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Checking the Robustness of a PWM Sliding Mode Controlled DC/DC Buck-Boost Converter Using its Matlab/Simulink Model

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***Abstract* - The modelling of sliding mode (SM) based controlled DC-DC buck-boost converter operating in continuous conduction mode (CCM) with pulse-width modulation (PWM) based is represented in this paper. The model is simulated by Matlab/Simulink software package. The system is modelled and the SM equations for the PWM implementation are illustrated. The performances of the system are tested for the static and dynamic performance is investigated. The simulation results show good and accepted values for voltage regulation which makes the model suitable for common DC-DC conversion purposes.**

***Index Terms*— Buck-boost converter, sliding mode control, pulse-width modulation..**

I. Introduction

Stated as variable structure control (VSC), the sliding mode control theory was originated in the early 1950's initiated by S. V. Emel'Yanov.

For a nonlinear control technique with remarkable properties such as accuracy, robustness, and easy tuning and implementation, sliding mode controllers (SMC) are recalled.

This type of controller is designed to drive the system states onto a surface in the state-space, which is called sliding surface. When the sliding surface is reached, the states are kept close neighborhood the sliding surface. Hence this type of controllers is a two phase designed controllers. The first part concerns the design of a sliding surface and the second phase is in which the selection of a control law is done, which will develop the switching surface and make it attractive to the system state [1].

The main two advantages of SMC are.

1- The dynamic behavior of the system may be adjusted by the specific choice of the sliding function.

2- The closed loop response is insensitive to uncertainties in some particular cases. So, practically SMC allows for controlling nonlinear processes which are subjected to external disturbances and model uncertainties.

The fundamental principles of SMC are given in the main references [1]-[3].

For small-signal model behavior of DC-DC converter system and for large transient cases, the response will be unaccepted and will be unstable. Such disadvantage drives the research works of in two directions; first one for more accurate linear models and the second for more simple nonlinear models used for the controller design [1].

Being of the second type, the sliding mode (SM) control is of nonlinear control structure which is introduced mainly for controlling systems which are called variable structure systems [2]. It seems that drawback of power losses and electromagnetic interference (EMI) associated with the application of SM, increases because of its variable frequency nature [3].

The basic three type of DC– DC converters, are, the buck, buck-boost, and the boost converters, which are classified as simple and most commonly used converters as regulated power supply's other type of converters are constructed using a combination of these three type converters [4].

The closed-loop feedback controller is almost designed for the DC–DC converters with main objectives given as:

1. Small acceptable steady-state output error,
2. Its dynamic response is fast.
3. Its overshoot is low.
4. Its noise is low.
5. Very high efficiency.

Also, other parameters will affect in choosing the value of switching frequency, capacitance and the inductance, the gain parameters, and controller type [5].

The different types of control used are.

1- Hysteric control systems.
2- Pulse-width modulation control systems.

Nowadays other alternative methods such as adaptive controllers, fuzzy controllers, neural control systems and finally the sliding mode controllers are used because of the failure of conventional linear and partial nonlinear control schemes, to operate satisfactorily especially for large-signal operating modes [6].

II PRINCIPLE OF SM CONTROL

When one MOSFET switch DC–DC converter is used, the main control law that represents a switching function is given as [7]

$$u = 0.5(1 + \mathrm{sign}(s)) \quad \text{.....(1)}$$

Where

u goes for the logic state (ON or OFF of the MOSFET) in the converter circuit.

S represents the instantaneous state, which for second -order controllers is given by

$$S = \alpha_1 x_1 + \alpha_2 x_2 + \alpha_3 x_3 = J^T x \quad \text{.....(2)}$$

The last equation is represented in Fig.(1) as a graph.

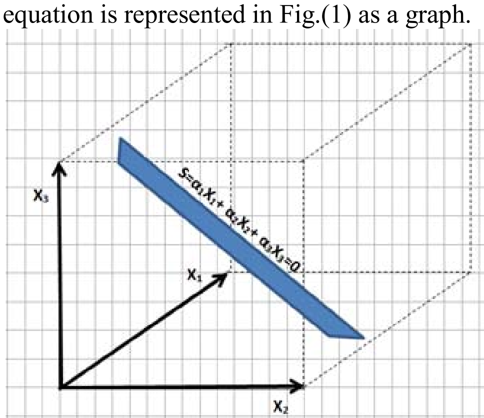


Fig.(1) Three-dimensional sliding plane in space.(Graphical representation)

Where

$J^T = [\alpha_1 \ \alpha_2 \ \alpha_3]$ and $\alpha_1 \alpha_2$ and α_3 representing the control parameters, $x_1, x_2,$ and x_3 denotes the desired state-space variables which are going to be controlled.

Using S = 0, a sliding plane can be obtained and the control process of the converter will be divided into two phases of the SM controller used which are called the reaching phase and the sliding phase. The trajectory of the state-space variables by a control decision will be driven just to the sliding plane all this is done in the first phase. After that the controller is in the sliding phase. In this phase the trajectory is directed toward the origin and maintained within a small region of the plane. In this case the equivalent trajectory is S= 0

i.e.

$$\frac{d^2x_1}{dt^2} + \frac{\alpha_1}{\alpha_2}\frac{dx_1}{dt} + \frac{\alpha_3}{\alpha_2}x_1 = 0 \quad \text{.....(3)}$$

According to Eq.(3) it seems that, the implementation of SM controllers requires some investigations for sufficient insights in designing practical SM controllers the converters. Now it is very important choice properly the state variables of the system which aff ects the control performance and decide how much will be the complexity of implementing the whole controlled system [9].

(1) Increasing the number of state-space variables means those more sensing devices and more computations of the state variables.

(2) Using voltage will make the state variables easterly sensed and needs requires less computations.

Some means of sensing voltages variables which are called the indirect methods such as, $\frac{dv_o}{dt}$ can be found when the current passing through the output capacitor is sensed.

(3) One of the main drawbacks is the sensing of capacitor current to produce the derivative of voltage variable and a very low-impedance current transformers are normally required [10].

III. BUCK-BOOST DC-DC CONVERTERS

One of the main types of DC-DC converters is the buck–boost converter. As shown in Fig.(2) the basic schematic of this converter contains one switching device with the main diode and the two energy storing devices of course plus the DC power source [12].

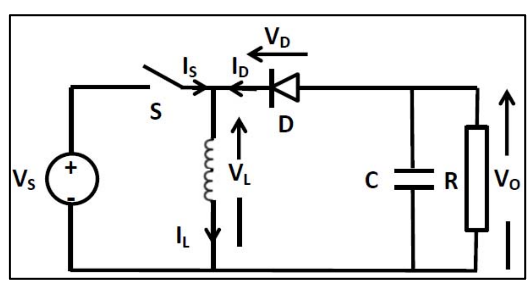


Fig. (2) The well-known DC-DC Buck-Boost converter schematic diagram

Its output voltage can be made greater than (Boost) or less than (Buck) the input voltage magnitude

Because of the capability of the two different ways of operation it is called buck–boost converter.

Figure (3) explains the operating principles of the buck–boost converter:

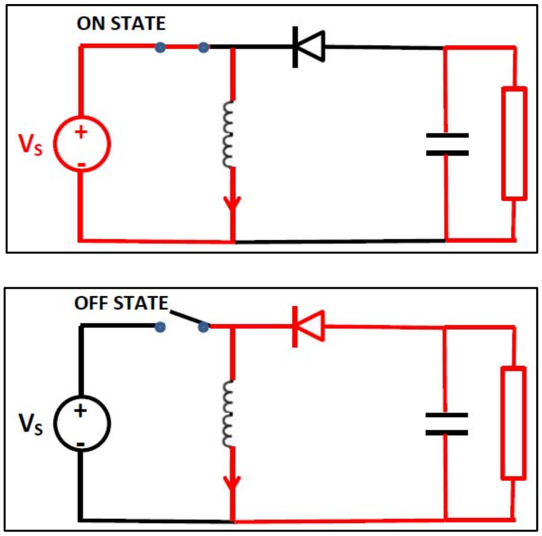


Fig.(3): The two stage configuration which represents the operating principles of the buck–boost converter:

(a) (First State)

In this state the main switch of the circuit is turned ON current is supplied to the inductor via the main DC supply and the capacitor is charged and supply's current to the resistive load.

(b) Second State)

In this stage the main switch of the circuit is switched OFF, and the inductor discharges its energy by forcing a current through the load via the main diode D.

When current passing through the inductor L never falls to zero during the commutation cycle of the first stage, continuous mode is achieved; otherwise it is the discontinuous mode of operation [13].

The output and the input DC voltages are related by the following:

$$\frac{V_o}{V_i} = \frac{D}{D-1} \qquad \text{.....(4)}$$

or

$$D = \frac{V_o}{V_o - V_i} \qquad \text{.....(5)}$$

where

D is the operating duty ratio of the converter

From Eq. (5), it is clear that the D changes from 0 to 1 so this will decide the polarity of the output voltage, which will be negative and the load voltage profile increases with D, up to very large negative values when D comes near unity. Speaking about absolute value of output voltage the converter may rise (a boost converter) the input voltage or decrease it (a buck converter).

VI. System Modelling

The three states of the state-space model can be expressed [7]

$$x = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} V_{\text{ref}} - \beta V_o \\ \frac{d(V_{\text{ref}} - \beta V_o)}{dt} \\ \int (V_{\text{ref}} - \beta V_o) dt \end{bmatrix} \qquad \text{--(6)}$$

$$x = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} V_{\text{ref}} - \beta v_o \\ \frac{\beta v_o}{r_L C} + \int \frac{\beta v_o \bar{u}}{LC} dt \\ \int x_1 dt \end{bmatrix} \qquad \text{--(7)}$$

$$\dot{x} = \mathbf{A}x + \mathbf{B}\bar{u} \qquad \text{---(8)}$$

$$\mathbf{A} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & -\frac{1}{r_L C} & 0 \\ 1 & 0 & 0 \end{bmatrix} \qquad \text{---(9)}$$

$$\mathbf{B} = \begin{bmatrix} 0 \\ \frac{\beta v_o}{LC} \\ 0 \end{bmatrix} \bar{u} \qquad \text{-- (10)}$$

β is the second output voltage

C Main capacitance of the power circuit

and

L is the main inductance in the power circuit

Using the set of equations shown above it is shown that the control voltage equation will be as follows

$$V_c = -k_{p1} i_C + k_{p2}(V_{\text{ref}} - \beta V_o) + \beta(V_o - V_i) \qquad \text{.....(11)}$$

where

VC is the control voltage

kp1 and kp2 are the sliding model controller gains

VII. Simulation of the SM Controlled DC-DC Buck-Boost Converter and Results

The complete schematic diagram of the PWM based SMVC buck-boost converter represented by Eq.(11), is given in [7], [8]. The implemented simulation model of the buck-boost converter is presented, using the well-known Matlab-Simulink software package including Power System Block set and parameters of the model are given in Table 1.

TABLE 1

LIST OF PARAMETERS

Description	Parameter	Nominal value
Input voltage	Vi	24 volt
Capacitance	C	220 μF
Capacitor ESR	r_C	36 mΩ
Inductance	L	200 μH
Inductor resistance	r_L	0.12 Ω
Switching frequency	f	200KHz
Minimum load resistance (buck)	$R_{L(Min.)}$	14 Ω
Minimum load resistance (boost)	$R_{L(Max.)}$	140 Ω
Desired output voltage (buck)	V_{od}	12 volt
Desired output voltage (boost)	V_{od}	48 volt

The modeling is probably the most important stage required in system control design work. When the system model is well designed this will provide valuable information about the system dynamics. The mathematical problems causes difficulty in solving the general nonlinear equations that is why we simulate using Simulink model which is a very good mathematical tool used to solve the nonlinear equations numerically, and show the required response of the system dynamics.

The complete dynamic model of the DC/DC converter and its response has been tested for a sudden step change in the resistive load and the supply DC voltage source for both buck and boost operations. The implemented simulink model of the proposed buck-boost SM based DC-DC converter, is shown in Fig. (4).

For the robustness test of the SM control scheme, the load resister RL has been forced to a step change from 100 Ω to 20 Ω. Fig.(5) shows the output voltage profile during the load step change for both, buck and boost operation of the converter. Figure (6) shows the effects of step change in input supply voltage (24-28-20-24 volt in step changes respectively) on the output voltage profile for both, buck and boost operations. Output voltage profile is shown for both, load resistance Fig.(7), input voltage variation Fig.(8) for both buck and boost operation.

VII. CONCLUSIONS

The simulation of the PWM-based SM DC-DC buck-boost converter has been simulated in this paper. The step-down and the step-up conversion process of the converter is feasible. The excellent robustness feature of the SM controller is examined likewise, the fast response capability of the controller.

The main disadvantage appear in this model is the requirement of a current sensor in the construction of the controller.

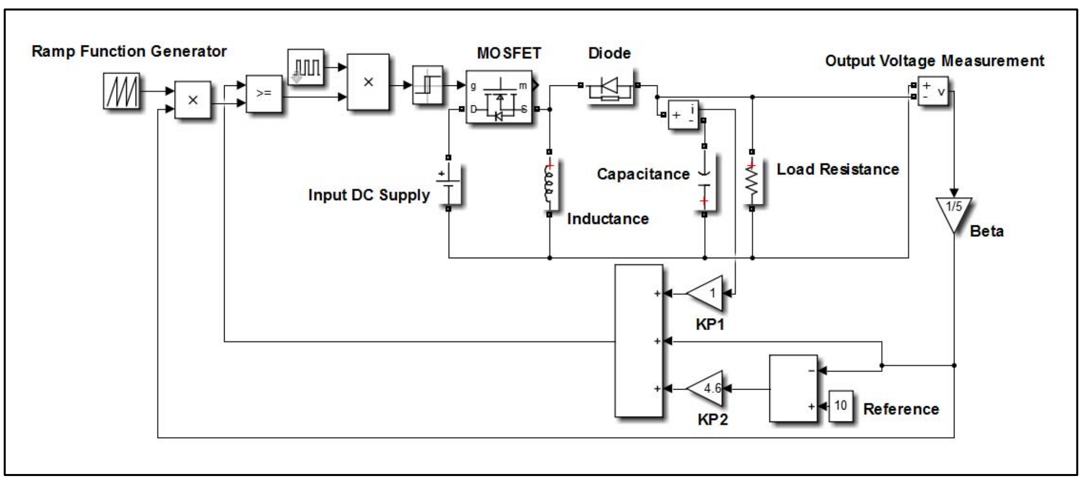
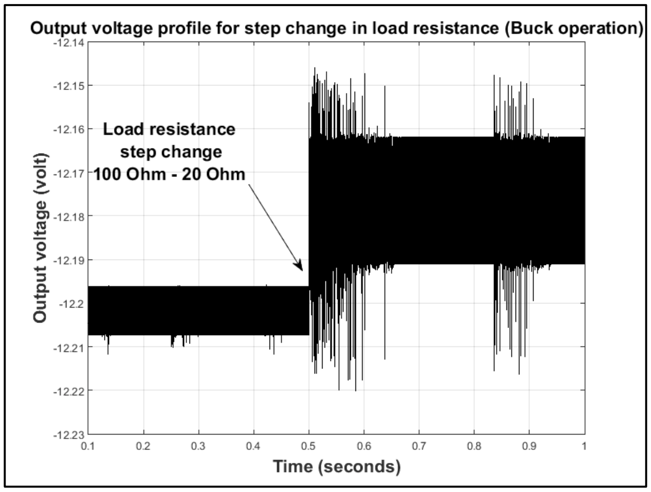
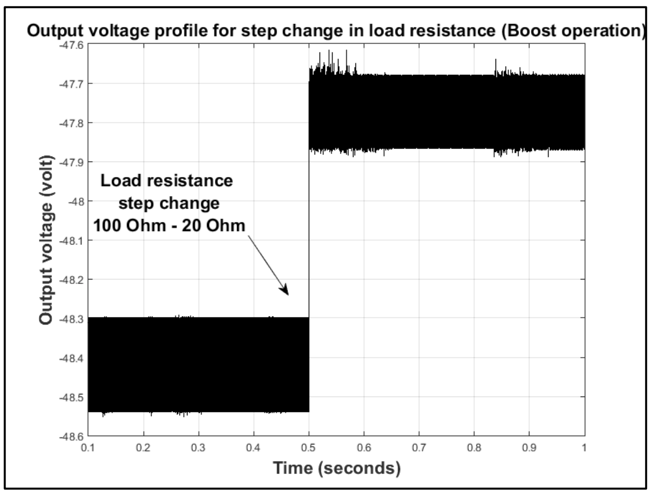


Fig.(4) Implemented Simulink model of the SM based controlled DC-DC buck-boost converter

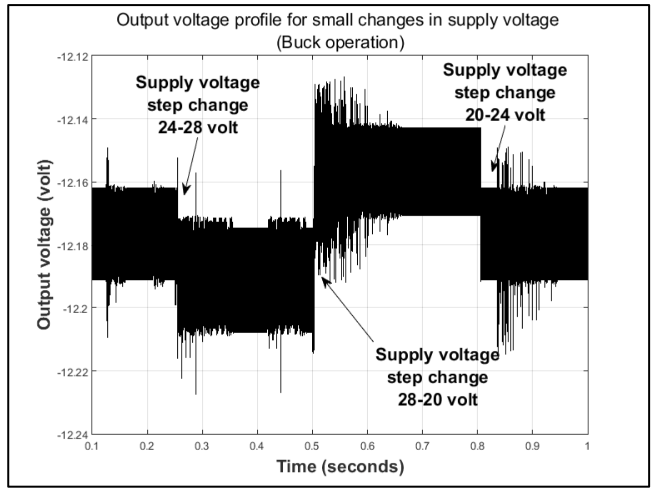


(a)

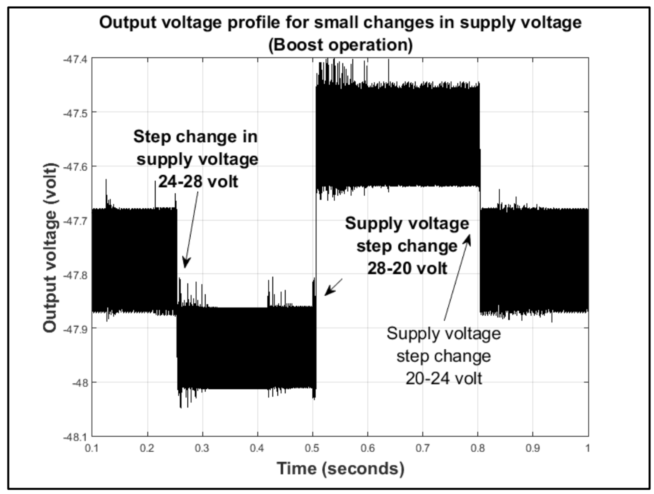


(b)

Fig. (5) Output voltage profile for a step change in load resistance (a) Buck operation (b) Boost operation

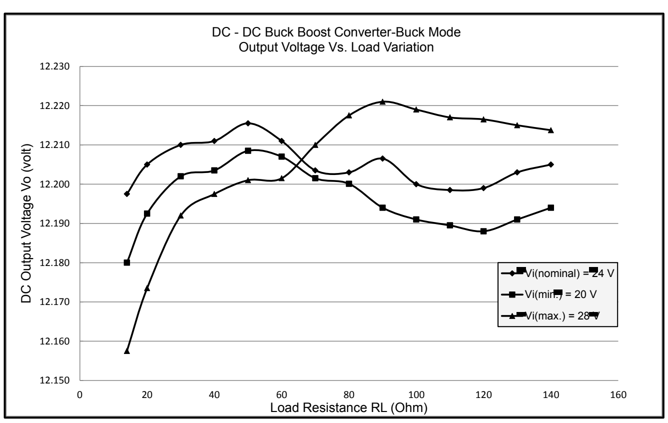


(c)

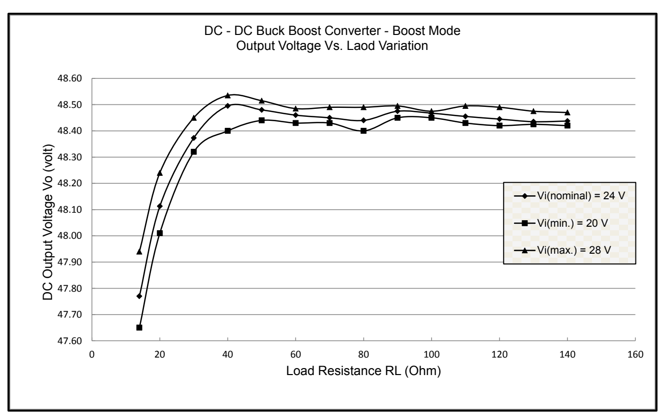


(d)

Fig. (6) Output voltage profile for a step change in input voltage (a) Buck operation (b) Boost operation.

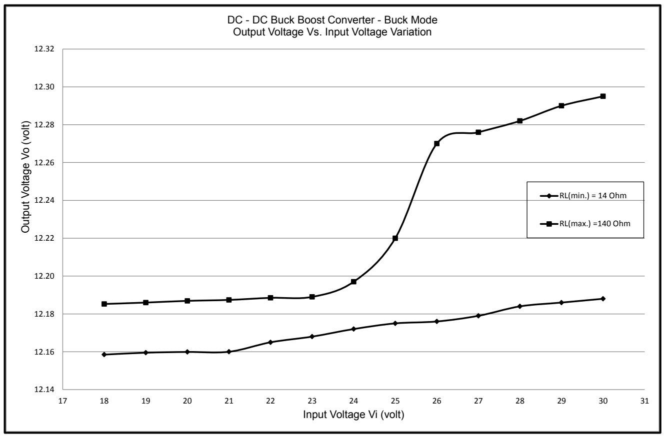


(a)

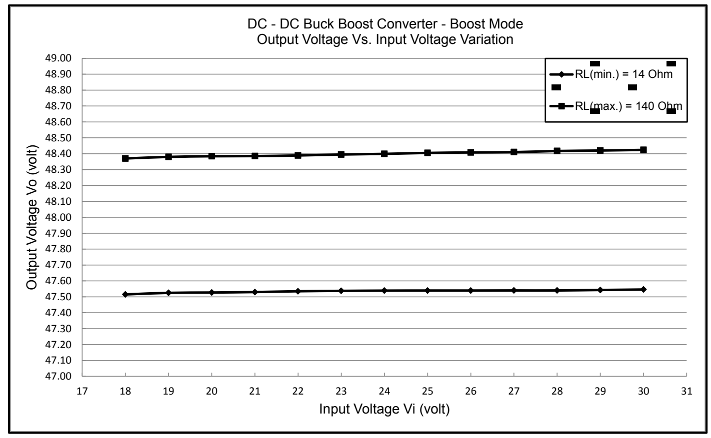


(b)

Fig.(7) Output voltage profile for load variation
(a) Buck operation
(b) Boost operation



(a)



(b)

Fig.(7) Output voltage profile for input voltage variation
(a) Buck operation
(b) Boost operatio

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