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DC/DC BOOST CONVERTER WITH PI CONTROLLER USING REAL-TIME INTERFACE

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ABSTRACT

This paper presents the design of Proportional Integral (PI) controller with Real Time Interface (RTI) to improve the dynamic response of digitally control dc to dc boost converter. The experiments were done under several load variations. DS1103 dSPACE RTI has been used as an interface controller between hardware and software by using MATLAB/Simulink model. The inputs and outputs from the hardware were connected to dSPACE PPC Controller Board CP1103. By using dSPACE RTI, the response time of the system could be observed in real-time. The results, showed that boost converter was capable to operate in fast response with the variation of output load. The PI controller was capable to achieve faster transient response, stable and was more robust with digital control.

Keywords: proportional integral, boost converter.

INTRODUCTION

Boost converter are the most popular dc converter widely used to step up a low voltage to high voltage level. Boost converter is also known as step up converter. The output voltage can be regulated within the Pulse Width Modulation (PWM) switching signal. A basic structure of dc to dc boost converter consists of resistor, dc power supply, inductor, capacitor, diode and power switch. Numerous researches have been done on dc to dc boost converter which cover wide range of applications such as in Switch Mode Power Supply (SMPS), Photovoltaic (PV) system(Jung *et al.*, 2011), Electrical Vehicle (EV) system and grid connected (S. H. Hosseini, Haghighian, Danyali, & Aghazadeh, 2012). Several issues have been discussed in order to optimize the performance in terms of efficiency, response time, output voltage and current ripple, size and weight. Besides, numerous close loop techniques had been proposed for example PID controller, Fuzzy Logic, One Cycle Control (Smedley, 1995) and Artificial Neural Network. Apart from that, some researchers came out with new circuit configurations, soft-switching technique (Kazimierczuk, 1988), high frequency power switches design and robust controller (Buccella, Cecati, & Latafat, 2012).

Within close loop system, PID controller is considered as a basic close loop technique. PID control is a traditional linear control method commonly used in many applications (Guo, Hung, Member, & Nelms, 2009). The PID controller is considered as a popular control feedback used in industrial area due to its feasibility and easy implementation in real application. Moreover, if the systems are unknown or complex, the PID can be designed to track an error and assume the system as 'black box'. This technique involves three main algorithms which are proportional, integral and derivatives, symbolize as P, I and D respectively. P is dependency on the present error, I is accumulation of past error and D is the predictive of the future error. Essentially, a PID controller calculates an error value as the difference between the measured process variable and the desired set-point (Calvo-Rolle & Corchado, 2014). PID controllers compute the error value as the difference related to the measured process and the desired reference. PID controller generally has to adjust three-gain impact to the system which would affect the transient response, rise time, settling time, steady-state error, overshoot and stability. However, it is not necessary for a system to have all three terms; it may only use one or two actions as PI, PD, ID, P, I or D.

Due to recent advances in microcontrollers and digital signal processors, there has been a growing interest in the application of digital controllers for high-frequency conversion systems and low- to medium-power dc/dc converters due to the low price-to-performance ratio for implementing complex control strategies (Mummadi, 2011). The development of software enables user to model and then directly implement in Real Time which can offer flexibility in control algorithm, solve complex process and programmability and easier system integration.

This paper presents the development of boost converter with PI controller. dSPACE hardware was used to realize the MATLAB/Simulink model. By using dSPACE hardware and software, Real Time Interface (RTI) could be achieved using ControlDesk software. The input and output configuration can be monitored and adjusted using Graphical User Interface designed in ControlDesk software. Despite that, with 1GHz CPU clock for rapid prototyping application and 16-bit A/D and D/A, the performance of the boost converter with the PI controller demonstrated a robustness performance throughout the analysis.

PROPORTIONAL INTEGRAL DERIVATIVE

PI controller implementation

A PI controller calculates an error value as the difference between a measured process variable and a desired set point. The controller attempts to reduce the error by adjusting the process through the use of a manipulated variable. Figure-1 shows the basic block diagram of the PI controller.

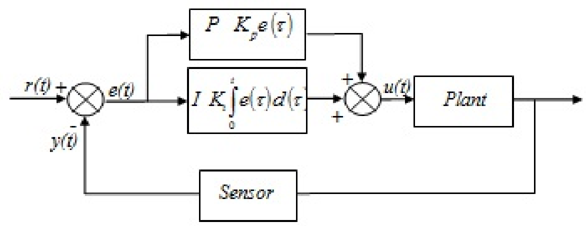

Figure-1. Block diagram of the PI controller system.

The error values are calculated via sensor or transducer and compared with desire set point. The detection is in terms of voltage, current, temperature, movement, angle and etc. The PI controller is adjusted manually by setting the value of K_i equal to zero.

The value of K_p is manually tuned most likely to Quarter Amplitude Decay (QAD) in order to eliminate any error between the set-point and process variable instantly. The PI controller will ensure the boost converter deliver a sufficient amount of voltage to the load. By increasing the value of K_i the system until the offset, it will decrease the rise time of the system. However, the system will become unstable and the overshoot will be increased. The value of K_i must be adjusted in certain amount to make sure the system endure the overshoot while decreasing the settling time and keeping the stability. The derivation of the PI controller is obtained as follow:

$$u(t) = K_p(t) + K_i \int_0^t e(\tau) d\tau \quad (1)$$

Circuit simulation

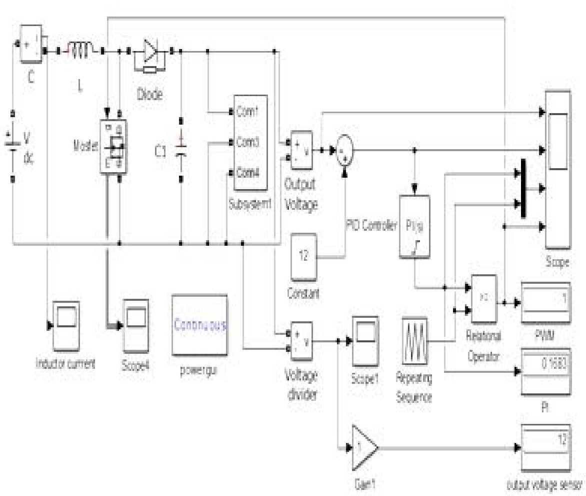

Figure-2. Circuit simulation of boost converter with PI controller using MATLAB/Simulink.

In this study, the simulation of boost converter model was done using MATLAB/Simulink software as shown in Figure-2. Circuit simulation and controller design were realized using MATLAB/Simulink software and RTI used Control Desk on dSPACE software. The output voltage was compared with the constant input voltage to produce an error. Afterward, the error was connected to the PI block and the output was then compared with the sawtooth signal to generate an equivalent duty cycle which was used to drive the switching devices of the converter.

Real time Interface using dSPACE

Figure-3 shows the design of the PI controller for boost converter using MATLAB/Simulink block diagram. The reference voltage was set using constant block. The output from the PID controller was connected to relational operator, which was then compared with repeating sequence (sawtooth) waveform to generate a PWM switching signal. The PWM switching was then gained before being connected to digital to analog converter. The output voltage is measured using DS1103_ADC_CON1 Simulink block. DS1103M_ADC_CON1 and DS1103L_DSP_PWM blocks were used for Master PPC, which was used as analog to digital converter and digital to analog converter respectively. The ADC measured output was then compared with the actual reference set point.

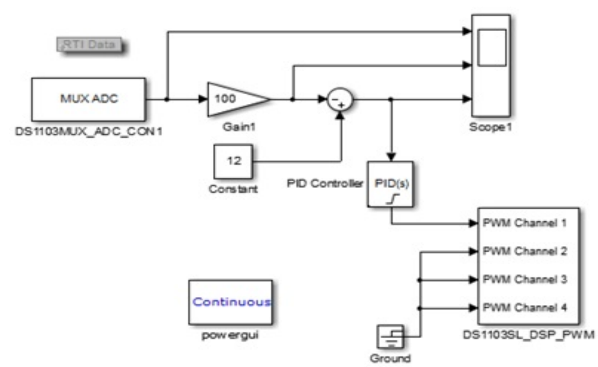

Figure-3. PI controller design for boost converter for RTI using MATLAB/Simulink.

RTI was the connection between dSPACE real-time systems and the development software MATLAB/Simulink from The Math Works. It extended Real-Time Workshop (C code generator) for seamless and automatic implementation of Simulink models on the dSPACE real-time hardware. The input and output could be identified graphically from the RTI block library. The parameter was dragged from within Simulink to make sure that the system could run continuously and the simulation time was set to infinite in MATLAB/Simulink configuration parameter to run the hardware continuously. Later, RTI compiled, downloaded, and started the entire real-time model.

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Prototype of boost converter

The experimental prototype was built to verify the system with switching frequency of 40 kHz constant frequency PWM mode. The boost converter design was based on the following specifications. Vin=10V, Vout=20V and Pout=20W. The voltage output was set to be ranges between 10V to 20V with duty cycle ranges from 0.1 to 0.5.

The boost converter used IRFP460 as a switching transistor and fast switching diode BYT79 with 50 ns typical reverse recovery time. The ripple is set to be less than 1% and operated in Continuous Conduction Mode (CCM). The calculated value of capacitor and inductor were calculated, where the chosen values were 330µF and 100µH respectively.

SIMULATION RESULTS

Figure-4 shows the simulation result for boost converter during start up transient response for (a) PI controller and (b) without PI controller. It shows that the overshoot of the system in (b) was high compared to (a). The overshoot of PI controller was reduced by 17 % compared to the system without PI controller. Besides, the system with PI controller was also more stable, whereby simulate settling time is 0.3ms. The PI controller produced a less ripple compare without PI controller. Figure-5 shows the simulation results of load transients response.

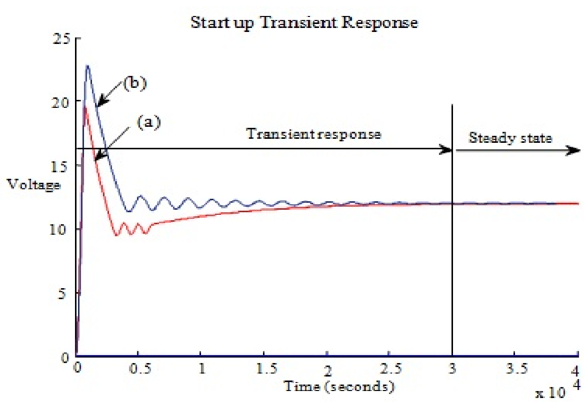

Figure-4. Simulation result for startup transient response using PI and without PI controller using MATLAB/Simulink software (a) without PI controller and (b) PI controller.

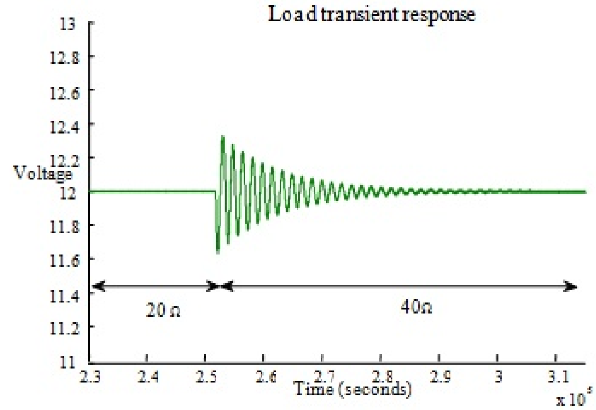

Figure-5. Load transient response using MATLAB/Simulink.

EXPERIMENTAL RESULTS

The system was tuned manually by adjusting the proportional gain, Kp and integral gain Ki using RTI. The parameter Kp is set to be at 0.01 and Ki =10. Increasing the value of Kp decreased the settling time, but the overshoot increased. Increasing the value of Ki the system until the offset, decreased the rise time of the system. However, the system became unstable and the overshoot increased. The value of Ki must be adjusted in certain amount to make sure the system be able to stand overshoot while decrease the settling time and keeping it stable.

Figure-6 and Figure-7 show the experimental results for start up and load transient response, respectively. The measured overshoot in Figure 6 was 16.6% and the rise time was about 15ms. The measured load response time was 20ms when the load changed (R = 20- 40Ω). Figure-7 demonstrates the load response time for 3 different settings of P and I element. It seemed that by increasing the value of I, the ripple voltage was increased which affected the stability of the system.

Figure-8 shows the measured ripple voltage of the system using RTI and plotted using MATLAB software. The Kp is kept constant and the Ki is varies from 6,8,10 and 15. It shows that the ripple voltage increased proportional to the increasing of Ki. The measured voltage ripple was at 0.27 % for Ki equal to 6 and 8. Meanwhile, measured ripple voltage increased at 0.33% to 1.07% when the Ki increased from 10 to 15.

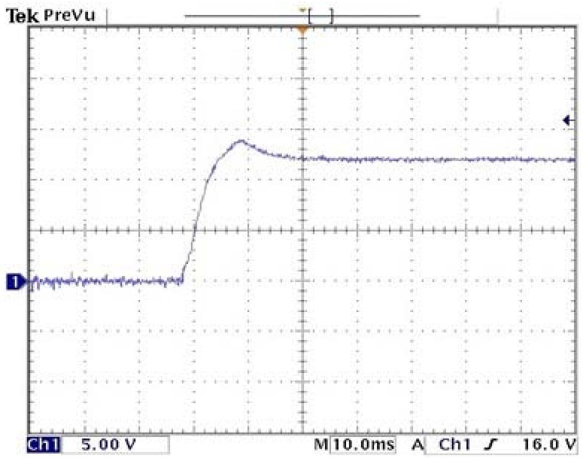

Figure-6. Start up transient response of the boost converter using PI controller method (5V/div, 10ms/div).

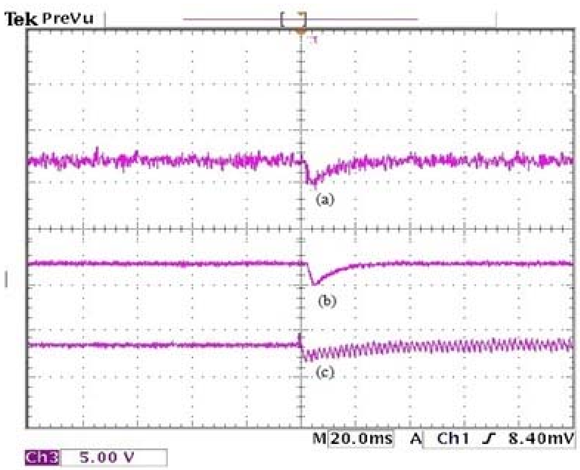

Figure-7. Transient response for the boost converter using the PI control method when the load changes (R= 20- 40 Ω) (5V/div, 20ms/div) (a) Kp=0.01 and Ki=8 (b) Kp=0.01 and Ki=10, and (c) Kp=0.1 and Ki=8.

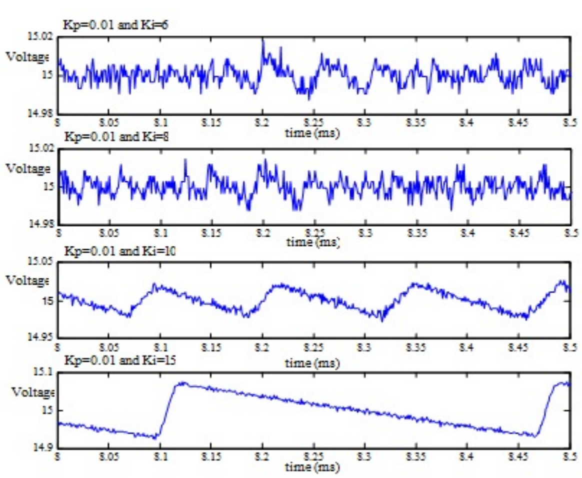

Figure-8. Measured ripple output voltage.

CONCLUSIONS

PI controller have been designed and implemented for a boost converter using RTI. The experimental results for the PI were have been compared, which show that fast transient response and stability of the system could be achieved using PI controller by adjusting the value of K_p and K_i accordingly. By using the advantages of high performance digital signal processing board the system can be tuned easily using real time interface. The experimental measurements are in close agreement with those obtained in the simulations..

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