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DESIGN OF OPTIMIZED PID CONTROLLER BASED ON ABC ALGORITHM FOR BUCK CONVERTERS WITH UNCERTAINTIES

IBRAHIM K. MOHAMMED

College of Electronics Engineering, Systems and Control
Engineering Department, Ninevah University, Mosul, Iraq
E-mail: ibrahim.mohammed@uoninevah.edu.iq

Abstract

In this study, a Proportional Integral Derivative (PID) controller is employed in feedback control of buck power converter system. The plant of the converter is mathematically modelled and then a lead compensator followed by an Integrator (I) is designed to achieve an output voltage regulation for buck converter. In this work, the PID controller is developed by using an Artificial Bee Colony (ABC) optimization algorithm, which is employed to obtain best values for controller gain parameters. MATLAB/Simulink environment is used to simulate the regulation behavior of the presented buck converter. The tracking performance of the optimized ABC-PID controller for the desired input trajectories is analysed based on standard control criteria, which includes rising time, settling time, overshoot and steady-state error parameters. Voltage regulation ability of the converter based on the optimized ABC-PID control is verified under three working conditions: variation in source voltage, reference voltage and load resistance. The closed-loop Buck converter with working perturbations is implemented using Simscape Simulink library without needing to derive a complex mathematical model. Finally, simulation results reveal that the proposed PID controller based on ABC tuning approach can be adopted to effectively adjust the output voltage of the Buck converter with uncertainties.

Keywords: Artificial bee colony, Buck converter, Optimization algorithm, Proportional integral derivative, Voltage regulation.

1. Introduction

The switching mode DC-DC converters are electronic devices that widely used in telecommunications, computer hardware, microprocessors, embedded systems, distributed power architectures and industrial applications [1-5]. Power converters are mainly classified into six categories which are Buck, Boost, Buck-Boost, Zeta, Sepic, and Cuk. Among these switching mode power converters, Buck DC-DC converters are incredibly used in wide applications fields due to their great simplicity in structure, easy to implement in hardware, performance reliability, highly efficient power distribution and reasonable cost [6, 7]. This conversion technique is a powerful approach to produce a desired output DC voltage irrespective of variations in input supply and load. Buck converter converts the input DC voltage to a specified output voltage at very high frequency.

It is worth considering that delivering a stable output DC voltage is subject to converter's uncertainties problems such as variation in voltage source, reference voltage and load resistance, which can lead to unstable output characteristics and performance degradation. To overcome effect of these variations problems and achieve a tight voltage regulation, a proper a closed-loop control system should be applied to the converter. Design a DC-DC Buck converter with a feedback control that is able to provide a regulated and stable DC output voltage for various applications is a topic that has attracted a lot of attention and incredible interest from power engineers.

A number of modern control approaches such as optimal control [8], pole placement [9], Linear Quadratic Regulator (LQR) control [10, 11], Linear Quadratic Qaussian (LQG) control [12], Sliding Mode (SM) control [13-17], geometric approach [18], robust control [7, 19], adaptive control [20] and hybrid controllers [21] etc. have been proposed to enhance the dynamic performance of power electronics buck regulators. Although, several control techniques are available for feedback operation of Buck power converter but, only PID controller technique is still most popular and powerful approach due to its simplicity in hardware setup as well as software implementation [22, 23].

Al-Greer et al. [24] introduced a comprehensive study in system identification techniques for power electronics applications. They presented parametric, non-parametric and dual hybrid identification approaches for DC-DC switch mode power converter applications, including health monitoring and fault detection. Parametric and non-parametric estimation algorithms are used to identify the model of the DC-DC buck converter. The estimated parameters are adopted to tune the PID controller used to regulate the output voltage of the buck converter.

In [25-27] the authors proposed an alternative controller approach to the classic PID controller technique for voltage control of DC-DC power converters. They used an adaptive PD compensator with an integral controller in the feedback loop.

The performance of the proposed adaptive regulation system is improved by using an adaptive Finite Impulse Response (FIR) prediction filter based on Recursive Least Square (RLS) with Dichotomous Coordinate Descent (DCD) algorithm, which is employed to reduce the prediction error signal. However, the performance of the proposed adaptive control system is not evaluated based on the working disturbances such as variation in supply voltage, reference voltage and load resistance.

Furthermore, a comparison between the control performance of digital PID controller and fuzzy controller for buck and buck-boost converters applications is presented by Guo et al. [28]. The comparison was based on the design methodology and regulation behaviour of the controllers. However, the proposed controller is not optimized by using numerical optimization algorithms, where the gain parameters of the controller are tuned manually by using trial and error approach.

In order to overcome the above issues, a new structure PID controller system is proposed in this paper to stabilize the output voltage of power converters under different working disturbances. In this work, a lead compensator followed by an integrator (I) is employed to implement the feedback control for DC-DC Buck converter system with disturbances.

Generally, the main challenge in implementation of controllers for Buck converters is the tuning of their gain parameters. In the presented controllers, the gain parameters are tuned manually using trial and error procedure that consumes more time and effort [29]. Consequently, there is no guarantee for achieving best performance. In order to improve the dynamic performance of Buck converters and achieve desired regulation response, the controller parameters should be tuned properly. The classic tuning approaches are used to optimize the performance of the closed-loop control system of Buck converters [30-33]. They employed classical frequency response techniques such as root locus-type and Ziegler-Nicholas methods to obtain best values of PID controller gain parameters. However, the proposed standard methods are insufficient in some solution processes due to early convergence or long calculating time. To overcome these drawbacks numerical techniques for obtaining optimal global solution of control problems under specific constraints called optimization algorithms are applied to find optimum values for controller gain parameters.

During the last decades, many intelligent optimization methods; Genetic Algorithm (GA) [34, 35], Bacterial Foraging Optimization (BFO) algorithm [36], [37], Particle Swarm Optimization (PSO) algorithm [38, 39], Big Bang-Big Crunch (BBBC) algorithm [1] and Fuzzy Logic (FL) [40] are successfully used by several researchers to optimize the feedback PID controller of buck power converters. However, there are some drawbacks and problems in implementation of these optimization algorithms. GA cannot be used to solve complex optimization systems due to the problems of emarture convergence and large number of iterations. Using the BFO algorithm to optimize unconstraint problems can lead to a local solution rather than the global one due to some drawbacks such as fixed chemotactic step size and the weak connection between bacteria. Regarding the PSO algorithm, obtaining an optimal global solution for control problems faces some difficulties such as defining initial algorithm parameters, working out the scattering problems and trapping into a local convergence especially with complex problems. While the BBBC algorithm has some drawbacks such as slow convergence and trapping in a local optimal solution. Sonmez et al. [40] used ABC algorithm to optimize the proposed PID controller however, the performance robustness of the employed ABC-PID controller is not verified based on hard working disturbances.

In this study, a PID controller is used to regulate output voltage of Buck converter, which is performed by a lead compensator (PD controller) followed by an integrator (I). ABC algorithm is adopted to tune the gain elements of the proposed lead compensator (PD controller) due to its simplicity in structure and ability to give strong solutions for various control problems [41]. Three hard input disturbances, variation in input voltage, reference voltage and load resistance are taken into consideration to verify the robustness of the proposed controller. In this work, the model of the converter with perturbations is constructed using Simulink Simscape electrical and power systems library. The model of the buck converter associated with the optimized feedback ABC-PID controller is simulated using MATLAB/Simulink software to investigate the performance characteristics of the proposed closed-loop buck regulator.

The rest of paper is organized as follows; configuration and dynamic modelling of buck regulator is given in section 2. Section 3 presents controller technique of the converter. Optimization method is introduced in Section 4. In section 5, control design of the proposed closed-loop power converter is described. Simulation results of Buck converter are obtained in section 6, followed by concluding remarks that given in section 7.

2. System Configuration and Modelling

2.1. Converter structure

The Buck regulator is a switched mode DC-DC power converter which produces an output voltage less than the input voltage, therefore, it is known as step down converter. The electric circuit of the ideal Buck converter is shown in Fig. 1. It is composing of controllable switch power MOSFET transistor, a freewheeling diode *D,* an inductor *L*, a filter capacitor *C*, and a load resistor *R*. In the converter circuit, the diode is used a controlled switch to achieve unidirectional power flow from input to output.

The inductor works as an energy storage that maintains flowing the current through the load during the OFF period of MOSFET. While the capacitor is employed to filter noise and reduce the ripple in the output voltage of the Buck regulator. The converter is operating with switching period (*T*) and duty cycle (*d*). It is worth considering that the converter has non-linear operating behavior due to using inductor and capacitor. Therefore, the system is linearized within certain range and time-period through utilizing the State Space Averaging (SSA) technique, which is a very common solution.

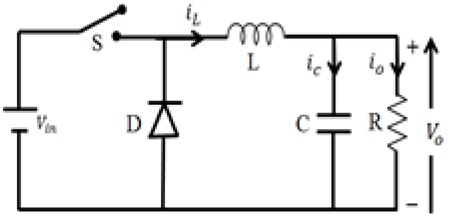


Fig. 1. Schematic diagram of a DC-DC Buck converter circuit.

2.2. System modelling

In this study, it is assumed that all the components of the Buck circuit are ideal, and the converter operates in Continuous Conduction Mode (CCM). In this mode, the current of the inductor flows continuously during the switching period (*T*). The operation of the Buck converter bases on the switching function. Therefore, based on the switch state, two electric circuits are considered, one for the ON state and other for the OFF state.

2.2.1 Switch ON mode

During the ON time T_{on}, the diode is reverse biased, and the supply voltage is directly connected to load through the inductor. The inductor current flows through the switch. The schematic circuit of the converter is shown in Fig. 2.

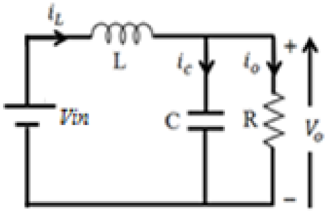


Fig. 2. Buck converter circuit based on switch ON state.

In this mode, $0 < t < d$ the inductor voltage is given by:

$$L\frac{di_L(t)}{dt} = V_{in} - V_o \tag{1}$$

while the capacitor current is as follows:

$$C\frac{dV_c(t)}{dt} = i_L(t) - i_o(t) \tag{2}$$

The state variables of the system are the inductor current and capacitor voltage. The state vector $x(t) = [x_1(t) \quad x_2(t)]^T = [i_L(t) \quad V_c(t)]^T$. The applied voltage to the Buck converter is considered the control input's vector such that, $u(t) = V_{in}(t)$. Based on Eqs. (1) and (2), the state space formulation is represented by the following state and output equations.

$$\begin{bmatrix} \dot{i}_L(t) \\ \dot{V}_c(t) \end{bmatrix} = \begin{bmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & \frac{1}{RC} \end{bmatrix} \begin{bmatrix} i_L(t) \\ V_c(t) \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} V_{in}(t) \tag{3}$$

$$y(t) = \begin{bmatrix} 0 & 1 \end{bmatrix} \begin{bmatrix} i_L(t) \\ V_c(t) \end{bmatrix} \tag{4}$$

$$\dot{x}(t) = A_1 x(t) + B_1 u(t) \tag{5}$$

$$y(t) = Cx(t) \tag{6}$$

where $A_1 = \begin{bmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & \frac{1}{RC} \end{bmatrix}$, $B_1 = \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix}$ and $C_1 = \begin{bmatrix} 0 & 1 \end{bmatrix}$

2.2.2 Switch OFF mode

During the OFF state of the switch, the freewheeling diode gets ON and provides a path to dissipate the stored energy in the inductor through the load resistor as shown in Fig. 3.

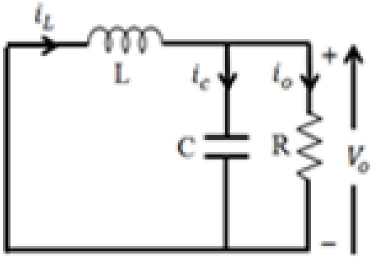


Fig. 3. Buck converter circuit based on switch OFF state.

In this working mode, $d < t < T$, the inductor current and capacitor voltage of the system are given by Eqs. (7) and (8) respectively.

$$\frac{di_L(t)}{dt} = -\frac{V_c(t)}{L} \tag{7}$$

$$\frac{dV_c(t)}{dt} = \frac{i_L(t)}{C} - \frac{V_C(t)}{RC} \tag{8}$$

The state and output equations of the Buck converter based on turn OFF switch are given by Eqs. (9) and (10) respectively.

$$\begin{bmatrix} \dot{i}_L(t) \\ \dot{V}_c(t) \end{bmatrix} = \begin{bmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & \frac{1}{RC} \end{bmatrix} \begin{bmatrix} i_L(t) \\ V_c(t) \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \end{bmatrix} V_{in}(t) \tag{9}$$

$$y(t) = \begin{bmatrix} 0 & 1 \end{bmatrix} \begin{bmatrix} i_L(t) \\ V_c(t) \end{bmatrix} \tag{10}$$

$$\dot{x}(t) = A_2 x(t) + B_2 u(t) \tag{11}$$

$$y(t) = C_2 x(t) \tag{12}$$

where $A_2 = \begin{bmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & \frac{1}{RC} \end{bmatrix}$, $B_2 = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$ and $C_2 = \begin{bmatrix} 0 & 1 \end{bmatrix}$.

The output equations in both working switch modes are the same. Using the state space averaging method, based on Eqs. (3), (9) and (10) the averaged state and output equations of the converter is obtained as below:

$$\dot{x}(t) = Ax(t) + Bu(t) \tag{13}$$

$$y(t) = Cx(t) \tag{14}$$

where $A = A_1 d + (1-d)A_2 = \begin{bmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{RC} \end{bmatrix}, B = B_1 d + (1-d)B_2 = \begin{bmatrix} \frac{d}{L} \\ 0 \end{bmatrix},$

$C = C_1 d + (1-d)C_2 = \begin{bmatrix} 0 & 1 \end{bmatrix}$

Taking the Laplace transform of Eq. (13), the transfer function of the DC-DC Buck converter system with respect to supply voltage is given by Eq. (15).

$$\frac{V_o(s)}{V_{in}(s)} = C(sI - A)^{-1} B + D \tag{15}$$

Based on Eqs. (13) and (14), the transfer function equation of the converter system Eq. (15) is expressed as follows:

$$\frac{V_o(s)}{V_{in}(s)} = \frac{\frac{d}{LC}}{s^2 + \frac{1}{RC}s + \frac{1}{LC}} \tag{16a}$$

$$\frac{V_o(s)}{d} = \frac{\frac{V_{in}(s)}{LC}}{s^2 + \frac{1}{RC}s + \frac{1}{LC}} \tag{16b}$$

In steady state, the average capacitor current is zero, then the inductor current equals the output current of the converter $(i_L(t) = i_o(t))$.

$$(V_{in}(t) - V_o(t))t_{on} = V_o(t)(T_s - T_{on}) \tag{17}$$

Based on the above equation the duty cycle (*d*) is given by:

$$d = \frac{T_{on}}{T} \tag{18}$$

3. Controller Technique

In this application, a PID controller (lead compensator followed by an integrator) is adopted to control the output voltage of Buck converter with known parameters as shown in Table 1. During the last decades, despite the continuous advances in control theory that have been seen during the last decades, the PID controller still the most popular control technique for wide industrial engineering applications.

Table 1. Electrical parameters of Buck converter.

Parameter	Symbol	Value
Source voltage	V_{in}	24 V
Resistor	R	10 Ω
Capacitor	C	220 μf
Inductor	L	0.5 H
Switching Frequency	f	10 Hz

The reason for this is not only due to its simple structure and easy to implement in practice, but also it provides adequate stable performance in various control problems. The PID controller is also known as "three term" controller as it is a composition of proportional, integral and differential. The standard time structure of the controller is as follows:

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)dt + K_d \frac{de(t)}{d\tau} \tag{19a}$$

where $u(t)$ is the controller command signal acting on the error signal $e(t)$, K_p, K_i, and K_d are the proportional, the integral and the derivative gain respectively. Taking the Laplace transform of the above equation, the s-domain transfer function of the controller is as follows:

$$G_{PID} = \frac{U(s)}{E(s)} = \frac{K_d s^2 + K_p s + K_i}{s} \tag{19b}$$

Lead compensator is one of the components of PID controller, it is essentially a PD controller. The transfer function of the lead compensator is given by:

$$G_c = \frac{U(s)}{E(s)} = c\frac{s+b}{s+a} \tag{20}$$

where a, b, and c are gain elements of lead compensator so that $|a|>|b|$. It can be employed to speed the response of the system and improve its stability.

4. Optimization Method

ABC method is one of the powerful and applicable optimizations algorithms that has been successfully applied to determine a potential solution for various types of optimisation problems [42] as it exhibits all the main required features for optimization algorithms such as low computational time, fast convergence to optimum value and flexibility. Consequently, ABC algorithm can be adopted as a promising tuning approach for finding optimum values of PID controller coefficients for Buck power converter. The procedure of the ABC tuning method proposed by Karaboga and Basturk [43, 44] is based on the foraging behavior of honeybees.

In this tuning method, the bee's colony is divided into three groups, employed bees (EB), onlookers (OL) and scouts (E), where each group performs different task during optimization process. The number of (EB) equals the number of food sources around the bee's hive. The possible solution of the optimisation problem is represented by the position of a food source. The quality of the solution is determined by the value of fitness function, which should be formulated based on desired performance characteristics parameters, rise time t_r, maximum overshoot M_o, settling time t_s and steady state tracking error e_{ss} [43].

The employed bees update the solution of the control problem through visiting food sources and looking for a better one in the neighbourhood of current solution. If the current food source has a greater objective value, it will be then saved by EB instead of previous one. The flowchart of the ABC tuning procedure used to optimize the proposed lead compensator PD is shown in Fig. 4, where SN represents the number of employed bees (food source), and D denotes the dimension of the control problem [namely a, b, c which are the gain elements of lead compensator] and MCN represents the maximum cycle number of ABC algorithm.

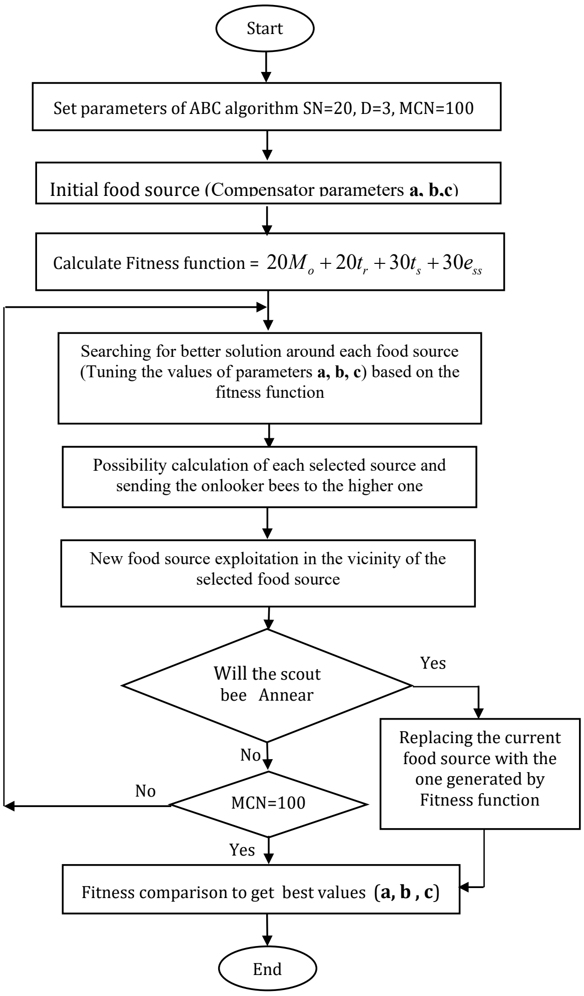


Fig. 4. Flowchart diagram of ABC tuning algorithm for Buck converter.

5. Control Design

A step-down DC-DC Buck converter is used to provide a stable desired output voltage. The basic diagram of the closed loop Buck converter is shown in Fig. 5.

The feedback control is based on PID controller which is designed to regulate the output voltage of Buck converter with uncertainties. The controller composes of a lead compensator followed by an integrator. The lead compensator is implied to speed the transient response and enhance the stability of the system, while the integrator is employed to generate Pulse Width Modulation (PWM) signals with varying duty cycle based on the output control signal of the lead compensator which are used to drive the switch device of buck converter. The integrator is served to reduce the steady state error of the system response.

In this work, the gain parameters of the controller are tuned using ABC optimization algorithm. The regulation performance of the closed-loop Buck converter is evaluated under three input disturbances, variation in input power, output voltage and load resistance, to verify the robustness of the proposed PID controller. The tracking performance of the optimized PID controller for the reference signal trajectories is evaluated based on parameters of transient and steady state responses which include rise and settling time, maximum overshoot and steady state error.

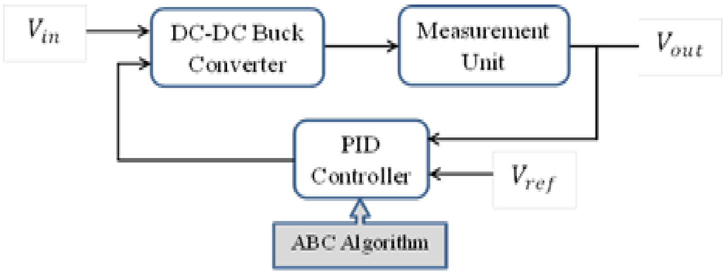


Fig. 5. Block diagram of ABC-PID control system for Buck converter.

In this paper, an optimized PD controller followed by an integrator system based on ABC optimization method is designed to improve the dynamic performance of Buck converter system through converting a varying DC input voltage (1-40 V) with operating frequency $f = 10$ kHz to a stable step and varying output voltage (1-5 V) under a specific and changing load resistance (1-10 Ω). The performance of control system is evaluated based on the transient and steady state performance characteristics, which are overshoot (M_o), rise time (t_r), settling time (t_s) and error steady state (e_{ss}) parameters. So, the suggested fitness function stated in (21) is formulated based on these parameters. The weight of these parameters is set depending on the required response: 20% for overshoot, 20% for rise time, 30% for settling time and 30% for error steady state.

In this study, ABC tuning algorithm is designed to minimize the proposed fitness function and meeting the following performance requirements: $t_r = 10$ s, $t_s = 0.7$ s, $M_o = 10\%$ and $e_{ss} = 0.02$ V through finding the optimized values of the gain parameters *a*, *b*, and *c* for the proposed PD controller.

$$f_t = 20M_o + 20t_t + 30t_s + 30e_{ss} \tag{21}$$

6. Simulation and Results

To verify the tracking performance of the proposed PID controller based on ABC algorithm for the Buck converter, the closed-loop converter system is simulated using MATLAB/Simulink environment. Figure 6 shows the Simulink diagram of the proposed DC-DC Buck converter with PID controller.

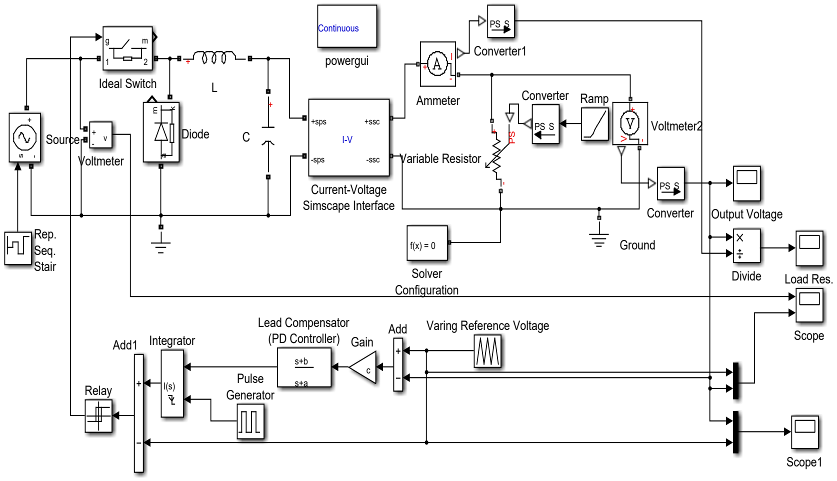
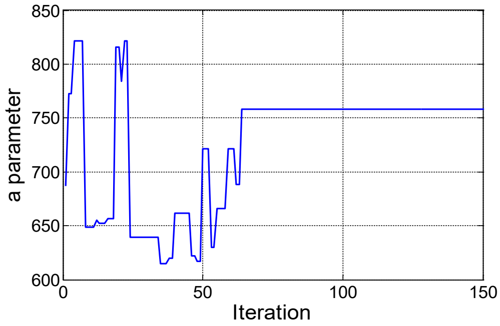


Fig. 6. Simulink model of closed-loop Buck converter based on ABC-PID.

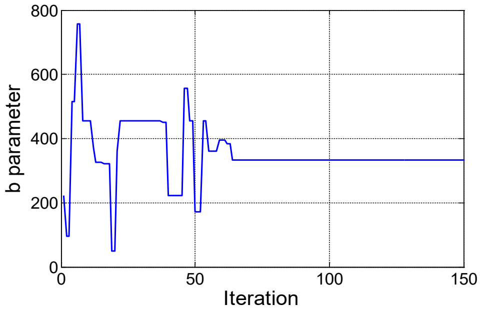
Most of the model components for the converter plant are inserted from Simulink power systems library, while the variable resistor is included from Simulink Simscape electrical components library. Coupling between power systems and Simscape components is achieved by a Current-Voltage Simscape interface block. This coupling unit performances a current source on the power systems components side and a voltage source on the load side.

In this study, the gain parameters of the PID controller used in the Simulink model are optimized using ABC tuning algorithm, which implemented in a MATLAB m.file script. The parameters values of the ABC algorithm used in all the simulation cases of the converter system with uncertainties are as follows: SN= 20, D=3 and MCN=100. The regulation performance and robustness of the optimized ABC-PID controller for Buck converter with a specified switching frequency of 10kHz are evaluated based on the following types of disturbances.

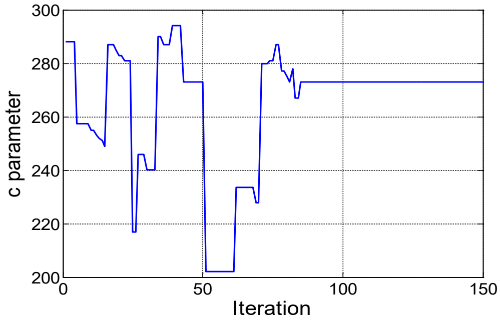
After tuning process using the ABC optimization algorithm, the optimized gain coefficients of the PID controller used in the below working conditions for the Buck converter are as follows: a = 758, b = 334, and c = 334. Figure 7 presents the converging process of the PID controller coefficients for Buck converter system through iteration using the ABC tuning method.



(a) Iteration of a parameter.



(b) Iteration of b parameter.



(c) Iteration of c parameter.

Fig. 7. Generation elements of ABC optimization algorithm based PID controller for Buck converter.

6.1. Case I: source voltage disturbance

In this case, the conversion performance of the Buck regulator system is investigated based on a sudden change in the converter source voltage. The optimized PID controller based on ABC tuning method is properly designed to provide a constant output DC voltage of 5 V across a specific load resistance of 10 Ω from varying input voltage with an assigned sequential repeated value of (20 – 30 – 10 – 40 V) during a period of 4 s. The output response and the input supply wave form of the closed-loop converter are illustrated in Figs. 8 and 9 respectively. From the mini figure of Fig. 8 it is clear that the Buck converter under action of the optimized ABC-PID controller succeeded to provide quick and smooth output response through delivering a stable output voltage efficiently without overshoot and minimal error steady state.

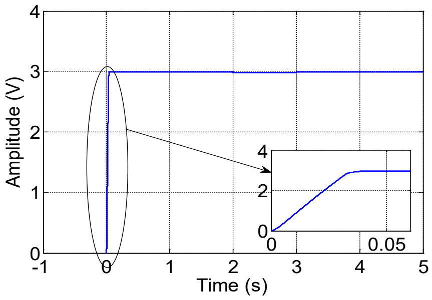


Fig. 8. Converter output based on variable source voltage.

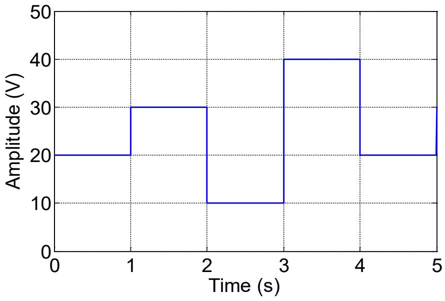


Fig. 9. Variation of converter supply voltage.

6.2. Case II: reference voltage disturbance

In the present case, the regulation performance of the Buck converter is evaluated based on repeated 0.5 Hz (1-10 V) triangle reference voltage signal during 5 s while keeping the source voltage unchangeable at 24 V and load resistance at 10 Ω. The waveform of the reference voltage and the converter output signal are shown in Fig. 10. It is obvious from Fig. 10, that the output voltage of the controlled Buck converter followed the desired input trajectory efficiently. The transient response of the captured voltage signal is fast, and overshoot is not existent while the error steady state is approximately of 3 mV

6.3. Case III: load resistance disturbance

A change in the load resistance value of the Buck converter is considered in this working case. In the present simulation, the voltage regulation performance of the Buck converter using the proposed ABC-PID controller is investigated under a linear variation in the load resistance (2-10Ω) during a period of 10 s while keeping the supply input at 24 V and reference input voltage at 5 V. Figure 11 reveals the output voltage of the converter for load resistance variations shown in Fig. 12. It is clear from Fig. 11, that the power converter based on ABC-PID controller is able to regulate its output signal effectively and deliver a stable and precise output voltage without overshoot and minimal steady state error.

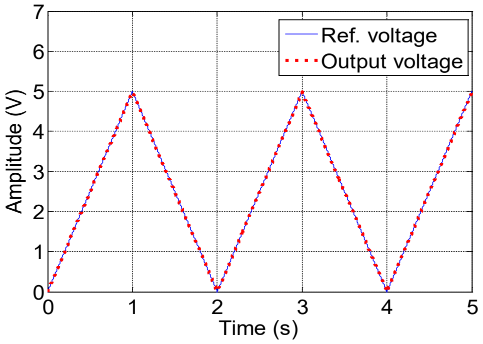


Fig. 10. Converter output based on reference input disturbance.

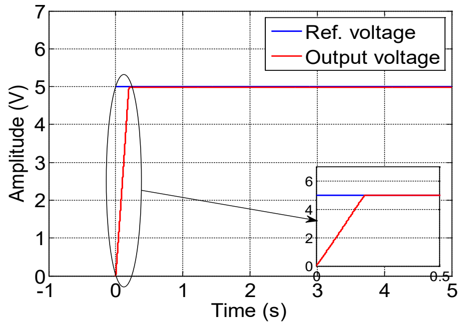


Fig. 11. Converter output based on resistance disturbance.

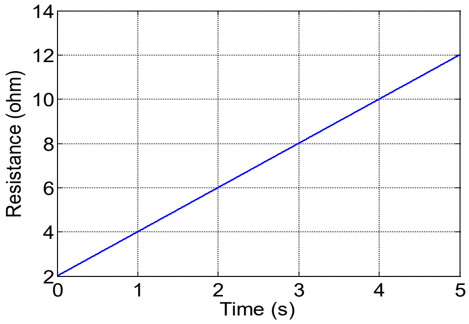


Fig. 12. Variation of load resistance.

6.4. Case VI: source, reference, and load disturbance

In this working case, three categories of uncertainties, variation in supply voltage, desired reference voltage and load resistance are considered in the converter model and its voltage regulation behavior is examined to validate the effectiveness of the proposed PID controller for Buck power converter. Under the same variation in the source voltage and load resistance that stated in Figs. 9 and 12 respectively, the desired reference input and the simulated output voltage of the Buck converter over time is illustrated in Fig. 13.

It can be clearly shown from Fig. 13 that the voltage-controlled Buck converter using an optimized ABC-PID controller followed the demand reference input trajectory efficiently without overshoot and minimal error steady state. To verify the regulation robustness of the presented closed-loop Buck converter, the tracking performance of the ABC-PID controller is investigated based on a 1 Hz square waveform reference input with 6 V amplitude.

Figure 14 presents reference voltage variation and closed-loop response of the voltage-controlled Buck converter using optimized ABC-PID controller. It is obvious from Fig. 14 that as the time progress the reference and converter output graphs become close together. The output of the Buck regulator under action of the optimized ABC-PID controller followed the desired reference input trajectory effectively with fast rise-fall times, no overshoot and minimal error steady state error. The good regulation performance of the closed-loop Buck converter under the above working disturbances conditions reveals the capability of the proposed PID controller based on ABC tuning algorithm to achieve an efficient tracking for the desired reference input voltage.

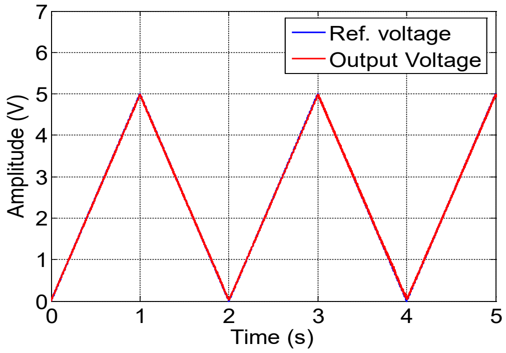


Fig. 13. Converter output based on supply and load disturbances under triangle reference input.

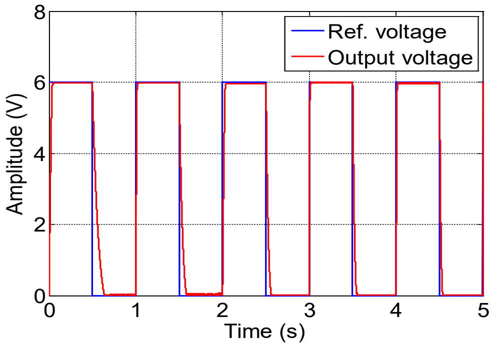


Fig. 14. Converter output based on supply voltage and load resistance disturbances under square waveform reference input.

7. Conclusion

Switching mode DC-DC Buck converter with uncertainties is adopted to provide a desired step-down voltage across load resistance. A lead compensator followed by an integrator is used to form the feedback control of the power converter. In this research, the proposed PID controller is optimized by employing ABC optimization algorithm, which is utilized to obtain optimum values for the controller gain parameters. The closed-loop Buck converter is modelled mathematically and then simulated using MATLAB tool to validate the proposed feedback PID controller for Buck regulator under uncertainties. In this study, three input disturbances, step variation in input and output voltages and change in the load resistance, are taken into consideration to verify the robustness of the optimized PID controller. The simulation results demonstrated the ability of the proposed ABC-PID controller to efficiently regulate the output of the Buck converter and deliver a stable voltage to the load with negligible perturbations.

In the future work, the presented voltage-controlled Buck converter with disturbances will be implemented in real time using digital signal processor to validate the proposed PID controller.

Nomenclatures

C	Capacitance, F
d	Duty cycle, s
D	Freewheeling diode
f	Switching frequency, Hz
L	Inductance, H
R	Resistance, Ω
T	Switching period, s
V_{in}	Input voltage, V

Abbreviations

ABC	Artificial Bee Colony
BFO	Bacteria Foraging Optimization
CCM	Continuous Conduction Mode
FL	Fuzzy Logic
GA	Genetic Algorithm
I	Integrator
LQG	Linear Quadratic Gaussian
LQR	Linear Quadratic Regulator
MOSFET	Metal-Oxide-Field-Effect Transistor
PD	Proportional Derivative
PID	Proportional Integral Derivative
PSO	Particle Swam Optimization
PWM	Pulse Width Modulation
SSA	State Space Averaging

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