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Buck-Boost Converter Small Signal Model: Dynamic Analysis under System Uncertainties

An accurate mathematical model of DC-DC converters is an imperative for high performance in all domains of electronic systems operations. In this work, a small signal circuit model for DC-DC buck-boost converter operated in continuous conduction mode (CCM) is developed. The proposed modeling is initialized from dynamic equations illustrating the converter. The non-linear behaviour of the pulse-width modulation and switching process are addressed via the application of waveform averaging and small-signal modeling techniques. A complete MATLAB/Simulink model is designed to check the robustness of the proposed converter under different input voltage and switched load variations. Simulation results present the superiority of proposed model in terms of transient and steady-state performance, such as small overshoot and short settling time. Furthermore, the proposed model can be useful to achieve input and output impedances, inductor current variations, and converter transfer functions to develop a robust closed-loop controller design that can meet stability and performance conditions of the DC-DC buck-boost converter.

Keywords: Buck-boost converter; state-space average method; continuous conduction mode; pulse-width modulated converters

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1. Introduction

Today's electronic systems need portable, high-quality, modular, reliable, and fast switching power supplies. Therefore, the widespread applications, (i.e., industrial, automotive and transportation, electrical machines, renewable energy systems, switching power supplies and communications, etc) of DC-DC converters have overwhelmed the power industry. During the modelling of switch mode power supply, ensuring stability is essential. Normally, a feedback control loop is used for this purpose to obtain the required performance. However, during the actual operation, various load disturbances and variation of the circuit component effect the performance of the system. These variations are critical to the behaviour of switch mode power supply that may result instability. Therefore, in modelling of power converters, design of controller for these converters is a most thoughtful issue [1], [2].

In literature, various researchers presented different control approaches to regulate the DC-DC converters, particularly bi-directional DC-DC converters, to acquire a robust output voltage. The bi-directional DC-DC converters are classified into two: digital simulation method and analytical modelling method [3]. Those modelling techniques are discussed in

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[4]. State-space averaging technique is one of the analytic modelling methods, and relatively simple with widely applications [5]. Since, DC-DC converters are characterized as non-linear, and time-variant systems, therefore, control of these converters using linear control techniques is an inefficient. To obtain the prototype of a robust controller, a small-signal linearized simulated model of the DC-DC converter is essential [6]. Time invariant over a constant duty cycle is significant benefit of such linearized model. Furthermore, there is no concern to handle switching and/or switching ripple, and only the DC components of the waveforms are taken during the modelling. This is obtained through the linearization taken around a specific operating point from the state space average mode [7], [8].

Moreover, until now various modelling approaches under different software simulation, viz., PSCAD/EMTDC software [9], internet-based platform PowerEsim [10], PSpice simulator [11], MATLAB/Simulink [12]–[14], Modelica [15], Scicos simulator [16], MULTISIM [17], XILINX FPGA [18], LabVIEW/MATLAB [19], of model for DC-DC converter applications have been appeared in hundreds of papers as well as in many textbooks to be applied in controller modelling and improve converter's performance. In [9], the authors presented a new technique for dynamic modelling of DC-DC buck-boost converter in continuous conduction mode. The proposed research is based on Laplace and Z-transforms. Simulations are performed in PSCAD/EMTDC software and its validity is then supported by experimental. In [10], the researchers applied PSpice simulator and Internet-based platform PowerEsim for the modelling of switched mode power supply. The design of Pulse With Modulated (PWM) DC-DC buck-boost converter in the PSpice simulator to reduce DC error and gain stability is the purpose of [11]. In [12]–[14], the researchers designed and simulated small signal averaged DC-DC converters in MATLAB/Simulink.

Similarly, study on DC-DC converters using Modelica is developed in [15]. Modelling of DC-DC converters in Scilab/ScicosLab is attempted in [16]. In [17], the authors designed DC-DC converter in MULTISIM. The model is tested experimentally with a data acquisition performed in LabVIEW. Some researchers also presented FPGA based modelling of DC-DC converter such as in [18]. The authors stated that with the use of PWM and XILINX FPGA minimizes the cost. In [19], modelling and experimental investigation of closed loop time domain based discrete PWM DC-DC converter is presented in LabVIEW/MATLAB.

This work presents an AC small-signal linear time-invariant circuit model of a DC-DC buck-boost converter in operated in CCM. The method is simple and convenient for any multi-variable system with state-space equations, linear or nonlinear, ideal or non-ideal. İn proposed method, an approximation is performed in such manner, that the current through the inductor can return to a steady state value with small overshoot and settling time, and hence, the true rms value of the currents through the converter components is taken to obtain the averaged values of waveform. Number of poles and zeros of the system are easily achievable considering the analytical expressions of the converter transfer functions. The proposed model is propitious to achieve the expressions for converter transfer function, the input impedance, the output impedance, and control-to-output voltage transfer function.

This paper is structured as: Section 2 provides methods and materials such as, state-space average methodology, power stage modelling steps, description about perturbation and linearization, and canonical form model. Section 3 illustrates proposed small signal Simulink model. Section 4 describes the simulation results, and conclusion is given in Section 5.

2. Methods and materials

The DC-DC converters are explained into two main types: (1) resonant and soft-switching converters and (2) hard-switching pulse PWM converters [2]. The PWM converters are preferred due to its high efficiency, relatively simple control, constant frequency operation, low component count, and ability to obtain high conversion ratios for both step-down and step-up applications. The circuit diagram of conventional DC-DC buck-boost converter is shown in Fig. 1, where D is the main switch, L is input inductor, D is the output diode, and R is load resistor. Fig. 2 provides the workflow involved in the small signal model. First, the state space is developed, followed by basic state space averaged modelling. Then, state space equations are perturbed with small AC variations $\widehat{d}$ and $\widehat{v_i}$ in the duty cycle and input vector, and the vectors $\widehat{x}$, $\widehat{y}$ are the resulting small variations in the output vectors. Next, final state space averaged model steady state (DC) model and dynamic (AC small signal) model (linearization) are obtained. Afterwards, the canonical circuit model is established.

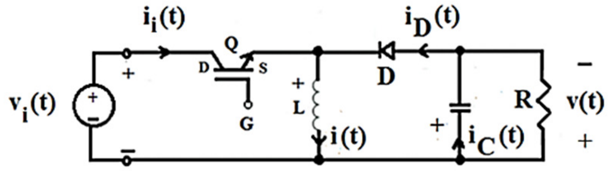

Figure 1. Structure of the buck-boost circuit topology.

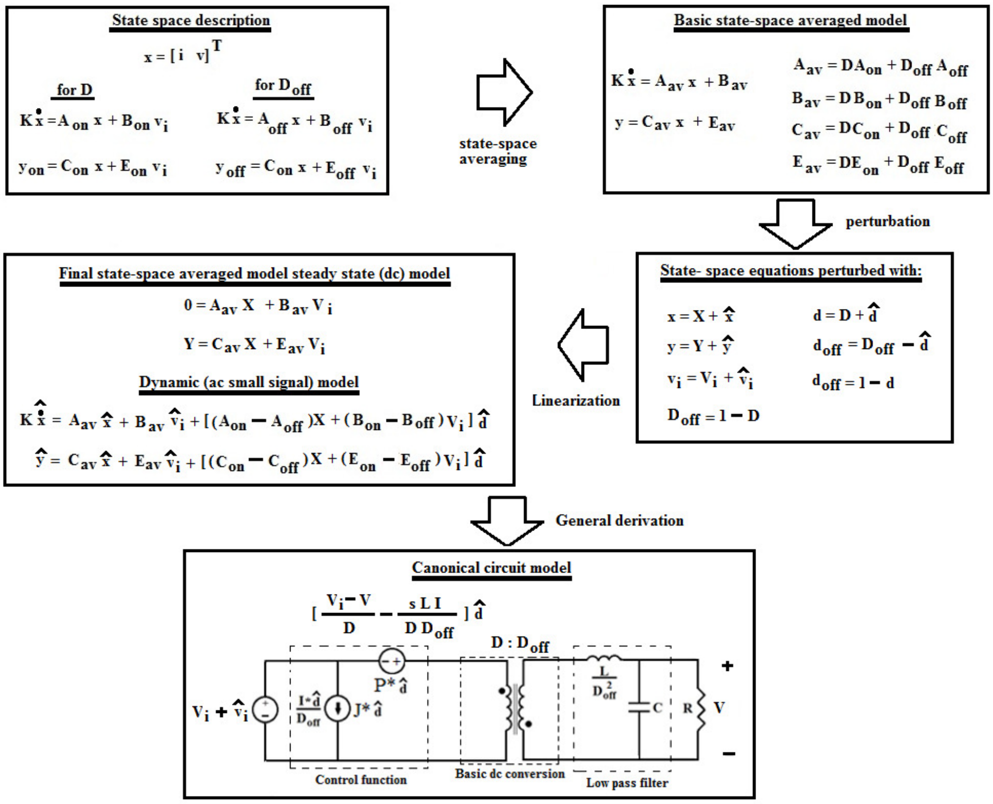

Figure 2. Flowchart of the small signal modelling approaches

2.1. Modelling of DC-DC Buck-Boost Converter

The state-space averaging approach utilizes the state-space formulation of dynamical systems to derive the small-signal averaged equations of PWM switching converters [20]. In this method, first the state space dynamics description of each time-invariant system is developed. Next, these descriptions are then averaged with respect to their switching period duration by eliminating the time variance. The final averaged model is nonlinear and time-invariant. Through linearization process, the model is then linearized around the quiescent operating point to develop a small-signal model. Then, the model is transformed into frequency-domain, or s-domain small-signal model, which generates transfer functions. The derived transfer functions possess all the standard s-domain analysis characteristics and frequency-domain small-signal dynamics [12]. In state-space averaging technique, a true state-space equation of the power stage is initially defined. The resulting state-space description is known as the switched state-space model.

a. Switch ON state period (switched state space model)

The buck-boost converter is obtained from the cascaded integration of step down and the step-up converters as illustrated in Fig. 1. After closing the switch Q, the diode is reverse biased, and the energy is stored in the coil which is shown in Fig.3. The power stage dynamics during ON-time period can be represented in the form of a state space equation as:

$$K\frac{dx(t)}{dt} = A_{on}\, x(t) + B_{on}\, u(t) \tag{1}$$

$$y(t) = C_{on}\, x(t) + E_{on}\, u(t) \tag{2}$$

Eqs. (1-2) can be written in terms of coil voltage, capacitor and source current as:

$$\begin{bmatrix} L & 0 \\ 0 & C \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i(t) \\ v(t) \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & -1/R \end{bmatrix} \begin{bmatrix} i(t) \\ v(t) \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \end{bmatrix} [v_i(t)] \tag{3}$$

$$[i_i(t)] = [1 \quad 0] \begin{bmatrix} i(t) \\ v(t) \end{bmatrix} + [0][v_i(t)] \tag{4}$$

b. Switch OFF state period

When the switch is open, the energy stored in the coil is transferred to the load. No energy is supplied by the source during this interval as shown in Fig. 4. The power stage dynamics during OFF-time period can be represented in terms of state space equation as:

$$K\frac{dx(t)}{dt} = A_{off}\, x(t) + B_{off}\, u(t) \tag{5}$$

$$y(t) = C_{off}\, x(t) + E_{off}\, u(t) \tag{6}$$

Eqs. (5-6) can be written in coil voltage, capacitor current and the source current as:

$$\begin{bmatrix} -L & 0 \\ 0 & C \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i(t) \\ v(t) \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & -1/R \end{bmatrix} \begin{bmatrix} i(t) \\ v(t) \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \end{bmatrix} [v_i(t)] \tag{7}$$

$$[i_i(t)] = [0 \quad 0] \begin{bmatrix} i(t) \\ v(t) \end{bmatrix} + [0][v_i(t)] \tag{8}$$

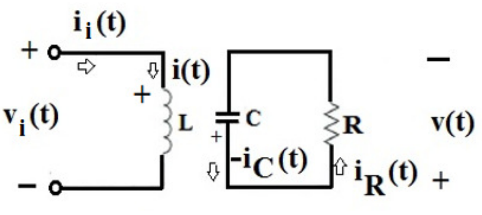

Figure.3. Buck-boost converter equivalent circuit in ON state

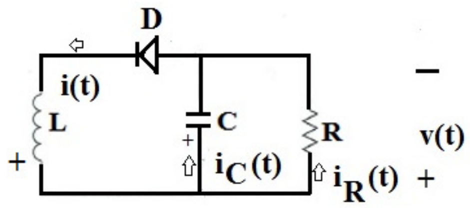

Figure.4. Buck-boost converter equivalent circuit in OFF state

2.2. Steady State Solution

The steady state solution is derived by synchronizing the rate of change of dynamic parameters to zero to obtain the state space averaged balance equations.

$$0 = A_{av}\, X + B_{av}\, U \tag{9}$$

$$Y = C_{av}\, X + D_{av}\, U \tag{10}$$

In Eqs. (9-10), A_{av}, B_{av}, C_{av} and D_{av} are the averaged matrices. Using Eq. $D + D_{off} = 1$, A_{av} is given as:

$$A_{av} = DA_{on} + D_{off}A_{off} = D\begin{bmatrix} 0 & 0 \\ 0 & -1/R \end{bmatrix} + D_{off}\begin{bmatrix} 0 & 1 \\ 1 & -1/R \end{bmatrix} = \begin{bmatrix} 0 & D_{off} \\ D_{off} & -1/R \end{bmatrix} \tag{11}$$

Similarly, the averaged matrices B_{av},C_{av}, and E_{av} are also evaluated as:

$$B_{av} = DB_{on} + D_{off}B_{off} = D\begin{bmatrix} 1 \\ 0 \end{bmatrix} + D_{off}\begin{bmatrix} 0 \\ 0 \end{bmatrix} = \begin{bmatrix} D \\ 0 \end{bmatrix} \tag{12}$$

$$C_{av} = DC_{on} + D_{off}C_{off} = D[1 \quad 0] + D_{off}[0 \quad 0] = [D \quad 0] \tag{13}$$

$$E_{av} = DE_{on} + D_{off}E_{off} = D[0] + D_{off}[0] = [0] \tag{14}$$

The equilibrium values of the averaged vectors can be derived from Eq. (9) and Eq. (10) as follows:

$$X = -A_{av}{}^{-1}B_{av}U = \begin{bmatrix} 0 & D_{off} \\ D_{off} & -\frac{1}{R} \end{bmatrix}^{-1}\begin{bmatrix} D \\ 0 \end{bmatrix}[V_i] = \begin{bmatrix} I \\ V \end{bmatrix} = \begin{bmatrix} -\frac{DV_i}{(D_{off})^2R} \\ -\frac{DV_i}{D_{off}} \end{bmatrix} = \begin{bmatrix} \frac{V}{R(1-D)} \\ \frac{DV_i}{1-D} \end{bmatrix} \tag{15}$$

$$Y = -\left(CA_{av}{}^{-1}B_{av} + E_{av}\right)U = [I_i] = -\left([D \quad 0]\begin{bmatrix} 0 & D_{off} \\ D_{off} & -\frac{1}{R} \end{bmatrix}^{-1}\begin{bmatrix} D \\ 0 \end{bmatrix} + 0\right)[V_i]$$

$$= \left[\frac{D^2V_i}{(D_{off})^2R}\right] = \left[\frac{DV}{(1-D)R}\right] \tag{16}$$

After any transients have been finished, the input voltage $v_i(t)$, the input current $i_i(t)$, the coil current $i(t)$ and the capacitor (or load) voltage $v(t)$ will approach the quiescent points V_i, I_i I and V, respectively.

where

$$V_i = \frac{(1-D)V}{D} \tag{17}$$

$$I_i = \frac{DV}{R(1-D)} \tag{18}$$

$$I = \frac{V}{R(1-D)} \tag{19}$$

$$V = \frac{DV_i}{1-D} \tag{20}$$

2.3. Perturbation and linearization of buck-boost converter

Another way of analyzing easily a non-linear system is its linearization around quiescent operating point by constructing a small signal model. Fig. 5 illustrates linearization of the *V–D* curve. The steady state load voltage is *V* and the duty cycle of the buck-boost converter is *D*. Assuming that converter runs in load voltage, $V=V_i$, coinciding to a quiescent duty cycle of $D = 0.5$. The ripples of D (means $\hat{d}$) around the quiescent point incites the ripples $\hat{v}$ in the load voltage V. If the amplitude of $\hat{d}$ is enough small, then it can be computed from the load voltage ripples via linearizing the curve. If the slope of the curve given in Fig.5 is made equal to the slope of the real curve at the quiescent point value, then the gain of the DC-DC converter will be equal to the slope value. When ripple of $\hat{d}$ is chosen sufficiently small, the linearized and nonlinear curve will be approximately equal in value.

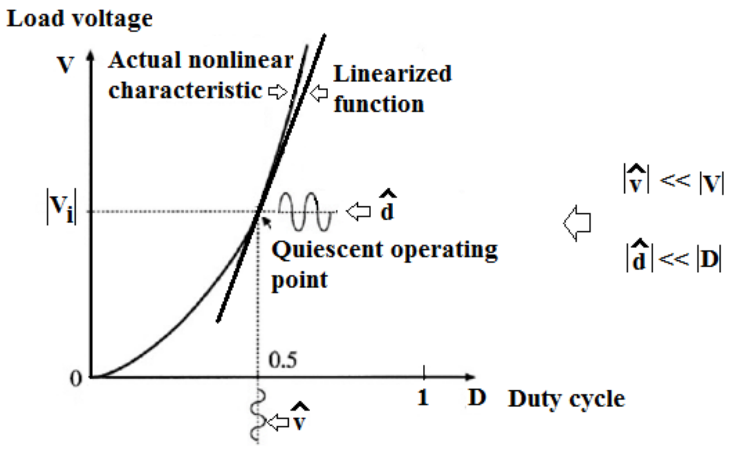

Figure 5. Linearization of the V(D) curve of the buck-boost converter around quiescent point for *D*=0.5.

The ripples in the coil current and load voltage waveforms are eliminated by taking the average during a period. The components with low frequency of the coil and load waveforms are written by equations of the form [26].

$$L\frac{d<i_L(t)>_T}{dt} =< v_L(t) >_T \tag{21}$$

$$C\frac{d<v(t)>_T}{dt} =< i_C(t) >_T \tag{22}$$

where $< x(t) >_T$ shows the mean value of $x(t)$ during a period T. The non-linear averaged equations of a DC-DC converter can be linearized around a quiescent point. Independent inputs of the DC-DC converter are taken as constant DC values and AC ripples with low amplitude. Using Eqs. (21) and (22), the converter nonlinear equations include DC terms, linear AC terms, and nonlinear terms. If the AC ripples are enough small in amplitude, the nonlinear variables are much smaller than the linear AC variables, because, they are ignored. The rest of the linear AC term represents the Small Signal Model (SSM) of the converter. By averaging the coil voltages and capacitor currents, the basic averaged model which describes the converter dynamics are given as:

$$K < \frac{dx(t)}{dt} >_T = \left[d(t)A_{on} + d_{off}(t)A_{off}\right] < x(t) >_T + \left[d(t)B_{on} + d_{off}(t)B_{off}\right] < u(t) >_T \quad (23)$$

$$< y(t) >_T = \left[d(t)C_{on} + d_{off}(t)C_{off}\right] < x(t) >_T + \left[d(t)E_{on} + d_{off}(t)E_{off}\right] < u(t) >_T \quad (24)$$

To design a SSM at a quiescent point (I, V), it is assumed that the source voltage $v_i(t)$ and the duty cycle $d(t)$ are equal to quiescent values V_i and D, and sum of superimposed AC variations with small amplitude $\hat{v_i}(t)$ and $\hat{d}(t)$. The capital letters show DC components and the letter with superscript $\hat{x}$ are AC components. Perturbation and linearization about a quiescent point is applied to design the SSM AC model as follows:

$$\begin{aligned} < x(t) >_T &= X + \hat{x}(t) \\ < u(t) >_T &= U + \hat{u}(t) \\ < y(t) >_T &= Y + \hat{y}(t) \\ d(t) &= D + \hat{d}(t) \end{aligned} \quad (25)$$

where, $\hat{u}$, $\hat{x}$, $\hat{y}$ and $\hat{d}$ are small AC variations in control, state, output vectors and duty ratio, respectively. It is known that AC ripples are much smaller than the quiescent values. As a result, the state space equations for large signals are obtained as:

$$K\left(\frac{d < X(t) >_T}{dt} + \frac{d < \hat{x}(t) >_T}{dt}\right) = (\overbrace{AX + BU}^{dc\ terms}) + (\overbrace{A\hat{x}(t) + B\hat{u}(t) + \left(\left(A_{on} - A_{off}\right)X + \left(B_{on} - B_{off}\right)U\right)\hat{d}(t)}^{1^{st} order\ ac\ terms\ (linear)}) + (\overbrace{\left(A_{on} - A_{off}\right)\hat{d}(t)\hat{x}(t) + \left(B_{on} - B_{off}\right)\hat{d}(t)\hat{u}(t)}^{2^{nd} order\ ac\ terms\ (nonlinear)}) \quad (26)$$

$$Y + \hat{y}(t) = (\overbrace{CX + EU}^{dc\ terms}) + (\overbrace{C\hat{x}(t) + E\hat{u}(t) + \left(\left(C_{on} - C_{off}\right)X + \left(E_{on} - E_{off}\right)U\right)\hat{d}(t)}^{1^{st} order\ ac\ terms\ (linear)}) + (\overbrace{\left(C_{on} - C_{off}\right)\hat{d}(t)\hat{x}(t) + \left(E_{on} - E_{off}\right)\hat{d}(t)\hat{u}(t)}^{2^{nd} order\ ac\ terms\ (nonlinear)}) \quad (27)$$

The right hands of equations (26) and (27) contain DC (steady state), linear and nonlinear terms. To obtain a small signal AC model, it is assumed that the DC terms are constant. The second order AC (nonlinear) terms are much smaller than the first order (linear). If it is synchronized to each other on both DC sides of the equations (26) and (27), the small signal linearized state space equations can be written as:

$$K\frac{d\hat{x}(t)}{dt} = A\hat{x}(t) + B\hat{u}(t) + \left(A_{on} - A_{off}\right)X + \left(\left(A_{on} - A_{off}\right)X + \left(B_{on} - B_{off}\right)U\right)\hat{d}(t) \quad (28)$$

$$\hat{y}(t) = C\hat{x}(t) + E\hat{u}(t) + \left(\left(C_{on} - C_{off}\right)X + \left(E_{on} - E_{off}\right)U\right)\hat{d}(t) \quad (29)$$

The resultant small signal AC equations of the ideal buck-boost converter are given as:

$$\begin{bmatrix} -L & 0 \\ 0 & C \end{bmatrix} \frac{d}{dt} \begin{bmatrix} \hat{\imath}(t) \\ \hat{v}(t) \end{bmatrix} = \begin{bmatrix} 0 & D_{off} \\ D_{off} & -\frac{1}{R} \end{bmatrix} \begin{bmatrix} \hat{\imath}(t) \\ \hat{v}(t) \end{bmatrix} + \begin{bmatrix} D \\ 0 \end{bmatrix} \widehat{v_i}(t)$$

$$+ \left(\begin{bmatrix} 0 & -1 \\ -1 & 0 \end{bmatrix} \begin{bmatrix} I \\ V \end{bmatrix} + \left(\begin{bmatrix} 1 \\ 0 \end{bmatrix} \right) V_i \right) \hat{d}(t) \quad (30)$$

$$-L \frac{d\hat{\imath}(t)}{dt} = D_{off} \hat{v}(t) + D\widehat{v_i}(t) + (V_i - V)\hat{d}(t) \quad (31)$$

$$-C \frac{d\hat{v}(t)}{dt} = D_{off} \hat{\imath}(t) - \frac{1}{R} \hat{v}(t) - I\hat{d}(t) \quad (32)$$

$$\widehat{\imath_i}(t) = \begin{bmatrix} D & 0 \end{bmatrix} \begin{bmatrix} \hat{\imath}(t) \\ \hat{v}(t) \end{bmatrix} + [0]\widehat{v_i}(t) + \left(([1 \quad 0] - [0 \quad 0])X + ([0] - [0])V_i \right) \hat{d}(t) \quad (33)$$

$$\widehat{\imath_i}(t) = \begin{bmatrix} D & 0 \end{bmatrix} \begin{bmatrix} \hat{\imath}(t) \\ \hat{v}(t) \end{bmatrix} + \left(([1 \quad 0]) \begin{bmatrix} I \\ V \end{bmatrix} \right) \hat{d}(t) \quad (34)$$

Fig.6 shows the resultant small signal model of the ideal buck-boost converter.

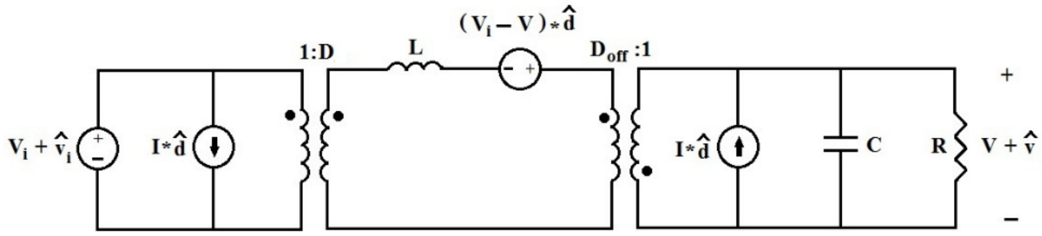

Figure 6. SSM of the buck-boost converter into canonical form

2.4. The Canonical Circuit Model

The alternating current equivalent circuit of any continuous current mode DC-DC converter can be expressed in the canonical form [15].

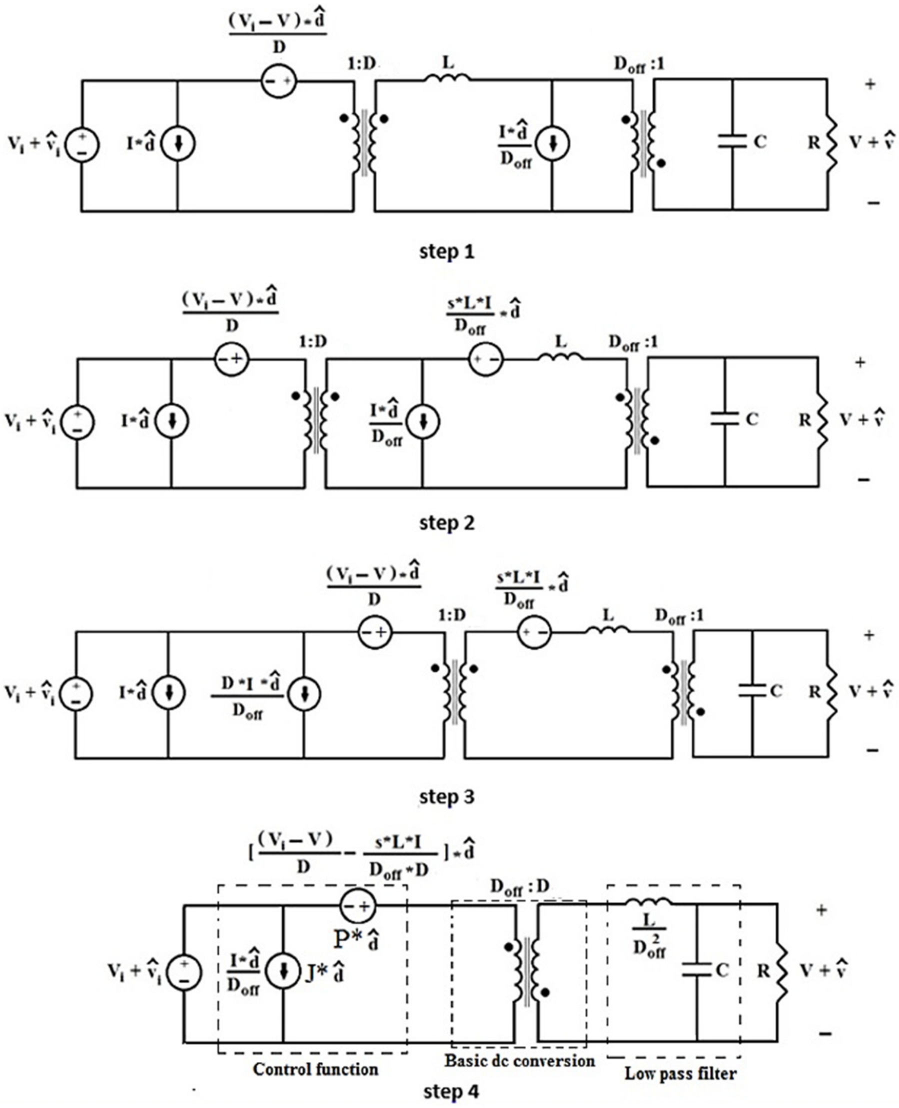

Figure 7. Obtaining the SSM of the buck-boost converter into canonical form step by step

The circuit model in Fig.6 is achieved using equations (31-34). Fig.7, explains developing of the canonical model of essential buck boost DC-DC converter in four steps. The turn ratio of the transformer shown in step 4 in Fig. 7 is D_{off} : D or 1: D/$(1 - D)$. This conversion ratio is a function of the quiescent duty cycle *D*. In addition, the control function of the model contains dependent voltage $P(s) * \hat{d}\ (s)$ and dependent current source $J(s) * \hat{d}(s)$ in Fig.7. Both sources are driven by $\hat{d}$. Model developed in Step 4 in Fig.7 is an equivalent circuit that shows the low frequency small signal variations in the converter waveforms. It can now be solved, using conventional linear circuit analysis techniques, to find the converter transfer functions, output impedance, and other AC quantities of interest.

3. Description of Proposed Simulink Model

The proposed Simulink model is shown in Fig. 8. The circuit consists of two controlled voltage sources, a controlled current source, an ideal transformer, a low pass filter and the time varying resistive load. The controlled voltage source 1 (CVS1) is DC input voltage of the DC-DC buck-boost converter, it generates variable step voltages without ripples (case 1) when connected to the signal builder block named *variable voltage without ripple*. Similarly, it generates variable step voltages with ripples (case 2), when connected to the embedded MATLAB block named *variable voltage with ripples* to end "s" of CVS1 in Fig.7. The controlled current source and CVS2 represent the control function of the SSM of DC-DC buck-boost converter. The dependent sources are related to duty cycle. The ideal transformer, an imaginary device, is widely used in DC-DC power conversion circuits to change the levels of voltage and current waveforms while transferring electrical energy. This block can be used to represent either an AC transformer or a solid-state DC-DC converter.

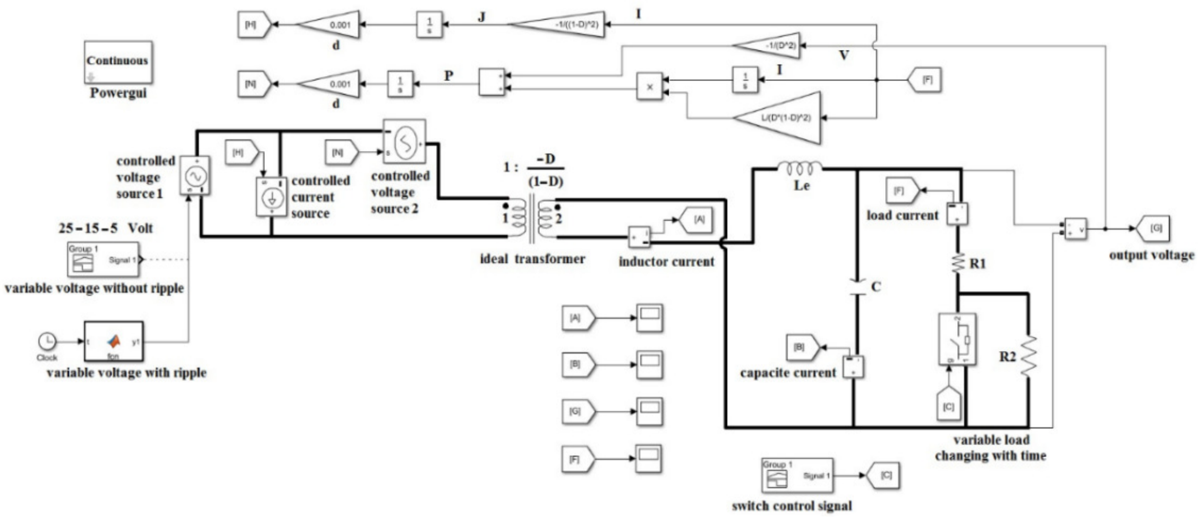

Figure 8. Proposed Simulink model of the buck-boost DC-DC converter

4. Simulation studies

The performance of the proposed DC-DC buck-boost converter model is checked at different input voltage and load variations in MATLAB/Simulink.

Case 1: Step changes in input voltage without ripple and the time varying load

Fig.9 shows variations at different intervals in input voltage and load without ripple. The simulated response of the load current due to step change in input voltage and the load is given in Fig.10. The simulated response of the load voltage due to step change in the input voltage and the load is shown in Fig.11. The simulated response of the inductor current due to step change in the input voltage and the load is given in Fig.12. The simulated response of the capacitor current due to step change in the input voltage and the load is also shown in Fig. 13. From these figures, output voltage tracks the input voltage with the prescribed quiescent duty cycle and the output voltage and inductor current can return to steady state value with small overshoot and settling time. The capacitor current almost zero value except in the instant of input voltage and load change.

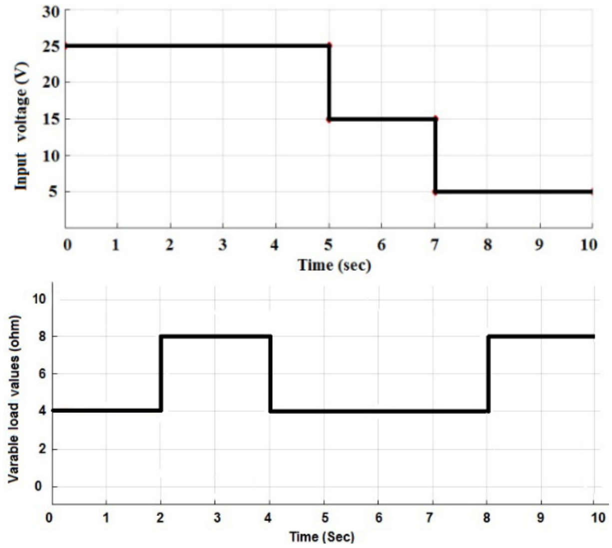

Figure 9. Input voltage variation and load profile form 4 Ω to 8 Ω

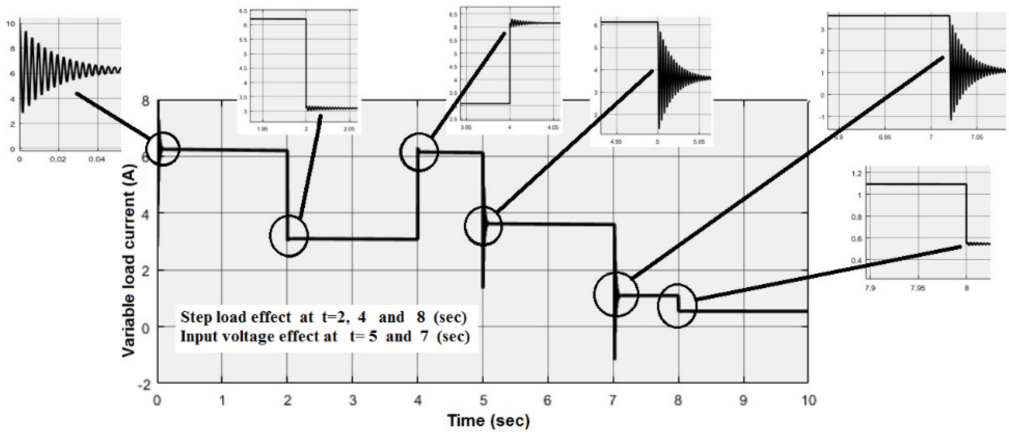

Figure10. Simulated response of the load current due to step change in input voltage and load

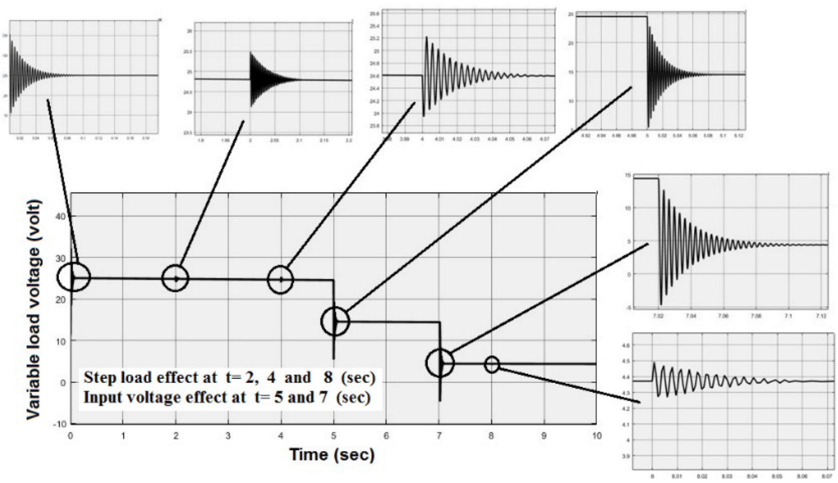

Figure11. Simulated response of the load voltage due to step change in the input voltage and load

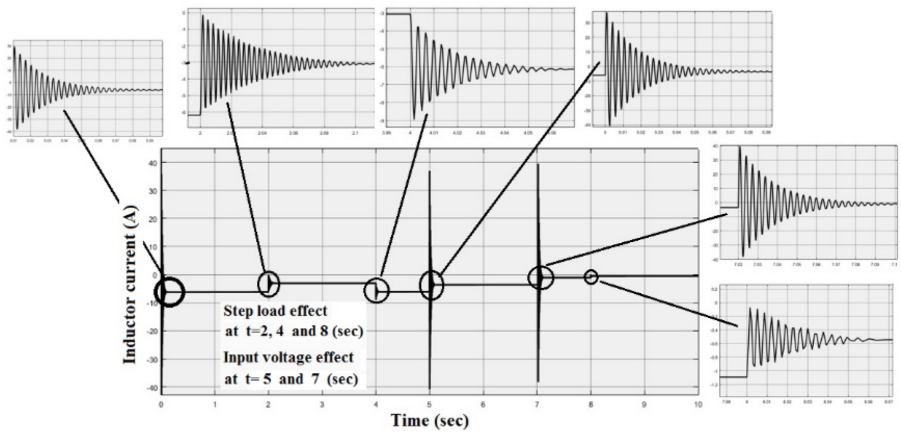

Figure12. Simulated response of the inductor current due to step change in the input voltage and load

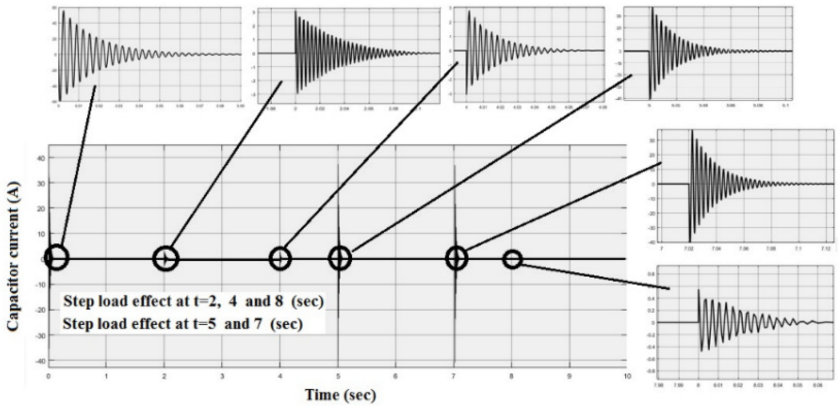

Figure13. Simulated response of the capacitor current due to step change in the input voltage and load

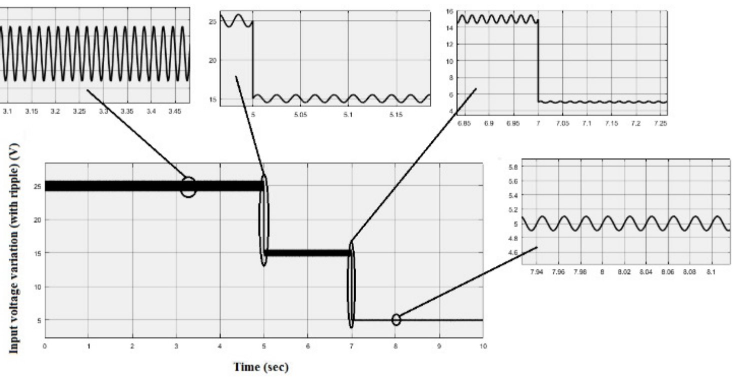

Figure14. Input voltage variation (with ripple)

Case 2: Step changes in input voltage with ripple and the time varying load

Fig.14 illustrates the input voltage variations with ripple having 3 steps from 24 V to 5 V at 10 sec, and at the same time the load variations from 4 Ω to 8 Ω at 10 sec are also applied to the proposed model. The simulated response of the load voltage due to step change in input voltage and the load is given in Fig.15. The simulated response of the load current due to step change in the input voltage and the load is given in Fig.16. The simulated response of the inductor current due to step change in the input voltage and the load is provided in Fig.17. From these figures, output voltage tracks the input voltage with the prescribed quiescent duty cycle and the output voltage and inductor current can return to a steady state value with small or large overshoot and settling time. For both of the cases, *D=0.5,* L_e*= (30e-6) *1/((1-D)^2) Henry, C=2.2 e-3 Farad, d=0.001, Ts=1e-5* are selected in Fig. 8.

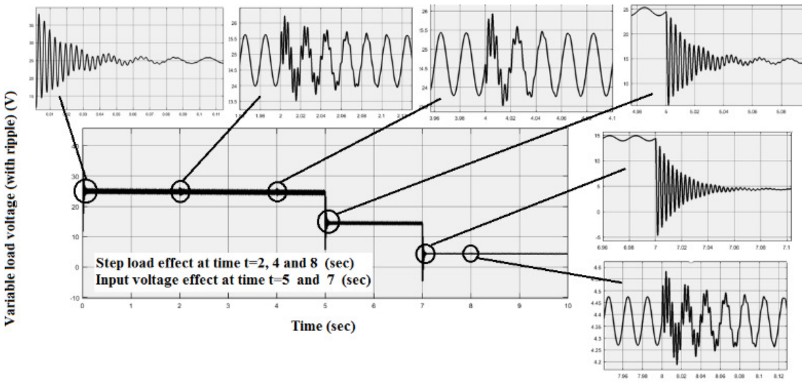

Figure.15. Simulated response of the load voltage due to step change in the input voltage (with ripple) and the load

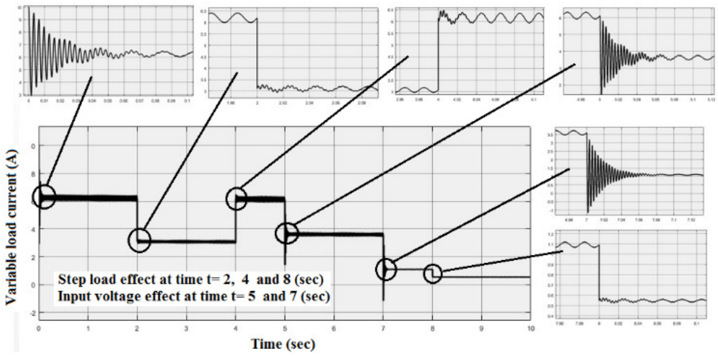

Figure.16. Simulated response of the load current due to step change in input voltage (with ripple) and the load

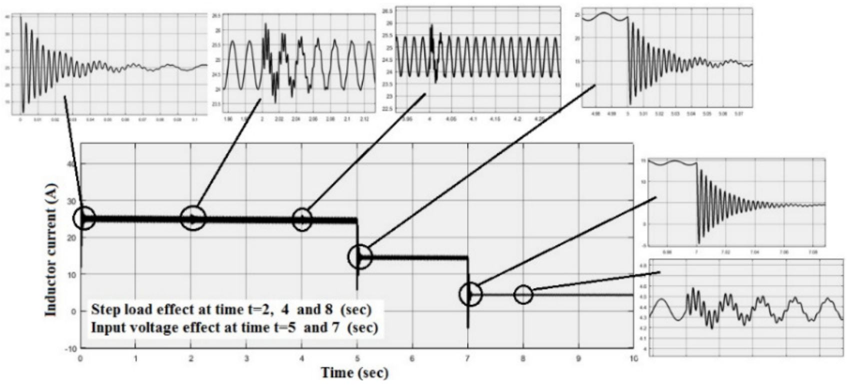

Figure.17. Simulated response of the inductor current due to step change in the input voltage (with ripple) and the load

5. Conclusion

This work not only provides the benefits of state-space averaging modelling, but also give the necessary steps and ways of building a dynamic model of the system for an application or algorithm analysis. The proposed model was checked in CCM under load changes and input voltage variations. Results were shown to indicate that the output voltage and inductor current can return to steady state with a small overshoot and settling time even under disturbances. The proposed model was shown to be very accurate in anticipating the large or low signal time domain transients. In addition, this model can also provide a new control technique to study closed loop performance of a system. The model can be used to develop strong, and robust closed loop controller, which can ensure stability and performance conditions of the DC-DC buck-boost converter, and can be beneficial to obtain circuit parameters, such as input and output impedances, inductor current variations, the converter transfer functions, etc.

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