Implementation of Linear Controller for a DC-DC Forward Converter

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Abstract

This paper discusses the controller implementation of a DC to DC Forward converter. The open loop response is obtained initially. Then the closed loop control is given in real time for the Forward converter. The MATLAB interfacing is done with the help of data acquisition card. The conventional PI controller is used for the closed loop control and the results are analyzed under MATLAB/SIMULINK environment.

Keywords: *Data acquisition card, Closed loop, Forward Converter, Interfacing, MATLAB, Open loop, PI Controller.*

I. Introduction

The DC to DC converters are used to get a required DC output even when the input is DC itself. That is to change the DC voltage from one level to another. DC to DC converter has wide range of applications in power electronics. DC to DC converters are of different types like Buck, Boost, Buck boost, Cuk, Flyback, Forward etc. The output of all these converters will not be equal to the required when there is a change in the input. This is because of the losses made by the passive components present in circuit. To reduce the losses there is necessity for different controller techniques to be used.

The forward converter is the DC to DC converter which uses the transformer to increase or decrease the output voltage depending on the transformer ratio and to offer galvanic isolation for the load. Since the output has the multiple winding, it is achievable to supply both higher and lower voltage inputs simultaneously [1] and [2]. One important application of forward converter is used in the cars as hifi amplifiers in which they are used to step up reasonably low battery voltage to higher voltage. Another common application of this converter is in switch mode power supply which is found in computers and TV sets.

In this work, the hardware implementation of the forward converter is interfaced with the MATLAB/SIMULINK and the real time controller implementation is carried out in the closed loop. The converter is tested by means of both PI and PID controllers in simulation and in real time. The PI controller implementation is done which is discussed in the paper by Mohammad Shahrokhi and Alireza Zomorrodi [3].

1. Proposed Forward Converter

1.1. Forward Converter Model

The circuit diagram of a forward converter which is taken up for study consists of MOSFET switches, diodes, capacitor, inductor and a transformer for isolation. Figure 1 shows the basic circuit for the forward converter

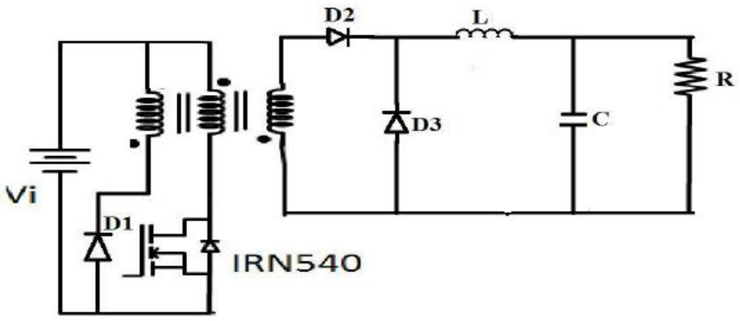


Figure 1. Circuit diagram of a forward converter

The various design parameters which are considered for the study is given in Table 1.

Table 1: Design Parameters Used

PARAMETERS	SYMBOL	VALUE
Input Voltage	Vin	15 V
Output Voltage	V out	5 V
Inductance	L	0.1 m H
Inductor Resistance	R_L	3 m Ω
Capacitance	C	1000 μ F
Capacitor Resistance	R_c	3 m Ω
Switching Frequency	Fs	20 KHz

1.2. Average State Space Model of the Proposed Forward Converter

The state space model and the average model of the forward converter are derived, when the MOSFET switch is in ON-state position and in OFF-state position. The circuit is considered in both the conditions and the matrices are obtained to find the state space model and thus changed to transfer function model for the ease of use [4].

From the ON-state and OFF-states, the state space model can be obtained for the matrices A, B,C, and D which is given in Equation 1 to Equation 4.

$$A= dA_1 + (1-d)A_2 \qquad (1)$$

$$B= dB_1 + d'B_2 \qquad (2)$$

$$C= dC_1 + (1-d)C_2 \qquad (3)$$

$$D= 0 \qquad (4)$$

Here d is taken as the effective duty cycle of the converter and the value is considered to be as 0.333 and d' is taken as 1-d. The matrices A,B,C and D obtained in state space form [5] which is given in Equation 5 to Equation 8 are as follows,

$$A = \begin{bmatrix} \frac{r_L}{L} & \frac{-1}{L} \\ \frac{1}{C}\frac{R}{R+r_c}(1-Cr_c)\frac{r_L}{L} & \frac{-1}{c}\frac{1}{R+r_c}(1+Cr_c\frac{R}{L}) \end{bmatrix} \qquad (5)$$

$$B= \begin{bmatrix} \frac{N_2}{N_1 L} \\ \frac{R}{R+r_c}\frac{N_2 r_c}{N_1 L} \end{bmatrix} \qquad (6)$$

$$C= \begin{bmatrix} 0 & 0 \\ 1 & 0 \end{bmatrix} \qquad (7)$$

$$D= \begin{bmatrix} 0 \\ 0 \end{bmatrix} \qquad (8)$$

After deriving the state space model, using MATLAB command the model is changed to transfer function model for ease of analysis which is shown in equation 9 and identified to be as second order model.

$$G(S) = \frac{0.0010s + 0.3298}{s^2 + 0.0458s + 0.9998} \qquad (9)$$

II. Controller Implementation

Initially, the open loop response is made with the obtained transfer function model. Before implementing the closed loop control in real time with PI and PID controller, the same is done in MATLAB environment.

2.1. Open Loop Response

The open loop response of the forward converter is studied by giving a step response according to the required output. The open loop simulink diagram for the forward converter is shown in Figure 2. The output waveform of the open loop response is given in Figure 3.

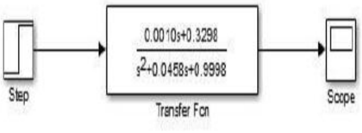


Figure 2. Open loop simulink diagram

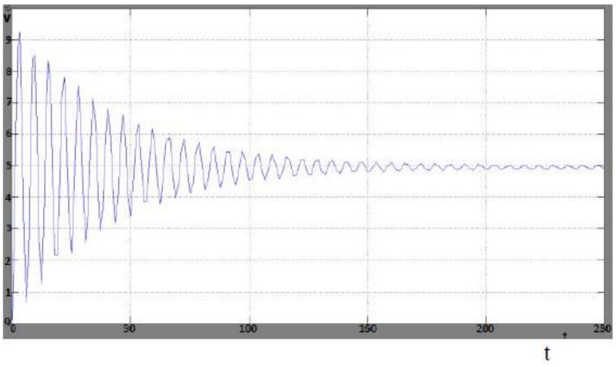


Figure 3. Open loop response

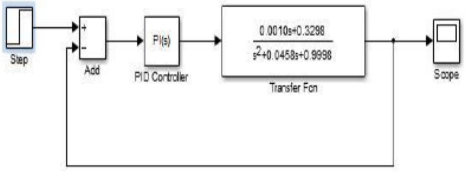
From the figure, it is observed that the output settles with the more oscillations. The peak overshoot was found to be 9.25 V. The oscillations are found to be high in open loop response and it settles at a time of 160 s.

2.2. Closed Loop Control

The idea of using the PI and PID controller is to minimize the overshoot and to make the system to settle faster. The simulation diagram with PI controller is shown in Figure 4. The tuning method, taken into consideration for the closed loop control is the Zeigler-Nichols method [3] and the tuning rule for the same is specified in Table 2. The K_p and K_i values were obtained from the open loop simulation after finding the ultimate gain and ultimate period [6] and [7]. The values for the K_p, K_i and K_d for the proposed forward converter is given in Table 3. Figure 5 shown the simulink diagram of a PID controller.

Table 2. Tuning rule for PI and PID controller

Controller	Kp	Ki	Kd
PI	0.45 Ku	0.833Pu	0
PID	0.6 Ku	0.5 Pu	0.125 Pu



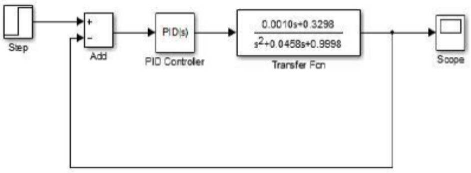


Figure 4. Closed loop control with PI controller

Figure 5. Closed loop control with PID controller

Table 3. Tuning Parameter Values for k_p, k_i and k_d

Controller	k_p	k_i	k_d
PI	3.42	0.1322	0
PID	4.56	0.0793	0.01984

2.2. Controller Implementation in Real Time

The closed loop control was set for the converter in real time with the help of data acquisition card. The interfacing card has an inbuilt microcontroller, PIC 18F45k20. The set point value is given to the comparator in order to get the difference signal so that it can be given as the input for PI controller to adjust the duty cycle. Hence the necessary output is obtained. The PWM input to the gate drive circuit of the forward converter is given from the data acquisition card. The hardware setup which we have used is shown in Figure 6 and the respective simulation diagram of the interfaced system is shown in Figure 7.

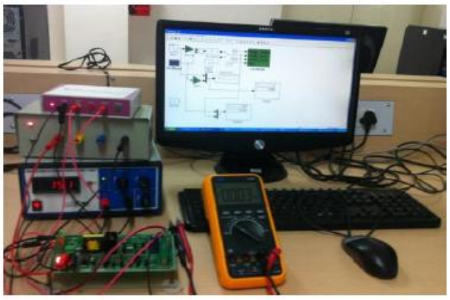


Figure 6 Hardware setup of the closed loop forward converter

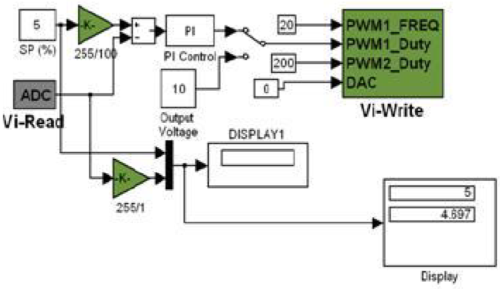


Figure 7. Simulation diagram in real time for closed loop PI controller

The set point tracking is done to the closed loop control with various set point values of 3 V and 5V so as to see the response of the controller. The reference given for this method is from a step input which has different initial and final values.

III. Results and discussions

The closed loop response of controllers is obtained in both simulation and real time. From each of the simulations obtained, the maximum overshoot and settling time are found and they are compared. The output of the closed loop with PI controller is shown in Figure 8.

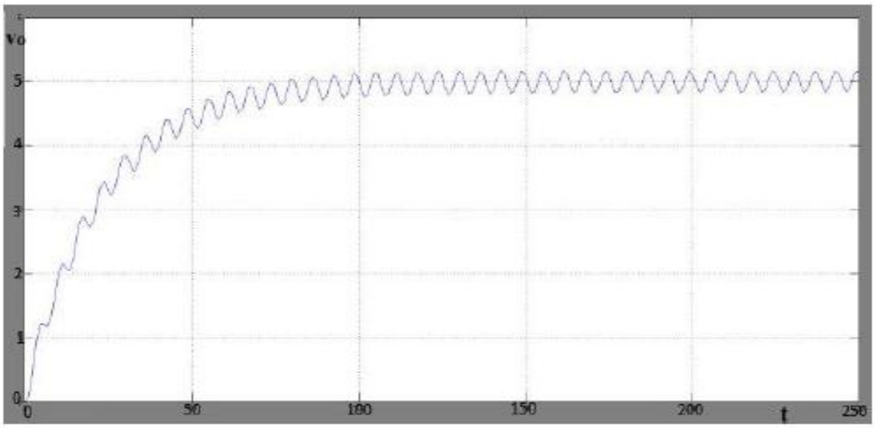


Figure 8 Closed loop simulation response with PI controller

It is noticed that the peak overshoot has been eliminated and the settling time is found to be 123.8 s with oscillations. But the oscillations are sustained like in open loop simulation. For the same set point the PI controller in closed loop is implemented in real time. The response obtained is shown in Figure 9.

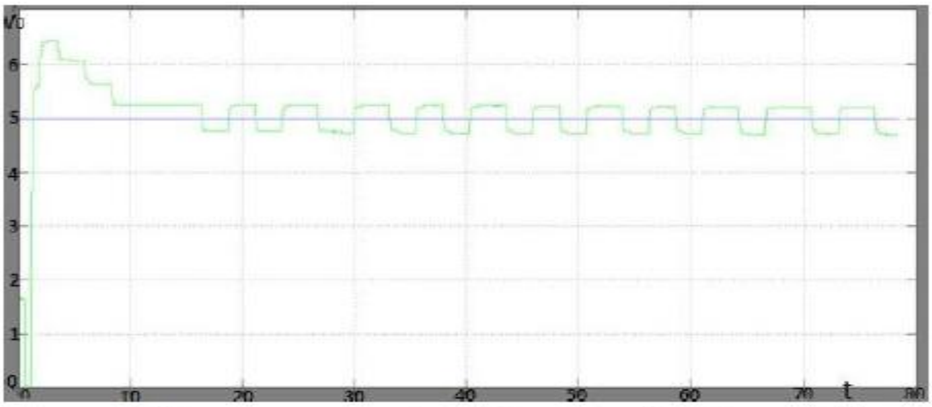


Figure: 9 Response using PI controller in real time

From Figure 9 it is observed that the peak overshoot is 6.4 V. The settling time is found to be 8 s with oscillations. The average output response was considered and the percentage ripple of the output is found to be 7%. Figure 10 shows the response of the PI controller for a different set point tracking. From this response, it can be noticed that the controller responds immediately when there is a change in set point value given to the system. Also the system finally settles to the average value of the required output within 7 s.

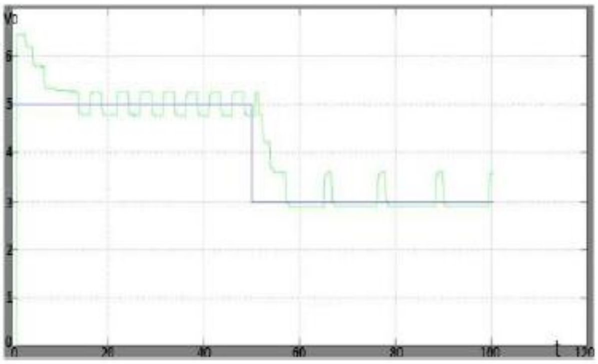


Figure 10. Closed loop response for different set point tracking

The performance of the converter in simulation with PID controller was analyzed which is shown in Figure 11.

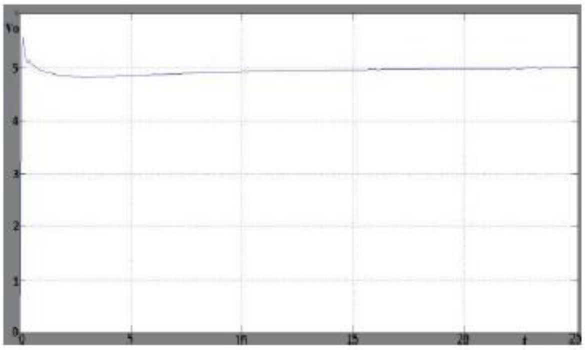
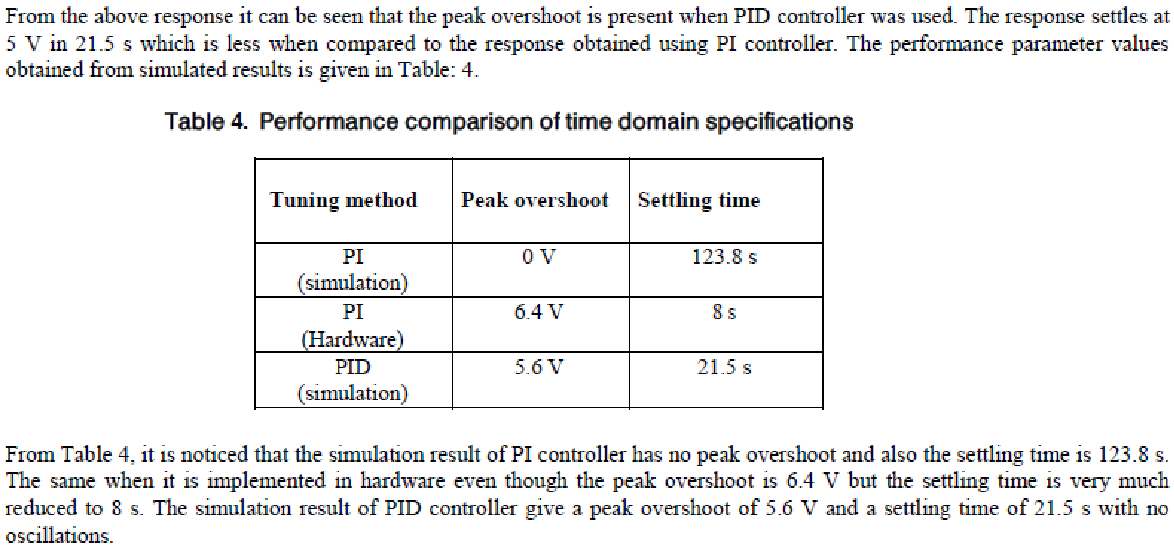


Figure 11. Response using PID controller in simulation



From the above response it can be seen that the peak overshoot is present when PID controller was used. The response settles at 5 V in 21.5 s which is less when compared to the response obtained using PI controller. The performance parameter values obtained from simulated results is given in Table: 4.

Table 4. Performance comparison of time domain specifications

Tuning method	Peak overshoot	Settling time
PI (simulation)	0 V	123.8 s
PI (Hardware)	6.4 V	8 s
PID (simulation)	5.6 V	21.5 s

From Table 4, it is noticed that the simulation result of PI controller has no peak overshoot and also the settling time is 123.8 s. The same when it is implemented in hardware even though the peak overshoot is 6.4 V but the settling time is very much reduced to 8 s. The simulation result of PID controller give a peak overshoot of 5.6 V and a settling time of 21.5 s with no oscillations.

V. Conclusion

The different controllers were implemented for the proposed forward converter. The closed loop responses are found for both simulation and in real time. In simulation, among the two controllers, the settling time is least when PI controller is used in real time. It is found that the peak overshoot and the settling time were increased when the real time implementation is done. It may be because of the charging and discharging property of the energy storage components in the hardware kit.

References

[1] R. Erickson, New York: Chapman and Hall, 1997, "Fundamentals of Power Elecronics".

[2] K.B. Khanchandani, M.D.Singh, "Power Electronics", MC TataGrawhill Publishers, 2005

[3] Mohammad Shahrokhi, Alireza Zomorrodi, Department of Chemical and Petroleum Engineering, Shariff University Of Technology," Comparison of PID Controller Tuning Methods".

[4] Vandana Jha, Pankaj Rai, VSRD-IJEECE, Vol.2 (8), 2012, "State Space Average Modelling Of Basic Converter Topologies ".

[5] Yeye Shen,Lie Xei, Xuiliang, IEEE Transaction 2013, "Explicit Hybrid Model Predictive Control Of The Forward DC to DC Converter".

[6] K.I.Hwu and Y.T. Tau. , IEEE PEDS 2005 "A Forward Converter having an FPGA-based PID Controller with Parameters On-line Tuned"

[7] Micheal Madegon and Mark Dennis, "50 W Forward Converter With Synchronous Rectification And Secondary Side Control".