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ANALYSIS AND DESIGN OF DIGITAL PID CONTROLLER FOR PUSH-PULL DC/DC CONVERTER

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Abstract- This paper presents a method for the design and simulation of digital controller based on Field Programmable Gate Array (FPGA) technique for DC/DC Push-Pull converter operating in continuous conduction mode. The Push-Pull converter is simulated using PSIM and controller is designed using MATLAB with the help of XILINX tool box. Using SimCoupler module in MATLAB, co-simulation of PSIM and MATLAB is obtained. The performance of FPGA based PID controller strategy is validated for line and load variations.

Key words- *Push-Pull converter, FPGA, PID controller, PSIM, MATLAB, SimCoupler.*

I. INTRODUCTION

Push-Pull converter is comes into the category of an isolated DC/DC converters [10-11]. Since this converter have steadier input current, create less noise on the input line, and capable for working efficiently at higher power. Such type of converters are used in many applications like in DC/DC Power supplies, space station applications, renewable energy applications, motor control etc. Till date lots of work is reported regarding Push-Pull converter and various controller techniques for the same [13-15]. Further, the research work on design of digital controller is scarcely available in literature.

In present work an efficient FPGA based digital controller technique for Push-Pull converter is proposed.

In recent years, digital controller techniques become popular over analogue controller due to numerous advantages like, lower power consumption, compactness, speed, etc. Microprocessor (µP) [2-3], digital signal processor (DSP) [4-5] and FGPA are some of the digital devices are favorites among the engineers. But with µP and DSP, the range of operating frequency for DC/DC converters is limited. This shortfall is overcome with the FPGA [6-7] controller technique.

Digital proportional-integral-derivative (PID) [7-8] controller is most adaptable controller strategy because of its high performance and simple structure. Because of its low cost, accuracy, and robustness they are widely used for many applications.

This paper explains the working of standard push-pull converter in brief, describes the digital PID controller with its structure its FPGA implementation using XILINX tool box in MATLAB. Finally simulated performances under various operating conditions are given which verifies the effectiveness of proposed controller strategy.

II. WORKING OF PUSH-PULL CONVERTER

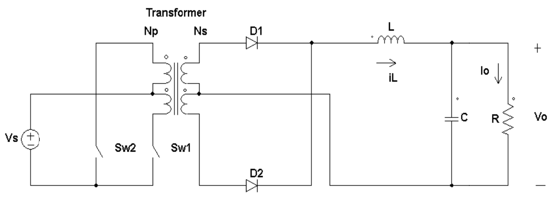

Fig. 1. Schematic of Push-Pull converter

In a push-pull converter, the transformer primary is supplied with current from the input line by pairs of switches in a symmetrical push-pull circuit. The switches are alternately switched on and off, periodically reversing the current in the transformer. Therefore current is drawn from the line during both halves of the switching cycle.

In practice, it is necessary to allow a small interval between powering the transformer one way and powering it the other: the switches are usually pairs of transistors or similar devices, and were the two transistors in the pair to switch simultaneously there would be a risk of shorting out the power supply. Hence, a small wait is needed to avoid this problem. This wait time is called dead time and is necessary to avoid transistor shoot-through.

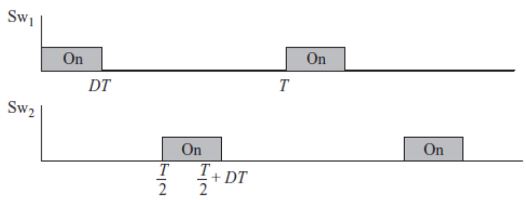

Fig. 2: Switching pulse

Figure 2 shows the switching pulses required for converter operation. T is total time period of one cycle and D is duty the ratio. For the period

switch one ( ) is on. During period –

both the switches are in off position. And in period

$\frac{T}{2} < t < \frac{T}{2} + DT$ switch two (Sw_2) is on. And again during period $\frac{T}{2} + DT < t < T$ both the switches are off.

III. TUNING OF PID CONTROLLER

The PID controller consist of three separate constant parameters namely proportional-integral-derivative and is accordingly sometimes called three-term control. In order to get desired response of the controller it is necessary to have the controller parameters should be tuned properly. There are various methods like Manual tuning, Ziegler- Nichols method, Software tools adopted for calculation of controller gain parameters. 'SISOTOOL' which is inbuilt function in MATLAB uses converter transfer function to obtain the controller parameters. This tool enables to plot various responses like step, impulse, bode, nyquist for various controller structures, which helps to understand and select appropriate controller for converter. Using state space averaging technique [10] the transfer function of Push-Pull converter is obtained.

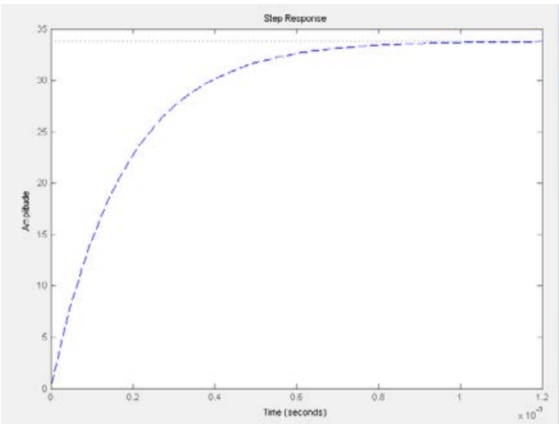

Fig.. 3. Step response without controller

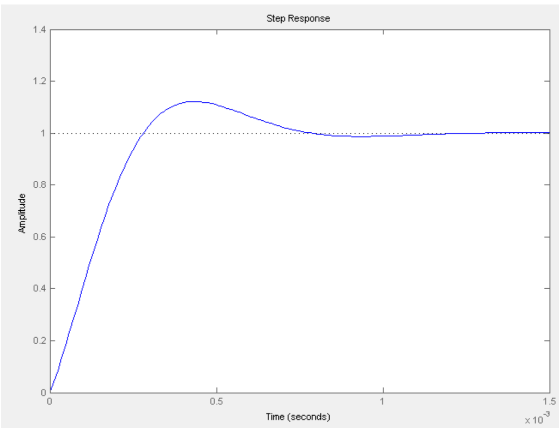

Fig.. 4. Step response with PID controller

In Fig. 3 the step response in open loop configuration is shown. Fig. 4 shows that with using PID controller the response of the converter is improved much better than without the controller.

A proportional controller (K_p) will have the effect of reducing the rise time but never eliminates the steady-state error. An integral control (K_i) will have the effect of eliminating the steady-state error, but it may make the transient response worse. A derivative control (K_d) will have the effect of increasing the stability of the system, reducing the overshoot, and improving the transient response. Effects of each of controllers K_p, K_d, and K_i on a closed-loop system are summarized in the Table I.

TABLE I: EFFECT OF GAIN PARAMETERS

Close loop response	Rise time	Settling time	Overshoot	Steady state error
K_p	Decrease	Increase	Small change	Decrease
K_i	Decrease	Increase	Increase	Eliminate
K_d	Small change	Decrease	Decrease	Small change

IV. DIGITAL PID CONTROLLER AND ITS IMPLEMENTATION USING SYSTEM GENERATOR

Consider the block diagram of digital control system as shown in Fig. 5.

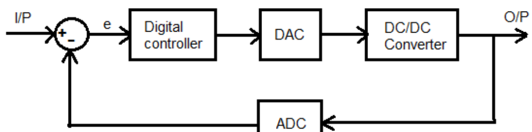

Fig. 5. Block diagram of digital control system The analytical equation,

$$P = K_p e + K_I \int e\, dt + K_D (de/dt) + P_I(0)$$

Where,
K_P= proportional gain
K_D= derivative gain
e= error in % of full scale range
K_I= integral gain
$P_I(0)$= value of integral gain at t=0

Taking Laplace transform of equation (1) will result in,

$$P(s) = K_P E(s) + \frac{K_I}{s} E(s) + K_D E(s)$$

Also the transfer function of PID controller is

$$D(s) = K_P + \frac{K_I}{S} + K_D S$$

Transforming equation (3) into digital domain gives the transfer function of digital PID controller,

$$D(z) = K_P + K_I \frac{T(z+1)}{2(z-1)} + \frac{K_D}{T} \frac{(z-1)}{z}$$

Equation (4) can be realized to direct form structure as:

$$D(z) = \frac{a_0 + a_1 z^{-1} + a_2 z^{-2}}{1 + b_1 z^{-1} + b_2 z^{-2}}$$

Normally for digital controller b_2=0 and b_1=-1. Therefore, coefficients a_0, a_1 and a_2 can be given as:

$$a_0 = K_P + K_I \frac{T}{2} + \frac{K_D}{T}$$

$$a_1 = K_P + K_I \frac{T}{2} - 2\frac{K_D}{2}$$

$$a_2 = \frac{K_D}{T}$$

Where,

K_P, K_I and K_D are proportional, integral and derivative parameters, respectively of digital PID controller and T is sampling period. Fig. 6 shows the direct form I of digital PID controller [1] which obtained from transforming the transfer function of PID control into digital domain.

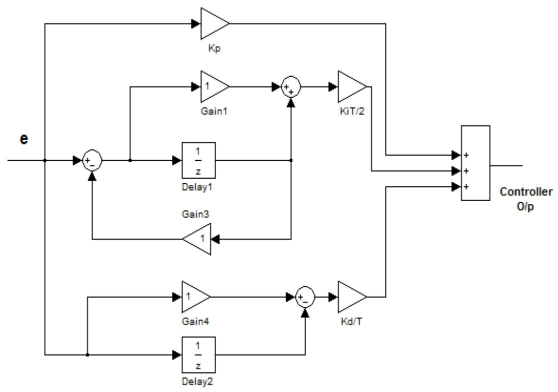

Fig. 6. Direct form I of digital PID controller

The System Generator (SysGen) is a Xilinx tool box available in MATLAB. The PID controller is implemented in Xilinx SysGen is show in Fig. 7. PID controller receives the error generated from comparison of converter output voltage with the reference value. And depending upon the error generated controller takes necessary action and generate control signal which adjusts the duty ratio of switching pulses. Ultimately the output the converter reaches its desired value in very short period of time. System generator implements the design by considering the correct hardware platform and also takes care of synchronization and interfacing problems. The System Generator serves as a control panel for controlling system and simulation parameters, and it is also used to invoke the code generator for net listing.

A separate test bench application for hardware (FPGA) verification is also not required. The simulation block can be used with the same Simulink test bench apparatuses that were used to test the original System Generator model. Along-disadvantages also, that is associated with the presented co simulation methodology/tools using automatic bit stream generation. With every release of System Generator, the top level output files change.

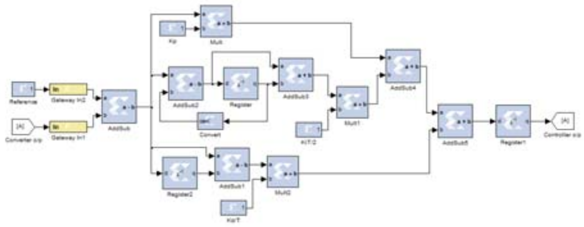

Fig. 7. Digital PID controller implementation using Xilix tool box

V. SIMULATIONS AND RESULTS

A. Main power circuit

Power circuit of Push-Pull converter is simulated in PSIM, which is shown in Fig. 8. ‘Out’ is output voltage of converter which is sensed using voltage sensor and is given to control circuit which is simulated in MATLAB and IN1 and IN2 are input signals are nothing but switching pulses which are generated by control circuit. The specifications of Push-Pull converter taken for simulation purpose are given in Table II.

Table II: CONVERTER SPECIFICATIONS

Rated input DC voltage (V_s)	100V
Transformer turns ratio (N_p/N_s)	10/6
Output voltage (Vo), Output current (I_O)	24V, 15A
Inductor (L), Capacitor (C)	24μH, 7.81μF
Load resistance (RL)	1.6Ω
Switching frequency (f)	100 kHz
Diode resistance (rd1, rd2)	0.01Ω
Inductor and Capacitor parasitic resistances (rL and rC respectively)	0.005 Ω, 0.008 Ω

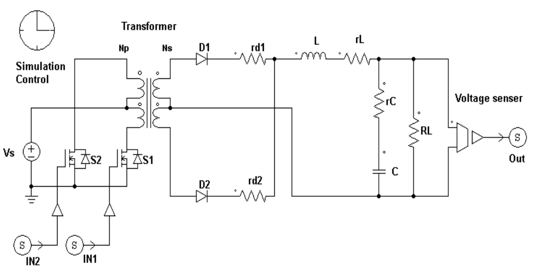

Fig. 8. Power circuit simulated in PSIM

B. Control circuit

Figure 8 shows the control circuit which is constructed using XILINX tool box in MATLAB. SimCoupler Module [9] is a tool box available in MATLAB, which enables the co-simulation between PSIM and MATLAB. The converter output voltage which generated in power circuit is compared with the reference value and the error generated from comparison is further given to PID controller. Output of the controller is compared with triangular pulses to generate the switching pulses required for switches.

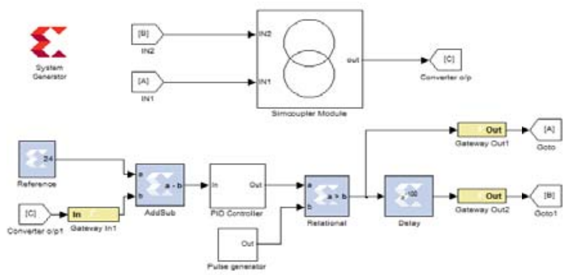

Fig. 9. Digital controller circuit simulated in MATLAB

C. Results

The simulated response of Push-Pull converter with an analogue PID controller is shown in Fig. 10 which gives the overshoot in output voltage as well as output current. With the settling time of 0.12ms.

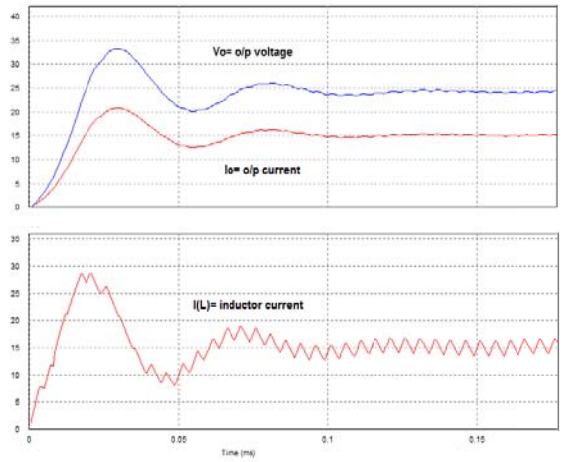

Fig. 10. Response characteristics with analogue PID controller

Figure 11 shows the simulation results with Digital PID controller, which shows no overshoot in output voltage and output current and very less settling time (0.05ms) than the analogue controller.

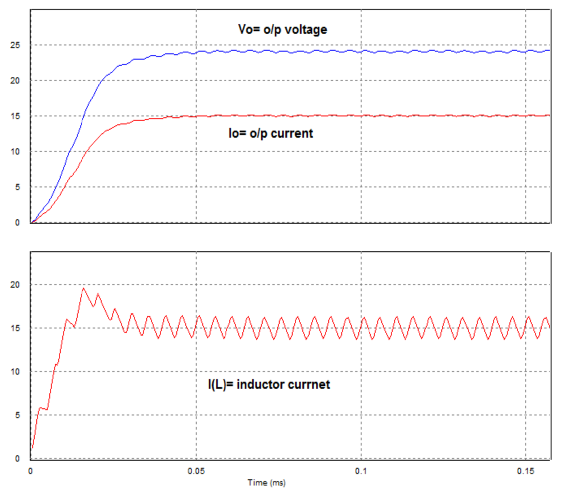

Fig. 11. Response characteristic with digital PID controller

1) With line variation:

Performance of digital controller with line variations at rated load is observed which is show in Fig. 12 and Fig. 13. In Fig. 11 input DC voltage is changed from 100V to 110V. With the sudden change in input voltage, output voltage settles to its rated value, 24V in very short duration with a small disturbance. Similaraly the with reduction in input voltage from 100V to 90V, output voltage settled to its rated value very quickly as shown in Fig. 13.

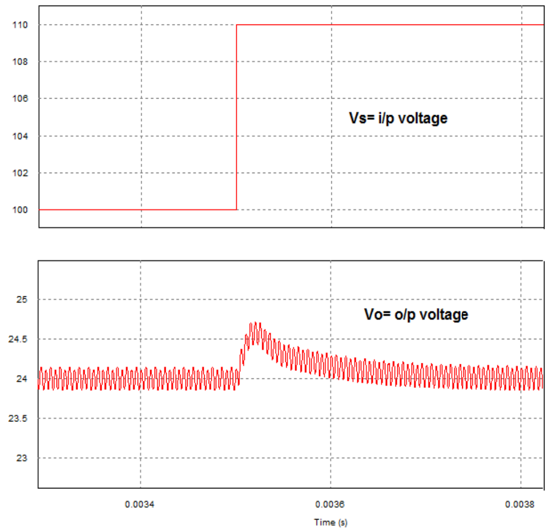

Fig. 12. Effect of increase in line voltage

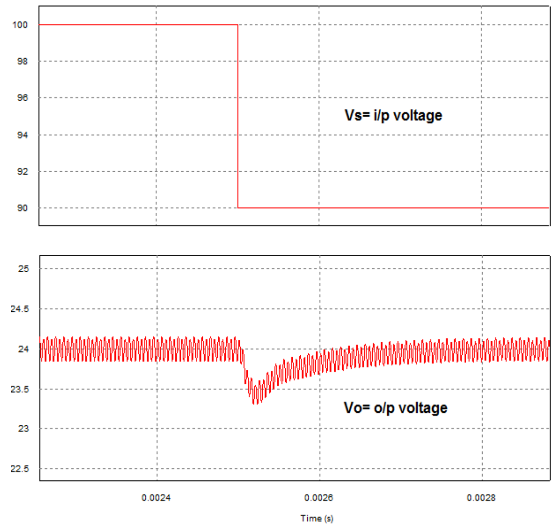

Fig. 13. Effect of reduction in line voltage

2) With load variation:

The performance of digital controller is now observed with sudden changes in load variation at rated input DC voltage.As shown in Fig. 14, the load resistance is reduced to 10% of its rated value, there is increase in inductor current but the output voltage remains at 24V with small dip for shorter duration. On the other hand with increase in load to 10% of its rated value, Fig. 15 shows that current increases but there is oscillations in output voltage for very small period which finally settle down to rated value.

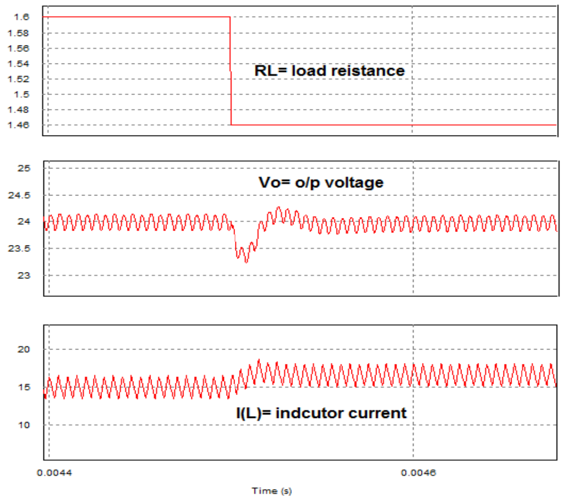

Fig. 14. Load resistance reduced

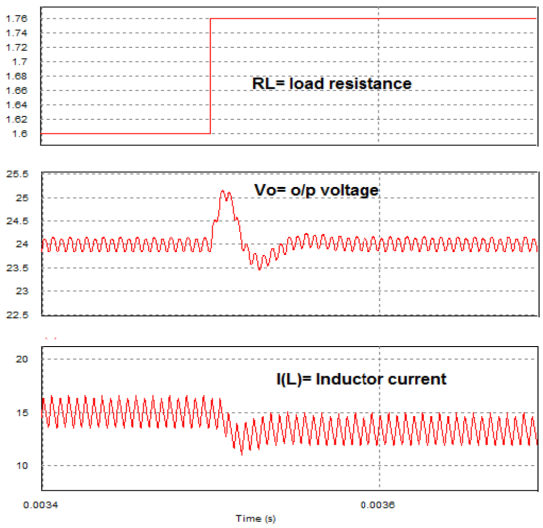

Fig. 15. Load resistance increased

VI. CONCLUSION

In this paper, FPGA based PID controller is designed and simulated for a Push-Pull coverter in MATLAB using XILINX tool box. With the help of SimCoupler module in MATLAB the co-simulation between PSIM and MATLAB is obtained. The comparison between analogue PID controller and digital PID controller using FPGA technique for DC/DC Push-Pull converter is highlighted. Simulation results shows that as compared to analogue PID controller, digital PID controller has less settling time as well as no overshoot in output voltage. And also this digital controller strategy provides robust control for transient load and line variation.

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