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Transcribing DSP Based Digital Control Method For DC-DC Converters

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***Abstract*: This paper transcribes the evolving scenario of Digital control method used in Power Electronics Systems (PES) using DSP controller for the implementation of the power electronic circuits. DC-DC converters topologies are widely used in PES for various voltage conversions. In DC-DC power converters Digital control is becoming more and more common because of the low cost, high performance Digital Signal Processing (DSP) controller. Power electronic peripherals such as analog to digital (A/D) converters and pulse width modulator (PWM) are integrated on DSP chip.**

***Keywords:* Digital control, Boost converter , DSP controller, closed loop control .**

I. INTRODUCTION

In control of power regulation, design of DC-DC converters plays an important role. Compared to other DC-DC converters topologies the boost converter offers higher efficiency and less component in use. A variety of methods in Digital control of DC-DC power converters is becoming more and more useful in industry due to low cost, high performance Digital Signal Processing (DSP) controller with several integrated peripherals such as analog to digital (A/D) converters, pulse width modulator (PWM), Timer, USART (universal asynchronous receiver and transmitter) and other USB (universal serial bus) protocols for communications. To meet specific customer needs digital control based on DSP allows implementation of flexible control of hardware modules with control schemes. Signal conditioning circuits plays an important role with respect to interfacing a digital hardware circuit with real world circuit under analysis. MATLAB is very useful tool for analysis of real time hardware with the exact simulating environment on personnel computer. Real time workshop (RTW) is an work bench in MATLAB to generate the real time code for the simulated work. This special feature of the MATLAB for code generation for real time hardware made the work of engineers and scientist to move up to next level of real time control of analog circuits through digital implementation.

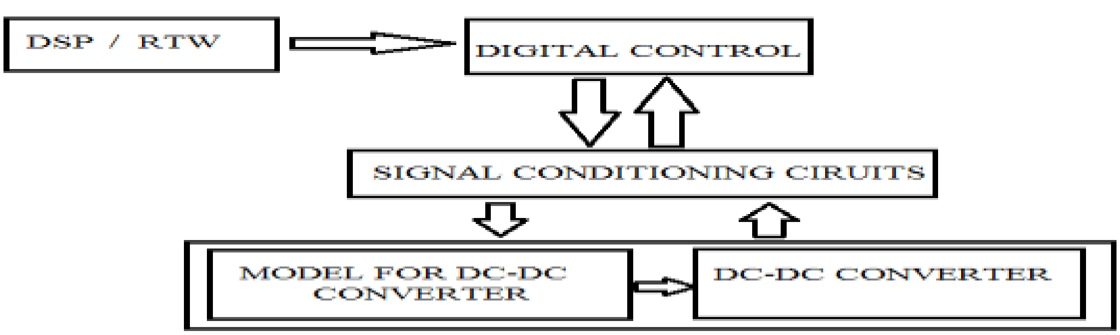

Fig.1. Principle block diagram.

II. DIGITAL CONTROL

As the advancement in the digital electronics and microprocessors is overwhelming although they are restricted to their specific field of applications .DSP based processors are the next generation family in the hybrid combination of Microprocessor and microcontroller abilities which has advantages over analog control .Therefore digital control has several advantages:

- They are easier to implement.
- Modifying code is very flexible.
- Noise sensitivity is very less.
- Environmental effects are also reduced.

As limitation is the part of life for dedicated activities therefore digital control also suffers with some little disadvantages:

- Finite word length of processor limits the signal resolution.
- Sampling delay time is restricted.
- Power computation is limited.
- Control loop bandwidth.

Digital controllers are very viable in high end switching power converters due to the price/performance ratio decline as the year's passes and technology advances.

III. DESIGN APPORACHES FOR DIGITAL CONTROL

There are generally two approaches to design a digital Controller:

- Digital Redesign approach
- Direct Digital approach.

Digital Redesign or digital emulation approach the controller is designed in the continuous domain, and then discretetized into the discrete form [2].

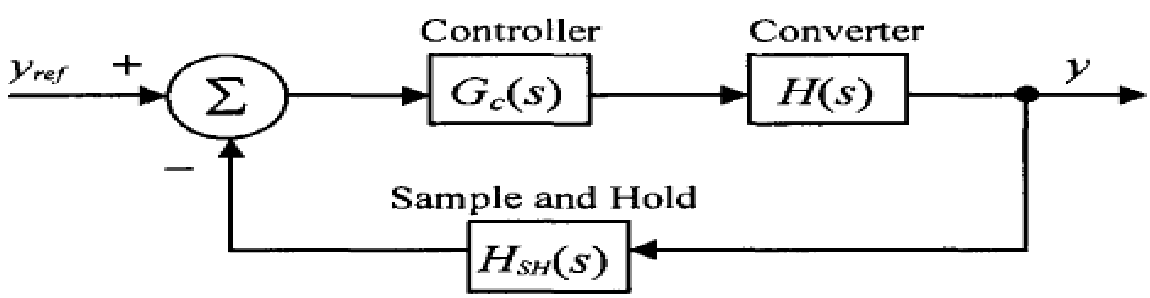

Fig.2. Single loop feedback control [14].

Direct Digital approach, on the other hand, the system plant in the continuous domain is first transformed into the z-domain, and the controller design is carried out directly in the z-domain [2].

In the digital redesign approach, an analog controller is first designed in the continuous domain. Fig.2. shows a system in the s-domain. In Fig. 2, *H(s)* is the plant of the converter, G_c(s) is the controller to be designed, H_{SH}(s) represents the time delay due to the sampling and hold process of the digital control. In modelling time delay of the processT_s, will be the sampling period. Expressed by:

$$1-\frac{e^{-T_s s}}{s} \quad (1)$$

$$1-\frac{e^{-T_s s}}{s}=\frac{1}{1+\frac{T_s s}{2}} \quad (2)$$

After the time delay term is linearized, the standard design approaches such as the Bode plot approach can be used to design the controller $G_c(s)$.

IV. DIRECT DIGITAL DESIGN APPROACH

The direct digital design provides superior performance as per stated in [8]. In direct digital design approach, the continuous time power stage model is first discretetized with zero order hold (ZOH). Once this is available, the digital controller is designed directly in the z-domain using methods similar to the continuous time frequency response methods. This has the advantage that the poles and zeros of the digital controllers are located directly, resulting in a better load transient response, as well as better phase margin and bandwidth for the closed loop power converter.

With the direct digital approach, the digital controller is designed in the discrete-time domain using the step invariant model of a continuous time plant when zero-order hold is used. Once a discrete-time approximation of the plant is available, the controller is designed directly in the z-domain using methods such as discrete-time frequency response method, root-locus method, or deadbeat method. The frequency response method is particularly convenient to practicing engineers who are familiar with the Bode plot design method in the s-domain, and can use the same concept such as the gain-cross-over frequency and gain phase margins. The limitation of this technique, however, is that the sampling frequency must be at least 10 times higher than the closed loop bandwidth. The root locus method is a graphical method that solves an n*-order polynomial. By adjusting the controller parameters, the poles/zeros of the system can be tuned to favourable positions. The tuning process, however, can be long especially if there are a number of undecided controller parameters.

The deadbeat control forces the output of the system to the expected value after a finite number of sampling intervals. This method is highly dependent on the accuracy of the plant function. Therefore, the advantage of the deadbeat controller is not obvious in most cases.

For the direct digital design approach, we propose to use the frequency response method first to obtain an initial design, then use the root locus to fine tune the controller. In this way, the advantages of both techniques are utilized, and optimum controller can be designed quickly and conveniently.

V. DC-DC CONVERTER TOPOLOGIES

DC-DC converter principle Operation:

The DC-DC converter is a semiconductor circuit which provides a relationship between input and output parameters at fast switching rate provided by a semiconductor switch therefore at times when the switch is on the input will be disconnected from the load, when switch is off the load is connected to the input.

Average voltage [7],

$$\frac{V_o}{V_s}=\left(\frac{T_{on}}{T_{on}+T_{off}}\right) \quad (1)$$

$$V_o=(T_{on}/T)V_s \quad (2)$$

$$V_o=\alpha V_s \quad (3)$$

$$\alpha=T_{on}/T \quad (4)$$

Uncontrolled parameters:

- V_s =Source Voltage.

Controlled parameters:

- α = Duty ratio.
- $T = T_{on} + T_{off}$=Chopping period.
- T_{on} = ON period.
- T_{off} =OFF period.

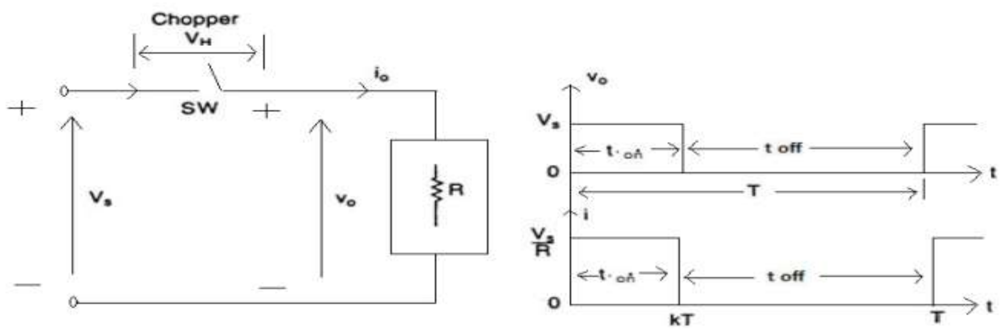

Fig.3. Resistive load Chopper circuit and waveform [7], [10].

- $f = \frac{1}{T}$=Chopping Frequency.

Step up (boost) switching converters transfers large packets of energy using similar devices as mentioned for buck converters but with slight changes in the circuit arrangements.

- Average output voltage of Boost converter in terms of duty ratio:

$$V_o = \frac{V_i}{1-\alpha} \quad (5)$$

General DC-DC converters topologies:

- Boost converter.
- Buck converter.
- Cuk converter.

Boost converter:

When the switch is on, the diode is reverse biased, thus isolating the output stage. The input supplies energy to the inductor. When the switch is off, the output stage receives energy from the inductor as well as from the input. Its main application is in regulated dc power supplies and the regenerative breaking of dc motors. In Boost converter the output voltage is always greater than the input voltage.

Buck converter:

It step down converter produces a lower average output voltage then the dc input voltage. Its main application is in regulated dc power supplies and dc motor speed control. During the interval when the switch is on, the diode becomes reverse biased and the input provides energy to the load as well as to the inductor. During the interval when the switch is off, the inductor current flows through the diode, transferring some of its stored energy to the load.

CUK converter:

This converter is obtained by using the duality principle on the circuit of buck-boost converter.

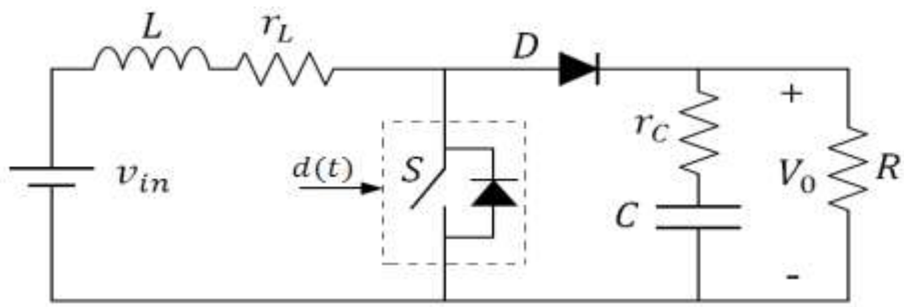

Fig. 4. Dc-Dc converter circuit diagram

Cuk converter provides a negative-polarity regulated output voltage with respect to the common terminal of the input voltage

VI. SMALL SIGNAL MODELLING OF BOOST CONVERTER

Mathematical models are used to design Linear controllers for DC-DC converters. To achieve a certain performance objective, an accurate model is essential. A number of ac equivalent circuit modelling techniques have appeared in the literature [9,10]. Development of small-signal transfer functions for non-linear pulse-width modulated (PWM) DC-DC Converters can aid in ease of understanding circuit performance and control. Among these methods, the state space averaged modelling is most widely used to model DC-DC converters. The duty cycle to output voltage and duty cycle to inductor current small signal transfer functions of a boost converter with resistive load, shown in Fig. 4, are given by:

$$G_{vd}(s) = \frac{V_o^{\wedge}(s)}{d^{\wedge}(s)} = \frac{G_{dv}\left(1+\frac{s}{w_{zv1}}\right)\left(1-\frac{s}{w_{zv1}}\right)}{\Delta(s)} \quad (1)$$

$$G_{dv}(s) = \frac{i_L^{\wedge}(s)}{d^{\wedge}(s)} = \frac{G_{di}\left(1+\frac{s}{w_{zi}}\right)}{\Delta(s)} \quad (2)$$

Where ***Vo*** is output voltage, ***C*** is the capacitance, ***L*** is the inductance and r_L is the internal resistance of the inductor.r_C is the internal resistance of the capacitor, ***n*** is the number of phases, ***m*** is the number of the parallel switches per phase, ***Vin*** is input voltage, ***D*** is the duty ratio and ***Ro*** is the resistance of the load. The transfer function (1) is a second order system, which has two LHP poles. The right half plane zero (*wzv2*) are functions of nominal duty cycle (*D*). In a closed-loop voltage control system, the system elements will change as the duty cycle changes, which means the transfer function will change accordingly.

VII. DIGITAL SIGNAL PROCESSORS (DSP)

The digital signal processors (DSPs) are finding wide application in many engineering fields especially the field of power electronics and these are suitable in almost all high frequency power conversion applications. This is because of their ability to perform complex mathematical computations within minimum amount of time and efforts. Furthermore, the digital controller is flexible as the implementation involves only software instructions and is independent of the converter size. The eZdsp™ F2808 DSP[23] is used for control strategy implementation and LEM current and voltage sensors are used for measuring feedback signals. In this paper, a real-time digital control based on TMS320F2808 DSP is transcribed in order to achieve a fast response during transient operation.

VIII. REAT TIME WORK SHOP

Real time workshop is a software integration environment for automatic code generation, program building, and the build process in C or other programming languages to create, test, and deploy real-time systems using the Real-Time Workshop software, successful emulation and deployment of real-time systems requires familiarity with parameters and design constraints. Real-Time Workshop technology explicitly with the Real-Time Workshop and Real-Time Workshop® Embedded Coder™ products.
In using the Real-Time Workshop product needs some requirements as:

- Generate source code and executables for discrete-time, continuous-time (fixed-step), and hybrid systems modeled in Simulink.
- Use the generated code for real-time and non-real-time applications, including simulation acceleration, rapid prototyping, and hardware-in-the-loop (HIL) testing.
- Tune and monitor the generated code by using Simulink blocks and built-in analysis capabilities, or run and interact with the code completely outside the MATLAB and Simulink environment.
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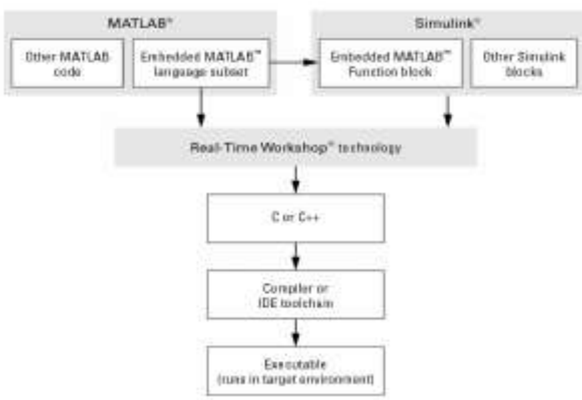

Fig. 5. Closed loop control example block with voltage feedback.

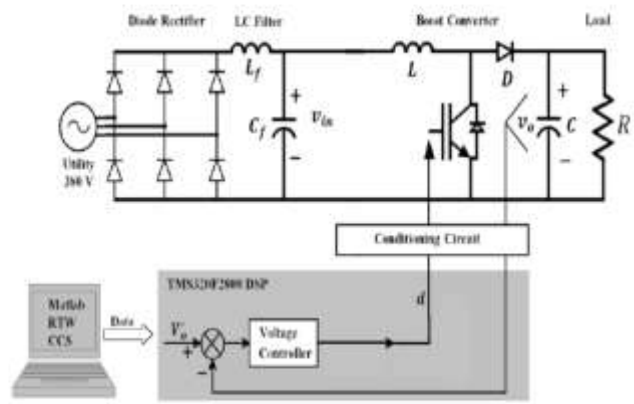

Fig. 6. Closed loop control example block with voltage feedback.

CONCLUSION

The integration of the above circuit topologies and device modeling leads us to upgrade our thinking in the field of power electronics to generate closed loop systems which can be driven from the Digital hardware namely preferred as the DSP based control methods. MATLAB provides the simulation environment called RTW for real time implementation for the power electronics systems.

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