The State Space Average Model of Buck-Boost Switching Regulator Including all of The System Uncertainties

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***Abstract*—In this paper a complete state-space average model for the buck-boost switching regulators is presented. The presented 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 switch are non ideal and they have a resistance in conduction condition. Some other non ideal effects look like voltage drop of conduction mode of the diode and active switch are also considered. This model can be used to design a precise and robust controller that can satisfy stability and performance conditions of the buck-boost regulator. Also the effects of the boost parameters on the performance of the regulator can be shown easily with this model. After presenting the complete model, the buck-boost converter Benchmark circuit is simulated in PSpice and its results are compared with our model simulation results in MATLAB. The results show the merit of our model.**

Keywords- Buck-boost regulator; average model; SMPS; MATLAB; PSpice

I. INTRODUCTION

DC-DC Power converters are one of the standard components of switch mode power supplies (SMPS). They are used in personal computers, laptops, PDAs, office appliances, aircrafts, satellite communication equipment and DC motor starting circuits. The input of these converters is an unregulated DC voltage and its output is a regulated voltage [1].

In these converters, the switching capabilities of power devices are utilized to achieve the high efficiency. The non ideal nature of switches and their conduction mode resistance, and because the voltage and current can not suddenly become zero in switching times, there is some power loss on them. Due to these effects, the typical efficiency of such converters are actually about 70% to 95% [2].

Among the varieties of DC-DC converters, the Buck-boost regulator is used in applications where the output voltage should be higher than the input. In comparison with the other converters such as Buck or Buck-Boost, designing a controller for it is more difficult since this converter is a non minimum phase system and has a zero in the right half plan. In other words, since the control input of this converter (duty cycle of triggering pulse) is presented in both voltage and current equations, the state equations solution and controlling this regulator are more difficult [3].

The topology of DC-DC converters consists of two linear (resistor, inductor and capacitor) and nonlinear (diode and active switch) 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 controller design in frequency domain for DC-DC converters are carried out by references [4-6].

Having a complete model which include all of the system parameters (such as turn-on resistance of the diode and active switch, 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 Buck-boost converters. Although work on buck-boost state space average model began in the 1970 decade by Cuke and Middlebrook [7], a model that consists of the aforementioned parameters was not presented.

Basso, Tomescue and Towati considered the boost regulator with inductance resistance, capacitance resistance and output current [8-10]. Benyakov only considers the capacitance resistance and output current regarding the said model and designs a robust controller. He mentioned the complexity of complete model and avoids presenting it in parametric form [11]. A linear model for Pulse Width Modulator(PWM) switch with an ideal diode and switch in both continuous and discontinuous current mode is presented in [12] and the effect of turn on resistance of diode and switch is considered in [13] for this model. An averaged model of boost regulator with consideration of capacitance and inductance resistances is demonstrated in [14]. Also, an average model to the PWM switch is presented by considering the diode and switch resistance and their voltage drop in discontinuous current mode without presenting the state space averaged model of regulator [15]. Finally, the state space average model of the boost regulator in the presence of all of the system uncertainties are presented in [16] and its P-Δ-K represented are introduced in [17].

In this paper, on the basis of state space average method, we first obtain the state space equations of a 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 switch on mode resistance and voltage drop, a load resistance and unidentified load current. Then the state equations are linearized around circuit operation point (input DC voltage and current versus output DC voltage). 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.

Finally the 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 very closed to each other.

II. Buck-Boost Regulator State Equatuons For On-Off Tme 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 $d\ T$, 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 buck-boost switching regulator. 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 $d\ T$ and $d'\ T$ seconds respectively, by “Fig.2” and “Fig.3”.

Consideration i_L and v_C as our state variables ($x = [i_L\ \ v_C]'$) and of writing the KVL for the loops of “Fig.2” we will have:

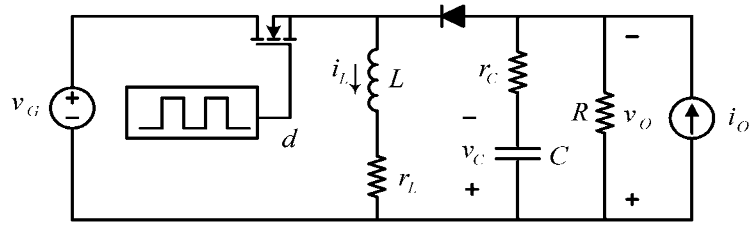

Figure 1. Buck-boost regulator circuit

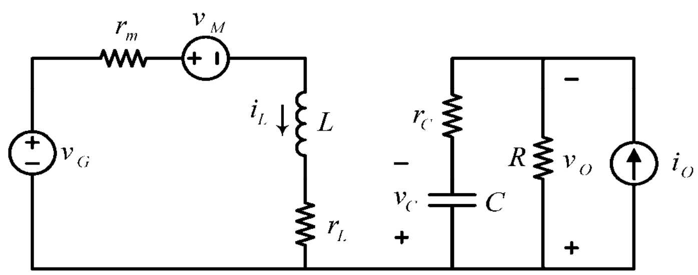

Figure 2. Equal circuit of Buck-boost regulator in on times

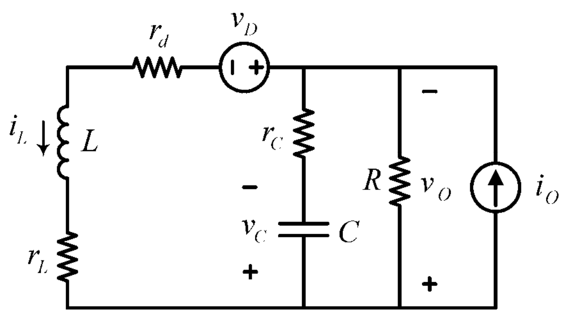

Figure 3. Equal circuit of Buck-boost regulator in off times

$$\begin{cases} \dot{x} = A_1\ x + B_1\ u \\ y = C_1\ x + D_1\ u \end{cases} \tag{1}$$

$$x = \begin{bmatrix} i_L \\ v_c \end{bmatrix} \quad u = \begin{bmatrix} v_G \\ i_O \\ v_M \\ v_D \end{bmatrix} \quad y = \begin{bmatrix} v_O \\ i_{out} \\ i_L \end{bmatrix} \tag{2}$$

$$A_1 = \begin{bmatrix} \frac{-(r_L + r_m)}{L} & 0 \\ 0 & \frac{-1}{(R + r_c)\ C} \end{bmatrix} \tag{3}$$

$$B_1 = \begin{bmatrix} \frac{1}{L} & 0 & \frac{-1}{L} & 0 \\ 0 & \frac{-R}{(R + r_c)\ C} & 0 & 0 \end{bmatrix} \tag{4}$$

$$C_1 = \begin{bmatrix} 0 & \frac{R}{R + r_c} \\ 0 & \frac{1}{R + r_c} \\ 1 & 0 \end{bmatrix} \tag{5}$$

$$D_1 = \begin{bmatrix} 0 & \frac{-R\,r_c}{R + r_c} & 0 & 0 \\ 0 & \frac{R}{R + r_c} & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \tag{6}$$

Also for off time or $d'\,T$ seconds the KVL equations from “Fig.3” are given by “(7)”.

$$\begin{cases} \dot{x} = A_2 \ x + B_2 \ u \\ y = C_2 \ x + D_2 \ u \end{cases} \tag{7}$$

$$x = \begin{bmatrix} i_L \\ v_c \end{bmatrix} \quad u = \begin{bmatrix} v_G \\ i_O \\ v_M \\ v_D \end{bmatrix} \quad y = \begin{bmatrix} v_O \\ i_{out} \\ i_L \end{bmatrix} \tag{8}$$

$$A_2 = \begin{bmatrix} -\dfrac{Rr_c + Rr_L + r_L r_c + Rr_d + r_d r_c}{L(R+r_c)} & \dfrac{-R}{L(R+r_c)} \\ \dfrac{R}{(R+r_c)C} & \dfrac{-1}{(R+r_c)C} \end{bmatrix} \tag{9}$$

$$B_2 = \begin{bmatrix} 0 & \dfrac{R\,r_c}{(R+r_c)\,L} & 0 & \dfrac{-1}{L} \\ 0 & \dfrac{-R}{(R+r_c)\,C} & 0 & 0 \end{bmatrix} \tag{10}$$

$$C_2 = \begin{bmatrix} \dfrac{Rr_c}{R+r_c} & \dfrac{R}{R+r_c} \\ \dfrac{r_c}{R+r_c} & \dfrac{1}{R+r_c} \\ 1 & 0 \end{bmatrix} \tag{11}$$

$$D_2 = \begin{bmatrix} 0 & \dfrac{-R\,r_c}{R+r_c} & 0 & 0 \\ 0 & \dfrac{R}{R+r_c} & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \tag{12}$$

The set of state equations “(1)” to “(12)” shows the state of buck-boost regulator in the on and off time of switch. We can combine these two set of equations as following [8,9]:

$$\begin{cases} \dot{x} = A_P \, x + B_P \ u \\ y = C_P \, x + D_P \ u \end{cases} \qquad \begin{cases} A_P = A_1 \, d + A_2 (1-d) \\ B_p = B_1 \, d + B_2 (1-d) \\ C_p = C_1 \, d + C_2 (1-d) \\ D_p = D_1 \, d + D_2 (1-d) \end{cases} \tag{13}$$

By substituting equations “(1)” to “(12)” , we can obtain coefficients of A_P to D_P.

$$A_P=\begin{bmatrix} -\dfrac{-\left(r_L+r_m\right)\left(R+r_c\right)+\left(r_m-r_d\right)\left(R+r_c\right)d'-Rr_c d'}{L\left(R+r_c\right)} & \dfrac{-Rd'}{L\left(R+r_c\right)} \\ \dfrac{Rd'}{\left(R+r_c\right)C} & \dfrac{-1}{\left(R+r_c\right)C} \end{bmatrix} \tag{14}$$

$$B_P=\begin{bmatrix} \dfrac{1-d'}{L} & \dfrac{Rr_c d'}{\left(R+r_c\right)L} & \dfrac{-1+d'}{L} & \dfrac{-d'}{L} \\ 0 & \dfrac{-R}{\left(R+r_c\right)C} & 0 & 0 \end{bmatrix} \tag{15}$$

$$C_P=\begin{bmatrix} \dfrac{Rr_c d'}{R+r_c} & \dfrac{R}{R+r_c} \\ \dfrac{r_c d'}{R+r_c} & \dfrac{1}{R+r_c} \\ 1 & 0 \end{bmatrix} \tag{16}$$

$$D_P=\begin{bmatrix} 0 & \dfrac{-Rr_c}{R+r_c} & 0 & 0 \\ 0 & \dfrac{R}{R+r_c} & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \tag{17}$$

III. LINEARIZATION OF STATE EQUATIONS AROUND OPERATING POINT

The results presented in section2 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 “(13)” 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 “(13)” 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 ($x = [I_L \quad V_C]'$) and the DC output values .

$$\dot{x}=A_P\,x+B_p\,u=0\Rightarrow X=-A_P^{-1}B_p\begin{bmatrix} V_G \\ I_O \\ V_M \\ V_D \end{bmatrix}=\begin{bmatrix} I_L \\ V_C \end{bmatrix} \tag{18}$$

$$X=\begin{bmatrix} \dfrac{\left(R+r_c\right)\left(1-D'\right)}{\Delta}V_G+\dfrac{R\left(R+r_c\right)D'}{\Delta}I_O-\dfrac{\left(R+r_c\right)\left(1-D'\right)}{\Delta}V_M-\dfrac{\left(R+r_c\right)D'}{\Delta}V_D \\ \dfrac{R\left(R+r_c\right)D'\left(1-D'\right)}{\Delta}V_G+\dfrac{R^2D'^2\left(R+r_c\right)-R\Delta}{\Delta}I_O-\dfrac{R\left(R+r_c\right)D'\left(1-D'\right)}{\Delta}V_M-\dfrac{R\left(R+r_c\right)D'^2}{\Delta}V_D \end{bmatrix} \tag{19}$$

Where

$$\Delta = (r_L + r_m)(R + r_c) + (R\,r_c + R\,r_d + r_c\,r_d - R\,r_m - r_m r_c)D' + R^2 D'^2 \qquad (20)$$

And

$$Y = C_p\,X + D_p\,U \quad , \quad Y = \begin{bmatrix} V_O \\ I_{out} \\ I_L \end{bmatrix} \qquad (21)$$

Where

$$V_O = \frac{R(R+r_c)D'(1-D')}{\Delta}V_G + \frac{R^2(R+r_c)D'^2 - R\Delta}{\Delta}I_O - \frac{R(R+r_c)D'(1-D')}{\Delta}V_M - \frac{R(R+r_c)D'^2}{\Delta}V_D \qquad (22)$$

$$I_{out} = \frac{(R+r_c)D'(1-D')}{\Delta}V_G + \frac{R(R+r_c)D'^2}{\Delta}I_O - \frac{(R+r_c)D'(1-D')}{\Delta}V_M - \frac{(R+r_c)D'^2}{\Delta}V_D \qquad (23)$$

And

$$I_L = \frac{(R+r_c)(1-D')}{\Delta}V_G + \frac{R(R+r_c)D'}{\Delta}I_O - \frac{(R+r_c)(1-D')}{\Delta}V_M - \frac{(R+r_c)D'}{\Delta}V_D \qquad (24)$$

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:

$$\begin{cases} x(t) = X + \hat{x} \\ d(t) = D + \hat{d} \\ u(t) = U + \hat{u} \\ v_o(t) = V_O + \hat{v}_o \end{cases} \qquad (25)$$

In which V_O, $x = [i_L \;\; v_C]'$ and $U = [V_G \; I_G \; V_M \; V_D]'$ are the nominal values of the DC output voltage, state variables and no controllable inputs respectively. Each of them has small variations (denoted with ^) around nominal values. By substituting equations "(25)" in "(13)" and assumed that the duty cycle d has also variation $\hat{d}$ ($d = D + \hat{d}$), we will have

$$\begin{cases} \dot{X} + \dot{\hat{x}} = A_P\,\hat{x} + B_P\,\hat{u} + \left[(A_1 - A_2)X + (B_1 - B_2)U\right]\hat{d} + \dot{X} \\ \dot{V}_O + \dot{\hat{v}}_o = C_P\,\hat{x} + D_P\,\hat{u} + \left[(C_1 - C_2)X + \underbrace{(D_1 - D_2)}_{0}U\right]\hat{d} + \dot{V}_O \end{cases} \qquad (26)$$

Or

$$\begin{cases} \dot{\hat{x}} = A_P\,\hat{x} + B_P\,\hat{u} + E\,\hat{d} \\ \dot{\hat{v}}_o = C_P\,\hat{x} + D_P\,\hat{u} + F\,\hat{d} \end{cases} \quad , \quad \begin{cases} E = (A_1 - A_2)X + (B_1 - B_2)U \\ F = (C_1 - C_2)X \end{cases} \qquad (27)$$

Where

$$E = \begin{bmatrix} \frac{K(1-D') + R^2(1-D')D' + \Delta}{L\Delta} V_G + \frac{KR(1-D') + R^3 D'^2 - R\Delta}{L\Delta} I_O - \frac{(1-D')\left(K + R^2 D'\right) + \Delta}{L\Delta} V_M - \frac{\left(KD' + R^2 D'^2\right) - \Delta}{L\Delta} V_D \\ \frac{-R(1-D')}{C\Delta} V_G + \frac{-R^2 D'}{C\Delta} I_O + \frac{R(1-D')}{C\Delta} V_M + \frac{RD'}{C\Delta} V_D \end{bmatrix} \quad (28)$$

And

$$F = (C_1 - C_2) X = \begin{bmatrix} \frac{-R r_c (1-D')}{\Delta} V_G + \frac{-R^2 r_c D'}{\Delta} I_O + \frac{R r_c (1-D')}{\Delta} V_M + \frac{R r_c D'}{\Delta} V_D \\ \frac{-r_c (1-D')}{\Delta} V_G + \frac{-R r_c D'}{\Delta} I_O + \frac{r_c (1-D')}{\Delta} V_M + \frac{r_c D'}{\Delta} V_D \end{bmatrix} \quad (29)$$

With

$$K = Rr_c + Rr_d + r_d r_c - r_c r_m - Rr_m \quad (30)$$

And Δ is defined by “(20)”.

IV. State Space Average Model

An important point in the set equations in 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:

$$\begin{cases} \dot{\hat{x}} = \left[A_1 d + A_2 (1-d)\right]\hat{x} + \left[B_1 d + B_2 (1-d)\right]\hat{u} + E\hat{d} \\ \hat{y} = \left[C_1 d + C_2 (1-d)\right]\hat{x} + \left[D_1 d + D_2 (1-d)\right]\hat{u} + F\hat{d} \end{cases} \quad (31)$$

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

$$\dot{\hat{x}} = \left[A_1 D + A_2 (1-D)\right]\hat{x} + \left[B_1 D + B_2 (1-D)\right]\hat{u} + E\hat{d} + (A_1 - A_2)\hat{d}\hat{x} + (B_1 - B_2)\hat{d}\hat{u} \quad (32)$$

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 $\hat{d}\,\hat{u}$.

$$\dot{\hat{x}} = A\hat{x} + B\hat{u} + E\hat{d} \quad (33)$$

In the same manner, the effect of $\hat{d}\,\hat{x}$ and $\hat{d}\,\hat{u}$ in second equation of “(32)” is negligible. Therefore we can represent the buck-boost regulator state equations like this:

$$\begin{cases} \dot{\hat{x}} = A\hat{x} + B\hat{u} + E\hat{d} \\ \dot{\hat{y}} = C\hat{x} + D\hat{u} + F\hat{d} \end{cases} \quad \hat{x} = \begin{bmatrix} i_L \\ v_C \end{bmatrix} \quad \hat{u} = \begin{bmatrix} v_G \\ i_O \\ v_M \\ v_D \end{bmatrix} \quad \hat{y} = \begin{bmatrix} v_O \\ i_{out} \\ i_L \end{bmatrix} \quad (34)$$

$$A=\begin{bmatrix} -\dfrac{-\left(r_L+r_m\right)\left(R+r_c\right)+\left(r_m-r_d\right)\left(R+r_c\right)D'-Rr_cD'}{L\left(R+r_c\right)} & \dfrac{-RD'}{L\left(R+r_c\right)} \\ \dfrac{RD'}{\left(R+r_c\right)C} & \dfrac{-1}{\left(R+r_c\right)C} \end{bmatrix} \tag{35}$$

$$B=\begin{bmatrix} \dfrac{1-D'}{L} & \dfrac{Rr_cD'}{\left(R+r_c\right)L} & \dfrac{-1+D'}{L} & \dfrac{-D'}{L} \\ 0 & \dfrac{-R}{\left(R+r_c\right)C} & 0 & 0 \end{bmatrix} \tag{36}$$

$$C=\begin{bmatrix} \dfrac{Rr_cD'}{R+r_c} & \dfrac{R}{R+r_c} \\ \dfrac{r_cD'}{R+r_c} & \dfrac{1}{R+r_c} \\ 1 & 0 \end{bmatrix} \tag{37}$$

$$D=\begin{bmatrix} 0 & \dfrac{-Rr_c}{R+r_c} & 0 & 0 \\ 0 & \dfrac{R}{R+r_c} & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \tag{38}$$

E and F are represented with equations “(28)” , “(29)” respectively.

V. SIMULATION WITH PSPISE AND MATLAB

To show the accuracy of our complete model, we simulate the buck-boost benchmark circuit with PSpice and then compare its consequences with the simulation results of presented model in MATLAB. “Fig. 4”, “Fig. 5” and “Fig. 6” show the buck-boost benchmark circuit in PSpice and its equivalent model in SIMULINK respectively. The simulations were performed under the following conditions: L = 200 μH, C = 220 μF, R = 44 Ω, r_m=r_d=r_C = 0.1Ω, r_L = 0.2 Ω and V_G = 12 V. The switching frequency is 240 kHz and various cases of simulation have been considered. In the first case, the forward voltage drop of the active switch accompanied by the load current and the diode voltage drop have been reckoned zero and 0.1 V respectively. In the second case, the voltage drop of the diode and active switch, and also load current are 0.1 V, 0 V and 1 A respectively. Finally, with the consideration of forward voltage drop equal to 1 V for the diode and active switch, a sudden change of 5V in the input voltage and 3 A in the output current have been taken into account for the converter.

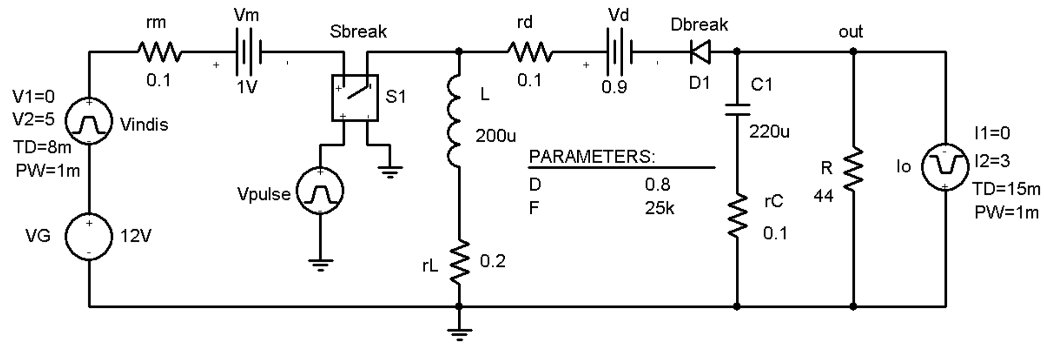

Figure 4. The buck-boost benchmark circuit in PSpice

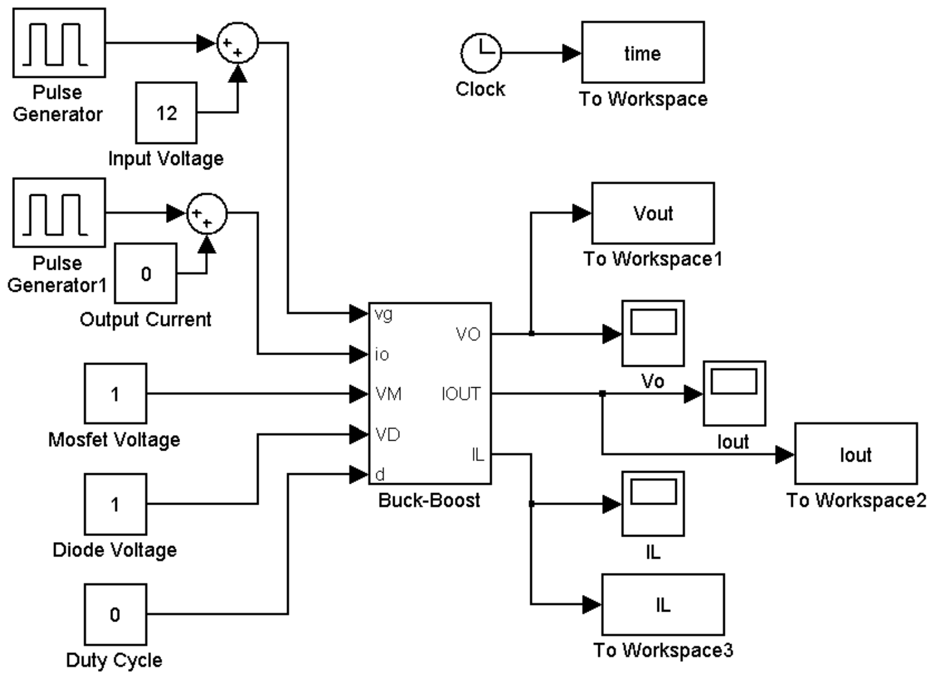

Figure 5. The buck-boost benchmark circuit in SIMULINK

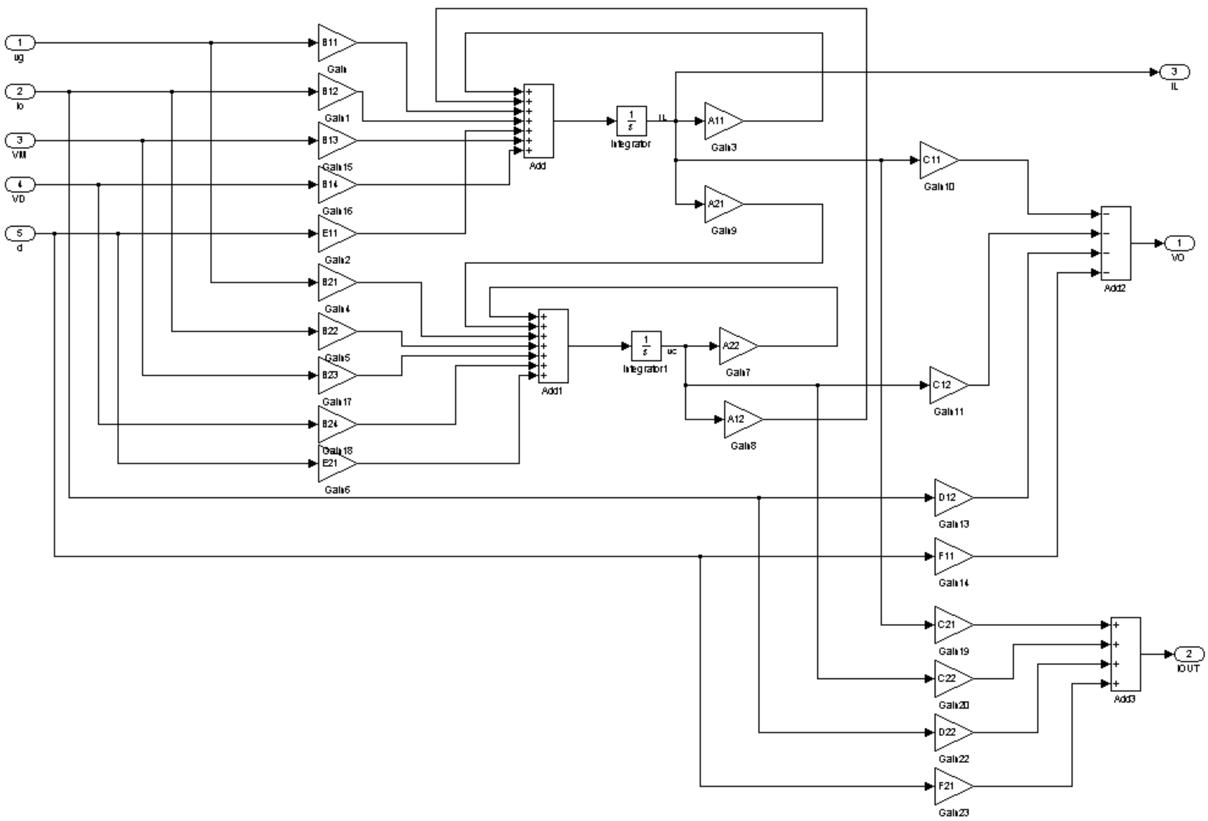

Figure 6. Equivalent model of Buck-boost regulator in SIMULINK

A. *Switches with no forward voltage drop and $I_0 = 0$ A*

The simulation results with zero output current were shown by “Fig. 7” and “Fig. 8” in PSpice and MATLAB respectively. Based on PSpice simulation, we assume that the diode and MOSFET conducting voltage drop in MATLAB are 0.1 V and 0 V. Table I compare the results of two simulations with each other.

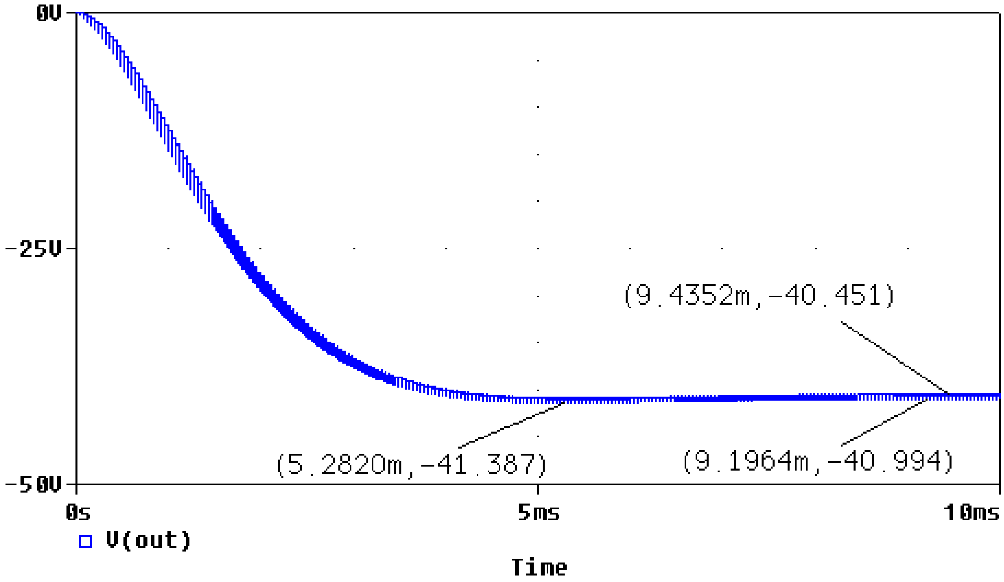

Figure 7. Output voltage with I_O = 0 A, V_D = 0.1 V and V_M = 0 V in PSpice

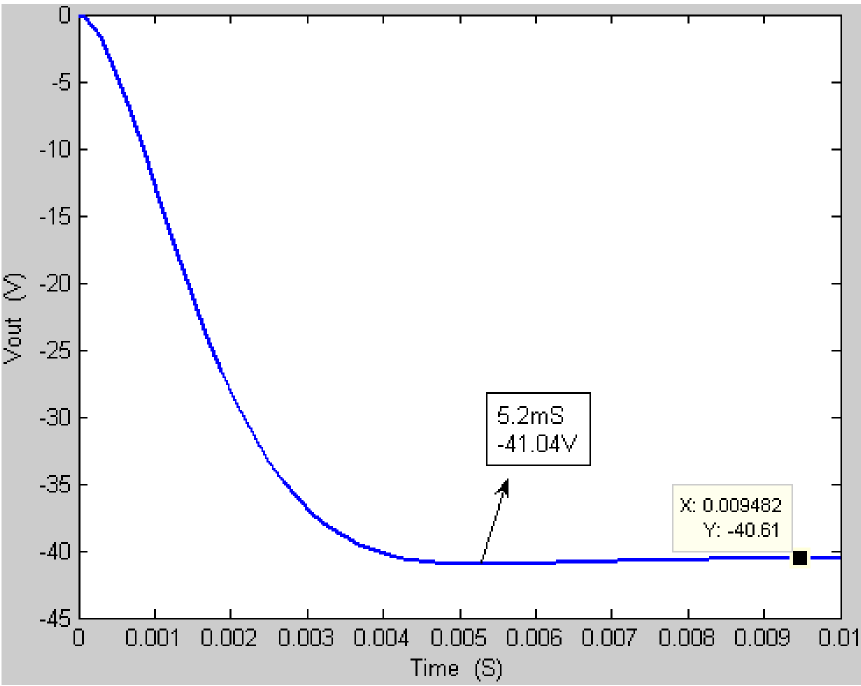

Figure 8. Output voltage with I_O = 0 A, V_D = 0.1 V and V_M = 0 V in MATLAB

TABLE I. COMPARING THE RESULTS WITH I_O = 0 A, V_D = 0.1 V AND V_M = 0 V

	Output Voltage	Overshoot
PSpice	Between -40.451 and -40.994	-41.387V
MATLAB	-40.61	-41.04V

B. Active switch with V_M= 5.7 V and I_O= 1 A

The results of simulation with I_O = 1 A, V_D =0.1 V and V_M =5.7 V are shown in “Fig. 9” and “Fig. 10”. V_M=5.7 V is the drain source voltage drop of IRF540 MOSFET in PSpice. The table II shows these simulation results and compares them.

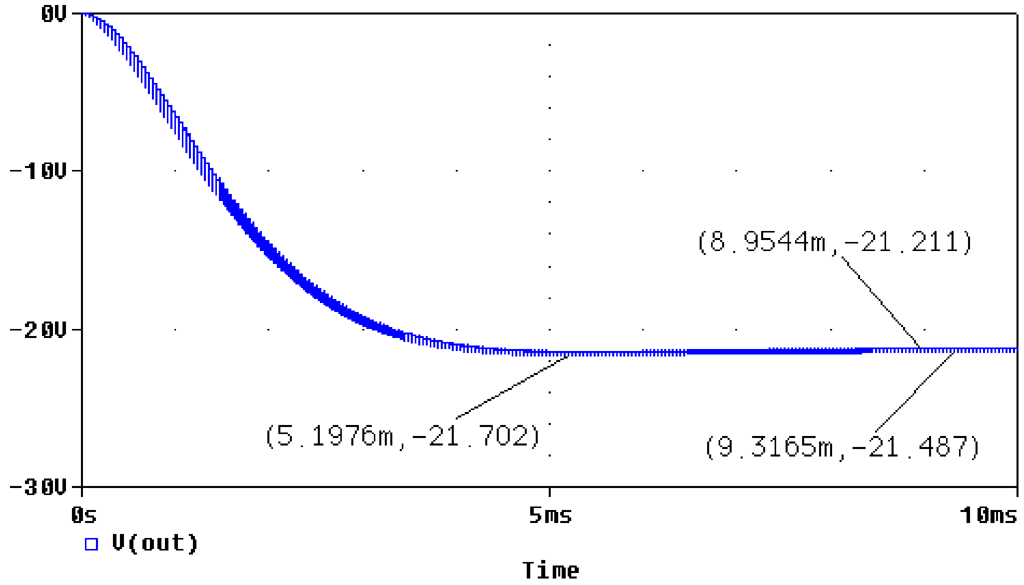

Figure 9. Output voltage with I_O = 1 A, V_D = 0.1 V and V_M = 5.7 V in PSpice

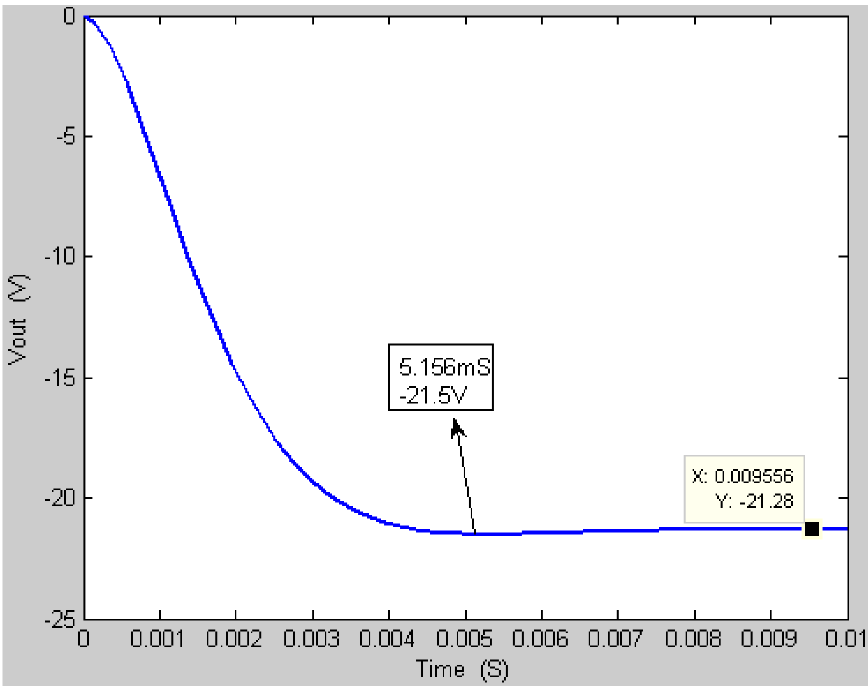

Figure 10. Output voltage with I_O = 1 A, V_D = 0.1 V and V_M = 5.7 V in MATLAB

TABLE II. COMPARING THE RESULTS WITH I_O = 1 A, V_D = 0.1 V AND V_M = 5.7 V

	Output Voltage	**Overshoot**
PSpice	Between -21.211 and -21.487	-21.702V
MATLAB	-21.28	-21.5V

C. 5V and 1A disturbances in the input voltage and load current

If we consider a BJT transistor like 2N6546 instead of IRF540 MOSFET, we will have a 1 V voltage drop on the collector-emitter of transistor. The results of simulation with I_O = 0 A and V_D =V_M =1 V are shown in "Fig.11" and "Fig. 12". There are a 5V and 1A disturbances in the input voltage and load current respectively. The table III shows these simulation results and compares them.

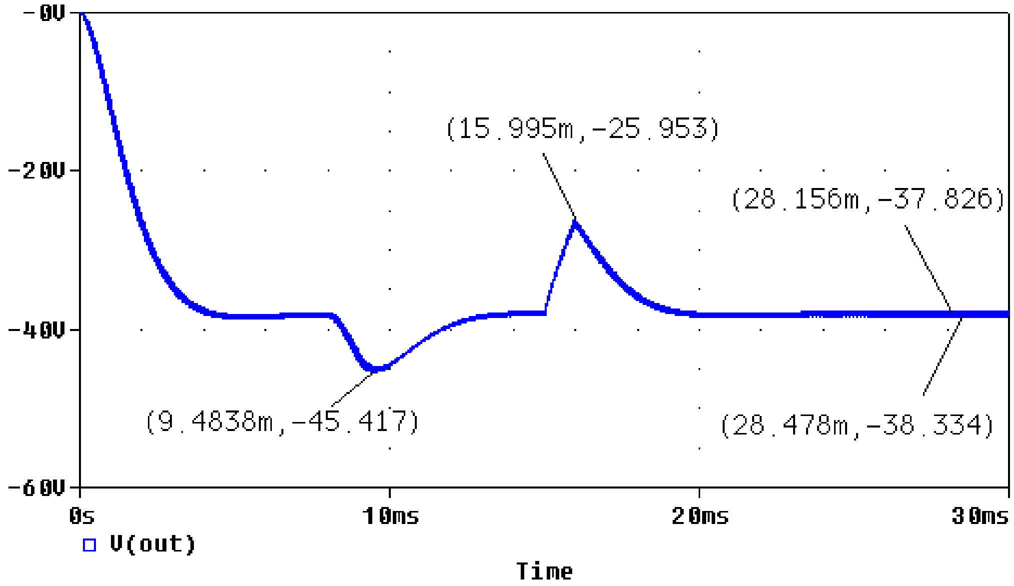

Figure 11. Output voltage with $V_D = V_M = 1$ V in PSpice. There are a 5V and 1A disturbances in input voltage and load current respectively

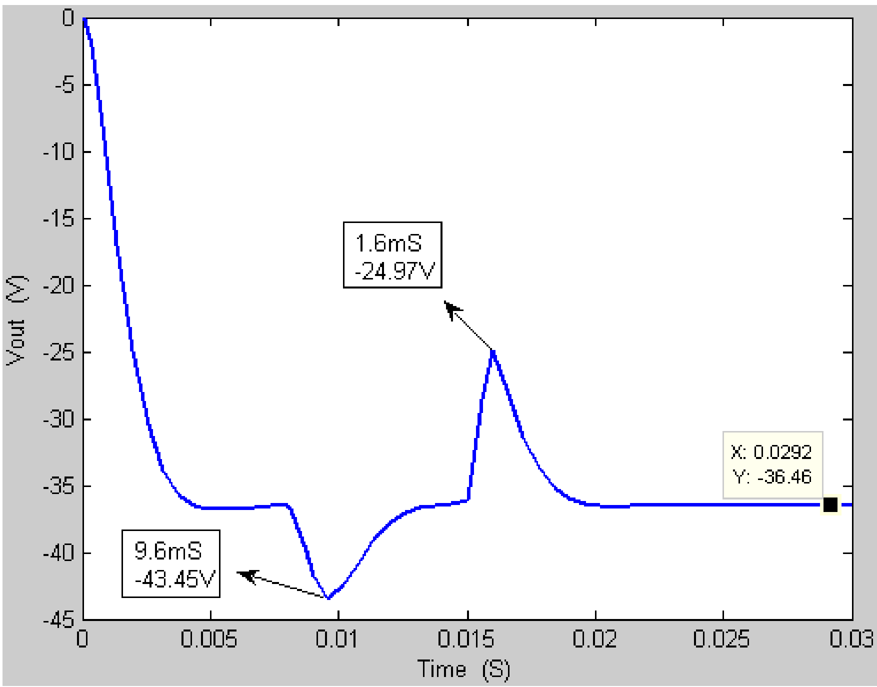

Figure 12. Output voltage with $V_D = V_M = 1$ V in MATLAB. There are a 5V and 1A disturbances in input voltage and load current respectively

TABLE III. COMPARING THE RESULTS WITH $V_D = V_M = 1$ V THERE ARE A 5V AND 1A DISTERBANCES IN INPUT VOLATGE AND LOAD CURRENT RESPECTIVILY

	Output Voltage	**Input Voltage Overshoot**	**Load Current Overshoot**
PSpice	Between -37.826 and -38.334	-45.417V	-25.9537V
MATLAB	-36.46	-43.45V	-24.97V

VI. CONCLUSION

There are a lot of uncertainties in DC-DC converters. Some of the most important uncertainties of buck-boost regulators are capacitance and its resistance, inductance and its resistance, resistance of diode and active switch and their conductive voltage drop, resistance and current of load and uncontrollable input voltage. In this paper, an average model is presented for buck-boost regulator with all of the above uncertainties. By neglecting some of them, we can easily convert this complete model to any other simple model. Also by converting it to the P-Δ-K configuration, we can analyze any linear controller by μ-synthesis theorem. Finally, the 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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