Feedback and Sliding Mode Control of D.C.-D.C. Converters

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ABSTRACT
The Performance of DC-DC converters with voltage, current and voltage cum current feedback controllers greatly improve their utility. Several integrated circuits are commercially available to provide linear feedback in dc-dc converters. Because of inherent nonlinearity of converters, linear feedback circuits provide good performance over a narrow range of variations of their parameters. Sliding mode controller is a nonlinear controller that can provide good performance over a wide range of variation of parameters. It is a robust controller especially suitable for variable structure systems like a converter. Example of design of a sliding mode controller for a dc-dc buck converter has been illustrated. A detailed list of references for advanced studies in this field is appended.

Keywords
Boost converter (DC-DC), Pulse width modulation, sliding mode controller

1. INTRODUCTION
Several circuits are available for converting d.c. voltage from a higher to lower values called buck converters and from lower to higher values called boost converters. A semiconductor switch is invariably used in all the converters. Inductors and capacitors are used to temporarily store energy.

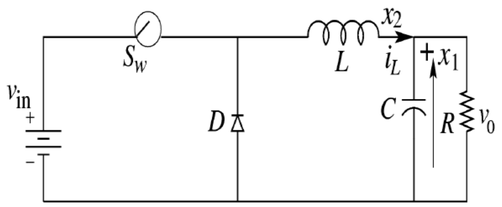


Fig 1. A typical buck converter

The semiconductors used (BJT, MOSFET etc.), either conduct (zero voltage across the device and full current through the device) or is cut off (zero current through the device and full voltage across the device). Therefore power loss in the semiconductor is minimum and circuit efficiency is high. Only switched mode d.c.-d.c. converters are therefore popular for handling bulk power.

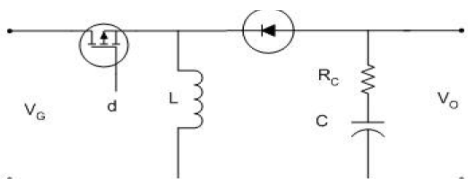


Fig 2. A typical buck-boost converter

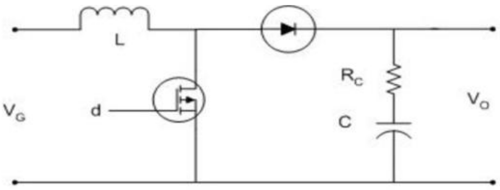
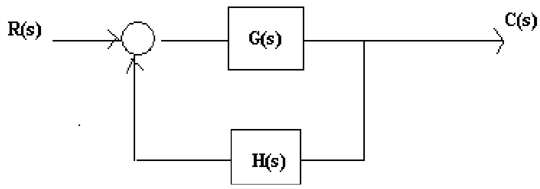


Fig 3. A typical boost converter

2. EFFECTS OF FEEDBACK



Transfer function of the system G(s) with feedback H(s) is given by G(s)/(1+G(s)H(s)). If G(s)H(s)>>1 then the transfer function can be approximated as 1/H(s)

It means that a system with feedback adopts some features of the feedback network. With high gain of the feedback network the system behaves as per the feedback system only and its own characteristics go to background. G(s) may be a high power system like a d.c.-d.c. converter and the feedback may be a low power system. H(s) may be a passive circuit, active circuit, digital circuit or even a microprocessor. Due to low power of H(s) a great flexibility exists in the selection of its components. It is therefore easy to tailor the characteristics of a chopper by proper selection of a feedback network. Some of the desired properties are constant voltage, constant current, constant voltage cum constant current, voltage drooping down or rising up with load current etc.

3. CONTROL OF CONVERTERS
Output of a converter can be changed by changing the duty ratio(D) of the semiconductor switch. It is therefore possible to maintain the output voltage or current constant against variations in the input voltage/current and the load current by changing its duty ratio. Neglecting the losses in the converter, its output volt-amperes are equal to its input volt-amperes.

3.1 Constant output Voltage Converters
A feedback circuit with input as change in output voltage and output as change in duty cycle is known as voltage regulator. This circuit is supposed to maintain constant output voltage against all other variations. As the load current is not controlled, it may go outside the thermal limit during overload or short circuit. Such circuits are therefore not safe for use.

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Such regulators are safe against overloads and short circuit. A signal proportional to voltage and another signal proportional to current are compared and higher of the two controls the output. This regulator can also be used as a current source.

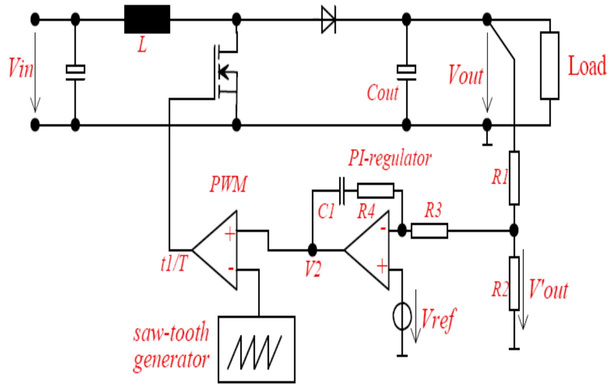

Fig4. Boost Regulator with Constant Load Voltage Control

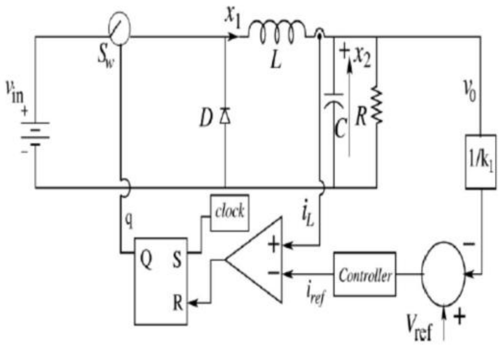

Fig5. Buck Regulator with Constant Voltage Cum Constant Current Control

4. PARALLEL CONNECTION OF CONVERTERS

If two or more converters are receiving power from different sources then their outputs can be connected in parallel if these are working in constant current output mode and their outputs can be connected in series if these are working in constant voltage output mode. This way of connection is very useful when several solar cells or fuel cells etc. having different characteristics are used to feed a common load and the load is shared between them as desired by the user. Practically if all the sources are connected to converters whose voltage droops with current, the load can be shared depending upon the drop.

5. VOLTAGE CONTROL HAVING CURRENT DEPENDENT DROP

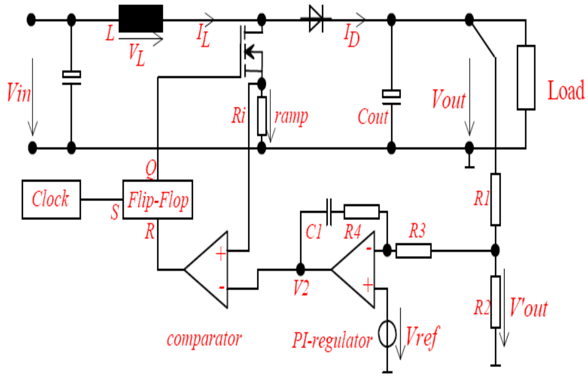

Fig6 voltage control circuit of converter

5.1 Compensating Circuit

Compensating circuits are used in the feedback network to make the system stable throughout the working range. Merely a stable system is not enough. In addition the output voltage should satisfy the steady state and transient response requirements as well. For particular values of input and output voltages, duty cycle and load current, P, PI or PID circuits can be designed to realize the requisite steady state and transient response and stability.

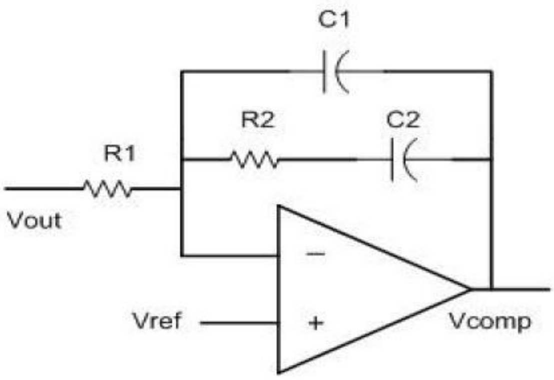

Fig7. PI Compensation Network

Transfer Function = (1+sR2C1)/sR1(C1+C2+sR2C1C2)

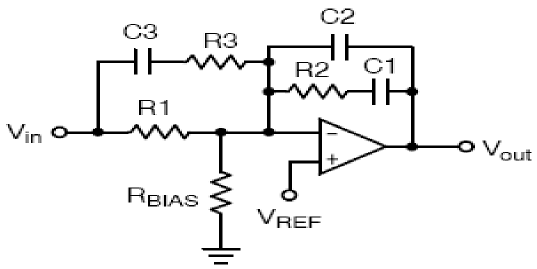

Fig8. PID Compensation Network

Transfer Function= (1+sR2C1)(1+s(R1+R2))C3/(s2 C1C2R2+s(C1+C2))(R1+SR1R3C3)

5.2 Proportional, Integral and Derivative (PID) Controller

Three control strategies proportional, integral and derivative are combined to get proportional integral derivative (PID) controller to control over steady state and transient errors. Therefore in this controller control signal is a linear combination of the error, integral of the error, and rate of change of error.

The constants used in PID controller are kp , ki , kd . These constants can be adjusted to get acceptable performance. If we increase kp & ki errors will be reduced but we cannot get adequate stability. Thus PID controller provides both acceptable degree of reduction in error and acceptable stability.

Two control strategies proportional and integral are combined to get proportional integral (PI) controller. The integral term in PI controller causes steady state error to reduce to zero. Due to lack of derivative term system becomes more steady in steady state operation, also it is less responsive to real and fast changes in state, so system will be slower as compared to PID controller

5.3 Commercial Regulators

Several IC manufacturers are offering switching regulators which can be used to design a regulator satisfying customer's specifications. High power components like switching device, inductor, input, output capacitors etc. are connected outside the IC to design the regulators. Several amplifiers, comparators, clock generators etc. are available inside the IC. Some of the popular IC's from National Semiconductor are LM2595 for buck converter and LM2585 for a boost converter. On semiconductor offers AND8143/D for Buck converter. AOZ101X controller from Alpha and Omega semiconductor offer a general purpose Buck converter

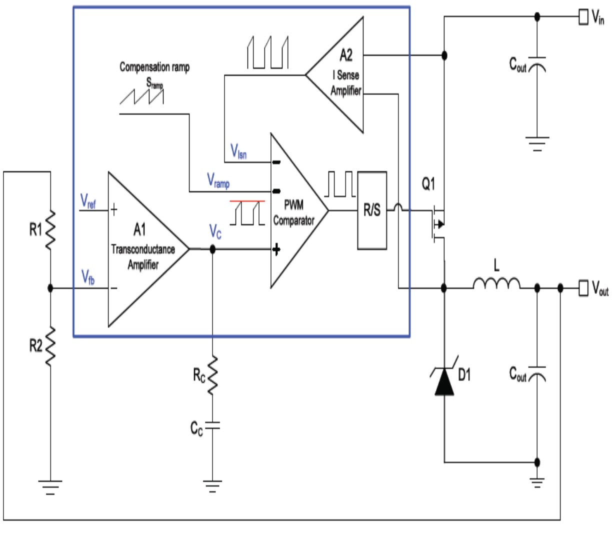

Fig9. AOZ101X Controller

Linear feedback circuits are however suitable for only a narrow range of the source voltage, load current and Duty ratio.

For a boost converter, transfer function of averaged output voltage versus small change of duty ratio D can be defined as:

(Vi (D-1)+sLi)/(s2 LC +s(L/R) + (1-D)2) where Vi is the input voltage and i is the capacitor current.

The transfer function varies with D. D varies between 0 and 1. If Vi, D and i remain constant, the transfer function parameters are constant and a linear controller can be designed to stabilize and control the regulator. For wide variations of these parameters, a nonlinear controller like; fuzzy, neural or sliding mode is used.

6. SLIDING MODE CONTROL FOR DC-DC CONVERTER

The sliding mode control (SMC) represents a powerful tool to enhance performances of power converters. This control technique has a less circuit complexity unlike other standard current-mode controllers. It also provides extreme robustness and fast response against supply, load and circuit parameter variations, even for higher-order converters. This method of control is suitable for variable structure converter (VSC) such as DC-DC system containing a switch.

Sliding mode controller maintains stability and provide consistence performance. In general the function of switching control law is to drive nonlinear plant's state trajectory onto a pre-specified surface and to maintain plant's state trajectory for subsequent time. The surface is known as switching surface which defines rules for proper switching. This surface is also called sliding surface. Feedback path has one gain when plant trajectory is above the surface and a different gain when trajectory is below the surface. Conventional controls such as stabilization, regulation, tracking can be obtained by proper design of sliding surface Sliding mode control for Buck Converter

$$x_1 = v_{ref}-v_o \quad (1)$$

$$x_2=d/dt\,[\,v_{ref}-v_o] \quad (2)$$

In the first step relations among various variables are expressed with Sw in on mode and also off mode. Equations for Buck Converter are

$$di_L/dt = v_{in}/L - v_o/L \quad (3)$$

$$dv_c\,/\,dt = i_L/C - v_o/RC \quad (4)$$

$$di_L/dt = -\,v_c/L \quad (5)$$

$$dv_c/dt = i_L/C - v_o/RC \quad (6)$$

In sliding mode, the control is discontinuous in nature. Here, the control switches at an infinite speed between two different structures. A sliding mode control system may be regarded as a combination of subsystems, each with a fixed structure and operating in a particular region of the state space. The sliding mode control design problem is to select parameters for each of the structure and define a switching logic.

Letting $x1 = I_L$ and $x2 = V{=}V_O$ *as* the new states of the system, the new state equations become

$$x_1=EU/L - x_2/L \quad (7)$$

$$x_2=x_1/C - x_2/RC \quad (8)$$

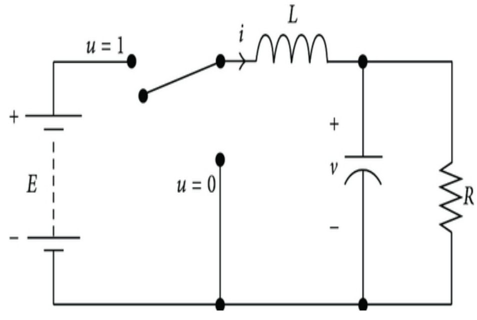

Fig10.Ideal switch representation of the DC/DC buck converter

Generally, the control for dc-dc converters is to regulate the output voltage at desired level. Now the aim here is to obtain a desired constant output voltage *Vd*. The desired output is then $x1^* = Vd/R$. The task is to ensure the actual current $x1$ tracks the desired current. That is, in steady state the output voltage should be the desired voltage *Vd.* Thus,$X_2=V_d$ $X_2=V_d=0$ Sliding mode controller uses a sliding surface which ensures output voltage to go to desired value once the system gets onto the sliding surface. The state variables may be used to construct the sliding function. From the general sliding mode control theory, the state variable error, defined by difference to the reference value, forms the sliding function $S=x_1 - x^*=0$ This means that the control forces the system to evolve on the sliding surface. The reference value $x1^*$ is derived internally to the controller from the output of the linear voltage controller.

In order to enforce sliding mode in the manifold $S = 0$, the corresponding control signal for the ideal switch in Figure [10]

$$U=1/2\ (1-\text{sign}\ (s)) \qquad (9)$$

Since the aim is to guarantee that the state trajectory of the system is directed to the sliding surface $S = 0$ and slides over it, this is achieved with a suitable design of control law using the reaching condition SS<0

The next design step is to synthesize the control input so that the state trajectories are driven and attracted towards the sliding surface and then remain sliding on it for all subsequent time. The SM control signal u consists of two components a nonlinear component un (orthogonal to the sliding surface called reaching phase to take the operating point from anywhere in the state space on to the sliding surface) and an equivalent component u_{eq} (To slide the operating point on the sliding surface towards origin).

$$U_{eq}=a_2\ I_L - a_2\ V_0 \qquad (10)$$

$$U_n=\text{sign}\ (s) \qquad (11)$$

$$U=U_{eq}+U_n \qquad (12)$$

Where a_1 & a_2 are the parameter of R,L,C

Un = +1 when S>0 and it is -1 when S<0

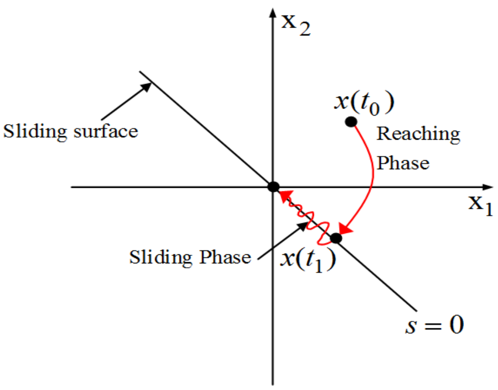

Fig11 graphical representation of sliding surface

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7. CONCLUSIONS

By adjusting the value of a_1 & a_2 we obtain the operating point on linear sliding surface which is Ueq. The constants used in PID controller are kp , ki , kd . These constants can be adjusted to get acceptable performance. If we increase kp & ki errors will be reduced but we cannot get adequate stability. Thus PID controller provides both acceptable degree of reduction in error and acceptable stability. So that dc to dc converter performance can be improve.

8. REFERENCES

[1] AJ. Foreyth and SV. Mollov, "Modeling and control of Dc-Dc converters", IEEE Power Engineering Journal.

[2] B. Nicolas, M. Fadel, Y. Chéron, “Robust Control of Switched Power Converters via Sliding Mode,” ETEP,Vol. 6, No. 6, November/Dicember, 1996, pp. 413-418.

[3] B. Nicolas, M. Fadel, Y. Chéron, “Sliding mode Control of DC-to-DC Converters with Input Filter Based on Lyapunov-Function Approach,” EPE Conf. Proc., 1995, pp. 1.338-1.343.

[4] H. Mingzhi and X.Jianping, "Nonlinear PID in Digital Controlled Buck Converters", March 2007.

[5] H Guldemir Buck Converter, Dc-Dc Converter, Sliding Mode Control 2011

[6] L. Malesani, L. Rossetto, G. Spiazzi, P. Tenti,"Performance optimization of Cuk converters by sliding-mode control," IEEE Transaction on Power Electronics, Vol.10, n.3, May, 1995, pp.302-309.

[7] L. Guo, J.Y. Hung and R. M. Nelms, "Design and implementation of a digital PID controller for a buck converter", July/August 2001

[8] R. Venkataramanan, A. Sabanovic, S. Cuk: "Sliding-mode control of DC-to-DC converters," IECON Conf. Proc., 1985, pp. 251-258.

[9] S.Dhali the sliding mode control scheme provides good voltage regulation and is suitable for boost DC-to-DC conversion purposes. lwww.ijera.com/papers/Vol2_issue1/CV21618623.pdf

[10] V.I.Utkin, Sliding modes and their application in variable structure systems, MIR Publishers, Moscow,1978.