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Meta-heuristic algorithm-based optimal PID controller design for Power Converters

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Abstract

The DC-DC converters are one of the important components of the renewable energy systems. In this study, meta-heuristic-based intelligent control schemes are applied, such as, proportional-integrator (PI), proportional-derivative (PD) and proportional-integrator-derivative (PID) control. The gain parameters of the PID controlled DC-DC buck or step-down converter is optimized with the artificial bee colony (ABC) algorithm. The obtained results indicate that PID control is better than the others together with proportional, integrator and derivative gain parameters 3.7560, 1.5947 and 3.6623, respectively.

Keywords: *Buck Converter; PID Control; Artificial Bee Colony.*

1. Introduction

Linear programming, gradient descent methods etc. conventional optimization techniques have some failures in solving complex problems. When the intelligent optimization compared with algorithms traditional methods, these have more advantages in solving continuous/discrete, multimodal and non-differentiable problems. In recent years, intelligent optimization algorithms have become more and more popular optimization tools [1].

The step-down or buck converters are widely used in applications, such as photovoltaic, energy storage systems, mobile power supply, DC power supply system, etc. In the design and implementation conveniences, the linear control strategies like PID control methods still by far play an important role [2-4]. The use of a control unit in DC-DC converters is a requirement to operate at the desired output voltage or current. The switching equipment of DC-DC converters is driven by a certain duty conversion. In the driver circuit, pulse width modulation (PWM) is controlled by the control unit for the reference value of output. Duty cycle of DC-DC converter is depended on PWM control scheme. So, output voltage or current is adjusted by duty cycle control technique.

The buck converter provides the constant output voltage under the variable load current and irregular input voltage [5]. Different controllers are used to eliminate the overshoot of output voltage and reduce the response time of the converter. PID controller is commonly used in industrial applications and has linear control method. Linear PID and Fuzzy Logic (FL) controller is implemented [6]. Sonmez et al. [7] optimized a buck converter's performance using the artificial bee colony (ABC) algorithm for only output voltage. Furthermore, the ABC was compared with the genetic algorithm (GA). The results showed that the ABC was better than the GA. Hekimoğlu and Ekinci [8] designed and compared optimal PID control system for step down converter using Whale Optimization Algorithm (WOA), Simulated Annealing (SA) and hybrid (WOASA) algorithm. According to obtained results; hybrid WOASA algorithm is better than WOA and SA algorithm. Sucu et al.[9] investigated of buck converter using digital PI controller-based implementation. Çimen et al. [10] presented chaotic flower pollination algorithm (CFPA)-based optimal PID controller design for buck converter. When the proposed algorithm is compared with firefly algorithm (FA) and whale optimization algorithm, obtained results shows that this algorithm is better than the other algorithms.

ABC algorithm takes an example of the modeling the food search behavior of bees. In literature, ABC-based optimal PID controller design is applied such as, train traction control [11], robot arm control [12], voltage and frequency control [13], continuous stirred tank reactor [14], position synchronization of dual linear motors [15], automatic generation control for interconnected reheat thermal power system [16] and DC motor [17]. Finally, engineering applications of ABC, modified-ABC and hybrid-ABC algorithms are reviewed [18].

In this study, the PI, PD and PID gain parameters of the converter are optimized using the ABC algorithm for the voltage fluctuations reduction. This study focuses on the improvement of dynamic behavior of the buck

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converter using the ABC algorithm. In addition, PI, PD and PID controller's gain parameters are optimized and compared.

2. Materials and Methods

In this study, firstly, step down or buck converter mathematically modeled. And then, PI, PD and PID gain parameters of the buck converter are optimized for optimal PID controller design. ABC algorithm is selected for optimal controller design of DC-DC converter. In this section, informations about DC-DC converter, PID control and ABC algorithm are presented above.

2.1. DC-DC Buck Converter

A buck converter circuit is shown in Fig 1. This circuit operates in two modes. Here, inductor current flows on inductor L, capacitor C, and load resistance R in Mod1 (S switch is closed). In Mod2 (S switch is off), inductor current starts to decrease, and thus it flows on the capacitor C, load resistance L and diode D. The buck converter parameters used in this study are given in Table 1.

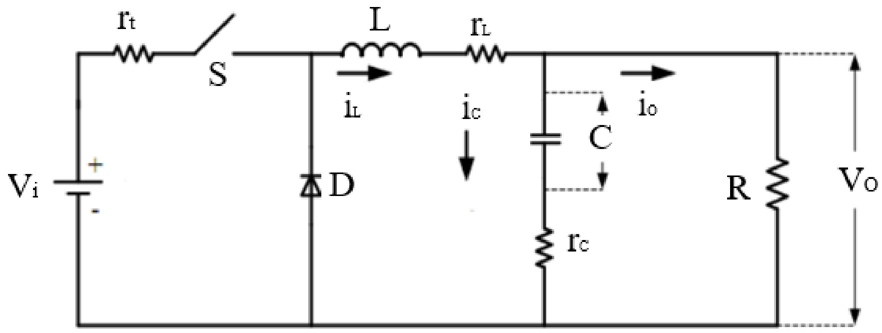

Figure 1. *Buck converter circuit diagram.*

Table 1. *The significant parameters of the buck converter*

Parameters	Value
Input Voltage (Vi)	35 V
Filter Coil	L-420 µH, rL=0.7 Ω
Filter Capacitor	C-1450 µF, rC=1.18 Ω
Switching Frequency (f_S)	100 kHz
Resistance of Switch (r_t)	0.2 Ω
Resistance of Diode (r_d)	0.7 Ω
Load Resistance (R)	118 Ω

Buck converter is step down chopper which converts unregulated DC to regulated DC. The chopper is operated by turning the switch (S) on/off at a high switching frequency switch is controlled by a pulse-width modulator (PWM) and it is turned on/off at a switching frequency (f_s) and duty cycle (D) and their relationship is given in Eq. (1) [19]. Thus, output voltage (V_o) is obtained by multiplying the input voltage (V_i) and duty cycle (D). In other words, V_o is determined by duty cycle as:

$$D = f_s t_{on} = \frac{t_{on}}{T} = \frac{t_{on}}{t_{on}+t_{off}} \quad (1)$$

where t_{on} is the time interval when the S is on/closed and t_{off} is the time interval when the S is off/open. Buck converter can be modeled by extracting of input/output voltage equations based on Kirchoff's voltage law. Diode is assumed as an ideal component. And then, voltage-current equations are written according to on and off cases of switch, considering resistance of semiconductor switch device [20], as expressed by:

$$L\frac{di_L(t)}{dt} = V_i(t) - [r_t + r_L]i_L(t) - V_o(t) \quad (2)$$

$$i_c(t) = i_L(t) - i_o(t) \quad (3)$$

$$C\frac{dv_c(t)}{t} = i_L(t) - \frac{V_o(t)}{R} \quad (4)$$

$$V_o = r_c i_c(t) + v_c(t) \quad (5)$$

The mathematical modeling of the buck converter is above. In this model, switch of the converter is driven by PID controller. So, duty cycle of the buck converter is controlled for regulate voltage. The PID controller is composed of a combination of Proportional (P), Integral (I) and Derivative (D) controllers. Therefore, it is called three term controller. It has got simple structure, good performance and wide range of applications, so it has been popular in the academic and industrial sectors. While it is designing, firstly control parameter is determined. The expression of parallel PID controller is given as follow;

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt} \quad (6)$$

where e(t) shows the difference between reference and actual values, u(t) denotes the control signal. The K_p, K_i and K_d express respectively proportional, integral and derivative gain parameters of controller. The rise time is reduced by K_p gain parameter. Overshoot and setting time are decreased by the value of K_d. The steady-state error is eliminated by K_i. The performance of the PID controller depends on the accuracy of its parameters. So, the controller gain parameters need to be adjusted to appropriate values [21].

An integral Time Absolute Error (ITAE) criterion is used in the optimization process done by the ABC algorithm. While the effect of error which occurred in beginning on the total errors is low in terms of ITAE criteria, it increases depend on time. These errors are too high at continuous oscillation systems. Here, ITAE expression is seen in Eq. (7).

$$ITAE = \sum |te(t)| \quad (7)$$

In this study, the buck converter is mathematically modeled for optimization process. Then suitable PID gain parameter values are obtained by the artificial bee colony (ABC) algorithm. The optimization process of the buck converter is illustrated in Fig. 2. In this process, PID parameters are determined by ABC algorithm. In this way, PWM control unit is controlled and switch of the power converter is drived. Thus, dynamic behavior of the converter is investigated to reference and instant output voltages' differences. So, meta-heuristic algorithm-based optimal PID controller is designed.

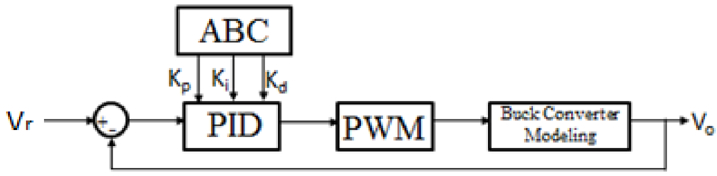

Figure 2. *The optimal PID control process of the buck converter.*

2.2. Artificial Bee Colony Algorithm

ABC algorithm was proposed by Karaboga [22]. Its performance was examined and compared with other optimization algorithms such as GA and Particle Swarm Optimization (PSO). These general results showed that ABC algorithm has better than other algorithms [23].

In the ABC algorithm, each cycle of the search take places three steps. Firstly; sending the employed bees onto the food sources and then measuring their nectar amounts are primary step. Secondly; selecting of the food sources by the onlookers after sharing the information of employed bees and determining the nectar amount of the foods processes are second step. And finally third step is determining the scout bees and then sending them onto possible food sources. The position of a food source indicates available solution of the optimization problem and the nectar amount of a food source fits to the quality (fitness) of the related solution. The number of the employed or the onlooker bees is same with the number of solutions in the population [24]. Analogously, in the optimization context, the position of a food source represents a candidate solution of the optimization problem and the nectar amount of a food source corresponds to the quality (fitness) of the associated solution. Detailed information about ABC algorithm is available in the literature [25-26]. Selected ABC parameter values to optimize the buck converter are given in Table 2.

Table 2. *The selected data values about the ABC algorithm*

ABC parameters	Value
Colony Size	50
Maximum Cycle	200
Parameter Intervals	0-4
Limit	100
Runtime	1

3. Results and Discussion

In this study, buck converter is mathematically modeled for optimal PID controller design. Best PID parameters are determined based on mathematical modeling using the meta-heuristic ABC algorithm. Obtained results are given and discussed below.

Step-down or buck converters decrease the output voltages. So, output voltage is lower than input voltages. Output voltage or current of the power converter is adjusted by PWM-based duty cycle ratio control unit. Thus, regulated output voltage or current is supplied to power load.

In the scope of this study, input and output voltages are selected as 35 V and 12 V, respectively. PI, PD and PID based PWM control studies are done for optimal constant output voltage control. Obtained optimal PI, PD and PID gain parameters are given in Table 3. As seen this table, K_P is over than 3 for all controllers. Integrator gain parameter (K_i) is 3.2011 also for PI controller. However, this parameter is very small for PID controller and its value is 1.5947. K_i parameter changing is half-and-half. However, derivative gain parameter (K_d) is near to limited value. Time-dependent absolute error (ITAE) and output voltage variation of these controllers are given in Table 3 and Figure 3, respectively. Obtained results show that PID control is better than PI and PD controllers. Output voltage variations and ITAE is lower than other controller. While the ITAE value of PID controller is 0.0125, it is 0.0164 and 0.0173 for PI and PD controllers. So, optimal control of the power converter is carried out. Meta-heuristic algorithm is helpful for optimal control of the power electronic control unit.

Table 3 *Optimal PID controller gain parameter results*

Controller	Kp	Ki	Kd	ITAE
PI	3.8287	3.2011	-	0.0164
PD	3.2589	-	0.5079	0.0173
PID	3.7560	1.5947	3.6623	0.0125

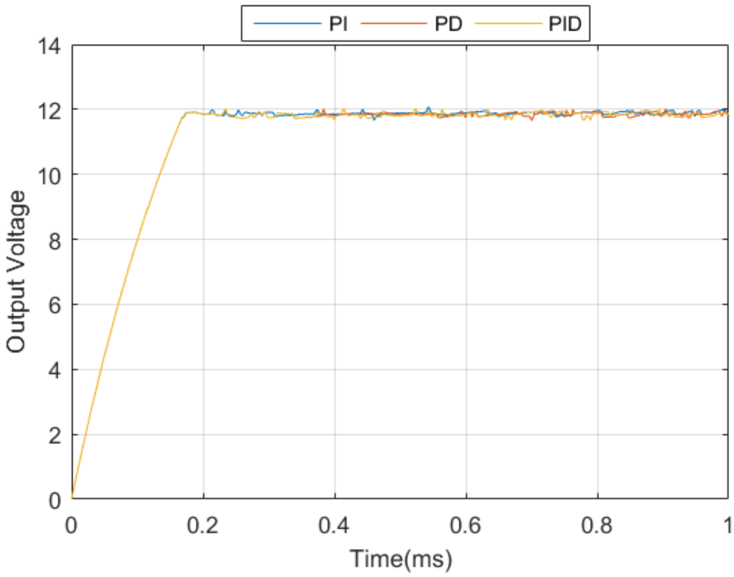

Figure 3. *Output voltage variations for optimal PID control of buck converter*

4. Conclusions

In this study, optimal gain parameter of PI, PD and PID controllers were investigated for step-down converter using meta-heuristic algorithm. Step-down converter was modeled and controlled by PID controller for regulated output voltages. Meta-heuristic process was done in order to decrease the output voltage variations. According to obtained results; PID controller is better than PI and PD controllers. Its time dependent error is more lees. So, optimal PID control of the buck convert was carried out. Meta-heuristic ABC algorithm is proposed for optimal control of power electronic circuit and engineering problems.

Nomenclature

Abbreviations

ABC	artificial bee colony
CFPA	chaos flower pollination algorithm
FA	firefly algorithm
FL	fuzzy logic
GA	genetic algorithm
PID	proportional, integral, derivative
PWM	pulse width modulation
SA	simulated annealing algorithm
WOA	whale optimization algorithm

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