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Application of AIS on Closed Loop Controller Design in Buck Converter

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Abstract*: *The present work details on design of closed loop controller in buck converter by using AIS (Artificial Immune System) algorithm. At present condition, the dynamic response by the conventional controller is not similar in various operating points. Hence, the work is carried out by keeping controller design as an optimum one and the parameters of controller are derived from AIS algorithm. The performance of the controller is tested under difference in load, reference voltage and input voltage.

Index Terms*: *AIS, Converter, Controller, Closed, Dynamic, Loop.

I. INTRODUCTION

The recent years, buck converter is used as a voltage source device in computer manufacturing industries. [1, 2] When Buck converter is operated under open loop, the voltage regulation will be reduced and the response is not suitable for this operation. To improve the voltage regulation issues, this converter is largely functioned in closed loop operation. In [3, 4] conventional controller design is presented and nonlinear controller design procedure for various applications is also discussed for synchronous buck converter. AIS [5-9] is a type of algorithm encouraged by immunology, immune function and standards observed in nature. Researchers have applied this algorithm to solve non-linear optimization problems effectively Burnet [10]. Various applications using AIS is presented in [11] In this work, a closed loop controller design in buck converter using AIS algorithm is carried out. Voltage regulation of buck converter as the optimal task here. To test AIS algorithm of a controller, modelling of buck converter is used in the entire process. This new controller removes all sort of noise and provides improved quality characteristics under dynamic with different operating points.

II. CONTROLLER DESIGN THROUGH ARTIFICIAL IMMUNE SYSTEM

A. Modelling of Buck Converter

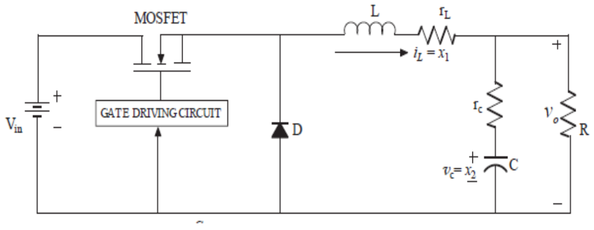

Fig. 1: Buck Converter

The current i_L and voltage v_c are considered as the state variables, and denoted by x_1 and x_2, respectively. When the switch is on and off, the state space equations are obtained by

$$\begin{bmatrix} \dot{x}1 \\ \dot{x}2 \end{bmatrix} = \begin{bmatrix} \frac{-1}{L}\left[r_L + \frac{Rr_c}{R+r_c}\right] & -\frac{R}{L(R+r_c)} \\ \frac{R}{C(R+r_c)} & -\frac{1}{C(R+r_c)} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} V_i \quad (1)$$

Converter output voltage is given by

$$v_0(t) = \begin{bmatrix} \frac{Rr_c}{(R+r_c)} & \frac{R}{(R+r_c)} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} \quad (2)$$

When the switch is turned off, the equation is changed into

$$\begin{bmatrix} \dot{x}1 \\ \dot{x}2 \end{bmatrix} = \begin{bmatrix} \frac{-1}{L}\left[r_L + \frac{Rr_c}{R+r_c}\right] & -\frac{R}{L(R+r_c)} \\ \frac{R}{C(R+r_c)} & -\frac{1}{C(R+r_c)} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \end{bmatrix} V_i \quad (3)$$

$$v_0(t) = \begin{bmatrix} \frac{Rr_c}{(R+r_c)} & \frac{R}{(R+r_c)} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} \quad (4)$$

When this model is operated under closed loop control, consider a small change of ΔV_o^*in reference voltage, then the error signal e(t) is given by

$$e(t) = \beta\left(\Delta V_0^* - \Delta v_o(t)\right) \quad (5)$$

Where β is the fraction of the actual output voltage v_o

This error signal is given to the PID controller and the output of the controller I given by

$$u(t) = [K_p e(t) + K_i \int e(t)dt + K_d \frac{d}{dt} e(t)] \quad (6)$$

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In equation (6) K_p, K_i and K_d are controller constants. From this equations, it is clear that the deviation of the output $\Delta v_o(t)$ depends on parameters of the controller. To achieve improved dynamic characteristics, the error is minimized by the suitable controller parameters. The objective function expressed as

$$\text{Minimize } F(\phi) = \sum_{t=0}^{T} (e(t))^2 \qquad (7)$$

Subject to $\phi_l < \phi < \phi_u$

Here, T is time taken under transient state, ϕ_l and ϕ_u are the boundary variables of K_p, K_i and K_d

B. Artificial Immune System (AIS)

For a complex networks and circuits AIS are adaptive systems inspired by many researchers [12]. The purpose of this algorithm is to identify the optimal PID controller parameters throughout the entire iterative process.
Steps involved in the AIS algorithm as followed by
Step 1: Antigen is identified
Step2: Initial antibody population is created.
In this work population size of 20 is considered for the entire iteration.
Step 3: Objective function evaluation
Here, the F (ϕ) is evaluated.
Step 4: Assessment of affinity
The antibody with maximum affinity is selected.

$$Affinity = \frac{1}{1+F(\phi)} \qquad (8)$$

Step 5: Permutation
Here, the probability factor given by the following expression:

$$\sigma = e^{(-\delta \times f)} \qquad (9)$$

Where σ = Rate of hypermutation , δ = Control factor of decay,
f = Antigenic affinity
Step 6: Reselection
Step 7: The existing population is replaced by the new cloned selection

Step 8: run the program and if it fails go back to step 2

III. RESULTS AND DISCUSSIONS

The parameters of AIS is given in Table 1

Table 1.AIS Parameters

size	20
Clonal selection %	50
No. of iterations	100
Multiplication factor	1.0

The analysis is carried out with variation in load, variation in reference and variation in input voltages. The objective is to fix the output voltage same as reference (error =0). The detailed diagram of the present work is shown in Fig 2.

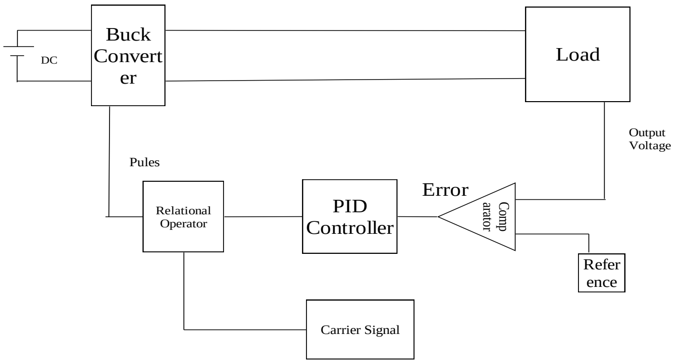

Fig 2 : Closed loop control of buck converter

Here, output of the load is compared with the reference signal and the error signal is sent back to controller itself. The main objective of the controller is to minimize the error. The parameters of the PID controller is obtained using AIS algorithm and it as shown in Table 2.

Table 2. Controller parameters

Parameters	Values
K_p	5.68
K_i	23.33
K_d	0.012

The simulation model of the buck converter is shown in Fig. 3

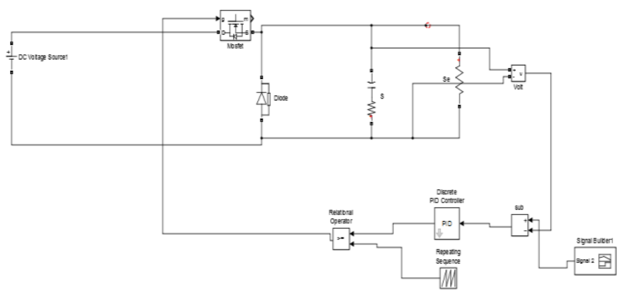

Fig 3: Simulation model of converter

Case 1: Change in applied voltage by change in reference signal
Here, the applied voltage of reference signal is varied in 3 steps namely 10 V(1.5 s) , 20V(1.5 to 3s) and 5 V (3 to 5s). The performance of the controller is analyzed with the change in reference voltage.
The characteristics curve of output voltage, current and error are shown in Fig 4, 5 and 6 respectively

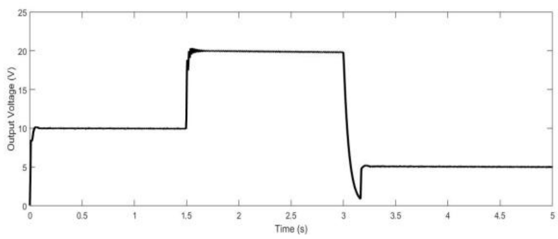

Fig 4 Change in output voltage in reference signal

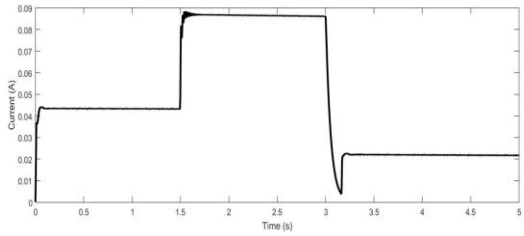

Fig 5a Output Current

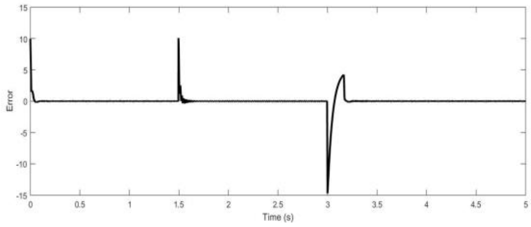

Fig 5b Error in reference voltage

From this figures, it is clear that the controller is tracking the reference in finite time, the input and output voltages are maintained as identical. The AIS based controller is so robust that the change in applied voltages in reference signal is achieved in the output side.

Case 1: Input voltage changes with fixed reference signal

In this case, the input voltage is changed into 15 V(1.5 s) , 20V(1.5 to 4s) and 25 V (4 to 5s) with fixing reference signal as 12 V. The waveforms of output and error are given in Fig 7 and 8.

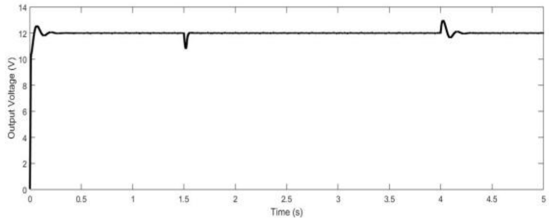

Fig 6 Output current for reference: 12V

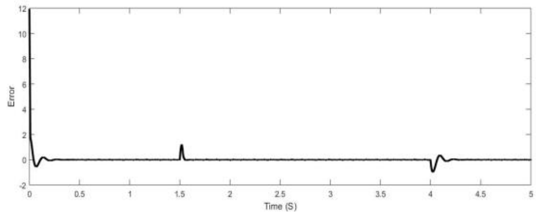

Fig 7 Error for reference: 12V

The same methodology is followed for a reference voltage of 20 V, and the characteristics are shown in Fig 8 and 9

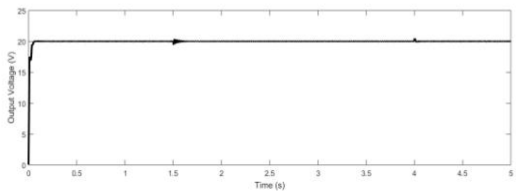

Fig 8 Output voltage for reference: 20V

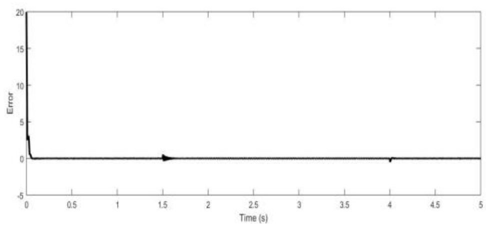

Fig 9 Output current for reference: 20V

It is clear from Fig 6 to 9 that the variation in input voltage is easily tracked by the controller and desired voltage is maintained in the output irrespective of variation in input. This shows the robustness of the controller.

Case 3 : Variation in load by variation in reference voltage.

In this case, two parameters namely load and reference voltages are changed and the performance of the controller is analyzed. The load is varied from 230 ohm (0-1.5s) to 400 ohm (1.5 to 4s) and the reference voltage is varied in 3 steps namely 10 V(1.5 s) , 20V(1.5 to 3s) and 5 V (3 to 5s). The characteristics are shown in 10 to 12.

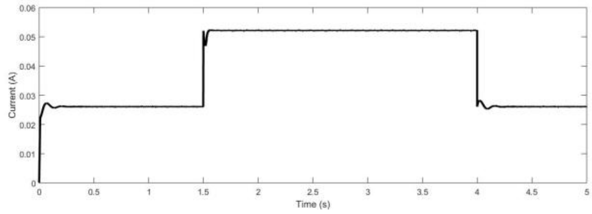

Fig 10 Output current of load

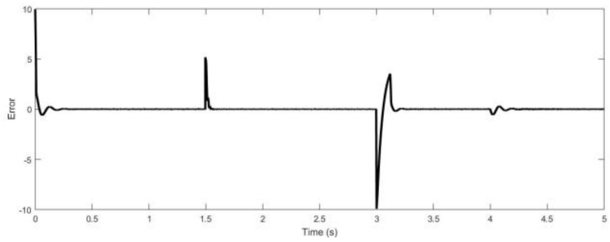

Fig 11 Load error

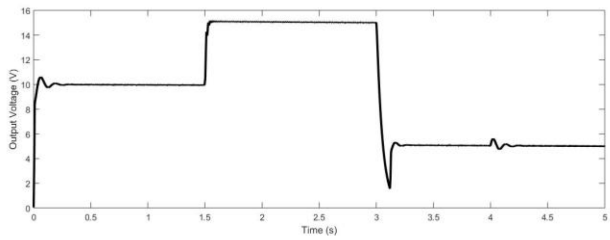

Fig 12 Output voltage of load

From the above figures it is clear that, even with variation in reference and load current, the controller maintains constant output voltage with respect to reference. The change in load current is not affecting the input voltage. The spikes in voltage and currents are lowered in this method.

IV. CONCLUSION

The proposed work of an application of AIS based closed loop controller in buck converter is tested with simulation software Simulink/MATLAB. The objective function to minimize the error is optimized by AIS algorithm and the parameters of PID controller are determined.The linearization process done through state-space model of a converter. Different case studies are investigated and the performance characteristics are verified with various operating conditions. For all cases, improved voltage regulation is obtained. The voltage and current spikes are reduced.

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