D \end{bmatrix} \qquad y = \begin{bmatrix} i_L \\ v_O \end{bmatrix} \tag{6}$$

$$A_2 = \begin{bmatrix} \frac{-(r_L + r_m) - (R\|r_{Co})}{L} & 0 & \frac{-R}{(R + r_{Co})\,L} \\ 0 & \frac{-1}{(r_d + r_m + r_C)C} & 0 \\ \frac{R}{(R + r_{Co})\,C_o} & 0 & \frac{-1}{(R + r_{Co})\,C_o} \end{bmatrix} \tag{7}$$

$$B_2 = \begin{bmatrix} 0 & \frac{R\| r_{Co}}{L} & 0 & \frac{1}{L} & 0 \\ \frac{1}{(r_d + r_m + r_C)C} & 0 & 0 & \frac{-1}{(r_d + r_m + r_C)C} & \frac{-1}{(r_d + r_m + r_C)C} \\ 0 & \frac{-R}{(R + r_{Co})\,C_o} & 0 & 0 & 0 \end{bmatrix} \tag{8}$$

$$C_2 = \begin{bmatrix} 1 & 0 & 0 \\ (R\| r_{Co}) & 0 & \frac{R}{(R + r_{Co})} \end{bmatrix} \tag{9}$$

$$D_2 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & -(R\| r_{Co}) & 0 & 0 & 0 \end{bmatrix} \tag{10}$$

The set of state equations "(1)" to "(10)" shows the state of KY buck-boost converter in the on and off time of switches. We can combine these two set of equations as following [5]:

$$\begin{cases} \dot{x} = A_P\, x + B_P\ u \\ y = C_P\, x + D_P\ u \end{cases} \qquad \begin{cases} A_P = A_1\, d + A_2\,(1-d) \\ B_p = B_1\, d + B_2\,(1-d) \\ C_p = C_1\, d + C_2\,(1-d) \\ D_p = D_1\, d + D_2\,(1-d) \end{cases} \tag{11}$$

By substituting equations "(1)" to "(10)" we can obtain coefficients of A_P to D_P.

$$A_P = \begin{bmatrix} \frac{-(r_L + r_m) - (R\|r_{Co}) - (r_m + r_C)d}{L} & \frac{d}{L} & \frac{-R}{(R + r_{Co})\,L} \\ \frac{-d}{C} & \frac{-d'}{(r_d + r_m + r_C)} & 0 \\ \frac{R}{(R + r_{Co})\,C_o} & 0 & \frac{-1}{(R + r_{Co})\,C_o} \end{bmatrix} \tag{12}$$

$$B_P = \begin{bmatrix} \frac{d}{L} & \frac{R\|r_{Co}}{L} & \frac{-2d}{L} & \frac{d'}{L} & 0 \\ \frac{d'}{(r_d + r_m + r_C)C} & 0 & 0 & \frac{-d'}{(r_d + r_m + r_C)C} & \frac{-d'}{(r_d + r_m + r_C)C} \\ 0 & \frac{-R}{(R + r_{Co})\,C_o} & 0 & 0 & 0 \end{bmatrix} \quad (13)$$

$$C_P = \begin{bmatrix} 1 & 0 & 0 \\ (R\|r_{Co}) & 0 & \frac{R}{(R + r_{Co})} \end{bmatrix} \quad (14)$$

$$D_P = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & -(R\|r_{Co}) & 0 & 0 & 0 \end{bmatrix} \quad (15)$$

III. LINEARIZATION OFF STATE EQUATIONS AROUND OPERATING POINT

The results presented in section II are acceptable when the circuit time constant is much larger than the period of switching. . If the duty cycle be a constant value ($d = D$), the state equations in "(11)" will become linear. For regulating the voltage on a desired value, we have to change the value of D by a controller. In general, the state equations of "(11)" are nonlinear and we have to linear them around an operating point (D). When the system is in equilibrium and the duty cycle is on its nominal value (D), then we can obtain the system state values in equilibrium points ($X = [I_L \quad V_C \quad V_{Co}]'$) and the DC outputs values.

$$\dot{x} = A_P\big|_{d=D}\, x + B_p\big|_{d=D}\, u = 0 \quad \Rightarrow \quad X = -A_P^{-1} B_p \begin{bmatrix} V_G \\ I_O \\ V_{M1} \\ V_{M2} \\ V_D \end{bmatrix} = \begin{bmatrix} I_L \\ V_C \\ V_{Co} \end{bmatrix} \quad with \quad d = D \quad (16)$$

$$Y = C_p\big|_{d=D}\, X + D_p\big|_{d=D}\, U \quad , \quad Y = \begin{bmatrix} I_L \\ V_O \end{bmatrix} \quad with \quad d = D \quad (17)$$

Where X was calculated from equation "(16)". Finally for linearization of the system, on basis of classic method, we divided our variables into two parts. The first part is static part (a fixed DC level), and the second part is a small amplitude that modulates the DC level. On this basis, the variables in the state equations can be defined as follows:

$$\begin{cases} x(t) = X + \hat{x} \\ d(t) = D + \hat{d} \end{cases} \qquad \begin{cases} u(t) = U + \hat{u} \\ y(t) = Y + \hat{y} \end{cases} \quad (18)$$

In which $Y = [I_L \quad V_O]$, $X = [I_L \quad V_C \quad V_{Co}]'$ and $U = [V_G \quad I_O \quad V_{M1} \quad V_{M2} \quad V_D]'$ are the nominal values of the DC outputs, state variables and no controllable inputs respectively. Each of them has small variations (denoted with ^) around nominal values. By substituting equations "(18)" in "(11)" and assumed that the duty cycle d has also variation $\hat{d}$ ($d = D + \hat{d}$), we will have

$$\begin{cases} \dot{X} + \dot{\hat{x}} = A_P\,\hat{x} + B_P\,\hat{u} + \left[\left(A_1 - A_2\right)X + \left(B_1 - B_2\right)U\right]\hat{d} + \dot{X} \\ \dot{Y} + \dot{\hat{y}} = C_P\,\hat{x} + D_P\,\hat{u} + \left[\underbrace{\left(C_1 - C_2\right)}_{0}X + \underbrace{\left(D_1 - D_2\right)}_{0}U\right]\hat{d} + \dot{Y} \end{cases} \tag{19}$$

$$\begin{cases} \dot{\hat{x}} = A_P\,\hat{x} + B_P\,\hat{u} + E\,\hat{d} \\ \dot{\hat{y}} = C_P\,\hat{x} + D_P\,\hat{u} \end{cases} \quad , \quad E = \left(A_1 - A_2\right)X + \left(B_1 - B_2\right)U \tag{20}$$

IV. STATE SPACE AVERAGE MODEL

An important point in the set equation "(20)" is that A_P and C_P are related to $d'=1-d$. Since $d = D + \hat{d}$ then A_P and C_P are related to $\hat{d}$. It can be shown that with good approximation this dependence is negligible. By sub situation A_P, B_P, C_P and D_P by their equivalents in term of d, A_1, B_1, C_1 and D_1 we will obtain:

$$\begin{cases} \dot{\hat{x}} = \left[A_1\,d + A_2\left(1-d\right)\right]\hat{x} + \left[B_1\,d + B_2\left(1-d\right)\right]\hat{u} + E\,\hat{d} \\ \hat{y} = \left[C_1\,d + C_2\left(1-d\right)\right]\hat{x} + \left[D_1\,d + D_2\left(1-d\right)\right]\hat{u} \end{cases} \tag{21}$$

$d = D + \hat{d}$ therefore, we have for the first above equation.

$$\dot{\hat{x}} = \left[A_1\,D + A_2\left(1-D\right)\right]\hat{x} + \left[B_1\,D + B_2\left(1-D\right)\right]\hat{u} + E\,\hat{d} + \left(A_1 - A_2\right)\hat{d}\,\hat{x} + \left(B_1 - B_2\right)\hat{d}\,\hat{u} \tag{22}$$

Since $\hat{d}$, $\hat{u}$ and $\hat{x}$ denotes small variation of the duty cycle, input and state of system respectively, their product is very small and we can neglect terms such as $\hat{d}\,\hat{x}$ and $\hat{d}\,\hat{u}$.

$$\dot{\hat{x}} = A\hat{x} + B\,\hat{u} + E\,\hat{d} \tag{23}$$

In the same manner, the effect of $\hat{d}\,\hat{x}$ and $\hat{d}\,\hat{u}$ in second equation of "(21)" is negligible. Therefore we can represent the KY buck-boost regulator state equations like this:

$$\begin{cases} \dot{\hat{x}} = A\,\hat{x} + B\hat{u} + E\,\hat{d} \\ \dot{\hat{y}} = C\,\hat{x} + D\hat{u} \end{cases} \quad \hat{x} = \begin{bmatrix} i_L \\ v_C \\ v_{Co} \end{bmatrix} \quad \hat{u} = \begin{bmatrix} v_G \\ i_O \\ v_{M1} \\ v_{M2} \\ v_D \end{bmatrix} \quad \hat{y} = \begin{bmatrix} i_L \\ v_O \end{bmatrix} \tag{24}$$

$$A = \begin{bmatrix} \dfrac{-\left(r_L + r_m\right) - \left(R \| r_{Co}\right) - \left(r_m + r_C\right)D}{L} & \dfrac{D}{L} & \dfrac{-R}{\left(R + r_{Co}\right)L} \\ \dfrac{-D}{C} & \dfrac{-D'}{\left(r_d + r_m + r_C\right)} & 0 \\ \dfrac{R}{\left(R + r_{Co}\right)C_o} & 0 & \dfrac{-1}{\left(R + r_{Co}\right)C_o} \end{bmatrix} \tag{25}$$

$$B=\begin{bmatrix} \frac{D}{L} & \frac{R\| r_{Co}}{L} & \frac{-2D}{L} & \frac{D'}{L} & 0 \\ \frac{D'}{(r_d+r_m+r_C)C} & 0 & 0 & \frac{-D'}{(r_d+r_m+r_C)C} & \frac{-D'}{(r_d+r_m+r_C)C} \\ 0 & \frac{-R}{(R+r_{Co})\,C_o} & 0 & 0 & 0 \end{bmatrix} \quad (26)$$

$$C=\begin{bmatrix} 1 & 0 & 0 \\ (R\| r_{Co}) & 0 & \frac{R}{(R+r_{Co})} \end{bmatrix} \quad (27)$$

$$D=\begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & -(R\| r_{Co}) & 0 & 0 & 0 \end{bmatrix} \quad (28)$$

E can be calculated with equation "(20)".

V. A SPECIAL CASE

By neglecting the parasitic resistances of the regulator's elements $(r_m=r_d=r_L=r_C=r_{Co}=0)$, the steady state average model of KY buck-boost converter will be simplified. During the off state of M_2 and M_4 Mosfets $(d'T=(1-D)T=T_{off})$, the voltage of input capacitance (C) will be constant $(V_C=V_G-V_{M1}-V_D)$. This capacitance is charged rapidly and saved its voltage during the time dT interval. In this situation, one of the state of the converter (v_C) was neglected and the steady state average model of KY buck-boost converter will be replaced by equations set "(29)".

$$\begin{cases} \dot{x}=A\ x+Bu+E\,d \\ y=C\ x+Du \end{cases} \qquad x=\begin{bmatrix} i_L \\ v_{Co} \end{bmatrix} \qquad u=\begin{bmatrix} v_G \\ i_O \\ v_{M1} \\ v_{M2} \\ v_D \end{bmatrix} \qquad y=\begin{bmatrix} i_L \\ v_O \end{bmatrix}$$

$$A=\begin{bmatrix} 0 & \frac{-1}{L} \\ \frac{1}{C_o} & \frac{-1}{RC_o} \end{bmatrix} \qquad B=\begin{bmatrix} \frac{2D}{L} & 0 & \frac{-2D}{L} & \frac{1-2D}{L} & \frac{-D}{L} \\ 0 & \frac{1}{C_o} & 0 & 0 & 0 \end{bmatrix} \qquad C=\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \quad (29)$$

$$D=\begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} \qquad E=\begin{bmatrix} \left(\frac{2}{L}V_G-\frac{2}{L}V_{M1}-\frac{2}{L}V_{M2}-\frac{1}{L}V_D\right) \\ 0 \end{bmatrix}$$

Applying the laplace transform to model equations "(29)" yields 12 transfer functions which the following output voltage and inductor current to duty-cycle (d) and input voltage transfer functions have been shown:

$$\frac{v_o}{d} = \frac{\frac{1}{LC_o}\left(2V_G - 2V_{M1} - 2V_{M2} - V_D\right)}{S^2 + \left(\frac{1}{RC_o}\right)S + \left(\frac{1}{LC_o}\right)} \tag{30}$$

$$\frac{v_o}{v_G} = \frac{\frac{2D}{LC_o}}{S^2 + \left(\frac{1}{RC_o}\right)S + \left(\frac{1}{LC_o}\right)} \tag{31}$$

$$\frac{i_L}{d} = \frac{\frac{1}{L}\left(2V_G - 2V_{M1} - 2V_{M2} - V_D\right)\left(S + \frac{1}{RC_o}\right)}{S^2 + \left(\frac{1}{RC_o}\right)S + \left(\frac{1}{LC_o}\right)} \tag{32}$$

$$\frac{i_L}{v_G} = \frac{\frac{2D}{L}\left(S + \frac{1}{RC_o}\right)}{S^2 + \left(\frac{1}{RC_o}\right)S + \left(\frac{1}{LC_o}\right)} \tag{33}$$

VI. SIMULATION WITH PSPISE AND MATLAB

To show the accuracy of our model, we simulate the KY buck-boost benchmark circuit with PSpice and then compare its consequences with the simulation results of presented model in MATLAB SIMULINK. "Fig. 4" and "Fig. 5" show the KY buck-boost benchmark circuit in PSpice and "Fig. 6" and "Fig. 7" show its equivalent model in SIMULINK respectively. The simulations were performed under the following conditions: L = 10 mH, C =1 mF, C_O = 1 μF, R =10 Ω, r_m=r_d=r_C = 0.1Ω, r_L = 0.2 Ω and V_G = 12 V. The switching frequency is 50 kHz and various cases of simulation have been considered.

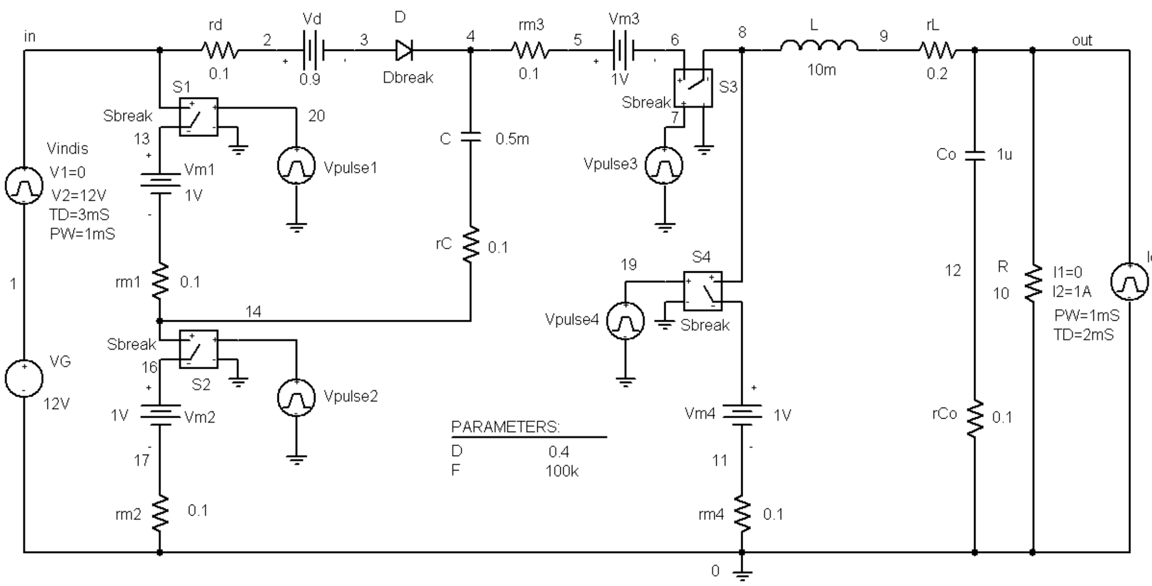

Figure 4. The KY buck-boost benchmark circuit in PSpice with Switch

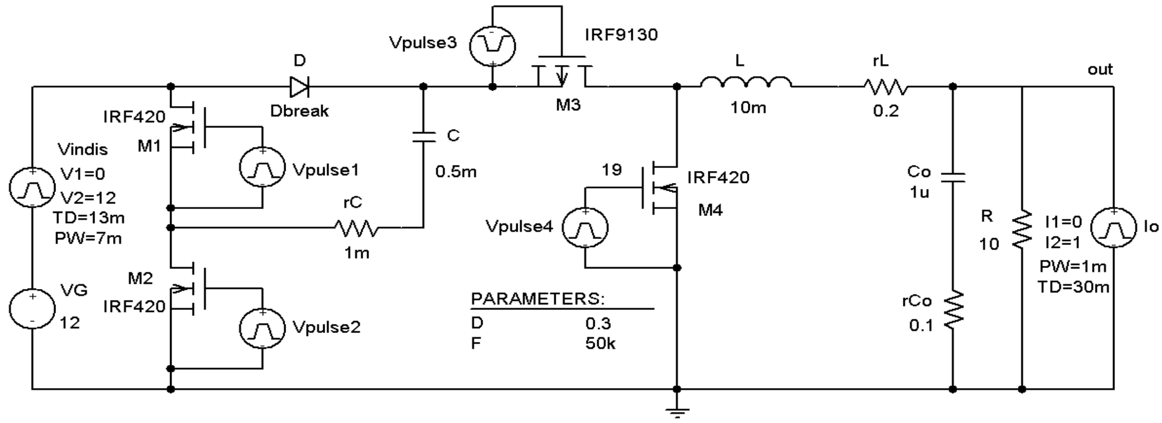

Figure 5. The KY buck-boost benchmark circuit in PSpice with Mosfet

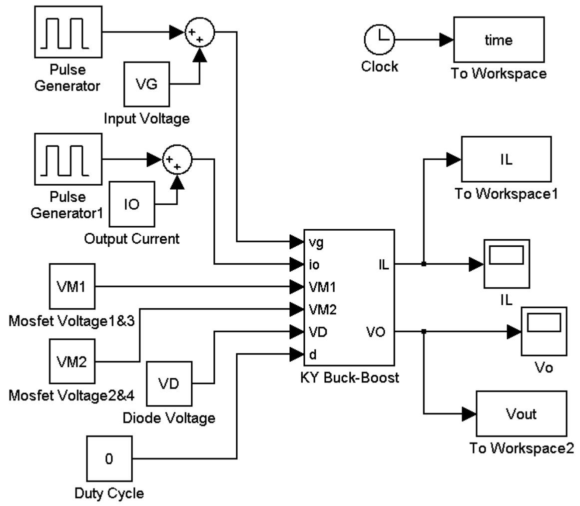

Figure 6. The KY buck-boost benchmark circuit in SIMULINK

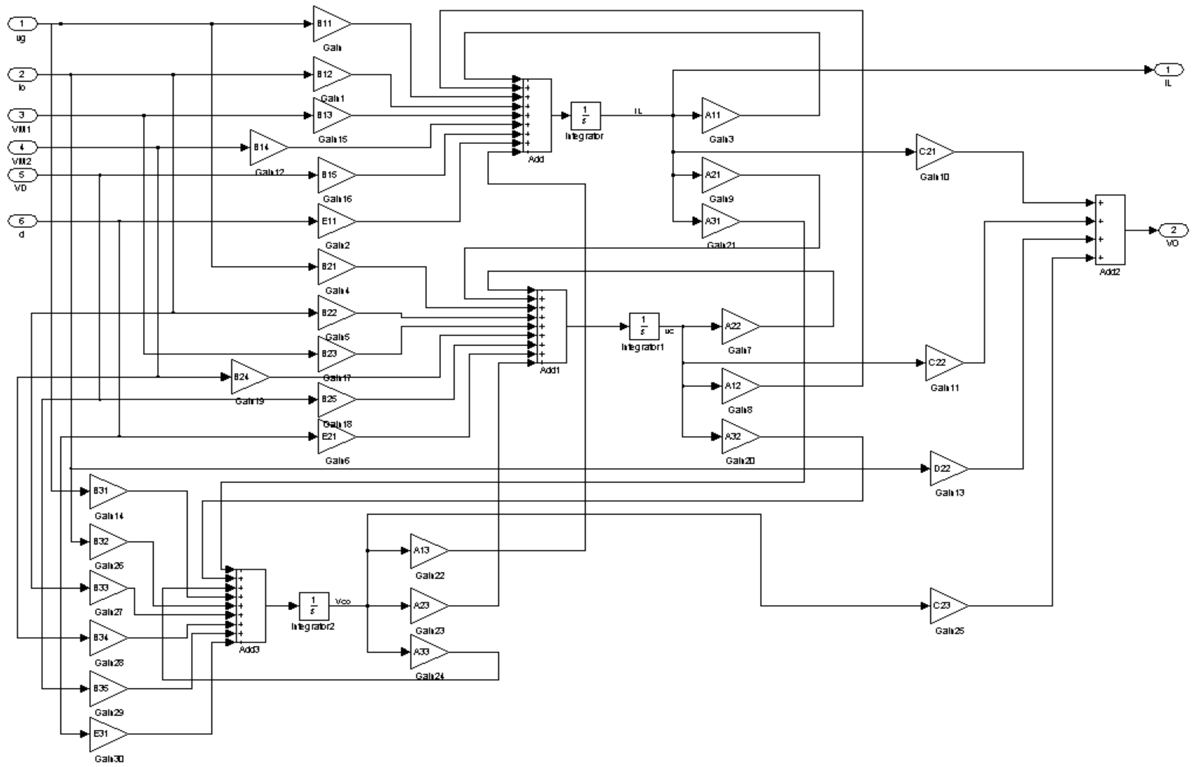

Figure 7. Equivalent model of KY Buck-boost regulator in SIMULINK

6.1. Analog switches with 1V forward voltage drop and disturbance in output current

In this scenario, "Fig. 4" with PSpice analog switches has been used. The resistance of switches and their forward voltage drop are r_m= 0.1Ω and V_{m1}= V_{m2} = 1V respectively. Also, the diode on state resistance and its forward voltage drop has been considered 0.1Ω and 0.9V. The output current is I_O=2A and there is a 1A sudden rise in it. The simulation results with D=0.4 were shown by "Fig. 8" and "Fig. 9" in PSpice and MATLAB respectively. The regulator works look like a Buck converter because its duty cycle is D=0.4, therefore, its output voltage will be 8.35V and 8.537V in PSpice and MATLAB respectively. In table I, the results of these two simulations have been compared with each other.

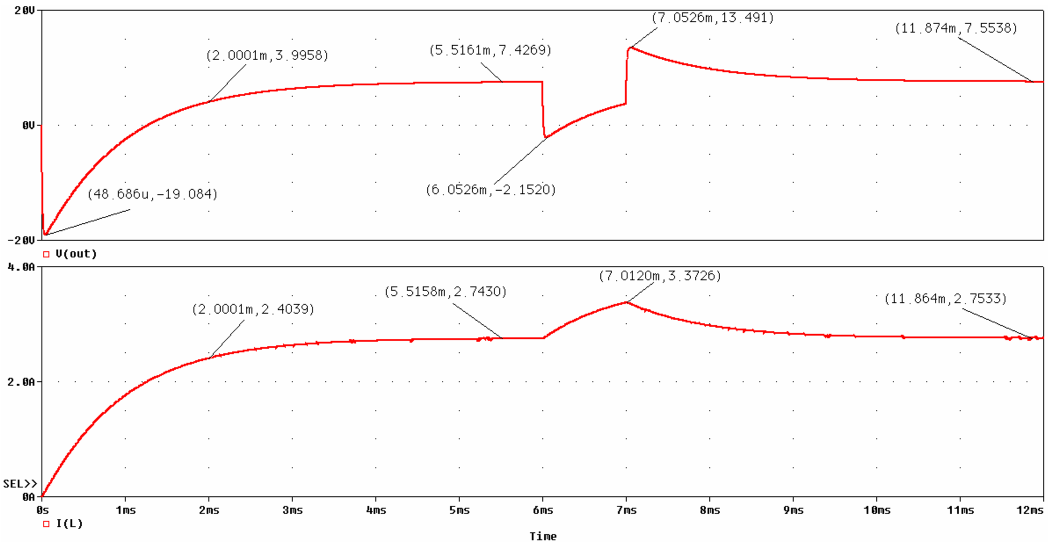

Figure 8. PSpice Output voltage and Load Current with I_O = 2 A, V_D = 0.9 V, V_M = 1 V and 1A sudden rise in I_O

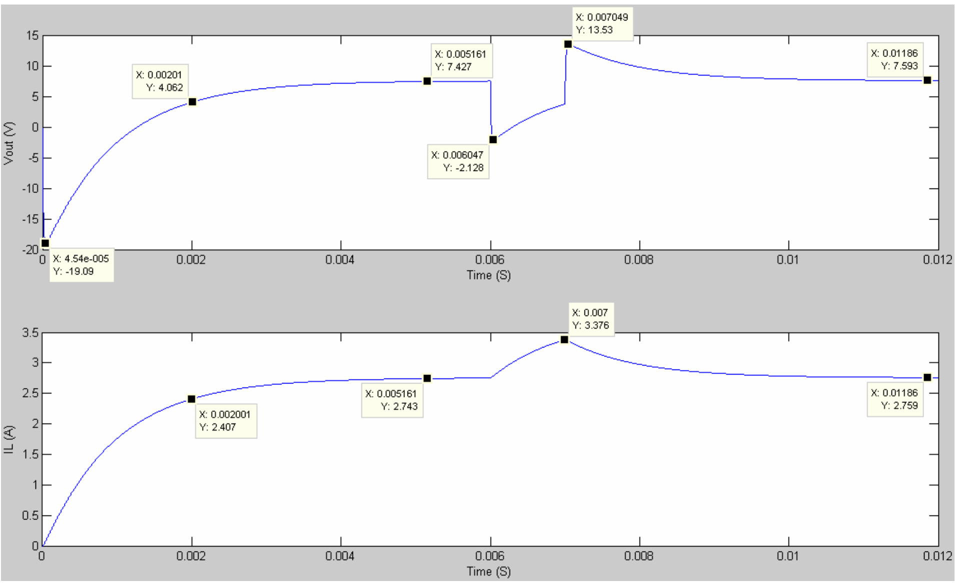

Figure 9. MATLAB Output voltage and Load Current with I_O = 2A,V_D = 0.9V,V_M = 1V and 1A sudden rise in I_O

TABLE 1. COMPARING THE RESULTS WITH I_O = 2 A, V_D = 0.9 V, V_M = 1 V AND 1A SUDDEN RISE IN I_O

	Steady State Output Voltage	**Steady State Output Current**
PSpice	7.4269 V	2.743 A
MATLAB	7.427 V	2.743 A

6.2. Analog switches with 1V forward voltage drop and disturbance in output voltage

In this scenario, "Fig. 4" with PSpice analog switches has been used. The resistance of switches and their forward voltage drop are r_m= 0.1Ω and V_{m1}= V_{m2} = 1V respectively. Also, the diode on state resistance and its forward voltage drop has been considered 0.1Ω and 0.9V. The output current is I_O=0A. The simulation results with D=0.8 and a 12V sudden rise in input voltage were shown by "Fig. 10" and "Fig. 11" in PSpice and MATLAB respectively. The regulator works look like a Boost converter because its duty cycle is D=0.8, therefore, its output voltage will be 14.691V and 14.77V in PSpice and MATLAB respectively. In table 2, the results of two simulations have been compared with each other.

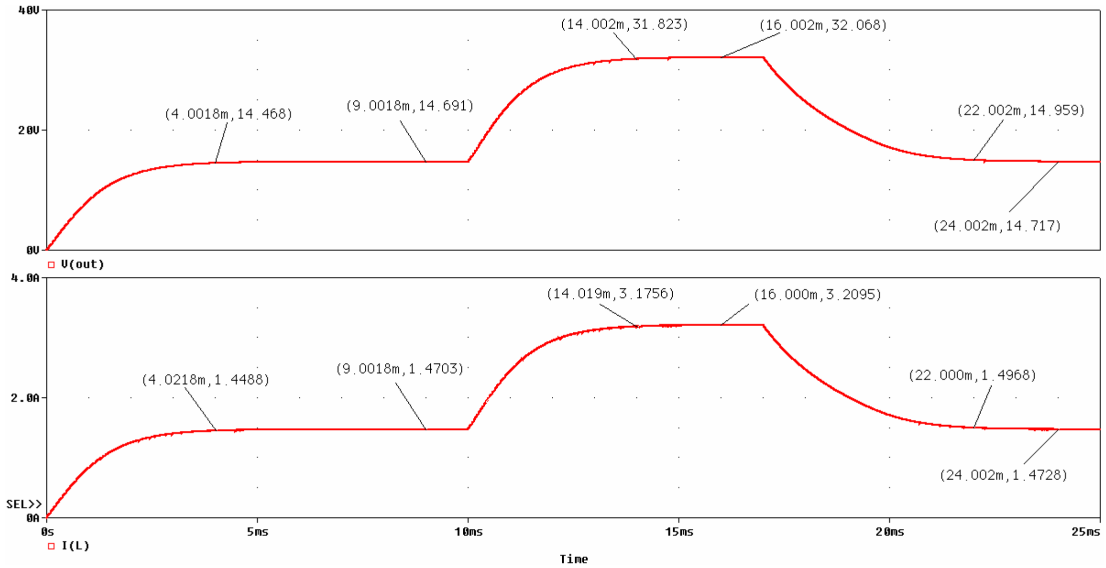

Figure 10. PSpice Output voltage and Load Current with I_O = 0 A, V_D = 0.9 V, V_M = 1 V and 12V sudden rise in *input Voltage*

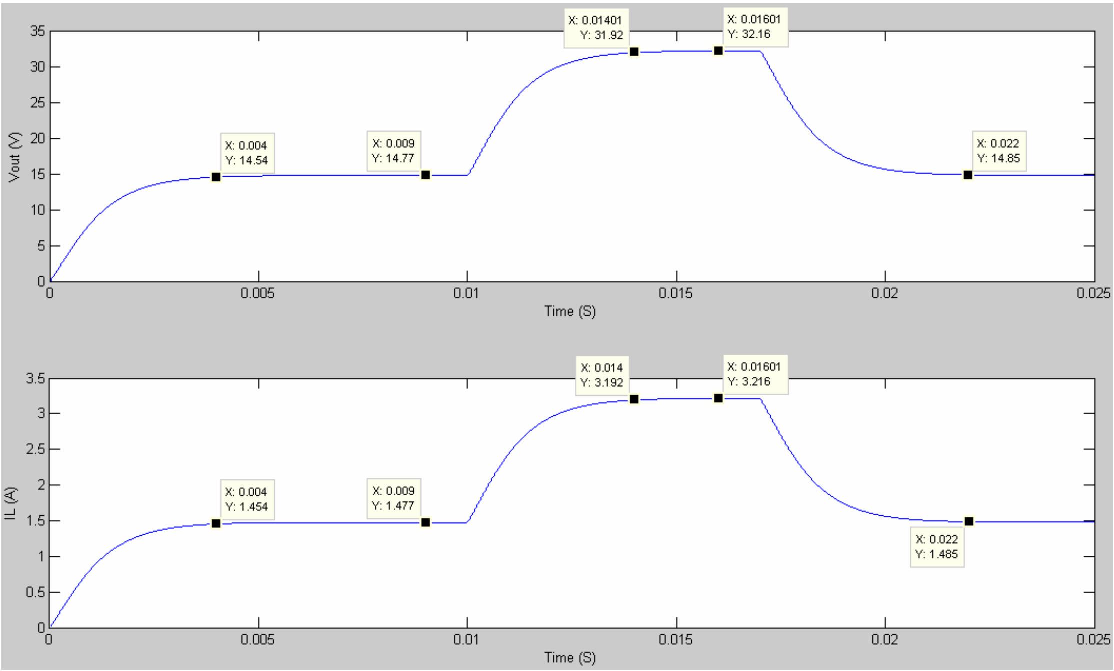

Figure 11. MATLAB Output voltage and Load Current with I_O = 0 A, V_D = 0.9 V, V_M = 1 V and 12V sudden rise in *input Voltage*

TABLE 2. COMPARING THE RESULTS WITH I_O = 0 A, V_D = 0.9 V, V_M = 1 V AND 12V SUDDEN RISE IN *INPUT VOLTAGE*

	Steady State Output Voltage	Steady State Output Current
PSpice	14.691 A	1.47 A
MATLAB	14.77 V	1.477 A

6.3. 12V and 1A disturbances in the input voltage and load current with IRF450 and IRF9130 Mosfets

If we consider three IRF450 n-Mosfet instead of M_1 , M_2 and M_4 switches, and one IRF9130 p-Mosfet instead of M_3 switch, we will have a practical simulation in PSpice. The results of simulation with I_O = 0 A, 12V sudden rise in input voltage and 1A pulse disturbance in output current were shown by “Fig.12” and “Fig. 13” in PSpice and MATLAB respectively. In table 3, the results of these simulations have been compared with each other.

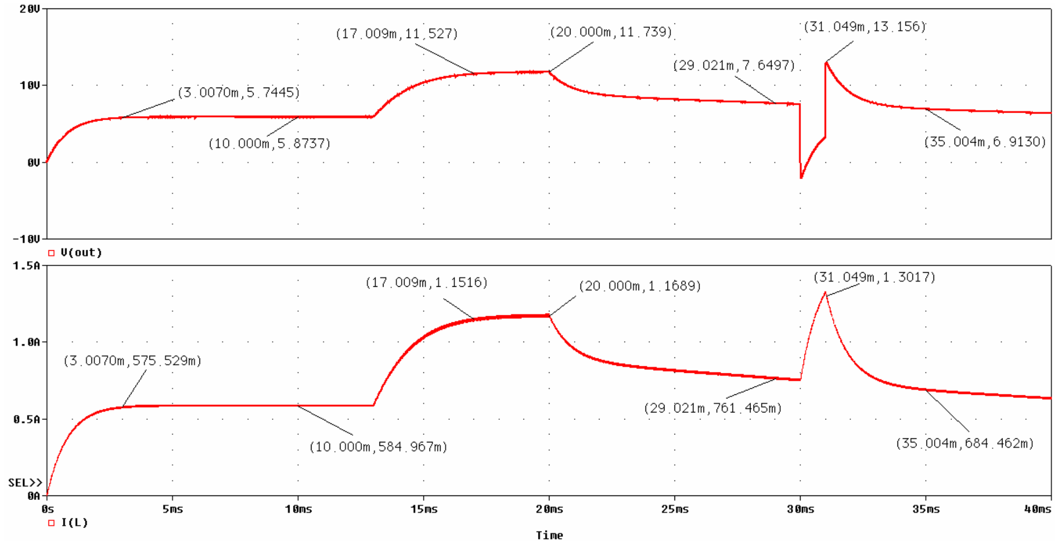

Figure 12. PSpice Output voltage and Load Current with *Real Mosfet and Diode*. There are a 12V and 1A disturbances in input voltage and load current respectively

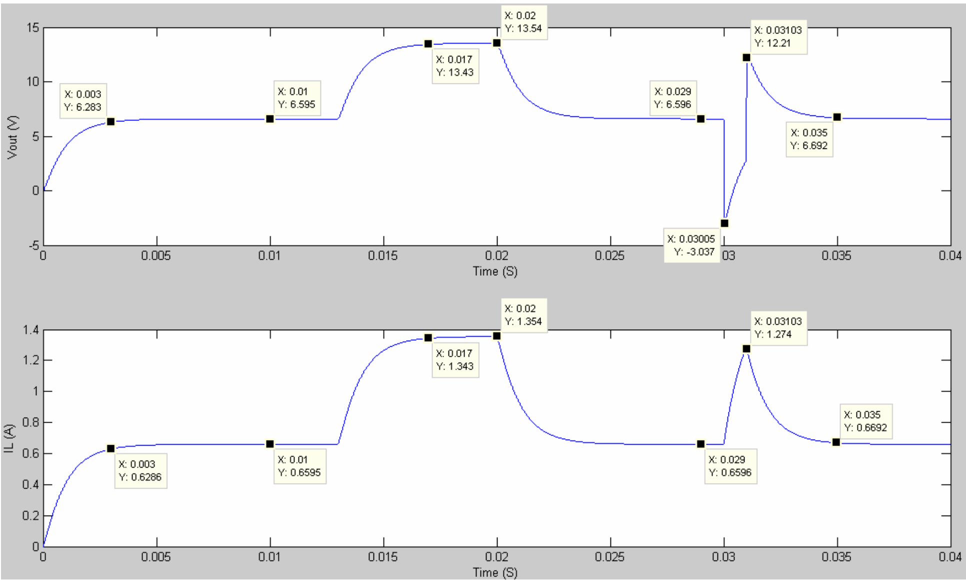

Figure 13. MATLAB Output voltage and Load Current with I_O = 0 A, V_D = 0.9 V, V_M = 1 V. There are a 12V and 1A disturbances in input voltage and load current respectively ively

TABLE 3. COMPARING THE RESULTS WITH $V_D = V_M = 1$ V . THERE ARE A 12V AND 1A DISTERBANCES IN INPUT VOLATGE AND LOAD CURRENT RESPECTIVILY

	Steady State Output Voltage	**Steady State Output Current**
PSpice	5.8737 V	0.584 A
MATLAB	5.695 V	0.6595 A

VII. FUTURE WORK

- Converting this complete model to the P-Δ-K configuration of μ-theorem. With this configuration, any linear controller can be analyzed by μ-synthesis theorem. This work was done in [16] for the boost converter.
- Design a precise controller that can satisfy robust stability and robust performance of the KY buck-boost converter in the presence of all the converter parameters. This work was done in [17] for the boost converter.

VIII. CONCLUSION

There are a lot of parameters in KY buck-boost converters. These are capacitances and their resistance, inductance and its resistance, resistance of diode and active switches and their conductive voltage drop, resistance and current of load and uncontrollable input voltage. In this paper, an average model with multi-input multi-output is presented for KY buck-boost converter with all of the above parameters. By neglecting some of them, this complete model can be easily converted to any other simple model. The simplified steady state average model of KY buck-boost converter with $(r_m = r_d = r_L = r_C = r_{Co} = 0)$ was presented in the paper. Based on our complete average model a SIMULINK block was presented to simulate the performance of the converter. Anybody can use it to evaluate the performance of its controller which was designed for the converter. Finally, the KY buck-boost converter Benchmark circuit is simulated in PSpice and its results are compared with our model simulation results in MATLAB. The results are so closed to each other.

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AUTHORS

Mohammad Reza Modabbernia was born in Rasht, IRAN, in 1972. He received the B.S. degree in Electronics Engineering and M.S. degree in control engineering from KNT, the University of Technology, Tehran, IRAN in 1995 and 1998 respectively. He is the staff member of Electronic group of Technical and Vocational university, Rasht branch, Rasht, IRAN. His research interests include Robust Control, Nonlinear Control and Power Electronics.

Seyedeh Shiva Nejati was born in Bandar-Anzali, Iran in 1982. She received her B.Sc. degree in electrical engineering from Guilan University, Iran, in 2005 and the M.Sc. degree in Electrical Engineering from Tabriz University, Iran, in 2008. Her research interests include optical fiber, optoelectronics and optical devices. She is a university lecturer at higher education Institute of Sardar Jangal, Rasht, Iran.

Fatemeh Kohani Khoshkbijari was born in Rasht, Iran in 1982. She received her B.Sc. degree in electrical engineering from Islamic Azad University of Lahijan, Lahijan, Iran, in 2005 and the M.Sc. degree in Electrical Engineering from Islamic Azad University Tehran South Branch, Tehran, Iran, in 2008. As a novel research in nanotechnology, her M.Sc. thesis was awarded by Iranian Nanotechnology Initiative Council. She is a university lecturer at Sama Technical and Vocational Training College, Islamic Azad University, Rasht Branch since 2009. Her research interests include Low Power Design, Device Physics, Process/Device Design, CAD Development for Process and Device Design, Simulation, Modelling and Characterization of Nanoscale Semiconductor Devices.