Cuk Convertor Circuit Controller Design Using Artificial Intelligent Techniques

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Abstract **- This paper presents to use the artificial intelligence to design the cuk converter circuit controller using Genetic Algorithms controller. The mathematical model of the cuk converter circuit operating in the continuous conduction mode in state-space form is presented. LQR controller and Genetic Algorithms controller techniques are used to design the controller. Analysis and comparison between simulation responses of open loop, close loop LQR controller and Genetic Algorithms controller results are performed for different, working conditions such as sudden changes in the load resistance. The results show that there are significant improvements in the results of the proposed Genetic Algorithms control technique. For this application, MATLAB-Simulink software is used.**

Keywords*: *Artificial intelligence; Cuk converter circuit; LQR controller; Genetic Algorithms controller.

I. INTRODUCTION

DC-DC Converters are predominantly used in day-to-day electronic gadgets like cell phone, laptops, and smart phones, tablet PC, etc. They also find very useful in modern day electric vehicles and industries using a DC power supply. DC-DC converters process DC power and are classified as Buck, Boost, Buck Boost and cuk, according to their operation. [1]

Cuk converter is a circuit which converts a source of DC from one voltage level to another by changing the duty cycle of the main switches in the circuit. Cuk converter is a nonlinear system, it represents a big challenge for control design [2].

Since classical control methods are designed at one nominal operating point, they are not able to respond satisfactorily to operating point variations and load disturbance while the cuk converter is important to supply a constant output voltage, regardless of disturbances on the input voltage, therefore the intelligent techniques are used.

There are many research works intelligence controllers such as fuzzy logic control have been reported in (Rubaai, A. et al., 2008)[3], neural network controller by (Mahdavi, J. et al., 2005)[4] and hybrid neuro-fuzzy control methods for Cuk converter by K. Mehran, D. Giaouris & B. Zahawi (2010)[5]. Furthermore, the implementations of the genetic algorithm control (GA) have been proposed recently in (K. KAVITHA, et al., 2014)[6].

In this paper, we present the detailed account in the control design of a cuk converter. Linear quadratic regulator (LQR) and genetic algorithm are the techniques proposed in this investigation to regulate the output voltage of the converter.

II. DYNAMIC OF THE CUK CONVERTER CIRCUIT

The Cuk converter circuit is shown in “Fig. 1”.This circuit performs a DC conversion function. It can either increase or decrease the magnitude of the output voltage with respect to the input and it inverts its polarity depend on the duty cycle value (α) [7].

Its principle of operation is as follows: During t_{on}, the inductor current i_{L1} build up. During t_{off} C_1 charges up by the current in L_1 and the DC source V_i, while diode d is conducting the positive polarity voltage of the left side plate of C_1 rises i_{L1} falls. During ton C_1 discharges through L_2, reverse biasing the diode D_1 and charges the capacitor C_2 with its lower plate becoming positively charged. The inductor current i_{L2} rises during this time, as does i_{L1}. For large enough values of capacitors C_1 and C_2 during the switching period T_s leads to output voltage (V_{c2}) to be constant for a given switching time. This voltage changes with changing the switching period (t_{on}).

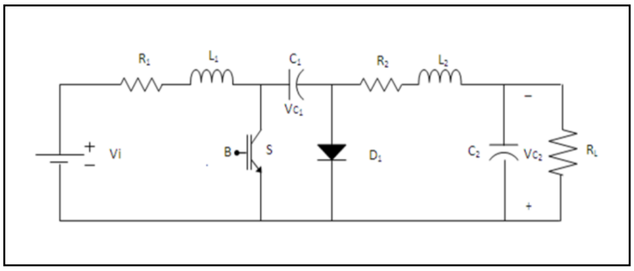

Figure 1. Circuit of cuk converter

III- STATE SPACE REPRESENTATION OF THE CUK CONVERTER CIRCUIT

The 1st order differential equations for the system in “Fig. 1”, can be written as follows [8]:

$$\dot{x}(t) = Ax(t) + Bu(t) \tag{1}$$

$$y(t) = Cx(t) + Du(t) \quad (2)$$

Where,
x (t)= state vector (n-dimensional vector) .
u(t) = input vector (r-dimensional vector) .
y (t)= output vector (m-dimensional vector) .
A = nn matrix .
B = nr matrix .
C = mn matrix .
D = mr matrix .

The state variables for the cuk converter circuit are assigned to be :
$x_1 = i_{L1}$, $x_2 = v_{C1}$, $x_3 = i_{L2}$, $x_4 = v_{C2}$.

$$x = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} = \begin{bmatrix} i_{L1} \\ vc_1 \\ i_{L2} \\ vc_2 \end{bmatrix} \quad (3)$$

The common differential equations of the system are

$$\dot{x}_1 = -\frac{R_1}{L_1} x_1 - \frac{(1-\alpha)}{L_1} x_2 + \frac{V_i}{L_1} \quad (4)$$

$$\dot{x}_2 = \frac{1-\alpha}{C_1} x_1 - \frac{\alpha}{C_1} x_3 \quad (5)$$

$$\dot{x}_3 = \frac{\alpha}{L_2} x_2 - \frac{R_2}{L_2} x_3 - \frac{1}{L_2} x_4 \quad (6)$$

$$\dot{x}_4 = \frac{1}{C_2} x_3 - \frac{1}{R_L C_2} x_4 \quad (7)$$

$$y = x_4 \quad (8)$$

From the loop equations of the circuit in “Fig. 1”, for the two states,the switch is on and switch off, the following state and output equations may be derived: (assuming ideal switch characteristics).

$$A = \begin{bmatrix} -\frac{R_1}{L_1} & \frac{-(1-\alpha)}{L_1} & 0 & 0 \\ \frac{1-\alpha}{C_1} & 0 & -\frac{\alpha}{C_1} & 0 \\ 0 & \frac{\alpha}{L_2} & -\frac{R_2}{L_2} & -\frac{1}{L_2} \\ 0 & 0 & \frac{1}{C_2} & -\frac{1}{R_L C_2} \end{bmatrix} \quad (9)$$

$$B = \begin{bmatrix} \frac{1}{L_1} \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad (10)$$

$$C = [0 \quad 0 \quad 0 \quad 1] \quad (11)$$

$$D = [0] \quad (12)$$

Where α be a symbol of the duty cycle of the circuit
α = 0 switch S is in position 0
α = 1 switch S is in position 1
“Fig. 2”, Shows the open loop modeling of cuk converter

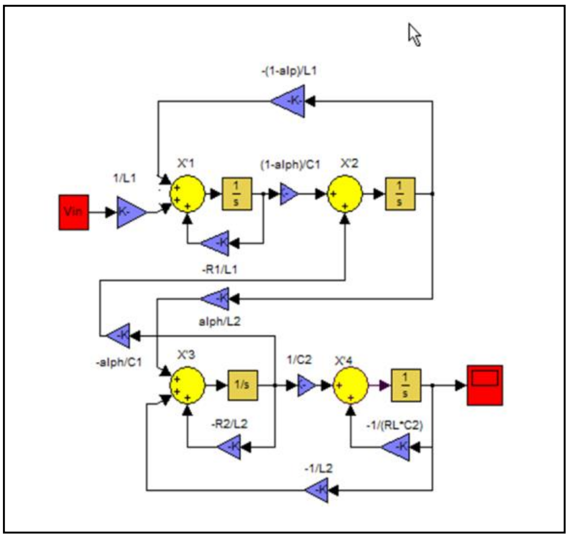

Figure 2. Open loop modeling of cuk converter

The values of parameters for cuk converter circuit in Figure 1. are (R_1=0.04 Ω, R_2=0.03 Ω, R_L=10 Ω, L_1=0.4mH , L_2=0.3mH, C_1=1000 µF , C_2=100 µF, V_{in}=12V) .

IV. Theoritical Basics

A- State Feedback Controller Design using LQR Technique [9]

The plant is primarily being originated into following state space format for equation (1) and (2), the feedback controller design is the process of getting a control signal (u= -Kx(t)) in order to minimize the performance index given by the following relation:

$$J = \int_0^\infty (x^T Q x + u^T R u) \, dt \quad (13)$$

Where K is the constant feedback gain obtained from the solution of the discrete algebraic Riccati equation, and Q is weighting factors of states (positive semidefinite matrix) and R is weighting factors of control variables (positive definite matrix). To design the LQR controller, the first step is to select the weighting matrices Q and R. The value R weight input is more than the states while the value of Q weight the state is more than the inputs.

After numerous simulations, the estimated best values for matrices Q and R are:

$$Q = \begin{bmatrix} 20 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \text{ and } R=[1] \quad (14)$$

These values provide a better performance of the system in terms of achieving smooth and short transitory responses.
The gain matrix K which solve the LQR problem is

$$K=R^{-1}B^{T}P^{*} \quad (15)$$

Where P* is unique, positive semidefinite solution to the Riccati equation;

$$A^{T}P + PA - PBR^{-1}B^{T}P + Q = 0 \quad (16)$$

The MATLAB 'lqr' command is used directly to solve the gain vector K given A, B, Q and R

B. Genetic Algorithm Controller Design [10]

The GA has been used for optimizing the parameters of a control system that are complex and difficult to solve by conventional optimization methods. GA maintains a set of candidate solutions called population and repeatedly modifies them. At each step, the GA selects individuals from the current population to be parents and uses them produce the children for the next generation. Candidate solutions are usually represented as strings of fixed length, called chromosomes. A fitness or objective function is used to reflect the goodness of each member of the population. Given a random initial population GA operates in cycles called generations.

The following sections (*1-4*) describe GA method and its operators:

1) The fitness function is a function which evaluates the degree of the fitness of each chromosome individual with the desired solution. In the present problem, the inputs to the GA are (K_1 to K_n) is related to the cuk converter circuit, and the output on the (K_1 to K_n) from which the best closed-loop system response in get. A GA controller is evaluated using the Index Absolute Error (IAE) *(J)*. The value of performance index calculated *J* has been get using :

$$\text{Performance index } (J) = IAE = \frac{1}{N}\sum_{1}^{N}|e_i| \quad (17)$$

$$\text{Where} \quad e_i = V_{ref} - V_o \quad (18)$$

2) The population undergoes reproduction in a number of iterations. One or more parents are chosen stochastically, but strings with higher fitness values have a higher probability of contributing an offspring.

3) Genetic operators, such as

a) Crossover: Causes pairs or larger groups of individuals to exchange genetic information with one another.

b) Mutation: causes individual genetic representations to be changed according to some probabilistic rule.

Crossover and mutation are applied to parents to produce offspring.

4) The offspring is inserted into the population and the process is repeated.

In this paper the population size is 20, the selection method is a roulette-wheel. The mutation function is Random gene (P_m=0.01), the crossover function is Heuristic (P_c=1.0), the stopping rules are the no of generation is 100.

The optimization process is summarized in the flowchart of "Fig.3", This shows the main steps used to explain the mechanism of the basic cycle process for the genetic algorithm program.

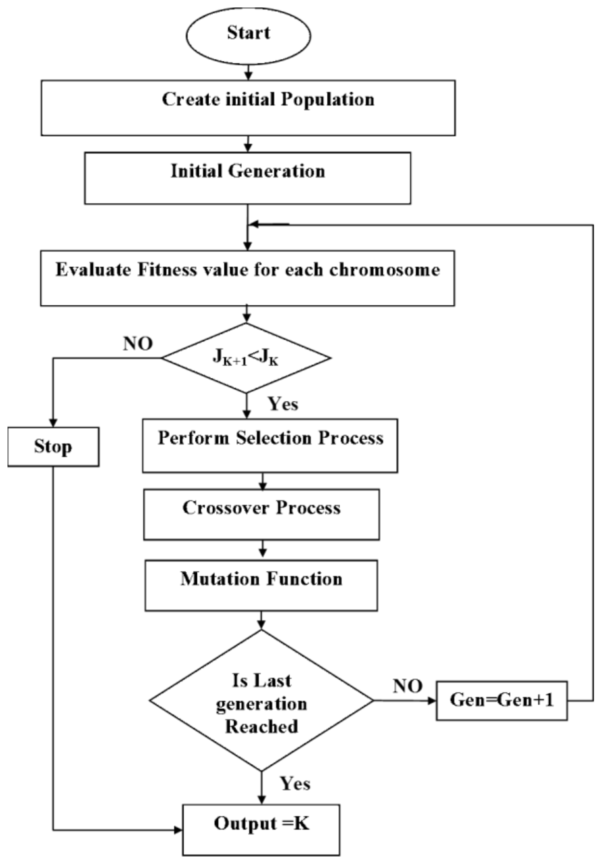

Figure 3. General flowchart for GA.

V. Simulation Results

The simulation is used MATLAB, both LQR and GA cuk converter controller design were considered. Here the LQR and GA are used to regulate the output voltage of the circuit. Several tests were considered for verification of the effectiveness of the proposed controllers when the circuit is subjected to input voltage =12v, when duty cycle (α) equal to 0.4 and 0.6, in addition to change load.

The output voltages for the simulated open loop and closed loop systems with both LQR and GA controllers at α=0.4 (decrease voltage state), for reference voltages (12) volt, for load resistance to (10) Ω are shown in "Fig.4", .

"Fig.5", shows the output voltage response for Open loop system, LQR and GA controller at α=0.6 (increase voltage state) for reference voltages (12) volt, for load resistance to (10) Ω.

From "Fig.4", and "Fig.5", they are shown that the advantage of the GA controller in terms of quick settling time and less overshoot comparison with LQR controller.

The output voltage responses for the open loop and closed loop systems with LQR and GA Controllers are shown on the same graph in "Fig.6", for reference voltages (12) volt, for varying the load resistance to (50) Ω at a time (t=0.06). It can see the disturbance after load change and the quick response from the GA controller to remain the system more stable.

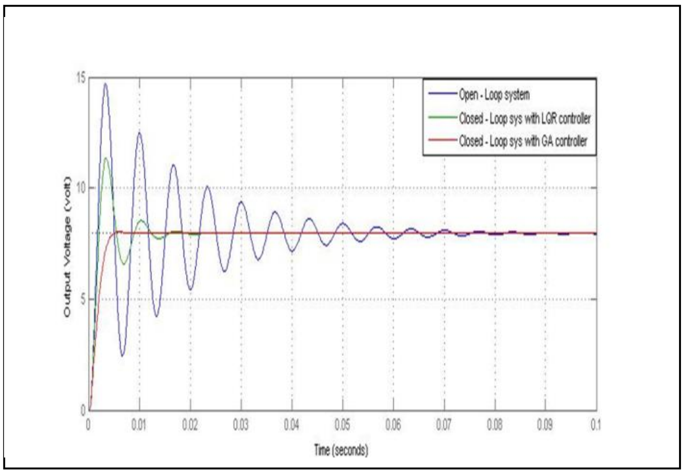

Figure 4. Output voltage response for open loop system with LQR and GA controller at α=0.4.

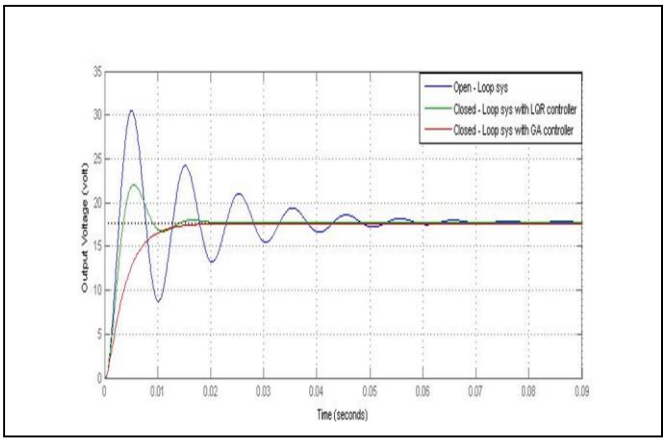

Figure 5. Output voltage response for open loop system with LQR and GA controller at α=0.6.

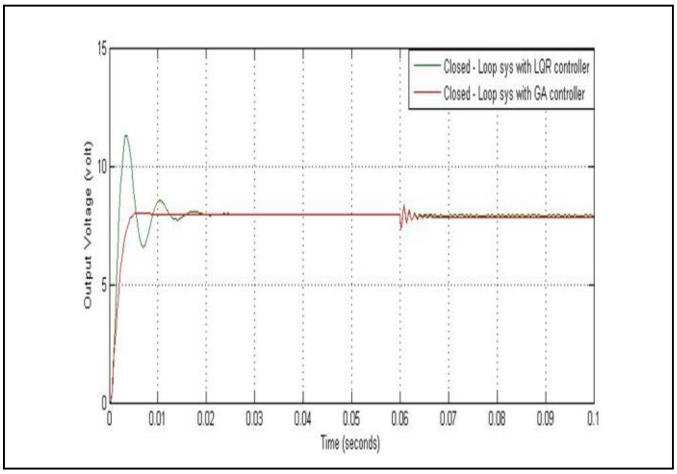

Figure 6. Output voltage response for close loop LQR and GA controller and load disturbance after 0.06 (sec).

Comparison between theoretical results for open loop, close loop with both LQR and GA controllers for voltage (12 volt) for α=0.4 and α=0.6 are shown in the Table 1. and Table 2. receptivity.

Table 1. Output voltage performance for open loop, closed loop with LQR and GA controllers at α=0.4.

System	Settling Time	Overshoot %
Open loop	0.0672	84.9
Closed loop with LQR	0.0148	42.4
Closed loop with GA	0.0043	0.828

Table 2. Output voltage performance for open loop, closed loop with LOR and GA controllers at α=0.6.

System α=0.6	Settling Time	Overshoot %
Open loop	0.0566	71.8
Closed loop with LQR	0.0136	24.2
Closed loop with GA	0.0134	0

From Table 1 and 2 above, they are shown that the performance of the converter for open loop system has high peak overshoot and the settling time. The system by LQR controller gains response performance (peak overshoot and settling time) have been improved, and genetic algorithm controller response performance (peak overshoot and settling time) has improvements. Comparison of the results shows that the proposed (GA) control is the best.

VI. Conclusion

In this paper cuk converter circuit has been designed. Its mathematical model in state space form has been developed. The circuit output voltage response as an open-loop system has been analyzed. Different techniques have been used to regulate the output voltage of the cuk converter circuit. The LQR controller technique has been used. Genetic algorithm technique has been proposed. Complete analysis for the open–loop and closed-loop circuit with LQR controller and the proposed GA controller was performed. The results show that the output voltage response of the cuk converter with closed loop of GA controller was better than of closed loop of LQR controller .

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