Hardware Implementation of Evolutionary Algorithm Assisted Digital PID Controllers for DC-DC Converters

S.Augustilindiya#, S.Palani*, K.Vijayarekha# and M.BreethiYeltsina#

Department of Electrical and Electronics Engineering, SASTRA University
Tirumalaisamudram,Thanjavur,Tamilnadu 613401, India
[1]lindiya@eee.sastra.edu
*Sudharsan Engineering College, Sathiyamangalam-622501,
Pudukkottai District, India

***Abstract*-Tuning PID controller parameters using Evolutionary algorithm for an asynchronous Buck converter is presented in this paper. PID controller is one of the solutions for controlling a Buck converter during transient conditions. There are straight forward ways for calculating the parameters for the PID controller in the literature and evolutionary algorithm based approach with a proper fitness function gives superior performance when compared to other methods. Ziegler Nicholas method, Hurwitz polynomial method and Genetic Algorithm based method are compared. It is found that Genetic Algorithm based method yields better result. The hardware implementation of Genetic Algorithm assisted PID controller with low cost is desired and such an implementation is taken in this paper. A low cost microcontroller with built-in PWM modules is implemented and the performance is compared with simulations.**

Keywords- PID, Evolutionary algorithms, Buck converter, Genetic Algorithms

I. INTRODUCTION

DC-DC Converters are predominantly used in day-to-day electronic gadgets like cell phone, laptops, and smartphones, tablet PC etc. They also find very useful in modern day electric vehicles and industries using DC power supply. DC-DC converters process DC power and are classified as Buck, Boost, Buck Boost, etc., according to their operation. In this paper Buck converters which step down the voltage is taken into consideration. Even though Buck converters are simple and small in construction, they are complex in behavior. Moreover constraints imposed by the target applications like quick rise time, settling time, less ripples, overshoots, undershoots along with robustness to changes in the line voltage and load makes design of these converters challenging. As the output of Buck converter has many constraints stated above, it is wise to add a control system to look after the performance of Buck converter. The main objective of this paper is designing such a controller for a converter with 24V input, 18V 10 W output which finds applications in car fan, small vacuum cleaner, polishers etc. Due to high input voltage, an asynchronous converter is designed using small signal model with switching frequency 48.828 kHz. The performance of the converter is studied in open loop and closed loop configuration with an evolutionary algorithm assisted PID controller in the closed loop path. The study is carried out in MATLAB® for feasibility study and later implemented using a microcontroller so that the product can be prototyped and later produced in bulk for the market.

This work is organized as follows: Section 1 describes about motivation, research background, problem statement, objectives and scope. In Section 2**,** a detailed explanation on small signal modeling and open loop response is discussed. Section 3 gives detailed information about various conventional PID methods for buck converteralong with GA PID controller with its various advantages and disadvantages. Section 4 shows the simulation results and hardware part of both open loop and closed loop buck converter. Section 5 concludes the research by shedding some light on the future scope of this work.

II. SMALL SIGNAL MODELLING

In asynchronous Buck converters shown in Figure 1, a MOSFET acts as a switch and the LC circuit filters the ripples to give a smooth DC output. The load can be a microprocessor, a memory module, or any such electronic system [1, 2]. The circuit shown in Figure 1 does not show parasitic elements associated with inductor and capacitor.

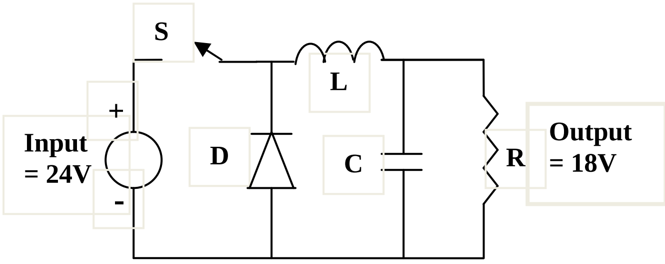

Fig. 1. DC-DC Buck topology

The Buck converter operating in continuous conduction mode takes two states depending on the state of the switch. The state space average modelling is used to find the control-to-output transfer function and it is useful in simulating the converter[3, 4]. Small signal model of the converter, the transfer function the Buck Converter is as follows

$$\frac{V_0(s)}{\delta(s)} = \frac{V_S}{LCs^2+\frac{L}{R}s+1} \tag{1}$$

For the following specifications:

V_s= 24 V, f= 48.828 kHz, $\Delta V_o/V_o$=0.013%, Δi_L= 0.092, and V_o=18V

Duty cycle

$$d = \frac{V_0}{V_{in}} \tag{2}$$

$$L = \frac{(V_{in}-V_0)*d}{\Delta i_L * f_{sw}} \tag{3}$$

$$C = \frac{\Delta i \Delta i_L}{8 * f_{sw} * \Delta V_0} \tag{4}$$

Using Equations 3 and 4 the values of inductance and capacitance are calculated. The parameters of the Buck converter are summarized in Table 1.

TABLEI
Buck Converter Parameters

Parameters	Symbol	Value
Voltage source	V_s	24V
Output voltage	V_o	18V
Filter capacitance	C	100µF
Converter inductance	L	1mH
Load resistance	R	100 Ω
Duty ratio	δ	0.75

III. EVOLUTIONARY ALGORITHM ASSISTED CONTROLLER DESIGN

Evolutionary algorithms are based on natural evolution and selection process is extensively used in optimization problems [5]. Genetic Algorithm is one of the evolutionary algorithms. They are good in searching extremely large solution space with respect to a fitness or objective function [6]. The problem of finding *Kp*, *Ki* and *Kd* of a PID controller for given constraints as in case of the Buck converter discussed in Section 2, is found to be suitable for applying Genetic Algorithm. The problem can be solved either by binary GA or real GA. In case of binary GA coding is to be done. Figure 2 shows a closed loop controlled Buck converter with GA assisting the PID controller.

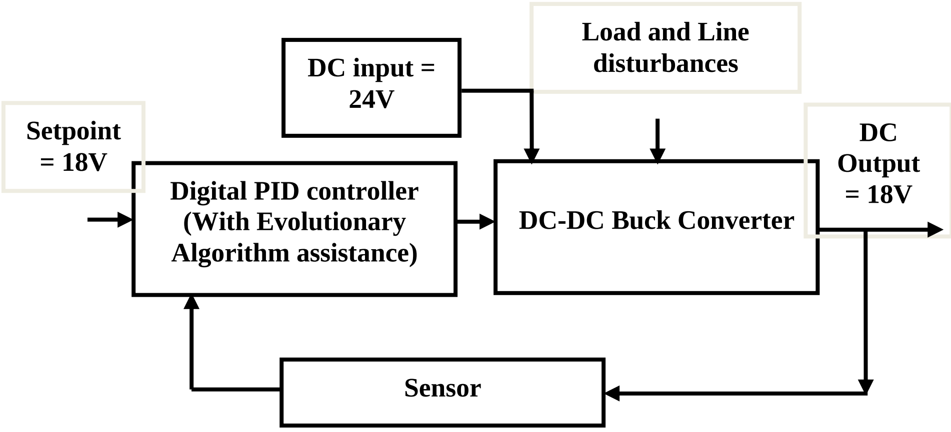

Fig. 2.DC-DC Buck converter with Evolutionary Algorithm assisted controller

The GA can be explained as stages: Stage 1 is initialization followed by *selection*, *crossover* and *mutation*. At each stage solutions with good fitness functions are retained, allowed to reproduce. Occasional mutation which is a small random change to few of the solution sets is introduced. The working, application and advantages of GA is well documented[6]. One of the main parameter in designing GA is a good objective function. In this research the objective function is set for reducing the rise time, settling time and ripples in the output voltage. The objective function is formulated as equation 5[5].

$$f = \frac{1}{((1+t_r)*(1+t_s)*(1+p)} \quad (5)$$

Where

t_r – rise time

t_s- settling time

p– peak overshoot

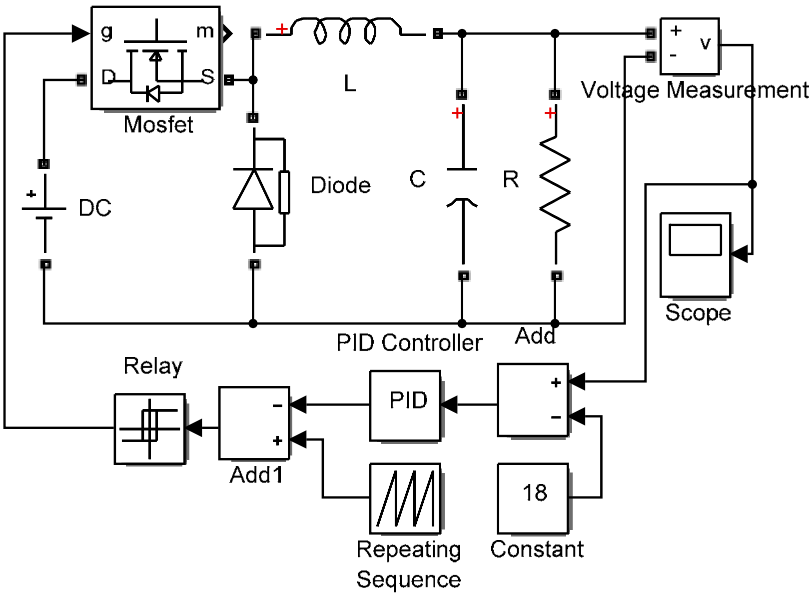

Fig. 3.Simulink realization of DC-DC Buck converter with Evolutionary Algorithm assisted PID controller

A. *Ziegler-Nichols Method*

Ziegler-Nichols tuning formulae is either derived from the step reposnseor from the frequency response. The formulae is given in various literature[4, 7, 8]. In this paper the step response is taken into account and the formulae are used to obtain the parameters of the PID controller.

B. Hurwitz Polynomial Method:

For caculating PID paramters with respect to Hurwirtz polynomial method[9] the closed loop transfer function is needed.Using the block diagram reduction method, the closed loop transfer function is obtained as,

$$\frac{C(s)}{R(s)} = \frac{(K_pT_is^2+K_pT_is+K_p)(\frac{V_{in}}{LC})}{s^3+\left(\left(\frac{K_pT_dV_{in}}{LC}\right)+\left(\frac{1}{RC}\right)\right)s^2+\left(\frac{K_pV_{in}+1}{LC}\right)s+\left(\frac{K_pV_{in}}{LCT_i}\right)} \quad (6)$$

The closed-loop characteristic polynomial of the PID controlled system is then given by

$$s^3 + \left(\left(\frac{K_pT_DV_{in}}{LC}\right) + \left(\frac{1}{rc}\right)\right)s^2 + \left(\frac{(K_pV_{in}+1)}{LC}\right)s + \left(\frac{(K_pV_{in})}{LCT_i}\right) = 0 \quad (7)$$

The coefficients *Kp*, *Ti*, and *Td* are chosen so that it becomes a third-order Hurwitz polynomial of the form

$$p(s) = (s^2 + 2lw_ns + w_n^2)(s + \alpha) \quad (8)$$

taking into account that ζ, ω_n, and α are positive quantities. Equating the characteristic polynomial coefficients (Eqn.7) with those of the desired Hurwitz polynomial (Eqn.8), the following values of the parameters for the PID controller are obtained.

$$k_p = \frac{2\zeta w_n\alpha LC+w_n^2LC-1}{E} \quad (9)$$

$$T_i = \frac{Ek_p}{LC\alpha w_n^2} \quad (10)$$

$$T_d = \frac{LC}{Ek_p}\left(\alpha + 2\zeta w_n - \frac{1}{RC}\right) \quad (11)$$

By substituting, Damping coefficient, α=35000, ζ =0.707, Natural frequency, w_n=2500rad/sec and other values according to Table 1, the values of K_p, T_i, T_d are0.4999, 5.4846e-4 and 3.2036e-4. Further tuning of these values will give smooth waveform for the output response of buck converter using PID controller.

Reprogramability, consumption of ultra low quiescent power are the advanatges of digital PID controllers. They can be easily changed for different specifications. Such approach is taken in this paper and the hardware methodology is shown in Figure 4. Both FPGA based systems and microcontroller based system are used in the literature for implementation [10, 12].

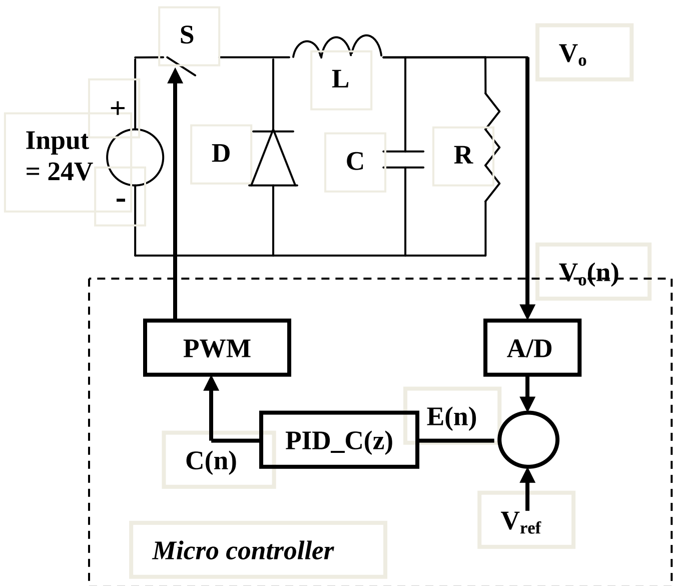

Fig. 4.Hardware implementation of Evolutionary Algorithm assisted controller

Hardware implementation of both open and closed loop buck converter is done. In the open loop, the pulse is driven with the help of microcontroller chip using NXP89V51RD2 [10] and in order to drive the switch(here power MOSFET is used),the output pulse from microcontroller is fed to driver IC IR2110 in order to turn on the switch. From the output of driver IC it is then given to gate of MOSFET. The load used here is resistance of 100ohms, 25watts.Therefore, the conduction of current flows and the voltage exists across the resistance from where the output is measured.

IV. RESULTS AND DISCUSSIONS

In this paper, the transient response of the converter is taken as an area and the parameters peak overshoot, settling time, risetime are minimized. In the minimization process various controller architecture are designed and tested for performance. The summary of the performance is plotted and shown in Figure 5. The figure clearly shows the advantage of GA-Assisted PID controller in terms of quick settling and less overshoot. The parameter values are tabulated in the Table II.

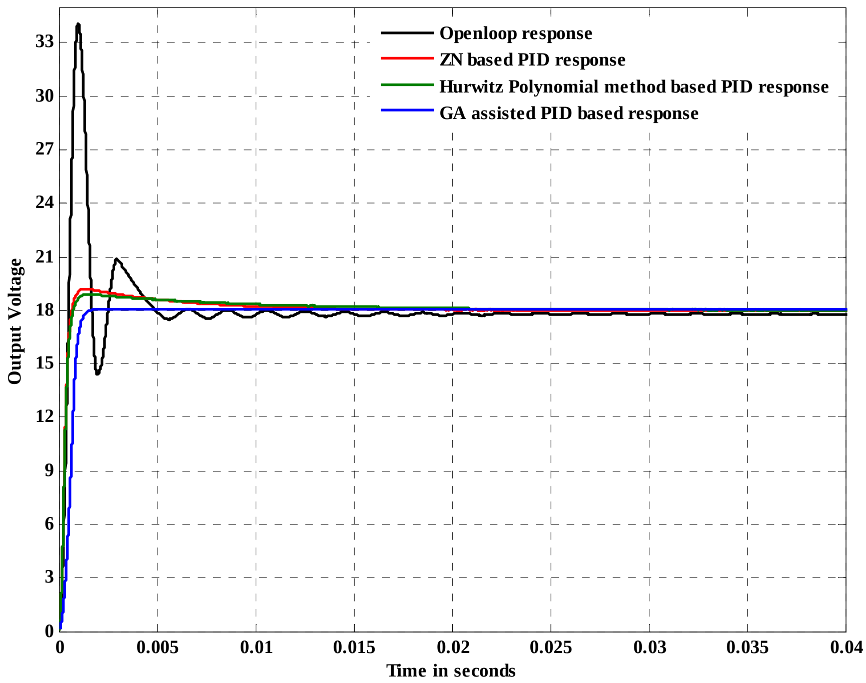

Fig. 5. Performance comparison of various controllers for a Buck converter

TABLE II
Buck Converter Parameters

Method	**Rise time**	**Settling time**	**Peak overshoot**
Open loop	NIL	30ms	88.8%
Closed loop(Hurwitz polynomial)	0.745ms	27ms	5.55%
Closed loop(Ziegler Nichols)	0.637ms	20ms	6.66%
Genetic algorithm	0.96ms	1.6ms	0%

In figure 6, Hardware used for implementation is given.

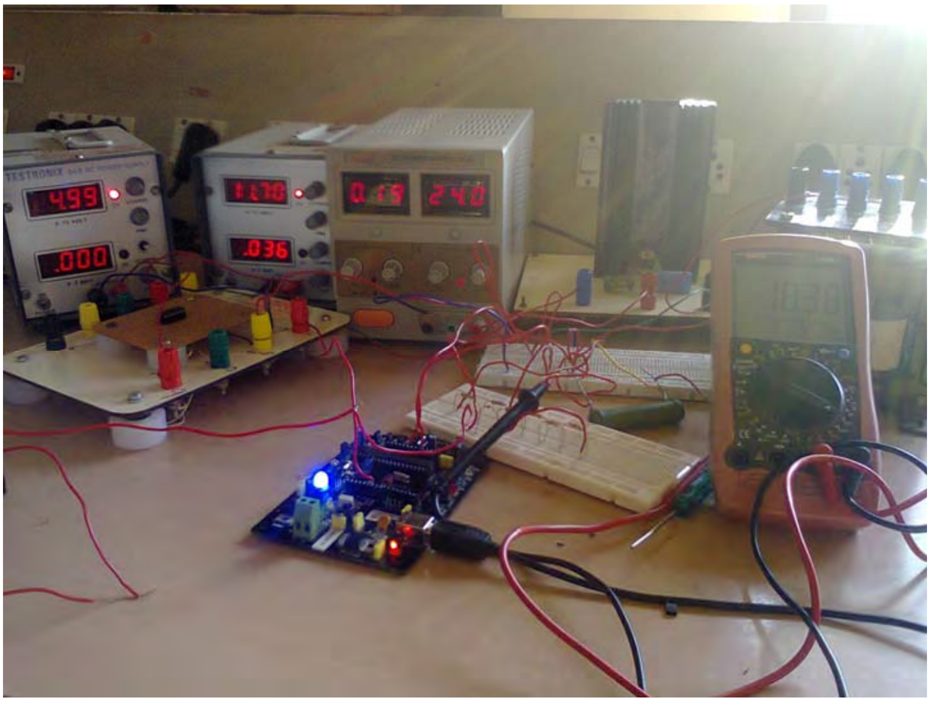

Fig. 6.Hardware implementation of Evolutionary Algorithm assisted controller

It is found that the GA assisted PID can be implemented as a digital controller with easy reprogramming capability. It is also found that the hardware used in the controller part is quiet simple and inexpensive when compared to the advantages it gives for the converter.

V. CONCLUSION

In this paper tuning of PID controllers for Buck converter is presented. Various tuning methods available in literature are taken for PID controller of a particular Buck converter specification. The converter and controllers are modeled and simulated. The hardware for the best tuning method is implemented and verified with simulation results. It is found that GA assisted PID controllers outperform other tuning methods. In future the same approach can be adopted for other DC-DC converter topologies like Boost, Buck-Boost, Cuk etc.

REFERENCES

[1] M.H. Rashid: *Power Electronics: Circuits, devices and Applications*, Pearson education Inc., Pearson Prentice Hall, 2004,.

[2] N. Mohan, T. M. Undeland, W. P. Robbins, *Power Electronics: Converters, Applications, and Design*, John Wiley & Sons, Inc., 1995.

[3] M.Gopal, *Digital control and state variable methods*, TATA McGraw Hill edition.

[4] A. Prodic, D. Maksimovic and R. W. Erickson, “Design and implementation of a Digital PWM controller for a high-frequency switching DC-DC power converter”, The 27th Annual Conference of the IEEE Industrial Electronics Society (IECON’01), Vol. 2,pp. 893 - 898, November 2001

[5] David E. Goldberg, "Genetic Algorithms in Search, Optimization, and Machine Learning" Addison-Wesley Professional; 1stEdition , 1989.

[6] Randy L. Haupt and Sue Ellen Haupt , *Practical Genetic Algorithms*, Wiley-Interscience; 2nd Edition 2004

[7] www.mathworks.com: “MATLAB/SIMULINK” Release 14 Notes,2004.

[8] Ned Mohan, W.P. Robbins and T.M.Undeland, R. Nilssen and Olive Mo: “Simulation of Power Electronic and Motion Control Systems”; *Proceedings of the IEEE*, Vol.82, No.8, August 1994, pp. 1287 – 1292

[9] HuiOuyang; JiguangYue; Yongqing Su, "Design and application of PID controllers based on interval computing theory," *International Conference onElectrical and Control Engineering (ICECE), 2011*, vol., no., pp.1505,1510, 16-18 Sept. 2011

[10]www.keil.com/dd/docs/datashts/philips/p89v51rd2.pdf

[11]Dingyu Xue, YangQuan Chen, and Derek P. Atherton, *Linear Feedback Control*, Society for Industrial and Applied Mathematics,2007

[12]Man Pun Chan and Philip K. T. Mok, "Design and Implementation of Fully Integrated Digitally Controlled Current-Mode Buck Converter", IEEE Transactions on Circuits and Systems—I: Regular Papers, Vol. 58, NO. 8, AUGUST 2011 pp 1980-1992