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Model Based Design of Regulated Bidirectional ZVS Bidirectional DC to DC Converer

G. Themozhi [1] and S. Rama Reddy[2]

Abstract-- **In the implementation of signal processing systems on FPGAs and ASICs, there is significant overlap between system design, HDL design, and verification tasks. DSP Builder is the leading synthesis technology for quickly and effortlessly implementing Simulink designs in the high-performance FPGA platform. In this paper a PID controlled closed loop ZVS bidirectional DC to DC converter is designed using the DSP Builder. The closed loop circuit is obtained using Simulink. Simulink open loop circuit is integrated with control loop using DSP builder. Simulation results of closed loop converter using Matlab Simulink and the integration of Simulink and Altera DSP builder are presented. Both the results are compared.**

I. INTRODUCTION

Regulated bidirectional DC to DC converters are extensively used in aero space applications to provide the means of coupling batteries and the high voltage side DC bus which provides power to the various flight control systems. When in a "step up mode" the converter functions to boost the battery voltage to the required high voltage bus voltage, and in "step down mode" the converter reduces the high voltage available at the DC bus to the voltage suitable for the battery charging. In both the modes the power switches are controlled by PWM technique. PWM (Pulse Width Modulation) technique is used in many voltage regulators. It changes the average value (i.e., DC component) of an output voltage by modulating its duty cycle [4] [5] [6].

Hui Li, Fang Zheng Peng and Jack Lawler (2003) introduced a medium power bidirectional isolated DC-DC sconverter for medium power applications and an extended averaged model was developed for the same. (2001). Danwei Liu & Hui Li (2005) dealt with the dynamic model and control design for a dual half bridge bidirectional DC-DC converter for Fuel

Cell Vehicles. Chuan Hongs and Xu (2004) proposed a PWM plus phase-shift control bidirectional DC-DC converter to reduce current stress and conduction losses, and to expand ZVS range.

Jeong-Gyn Lim (2007) presented the modeling and design of sthe digital controller for a phase shifted full bridge converter which has number of advantages over analog controller. Pritam Das (2009) proposed a non isolated Bidirectional DC to DC converter with outstanding features such as operating with continuous inductor current, fixed switching frequency, and the low switch stresses than a conventional PWM converter regardless of the direction of power flow. S. Jalbrzykowski and T. SCitko (2009) proposed a novel class E buck/boost resonant bidirectional DC-DC Converter for renewable energy system. Among important features of the presented converter topology are low size, less weight and high dynamics because of the transistors' ZVS switching process with high frequency.

This paper presents a PID controlled regulated ZVS bidirectional DC to DC converter using PWM technique. The feedback circuit is developed with Altera development tool. Bidirectional DC to DC Converter is developed with the blocks available in Matlab Simulink. The Altera DSP Builder integrates these tools by combining the algorithm development, simulation, and verification capabilities of the MathWorks MATLAB and Simulink system-level design tools with VHDL synthesis, simulation, and Altera development tools. DSP Builder shortens DSP design cycles by helping us to create the hardware representation of a DSP design in an algorithm-friendly development environment [9].

The soft switched converter accomplishes the voltage conversion with minimal number of components which offers advantages in weight and size. As with most components intended for aero space applications the minimization of the size and weight of bidirectional DC to DC converters is of great concern. Also in concern of the aerospace system is the electromagnetic Interference (EMI) generated by any component. The above literature does not deal with simulation of PID controlled ZVS bidirectional DC to DC converter using DSP Builder. In the present work, an attempt is made to simulate regulated DC to DC converter using the tools Altera DSP builder integrated with Matlab Simulink.

II. SYSTEM OVERVIEW

This paper presents a bidirectional DC to DC converter topology for application as battery charger/discharger. The DC to DC converter in Fig.1 is a combination of two well known topologies, namely half bridge and current fed push pull. The DC to DC converter provides the desired bidirectional power flow for battery charging and discharging using only one transformer, as opposed to two in conventional schemes. It utilizes the bidirectional power transfer property of MOSFETs. Other advantages of the

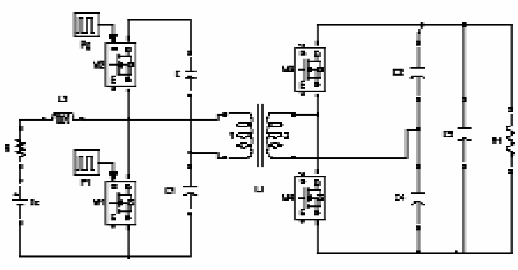

Fig. 1.Soft-switched bidirectional half-bridge DC to DC converter

Research Scholar[1] (Member IACSIT), Professor[2]
Electrical Engineering Department, Jerusalem College of Engineering Centre for collaborative research, Anna University, Chennai, India. (email:gthemozhi@rediffmail.com1 srrvictory@yahoo.com)

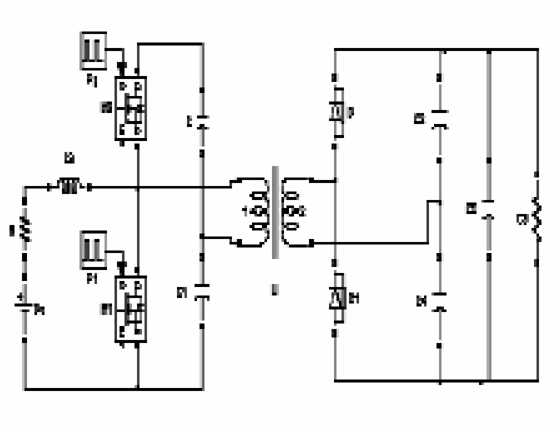

Fig. 2 Boost mode operation equivalent circuit

proposed topology include (a) reduced part count due to use of the same components in both directions of power flow (b) low stresses on the switches (c) galvanic isolation (d) low ripple in the battery charging current(e)fast switchover on failure and reappearance of DC mains (f) minimal number of active switches [1-3][8]. The equivalent circuit of boost mode operation is shown in Fig.2

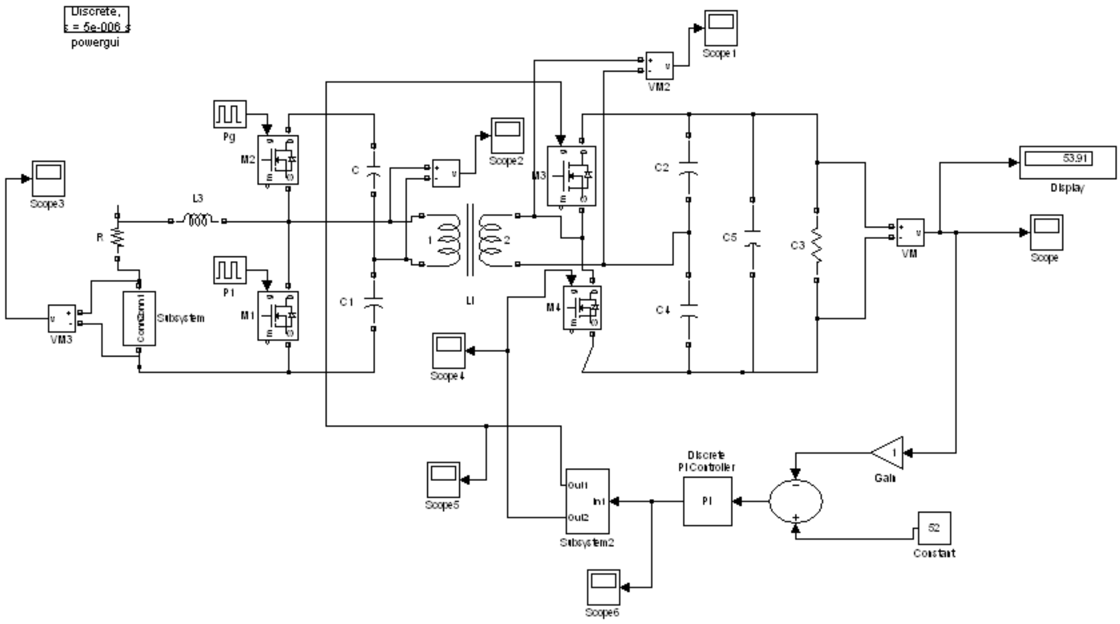

Fig 3 Circuit diagram of closed loop DC to DC converter with PID Controller

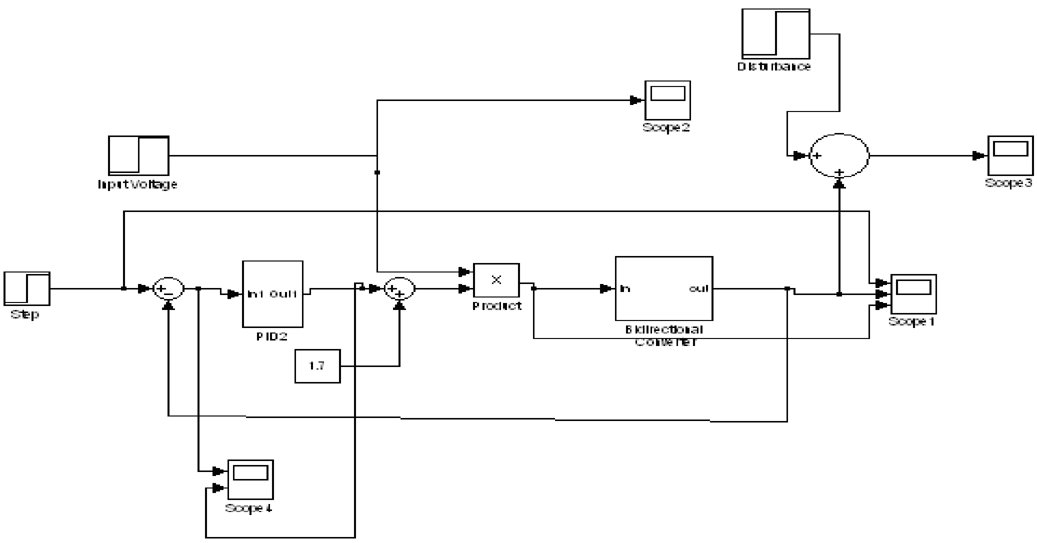

Fig 4 Block diagram of closed loop DC to DC converter with PID Controller using Mathematical model.

The mathematical model of the proposed converter using average model [1] [2] is obtained

$$\begin{pmatrix} \dot{\tilde{i}}_1 \\ \dot{\tilde{V}}_{12} \\ \dot{\tilde{V}}_{34} \end{pmatrix} = \begin{pmatrix} 0 & -\frac{1}{2L_{dc}} & 0 \\ \frac{1}{C_p} & 0 & \frac{-2\varnothing_1(\pi-\varnothing_1)}{K1} \\ 0 & \frac{2\varnothing_1(\pi-\varnothing_1)}{K3} & \frac{-2}{C_i R} \end{pmatrix} \begin{pmatrix} \tilde{i}_1 \\ \tilde{v}_{12} \\ \tilde{V}_{34} \end{pmatrix} + \begin{pmatrix} \frac{1}{L_{dc}} & 0 & 0 \\ 0 & \frac{-2\varnothing_1(\pi-2\varnothing_1).V_{34}}{K1} & 0 \\ 0 & \frac{-2\varnothing_1(\pi-\varnothing_1).2V_{in}}{K2} & \frac{-2}{C_i} \end{pmatrix} \begin{pmatrix} \tilde{V}_{in} \\ \varnothing_1 \\ \tilde{i}_o \end{pmatrix} \quad (1)$$

$$\tilde{V}^0 = [0\ \ 0\ \ 1]\,[\tilde{i}_1\ \tilde{v}_{12}\ \ \tilde{v}_{34}]^T$$

Where $K1 = 2T_sW^2L_sC_p$; and $K2=2T_sw^2L_sC_o'$.

Open loop Matlab Simulink model was developed and the open loop output voltage obtained is shown in the fig (5). A step disturbance of 5V is

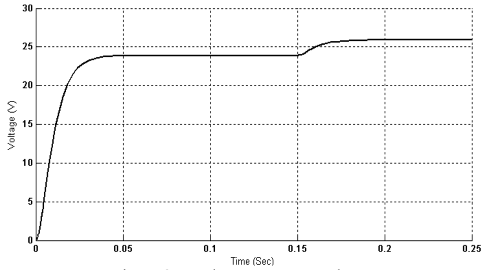

Fig.5 Open loop output voltage
Scale x axis 1unit = 1msec
y axis 1 unit = 5V

applied at 0.4sec. This disturbance affects the output voltage. The effect of disturbance can be observed from the output voltage as shown in Fig (5).

A. PI/ PID Controlled Closed Loop System

Initially PI controller is used in the closed loop system. The closed loop circuit diagram using PI controller is shown in Fig.3. The output obtained is shown in Fig.6. A disturbance of 2V is given in the input side at 0.4 sec. To regulate the output the control circuit takes 0.5 sec without any oscillations

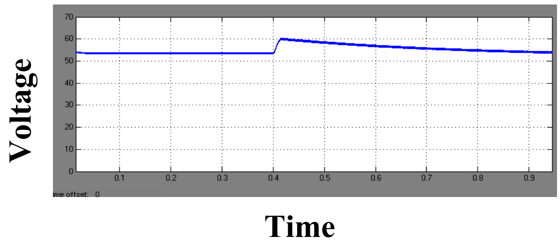

Fig.6 PI controlled closed loop
output voltage
Scale x axis 1unit = 0.1 sec
y axis 1 unit = 10

Later a SISO tool based PID controlled closed loop circuit is developed with Matlab Simulink as shown in Fig.4. The SISO tool is a graphical user Interface (GUI) that facilitates the design of compensators for single-input single-output feedback loops. The SISO Design Tool allows us to iterate rapidly on our designs and perform the following tasks: Manipulate closed-loop dynamics using root locus techniques, Shape open-loop Bode responses, Add compensator poles and zeros, Add and tune lead/lag networks and notch filters, Inspect closed-loop responses (using the LTI Viewer), Adjust phase and gain margins and Convert models between discrete and continuous time.

In the closed loop model, the set voltage can change the duty cycle of the gate pulse using PID controller. The parallel form of PID controller equation is

$$u(t) = K_P e(t) + K_I \int e(\tau)d\tau + K_D \frac{d}{dt} e(t) \quad (2)$$

Where the error e(t), the difference between command and plant output, is the controller input and the control variable u (t) is the controller output.

The three parameters are the proportional gain (K_P), integral gain (K_I) and derivative gain (K_D). K_P, K_D, and K_I values obtained using SISO utility tool for the closed loop circuit are $K_{P=}$ 0.0028279, $K_{D=}$2.764615799 and $K_{I=}$ 7.2316e-007

The simulation result with PID controller is shown in figure (7). Input voltage is set at 12V. A disturbance of 1V is given at 0.4 sec. in the output. The estimated voltage is 24V. Due to the disturbance, a spike is found in the output voltage at 0.4sec. The PID controller takes only 0.02sec. to overcome the disturbance.

Next the PI controller in Fig 3 is replaced with SISO tool based PID

Controller and the output voltage waveform is obtained as shown in Fig. 8.

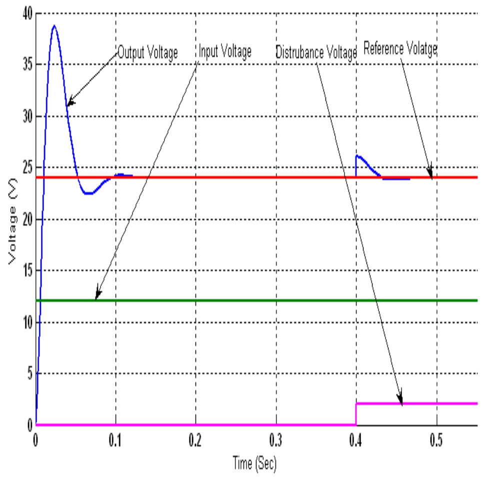

Fig.7 PID controlled closed loop
sOutput voltage
Scale x axis 1unit = 1msec
y axis 1 unit = 5V

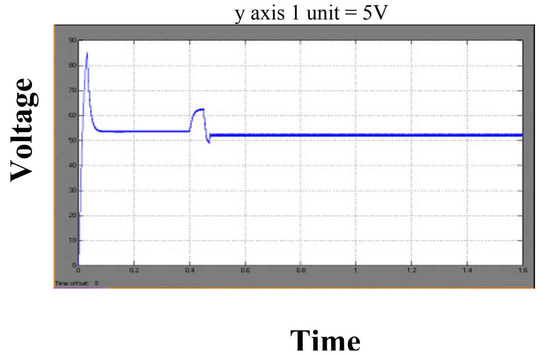

Fig.8. closed loop output voltage of DC
to DC converter circuit using
PID controller
Scale x axis 1unit = 1msec
y axis 1 unit = 5V

B. Closed Loop System using Altera DSP Builder

The control circuit is developed using DSP (Digital signal processing) system design in Altera PLD (programmable logic devices) which requires both high-level algorithm and Hardware Description Language (HDL) development tools. Blocks in DSP Builder are used to create a hardware implementation of a system modeled in Simulink in sampled time. DSP Builder contains bit- and cycle-accurate Simulink blocks, which cover basic operations such as arithmetic or storage functions and takes advantage of key device features such as built-in PLLs, DSP blocks or embedded memory.

The equation for PID controller is

$$U(Z)=[K_P+\frac{K_I}{1-Z^{-1}}+K_D(1-z^{-1})]\,E(Z)\,] \quad 3)$$

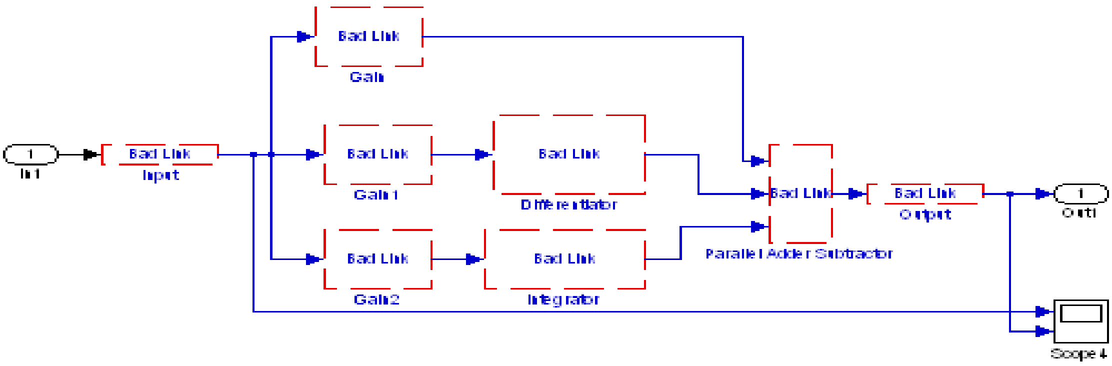

Fig. 9 Block diagram of PID controller using DSP builder

The internal diagram of the PID controller obtained using Altera development tool as shown in Fig.9.

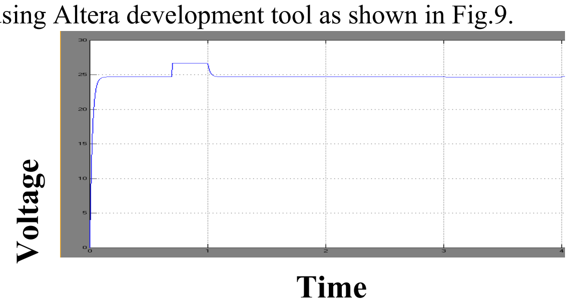

Fig.10. closed loop output voltage of DC to DC converter circuit Using DSP builder Scale x axis 1unit = 1msec y axis 1 unit = 5V

Flow Status	Successful - Thu Jun 17 17:03:26 2010
Quartus II Version	7.2 Build 151 09/26/2007 SJ Web Edition
Revision Name	PID
Top-level Entity Name	PID
Family	Cyclone II
Device	EP2C5F256C8
Timing Models	Final
Met timing requirements	Yes
Total logic elements	109 / 4,608 (2 %)
Total combinational functions	109 / 4,608 (2 %)
Dedicated logic registers	48 / 4,608 (1 %)
Total registers	48
Total pins	34 / 158 (22 %)
Total virtual pins	0
Total memory bits	0 / 119,808 (0 %)
Embedded Multiplier 9-bit elements	0 / 26 (0 %)
Total PLLs	0 / 2 (0 %)

Fig.14 Flow summary in the Compilation Report

Timing Analyzer Summary

	Type	Slack	Required Time	Actual Time	From	To	From Clock	To Clock	Faile Path
1	Worst-case tsu	N/A	None	13.434 ns	e_in[1]	u_prev[15]	--	clk	0
2	Worst-case tco	N/A	None	16.932 ns	u_prev[1]	u_out[11]	clk	--	0
3	Worst-case tpd	N/A	None	20.767 ns	e_in[1]	u_out[11]	--	--	0
4	Worst-case th	N/A	None	0.081 ns	e_in[15]	e_prev[1][15]	--	clk	0
5	Clock Setup: 'clk'	N/A	None	104.19 MHz (period = 9.598 ns)	u_prev[1]	u_prev[15]	clk	clk	0
6	Total number of failed paths								0

Fig. 12 Timing Analysis in Compilation report

The controller part is integrated with Simulink model of ZVS bidirectional model in boost mode. The regulated output voltage waveform obtained is shown in Fig. 10. The Flow Design and Timing analysis of the Compilation Report are shown in Fig. 11 and Fig.12 respectively. Cyclone II processor and EP2C5F256C8 device are used for Implementation. The system is operating with a Clock frequency of 104.19MHz

III. Conclusion

A closed loop converter model with PI controller is developed and the simulation result for the regulated output is obtained. An average model for the DC to DC converter is obtained using MATLAB Simulink. A closed loop Matlab Simulink model is developed with SISO tool based PID controller. This in turn reduces the time required in tuning the PID controller against mathematical calculations. The simulation results are obtained for the closed loop converter with SISO tool based PID controller. The PID controller block is next developed with Altera development tool and it is integrated with the Simulink model. The regulated output is obtained. PI controller requires more time to overcome the disturbance than the PID controller. The response with DSP builder is free from oscillations.

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G. Themozhi has obtained her A.M.I.E from the Institution of Engineers' (India) and Master of Engineering from the Madras University, India. At present, she is pursuing research from Jerusalem Engineering College, Centre for collaborative Research, Anna University, Chennai, India. Her area of research is DC-DC Converters.

Dr. S. Rama Reddy received his M.E degree from the College of Engineering, Anna University, Chennai. India in 1987. He received PhD Degree in the area of Resonant Converters from the College of Engineering, Anna University, Chennai, India in 1995. Presently he is working as the Professor in Electrical & Electronics Dept., Jerusalem College of Engineering, Chennai. He has worked in Tata Consulting Engineers and Anna University, Chennai, India. He is a fellow member of Institution of Electronics and Telecommunication Engineers (India), Life Member of Institution of Engineers (India), Member of ISTE, Member of CSI and Member of SPE, India. He has authored text books on Power Electronics, Electronic Circuits and Electromagnetic Fields. He has published 30 research papers in reputed Journals. His research areas are Power Electronic Converters, Drives and FACTS.