



# ENHANCING PERFORMANCE AND EFFICIENCY OF DC-DC BOOST CONVERTER USING GOLDEN EAGLE OPTIMIZATION

Jafar Jallad<sup>1</sup> and Ola Badran<sup>2</sup>

<sup>1</sup> Associate Professor, Department of Electrical Engineering, Faculty of Engineering and Technology, Palestine Technical University –Kadoorie, Tulkarm, Palestine,  
Email: [j.jallad@ptuk.edu.ps](mailto:j.jallad@ptuk.edu.ps).

<sup>2</sup> Associate Professor, Department of Electrical Engineering, Faculty of Engineering and Technology, Palestine Technical University –Kadoorie, Tulkarm, Palestine,  
Email: [o.badran@ptuk.edu.ps](mailto:o.badran@ptuk.edu.ps).

<https://doi.org/10.30572/2018/KJE/170118>

## ABSTRACT

Despite DC-DC converters are currently extensively utilized within power electronics for their effectiveness in generating a stable DC output with high efficiency, the fact that they are inherently nonlinear makes the selection of advanced converter components and control techniques indispensable for their improvement. In the context of overcoming the performance constraints of DC-DC boost converters, the purpose of the current research work is to use the concept of optimization, which targets the critical parameters of the continuous conduction mode. During the optimization procedure, the objective is to identify the best possible parameters for the inductor, the capacitor, as well as the frequency of switching. In addition to that, the adjustment of the parameters of the Proportional-Integral (PI) controller is carried out to improve the performance characteristics of the DC-DC boost converter circuit. The use of the Golden Eagle Optimization algorithm functions as the basis of the presented optimization approach. The validity of the current technique using the Golden Eagle Optimization algorithm for the design of the DC-DC boost converter circuit is demonstrated through a MATLAB/Simulink simulation. From the results, it can be seen that the proposed design using GEO outperforms various classical optimal techniques such as Grey Wolf Optimizer, Firefly Algorithm, Simulated Annealing, Particle Swarm Optimization, and Moth Flame Optimization. This proposed design using GEO results in a power loss reduction of over 6% and has 10% improvement in output voltage over the latest techniques proposed by Grey Wolf Optimizer.



This again manifests the potential of GEO in developing boost converters in terms of power electronics and renewable energy sources.

**KEYWORDS**

Boost Converter Parameter, Golden Eagle Optimization, PI Controller, Closed-Loop Control, MATLAB/Simulink.

## 1. INTRODUCTION

Power conversion systems in recent years have gained wide usage in industries such as aerospace, renewable energy, automotive, and railway trains. The main purpose of these systems is to provide a control of power in electronic devices; thus, the output from these systems is arranged through a high-frequency switching control device which changes the current and voltage signals to the desired values (Sira-Ramirez and Silva-Ortigoza, 2006; Águila-León et al., 2020). Important advances have improved DC-DC converters, above all in energy-storing components, that have turned out much smaller and more efficient (Jallad, 2012; Badran and Jallad, 2014). Further, the switch devices also experienced advancements, such as improved response times, lower parasitic resistance, and better voltage blocking characteristics. Though considerable progress has been achieved, optimal parameter setting in the converters is currently difficult and hence require an optimizing procedure for meeting sizing requirements and efficiencies (Leyva et al., 2012). Boost Converter is an electronic circuit that works towards increasing the input voltage and sustaining it at the desired level (Kalirasu and Dash, 2010; Babaa et al., 2018). A review of the available literature indicates that different studies on converters have opted for their best set of design parameters, with individual choices of objective functions, constraints, and methodologies employed for determining the optimized solution. For example, Yousefzadeh et al. (Yousefzadeh and Maksimovic, 2006) proposed a technique to achieve the ultimate efficiency in dc-dc converters having synchronous rectifiers by sensorless dead-time optimization. However, despite the effectiveness of the approach in controlling DC-DC converters digitally without using any extra sensors, it is restricted to single-parameter optimization in this study. The approach cannot easily be generalized for other optimization problems with multiple parameters. Optimization efforts targeted parameters like ripple of current, oscillation of voltage, and switching frequency at the MOSFET gate to improve monolithic converter performance. However, the method involves pairing variables for optimization using graphical techniques. While the results illustrate the impact of component parameters, design constraints are not considered in the process (Kursun et al., 2004). Juergen Biela et al. (Biela, Badstuebner and Kolar, 2009) conducted an analysis of volume and efficiency optimization, though concentrating on a limited range of options. Furthermore, Musunuri et al. (Musunuri and Chapman, 2005) applied optimization methods to reduce CMOS transistor dimensions while meeting specified loss thresholds. Nonlinear programming approach was used in a half-bridge DC-DC converter by Wu et al. (Wu et al., 1980). A penalty function technique was applied, which provided precise information on the balances between weight and loss, the ideal operating repetition, and the impacts of device

features. Yousefzadeh et al. (Yousefzadeh, Alarcon and Maksimović, 2006) illustrated a graphical optimization technique aimed to high efficiency and wide bandwidth through optimized band separation and filter design, while Gerber et al. (Gerber et al., 2004) presented a graphical optimization method for tuning the duty cycle in interleaved DC-DC converters. Furthermore, Takayama et al. (Takayama and Maksimović, 2006) conducted a thorough examination of converter losses. Furthermore, Ray et al. and Yuan et al. (Ray, Chatterjee and Goswami, 2010; Yuan, Li and Wang, 2010) investigated the challenges of reducing electromagnetic interference and improving efficiency of converter. Seeman et al. (Seeman and Sanders, 2008) employed a Lagrangian function for optimization, while Wu et al. (Wu et al., 1980) utilized an augmented Lagrangian method. Moreover, optimization techniques including quadratic programming (Busquets-Monge et al., 2004) and Monte Carlo simulations (Neugebauer and Perreault, 2003) are applied to enhance converter designs for diverse end applications. Leyva and Stupar et al. (Leyva, 2016; Stupar et al., 2019) concentrated on optimizing the DC-DC converter design using geometric programming, which deals with the use of monomial and posynomial functions in overcoming the optimization problem in geometric programming. In recent years, new approaches have emerged, including graph-based methods (Li et al., 2022) and machine learning for choosing parameters (Wang et al., 2022). In addition, different optimization methods such as the firefly algorithm (FA) (Saharia and Sarmah, 2019), mating algorithms of honey bees (Kumar and Krishna, 2018), particle swarm optimization (PSO) (Ferreiro et al., 2017), genetic algorithms (Sundareswaran and Kumar, 2004), and simulated annealing (SA), have been utilized in optimizing the DC-DC converter. Typically, optimization approaches focus on single parameters, with selections varying from minimizing losses, enhancing efficiency, reducing ripple, minimizing voltage swings, optimizing component weights, to minimizing electromagnetic interference (EMI).

In many cases, optimization strategies involve addressing one parameter at a time. However, the approach restricts all possible constraints in the optimization process that follows. For example, in the research conducted by Saharia and Sarmah (Saharia & Sarmah, 2019), a small set of ratios of duties for switching power converters is selected, which significantly restricts the search space for the variable in the PSO approach for the optimization of a DC-DC buck converter circuit. A model developed by Tian et al. (Tian et al., 2022) is created to demonstrate the effectiveness of semiconductor materials as well as magnetic components; moreover, the artificial neural network is trained using data generated from Spice simulation to develop a quick and accurate model for the semiconductor loss. However, ANNs require a large amount of data for training, and they can be computationally expensive to train and deploy, especially

for complex optimization problems.

Abdal-Razak Shehab Hadi et al. examined the effectiveness of Learning Sliding Mode Control (LSMC) in comparison to Proportional Integral Derivative Sliding Mode Control (PIDSMC) and Fuzzy Logic Control (FLC) in regulating the output voltage of DC-DC boost converters. The result clearly indicates that LSMC has a more stable output voltage without chattering and zero error in steady state, making it more superior in regulating voltage in applications where high precision is required. However, LSMC has a higher settling time than PIDSMC. This may be inappropriate in applications where high response rates are required (Hadi et al., 2024). Abdullah Muwafaq Alyousuf and Fatih Korkmaz (Alyousuf & Korkmaz, 2023) examined the effectiveness of wind energy systems utilizing doubly-fed induction generators (DFIG) in addition to back-to-back converters. The authors emphasize the importance of advanced control systems in improving the efficiency of wind energy systems. The result indicates the effectiveness of vector control and phase-locked loop (PLL) control in wind energy systems. Based on the result above, it is clear that optimization techniques are both important and very effective in the design of different types of converters. This is because it greatly enhances efficiency.

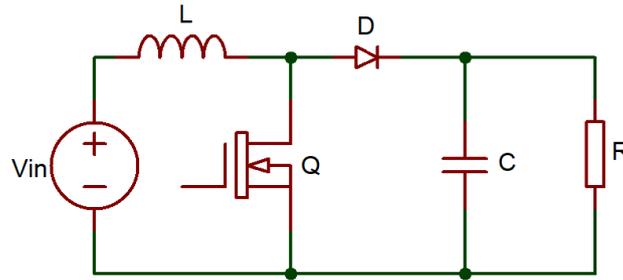
The Grey Wolf Optimizer (GWO) is also applied to determine the optimized parameters of the boost converter by Saharia and Sarmah (Saharia and Sarmah, 2023). However, in this research paper, the selection of the values of the converters is done by predefining the duty cycle without taking into consideration the output voltage. Consequently, the output of the designed boost converter implemented in MATLAB Simulink does not attain the required output voltage. Ghaith Majd Fadhil et al. (Fadhil, Abed, and Jasim, 2021) have investigated the application of the Genetic Algorithm (GA) for the optimization of the parameters of a PID controller to improve the performance of the system by reducing the overshoot, ripple, and error. The research has shown the superiority of the Genetic Algorithm (GA) PID controllers over the existing methods in terms of response time and stability for different test plants. The time complexity of the Genetic Algorithm (GA) may restrict its applicability in real-time systems. In 2024, Jallad and Badran (Jallad and Badran, 2024) used the Firefly Algorithm (FA) to optimize the coefficients of the PID controller to achieve accurate angular position control in DC motors without overshooting and oscillations. In addition, Robandi in (Robandi, 2022) also used the Firefly Algorithm to design an intelligent voltage controller for the DC-DC boost converter. Among the various available optimization techniques, the Golden Eagle Optimization algorithm has several benefits, including the capability to be used in continuous as well as discrete problems, the absence of the need to perform complex calculations such as

derivatives, and the low likelihood of entrapment in the local optimum solution (Deng et al., 2023).

However, the design of a DC-DC boost converter has remained a challenge despite the development of optimization algorithms and power electronics because of the complexity involved in handling various constraints, such as current ripple, voltage ripple, and the bandwidth of the continuous conduction mode (CCM). The existing techniques, namely Particle Swarm Optimization (PSO), Moth Flame Optimization (MFO), Grey Wolf Optimizer (GWO), and Firefly Algorithm (FFA), have difficulty in achieving the lowest power losses efficiently. Additionally, these techniques either demand a large amount of computational time or do not converge to the global optimum. The current research fills the existing gap by using the GEO algorithm to improve the efficiency and accuracy of the design of the DC-DC boost converter by achieving a substantial reduction in power losses compared to the existing techniques. The objective of the current research is to determine the optimum values of the components of the DC-DC boost converter to achieve the lowest power losses in addition to the determination of the suitable values of the PI coefficients for the design of the voltage controller. The proposed voltage controller has the objective of keeping the output of the boost converter at its required level by controlling the duty cycle. The current research is structured as follows: a description of the mathematical modeling of the boost DC-DC converter and the problem formulation for the optimum selection of the design parameters is described in section 2. It also explains the design optimization problem formulation utilized in the GEO algorithm. Moreover, this section also presents a designed PI controller to minimize the absolute value of the output voltage with the desired value. Section 3 presents the findings and provides a comparative analysis of the GEO algorithm against other widely used algorithms like FA, PSO, and SA.

## **2. MODELING OF DC-DC BOOST CONVERTER**

The DC-DC boost converter performs well in the observation of photovoltaic (PV) systems operating in high radiation and temperature conditions. This section describes the modelling process of the DC-DC boost converter, taking into account the system losses, current and voltage ripples, and other significant constraints that play an important role in identifying the best design for the boost converter. Fig. 1 below illustrates the boost converter circuit diagram (Jallad, 2012; Hadi et al., 2024).



**Fig. 1. DC-DC Boost converter circuit**

The equations of the modeling of boost converter is shown in Eq. 1, Eq. 2 and Eq. 3 (Umanand, 2009).

$$x = \begin{bmatrix} i_L \\ v_C \end{bmatrix} \quad (1)$$

$$\frac{di_L}{dt} = \frac{-v_C}{L} (1 - u) + \frac{V_{in}}{L} u \quad (2)$$

$$\frac{dv_C}{dt} = \frac{i_L}{C} (1 - u) + \frac{v_C}{RC} \quad (3)$$

In Eq.1,  $i_L$  signifies the current passing through the inductor, and the output voltage is represented as  $v_C$ . The parameter  $u$  in Eq.2 and 3 indicates the switch state:  $u=1$  signifies the switch is on (with  $Q$  active and  $D$  inactive), while  $u=0$  indicates the switch is off (with  $Q$  inactive and  $D$  active). The initial value of  $u$  acts as the control signal regulating the converter's operation. The circuit parameters are represented by  $L$  for the inductor,  $C$  for the capacitor,  $V_{in}$  for the input voltage, and  $R$  for the load resistance. A slight voltage fluctuation in the capacitor results in a current ripple that takes the shape of a triangular waveform. The amplitude of this ripple is influenced by the rate of change during the OFF period and the duration for which the current stays in the OFF state.

$$\Delta i_1 = \frac{V_{in} \times d}{L \times f_s} \quad (4)$$

Where  $f_s$  denotes the frequency of the switching device, and  $d$  represents the duty cycle of the switching signal, calculated as the ratio of the ON-time ( $T_{ON}$ ) to the total switching period ( $T_{ON} + T_{OFF}$ ).

According to Erickson and Maksimovic (Erickson and Maksimovic, 2007), the ripple of voltage can be described as

$$\Delta v_C = \frac{V_C \times d}{C \times f_s \times R} \quad (5)$$

where  $V_C$  represents the constant output voltage in the steady state. The following constraint ensures continuous conduction mode (CCM) operation for the boost converter:

$$L f_s > \frac{V_C}{2 \times I_0} d(1 - d)^2 \quad (6)$$

Another essential criterion for a design is to have a sufficiently wide bandwidth. Eq.7 and Eq.8 define the minimum necessary bandwidth, denoted as  $\omega_0$ :

$$\omega_0 = \frac{(1-d)}{\sqrt{L \times C}} \quad (7)$$

$$\omega_0 > 2 \times \pi \times \alpha \times f_s \quad (8)$$

Where  $\alpha$  represents a fraction of the switching frequency.

### 2.1. Power consumption in the boost converter

The calculations of total power loss are based on the losses that occur during the operation of the boost converter. These losses include the inductance power losses  $P_{ind}$  due to parasitic resistance  $r_{ind}$ , capacitor power losses  $P_{Cap}$  caused by parasitic capacitance  $r_{Cap}$  and power dissipated by the diode  $P_{Diode}$  as shown in Eq. 9, Eq. 10 and Eq. 11.

$$P_{ind} = \left( \left( \frac{I_0}{1-d} \right)^2 + \Delta i_L^2 \right) \times r_{ind} \quad (9)$$

$$P_{Cap} = \frac{V_C^2 \times d \times r_{Cap}}{(1-d) \times R^2} \quad (10)$$

$$P_{Diode} = V_f I_0 (1-d) + Q_{rr}^{Schottky} V_C f_s \quad (11)$$

Where  $\Delta i_L$  represents the ripple in inductor current,  $I_0$  represents output current and  $V_f$  signifies the forward voltage drop across the diode. The reverse recovery charge in the diode, denoted as  $Q_{rr}^{Schottky}$ , is taken into account. It's assumed that the diode is made using Schottky technology. For simplicity, ohmic losses in the diode have been disregarded to facilitate comparison with the findings of Saharia and Sarmah (Saharia and Sarmah, 2023).

Furthermore, the loss caused by the device's on-off state transitions after each cycle influences the converter's efficiency. The total power consumption of MOSFET  $P_Q$  comprises conduction losses, denoted as  $P_{ON}$ , and switching losses, denoted as  $P_{SW}$ . Thus, the power consumption of MOSFET  $P_Q$  is given in Eq.12, Eq. 13 and Eq. 14.

$$P_Q = P_{ON} + P_{SW} \quad (12)$$

$$P_{ON} = \left( \left( \frac{I_0}{1-d} \right)^2 + \frac{\Delta i_L^2}{12} \right) \times d \times r_{DS} \quad (13)$$

$$P_{SW} = (V_C - V_f) \left( \frac{I_0}{1-d} - \frac{\Delta i_L}{2} \right) f_s (T_{SW\_on} + T_{SW\_off}) \quad (14)$$

$T_{SW\_on}$  and  $T_{SW\_off}$  denote the transition time for turning on and off, respectively. These times are contingent on the gate drive and MOSFET characteristics, where  $r_{DS}$  signifies the on-resistance of the MOSFET.

Finally, the total power dissipated by the boost converter  $P_{boost}$  can be expressed as Eq. 15.

$$P_{boost} = P_{ind} + P_{Cap} + P_{Diode} + P_Q \quad (15)$$

## 2.2. PID controller for a boost converter

Typically, systems can be controlled through two main methods: an open control system and a closed control system. When implementing the open control system with the converter, the electrical output voltage may not precisely match the desired voltage. This discrepancy occurs because the actual electrical output value is directly influenced by the duty cycle, as described by the Eq. 16, which elucidates the circuit's efficiency.

$$\eta_{Regulator} = \frac{V_{C,real} - d \times V_{C,desired}}{V_{in}} \quad (16)$$

Where  $V_{C,real}$  and  $V_{C,desired}$  are the steady state of actual output voltage and desired voltage, respectively. To eliminate the difference between the desired and measured voltage, applying a PID closed-loop control is used. A PID controller is a device that uses a combination of proportional, integral, and derivative gains for accurate control of a system (Jallad & Badran, 2024). As seen in Fig. 2 below, the feedback system continuously checks for the difference between the output voltage and the reference voltage and uses this difference as input for the PID controller to produce an appropriate control action. The proportional term responds to the current error, the integral term accounts for past errors over time, and the derivative term predicts future errors based on the current rate of change. By dynamically adjusting the control signal sent to the boost converter, the PID controller ensures precise regulation of the output voltage, maintaining stability and efficiency in the system.

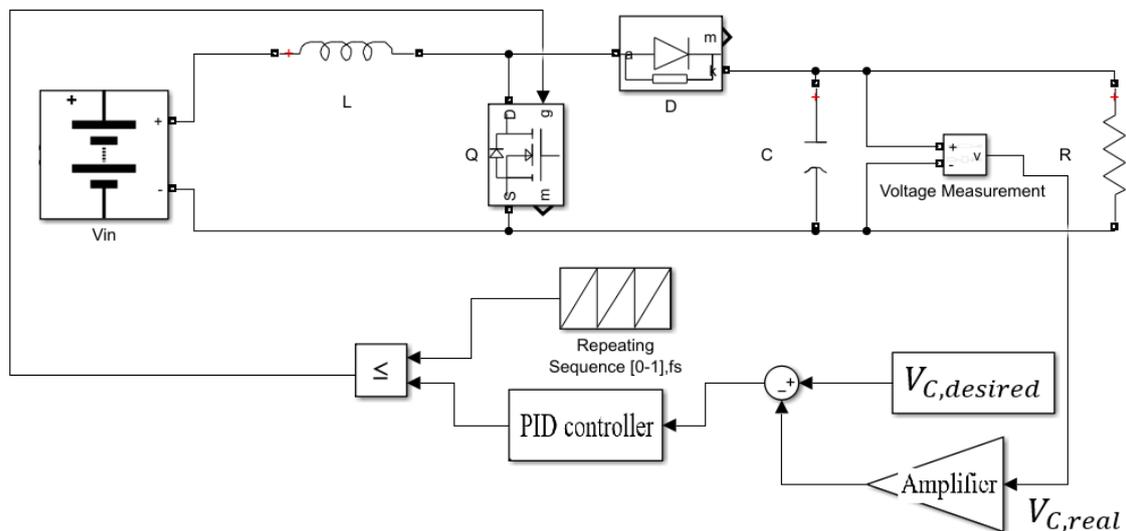


Fig. 2. Block diagram of PID closed-loop control of boost converter

## 2.3. Objective function and constraints

The first problem is determining the value for the components of boost converter which includes capacitor, inductor, diode and the switching frequency for operating the MOSFET that achieve

the minimum total power dissipated by the boost converter as illustrated in Eq. 15. The second problem is finding optimal PID coefficients which makes the actual output voltage reaches to the desired output voltage under the minimum difference between them. The objective function  $Obj_{Fun}$  is a unitless value and it can be formulated using Eq. 17. The  $Obj_{Fun}$  is used within the optimization technique to minimize its value by finding the optimum value of capacitor, inductor and switching frequency.

$$Obj_{Fun} = \frac{P_{boost}}{P_{boost} + P_R} + \frac{|V_{c,real} - V_{c,desired}|}{V_{c,desired}} \quad (17)$$

where  $P_{boost}$  is total power dissipated by the boost converter after optimization.  $P_R$  represents the average power at the load

The mathematical depiction of minimizing  $Obj_{Fun}$  incorporates the following constraints:

$$L_{minimum} \leq L_{optimum} \leq L_{maximum} \quad (18)$$

$$C_{minimum} \leq C_{optimum} \leq C_{maximum} \quad (19)$$

$$f_{s,minimum} \leq f_{s,optimum} \leq f_{s,maximum} \quad (20)$$

$$\Delta i_L \leq \alpha \times I_0 \quad (21)$$

$$\Delta v_C \leq \beta \times V_C \quad (22)$$

$$0 \leq k_p \leq k_{p,maximum} \quad (23)$$

$$0 \leq k_i \leq k_{i,maximum} \quad (24)$$

$$0 \leq k_d \leq k_{d,maximum} \quad (25)$$

The parameters mentioned in the previous Equations set constraints on the design and operation of a converter. Specifically, the inductance L, capacitance C, and switching frequency  $f_s$  must fall within specified minimum and maximum bounds. Here,  $\alpha$  and  $\beta$  are factors that determine the allowable ripples in terms of the output current and the output voltage. Furthermore, Eq.6 demonstrates the attainment of continuous conduction mode (CCM) through the satisfaction of the inequality based on selected value.

#### 2.4. Finding the minimum value of the objective function Based on the golden eagle optimization

The Golden Eagle Optimization (GEO) is a metaheuristic approach that was developed based on the hunting actions of golden eagles. Actually, these eagles have a great ability to scan vast areas for searching for their targets and to attack them quickly if they find suitable ones. The proposed algorithm was created by Mohammadi-Balani (Mohammadi-Balani et al., 2021). According to this method, this ability is reflected by randomly initializing a set of solutions, called “eagles,” and then these eagles will scan the area to find better solutions than their current

ones. If an eagle finds better solutions, they will share this information with other eagles to achieve faster convergence to the global optimum. The aim of this method is to balance exploration and exploitation. As shown in the flowchart in Fig. 3, this method is used for optimal component selection for DC-DC converters. Moreover, this method is employed to find PID coefficients to optimize the voltage regulation of DC-DC converters. It is worth mentioning that the termination criterion for this method could be maximum iterations, maximum improvement in solution, or precision. The steps for this method are as follows:

1. Set the population size and the number of iterations for the GEO algorithm. Define the population size and the maximum number of iterations for the optimization process.
2. Define the system parameters and constraints. Specify the range of values for the variables to be optimized as Eqs.18,19,20,21,22,23,24 and 25.
3. Create a random initial population matrix  $X$  that satisfies all constraints. Each row in the matrix represents an individual solution (eagle) with the following structure:

$$X = \begin{bmatrix} C_1 & L_1 & f_{s1} & K_{p1} & K_{i1} & K_{d1} \\ C_1 & L_2 & f_{s2} & K_{p2} & K_{i2} & K_{d2} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ C_m & L_m & f_{sm} & K_{pm} & K_{im} & K_{dm} \end{bmatrix} \quad (26)$$

Where  $m$  is the population size, and each column represents one of the variables to be optimized.

4. Evaluate the fitness function for each individual using Eq. 17.
5. Sort the population in ascending order of fitness values to minimize the fitness function, and identify the best solution as the individual with the lowest fitness value.
6. Update the position of each eagle (individual) in the population using the GEO equations:

$$x_i^{new} = x_i^{old} + \gamma \cdot (x_{best} - x_i^{old}) + \delta \cdot (x_{rand} - x_i^{old}) \quad (27)$$

where:

$x_i^{old}$  is the current position of the solution,  $x_{best}$  is the position of the best solution in the population, and  $x_{rand}$  is a randomly generated position in the search space.  $\delta$  is attack propensity and  $\delta$  is cruise propensity which are considered as control parameters that balance exploration and exploitation. To calculate  $\gamma$  and  $\delta$  use the Eq.28 and Eq.29

$$\gamma = rand. (fitness_{best} - fitness_i) \quad (28)$$

$$\delta = (1 - \gamma) \quad (29)$$

7. Check for constraint violations by ensuring that the updated values of  $C$ ,  $L$ ,  $f_s$ ,  $K_p$ , and  $K_i$  remain within their specified ranges, adjusting any out-of-bound values to the nearest permissible limit.

8. Repeat steps 4 to 7 until the maximum number of iterations is reached or a convergence criterion, such as negligible improvement in the fitness value, is met.

9. After the final iteration, the best solution in the population represents the optimal values for  $C$ ,  $L$ ,  $f_s$ ,  $K_p$ , and  $K_i$ , minimizing power losses and achieving a voltage profile closest to the desired target.

The block diagram illustrated in Fig. 4 above highlights the proposed methodology for designing a DC-DC boost converter, with specific focus on optimizing its parameters and coefficients of the PID controller by utilizing the Golden Eagle Optimization (GEO) method. The optimized method ensures that the optimal values for the inductor, capacitor, and switching components are identified and optimized, thereby increasing the efficiency and performance of the boost DC-DC converter. The optimized method ensures that the output voltage is constantly monitored and fed back into the system, which is controlled by utilizing the PID controller with optimized coefficients by the GEO method. Such optimized methodology ensures that stability and responses to variations are realized. The optimized method, which employs the use of GEO to optimize its parameters and coefficients, ensures that effectiveness and optimal dynamic performance are realized in DC-DC converters. Fig. 4 above illustrates the block diagram representing the connection between an m-file and MATLAB Simulink, which requires optimized parameters. In this study, the derivative component in PID controllers is eliminated because it can increase the system's sensitivity to high-frequency noise. In noisy environments, selecting a PI controller can mitigate this problem.

### 3. RESULTS AND DISCUSSION

The DC-DC boost converter's input and output are critical in determining the design specifications. Table 1 displays the specifications of the DC-DC boost converter and the constraints employed in the optimization problem in this research. The DC-DC boost converter's design parameters are optimized using the GEO optimization approach to minimize operating losses. In addition, these parameters are also used in the PID's design as a voltage controller.

To evaluate the effectiveness of the proposed method, two different case studies were performed. The first case study searches only for power loss minimization of the open-loop DC-DC boost converter using GEO compared with other optimization techniques. In this instance, only the first term from Eq. 17 was utilized as the objective function.

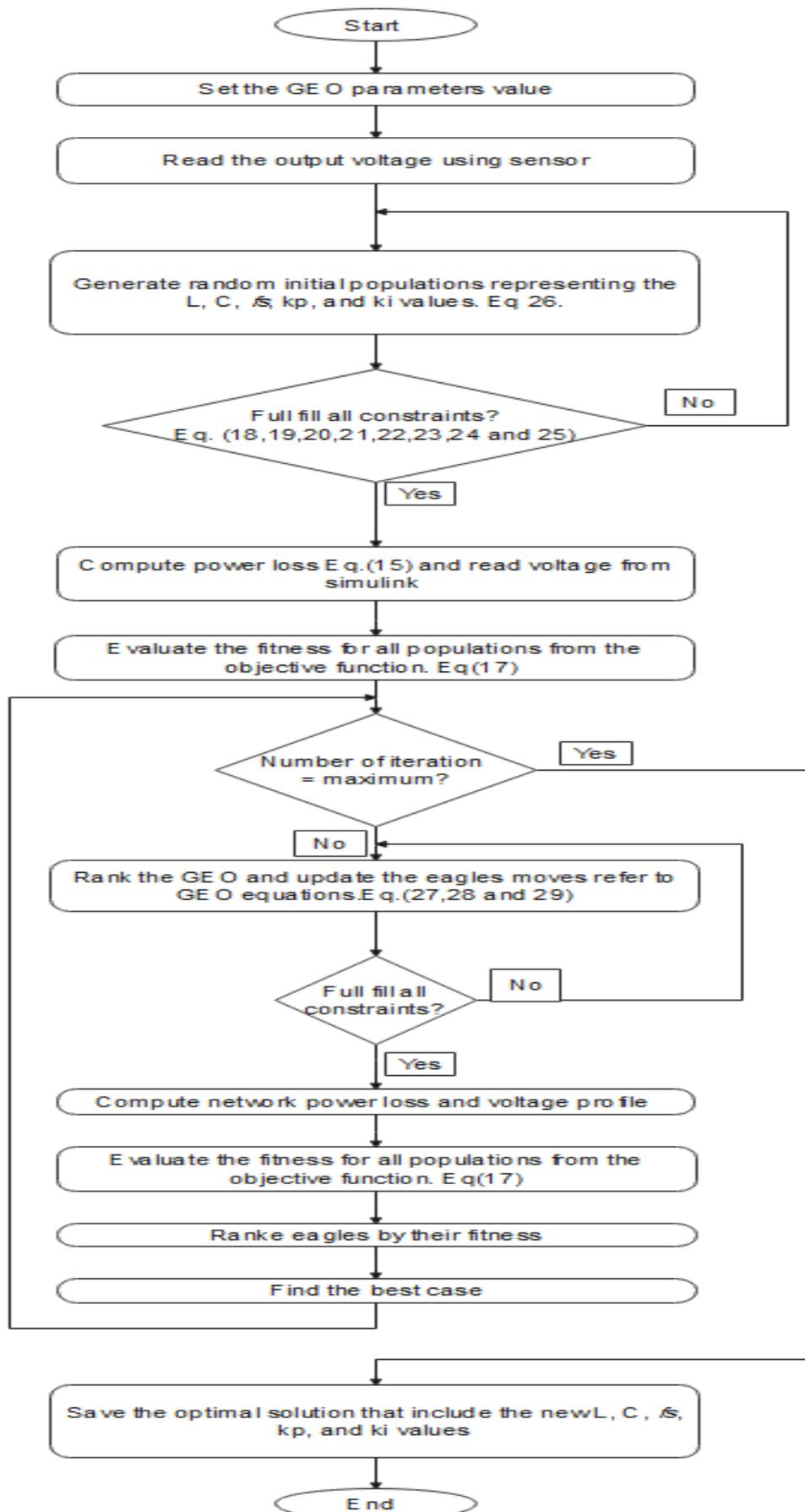


Fig. 3. Flowchart of GEO algorithm

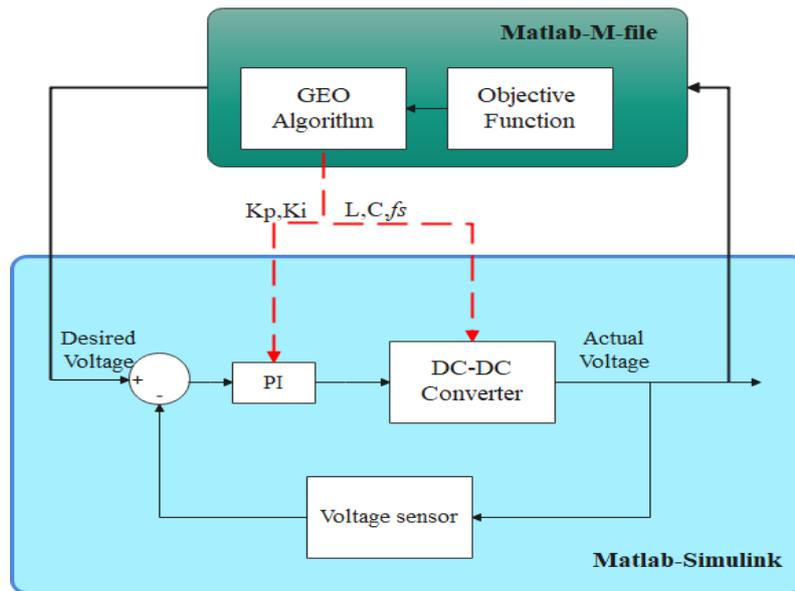


Fig. 4. Block diagram of the proposed method for designing a DC-DC converter

Table 1. Design parameters for optimization DC-DC boost converter (Ribes-Mallada, Leyva and Garcés, 2011)

Parameter	Value	Parameter	Value
$V_{in}$	5 V	$L$	0.1 uH -100 mH
$V_C$	10 V	$C$	0.1 -100 uF
$I_O$	2 A	$f_s$	10-800 kHz
$r_{DS}$	5.2 mΩ	$Q_{rr}^{Schottky}$	$50 \times 10^{-9} A$
$T_{SW-on}$	$10^{-8} s$	$\alpha$	15%
$T_{SW-off}$	$10^{-8} s$	$\beta$	15%
$V_f$	0.9 V	$K_p, K_i$	0-300

Because the optimization approaches are stochastic, all modelled algorithm undergoes at least 100 iterations, Sampling time 1 microsecond and the duration of simulation is 1 second. To ensure consistent evaluation of the algorithms' performance, the population size is set to 30 for GWO, MFO, PSO, SA, GP and GEO. The study reveals that the optimal design of the DC-DC converter achieves a power loss of 1.6358W. All optimization algorithms utilized in the research converged to this result, confirming the successful identification of the global optimum. Among these methods, the GEO algorithm stood out as the most effective, demonstrating the lowest number of iterations to reach to the optimum values of components of DC-DC converter which reflects on reducing computational time. This highlights GEO's robustness and efficiency in solving complex optimization problems.

Table 2 provides the results for the comparison of the operational power loss in the DC-DC boost converter using grey wolf optimization, moth flame optimization, particle swarm optimization, and golden eagle optimization.

Results in Table 2 show the effectiveness of the proposed Golden Eagle Optimization (GEO) technique in optimizing the design of the DC-DC boost converter. From the results, it can be

seen that the power loss in the design optimized by the proposed technique is 1.6358 W, which is much lower compared to the results obtained using other techniques such as GWO (1.75388 W), MFO (1.75370 W), PSO (1.75340 W), SA (1.82540 W), and GP (2.09700 W). Moreover, the proposed technique results in a substantial reduction in the inductor value of  $L = 0.0990$  mH, which is much lower compared to the results obtained using other techniques such as GWO of 6.21 mH and GP of 79.95 mH. This will not only result in increasing the efficiency of the DC-DC boost converter but will also result in lowering its cost and size. In addition, the results obtained in this design show competitive values for the capacitor of  $C = 100$   $\mu$ F and switching frequency of  $f_s = 84.876$  kHz.

In comparison to previous research, including the study by [Ribes-Mallada et al. \(2011\)](#) utilizing GP, the proposed method utilizing GEO shows considerable improvement, with power loss reduction of 22% and inductor value reduction of 99.8%. Alongside, GEO performs better than recent research utilizing GWO, as mentioned by [Saharia and Sarmah \(2023\)](#), with power loss reduction of 6% and improvement in output voltage by 10%. Such advancements confirm the effectiveness of GEO as an optimal solution for DC-DC boost converters. Nevertheless, one of the shortcomings of this research is its limited scope to specific converter types and situations, which might not reflect its effectiveness in real-world situations. Future research studies can investigate the extensibility of GEO for other topologies of converters and conditions of operation in validating the effectiveness of GEO in industrial and renewable energy applications. In summary, the results highlight the significance of employing sophisticated optimization algorithms such as GEO in overcoming the challenges of nonlinearity in power electronics.

**Table 2. Comparison of the power loss of the DC-DC boost converter for different algorithms**

Algorithm	Power loss (W)	L (mH)	C ( $\mu$ F)	$f_s$ (kHz)
GWO ( <a href="#">Saharia and Sarmah, 2023</a> )	1.75388	6.21	100	100.02
MFO	1.75370	9.97	100	100.03
PSO	1.75340	10	100	100
SA	1.82540	7.91	94.8	109.25
GP ( <a href="#">Ribes-Mallada, Leyva and Garcés, 2011</a> )	2.09700	79.95	95.946	104.23
GEO (Proposed Method)	1.63580	0.0990	100	84.876

It is clear from [Table 2](#) that GEO has the lowest power loss, which leads to a total efficiency of 92.43% in the converter.

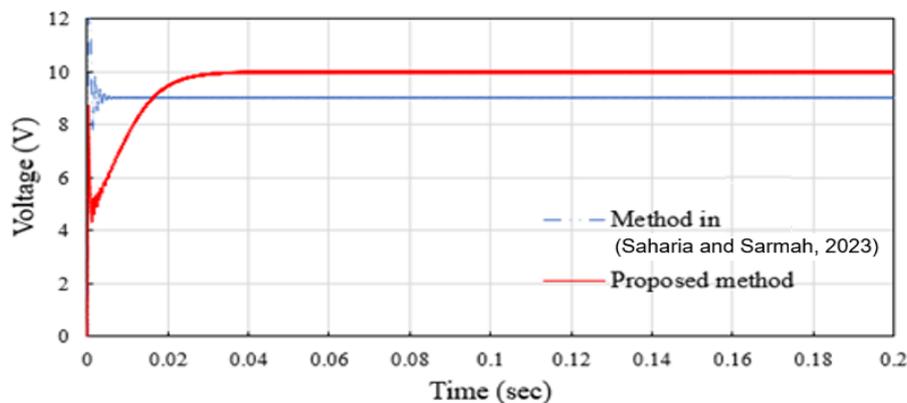
The results shown in [Table 3](#) highlight the excellent computational efficiency of five optimization algorithms, namely GWO, MFO, PSO, SA, and GEO. Of all, GEO has been identified as the most efficient, taking only an incredible 0.548 seconds to perform the optimization process. The excellent computational efficiency of GEO not only identifies it as

the fastest algorithm but also suggests that it has great potential as the most ideal optimization algorithm for any application that demands fast and efficient optimization processes. GWO comes second, taking a very good computational time of only 0.655 seconds, thereby demonstrating a good blend of speed and efficiency. MFO and PSO follow with equal computational time of 0.692 and 0.693 seconds, thereby demonstrating low levels of efficiency. The least efficient algorithm is SA, taking the longest time of 1.386 seconds, thereby making it the least efficient algorithm. The results clearly indicate that GEO is the best algorithm with regard to computational speed, followed by GWO. The results clearly indicate the importance of time computation in choosing an algorithm, especially when efficiency is considered an important factor.

**Table 3. Comparison of Computational time for different algorithms**

Algorithm	GWO	MFO	PSO	SA	GEO
Computational time (sec)	0.655	0.692	0.693	1.386	0.548

In the second case study, the DC-DC Boost Converter utilized GEO for determining the optimum values with the values of the PI controller for minimum power loss with closed output voltage to the desired value. Therefore, in this case it was used the objective function in Eq.17. Simulink offers a powerful co-simulation environment for integrating MATLAB m-files. This feature helps in finding the optimal values of a DC-DC boost converter design. The m-file will employ the Golden Eagle Optimization algorithm to find the optimum values for converter parameters and the coefficients controller's  $K_P$  and  $K_i$ . The objective function will minimize operational power loss while ensuring the actual output voltage closely matches the desired value. This combined Simulink with the m-file code for facilitates an iterative GEO optimization process, refining the controller parameters for superior converter performance. Fig. 5 shows a comparison of output voltage of DC-DC boost converter for the method in (Saharia and Sarmah, 2023) and the proposed method.



**Fig. 5. Output voltage of DC-DC boost converter for the method in (Saharia and Sarmah, 2023) and the proposed method.**

Despite the optimal values for the converter being chosen using the method mentioned in reference (Saharia and Sarmah, 2023), the device still fails to meet its primary goal of boosting the input voltage to 10 volts at the output. Instead, the voltage was only increased to 9 volts as shown in Fig. 5. On the other hand, the proposed method successfully boosts the input voltage to 10 volts while simultaneously minimizing power loss to 1.8698 watts. Table 3 shows the parameters of the proposed DC-DC converter.

**Table 3. Parameters of the proposed DC-DC converter**

Parameter	L [mH]	C [ $\mu$ F]	fs [kHz]	Kp	Ki
Value	0.0816	100	112.109	0.1	100

It is worth mentioning that the power loss in the DC-DC converter using the proposed method increased by 0.23 watts compared to the first scenario, which does not ensure that the output voltage reaches the desired value. This increase in power loss is due to the use of a closed-loop system including a PI controller, which results in a duty cycle of 0.5482. Therefore, the value of the duty cycle directly affected on the power losses based on the Eq. 14.

#### 4. CONCLUSION

This paper proposes an optimized design of a DC-DC boost converter with its voltage controller by using GEO. The designed parameters included the specifications for the inductor, capacitor, operational frequency of the switching device, and coefficients for the PI controller. The issue of minimizing total operational losses was examined while considering CCM and bandwidth constraints. The algorithm's performance is compared to other optimization techniques, including MFO, PSO, SA, FA, and GWO, based solely on power losses. The superior performance of the GEO algorithm in reducing operational power losses of the DC-DC converter makes it the best choice for addressing this problem. On the other hands, the proposed method achieves both a minimum operational power loss with a desired output voltage. The simulation is carried out using the MATLAB/Simulink environment. In future work, it should be carried out to make the controller adaptable to any disturbances, utilizing artificial neural networks or machine learning techniques to be more suitable for practical applications such as solar PV systems.

#### ACKNOWLEDGMENTS

The authors would like to thank the Palestine Technical University-Kadoorie for their financial support to conduct this research.

#### 5. REFERENCES

Águila-León, J., Chiñas-Palacios, C.D., Vargas-Salgado, C., Hurtado-Perez, E. and García, E.X.. (2020). 'Optimal PID parameters tuning for a DC-DC boost converter: a performance

comparative using Grey Wolf optimizer, particle swarm optimization and genetic algorithms', 2020 IEEE Conference on Technologies for Sustainability (SusTech). 2020. IEEE. pp. 1-6. <https://doi.org/10.1109/SusTech47890.2020.9150507>.

Alyousuf, A. M. and Korkmaz, F. (2023). 'PERFORMANCE INVESTIGATION OF WIND TURBINES BASED ON DOUBLY FED INDUCTION GENERATORS WITH BACK-TO-BACK CONVERTER', *Kufa Journal of Engineering*, 14 (1), pp. 1-12.).

Babaa, S.E., El Murr, G., Mohamed, F. and Pamuri, S. (2018). 'Overview of boost converters for photovoltaic systems', *Journal of Power and Energy Engineering*, 6 (4), pp. 16-31. <https://doi.org/10.4236/jpee.2018.64002>.

Badran, O. and Jallad, J. (2014). 'Experimental characterization of lead–acid storage batteries used in PV power systems'.

Biela, J., Badstuebner, U. and Kolar, J. W. (2009). 'Impact of power density maximization on efficiency of DC–DC converter systems', *IEEE Transactions on Power Electronics*, 24 (1), pp. 288-300. <https://doi.org/10.1109/TPEL.2009.2006355>.

Busquets-Monge, S., Crebier, J.C., Ragon, S., Hertz, E., Boroyevich, D., Gurdal, Z., Arpilliere, M. and Lindner, D.K. (2004). 'Design of a boost power factor correction converter using optimization techniques', *IEEE Transactions on Power Electronics*, 19 (6), pp. 1388-1396. <https://doi.org/10.1109/TPEL.2004.836638>.

Deng, J., Zhang, D., Li, L. and He, Q. (2023). 'A nonlinear convex decreasing weights golden eagle optimizer technique based on a global optimization strategy', *Applied Sciences*, 13 (16), p. 9394. <https://doi.org/10.3390/app13169394>.

Erickson, R. W. and Maksimovic, D. (2007). *Fundamentals of power electronics*. Springer Science & Business Media.

Fadhil, G., Abed, I. and Jasim, R. (2021). 'Genetic algorithm utilization to fine tune the parameters of PID controller', *Kufa Journal of Engineering*, 12 (2), pp. 1-12.

Fermeiro, J.B.L., Pombo, J.A.N., Calado, M.R.A. and Mariano, S.J.P.S. (2017). 'A new controller for DC-DC converters based on particle swarm optimization', *Applied Soft Computing*, 52 pp. 418-434. <https://doi.org/10.1016/j.asoc.2016.10.025>.

Gerber, M., Ferreira, J.A., Hofsjager, I.W. and Seliger, N. (2004). 'Interleaving optimization in synchronous rectified DC/DC converters', 2004 IEEE 35th Annual Power Electronics

Specialists Conference (IEEE Cat. No. 04CH37551). 2004. IEEE. pp. 4655-4661. <https://doi.org/10.1109/PESC.2004.1354823>.

Hadi, A.R.S., Abaas, S., Al-Modaffer, A.M. and Mawat, R.H. (2024). 'Enhancing Stability And Regulation Of Output Voltage In Boost Converters With Learning Sliding Mode Control', *Kufa Journal of Engineering*, 15 (3), pp. 134-147.).

Jallad, J. and Badran, O. (2024). 'Firefly algorithm tuning of PID position control of DC motor using parameter estimator toolbox', *Bulletin of Electrical Engineering and Informatics*, 13 (2), pp. 916-929. <https://doi.org/10.11591/eei.v13i2.6216>

Jallad, S.E.A.H.J. (2012). 'Design and Simulation of a Photovoltaic System with Maximum Power Control to Supply a Load with Alternating Current', Faculty of Graduate Studies, An-Najah National University, Nablus, Palestine).

Kalirasu, A. and Dash, S. S. (2010). 'Simulation of closed loop controlled boost converter for solar installation', *Serbian Journal of Electrical Engineering*, 7 (1), pp. 121-130.).

Kumar, N. and Krishna, R. (2018). 'A comprehensive review on various optimization techniques for zero ripple input current DC–DC converter', *International Journal of Pure and Applied Mathematics*, 118 (05), pp. 39-49.).

Kursun, V., Narendra, S.G., De, V.K. and Friedman, E.G. (2004). 'Low-voltage-swing monolithic dc-dc conversion', *IEEE Transactions on Circuits and Systems II: Express Briefs*, 51 (5), pp. 241-248. <https://doi.org/10.1109/TCSII.2004.827557>.

Leyva, R. (2016). 'Optimal sizing of Cuk converters via Geometric Programming', *IECON 2016-42nd Annual Conference of the IEEE Industrial Electronics Society*. 2016. IEEE. pp. 2480-2485. <https://doi.org/10.1109/IECON.2016.7793443>.

Leyva, R., Ribes-Mallada, U., Garces, P. and Reynaud, J.F. (2012). 'Design and optimization of buck and double buck converters by means of geometric programming', *Mathematics and Computers in Simulation*, 82 (8), pp. 1516-1530. <https://doi.org/10.1016/j.matcom.2012.03.004>.

Li, Y., Kuprat, J., Li, Y. and Liserre, M. (2022). 'Graph-theory-based derivation, modeling, and control of power converter systems', *IEEE journal of emerging and selected topics in power electronics*, 10 (6), pp. 6557-6571. <https://doi.org/10.1109/JESTPE.2022.3143437>.

- Mohammadi-Balani, A., Nayeri, M.D., Azar, A. and Taghizadeh-Yazdi, M. (2021). 'Golden eagle optimizer: A nature-inspired metaheuristic algorithm', *Computers & Industrial Engineering*, 152 p. 107050. <https://doi.org/10.1016/j.cie.2020.107050>.
- Musunuri, S. and Chapman, P. L. (2005). 'Optimization of CMOS transistors for low power DC-DC converters', *2005 IEEE 36th Power Electronics Specialists Conference*. 2005. IEEE. pp. 2151-2157. <https://doi.org/10.1109/PESC.2005.1581930>.
- Neugebauer, T. C. and Perreault, D. J. (2003). 'Computer-aided optimization of DC/DC converters for automotive applications', *IEEE Transactions on Power Electronics*, 18 (3), pp. 775-783. <https://doi.org/10.1109/TPEL.2003.810866>.
- Ray, R., Chatterjee, D. and Goswami, S. (2010). 'Reduction of voltage harmonics using optimisation-based combined approach', *IET power electronics*, 3 (3), pp. 334-344. <https://doi.org/10.1049/iet-pel.2008.0299>.
- Ribes-Mallada, U., Leyva, R. and Garcés, P. (2011). 'Optimization of DC-DC Converters via Geometric Programming', *Mathematical problems in Engineering*, 2011 (1), p. 458083. <https://doi.org/10.1155/2011/458083>.
- Robandi, I. (2022). 'Intelligent voltage controller based on firefly algorithm for DC-DC boost converter', *Indonesian Journal of Electrical Engineering and Computer Science*, 28 (2), pp. 735-743. <https://doi.org/10.11591/ijeecs.v28.i2.pp735-743>.
- Saharia, B. J. and Sarmah, N. (2019). 'A Soft Computing Approach for Optimal Design of a DC-DC Buck Converter', *Pattern Recognition and Machine Intelligence: 8th International Conference, PReMI 2019, Tezpur, India, December 17-20, 2019, Proceedings, Part I*. 2019. Springer. pp. 297-305. [https://doi.org/10.1007/978-3-030-34869-4\\_33](https://doi.org/10.1007/978-3-030-34869-4_33).
- Saharia, B. J. and Sarmah, N. (2023). 'Grey wolf optimizer for the design optimization of a DC-DC boost converter', *Bulletin of Electrical Engineering and Informatics*, 12 (6), pp. 3263-3270.
- Seeman, M. D. and Sanders, S. R. (2008). 'Analysis and optimization of switched-capacitor DC-DC converters', *IEEE transactions on power electronics*, 23 (2), pp. 841-851. <https://doi.org/10.1109/TPEL.2007.915182>.
- Sira-Ramirez, H. J. and Silva-Ortigoza, R. (2006). *Control design techniques in power electronics devices*. Springer Science & Business Media.

- Stupar, A., McRae, T., Vukadinović, N., Prodić, A. and Taylor, J.A. (2019). 'Multi-objective optimization of multi-level DC–DC converters using geometric programming', *IEEE Transactions on Power Electronics*, 34 (12), pp. 11912-11939. <https://doi.org/10.1109/TPEL.2019.2908826>.
- Sundareswaran, K. and Kumar, A. P. (2004). 'Voltage harmonic elimination in PWM AC chopper using genetic algorithm', *IEE Proceedings-Electric Power Applications*, 151 (1), pp. 26-31. <https://doi.org/10.1049/ip-epa:20040061>.
- Takayama, T. and Maksimović, D. (2006). 'A power stage optimization method for monolithic DC-DC converters', 2006 37th IEEE Power Electronics Specialists Conference. 2006. IEEE. pp. 1-7. <https://doi.org/10.1109/pesc.2006.1711765>.
- Tian, F., Cobaleda, D.B., Wouters, H. and Martinez, W. (2022). 'Parameter Design Optimization for DC-DC Power Converters with Deep Reinforcement Learning', 2022 IEEE Energy Conversion Congress and Exposition (ECCE). 2022. IEEE. pp. 1-7. <https://doi.org/10.1109/ECCE50734.2022.9948201>.
- Umanand, L. (2009). *Power electronics: essentials and applications*. Wiley India Pvt. Limited.
- Wang, S., Murphey, Y., Su, W., Wang, M., Bui, V., Chang, F., Huang, C., Xue, L. and Glatt, R. (2022). *An intelligent system for automatic selection of dc-dc converter topology with optimal design*: Lawrence Livermore National Lab.(LLNL), Livermore, CA (United States).
- Wu, C.J., Lee, F.C., Balachandran, S. and Goin, H.L. (1980). 'Design optimization for a half-bridge dc-dc converter', 1980 IEEE Power Electronics Specialists Conference. 1980. IEEE. pp. 57-67. <https://doi.org/10.1109/PESC.1980.7089433>.
- Yousefzadeh, V. and Maksimovic, D. (2006). 'Sensorless optimization of dead times in DC–DC converters with synchronous rectifiers', *IEEE Transactions on Power Electronics*, 21 (4), pp. 994-1002. <https://doi.org/10.1109/TPEL.2006.876850>.
- Yousefzadeh, V., Alarcon, E. and Maksimović, D. (2006). 'Band separation and efficiency optimization in linear-assisted switching power amplifiers', 2006 37th IEEE Power Electronics Specialists Conference. 2006. IEEE. pp. 1-7. <https://doi.org/10.1109/pesc.2006.1712188>.
- Yuan, X., Li, Y. and Wang, C. (2010). 'Objective optimisation for multilevel neutral-point-clamped converters with zero-sequence signal control', *IET Power Electronics*, 3 (5), pp. 755-763.