International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2016): 79.57 | Impact Factor (2015): 6.391

A Hitchhiker's Guide to Hysteretic Voltage Mode Control DC-DC Converters

Vishwanath D Tigadi

Design Engineer, Sankalp Semiconductors Pvt. Ltd

Abstract: ***Battery-supplied systems demand fast, efficient and compact power converters. Pulse-width-modulated (PWM) switch mode power converters(SMPS) are considerably efficient, but also slower, limited by their low band width.An improved Hysteretic pulse frequency modulated (PFM)nonlinear control method for DC-DC converters is illustrated in this paper. The basic disadvantages of linear control methods and their solutionsare explained. The buck converter is taken as an example and Hysteretic voltage mode of control is implemented. The basics of hysteresis, working of hysteretic comparator, ease of implementation and working of control loop are explained and implemented using Texas Instruments Network Analyser (TINA). Advantages and disadvantages of Hysteretic control methods are discussed along with future scope***

1. Introduction

With advancing fabrication technology and increasing power management demands development of improved control methods from DC-DC power conversion has created a huge demand in the market. The classical control methods of linear control systems are robust and have created a foundation for power management for the past two to three decades. However, the advanced nonlinear methods have slowly started to replace the traditional methods. Yet, the classical methods remain widely used. Apart from the classical control methods, we have hysteretic/non-linear methods, digital control methods, and time domain control methods and in the recent days we have also seen digital signal processing methods such as DFT etc., also can be implemented in DC-DC power management systems.

The main purpose of these control systems/control scheme is to regulate the output voltage within the required limits with the specified input and output variations. Any of the methods mentioned above can be implemented to achieve the task. However each control method comes with its own set of liabilities. The figures of merit of any control method are decided by the following parameters:

1) Output ripple
2) Line regulation
3) Load regulation
4) Transient response
5) Stability

Each control methods can be implemented with sensing of output information using different sensing techniques and implementation of one or more control loops in the closed loop path. Depending on the sensing element and the controlled variable the control modes are classified into voltage mode, peak current mode, valley current mode, average current mode etc. This case steady deals with the analysis of Hysteretic voltage mode control of Buck DC-DC converters. Apart from the basic hysteretic control methods there are several modifications of hysteretic mode exist such as Dcap, Dcap2, Dcap+ and DCS architectures. All these architectures are developed by the company Texas Instruments.

2. Block Diagram

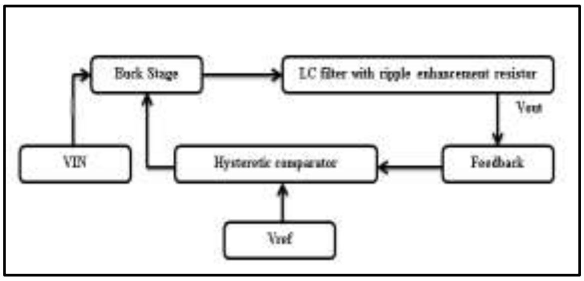

Figure 1: Block diagram if hysteretic voltage mode of control of buck converter

3. Basic Operation

Hysteretic mode of operation is a non-linear method of control loop implementation for DC-DC converter. The operation depends solely on the hysteresis of the comparator. The comparator has two thresholds. Whenever the rising edge of the feedback voltage reaches the upper threshold of the hysteretic comparator it turns the high side switch off. And when the falling edge of the feedback voltage hits the lower threshold of thehysteretic comparator, high side switch is turned on. Hence the Vout gets regulated such that feedback voltage is always within the bounds of comparator hysteresis.

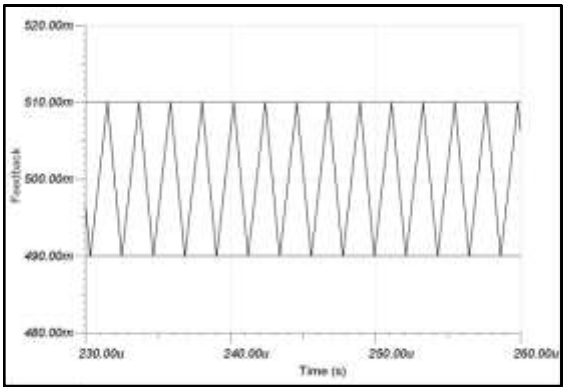

Figure 2: Feedback voltage regulation at 500mV with hysteresis of ±10mV

Licensed Under Creative Commons Attribution CC BY

International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2016): 79.57 | Impact Factor (2015): 6.391

4. Previous Study

Prior to studying the hysteretic mode control of DC-DC converters, it is necessary to understand the linear voltage mode control of PWM converters. PWM voltage mode control is the basic and fundamental control method for DC-DC power supplies. It can be noticed how the output of the SMPS is regulated using the linear error amplifiers and PWM waveform for duty cycle generation is done using the comparison between fixed frequency oscillator and the error amplifier output. There is also a scope for understanding of different compensation techniques and feed forward techniques.

5. Hysteretic Comparator and its Working Principle

A comparator is device which compares 2 analog inputs signals and out puts a digital signal depending on input levels. Hence comparators are also called 1 bit ADC. Hysteretic system means a system in which the response lags behind the excitation. The best example of hysteresis is the inductor BH curve. Hysteresis is the inherent property of any comparator (non-ideal). This feature serves as an advantage because any noise on the reference voltage or in the input signal could trigger the output and cause a large number of bursts in the comparator output. This application deals with deliberately enhancing the hysteresis thresholds such that 500mV threshold voltage is split into 2 different thresholds of 450mV and 550mV low and high respectively. Further for the control loop implementation of Buck converter, this hysteresis is reduced to ±10mV from ±50mV.

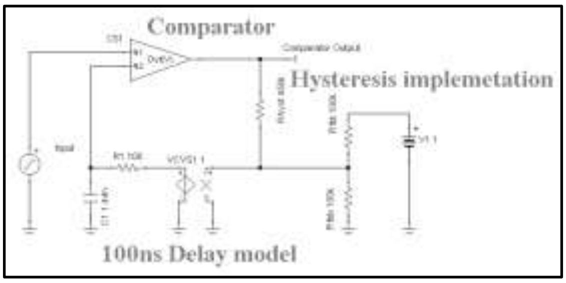

Figure 3: Schematic of Hysteretic comparator

From the simulations below it is clear that the comparator sets to high when the input voltage crosses/hits the lower hysteretic threshold level of 450 mV. And the output sets to low when the input crosses/hits the higher hysteretic threshold level of 550mV.

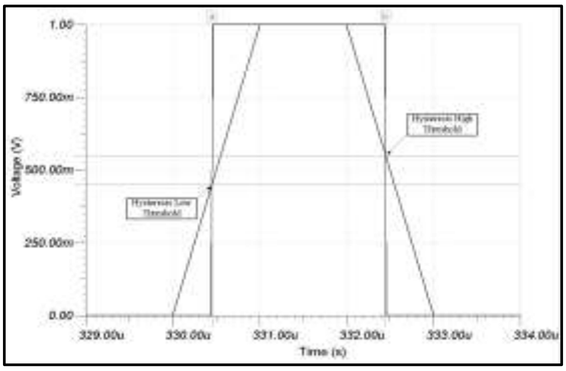

Figure 4: Transient simulations of hysteretic comparator

6. Schematic of Hysteretic Voltage control loop

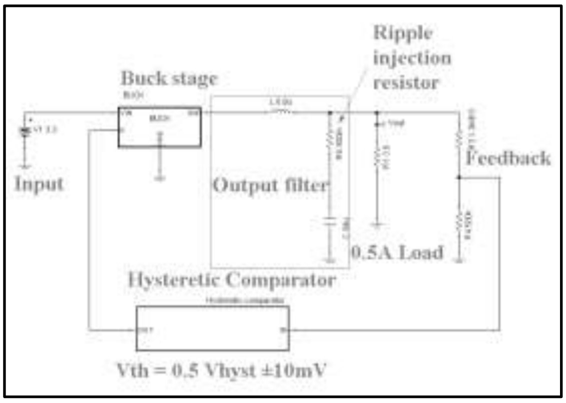

Figure 5: Schematic of Hysteretic control mode Buck converter

Table 1: Design elements of Hysteretic Buck converter

Parameter	Value
Lout	6.8uH
Cout	2*47uF
Ripple Injection resistor	300mΩ
Feedback resistances	1.3MΩ + 500kΩ

7. Simulation Results

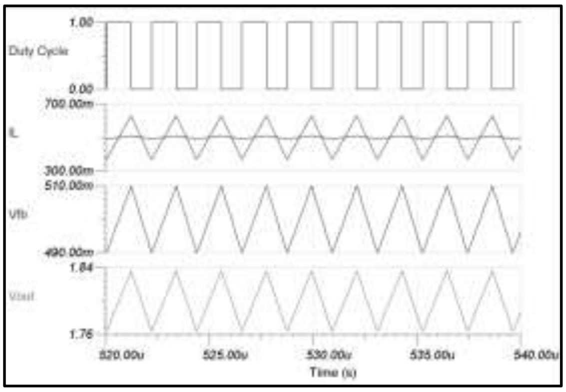

Figure 6: Steady state simulation results of hysteretic voltage mode buck converter in CCM

Table 2: Steady state results

Parameter	Value
Vin	3.3V
Vout	1.8V
Iout	500mA
Duty Cycle	54.55%
IL peak to peak	258mA
Vout peak to peak	80mV
Switching Frequency	833.3kHz

The speciality of hysteretic control method is error correction can be done almost instantaneously within one switching cycle. This feature cannot be implemented using liner control methods since the UGB of linear control systems is set at least to 1/10th of the switching frequency. This is done to avoid switching noise in the control loop. But this disadvantage is aggressively overcome in hysteretic control methods.

Licensed Under Creative Commons Attribution CC BY

Inductor selection: Generally $\Delta I_L$is assumed to be 30% of load current for wide range of applications. Minimum inductance needed, can be calculated keeping frequency fixed.

$$D = \frac{Vout}{Vin}$$

$$L\_min = \frac{Vin - Vout}{FSW * \Delta I_L}$$

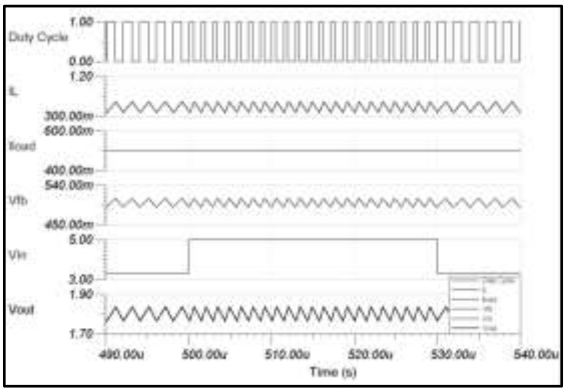

Figure 5: Input (line) voltage transient (3.3V to 5V) response and illustration of cycle by cycle error correction

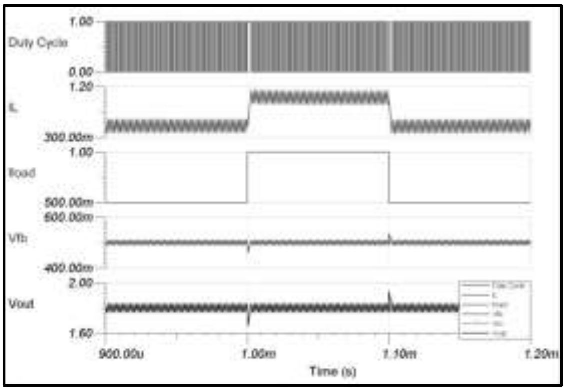

Figure 6: Load current transient response (500mA to 1A) and illustration of cycle by cycle error correction

Advantages and disadvantages of Hysteretic voltage mode control

A. Advantages

1) Fast transient response. Error correction can be done as quickly as within one switching cycle.
2) Easy and cost efficient implementation. Elimination of components like error amplifier, compensation etc., reduces cost and transient delays.
3) No compensation requirements. Due to nonlinear method of implementation the need for the phase boost part is eliminated.
4) The bandwidth is limited only by the bandwidth of the comparator and its slew rate.

B. Disadvantages

1) Varying switching frequency. Any transient in the input voltage leads to variation in switching frequency. Hence this control technique cannot be synchronised with external clock circuits.
2) High ripple at the output voltage. Since minimum and maximum threshold must be hit at every switching cycle for Vout to regulate, Hysteretic mode craves for high ripple at the output.
3) Vulnerable to switching noise. Due to high bandwidth compared to linear application these hysteretic controllers are susceptible to Switching noise and exhibit low PSRR.

8. Conclusion

The hysteretic voltage mode of control has been implemented on buck DC-DC converter. The basic working principle and operation of the voltage correction loop have been explained. Transient and steady state simulations have been run. Feedback voltage regulation has been successfully illustrated at a small range up to ±10mV. Advantages and disadvantages of Hysteretic control technique have been discussed.

9. Future Scope

Hysteretic mode of SMPS regulation has developed from the basic Voltage mode hysteretic regulation to advanced architectures such as constant on time (COT) method. Future scope lies in understanding and implementation of currentmode architecture for the hysteretic control. Apart from the conventional linear methods enhanced hysteretic control methods and time domain control methods need to be explored.

References

[1] Art Kay and Timothy Claycomb, Comparator with Hysteresis Reference Design. Source:http://www.ti.com/lit/ug/tidu020a/tidu020a.pdf
[2] AN-1487 Current Mode Hysteretic Buck Regulators. Texas Instruments May 2013. Source:http://www.ti.com/lit/an/snva170b/snva170b.pdf
[3] Power electronics, a text book by Daniel W Hart Valparaiso University Indiana.
[4] Voltage Mode Control: The Modulator in Continuous Current Mode (CCM) of operation. Source: https://www.exar.com/appnote/anp-15_voltagemodecontrol_d_112006.pdf
[5] Sanjaya Maniktala, Voltage-Mode, Current-Mode (and Hysteretic Control), 2012. Source: https://www.microsemi.com/document-portal/doc_view/124786-voltage-mode-current-mode-and-hysteretic-control
[6] Hysteretic Buck Regulators Source: http://www.montefiore.ulg.ac.be/~geuzaine/ELEC0055/hysteretic_buck_regulators.pdf
[7] Robert Sheehan, UNDERSTANDING AND APPLYING CURRENT-MODE CONTROL THEORY Source: http://www.ti.com/lit/an/snva555/snva555.pdf
[8] Control-Mode Quick Reference Guide Step-Down Non-Isolated DC/DC Source:https://training.ti.com/sites/default/files/docs/slyt710.pdf
[9] Data sheet LM3485 Texas Instruments. Source:http://www.ti.com/lit/ds/snvs178h/snvs178h.pdf
[10] Richard Nowakowski, Survey of Control Modes for Step down Converters and Controllers.

Licensed Under Creative Commons Attribution CC BY

Source:https://training.ti.com/survey-control-modes-step-down-converters-and-controllers
[11] Voltage Mode Control: The Modulator in Continuous Current Mode (CCM) of operation. Source:https://www.exar.com/appnote/anp-15_voltagemodecontrol_d_112006.pdf
[12] Amir M. Rahimi, Parviz Parto, and Peyman Asadi, Compensator Design Procedure for Buck Converter with Voltage-Mode Error-Amplifier. Source: https://www.infineon.com/dgdl/an-1162.pdf?fileId=5546d462533600a40153559a8e17111a

Author Profile

Vishwanath D Tigadi was born in Hubli India on Oct 02, 1994. He is a Design Engineer from Sankalp semiconductors PVT.LTD. And has completed Bachelor of Engineering in Electrical and Electronics from KLE Technological University Hubli formerly known as BVBCET in 2016. The author’s fields of interest lie in Analog design, Power electronics and control systems.

Licensed Under Creative Commons Attribution CC BY