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Comparative Analysis of Different Control Schemes for DC-DC Buck Converter

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ABSTRACT
DC-DC converter is some power electronic circuits that convert the DC voltage from one level to another. They have a very large area of applications ranging from computing to communication. They are widely used in appliance control, transportations and high-power transmission. Its increasing demand is based on its capability of electrical energy conversion. The basic topology of DC-DC converter are Buck converter and Boost converter, other topologies are derived from this two basic topology. Mathematical modelling of both Buck converter and Boost converter is done. In this paper the mathematical modeling for buck converter is performed. Some of the control schemes are summarized in this paper which includes Internal Model Control based PID control and Genetic Algorithm based PID control. Extensive simulation is carried out and the results are compared on the basis of transient parameters.
KEYWORDS: Buck Converter, PID, IMC, Genetic Algorithm

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I INTRODUCTION

The switch mode DC-DC converter are the simplest power electronic circuit that efficiently converts an unregulated DC voltage into a regulated DC voltage.
Solid state device such as transistors and diodes are used as switching power supplies. They operates as switch either in completely ON or completely OFF state. The energy storing elements such as inductor and capacitor are used for energy transfer and works as a low pass filter. The Buck converter and Boost converter are the two fundamental topologies of switch mode DC-DC converter whereas the other topologies are either buck-derived or boost-derived converters.
DC-DC converters have a wide area of applications. The drastic use of these converters in appliances control, telecommunication equipment's, DC-motor drives, automotive, aircrafts, etc. increases its interests in many fields.
The analysis along the control of switching converters are the main factor to be considered. Various control schemes are used to control the switch mode DC-DC converter which includes Internal Model Control and Genetic Algorithm.. There are many advantages and disadvantages related to every control methods.
In this paper the following works are done:
(1) Mathematical Modelling of the DC-DC Buck Converter is shown in section III.
(2) Internal Model Control scheme is implemented in the Buck Converter transfer function is shown in section V.
(3) Implementation of the Genetic Algorithm based PID control for Buck Converter is shown in section VI.

II SWITCH MODE DC-DC CONVERTER:

The switch mode DC-DC converters are those which converts the unregulated DC voltage to a regulated DC voltage with high efficiency and flexibility. The different types of DC-DC converters includes buck converter, boost converter, buck-boost converter, Cuk converter, etc. both buck converter and boost converter are the two

fundamental topologies of switch mode DC-DC converter whereas buck-boost converter and Cuk converter are the combination of the two basic converter topologies.
DC-DC converter usually operates in two mode of operation: continuous mode and discontinuous mode. In case of continuous mode the current through the inductor never falls to zero whereas in case of discontinuous mode the current through the inductor falls to zero as the switch is turned off.

2.1 Buck Converter:
The buck converter is shown in figure 1. It is the step down converter in which a fixed high voltage is step down to a desired low voltage level. It consist of non-dissipative switch, inductor, capacitor. The switches will operate at the rate of PWM switching frequency. The ratio of ON time when the switch is closed to the entire switching period is known as the duty cycle and is represented as: t_{ON}/T and the output voltage is controlled by varying the duty cycle.

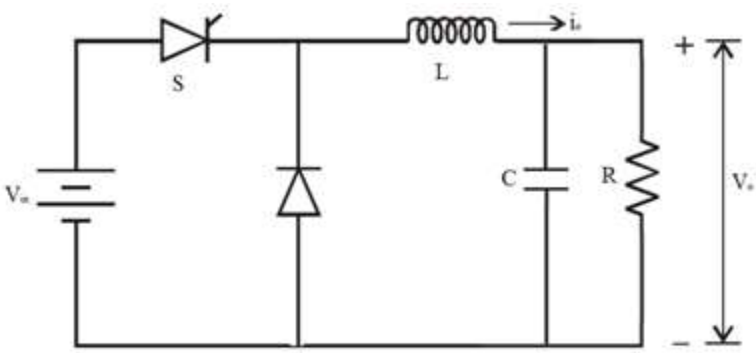


Figure1: Basic Buck Converter

In the first sub circuit state when the switch S1 is closed, the diode is reversed biased and the energy is transferred from the source to the inductor and the current through the inductor gradually increases during this time interval as shown in figure 2(a). In the next sub-circuit state when the switch S is closed, the source is disconnected from the network. The diode will be forward biased and the current will flow through the freewheeling diode. During the second time interval the current through the circuit decreases linearly as the energy in the inductor discharges as shown in the figure 2(b).

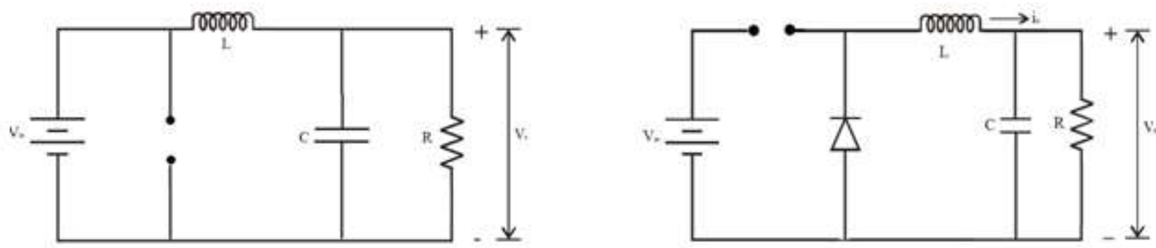


Figure2: Buck Converter when (a) Switch is ON (b) Switch is OFF

III MATHEMATICAL MODELING OF THE BUCK CONVERTER

Switch On: When the switch is closed (ON-state) and diode is reverse biased, the inductor current $i_L(t)$, capacitor voltage $v_c(t)$ and output $v_{out}(t)$ are

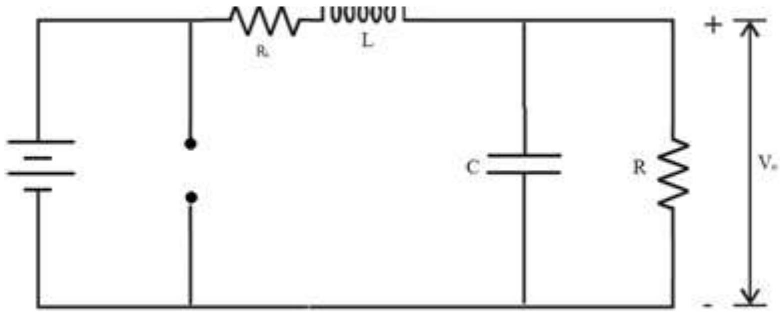


Figure3: Buck Converter when switch is ON

$$V_g = L\frac{di_L}{dt} + R_L.i_L - v_{out}$$

$$\frac{di_L}{dt} = \frac{1}{L}V_g - \frac{R_L}{L}.i_L + \frac{1}{L}v_{out}$$

$$\frac{dv_c}{dt} = i_L - i_{out}$$

The main difference among this model and the lossless model is that the output voltage is not equal to the capacitance voltage.

$$v_{out} = i_L.\frac{R_c R}{R+R_c} + v_c.\frac{R}{R+R_c}$$

$$i_{out} = \frac{v_{out}}{R} = i_L.\frac{R_c}{R+R_c} + v_c.\frac{1}{R+R_c}$$

Putting the value of v_{out} and i_{out} in the above equations we have:

$$\frac{di_L}{dt} = \frac{1}{L}V_g - \frac{1}{L}\left(R_L + \frac{R_c R}{R+R_c}\right)i_L - \frac{R}{R+R_c}v_c$$

$$\frac{dv_c}{dt} = \frac{1}{C}\left(\frac{R}{R+R_c}\right)i_L + \left(\frac{1}{R+R_c}\right)v_c$$

State space representation when switch is 'ON'

$$\begin{pmatrix} L & 0 \\ 0 & C \end{pmatrix} x' = \begin{pmatrix} -R_L - \frac{R_c R}{R+R_c} & -\frac{R}{R+R_c} \\ \frac{R}{R+R_c} & \frac{1}{R+R_c} \end{pmatrix} x + \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix} u$$

$$y = \begin{pmatrix} \frac{R_c R}{R+R_c} & \frac{R}{R+R_c} \\ \frac{R_c}{R+R_c} & \frac{1}{R+R_c} \end{pmatrix} x$$

OFF-State

When the switch is open (OFF-state) and diode is forward biased, the inductor current $i_L(t)$, capacitor voltage $v_c(t)$ and output voltage $V_o(t)$ are

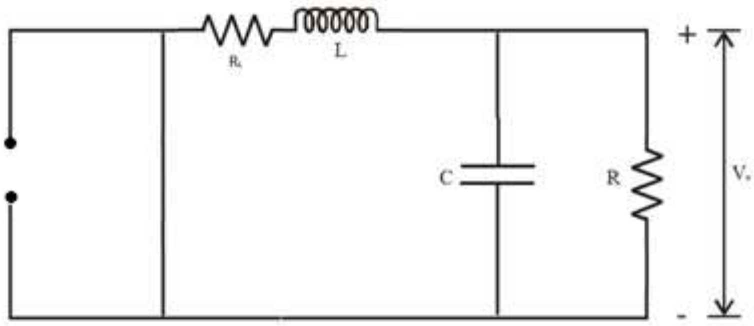


Figure 4: Buck Converter when switch is OFF

$$L\frac{di_L}{dt}+R_L.i_L=-v_{out}$$

$$\frac{di_L}{dt}=-\frac{R_L}{L}.i_L-\frac{1}{L}v_{out}$$

$$\frac{dv_c}{dt}=i_L-i_{out}$$

The main difference among this model and the lossless model is that the output voltage is not equal to the capacitance voltage.

$$v_{out}=i_L.\frac{R_cR}{R+R_c}+v_c.\frac{R}{R+R_c}$$

$$i_{out}=\frac{v_{out}}{R}=i_L.\frac{R_c}{R+R_c}+v_c.\frac{1}{R+R_c}$$

Putting the value of v_{out} and i_{out} in the above equations we have:

$$\frac{di_L}{dt}=-\frac{1}{L}\left(R_L+\frac{R_cR}{R+R_c}\right)i_L-\frac{R}{R+R_c}v_c$$

$$\frac{dv_c}{dt}=\frac{1}{C}\left(\frac{R}{R+R_c}\right)i_L+\left(\frac{1}{R+R_c}\right)v_c$$

State space representation when switch is 'OFF'

$$\begin{pmatrix} L & 0 \\ 0 & C \end{pmatrix} x' = \begin{pmatrix} -R_L-\frac{R_cR}{R+R_c} & -\frac{R}{R+R_c} \\ \frac{R}{R+R_c} & \frac{1}{R+R_c} \end{pmatrix} x + \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix} u$$

$$y=\begin{pmatrix} \frac{R_cR}{R+R_c} & \frac{R}{R+R_c} \\ \frac{R_c}{R+R_c} & \frac{1}{R+R_c} \end{pmatrix} x$$

In the Buck Converter, A1 = A2, B2 = 0, C1 = C2.

Finally, the average model in one switching period is:

$$\begin{pmatrix} L & 0 \\ 0 & C \end{pmatrix} x' = \begin{pmatrix} -R_L - \dfrac{R_c R}{R+R_c} & -\dfrac{R}{R+R_c} \\ \dfrac{R}{R+R_c} & \dfrac{1}{R+R_c} \end{pmatrix} x + \begin{pmatrix} k & 0 \\ 0 & 0 \end{pmatrix} u$$

$$y = \begin{pmatrix} \dfrac{R_c R}{R+R_c} & \dfrac{R}{R+R_c} \\ \dfrac{R_c}{R+R_c} & \dfrac{1}{R+R_c} \end{pmatrix} x$$

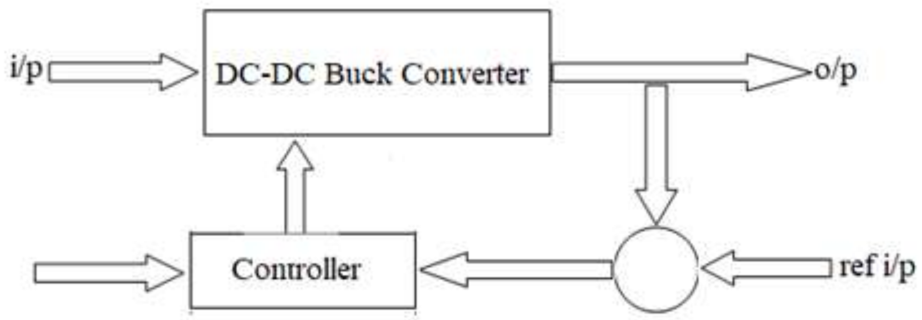
Control-to-output transfer function

From equation (xiii) the transfer function that relates the output voltage when the duty cycle is constant and having a value of *k* is:

$$\frac{\hat{v}_{out}(s)}{\hat{k}(s)} = \frac{v_{out}}{k} \left[\frac{1 + sR_{cR}}{1 + s\left(R_c C + [R \parallel R_L]C + \dfrac{L}{R+R_L} \right) + s^2 LC\left(\dfrac{R+R_c}{R+R_L} \right)} \right]$$

IV CONTROL TECHNIQUES USED IN DC-DC BUCK CONVERTER:

In DC-DC converter for a given input voltage, the output voltage can be controlled by controlling the ON or OFF duration of the switch. Pulse Width Modulation (PWM) is one of the method in which control circuit regulates the output by varying the ON time of the switch and by fixing the switching frequency. When the converter operates in a closed loop mode with a controller produces a control signal which is then compared with a carrier signal to generate a pulse that triggers the switch of the converter. This results in a output voltage from the converter.



V INTERNAL MODEL CONTROL BASED PID CONTROL

The IMC configuration is designed for setting up a comparison between the process and model output to form a standard feedback structure. Figure 5 shows the basic IMC implementation in the process transfer function.

The transfer function for our Buck converter is:

$$\tilde{g}_p(s) = \frac{k_p(\beta s + 1)}{\tau^2 s^2 + 2\varepsilon\tau s + 1}$$

$$\tilde{g}_p(s) = \tilde{g}_{p+}(s)\,\tilde{g}_{p-}(s)$$

$$\tilde{g}_{p+}(s) = \frac{k_p(\beta s+1)}{\tau^2 s^2 + 2\varepsilon\tau s + 1}$$

$$q(s) = \tilde{g}_{p+}(s)^{-1} f(s) = \frac{\tau^2 s^2 + 2\varepsilon\tau s + 1}{k_p(\beta s+1)}$$

$$g_c(s) = \frac{q(s)}{1 - q(s)\,\tilde{g}_p(s)}$$

$$g_c(s) = \frac{\tau^2 s^2 + 2\varepsilon\tau s + 1}{\lambda s(\beta s+1)}$$

The transfer function for the PID controller is:

$$g_c(s) = k_c\left[\frac{\tau_i\tau_d s^2 + \tau_i s + 1}{\tau_i s}\right]$$

Then the PID parameters based on IMC will be derived as:

$\tilde{g}_p(s)$	$f(s)$	k_c	τ_i	τ_d
$\frac{k_p(\beta s+1)}{\tau^2 s^2 + 2\varepsilon\tau s + 1}$	$\frac{1}{(\lambda s+1)}$	$\frac{2\varepsilon\tau}{k_p(\beta s+1)}$	$2\varepsilon\tau$	$\frac{\tau}{2\varepsilon}$

Table 1: IMC based PID parameters for Buck Converter

VI GENETIC ALGORITHM BASED PID CONTROL

Genetic Algorithm generates solutions to optimization problems using techniques inspired by natural evolution. Compared with other optimization techniques, GA starts with an initial population containing a number of chromosomes where each one represents a solution of the problem which performance is evaluated by a fitness function. Basically, GA consists of three main stages: Selection, Crossover and Mutation. The application of these three basic operations allows the creation of new individuals which may be better than their parents. This algorithm is repeated for many generations and finally stops when reaching individuals that represent the optimum solution to the problem.

6.1 Genetic Algorithm for Controller Design

The following flow chart is necessary in order to design a PID Controller using Genetic Algorithm for Buck Converter:

(1) Create a population of initial solution of parameters (K_p, K_i & K_d).

(2) Evaluation of objective function.

The objective function is defined as: $\frac{1}{1+f(\phi)}$

(3) Evaluation of fitness function.

The fitness function is defined as: $f(\phi) = \sum_{t=0}^{T}(v_{ref} - v_o)^2$

(4) Generation of offspring.

(5) Replace the current population with the new population.

(6) Terminate the program if termination criterion is reached; else go to step 2.

VII RESULTS:

In this work, more emphasis is given for improving the dynamic response of the DC-DC buck converter by identifying proper controller parameter. The following dynamic parameters are considered in this work. i) Rise Time ii) Settling Time iii) Peak Overshoot

In order to examine the effectiveness of the proposed algorithm, extensive simulation and experimental studies have been carried out on the closed loop system of Buck converter.

7.1 Response Based on IMC based PID controller:

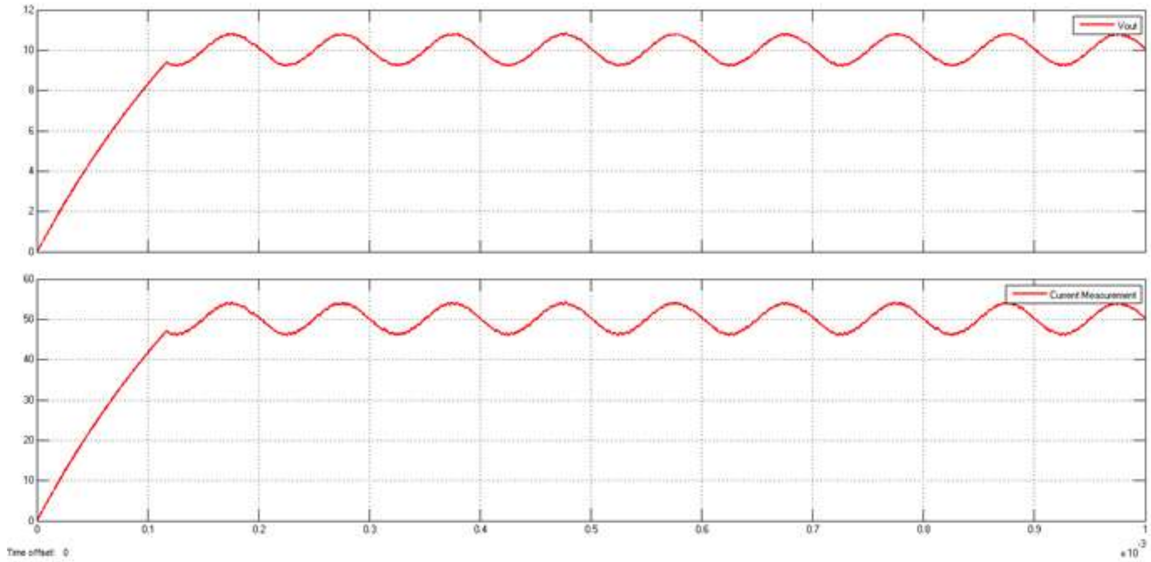


Figure 6: Response of Buck Converter based on GA-PID Control

7.2 Response Based on GA based PID controller:

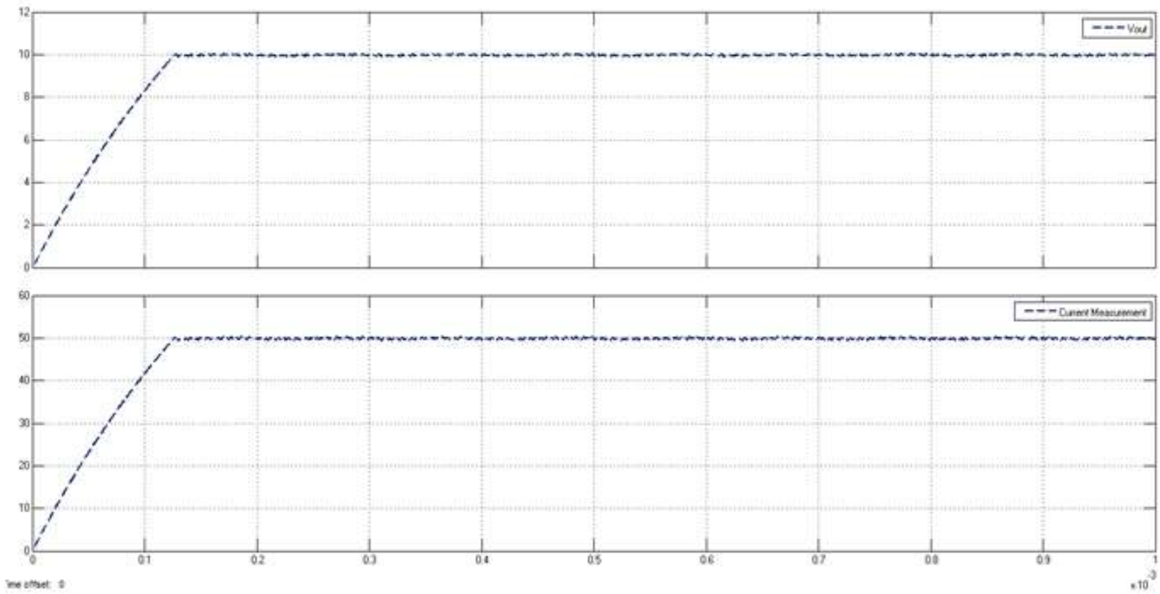


Figure 7: Response of Buck Converter based on GA-PID Control

Transient Response of the Buck Converter based on two control schemes:

Sl.No	Transient Parameters	GA – PID Control	IMC-PID Control
1	Settling Time	1.44×10^3	1.63×10^3
2	Peak Time	745	665
3	Rise Time	100.64	101.19
4	Overshoot	5.58	7.56

VIII CONCLUSION

The design of controller for the buck converter is perceived as an optimization task and the controller constants are estimated through different control algorithms. Initially the designs of PID controller parameters for the buck converter were designed based on Internal Model Control (IMC)) and later the results are compared with Genetic Algorithm (GA). By observing the rise time, settling time, peak overshoot from the response curves which are obtained by using the controller parameters of two different control schemes it can be concluded that GA based parameter gives good and robust response compared to IMC.

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