DESIGN, ANALYSIS AND IMPLEMENTAION OF DC-DC CONVERTER USING SIMULINK

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Abstract - **This paper mainly focuses especially the design and simulation of dc-dc converters. It contains the theoretical derivations and parameters equations with design and examples.**
Simulation results for buck boost and buck-boost converters are shown with the chance of different input parameters. In this work we have analyzed the equation of a buck, boost and buck boost converters and proposed the design components and simulation of these converters. Changing the input parameters like inductance, capacitance and switching frequency in order to observe the changes in output voltage has been added with simulation graph. These parameters and their equations should be well understood before designing buck or boost or buck boost converters.
Simulation procedures in Matlab are also added in this paper. We have achieved performance parameter equations for these three regulators. It was completed the design and investigation of these three converters through mathematical examples and have generated the circuits for simulating buck, boost and buck boost converters.
And also have attained different output voltage curve with the change of input parameters. The output graphs for all the converters are well fitted.

Keywords:* *Dc-Dc Converters*, *Buck, Boost and Buck Boost Converters.

I. INTRODUCTION

Every Electronic circuit is assumed to operate off some supply voltage which is usually assumed to be constant. A voltage regulator is a power electronic circuit that maintains a constant output voltage irrespective of change in load current or line voltage. Many different types of voltage regulators with a variety of control schemes are used. With the increase in circuit complexity and improved technology a more severe requirement for accurate and fast regulation is desired. This has led to need for newer and more reliable design of dc-dc converters.

The dc-dc converter inputs an unregulated dc voltage input and outputs a constant or regulated voltage. The regulators can be mainly classified into linear and switching regulators. All regulators have a power transfer stage and a control circuitry to sense the output voltage and adjust the power transfer stage to maintain the constant output voltage. Since a feedback loop is necessary to maintain regulation, some type of compensation is required to maintain loop stability. Compensation techniques vary for different control schemes and a small signal analysis of system is necessary to design a stable compensation circuit.

State space analysis is typically used to develop a small signal model of a converter and then depending on the type of control scheme used, the small signal model of converter is modified to facilitate the design of the compensation network. In contrast to a state space approach, PWM switch modeling develops a small signal of switching components of converter.

Behavioral modeling of the IC system represents the functionality of an IC with macro models rather than actual implementation of the circuit using more efficient modeling techniques. Matlab Simulink and Verilog-A are powerful tools to develop behavioral models of electronic system. Simulink offers the advantage of its graphical user interface and block diagram implementation of any system. It also supports writing your own function and integration of C program code.

The study undertaken in this thesis develops a system level design approach for switching voltage regulators of the three major control schemes. The basic converter topologies and their waveforms are reviewed. In Particular, a small signal model along with the various transfer functions of a buck converter are derived using state space method. A very simple and easy technique to arrive at the PWM model and compensation for three types of control schemes: namely voltage control, current control and V^2 control scheme is discussed. The performance of the two control schemes namely voltage mode and V^2 mode is compared to load and line variation. The current mode response to load and line variation is inferred from simulation results of other two schemes. The buck converter is implemented with all control schemes and the merits and demerits of each of them are highlighted. The simple techniques developed can be applied to the design of any converter system. A set of macro models for all sub-blocks of the three control schemes are connected to come up with complete dc-dc converter models suitable for simulation. The control circuitry is discussed and implemented. The V^2 control scheme is tested to study the feasibility of its implementation on silicon on sapphire technology. The complete macro model is used to get performance metrics of each sub-block and to establish a road map for silicon on sapphire implementation.

System level models are implemented using the simulink in Matlab. The following study provides details of methodologies for designing each component or block used in the switching regulator. Finally, simulation results are presented for voltage and V^2 control schemes and their performance results are compared and inferences are drawn on the performance of current mode control.

II. SWITCHED CONVERTER TOPOLOGIES OVERVIEW

2.0 Introduction

Switching regulators are preferred over linear regulators for their high efficiency and providing step up, step down or inverter output unlike linear regulator which does only step down operation. In practice, the conversion efficiency of linear regulators is limited to only 30% and they find application in analog circuits to ensure nearly constant supply voltage providing high power supply rejection ratio (PSRR).

In switching regulator circuits, semiconductor switches control the dynamic transfer of power from input to output with very short transition times. Because of this switching action there is ripple added to output voltage. The output requirement is a dc voltage with a minimum superimposition of ac ripple. Pulse width modulation (PWM) is the most widely used method for controlling the output voltage. It maintains a constant switching frequency and varies the duty cycle. Duty cycle is defined as the ratio of switch on time to reciprocal of the switching frequency (f_{SW}). Since the switching frequency is fixed, this modulation scheme has a relatively narrow noise spectrum allowing a simple low pass filter to sharply reduce peak-to-peak ripple at output voltage. This requirement is achieved by arranging an inductor and capacitor in the converter in such a manner as to form a low pass filter network. This requires the frequency of low pass filter to be much less than switching frequency (f_{SW}).

2.1 Buck Converter

The buck converter is used for step down operation. A buck converter with its output filter arrangement is as shown in figure 2.1

When the transistor Q1 is on and Q2 is off, the input voltage appears across the inductor and current in inductor increases linearly. In the same cycle the capacitor is charged. When the transistor Q2 is on and Q1 is off, the voltage across the inductor is reversed. However, current in the inductor cannot change instantaneously and the current starts decreasing linearly. In this cycle also the capacitor is also charged with the energy stored in the inductor.

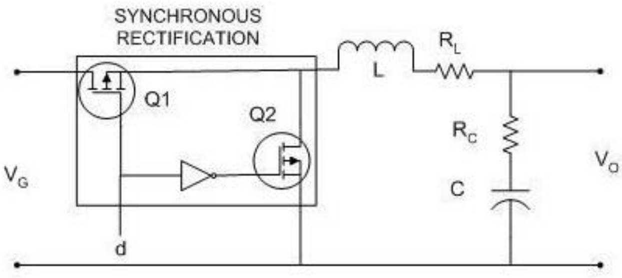

Figure 2.1: Buck Converter.

There is the possibility of two modes of operation namely continuous and discontinuous mode. In continuous mode, the inductor current never reaches zero and in discontinuous mode the inductor current reaches zero in one switching cycle. At lighter load currents the converter operates in discontinuous mode. The regulated output voltage in discontinuous mode no longer has a linear relationship with the input voltage as in continuous conduction mode operation.

III. BUCK CONVERTER REGULATOR SYSTEM

Switch mode power converters are nonlinear and discontinuous in nature and are cumbersome to analyze directly using standard linear circuit theory due to their inherent large signal nature. Linearizing the converter circuit is essential to understanding converter circuit as it allows the designer to apply the control theory. Any model of converter circuits should readily accommodate both monitor and control circuitry. A typical dc-dc system incorporating a buck converter and feedback loop block diagram is shown in figure 3.1.

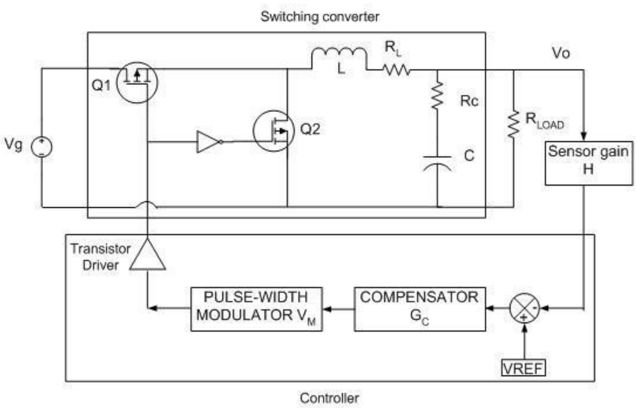

Figure 3.1: Buck converter regulator system

A dynamic switching converter model is helpful in analyzing how the variations in the input voltage, the load current, or the duty cycle affect the output voltage. Traditionally, State space representation of dynamical systems is used to derive the small- signal averaged equations of PWM switching converters. However, in [4], a simplified model is developed by modeling only the non-linear switching action of a converter as a three terminal circuit element. This model is easily applied to any converter topology. The following section summarizes the use of state space approach for buck converter modeling, which can be generalized to any converter topology.

IV. CONTROL SCHEMES AND COMPENSATION TECHNIQUES

4.0 Introduction

Negative feedback is employed to maintain voltage regulation regardless of disturbances in input voltage, vg(t), or load current, I load(t), or variations in component values. The duty cycle is varied in the feedback loop to compensate for these variations. A typical block diagram of a Switching regulator is as shown in figure 4.1.

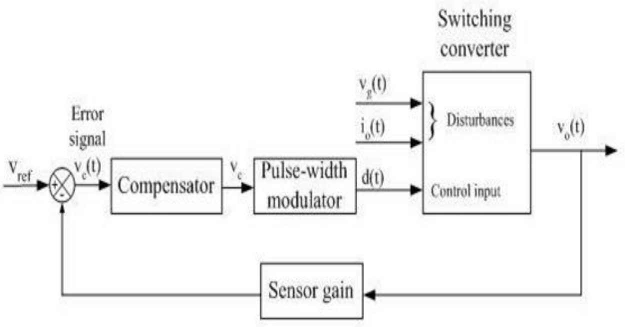

Figure 4.1: Block diagram of feedback system

A voltage reference is used to compare with the output voltage. Sensor gain is used to scale down the output to be equal to voltage reference. The error signal thus generated is fed to the compensator which is the key part to be designed to ensure stability of total feedback loop. Compensator design affects the overshoot, steady state error and transient response of the loop. The PWM block compares the compensator output with another ramp signal to give the variation in duty cycle. The source from where the ramp signal is generated leads to different control schemes. The three most common control schemes are voltage mode control, current mode control and V^2 control. Other hybrid schemes are derived from combinations of these control schemes.

The small signal transfer function for the buck regulator was discussed in chapter

The following topics discuss the effect of feedback loop on the small signal transfer function for all the three control schemes. Also, the compensation techniques for each control scheme are discussed.

4.1 Basic control operation

The switching converter along with feedback controller in its simplest form is as shown in the figure 4.2. An internal oscillator operating at switching frequency (f_{SW}) and generates narrow pulses at the start of each switching cycle. The output of the switching converter is subtracted from the reference signal to generate an error signal. This error signal is compared with a ramp signal to generate a pulse to reset the flip-flop and maintain a steady state duty cycle.

For any variations in the input voltage or output load current, the error signal either increases or decreases. If the output voltage increases, the error signal increases and the reset pulse is generated earlier to reduce the duty cycle and eventually lower the output voltage. Similarly, if the output voltage decreases, the error signal decreases and the reset pulse is generated at later duration to increase the duty cycle and bring the output voltage back into equilibrium.

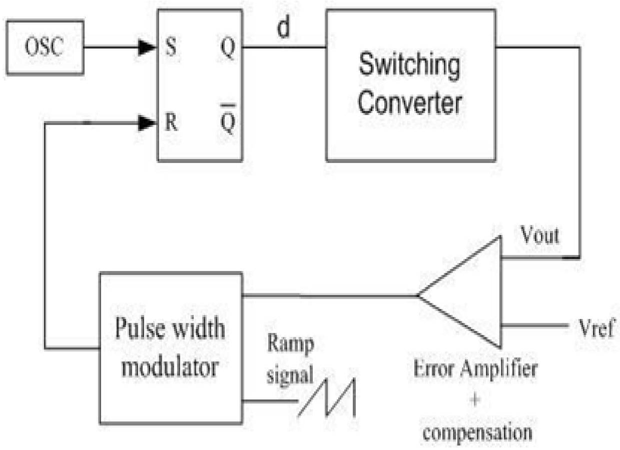

Figure 4.2: Basic control principle

4.2 Comparison of three control schemes

The following table compares the important features of three types of control schemes.

Table 4.1: Comparison of control schemes

Features	Voltage mode	Current mode	V^2 mode
Ramp Signal	External ramp	Inductor current	Output voltage
Transient response to line variation	Limited by error amplifier response	Limited by current sense amplifier response	Not limited
Transient response to load variation	Limited by error amplifier response	Limited by error amplifier response	Fast
Compensation	Second or third order required	First order	Single capacitor to ground
Over current protection	Current sensing and circuitry required	Inherent	Current sensing and circuitry required
Over voltage protection	Extra circuitry required	Extra circuitry required	Inherent due to fast transient response
Slope compensation	Not required	Required	Required

The use of ramp signal derived from the system itself is attractive for fast transient response. V^2 scheme uses output voltage as ramp signal and has fastest transient response to both line and load variation. Also the compensation for V^2 is simple as compared to voltage and current mode. Over current protection is to be implemented separately in V^2 mode but overvoltage protection is inherent. The hybrid of current control and V^2 control has both type of protection inherent in the system [9]. Slope compensation is required for current mode and V^2 mode to avoid sub-harmonic oscillation. With fast transient response and ease of compensation, V^2 scheme is widely embraced for use in power supplies.

This chapter outlined the three basic control schemes for DC-DC control. The small signal for the loop was derived for all the control schemes and the compensation design for each of the scheme was illustrated. The performance using each of control schemes is discussed. The next chapter details about the simulink implementation of all control schemes and their performance is compared for variations in line and load.

V. RESULTS

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V. CONCLUSION

DC-DC converters and their design remain an interesting topic and new control schemes to achieve better regulation and fast transient response are continually developed. Step down switching regulators are the backbone of electronic equipments that employ IC's running at supply voltages lower than 5V. A key challenge to design switching regulators is to maintain almost constant output voltage within acceptable regulation. Pspice is the industry standard for design and simulation of electronic circuits. But the problem of convergence and time for simulation makes it inconvenient for complex systems such as a DC-DC converter to be simulated. In this thesis, Matlab simulink is preferred over Pspice for its enhanced equation solver. The block diagram of the converter system in Matlab simulates the functionality of the system while providing specification for each individual block to facilitate IC implementation.

Traditional method of arriving at small signal model is complex. In this thesis, a simple graphical method to develop the small signal system model for three most predominant control schemes is discussed. The small signal model so developed is then used to develop the loop equation without compensator. The stability is then examined via the bode plot of loop gain and the compensator is designed to make the SMPS stable in closed loop. The results from graphical method closely match with the traditional method. The converter system so designed is simulated under different load condition

In particular, the state of the art V2 control scheme is analyzed in detail. IC versions of the scheme are implemented but not much analysis has been documented on its small signal model and compensation on its relative figure of merit versus other control schemes. The graphical method is applied to this scheme and the compensation is designed. The full system model is implemented with compensation and transient response is observed under different load conditions. It is concluded that V2 has fast transient response and easy compensation that doesn't require demanding performance from the OTA.

Future work

Protection circuits are integral part of the converter system to protect the load from application of high voltage in case of failure in converter. Over-voltage and over- current protection could be added to existing block diagram. Soft-start is necessary to avoid inrush of current at start up and could be appropriately modeled. An easy way to implement soft-start is by using a RC network following the reference voltage. The discussed modeling technique can be extended to enhanced V2 control scheme and to verify the improvement in transient response and avoid the use of external over voltage and over current protection scheme.

REFERENCES

[1] Wang, M.; "*Power supply design with fast transient response using V^2* control scheme", International IC'99 Conference Proceedings-,Page(s): 189 – 199

[2] Goder, D.; Pelletier, W.R.; "*V^2 architecture provides ultra-fast transient response in switch mode power supplies*", Switch Power Inc., Campbell, CA

[3] Data Sheet "*CS51313 Synchronous CPU Buck Controller Capable of Implementing Multiple Linear Regulators*", ON Semiconductor, 2001.

[4] Vorperian, V., "*Simplified Analysis of PWM Converters Using the Model of the PWM Switch*", Aerospace and Electronic Systems, IEEE Transactions on, Volume: 26,Issue: 2, March 1990

[5] Robert W Erickson, *Fundamentals of Power Electronics*, International Thomson Publishing (1997)

[6] Abraham I. Pressman, *Switching Power Supply Design,* McGraw-Hill (1998)

[7] Su, J.H.; Chen, J.J.; Wu, D.S.; "*Learning feedback controller design of switching converters via Matlab/Simulink*" Education, IEEE Transactions on, Volume: 45 Issue: 4, Nov. 2002 Page(s): 307 -315

[8] Mattingly, D.; "*Designing stable compensation networks for single phase voltage mode buck regulators*" Technical Brief, Intersil, Dec. 2003

[9] Huang, W.; *A new control for multi-phase Buck converter with fast transient response*, ON Semiconductor (2001).

[10] Ridley, R.B.; "A new, continuous-time model for current mode control" Power Electronics, IEEE Transactions on, Volume: 6 Issue: 2, April 1991 Page(s): 271- 280

[13] Ridley, R.B.; "A new small-signal model for current mode control" Ph.D. dissertation, Virginia Polytechnic Institute and State University, Blacksburg, Nov. 1990

[14] Rashid, M.H., *Power Electronics Circuits, Devices and Applications*, PHI (1996)

[15] Lenk, R., *Practical design of power supplies*, McGraw-Hill (1998)

[16] Severns, R.P.; Bloom, G.; Modern DC-TO-DC switchmode power converter circuits, Van Nostrand Reinhold Company (1985)

[17] Locher, R.; "Introduction to POWER MOSFETs and Their Applications", AN-558, National Semiconductor, Dec 1998

[18] Data Sheet "*NCP1570 Low Voltage Synchronous Buck Controller*", ON Semiconductor, 2002

[19] Data Sheet "*LTC1625 No Rsense Current Mode Synchronous Buck Step-Down Switching Regulator*", Linear Technology, 2002

[20] Data Sheet "*UC1842 Current Mode PWM Controller*", Texas Instrument, 2002

[21] Yao, K.; Meng, Y; Lee, F.; "Control Bandwidth and Transient Response of Buck Converters", Virginia Polytechnic Institute and State University, Blacksburg, Nov. 2002