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Optimal Fractional Order Controller Design for a DC Buck Converter

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Abstract: The inherent non-linear characteristics of power converters pose challenges in control, prompting a continuous and persistent search for intelligent and efficient controllers.In recent years, fractional-order controllers (FOCs) have performed well in electronic systems. Nevertheless, obtaining optimal parameters for these controllers in such systems continues to be a challenging task. This article introduces optimized controllers with fractional-order characteristics, specifically the fractional-order proportional-integral (FOPI), proportional-derivative (FOPD), and proportional-integral-derivative (FOPID) controllers,designed for the control of a DC buck converter through the utilization of the Mayfly optimization technique (MOA). The MOA draws its inspiration from the flight behavior and mating process of mayflies, and it amalgamates key benefits from both swarm intelligence and evolutionary algorithms.The proposed method combines the objectives of Zwe-Lee Gaing (ZLG) and the integral of squared error (ISE) into a new cost function. The results indicate that the utilization of the FOPID controller leads to improved closed-loop performance and strengthens the system's robustness. In contrast to the conventional controller, the MOA-FOPID controller exhibits enhanced transient and dynamic response characteristics.

Keywords: DC buck converter; Fractional calculus;Fractional order controller; Mayfly Optimization algorithm; Cost function

1. Introduction

The control system has seen a notable increase in usage recently because of their versatility and adaptability, rendering them suitable for a wide range of applications in various domains. The increasing technological requirements have led to the development of advanced controllers that can effectively handle complex processes. These controllers are designed to achieve high performance and optimal outcomes while adapting to fluctuations in parameters. Continuously emerging are novel methods for enhancing product quality and performance, enabled by the advancement of improved controllers. Even with these advancements, the PID controller continues to be extensively utilized in process control. Its popularity persists because of its simplicity and straightforward implementation despite the existence of more sophisticated alternatives[1,2]. The extensive adoption of traditional PID controllers has inspired researchers to pursue improved design methods and explore advancements in PID control structures. When dealing with real-world scenarios involving parametric and load variations, as well as non-linearities, the performance of a PID controller may be inadequate. In such cases, more advanced controllers are necessary to achieve a satisfactory response.

Over the past few decades, the control of power electronic systems has acquired considerable significance and evolved into a difficult endeavor that has attracted the interest of researchers. Power electronic equipment commonly employs DC converters for voltage regulation in a broad spectrum of applications, owing to their versatility and adaptability[3]. Efficiently managing power converters is crucial in optimizing the performance of power electronic systems. The primary objectives of control involve creating systems that are economical, dependable, and resilient, while also maximizing energy efficiency, minimizing space requirements, and simplifying complexity. The selection of an appropriate controller should be guided by criteria such as robustness, precision, and stability, in addition to evaluating the controller's dynamic performance, including its ability to swiftly respond and effectively handle disturbances, among other factors.The input voltage of a DC buck converter is decreased to a lower output voltage utilizing pulse-width modulation (PWM) techniques. DC buck converters exhibit inherently time-varying and non-linear characteristics owing to their switching mode, which generates switching transients, output voltage fluctuations, and produces harmonics when connected to the power system. Significant research efforts have been conducted on the development of more robust and effective controllers for power converters. Conventionally, these systems are controlled using widely adopted techniques such as PI/ PID control,predictive control, H_∞ control, sliding mode control as well as non-linear methods including fuzzy control and intelligent control[4-6]. Various researchers including Tsang and Chan[7], Diaz and Sariano[8], Abro et al.[9], Ling et al.[10], and Wang et al.[11] have explored distinct controller techniques to handle these buck converter perturbations. Developing an effective controller for the DC-DC buck converter is crucial to ensure the stability, efficiency, and reliability of systems. The nonlinear characteristics of buck converters presents difficulties in controller design[12]. In order to achieve resilience, dynamic responsiveness, and greater sensitivity to parameter disturbance, a complex control technique is therefore needed, elevating the importance of control to a new level.In response to these challenges, researchers have investigated various types of controllers to attain the desired system characteristics[13].Extensive research has been conducted, employing a variety of optimization approaches for DC-DC buck converters. In bothIzci et al.[14]and Izci and Ekinci[15], advanced metaheuristic algorithms have been employed to optimize FOPID controlles for DC-DC buck converters, establishing them as among the most effective systems in the domain. Sangeetha et al.[16] introduced an optimized FOPID controller for a DC-DC buck converter by employing a hybrid approach that combines Golden Jackal Optimization(GJO) and the Capuchin Search Algorithm (CapSA).

Fractional calculus (FC) has found widespread application in the domain of control systems. In this domain, fractional order (FO) differentiation and integration are harnessed within controllers. This approach extends the traditional integer-order calculus by incorporating a range of operators, including real, complex, variable, or distributed values[17]. This mathematical approach finds application in enhancing the precision of modeling and controlling dynamic systems. The advent of FC and its application to non-integer order controllers in a variety of technological domains haveled to significant improvements in closed-loop performance and robustness, compared to conventional PID controllers in recent decades. Recent research conducted in the field of FOCs demonstrates that these systems exhibit enhanced control capabilities under real-time operating conditions.The use of fractional derivatives and integrals in FO systems has led to the development of various non-integer controllers. These controllers include the FO integrator, FO differentiator, FOPI controller, FOPID controller, and others are some of these controllers. In contrast to a PID controller, a FO PI/PID controller usually requires additional parameters to be tuned since it includes additional parameters. Despite their similarity to PID controllers, FOPID controllers offer more flexibility for meeting various design specifications due to additional parameters[18]. The tuning challenge associated with FOCs can be offset by the increased degrees of freedom they offer, enabling the satisfaction of a wider range of designs. In comparison to PID controllers, FOCs are considered more desirable due to their enhanced capability to manage uncertainties and maintain stability during disturbances. Fractional order systems possess the advantageous property of iso-damping, which enhances their robustness in the face of gain variations. This quality renders them a more appealing choice when contrasted with linear PID controllers[19,20]. Such controllers have been applied to regulate the wide range of DC-DC converters including buck, boost, and buck-boost converters in diverse applications[21-24].A comprehensive overview of the utilization of FOC in different power electronics systems can be found in[25].

Fine-tuning the parameters for FOPID controllers can pose a challenge.Numerical techniques for controller design use a variety of optimization strategies, each accompanied by a specific algorithm chosen by the designer based on the application. The selection of cost functions in controller design often includes commonly used parameters such as control performance indices like integral absolute error (IAE), integral time absolute error (ITAE), integral of squared error (ISE), and integral of time squared error (ITSE),and time domain specifications.

In[26], the authors recommended a new estimation criterion that includes both time and frequency domains for the evaluation of the fitness function of the system. Even though numerous FOPID tuning methods are recommended in the literature, further research can still improve the optimal design, dynamic response, and stability of the FOPID controller.This work is focused on developing an optimal controller with a fractional order for the buck converter. The basic motivation behind this article include, a new cost function that combines the objectives of Zwe-Lee Gaing (ZLG) and ISE is proposed along with Mayfly optimization, to produce an output that depicts optimal performance indices and fine-tuning of FOPID controller for DC buck converter.

The paper’s organization is as follows: Section 2 provided an overview of the buck converter, fractional order systems, and fractional PID controller. Section 3, presents the fundamental methodology and optimization algorithms. Section 4 addresses the results and discussion, and finally, in section 5, the work is concluded.

2. Description of the system

2.1 Buck Converter

Switching-mode power converters are widely used in a variety of industries, such as electric vehicles, televisions, mobile devices, computers,and power management systems that make use of microprocessors. These converters are favored for their attributes such as high efficiency, rapid switching capabilities, compact size, and cost-effectiveness. Among the various converter types, the buck converter stands out as a switching-mode regulator engineered to transform a higher DC voltage into a lower magnitude DC voltage. The regulation is normally achieved by high-switching devices like MOSFET, BJT, or IGBT and pulse width modulation (PWM) at a particular frequency. Nevertheless, these converters are classified as variable structure systems and have inherent nonlinearities, potentially causing oscillations during their operation[27)]. To address this issue, researchers have extensively studied and analyzed different control techniques to minimize oscillations, especially in non-linear scenarios, during the converter's operation.

A DC-buck converter is a merge of a low-pass LC filter plus a PWM-based controller. The typical circuit is depicted in Fig.1.

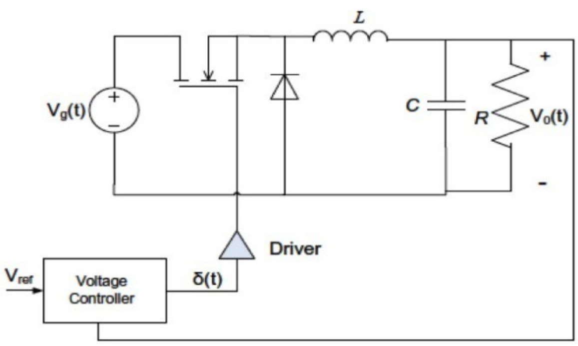

Fig. 1: Schematic of a buck converter with a voltage controller

The transfer function of the buck converter can be derived by comparing the Laplace transform of the regulated voltage to the input voltage of the PWM modulator, and it can be expressed as follows:

$$G(s) = \frac{V_{ref}}{LCs^2 + \left(\frac{L}{R} + R_L C\right)s + \left(1 + \frac{R_L}{R}\right)} \quad (1)$$

The parameter values of the buck converter are given in Table 1.

Table 1. DC buck converter specifications.

Parameter	**value**
Input Voltage, Vref(V)	207
Output Voltage, V_o(V)	55
Load Resistance, R(Ω)	1
Inductor Resistance, R_L(Ω)	0.052
Inductance, L(H)	0.692
Capacitance, C(F)	0.000003125

In[28)] the transfer function of the un-tuned designed buck converter is presented. The authors successfully applied the Nead-Mead technique to tune the parameters of the FOPID controller for the DC buck converter. The implementation of this controller yielded enhanced performance in the transient response of the device, as demonstrated by the simulation results.

$$G(s) = \frac{207}{2.1625 * 10^{-6}s^2 + 0.6920s + 1.052} \quad (2)$$

2.2 Fractional order system

Fractional calculus (FC) is a mathematical field that focuses on differentiating and integrating functions with non-integer orders, which can be real or even complex. In contrast to traditional calculus, fractional calculus involves derivatives and integrals with fractional orders. These fractional derivatives and integrals are described using an integro-differential operator as ${}_aD_t^\alpha$, where α represents the fractional order, while a and t denote the bounds of operations and $R(\alpha)$ signifies the real part of α[29)].

$$\begin{Bmatrix} \frac{d^\alpha}{dt^\alpha} & R(\alpha) > 0 \\ 1 & \alpha = 0 \\ \int_a^t (dt)^{-\alpha} & R(\alpha) < 0 \end{Bmatrix} \quad (3)$$

Numerous definitions of FC exist in the literature, with the Grunwald Letnikov, Riemann-Lioville, and Caputo definitions being the most widely adopted ones[30)]. Fundamentals and definitions of FOS can be found in[31)].

- Grunwald-Letnikov (GL) definition

$${}_aD_t^\alpha f(t) = \lim_{h\to 0} h^{-\alpha} \sum_{r=0}^{\left[\frac{t-a}{h}\right]} (-1)^r \binom{\alpha}{r} f(t - rh) \quad (4)$$

Here, [.] represents the integer part.

- Riemann-Liouville definition

$${}_aD_t^\alpha f(t) = \frac{1}{\Gamma(p-\alpha)} \left(\frac{d}{dt}\right)^p \int_a^t \frac{f(\tau)}{(t-\tau)^{\alpha-p+1}} d\tau \quad (5)$$

- Caputo's Explanation

$${}_0D_t^\alpha f(t) = \frac{1}{\Gamma(p-\alpha)} \int_0^t \frac{f^{(p)}(\tau)}{(t-\tau)^{\alpha-p+1}} d\tau \quad (6)$$

In these equations, p represents an integer, and α denotes a non-integer value between $p-1$ and p.

2.3 Fractional order PID Controller

The concept of FC is relevant to FOC where controller parameters include fractional orders.To enhance the tuning of control parameters in fractional order control, two additional parameters are introduced alongside the conventional three parameters. This inclusion leads to increased complexity and flexibility in the tuning process. To optimize the adjustment of these parameters in FOC, various analytical methods and numerical techniques have been extensively investigated in[19,32]. Various approximation techniques exist in the literature for converting non-integer into integer order systems. The Oustaloup recursive approximation, proposed in[33] is widely adopted to obtain nearly accurate values of fractional operators within a specified frequency range (w_b, w_h). FOC's standard mathematical output is as follows:

$$C_{FOPID}(s) = K_p + \frac{K_i}{s^{\lambda}} + K_d.s^{\mu} \quad ,0 < (\lambda, \mu) < 2 \tag{7}$$

The FOC employs integral and differential orders λ and μ, respectively, which range from 0 to 2. To approximate the FOCs, Oustaloup method has been utilized, with a frequency band $10^{-3} - 10^{+3}\text{rad/sec}$ and an approximation order of 5. All classical controllers can be achieved with the FOPID controller by combining various sets of λ and μ values. By extending the traditional controller to a fractional controller, more design flexibility is provided, resulting in more precise control of real-world processes. In order to identify the parameters of the FOPID controller, fractional differential equations are solved using optimization algorithms.

3. Methodology

3.1 Fine tuning of Fractional order controller

The cost function plays a pivotal role in optimizing controllers for any control system, and it relies on the error signal for fine-tuning the controller's parameters. The parameters (K_p, K_i, K_d,λ,μ) are then generated from each optimization algorithm and fed into the buck converter. The lower and upper bounds of the $PI^{\lambda}D^{\mu}$controller are specified as follows: K_p= (0.1,120), K_i= (0.1,70), K_d= (0.1,50), λ= (0.1,1.5) μ= (0.1,1.4). The system then recalculates the error value and repeats the procedure till the termination criteria are achieved. The cost function uses steady-state error, rise time, settling time, and overshoot as input during each iteration to generate an optimum value of the cost function.

3.2 Cost Function

A cost function serves as a numerical expression that must be maximized or minimized using an appropriate optimization algorithm. By optimizing the cost function, it is possible to derive the optimal system variables. While numerous cost functions have been suggested in the field,most of them can be expressed as weighted combinations of controller parameters and system error. A few new objective functions are represented in[34-37] which are used for minimizing errors and enhancing the performance metrics.The presence of these weighting factors often complicates and prolongs the optimization process, resulting in higher-dimensional optimization issues. In the literature, four commonly used cost functions IAE, ITAE, ISE, and ITSE are employed for selecting the optimum gains of a FOPID controller. Additional weighting factors are not required when using these performance indices as objective functions. Performance indices serve as metrics for assessing the effectiveness of closed-loop control systems, and they are derived from error signals. In optimal control, these indices are utilized to adjust system parameters in such a way that the index is minimized[38]. The ISE is a specific type of performance index that places greater emphasis on penalizing large errors while disregarding minor errors[39].The absence of the weighting factors makes the proposed cost function easy to use and efficient.In this work, a cost function (ZLG) defined in[36] is combined with ISE functions individually to form a single objective function. The mathematical formula is defined as:

$$\text{J} = \left(1 - e^{-\beta}\right).\left(M_p + E_{ss}\right) + e^{-\beta}.\left(T_s + T_r\right) + ISE \tag{8}$$

The proposed cost function along with the Mayfly optimizer, produces an output that depicts optimal performance indices and optimal tuning of the FOPID controller for the DC buck converter.

3.3 Optimization Algorithm

There is no single optimization algorithm that can effectively address all optimization challenges. The behavior of different optimizers is quite similar, and despite the widespread use of optimization algorithms, many problems remain unsolved[40,41]. To tackle these issues, the development of a new algorithm becomes essential. The optimization problems encountered in various engineering fields are highly complex, and traditional approaches, while unique, are not universally applicable. They typically rely on specific solutions tailored to particular problems, limiting their versatility due to various shortcomings. Consequently, solving real-world problems using traditional techniques is challenging, leading to the extensive adoption of meta-heuristic optimization methods. These methods are becoming increasingly popular because they are easy to implement, capable of avoiding local optima, and adaptable to a wide range of challenges across diverse domains. In this work, a newly developed optimizer algorithm is used to enhance the characteristic behavior of a DC buck converter.

3.3.1 Mayfly Optimizer:

In 2020, K. Zervoudakis and S. Tsafarakproposed a novel optimization method, called the Mayfly optimization algorithm[42,43)](MOA). This proposed optimization is a modification of PSO that combines the main benefits of PSO[44)], GA[45)], and the firefly algorithm[46)]. It offers an efficient hybrid algorithm based on mayfly behavior, the performance of the PSO algorithm with cross technique, and local search. To achieve coordinated and simultaneous tuning of supplementary damping controller parameters, MOA was employed[47)].In the MOA, mayflies in swarms would indeed be differentiated into masculine and feminine individuals. Since masculine mayflies are stronger,their performance is better in optimization. Individuals in the MOAs, like those in PSO swarms, would update their positions at the current iteration based on their velocity $V_i(t)$ and recentlocation $Y_i(t)$. Though the masculine and feminine mayflies would use Eq. (9) to update their positions and the velocity of the mayflies will vary in different ways.

$$Y_i(t+1) = Y_i(t) + V_i(t+1) \tag{9}$$

- **Masculine mayflies moving action:**

Even when swarms of male mayflies are gathered, they persist in their exploration and exploitation activities. The adjustment of their velocity is influenced by their current fitness values, denoted as$F(z_i)$, as well as the optimal fitness values from past trajectories, denoted as $F(z_{h_i})$. When $F(z_i)$ surpasses $F(z_{h_i})$, these male mayflies enhance their velocities by considering their recent speeds, the gap between these speeds, and the global optimal location, along with historical best trajectories.

$$V_i(t+1) = \mathrm{g}.V_i(t) + a_1 e^{-\beta r_p^2}\left[z_{h_i} - z_i(t)\right] + a_2 e^{-\beta r_g^2}\left[z_g - z_i(t)\right] \tag{10}$$

The variable g undergoes a linear descent from its maximum to minimum values. To achieve a balance in the values, constants a_1, a_2, and β were employed. The variables r_p and $r_g$represent the Cartesian distances between individuals and their respective previous best positions, as well as the global best position. The second element in the distance array corresponds to the Cartesian distance.

$$\left\|z_i - z_j\right\| = \sqrt{\sum_{k=1}^{n}\left(z_{ik} - z_{jk}\right)^2} \tag{11}$$

If $F(z_i) < F(z_{h_i})$, male mayflies will adjust their velocities by transitioning from recent velocities to a new random dance coefficient d.

$$V_i(t+1) = g.V_i(t) + \mathrm{d}r_1 \tag{12}$$

Where r_1 is defined randomly within [-1,1] uniformly.

- **Feminine mayflies moving action:**

The velocities of feminine mayflies exhibit a distinctive variation. Given that mayfly's lifespan is limited to just one week, they are in a rush to find a suitable male mate for reproduction. Consequently, the velocity of female mayflies is adjusted based on the velocity of the male mayfly they intend to mate with. The breeding process involves pairing the best female with its corresponding male as the first mate, followed by the next best female mating with the next available male, and so on. In the case of the ith female mayfly, if $F(y_i) < F(z_i)$:

$$V_i(t+1) = \mathrm{g}.V_i(t) + a_3 e^{-\beta r_m^2}[z_i(t) - y_i(t)] \tag{13}$$

Where a_3 is constant utilized for adjusting velocities and r_m represents the Cartesian distance between them. If $F(y_i) > F(z_i)$, the velocities of female mayflies will be updated, transitioning from recent speeds to a different random dance factor denoted as f:

$$V_i(t) = g.V_i(t) + \mathrm{f}r_2 \tag{14}$$

Where r_2 is a random number within 0 to 1 in uniform distribution.

- **Reproducing of mayflies:**

Each upper half of feminine and masculine mayflies will be paired together for mating, and they will produce a number of broods. The creation of their offspring will occur randomly, based on their respective parentage.

$$\begin{aligned} \mathrm{brood}_1 &= \mathrm{L.masculine} + (1-\mathrm{L}).\mathrm{feminine} \\ \mathrm{brood}_2 &= \mathrm{L.feminine} + (1-\mathrm{L}).\mathrm{masculine} \end{aligned} \tag{15}$$

The masculine and feminine parents are denoted by their respective genders, masculine and feminine, while L represents a specific value within a given range. The initial velocities of the offspring are established at zero.

4. Results and Discussion

4.1 Initial response characteristic of a buck converter

In this work, the tuning of FOPID, FOPI, and FOPD controllers has been designed to enhance the performance of the buck converter. An m-file implementation of the MOA has been utilized to augment the initial voltage response of the buck converter circuit, with the adjustable design variables being the parameters of the FOPID, FOPI, and FOPD controllers. Table 2 presents the tuned values of these controller parameters obtained through MOA after 100 iterations, based on the proposed cost function.

The effectiveness of the proposed controller is assessed in the time domain using the MATLAB 19a programming platform in conjunction with FOMCON and the control system toolbox. Figure 2 illustrates the closed-loop system response in the absence of a controller.

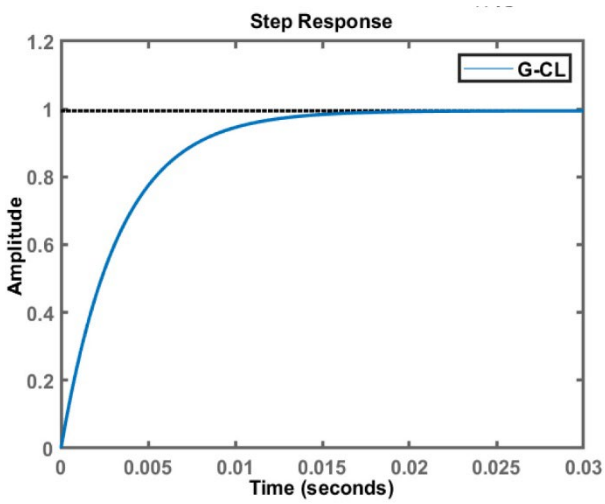

Fig. 2: Step response of closed loop DC-buck converter in the absence of controller

This figure collectively demonstrates that the system operates in an overdamped manner and exhibits characteristics typical of a second-order system.

Hence, compensation becomes essential in order to effectively regulate and control the output voltage of the converter. To enhance the system's response, optimal tuning of the FOPI, FOPD, and FOPID controllers is required.

In the context of the conventional IOPI controller, parameters are optimized using the Ziegler-Nichols(ZN) technique. The resulting system responses when employing this controller are depicted in Fig. 3.

A novel approach was developed in this research for designing a DC buck converter with FOPI, FOPD, and FOPID controllers. This approach combines the ZLG index combined with the ISE fitness function with the MOA. The respective cost function (ZLG+ISE) index, is continuously computed, and the parameters of FOPID, FOPI, and FOPD controllers are updated iteratively. Once a termination condition is met, both the updated controller parameters and the cost function are returned as the optimized results.

In work focuses on achieving an optimal design for the FOPID, FOPI, and FOPD controllers with the ultimate goal of enhancing the time domain performance of the DC buck converter. The performance of the DC buck converter is evaluated using the MOA in combination with the FOPI, FOPD, and FOPID controllers, and the results are compared with each other.

The values of K_p, K_i, K_d, λ, and μ which correspond to the minimum fitness function values achieved through the MOA, are considered the most suitable parameter values for this specific controller. This optimization process aims to achieve the best possible controller settings that result in improved system performance, such as faster response times and reduced error in regulating the output voltage of the DC buck converter.

Firstly, the FOPI controller is fine-tuned using the MOA, the tuned values of the MOA-FOPI controller parameters are K_p=85.83, K_i=46.72, and λ=1.07 respectively. Figure 4 illustrates the system's step response when controlled by this MOA-FOPI controller.

Subsequently, further optimization is performed on the MOA-FOPD controller, leading to the following parameter values: K_p=111.86, K_d= 45.5, and μ= 0.17. The step response of the system utilizing this MOA-FOPD controller is depicted in Fig. 5.

The MOA-FOPID controller's performance is characterized by the following set of parameters: K_p=93.61, Ki=47.83, K_d= 38.26, λ=1.01, and μ= 0.996. Figure 6 illustrates the system's step response when controlled by this specific MOA-FOPID controller.

The performance of each controller is assessed by comparing their time domain responses, as depicted in Fig.7. A comparative analysis of the performance characteristics is contrasted in Table 2. From the table, it's evident that the MOA-FOPID controller exhibits the minimum rise time and settling time among all the proposed MOA-FOPI and MOA-FOPD controllers. Consequently, the MOA-FOPID controller is deemed the most suitable for the DC buck converter application.

Furthermore, it's worth noting that among all the controllers considered, the MOA-FOPD controller demonstrates the slowest performance.

The simulation results highlight the superior performance of MOA-based FOPID controllers, which not only enhance the converter's stability but also improve its dynamic response. The comparison of their performance characteristics reveals that using a MOA-FOPID-based controller leads to significant improvements in the control action of the DC buck converter.

In a related study[28)], the Nelder-Mead algorithm was employed to optimize the FOPID controller, aiming to improve the performance of the DC buck converter. However, the outcomes of the current work, when compared directly to prior findings, undeniably demonstrated a significantly elevated level of performance.These findings indicate significant improvements in the converter's transient response, characterized by reduced overshoot and faster settling times, which are critical factors in achieving stable and efficient power conversion.

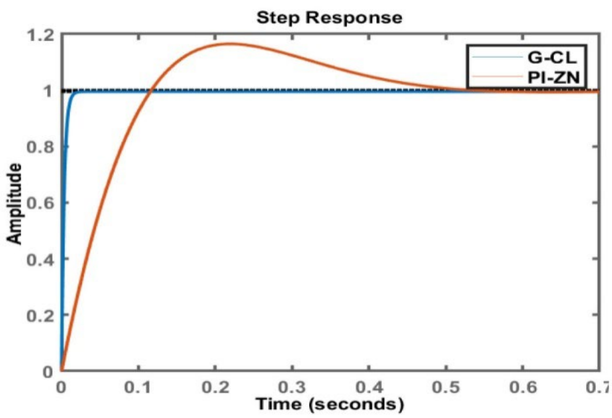

Fig. 3: Step response of Closed-loop DC-buck converter with ZN-PI controller

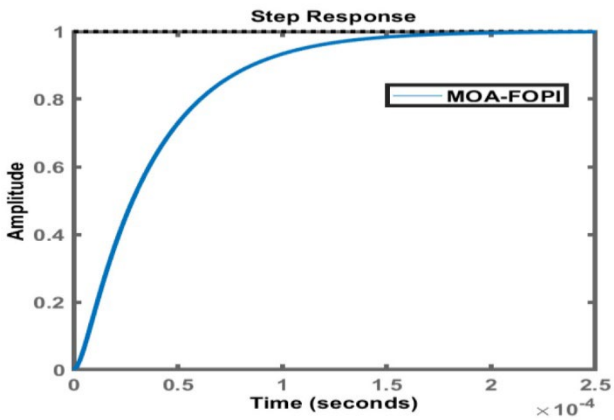

Fig. 4: Closed-loop DC-buck converter step- response with MOA-FOPI controller

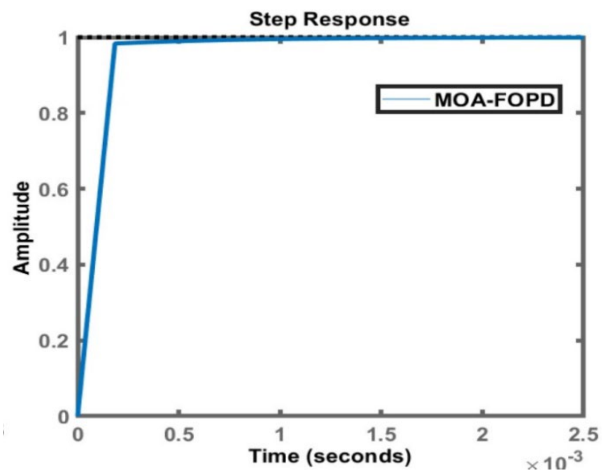

Fig. 5: Closed-loop DC-buck converter step response with MOA-FOPD contorpoller

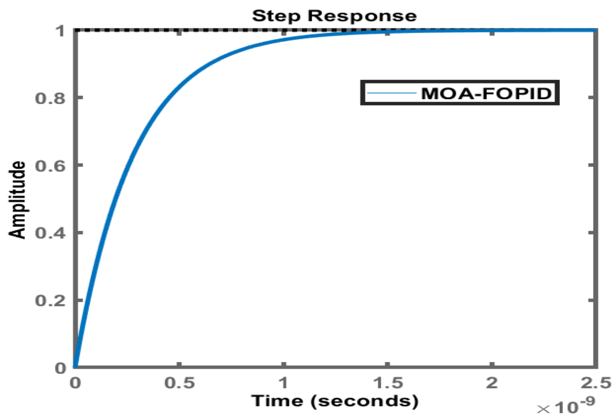

Fig. 6: Closed-loop DC-buck converter step response with MOA-FOPID controller

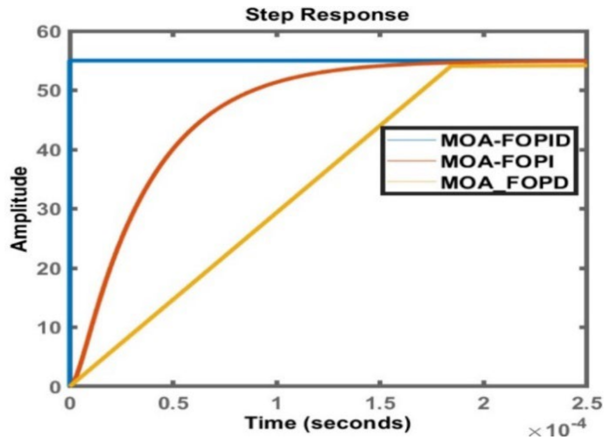

Fig. 7: Comparative step response of buck converter for each proposed controller

Table 2 Contrasting of performance characteristics

Parameters	Without controller	IOPI-ZN	MOA-FOPI	MOA-FOPD	MOA-FOPID
K_p	-	0.047	85.83	111.86	93.61
K_i	-	0.390	46.72	0	47.83
K_d	-	-	0	45.5	38.26
λ	-	1	1.07	0	1.01
μ	-	-	0	0.17	0.996
Settling time in secs	0.013	0.458	$1.43*10^{-4}$	$1.83*10^{-4}$	$1.099*10^{-9}$
Rise time in secs	0.007	0.088	$7.86*10^{-5}$	$1.49*10^{-4}$	$6.16*10^{-10}$
Max overshoot %	0	16.495	0	0	0

4.2 Response of the MOA-FOPID optimized system to parametric uncertainties

The buck converter, employing the MOA-optimized FOPID controller with the proposed cost function, was exposed to parametric fluctuations. The system's dynamic response was examined by varying the filter inductance and capacitance within the ranges of L=0.692H to L=0.5H and capacitance from C=3.125μF to C=10μF, respectively. The response of the MOA-FOPID optimized system to filter parameter variations is shown in Fig. 8.

Similarly, the dynamic response was also analyzed while changing the load resistance from R=1Ω to R=5Ω and then from 5Ω to 10Ω. Figure 9 illustrates the system's response to load variations. The simulation results demonstrate that the same FOPID controller efficiently handled the parametric variations without the need for retuning.

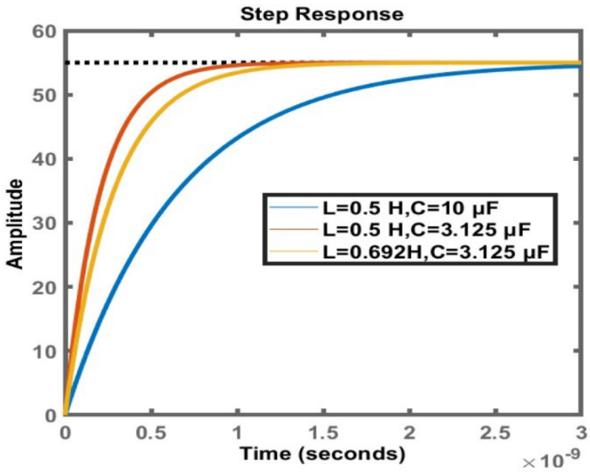

Fig. 8: MOA- FOPID optimized system response to filter parametric fluctuations

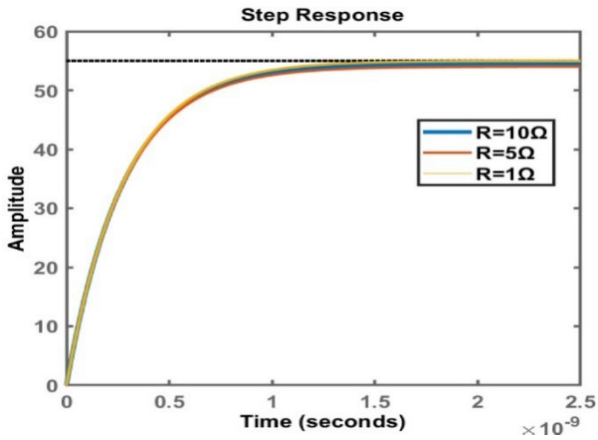

Fig. 9: MOA- FOPID optimized system response to load variations

5. Conclusions

This article presents an innovative approach to designing a FOPID controller for a buck converter using the Mayfly, algorithm. The proposed cost function ZLG+ISE was optimized using the Mayfly optimization technique, resulting in a rapid initial response and a smooth dynamic response being showcased. The performance of the system using the MOA-FOPID was compared with the MOA-FOPI and MOA-FOPD controllers for the proposed cost function. Simulation results demonstrate that the MOA-FOPID controller with the proposed cost function can produce better performance than other controllers in terms of transient response, hence enhancing the dynamic response, and improving the stability of the converter. The comparison of performance characteristics is also carried out for them, which offers desirable improvements in the control action of the DC buck converter when an MOA-FOPID-based controller is used. It provides notable enhancements in controlling the DC-buck converter, surpassing the capabilities of other fractional order controllers. The MOA-FOPID controller exhibits superior performance compared to all others. Future research can be performed for multi-objective functions, minimizing the weighted combination of performance indices, and extending the control strategies to other converters like the boost and buck-boost converters.This research contributes valuable insights into the field of power electronics and control systems, offering practical solutions for achieving better performance and stability in DC buck converter applications.

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