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DC-DC BUCK CONVERTER USING SLIDING MODE CONTROL WITH LOAD OF CONSTANT POWER

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ABSTRACT

This paper describes a sliding mode duty ratio controller which is used for dc-dc converter with constant power load. It can stabilize the dc power system over the wide range of power and voltage variation. The proposed sliding mode controller over comes the chattering effect and the result of SMDC is validated using matlab/Simulink model. The proposed sliding mode controller is also better than PID controller.

Keywords: Sliding-mode control, dc–dc converter, constant power load, variable structure system,pulsewidth modulation.

I. INTRODUCTION

With the introduction of power electronics there have been new utilization for DC-DC converters in various aspects of electronics. People utilize power converters due to its important features that regulated power converters exhibit tightly. This feature is an almost-accurate regulation at the output terminals that is not depending of the changes made at the input terminals [1]. Due to this important feature power electronics depend power supplies are searching their path into environments like aircrafts, vehicles and ships [1].**S**liding-mode controllers (SMCs) find most applications for DC-DC converters because of the factor of their inner nature of variable structure [1]. The merits of a constant output that does not depend on input changes, a tightly regulated almost accurate power converter has a feature at the input terminals that gives a load of constant power. CPLs has a feature of negative impedance at the input terminals creates an effect on the system stability.Knowing the stability problem due to the negative input impedance and mitigating this instability with the variation of the input source impedance is the prime objective of this paper.

This control methodology gives various merits over the other control method which appears as stable even for large line and load variations, robustness, better dynamic response and easy implementation. Variable structure systems (VSS) are referred assystems whose physical structures are intentionally changed during time with respect to the control law structure. The situation at which the changing of the structure arrives are obtained by the system current state.However the converter switches are running as a function of the instantaneous values of the state variables in such a way that pushes the system trajectory to stand on an accurate selected surface in the state space known assliding surface.The SMC technology provides one particular analysis to robust controller design.The SMC is a precious type of the VSCS, which is featured by a suitability of feedback control laws and a decision rule. The decision rule knows the switching function has at its Input features of some measure of the current system behavior and generates as an output the particular type of feedback controller should be utilized at that instant of time. A VSS may be referred as a combination of subsystems in which each subsystem control structure which is fixed and is valid for some specified regions of the system behavior.

Buck converter as constant power load

A buck converter behaves as a CPL at the input terminals due to the way the load produced across the output terminals. A dueof basic equations are essential to mathematically describe the way the load appears. With Ohm's Law $V=IR$ where V is known as voltage, I is current and R is resistance. Power P is obtained by relation$P = IV$ and measured in Watts (W). After substitution of Ohm's Law into the power equation the expression obtained:

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$$P = \frac{V^2}{R} \quad (1)$$

Which helps in measuring the load. Since output voltage regulation of the power converter is tight the output voltage is maintain constant. When the load V^2/R enhances since R decrease the power converter need large input current in order to maintain the output voltage constant.The only method to differ the load or power level in (1) is to change the value of resistor. With the change in the load there is a change in power level andthis effects the stability at the input terminal of the buck converter.

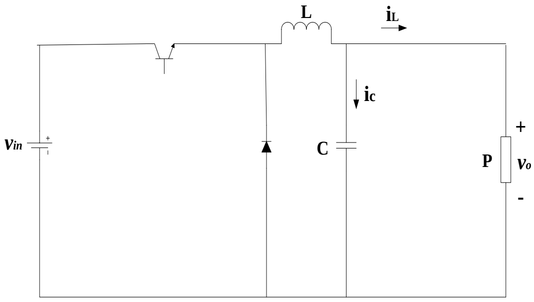

Fig.1 buck converter with constant power load

A buck converter shown in fig.1 is taken as an example to show the dc-dc converter instability with a constant power load.
The state–space model of buck converter can be expressed as

$$\begin{cases} \dfrac{di_L}{dt} = \dfrac{1}{L}(v_{in}d - v_0) \\ \dfrac{dv_0}{dt} = \dfrac{1}{C}\left(i_L - \dfrac{P}{v_0}\right) \end{cases} \quad (2)$$

Sliding mode control for DC-DC converters

DC-DC converters that are used in practice the current motion rate is much higher than the motion rate of the output voltage. The control issue can be eliminated by cascaded control structure having two control loops one is an inner current control loop and other is an outer voltage control loop[5]. Here the sliding mode methodology is used for the control of output voltage. Fig.2 defines the general structure of SMC for DC-DC converters.The sliding mode control is an essential robust control techniques to control a nonlinear systems. The most essential issue in implementing an SMC is to construct a switching control law to drag the plant state to a switching surface and held it on the surface upon. If there is an enforcement in sliding mode the closed-loop control system will have benefits of robustness to disturbances and low sensitivity to constraint changes [6]. From that point of view, the DC-DC converter is more suitable for the application of the SM due to its controllable state the system is controllable if there is an effect on input signal of every state variable.

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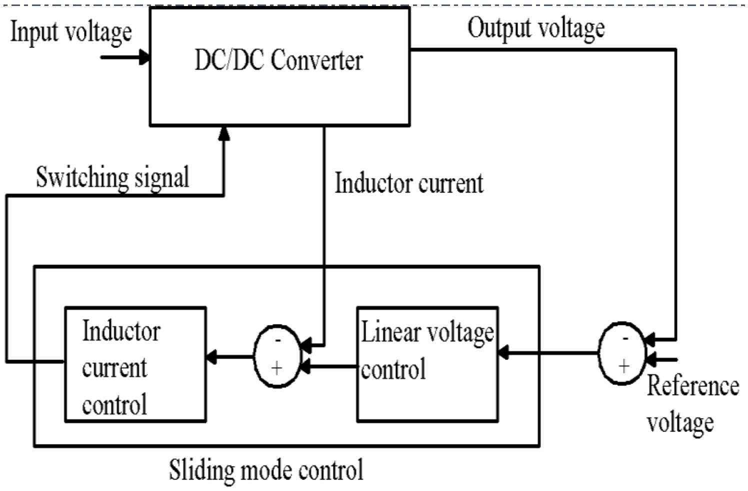

Fig. 2 Block diagram of SMC for DC-DC converter

Let's a unified state-space formulation of a dc-dc converter [10]: $\dot{x} = Ax + uBx$,in which scalar *x* is known as the state of the DC-DC buck converter, scalar *u* isis known as the control signal which is produced usinga switching control law derived by different satisfying conditions and *A* and *B* are known as parameter matrices of the converter. Consider x_d as the reference value for *x* then error can be expressed as $\tilde{x} = x - x_d$. The switching control law is commonly implemented as $u = u_{sw} = 1/2[1 + \text{sign}(s)]$, where *s* is referred a function of the error known asas $s = c^T \tilde{x}$, and vector *c indicates* the gradient of *s* with respect to $\tilde{x}$. Meanwhile an *n*th-order *s* function [8] can be implemented as

$$s(x;t) = \left(\frac{d}{dt} + \lambda \right)^{n-1} \tilde{x} \tag{3}$$

Whereλ is known a positive constant. Consider a candidate Lyapunov function $V(s) = s^2/2$. Then for controller stability and convergence of the state trajectory to the sliding surface, the recommended switching control should guarantee that thederivative of time of$V(s)$ is always negative when the value of$s \neq 0$, i.e.,

$$\dot{V}(s) = s \cdot \dot{s} < 0 \tag{4}$$

Due to the definition of *s*, the time derivative of *s* can be obtained as

$$\dot{s} = c^T \dot{x} = c^T \left(Ax + uBx \right) = c^T Ax + \frac{1}{2} c^T Bx + \frac{1}{2} sign(s) c^T Bx \tag{5}$$

Hence by substituting method

$$s\dot{s} = s\left(cAx + \frac{1}{2} c^T Bx \right) + |s| c^T Bx < 0 \tag{6}$$

Then the essential condition for the existence of the sliding mode in the vicinity of $s(x;t) = 0$ can be obtained as given below:

$$\begin{cases} c^T Ax < -cBx, & s > 0 \\ c^T Ax > 0, & s < 0 \end{cases} \tag{7}$$

In the SMC control system the dynamics of the state of interest in the sliding mode can be obtained as $\dot{s} = 0$. When solving this equation an expression can be calculated for *u* which is known as the equivalent control law u_{eq} [11]. The equivalent control law can be assumed asas a continuous control law that would held $\dot{s} = 0$, if the

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plant dynamics are exactly obtained. For the DC-DC converter, u_{eq} can be obtained by putting eq(6) to be 0, which produces $u_{eq} = -c^T Ax / c^T Bx < 1$.

SMC for buck converters with constant power loads

Let'sthe DC-DC buck converter at a constant power load in. According to eq.(3), an s function is expressed as follows:

$$s = \left(\frac{d}{dt} + \lambda\right)^2 \left(\int_0^t \tilde{x} dt\right) = \dot{\tilde{x}} + 2\lambda\tilde{x} + \lambda^2 \int_0^t \tilde{x} dt \qquad (8)$$

In which $\tilde{x}$ is known as the output voltage tracking error, which is referred as $\tilde{x} = e_v = V_{ref} - v_0$ and V_{ref} is the reference value for the output voltage of the buck converter. Then, (8) can be expressed as

$$s = a_1\dot{e}_v + a_2 e_v + a_3 \int e_v dt$$

Where a_1, a_2, and a_3 are regarded as positive coefficients. The switching control law of the SMC is implemented as

$$u = u_{sw} = \frac{1}{2}[1 + sign(s)] = \begin{cases} 1, & when\ s > 0 \\ 0, & when\ s < 0 \end{cases} \qquad (9)$$

To derive a essential condition to ensure the existence of the sliding mode and that eq.(4) is always valid the following method is concluded. First, the time derivative of s is obtained as $\dot{s} = a_1\ddot{e}_v + a_2\dot{e}_v + a_3 e_v$. Because ofthe dynamic model eq.(3) of the DC-DC buck converter, the first and second time derivatives of the voltage tracking error can be obtained as

$$\dot{e}_v = -\dot{v}_0 = -\frac{1}{C}\left(i_L - \frac{P}{v_0}\right)$$
$$\ddot{e} = \frac{P}{C^2 v_0^2} i_c - \frac{v_{in}}{LC} u + \frac{v_0}{LC} \qquad (10)$$

By substituting eq.(10) into the expression of $\dot{s}$ produces

$$\dot{s} = \left(\frac{a_1 P}{v_0^2 C^2} - \frac{a_2}{C}\right) i_C - \frac{a_1}{LC}\left(v_{in} u - v_0\right) + a_3\left(V_{ref} - v_0\right) \qquad (11)$$

According to eq.(4), to give controller stability and convergence to the sliding mode, $\dot{V} = s\dot{s} < 0$ should be always satisfied using the switching control law eq.(7).Then the following two terms can be derived by substituting eq.(10) into eq.(11) and also ensuring $s\dot{s} < 0$.

- If s >0, u_{sw} is equal to 1, and $\dot{s}$ requires to be

$$\dot{s} = \left(\frac{a_1 P}{v_0^2 C^2} - \frac{a_2}{C}\right) i_C - \frac{a_1}{LC}\left(v_{in} - v_0\right) + a_3\left(V_{ref} - v_0\right) < 0 \qquad (12)$$

- If s <0, is equal to 0, and $\dot{s}$ requires to be

$$\dot{s} = \left(\frac{a_1 P}{v_0^2 C^2} - \frac{a_2}{C}\right) i_C + \frac{a_1}{LC} v_0 + a_3\left(V_{ref} - v_0\right) > 0 \qquad (13)$$

Based on eq.(12) and (13), the ranges of the coefficients a_1, a_2, and a_3 are obtained

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Control law design for the SMDC

As discussed in earlier section, if the converter dynamics are exactly obtained, u_{eq} can be used as a continuous control law for maintaining $\dot{s} = 0$ .To handle converter disturbances a switching term with a variable magnitude is putto u_{eq} for forming the complete control law for the SMDC as follows:

$$u = u_{eq} + \frac{|e_v|}{v_{in}} sign(s) \tag{14}$$

Where u_{eq} is obtained by putting eq.(11) to be zero

$$u_{eq} = \frac{L}{v_{in}} \left[\left(\frac{P}{Cv_0^2} - \frac{a_2}{a_1} \right) i_C + \frac{1}{L} v_0 + \frac{a_3 C}{a_1} \left(V_{ref} - v_0 \right) \right] \tag{15}$$

According to control law, the value of u_{eq} be limited between 0 and 1. Hence the time derivative of the candidateLyapunov function is obtained as

$$\dot{V}(s) = s \cdot \dot{s} = s \cdot \left(0 - \frac{a_1 v_{in}}{LC} \cdot \frac{|e_v|}{v_{in}} sign(s) \right) = -\frac{a_1}{LC} |s| \tag{16}$$

In eq.(16), a_1 is referred a positive coefficient of the *s* function. Then eq.(16) is always negative when the value of $s \neq 0$. This ensures the stability of controller and convergence to the sliding mode.

II. SIMULATION AND RESULT

To give the effectiveness of SMDC for various constant power load situation, the output power is differ in steps. Results are taken for three various values of constant power like 50W, 250W, and 660W.Also the input voltage of buck converter that is step changed from 0V to various values to see the effectiveness of the SMDC for various input voltage conditions. The parameters of buck converter are given in table 1.

Parameters	Values
L	18 mH
C	10 uF
a_1	10
a_2	30
a_3	10
V_{in}	200/400/600 V
P	50/250/660 W

Output regulated voltage of buck converter at constant power load when needs an output power should be 50W is given in figure 4(a). In initiation there are certain transients but it will fed away within 3 to 4ms. The voltage is chattered around 100V after this transient period. In transient period the maximum overshoot approaches to 20 percent which can be easily maintained by medium power rating machines. The waveform for inductor current is given in figure 4(b).

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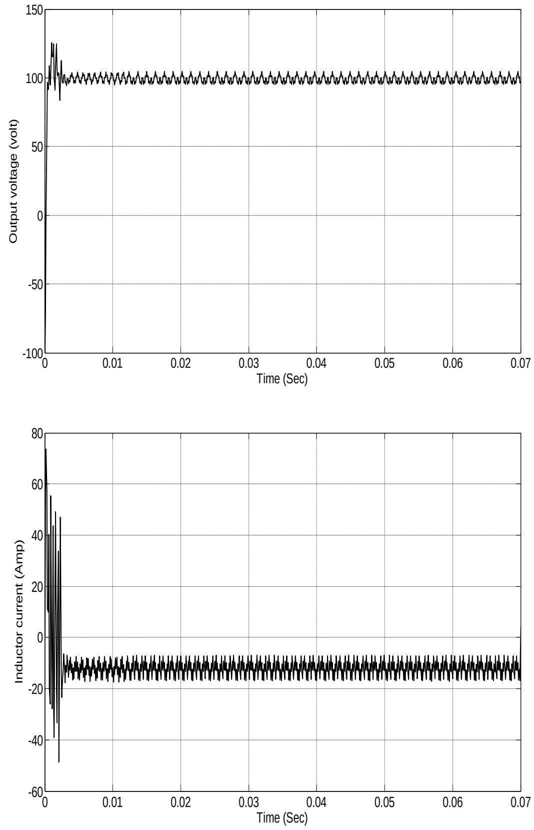

Fig.4.(a).Output voltage of buck converter and (b) Inductor current of buck converter with CPL when power is 50W

Fig.5. (a) indicates the output voltage when power is close to 250W. In this condition the maximum overshoot reduces with respect to earlier case. However the steady state is approached in comparatively low time. So, when power expanded then the performance of SMDC improves better. Inductor current for this power is given in fig.5 (b).

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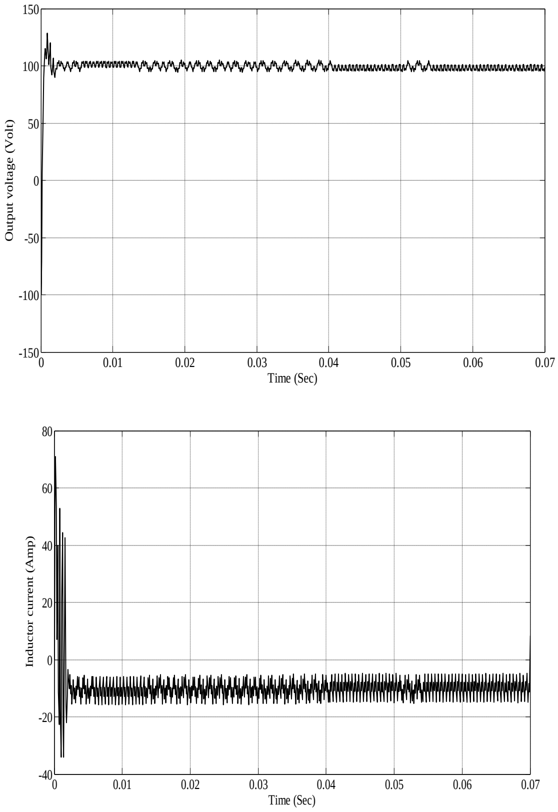

Fig.5. (a) Output voltage of buck converter and (b) Inductor current of buck converter with CPL when power is 250

Fig.6 (a) and 6 (b) is the output voltage and inductor current waveform of the buck converter with SMDC when output power taken as 660W respectively.

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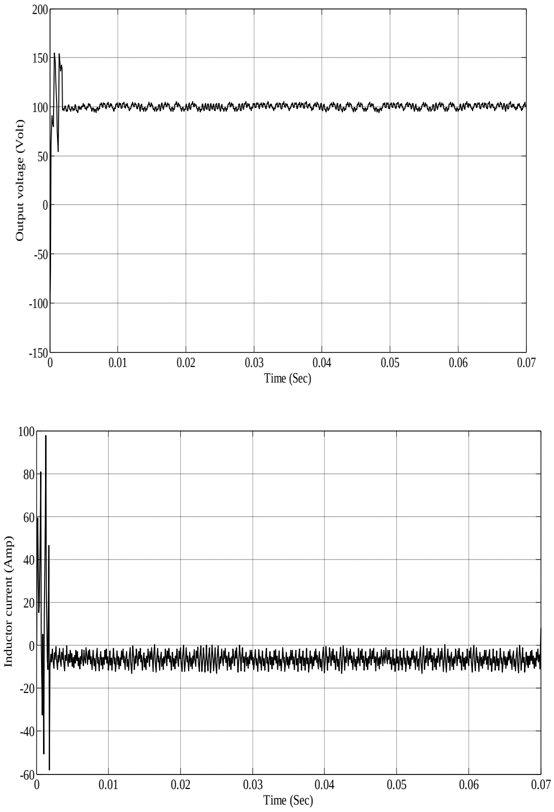

Fig.6. (a) Output voltage of buck converter and (b) Inductor current of buck converter with CPL when power is 660 W

It is cleary indicate that in this condition maximum overshoot is increases with respect to pevious cases. So result quality detroiate. Also in this condition the inductor current is comparetively low.

III. CONCLUSION

In this paper simulation results of SMDC for buck converter atconstant power load are obtained. Results are taken for three values of different power. Results indicatesthat irrespective of load variations output voltage tracks the reference voltage. In starting momentary transients were analysed. Also there is a discussion of the output voltage of second order sliding mode controller for buck converter with resistive load. It indicates chattering is low in this control technique. In this paper we discussed about negative incremental impedance introduces instability of a DC-DC buck converter with constant power loads. Such type of power electronics system cannot be stabilized with the help of conventional linear controllers. To overcome this issue SMDC is used to stabilize DC-DC converter with constant power loads. Simulation results have been carried out in MATLAB/Simulink to validate the SMDC for stabilizing a DC-DC buck converter with constant power loads. Results indicates that the SMDC has ability to stabilize the DC power systems under significant load power and variations of supply voltage.

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