Different Methods of Control Mode in Switch Mode Power Supply- A Comparison

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ABSTRACT: Switch mode power supplies are used in nearly all electronic devices in our day today life and in industries. Many control methods are developed for the control of DC-DC converter. To obtain a control a control method has the best performance under any condition is always demand. The main objective of this paper is study different control methods implemented in DC-DC converter. This paper reviews comparison of various control methods under the response of different parameters.

Keywords: current control, voltage control, hysteretic control and converter topologies.

I.   INTRODUCTION

A DC to DC converter must provide a regulated DC output voltage under varying load and input voltage under varying load and input voltage conditions. The converter components values are also changing with time, temperature, pressure and so forth. Hence, the control of the output voltage should be performed in a closed loop manner, using principles of negative feedback. The most common closed loop control methods for PWM DC to DC converter are namely the voltage mode control, current mode control and hysteretic control. The voltage mode control is typically used forward mode topologies. In voltage mode control only the output voltage is monitored. The current mode converter is typically used with boost mode converter and it monitor both output voltage and out current. Among the other control methods of DC to DC converters a hysteretic (or bang bang) control is very simple for hardware implementation. By this method of control which tries to keep a monitored parameter between two limits. In this paper we see about comparative study of three control methods used in switch mode power supply.

II.   RELATED WORK

In Switch mode power supply mainly focused on voltage mode and current mode control method. Here hysteretic mode control method compared with voltage mode and current mode control, it shows the features and advantages of hysteretic mode control in switch mode power supply.

III.   VOLTAGE MODE CONTROL

The voltage feedback arrangement is known as voltage-mode control when applied to dc-dc converters. Voltage-mode control (VMC) is widely used because it is easy to design and implement, and has good community to disturbances at the references input. VMC only contains single feedback loop from the output voltage [8]. A single loop voltage mode control is used to compare the output voltage with reference voltage. The error between the two controls the switching duty ratio by comparing the control voltage with a fixed frequency sawtooth waveform. Applied switching duty ratio adjusts the voltage across the inductor and hence the inductor current and eventually brings the output voltage to its reference value. Voltage-mode control of dc-dc converters has several disadvantages including,
1.   Poor reliability of the main switch,
2.   Degraded reliability, stability, or performance when several converters in parallel supply one load,
3.   Complex and often inefficient methods of keeping the main transformer of a push-pull converter operating in the center of its linear region, and
4.   A slow system response time, this may be several tens of switching cycles.
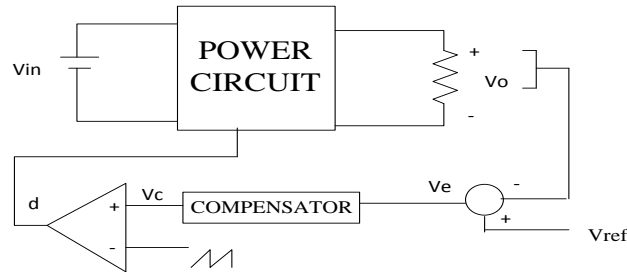
Fig. 1: Voltage mode control

Table 1: Common control methods

Control method	OC protection	Response time	Preferred Topologies
Voltage mode	Average OC	Slow	Forward mode
	Pulse by pulse OC	Slow	Forward mode
Current mode	Intrinsic	Rapid	Boost mode
	Hysteretic	Rapid	Boost & forward mode
Hysteretic	Average	Slow	Boost & forward mode

IV.   CURRENT MODE CONTROL

By current control method we can control both output voltage and output current of the switch mode power supply. It is typically preferred for boost mode converter. Here the voltage error signal is used to control the peak current within the magnetic elements during each power switch on-time. Current mode control has a very rapid input and output response time, and has a inherent over-current protection. It is commonly used for forward mode converters.[5] Compared with voltage-mode control, current-mode control provides an additional inner control loop control. The inductor current is sensed and used to control the duty cycle, as shown in Fig. An error signal is generated by comparing output voltage Vo with reference voltage Vref.
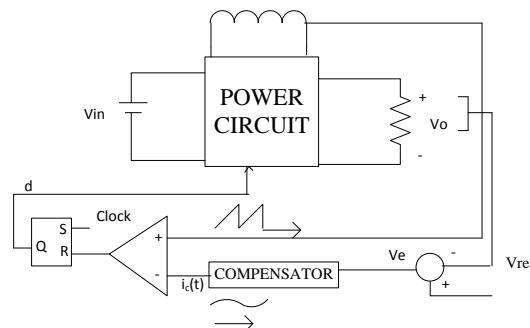

Fig. 2: Current mode control

Then this error signal is used to generate control signal ic. The inductor current is then sensed and compared with control signal ic to generate the duty cycle of the switch and drive the switch of the converter. If the feedback loop is closed, the inductor current becomes proportional with control signal i_c and the output voltage becomes equal to reference voltage V_{ref}.

V. HYSTERETIC MODE CONTROL

Hysteretic control power converters are inherently fast response and robust with simple design and implementation. They response to disturbances and load change right after the transient take place, so they give excellent transient performance. Also, they do not require components for the closed loop compensation network. This reduces the component count and solution size in implementation, and eliminates the design effort in adjusting component values for the network upon parameters (like input voltage, inductor, bulk capacitors) change. The above advantages make hysteretic control power converters a good solution for power supply. In spite of the advantages, one major concern of using hysteretic control power converters is the stability issue. Although the design and analysis of fixed frequency PWM power converters have been well developed using the averaging and linearization approach , analytical analysis of hysteretic control power converters is rare, and focus on the large signal dynamic response. Such method cannot reflect the steady state high frequency oscillations. Also, the commonly used bode plot in the frequency domain will be inaccurate above half of the operating frequency. Unlike PWM converters with fixed operating frequency, the operating frequency can be very low during some loading condition or transient. For a same converter, the operating frequency can be a few hundred kHz for full load, but lower than around 10 kHz at very light load. The use of linear system tools may not be appropriate for variable operating frequency converters.[18]

Hysteretic control, also known as bang-bang control or ripple regulator control, maintains the converter output voltage within the hysteretic band centered about the reference voltage. The hysteretic- controlled regulator is popular because of its inexpensive, simple and easy -to- use architecture. The advantage of hysteretic control is fast transient response and eliminates the feedback loop compensation. The varying frequency is the well known characteristics of hysteretic control. However, the regulation inaccuracy issue of the hysteretic-controlled converter is almost unknown to engineers. In hysteretic regulator, research mainly focused on transient modeling and transient analysis.

A. Variable Frequency Hysteretic Control

In this section, the basic ideas about the hysteretic controlled converters with variable switching frequency are described. As shown in Figure 3, the voltage hysteretic controller regulates the output voltage ripple within the hysteretic band. Similarly, a current hysteretic controller directly regulates the inductor current of the converter by regulating the inductor ripple or a scaled version of it within the hysteretic band.

B. Hysteretic Voltage-Mode Control

Hysteretic voltage-mode control is the simplest control method available. The concept of operation is very simple. The switch is turned on, when the output voltage falls below minimum set point (i.e., lower boundary) and turns off when output voltage is higher than maximum set point (i.e., upper boundary). During transient condition, the converter react quickly to make the better solution without compensation network. However, the drawback of the voltage-mode hysteretic controller is its reliance on the converters output capacitor parasitic.[3]
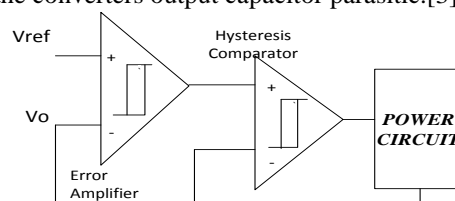

Figure 3: Hysteretic voltage control

C. Hysteretic Current-Mode Control

The maximum and minimum inductor current can be controlled by using hysteretic current mode control method. The ability to provide a fast response at transient condition doesn't require external oscillator or sawtooth generator. Figure 4, illustrates a block diagram of a current-mode hysteretic controlled dc-dc converter. [4] The power converter circuit with feedback control generally consists of:

1. A power stage with switches and, and storage elements and , w_S DLC
2. An inner controller preserving the converters working principle by switching the circuit topology,
3. An outer controller adjusting the inner loops reference in response to deviations from the desired output.
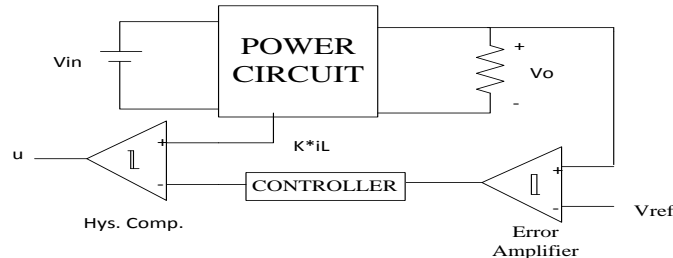
Fig. 4: Hysteretic current control

The control system shown in figure consists of two control loops. One is the current control loop and the other is the voltage control loop. The error between the actual output voltage and reference voltage gives the error voltage. A P or PI control block can use the voltage error signal to provide a reference current for hysteresis control. Hence the current hysteretic control method can be viewed as a sliding mode control system.

The hysteretic comparator implements the control law

$$\begin{cases} 1, & s > 0 \\ 0, & s < 0 \end{cases} \qquad (1)$$

where, S is the sliding surface, which is defined as the difference between the two comparator inputs.

$$S = K_p (V_{ref} - V_o) - K i_L \qquad (2)$$

Where K, is the current sensing gain which has a fixed value and is proportional gain as we consider a proportional controller here. From the previous chapter, we know that the buck converter power circuit is described by two sets of differential equations that are,

$$L (di_L/dt) = Vin - Vo \text{ and } C(dV_c/dt) = i_L - (Vo/R) \qquad (3)$$

Let the two state variable of the control system are $X_1 = (V_{ref} - V_o)$ and $X_2 = i_L$, then by taking the derivative,

$$L\dot{x}_2 = V_{in} - V_{ref} + x_1$$

$$\dot{x}_2 = (1/L)x_1 + (V_{in}/L) - (V_{ref}/L) \qquad (4)$$

$$\dot{x}_2 = Cx_1 + (V_{ref} - x_1)/R$$

$$\dot{x}_1 = (-x_2/C) - (x_1/RC) + (V_{ref}/RC) \qquad (5)$$

The state space model in terms of state variables is given by,

$$\dot{x} = A_1 x + B_1 u + D;$$

$$\begin{bmatrix} x1 \\ x2 \end{bmatrix} = \begin{bmatrix} -(1/RC) & (1/C) \\ -(1/L) & 0 \end{bmatrix} \begin{bmatrix} x1 \\ x2 \end{bmatrix} + \begin{bmatrix} 0 \\ (Vin/L) \end{bmatrix} u + \begin{bmatrix} 0 \\ (Vref/L) \end{bmatrix}$$

Where, 'u' is a discontinuous input that is either 0 or 1. The sliding dynamics of the system are obtained by using the equivalent control method. The discrete form of the control input is substituted with a continuous function. The dynamics of the closed loop system, assuming that an ideal sliding motion (infinite switching frequency) exists on the switching surface, 'S', is governed by the conditions,

$$S = 0 => S = 0$$

$$ds/dt = \sum_{i=1}^{n} \left(\frac{\partial s}{\partial x1}\right) (dx_i/dt) \qquad (8)$$

Table 2: Comparison between CMC, VMC and Hysteretic control methods

Characteristics	CMC	VMC	Hysteretic control
Rejection of line disturbances (dynamic line response)	Good(Inherent)	Very good (with line feed forward)	Excellent (Inherent)
Rejection load disturbance (dynamic load response)	Good (constant bandwidth)	Good	Excellent (Inherent)
Constant frequency	Excellent	Excellent	Poor, need to vary hysteresis band, or use constant ON-Time (Buck), or use constant OFF-Time (Boost)
Predictable EMI	Excellent	Excellent	OK (with above COT techniqes)
Audible noise suppression	Excellent	Excellent	OK (with above COT techniques)
Extreme down conversion (Buck)	Poor	Good	Excellent with COT techniques
Insensitivity to PCB layout	Poor	Excellent	Good, with artificial ramp generation otherwise poor
Excellent stability of loop responses (Tolerances and long time drifts)	Excellent	Good	Fair
Simplicity of compensation	Good	Poor	Excellent
IQ (Quiescent current)	Good	Poor	Excellent
Loop stability with use of output ceramic capacitors	Excellent (with type 3 compensation)	Very good	Good, with artificial ramp generation otherwise poor
Auto tuning	Complex	Very complex	Inherent

$$ds/dt = \nabla S . \dot{x} = G\dot{x}$$

where G is a 1 by n matrix and the above equation is given as,

$$G\dot{x} = (A_1 x + B_1 u_{eq} + D_1) = 0$$

The equivalent continuous control input u_{eq} can be written as,

$$u_{eq} = -(GB_1^{-1})\,G\,(A_1 x + D_1)$$

$$x = A_1 x + D_1 - B_1(GB_1^{-1})G(A_1 x + D_1)$$

$$x = [I - B_1\,(GB_1^{-1})\,G]\,(A_1 x + D_1)$$

This equation describes motion equation of the converter when operating in SM operation.

VI.   COMPARISION BETWEEN VMC, CMC AND HYSTERETIC CONTROL

The voltage mode control is the traditional control method used in switched mode power supplies, as compared to current mode control and hysteretic control method. The current-mode control regulates the inductor current directly. This current feeds the output capacitor C_{out} and the load resistance RL . $Cout$ and RL form a first order system and the step response is an exponential function. The voltage-mode control regulates the duty cycle $t1/T$, which means that the voltage across L is controlled. This voltage operates on a second order system, formed by L, $Cout$ and R_L. The step response of such a system is a sinusoidal transient approaching a fixed value.[16] Since hysteretic mode control was introduced to power electronics in 1967, it has been a completive control strategy due to its good stability, fast dynamic performance, inexpensive and easy to use architecture.[11]

A.   Auto-Tuning
Nowadays, system houses want the flexibility, not only of voltage margining via I2C control, but also the ability to change switching frequencies, say, over a typical $\pm$50% range. The idea is to be able to avoid certain frequencies after a

pre-release EMI/audio scan. In general, beat frequencies also need to be avoided in cases of multiple free-running regulators switching at a frequency fairly close to each other. So the concept of auto-tuning is gaining ground. Design houses are spending a lot of time starting out with CMC or VMC and learning to re-position the poles and zeros automatically in case the frequency is changed. Hysteretic control, in particular COT, offers the advantage of having no traditional loop compensation components. Being "energy on demand", it has inherent auto-tuning capabilities. In future hysteretic controllers are thus being designed to provide effective support for auto-tuning features. The table 2, shows the comparison between the current control, voltage control and hysteretic control methods.

VII.   CONCLUSION

Different control methods have been evaluated for switch mode power supplies, based on the various converter topologies. A comparison study has been carried out for studying the effect of PWM controllers on the DC-DC converter response in steady state, under load response and different component variations. It is believed that the classification and review of the control techniques presented in this paper would be useful to SMPS researchers and designers.

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