

Development of Genetic Algorithm (GA) Based Optimized PID Controller for Stability Analysis of DC-DC Buck Converter

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Abstract

This paper delineates a conventional buck converter controlled by optimized PID controller where Genetic Algorithm (GA) is employed with a view to enhancing the performance by analyzing the performance parameters. Genetic Algorithm is a probabilistic search algorithm which is substantially used as an optimization technique in power electronics. A bunch of modifications have already been introduced to enhance the performance depending upon the applications. However, in this paper, modified genetic algorithm has been used in order to tune the key parameters in the converter. Hence, an analysis is carried out where the performance of the converter is illustrated in terms of rise time, settling time and percentage of overshoot by deploying GA based PID controller and the overall comparative study is presented. Responses of the overall system are accumulated through rigorous simulation in MATLAB environment.

Keywords

Genetic Algorithm, Optimization, PID Controller, Converter: State Space Average Method

1. Introduction

As human civilization is stepping into 22nd century the researchers are more enthusiastic to build robust and electrically stable systems. In this regard, DC-DC converters [1] are top of the list as it is utilized in numerous equipment like Motor drivers, Robotic hands [2], and Smart Home systems [3] and so on. Among various DC-DC converters, Buck, Boost, Buck-Boost, SEPIC and Cuk

[4] [5] [6] [7] [8] converters are the most commonly used converters. Generally, Boost converters increase the output voltages according to the demand on load side and duty cycle. Both Buck-Boost and Cuk converters can increase and decrease the output voltage. In case of the boost converters researchers have found that the efficiency is very poor for high gain and it fails big time when it comes in case of controlling it. On the other hand, for Buck-Boost converters, the charging current of output capacitor is discontinuous and the controlling mechanism is also troublesome [9] [10].

Therefore, Buck converters significantly overcome the above problems and can be controlled by numerous controlling methods. Among various methods, PID (Proportional, Integral, and Differential) controller [11] [12] is the most widely employed controller. But tuning these parameters and obtaining the optimized values are the major challenges for control engineers. Therefore, different algorithms *i.e.* inpaint [13] [14], spectroscopy [15], annealing are deployed in order to achieve the optimized values of the controller. For this, Genetic Algorithm proves to be a handy tool as it utilizes the concept of probabilistic search algorithm. In each generation, the fitness of the whole population is evaluated, multiple individuals are stochastically selected from the current population (based on their fitness) and modified (mutated or recombined) to form a new population. This process is repeated until the conditions are satisfied [16] [17] [18] [19] [20].

In Section 2, the circuit of conventional Buck converter is studied and State Space Modeling of the converter is illustrated. The elaborate discussion on implementation of Genetic Algorithm is depicted in Section 3 where overviews, objective function of the algorithm and design of the GA based PID Controller are stated. Finally, the results of the simulation and stability analysis of the system are shown and discussed in Section 4. Lastly, the overall comparative analysis is presented. All the simulations are carried out in MATLAB.

2. State Space Average Method

The conventional DC-DC Buck Converter comprises of inductor (L), capacitor (C), diode D, switch (S) and load resistance (R) which is shown in **Figure 1**.

When the switch S is ON, the diode becomes open and capacitor (C) discharges through load resistance (R). When the switch (S) is OFF, the diode is closed and current i_L passes through the capacitor (C) and load resistance (R). For mathematical modeling of DC-DC Buck Converter, State Space Modeling [22] is employed so that the system can be illustrated by first order differential equations followed by matrix representation.

The system matrix is denoted as A, B, C and D; u and y are referred as input and output respectively. The state variable is indicated as x and x' is the derivative of state variables. Here, current i_L and voltage v_C are system variables which are mapped as $i_L = x_1$ and $v_C = x_2$.

$$x' = Ax + Bu \quad (1)$$

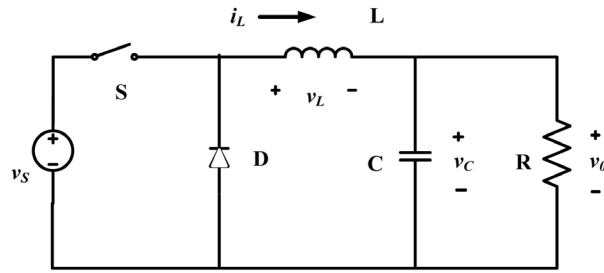


Figure 1. Circuit diagram of conventional buck converter [21].

$$y = Cx + Du \tag{2}$$

The circuit diagrams for ON and OFF condition of the switch (S) are shown in **Figure 2(a)** and **Figure 2(b)** respectively. The equations derived for these two conditions are presented as follows.

When S is ON:

$$v_s = L \frac{di_L}{dt} + v_C \tag{3}$$

$$i_L = C \frac{dv_C}{dt} + \frac{v_C}{R} \tag{4}$$

$$x'_1 = -\frac{1}{L}x_2 + \frac{1}{L}v_s \tag{5}$$

$$x'_2 = \frac{1}{C}x_1 - \frac{1}{RC}x_2 \tag{6}$$

$$\begin{pmatrix} x'_1 \\ x'_2 \end{pmatrix} = \begin{pmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{RC} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + \begin{pmatrix} \frac{1}{L} \\ 0 \end{pmatrix} v_s \tag{7}$$

When S is OFF:

$$0 = v_C + L \frac{di_L}{dt} \tag{8}$$

$$i_L = C \frac{dv_C}{dt} + \frac{v_C}{R} \tag{9}$$

$$x'_1 = -\frac{1}{L}x_2 \tag{10}$$

$$x'_2 = -\frac{1}{C}x_1 - \frac{1}{RC}x_2 \tag{11}$$

$$\begin{pmatrix} x'_1 \\ x'_2 \end{pmatrix} = \begin{pmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{RC} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + \begin{pmatrix} 0 \\ 0 \end{pmatrix} v_s \tag{12}$$

The average of the state space model is illustrated below where switching duty cycle (d) is taken into consideration.

$$A' = A_{ON}d + A_{OFF}(1-d) \tag{13}$$

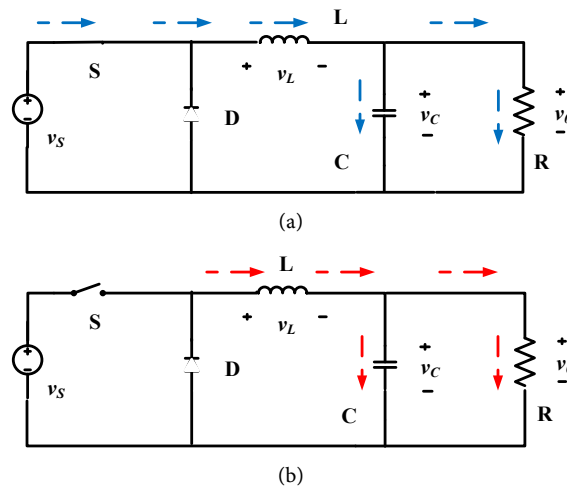


Figure 2. Circuits of buck converter at switch, S (a) ON and (b) OFF.

$$A' = \begin{pmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{RC} \end{pmatrix} d + \begin{pmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{RC} \end{pmatrix} (1-d) = \begin{pmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{RC} \end{pmatrix} \quad (14)$$

$$B' = B_{ON}d + B_{OFF}(1-d) \quad (15)$$

$$B' = \begin{pmatrix} \frac{1}{L} \\ 0 \end{pmatrix} d + \begin{pmatrix} 0 \\ 0 \end{pmatrix} (1-d) = \begin{pmatrix} \frac{d}{L} \\ 0 \end{pmatrix} \quad (16)$$

Hence, the completed buck converter state space model is shown below:

$$\begin{pmatrix} x_1' \\ x_2' \end{pmatrix} = \begin{pmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{RC} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + \begin{pmatrix} \frac{d}{L} \\ 0 \end{pmatrix} v_s \quad (17)$$

3. Implementation of Genetic Algorithm

Genetic algorithm (GA) is the method for solving both constrained and unconstrained optimization problems based on natural selection process that mimics biological evolution. The algorithm repeatedly modifies a population of individual solutions. At each step, the genetic algorithm randomly selects individuals from the current population and uses them as parents to produce the children for the next generation [23] [24] [25]. In genetic algorithm, a fitness function is taken into account to check how close a given design solution is in order to achieve the set value. Chromosome or genotype is a set of parameters which defines a proposed solution to the problem that the algorithm is trying to solve. The set of all solutions is known as the population.

However, crossover is a genetic operator used to vary the programming of a chromosome or chromosomes from one generation to the next. It is analogous to reproduction and biological crossover, upon which genetic algorithms are based on. Mutation is a used to maintain genetic diversity from one generation

of a population to the next generations. It alters one or more gene values in a chromosome from its initial state. Moreover, Selection is the stage of a genetic algorithm in which individual genomes are chosen from a population for later breeding. The flow chart for the algorithm is shown in **Figure 3**.

In order to implement Genetic Algorithm, objective functions are chosen to evaluate the fitness of the chromosome [27]. In this paper, four performance indices are selected to minimize the error which defined as Integral of Absolute Magnitude of Error (IAE), Integral of Time multiplied by Absolute Error (ITAE), Integral of Squared Error (ISE) and Integral of Time multiplied by Squared Error (ITSE).The corresponding equations of the performance indices are as follows:

$$IAE = \int_0^{\tau} |e(t)| dt \tag{18}$$

$$ITAE = \int_0^{\tau} t |e(t)| dt \tag{19}$$

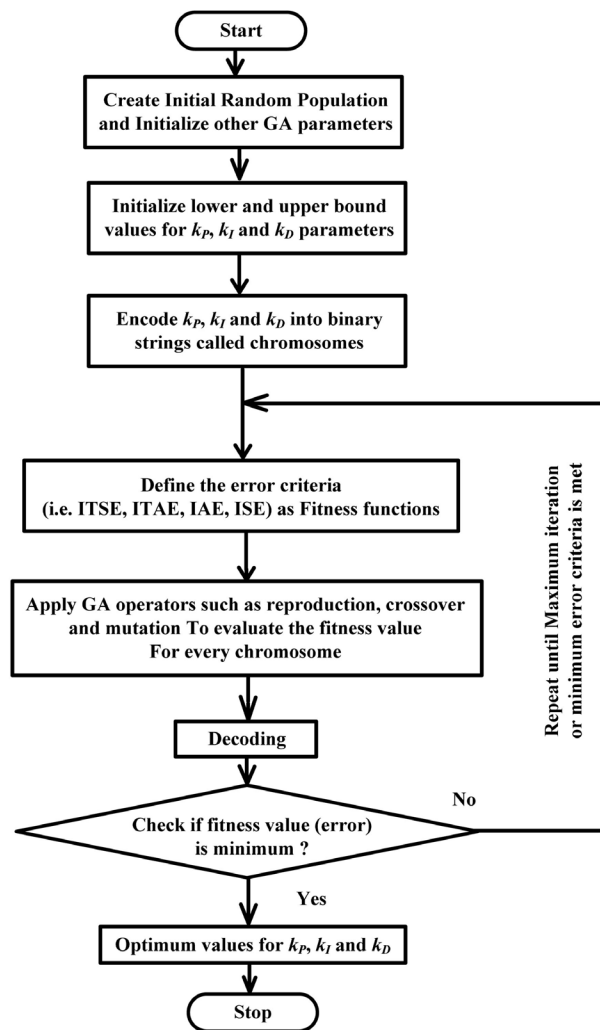


Figure 3. Flow chart of genetic algorithm [26].

$$\text{ISE} = \int_0^{\tau} e(t)^2 dt \quad (20)$$

$$\text{ITSE} = \int_0^{\tau} te(t)^2 dt \quad (21)$$

The basic block diagram of the system is shown in **Figure 4**. In order to tune the parameters of PID controller through genetic algorithm, the k_P , k_I and k_D are taken and the chromosome is formed. The main objective of the study is to minimize the error between the input and the plant's output.

4. Simulation Results and Stability Analysis

Model order reduction technique is carried out in MATLAB so that the higher order transfer function obtained from the state space modeling can be converted into a simpler form. **Table 1** presents the converter parameters that are used for mathematical calculation and simulation of the stability of the Buck converter.

Firstly, Buck converter for the conventional PID controller is employed and the response is taken to observe the stability of the system which is shown in **Figure 5**.

So, from **Figure 5**, gain values of k_P , k_I and k_D are accumulated, tabulated and shown in **Table 3**. After that, Genetic Algorithm (GA) based PID controller is deployed in the system to determine more optimum values of k_P , k_I and k_D . The parameters are listed in **Table 2**.

After rigorous simulation in MATLAB, the values of k_P , k_I and k_D are obtained for all of the four performance indices of GA based PID controller which is evident in **Table 3** along with the conventional PID controller.

Step responses for IAE, ITAE, ISE and ITSE and performance parameters are illustrated in **Figures 6-9** respectively.

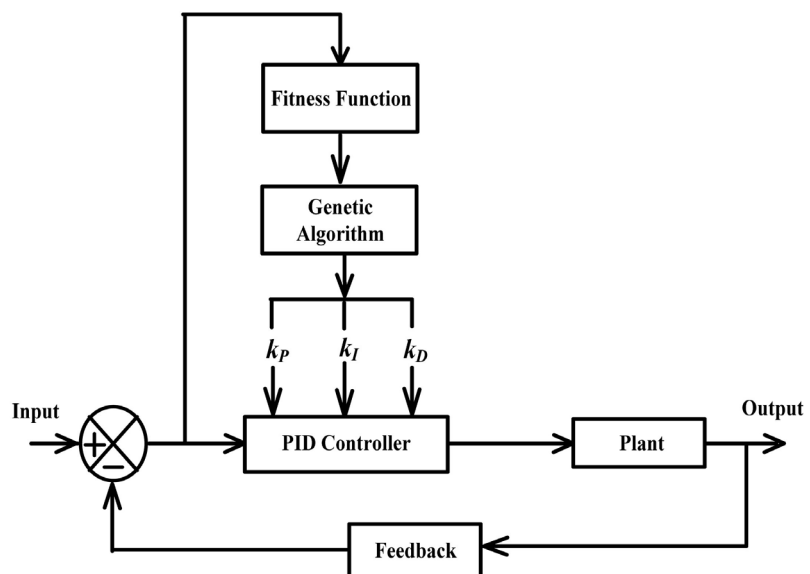


Figure 4. Basic block diagram of GA based PID controller [28].

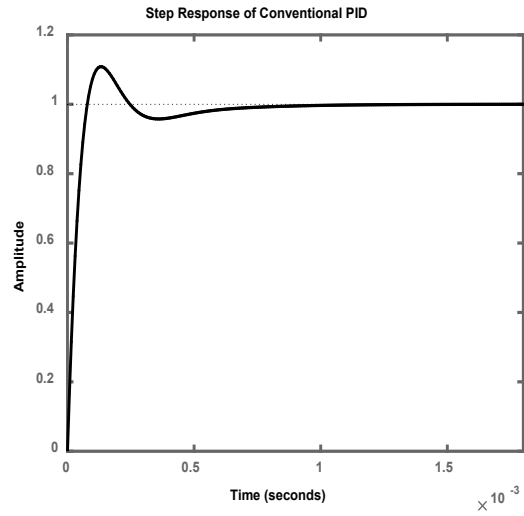


Figure 5. Step response of conventional PID controller.

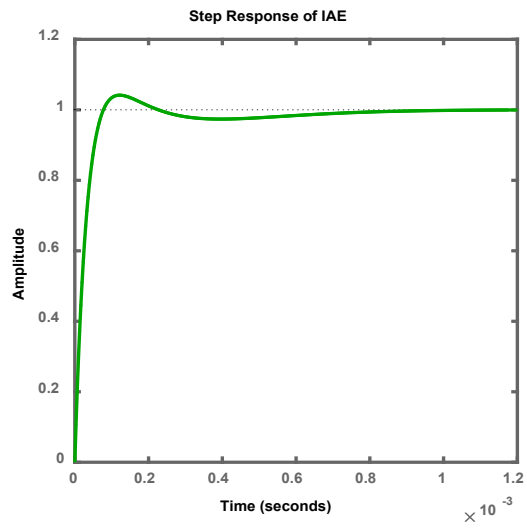


Figure 6. Step response of IAE.

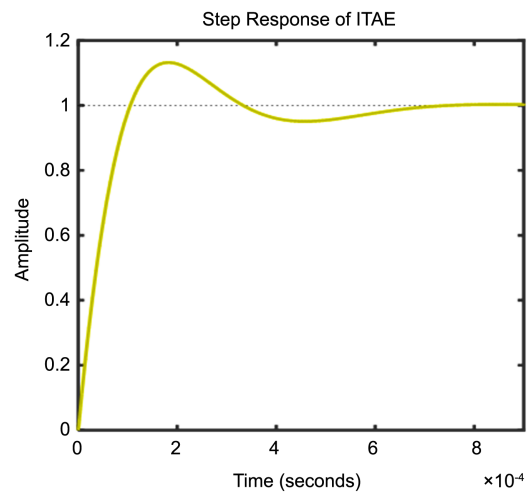


Figure 7. Step response of ITAE.

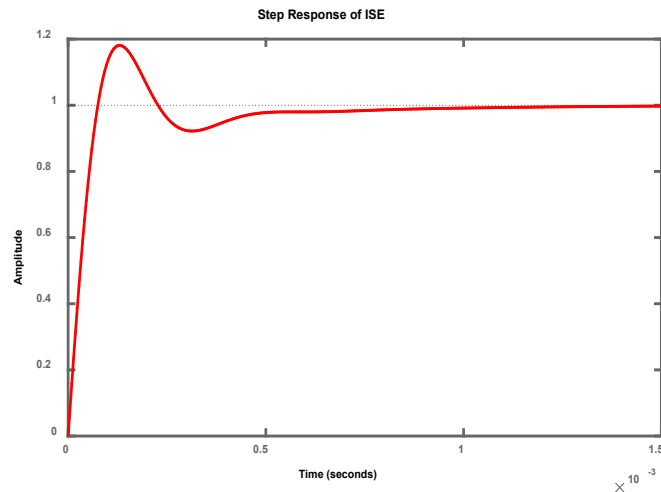


Figure 8. Step response of ISE.

Table 1. Parameters of the buck converter.

Name of the Components	Values
Input Voltage, v_s	12 V
Output Voltage, v_o	5.574 V
Capacitor, C	200 μ F
Inductor, L	145 μ H
Output Resistor, R	1 Ω

Table 2. Parameters of genetic algorithm.

Name of the Parameters	Values
Population	50
Fitness Scaling	Rank
Selection	Stochastic Uniform
Mutation	0.1
Crossover	0.8

Table 3. Gain values for both conventional and GA Based PID controller.

Gain	Conventional PID	GA-PID			
		IAE	ITAE	ISE	ITSE
k_p	19.1228	18.85	11.38	22.046	14.268
k_i	60,517.0162	64,869.2	59,637	48,926.2	45,350.9
k_d	0.00135	0.002	0.000943	0.001	0.001

The performance parameters like Percentage of Overshoot (%OS), Rise Time (Tr), Settling Time (Ts) and Peak Amplitude are tabulated for both conventional and GA based PID Controller which is presented in **Table 4**.

It is evident from the results that IAE portrays better results than other controllers. The overall comparative analysis of the step responses is illustrated in **Figure 10**.

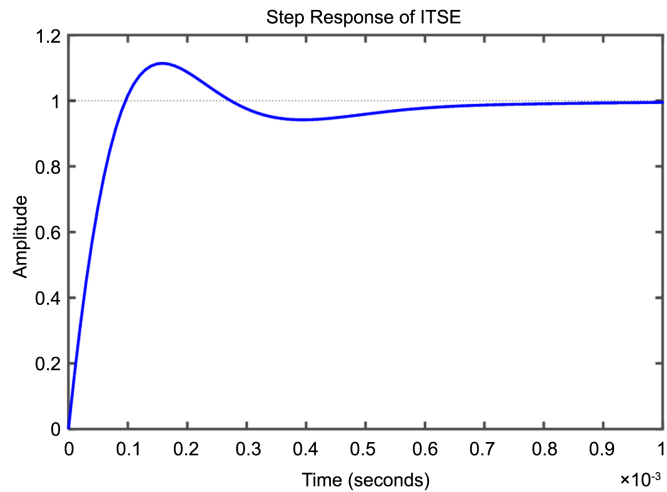


Figure 9. Step response of ITSE.

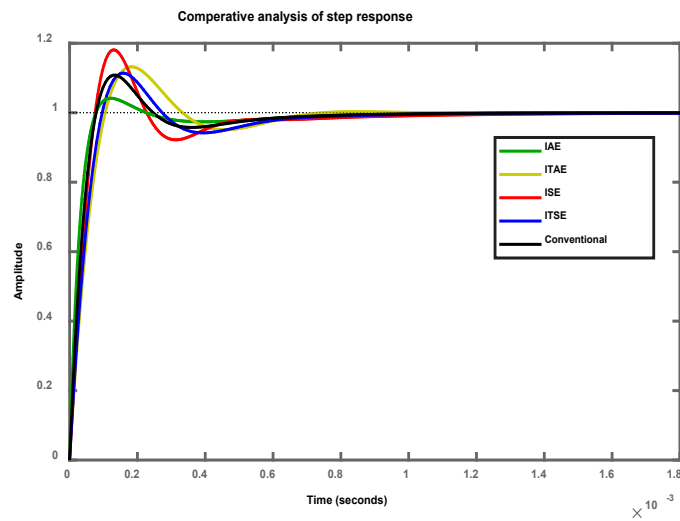


Figure 10. Comparative analyses of step responses.

Table 4. Performance parameters for both conventional and GA based PID controller.

Performance Parameters	Conventional PID	GA-PID			
		IAE	ITAE	ISE	ITSE
<i>%OS</i>	10.8	4.17	13.2	18.1	11.4
<i>TR</i>	0.0000573	0.0000504	0.0000784	0.0000575	0.0000712
<i>TS</i>	0.000552	0.000538	0.000614	0.000634	0.000616
<i>Peak Amplitude</i>	1.11	1.04	1.13	1.18	1.11

5. Conclusion

In this paper, an investigative study on stability analysis of closed loop Buck converter is brought into action by GA based PID controller. It is observed that IAE depicts more optimized results in terms of overshoot (4.17%), rise time (0.0000504 s), settling time (0.000538 s) than other performance indices. The

overall comparative analysis of step response provides an idea of the stability of the converter. Hence, it can be concluded that GA based PID controller is more convenient than other tuning methods for Buck converter. Thus, more efficient and stable equipment can be designed by utilizing this modern algorithm based technique.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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