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PI Parameter Optimization By Fire Fly Algorithm For Optimal Controlling Of A Buck Converter's Output StateVariable

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ABSTRACT

In this study, the buck converter circuit which is the topology of the power electronic circuit has been investigated to obtain the desired output voltage. The state variable of the circuit that is also used output of the system have been optimally controlled. The PI controller which is the basic structure and widely used in the practical applications has been run in discrete time. The PI controller parameters can be calculated by using a method based on the rootlocus, pole placement or Ziegler–Nichols method. However, these methods can not provide a solution with highe fficiency signal output voltage. In order to obtain the minimal cost value of the control process, Kp and Ki control parameters are optimized by using the Fire Fly (FF) algorithm based on swarm intelligence. The Matlab-Simulink program has been utilized for the simulations. The results show that the FF algorithm may observe the optimal values for the controller parameters.

Keywords: Firefly algorithm, optimization, parameter, PI controller, discrete time, buck converter

1. INTRODUCTION

A lot of classical and modern control methods are available for controlling buck type DC-DC buck converter output states. In this paper, converter output voltage has been taken under control using discrete time PI controller.

When control parameter values are calculated using modern optimization techniques the results of output dynamics improve significantly [1].

On the solution of optimization problems there are well known classical methods. Because of these kinds of inelasticity methods are used intensively the scientists has augmented their effort to increase general purposes and to have high performance methods so they has started to inspire from natural events.

The optimization algorithms that are developed based on natural events have been named as heuristic methods [2]. A parts of the heuristic optimization technique have been named as swarm intelligence algorithms. Swarm intelligence algorithm is developed by examining survival common behaviors of the living beings who lives in swarms at nature [3].

In the firefly algorithm that is one of these algorithms, the objective function of a given optimization problem must be related to the intensity of the flashing light or light which helps

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to go to bright and more attractive places in the firefly's swarm in order to obtain an efficient optimal solution [4].

Various contemporary works are available in an attempt to buck type DC-DC converter circuit output with minimum cost is able to bring under control. For instance, Xutao Li et al. have been providingthe control of a buck type converter output by using the continuous time PID controller. They had assigned Kp, Ki and Kd parameters at proper values in order to keep an audit cost low by use of PSO algorithm [5]. Muhammad Yaqoobet al. have enhanced the buck type converters' dynamic behavior in the transient time interval by use of a FF algorithm [6]. Also, the most suitable values for PID controller parameters by Bacterial Foraging Algorithm hasbeen appointed by Abolfazl Jalilvandet al. [7].

In this study, the output voltage of a buck converter is controlled with discrete time PI controller algorithm. The dynamic behavior of the output voltage in transient and continuous time interval with FF algorithm optimization is used in order to ensure low overshoot, low setting time and steady-state error desirable level. Benefit from this optimization algorithm suitable values are identified to control parameters. Then, control process and the results run in Matlab-Simulink platform and control success were tested simultaneously.

2. FIRE FLY ALGORITHM

The FF algorithm has been used in an attempt to find the coupling partner of flashlight or pull along the potential hunts. The FF algorithm is reaching in contact with the opposite sex by checking the flashing speed and the rhythm of the light produced. The main purpose for a firefly's flash is to act as a signal system to attract other fireflies, as given in Figure 1 [8].

The FF algorithm was developed by Xin-She Yang. He had mooted search strategy, controlled random value production by using Gaussian distribution. The FFA is better than other heuristic algorithms the terms of the efficient local search and best solution selection processes. FF algorithm, which is adapted to the behavior of firefly, has 3 different working phases. In the first phase, all fireflies are of the same sex and will be attracted by other fireflies. The second phase is the process of attracting the opposite side with the glow that fireflies have come from. Two flashes of fire will be drawn towards the brighter one, which is brighter than the brighter ones. Charm is proportional to brightness. As the distance increases, both variable values decrease. If the firefly does not see a brighter light than its own light, the mode of movement becomes random.

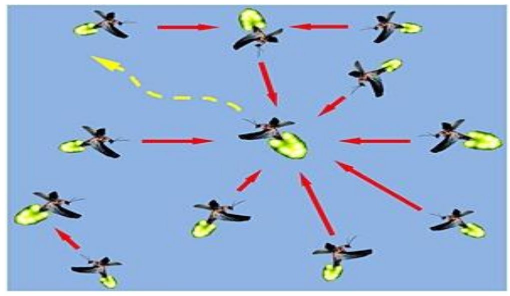

Figure 1. Light beetle heading towards strong light [8]

In the third phase, the orientation to the most intense light environment is initiated.

2.1. Attractiveness and Light Density

On firefly algorithm are available two basic variable accounts for light intensity and attractiveness. The FF algorithm's new position is calculated based on these two variable values. In the Eq. (1) light intensity is defined.

$$\mathrm{I(r)} = \frac{\mathrm{I_0}}{\mathrm{r^2}} \tag{1}$$

Where,

$I(r)$: Light intensity

r : Distance between two fireflies

I_0 : Initial light intensity

denote. In order to remove the singularity in the expression given in Eq. (1), the distance expression in the denominator is formed as exponential coefficient, Eq. (2).

$$I(r) = I_0 e^{-\gamma r} \tag{2}$$

Attractiveness is proportional to the intensity of light seen by neighboring fireflies. The attractiveness of a firefly is represented by β, and it is calculated as in Eq. (3).

$$\beta(r) = \beta_0 e^{-\gamma r^m} \tag{3}$$

Where,

β_0: Initial attraction value

γ : Light absorption coefficient

m: Attractiveness control parameter, m≥1

denote.

2.2. New Location

The distance between m_j and m_i must be calculated before the new position of firefly is find out, Eq. (4).

$$r_{ij} = \|x_i - x_j\| = \sqrt{\sum_{k=1}^{d}(x_{i,k} - x_{j,k})^2} \quad (4)$$

After by calculating the distance, the new position of the firefly is calculated as in the Eq. (5).

$$x_i(t+1) = x_i(t) + \beta_0 e^{-\gamma r_{ij}^2}\left(x_i(t) - x_j(t)\right) + \alpha\varepsilon_i \quad (5)$$

In Eq.(4) and Eq.(5), d, α and ε_i are defined as below.

d: Number of firefly

α: Multiplicity, $0 < \alpha < 1$

ε_i: A random value, obtained from the Gaussian distribution.

3. MODELLING BUCK CONVERTER

The Buck type reducer power electronics circuit topology has given in Figure 2.

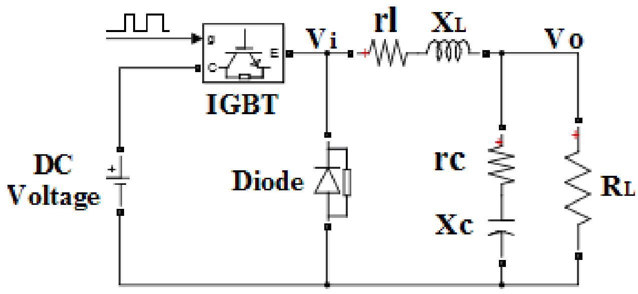

Figure 2. Buck converter topology

Basic elements of the circuit are a coil and a capacitor.

Power consumption is performed by R_L load, and battery is used as a power source. A PWM core is used as the pulse source and an IGBT is used for power transmission and cutting.

Also, the buck circuit topology in the simulation environment, for the purpose of to be highest similarity with those of hardware environment is connected with series equivalent resistances (ESR) that belong to the capacitor and the coil elements.

If the ejection of the transfer function T(s) of the system is solved base on electronic circuit analysis, the mathematical relation between input and output voltages has given in the Eq. (6) in the Laplace space.

$$\frac{V_o(s)}{V_i(s)} = T(s) = \frac{(X_c(s)+R_c)//R_{load}}{X_L(s)+R_l+(X_c(s)+R_c)//R_{load}} \quad (6)$$

X statements used in Eq. (6) is defined as,

$X_L(s)$: sL

R_l: ESR resistor of inductance in ohms

$X_c(s)$: $(sC)^{-1}$

R_c: ESR resistor of capacitor in ohms

For the study to be realized in the simulation environment, a capacitor with 2200µF/80V/ 280mΩ values produced by the Panasonic Electronic Components Inc. and a coil selection with 300µH/3A/140mΩ values by Murata Power

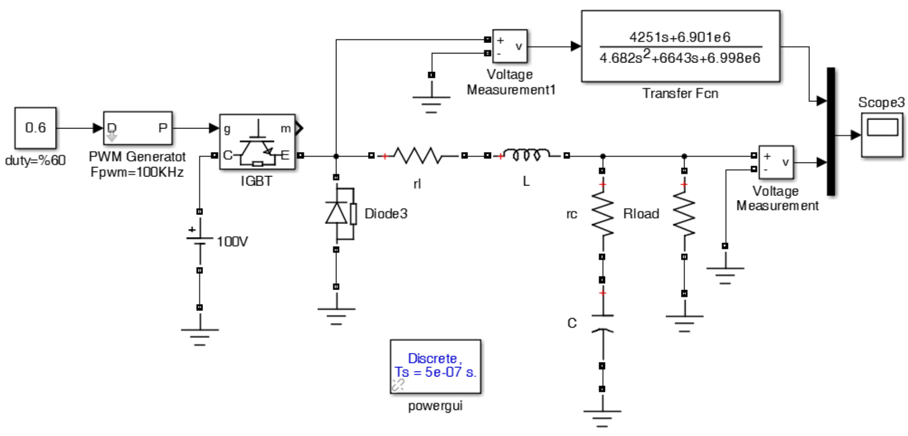

Figure 3. Simulation platform for T(s)'s accuracy test

Solutions Inc. have been made. The transfer function T(s) for a 100 Ω load resistor has been regulated to become final numeral form as in Eq. (7).

$$T(s) = \frac{4251s+6.901*10^6}{4.682s^2+6643s+6.998*10^6} \quad (7)$$

Accuracy of the derivation process that belongs to the transfer function of T(s) must be tested to ensure that the next step of the control process can be possible. For this reason, the buck circuit, which was designed with T(s) transfer function and power electronic elements, have been run together in the simultaneous Matlab-Simulink environment as given in Figure 3. Both systems in Figure 3 are run for %60-duty input voltages. As a result, obtained overlap output voltage waveforms has been shown in Figure 4.

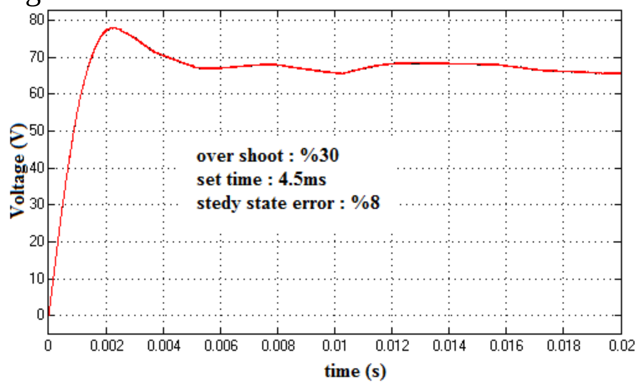

Figure 4. For %60 duty input voltages, T(s) and power system outputs

4. CONTROL STRUCTURE

In Figure 5, the circuit diagram of the discrete-time closed-loop control system is given. The buck converter structure has got coil, capacitor and Resr resistances. A pure ohmic resistor has been chosen as the load. The input reference step voltage and the Buck converter output voltage difference have been applied to the discrete time PI algorithm with Ts period to obtain the control input signal. The control signal has been applied to the buck converter for following the input reference signal value of the output signal.

In the Figure 5, discrete time integral transfer function has been derived by Euler's method and given in Eq. 8.

$$s = \frac{1}{T_s}(z-1) \tag{8}$$

Where, Ts denotes sample time.

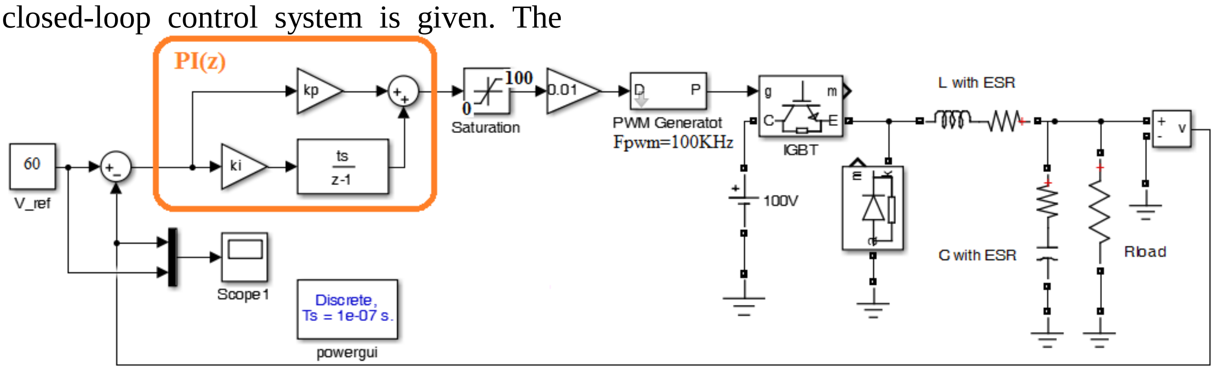

Figure 5. PI(z) based Buck converter control block diagram

5. PARAMETER CALCULATION

In this study, Kp and Ki parameters are optimized by a heuristic optimization algorithm called FF algorithm. FF algorithm has to observe cost value belong to control processes for optimum Kp and Ki parameters. The ISE, IAE, ITAE and dTISDSE are discrete time cost functions [9]. Mathematical equations for cost functions have shown in Eq. (9, 10, 11 and 12) respectively.

$$ISE(e) = \sum_{k=0}^{t_{sim}/T_s} e_k^2 \tag{9}$$

$$IAE(e) = \sum_{k=0}^{t_{sim}/T_s} |e_k| \tag{10}$$

$$ITAE(e) = \sum_{k=0}^{t_{sim}/T_s} k|e_k| \tag{11}$$

$$dTISDSE(e) = \sum_{k=0}^{t_{sim}/T_s} k\left(e_k^2\right)^2 \tag{12}$$

Where "e" denotes the control process error that is the difference between input reference signal and output system signal. The some important control initialization parameters of the optimization process are given in Table 1. In addition, the flowchart of the FF algorithm in which these parameters are used is shown in Figure 6. This flowchart diagram have been run based on 4 different cost functions. The results obtained have shown in Figures 7, 8, 9 and 10.

Table 1. Initial parameters of optimization process

Parameter	Value
Tsample	10µs
Tsim	1000µ
Iteration	80
Number of fireflies	75
γ	50
β	%20
α	%10

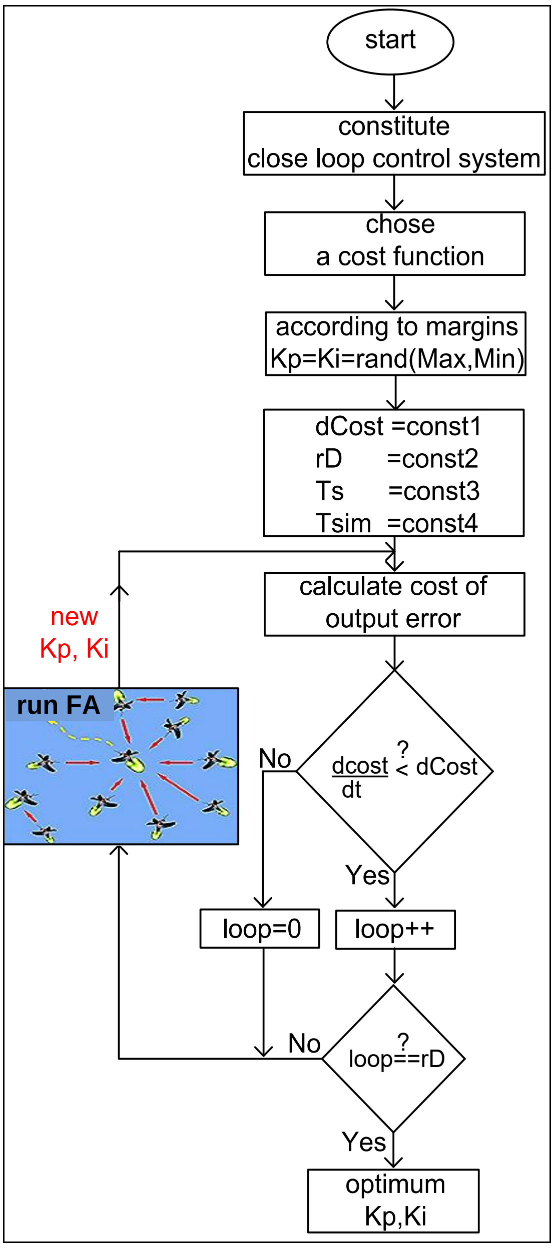

Figure 6. Kp and Ki optimization process

S Based on four different cost function had been optimized. Kp and Ki controller parameter numerical values are given in Table 2.

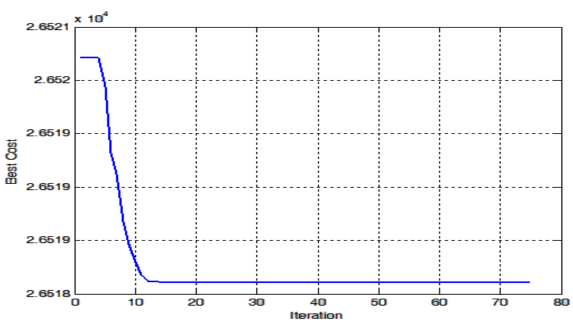

Figure 7. The value decreasing of ISE

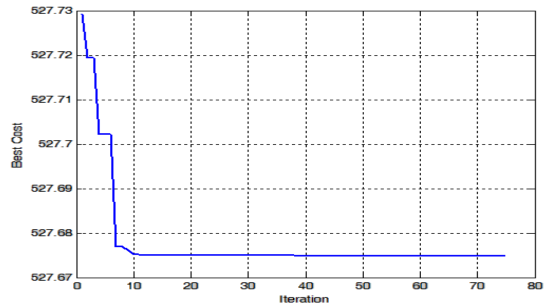

Figure 8. The value decreasing of IAE

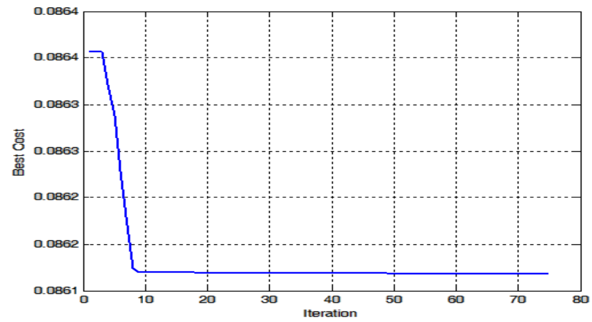

Figure 9. The value decreasing of ITAE

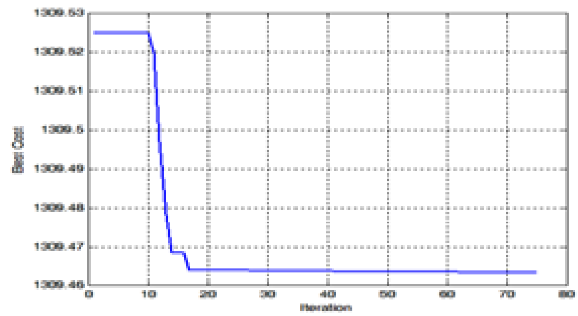

Figure 10. The value decreasing of dTISDSE

Table 2. Kp and Ki values based on cost functions

Parameter	IAE	ISE	ITEA	dISDSE
Kp	51.59	46.86	49.87	25.12
Ki	56.88	50.23	60.00	48.99

6. SIMULATION RESULTS

The closed loop control system shown in Figure 5 was installed with 4 different control systems in Matlab-Simulink simulation environment for 4 different optimum controller parameters obtained by using 4 different cost functions, as given Figure 12. For the reference output voltage 60V, the dynamical behaviors of the output voltage that belongs to the buck converter's controlled by the discrete time PI controller have shown in the Figure 11.

The PI controller parameters based on 4 different cost functions have been used in the optimization process. The performance criterion responses of the PI controller based closed loop system are given in Figure11. According to these results, while the dynamic behavior of the system is obtained the same for ISE, IAE and ITAE cost functions, the dTISDSE cost function have got the highest overshoot and high steady state error values.

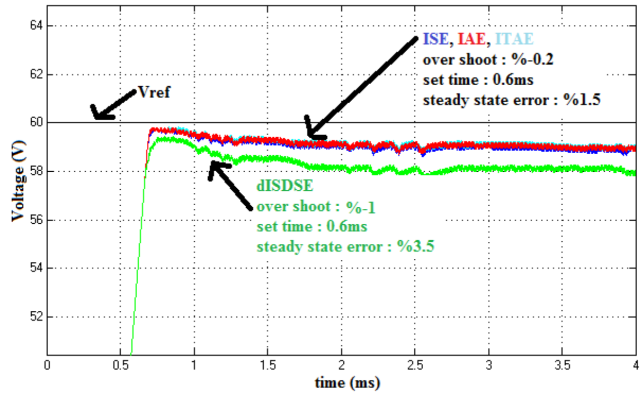

Figure 11. Control results for 4 different Kp and Ki parameters

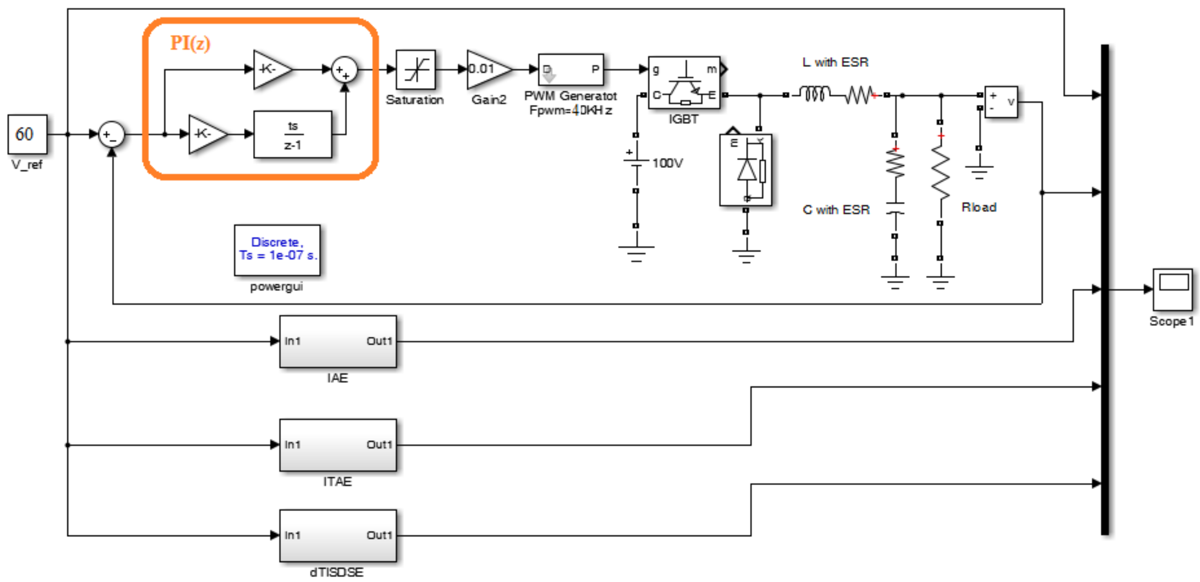

Figure 12. 4 control systems with 4 different controller's parameters

7. CONCLUSIONS

In this study, a buck type power electronic circuit was investigated. Due to the circuit structure of the buck converter, voltage drop can be realized with high efficiency. However, an additional circuit, which necessarily includes a control algorithm, will be needed so that the circuit output voltage magnitude can be fixed at a desired reference value. Added circuit parameters have to be optimized for high efficiency output. In our study, we used the FF heuristic algorithm for optimization controller parameters. It is seen from the experiments performed in the simulation environment that if the FF heuristic optimization algorithm run with IAE cost function, controller parameters will have the most optimum values. Discrete time PI control algorithm with optimum calculated parameters stabilizes the buck converter output voltage with the lowest overflow and with the lowest habitation time.

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