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ENHANCING THE PERFORMANCE OF SOLAR BOOST CONVERTER USING GREY WOLF OPTIMIZER

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Abstract

One of the DC-DC conversion systems is boost converters which are used in commonly with solar systems to convert low DC voltage levels to higher ones. This is particularly useful in solar systems because the voltage generated by solar panels can vary widely depending on factors such as the amount of sunlight and the temperature of the panels. The duty cycle of the boost must be controlled to have the maximum output power. Using the Grey Wolf Optimizer to control the duty cycle of a boost converter is one of the ways to have this maximum power. The optimization problem can be stated as minimizing the voltage error of the boost converter output by optimizing the duty cycle. The objective function can be defined as the difference between the desired output voltage and the actual output voltage of the boost converter. The duty cycle can be optimized by adjusting the PWM signal's pulse width that controls the boost converter switch.

Keywords: Boost converter, solar system, grey wolf optimizer, boost converter-based GWO algorithm, optimization techniques

1. INTRODUCTION

Maximum Power Point Tracking (MPPT) controllers find widespread application in photovoltaic (PV) systems to improve power production from solar panels. These controllers dynamically alter the PV system's operating point to ensure that it works at its maximum power point (MPP) independent of environmental changes.

Grey Wolf Optimizer is one of the well-liked optimization algorithms employed in MPPT control (GWO). GWO is a metaheuristic algorithm inspired by nature that mimics the ways that grey wolves hunt. Due to its simplicity and efficiency, it has been effectively used for numerous optimization issues [1].

The GWO-based MPPT controller use the GWO algorithm to look for the PV system's ideal operating point. In order to keep the system operating at its MPP, the controller continuously measures the solar panels' output power and modifies the DC-DC converter's duty cycle. By iteratively updating the position of each wolf in the search space, the GWO algorithm converges towards the global optimum, ensuring that the PV system operates at its maximum efficiency [2].

The GWO-based MPPT controller offers several advantages over traditional MPPT techniques. Firstly, it provides faster convergence and improved tracking accuracy, allowing for higher energy harvesting from the solar panels. Secondly, it is robust against partial shading and other environmental disturbances, ensuring consistent performance under varying conditions. Finally, the GWO algorithm requires minimal computational resources, making it suitable for real-time implementation in practical PV systems.

In conclusion, the GWO-based MPPT controller is a promising approach for optimizing the power output of solar panels in PV systems. Its utilization of the GWO algorithm allows for efficient and accurate tracking of the maximum power point, leading to increased energy harvesting and improved system performance [3].

2. BOOST CONVERTER

Figure 1 depicts a boost converter, which is a form of DC-DC converter that raises the voltage of a DC power supply. It works by storing energy from the input voltage in an inductor and releasing it to the output voltage [4].

The output voltage is greater than the input voltage because the inductor stores energy during the ON time of the switch and then releases it during the OFF duration of the switch. The boost converter is commonly used in applications where the input voltage is too low to power the desired load, such as in battery-powered devices and solar arrays [5].

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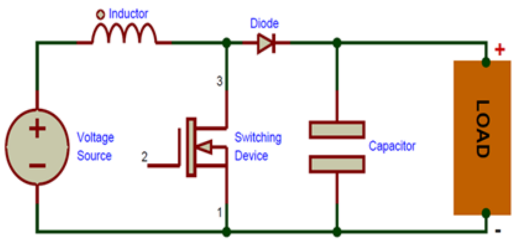


Fig. 1. The boost converter circuit diagram

3. GREY WOLF OPTIMIZER

The social behavior of grey wolves in nature served as the model for the Grey Wolf Optimizer (GWO), a population-based metaheuristic optimization algorithm. The algorithm was first proposed by Seyedali Mirjalili and Andrew Lewis in 2014. The GWO algorithm is based on the hunting behaviour of grey wolves, which involves three main roles: alpha, beta, and delta wolves. Each wolf in the population serves as a potential solution to an optimization problem in the GWO algorithm. The position of each wolf in the search space corresponds to a particular solution, and the fitness of each wolf is evaluated based on an objective function [6].

The algorithm updates the positions of the alpha, beta, and delta wolves based on how they hunt throughout each iteration. The alpha wolf's location is updated based on the best solution identified thus far, and the beta and delta wolves' placements are updated based on the positions of the other wolves in the population [7].

Based on the placements of the alpha, beta, and delta wolves as well as a random exploration term, the positions of the remaining wolves in the population are updated. This allows the algorithm to explore the search space in a balanced way, while additionally utilizing promising search space locations [8]. The GWO approach has been demonstrated to be effective for a wide variety of optimization problems, including unconstrained and restricted optimization issues. The algorithm is simple to construct and requires only a few parameters to be modified. Overall, the GWO algorithm is a promising optimization technique that can be utilized to solve a wide range of optimization issues [9, 10].

3.1. Grey wolf optimizer algorithm

Figure 2 depicts the Grey Wolf Optimizer (GW O), a metaheuristic optimization algorithm inspired by grey wolf social behaviour [11].

Researchers Mirgalili and others developed the GWO grey wolf algorithm, which relies on learning derived from the hunting behaviour of grey wolf packs (Canis lupus) in their natural habitats [12-13]. The algorithm is based on the formulation of leader and hunting abilities within the optimization framework. A wolf hunting pack of this type often contains 5-12 member wolves. Each member has its own function depending on its abilities and status, with a dominance hierarchy. The algorithm adopts this order to perform the optimization process.

The alpha wolf (α) represents the leader of the pack. He leads the group, and is not necessarily the strongest wolf in the pack [14]. The alpha wolf (α) is one of his most important responsibilities, directing the entire herd in the process of searching for prey. The beta wolf (β) comes in second in status after the leader in the hierarchy and is responsible for arranging the hierarchical wolves in the pack and supporting the leader wolf α in the form of reactions and signals. While the wolf omega (ω) is ranked lowest in the pyramid. The delta wolf (δ) includes all wolves in the pack other than α, β, or ω. Wolves include hunters, scouts, guards, and those who provide service and care for young and old wolves. The algorithm works on the best solution and arrangement, which is $\alpha>\beta>\delta$. The remaining solutions are the solution ω that lies at the bottom of the herd hierarchy [15]. A sports model can be created that represents the process of hunting, pursuing, and surrounding prey with the following sports rates:

$$\vec{D} = |\vec{C}.\overrightarrow{Xp}(i) - \vec{X}(i)| \quad (1)$$

$$\vec{X}(i+1) = |\overrightarrow{Xp}(i) - \vec{A}.\vec{D}| \quad (2)$$

Where $\vec{X}$and $\overrightarrow{Xp}$ are vectors representing the position of the grey wolf and the prey, while i represent the current iteration number. Thus, the numerical calculation of the coefficient vectors $\vec{A}$ and $\vec{C}$ is as follows:

$$\vec{A} = 2.\vec{a}.\vec{r_1} - \vec{a} \quad (3)$$

$$\vec{C} = 2.\vec{r_2} \quad (4)$$

The vectors r_1 and r_2 are random parameters with values in the range (0, 1) and the vector $\vec{a}$ decreases linearly from 2 to 0 over the course of iterations. In equation (1) and (2) mathematically, it is the positional update of the herd members around the prey in a random manner. The α grey wolf leads the pack in the hunt, and the others follow [16]. The mathematical formulation of this process assumes that information about the location of the prey is already available to the α wolf, and accordingly, the β and δ wolves update their location accordingly. The three best solutions for α, β, and δ are highlighted there, while the remaining search members in the pack update their positions accordingly. This is given as:

$$\overrightarrow{D_\alpha} = |\overrightarrow{C_1 X_\alpha} - \vec{X}| \quad (5)$$

$$\overrightarrow{D_\beta} = |\overrightarrow{C_2 X_\beta} - \vec{X}| \quad (6)$$

$$\overrightarrow{D_\gamma} = |\overrightarrow{C_3 X_\gamma} - \vec{X}| \quad (7)$$

During hunting, grey wolf members adjust their locations, as given in equations as:

$$\overrightarrow{X_1} = \overrightarrow{X_\alpha} - \overrightarrow{A_1}.(\overrightarrow{D_\alpha}) \quad (8)$$

$$\overrightarrow{X_2} = \overrightarrow{X_\beta} - \overrightarrow{A_2}.(\overrightarrow{D_\beta}) \quad (9)$$

$$\overrightarrow{X_3} = \overrightarrow{X_\gamma} - \overrightarrow{A_3}.(\overrightarrow{D_\gamma}) \quad (10)$$

The best position or candidate solution in the current iteration that works as a tool for updating the grey wolf's whereabouts is provided mathematically as:

$$\vec{X}(i+1) = \frac{\overrightarrow{X_1}+\overrightarrow{X_2}+\overrightarrow{X_3}}{3} \qquad (11)$$

The parameter $\vec{A}$ is responsible for exploring and exploiting the algorithm. The GWO flowchart is shown in figure 2.

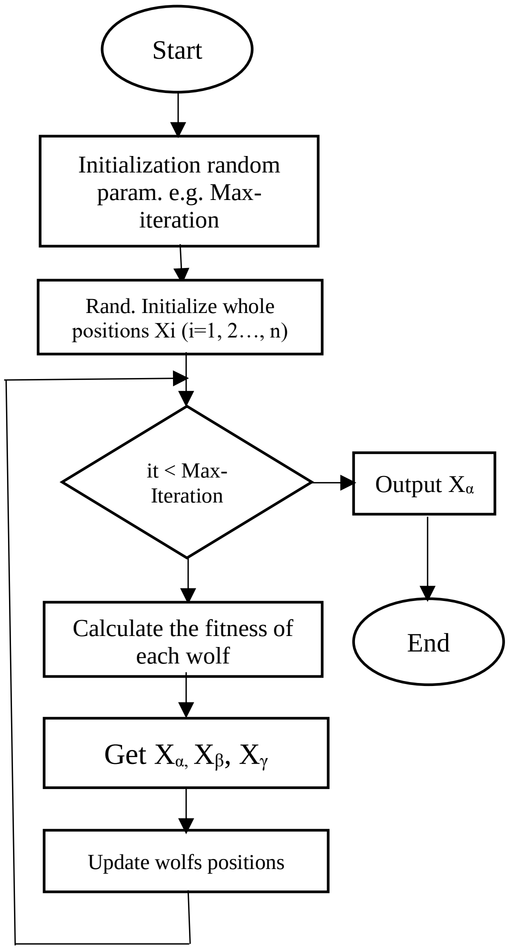


Fig. 2. The grey wolf optimizer flowchart

4. INCREMENTAL ALGORITHM

The slope of the P-V curve is detected by the incremental conduction (IC) technique, and the MPP is tracked by searching for the peak of the P-V curve. Figure 3 is the characteristics of photovoltaic array under different lighting conditions [18].

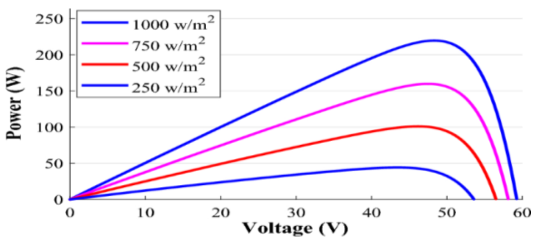


Fig. 3. Characteristics of photovoltaic array under different lighting conditions

For MPPT algorithm, instantaneous I/V coupling and dI/dV incremental coupling are used. The location of the PV module operating point in the PV curve can be determined based on the relationship between the two values, as shown in (12-13), i.e. (12) indicates that the PV module operates at MPP, while (13) and (14) indicate indicates that the PV module operates on the left and right side of the MPP in the PV curve, respectively.

$$di/dv = -1/V \qquad (12)$$

$$di/dv > -1/V \qquad (13)$$

$$di/dv < -1/V \qquad (14)$$

The above equations are obtained from the concept that the slope of the P–V curve at MPP is zero, i.e.:

$$dp/dv = 0 \qquad (15)$$

Rewriting equation 15, the following equation is obtained as:

$$I + V\frac{di}{dv} = 0 \qquad (16)$$

In the traditional incremental conduction algorithm, equation (16) is used to detect the maximum power point and the voltage and current of the PV module that are measured by the MPPT controller. If equation (13) is satisfied, then the duty cycle of the DC to DC boost converter should be reduced, and vice versa if equation (14) is satisfied, while there is no change in the duty cycle if equation (16) is satisfied.

5. MPPT ALGORITHM FOR GREY WOLVES OPTIMIZER

The GWO algorithm can be used to optimize the design parameters of the Boost Converter. The duty cycle is used here to change the boost output voltage to improve its efficiency and output power. The GWO algorithm works by simulating the hunting behaviour of grey wolves, which coordinates their hunting behaviour to discover the optimal answer to the optimization problem. About the Boost Converter, the GWO algorithm can be used to find the optimal values of the design duty cycle according to the optimal values of each current and voltage of the PV array that find the maximum power output of the converter. The input voltage and output voltage can be used to find the ideal duty cycle values that used to give the optimal point of each current and voltage of the PV array to optimize the output power of the Boost Converter. The output power of the converter is the objective function to be optimized, which is provided by:

$$V_{out} = V_{in}/(1 - Du) \qquad (17)$$

Where V_{in} is the input voltage, V_{out} denotes the output voltage, and Du denotes the duty cycle.

The hunting behaviour of the wolves is then simulated by updating their positions based on their fitness values, which are computed using the objective function. After a given number of rounds, the alpha wolf's position correlates to the optimal set of duty cycle settings that optimize the boost converter's power output. The Grey Wolf Optimization GWO technique can be used to improve the efficiency and power output of a boost converter. The GWO algorithm simulates grey wolf hunting behaviour to determine the ideal design parameters that maximize the converter's power output [19-20].

6. METHODOLOGY

This study deals with improving the performance of a solar power inverter using "grey wolf" algorithm. The study began by defining the transformer requirements and design, and then grey wolf variables and relevant environmental conditions were identified. Then Grey Wolves algorithm was used to improve the performance of the converter by modifying the variables. Finally, the results were analyzed and verified for accuracy, contributing to the understanding of the efficiency of Grey Wolves algorithm in dynamically optimizing the solar energy converter.

7. SIMULATION AND RESULTS

A PV system and a boost converter were simulated using MATLAB/Simulink. MPPT control behaviour and tracking was modified using grey wolf optimizer GWO. Figure 4 shows a solar cell system module with a boost-converter controller. The simulation model consists of solar panels, a boost converter, and a controller that generates the signal of pulses to trigger the boost converter.

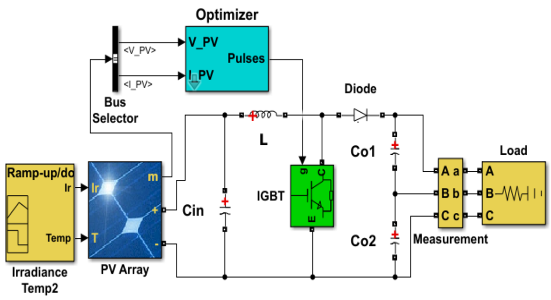


Fig.4. Boost converter-based GWO Simulink circuit

The materials that are used in this research are:

PV Solar Module: the PV that is used in the simulation is SunPower SPR-305E-WHT-D with 66 parallel string and 5 Series-connected modules per string. The parameters are in table 1.

Table 1. PV array parameters

Type	SunPower SPR-305E-WHT-D
Output Power	100kW (Nser=5, Npar=66)
Open Circuit Voltage Voc	64.2V
Short Circuit Current Isc	5.96A
Voltage at maximum power point Vm	54.7V
Current at maximum power point A	5.58A

The boost converter parameters are in table 2.

Table 2. Boost parameters

Type	Boost converter used in figure 4
L	5mH
Cin	100μF
Co1&Co2	Each of 12000μF
Switching freq.	5kHz

Figure 5 is the input irradiation to the PV array at constant temperature of 25^0 C.

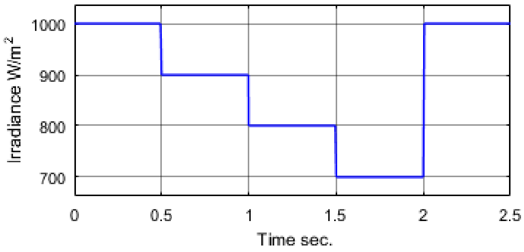
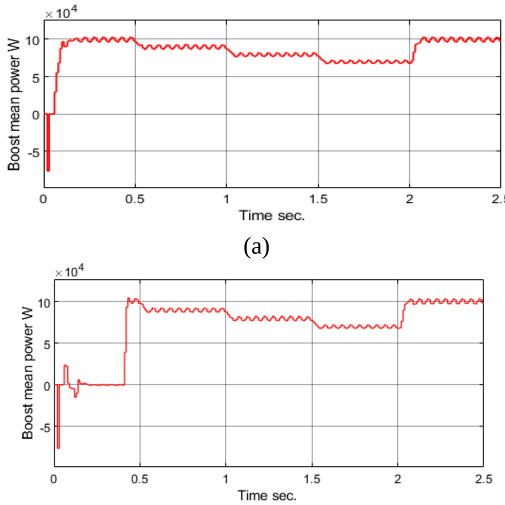


Fig. 5. Input irradiance W/m^2

Figure 6 is the output power of the boost converter. (a) is for GWO and (b) is for IC, the GWO output power is more stable and fast response compared with IC one.



(a)

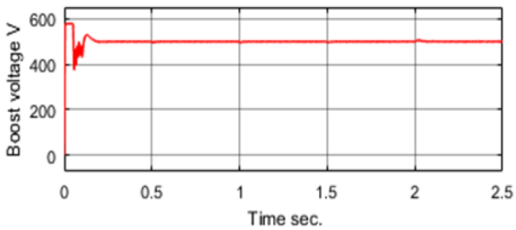
(b)

Fig. 6. The boost convweter output power for GWO and IC res

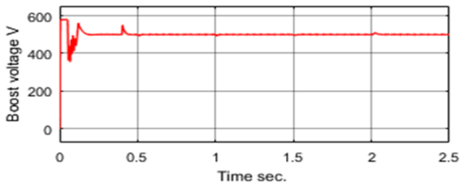
Figure 7 is the output voltage of the boost converter. (a) is for GWO and (b) is for IC, the GWO output power is more stable compared with IC one.

Figure 8 is the PV mean power. (a) is for GWO and (b) is for IC, the GWO mean power of PV is more stable and fast response compared with IC one.

Figure 9 is the PV output voltage. (a) is for GWO and (b) is for IC, the GWO voltage of PV is more stable and fast response compared with IC one.

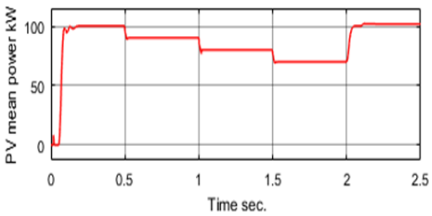


(a)

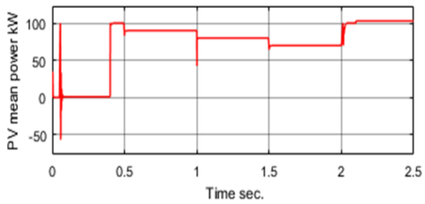


(b)

Fig. 7. The boost convweter output voltage for GWO and IC res

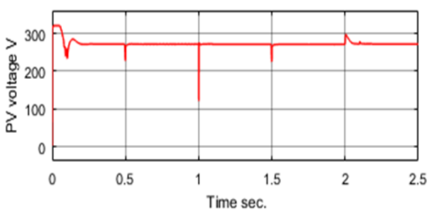


(a)

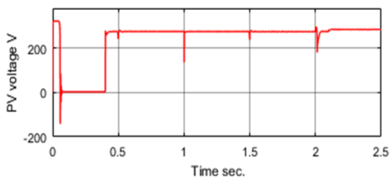


(b)

Fig. 8. The PV mean power for GWO and IC res



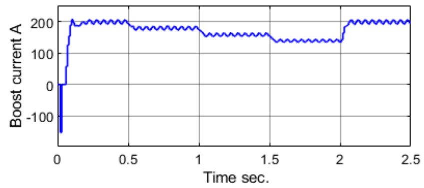
(a)



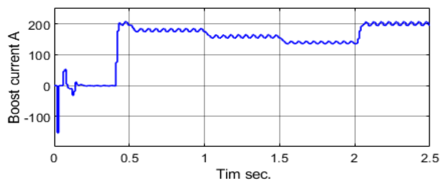
(b)

Fig. 9. The voltage for GWO and IC res

Figure 10 is the current for boost converter, (a) is for GWO and (b) is for IC.



(a)



(b)

Fig. 10. The current for GWO and IC res

8. CONCLUSIONS

A module for solar cells with a boost converter was designed using Matlab/Simulink, and the electronic switch MOSFT of the boost converter was controlled and driven by a pulse signal generated by the grey wolf controller.

Grey wolves improve the performance of the boost converter for the solar cell module by finding the closest values for the solar module voltage as well as the current that produce the greatest power. The process is done by gradually approaching the maximum power value and then capturing, retaining and following up on this value.

The results obtained from the Grey Wolves start-up algorithm were compared to the traditional Incremental method, and the Grey Wolves results were better in terms of the boost output voltages reaches the steady state at 0.2 sec. where in the IC algorithm the voltage reaches the steady state at 0.4 sec., the power of the boost converter also reached the steady state at 0.1 sec. For GWO and at 0.4 sec. For IC algorithm.

GWO is effective in the fields of engineering and numerical optimization thanks to its integration with natural wolf behaviour. This method is also better in terms of cost, as precise controllers are used with low cost and greater development capabilities.

At irradiance 1000W/m2, the mean power, which obtained by GWO, as shown in figure 8, remained fix from (0 to 0.5) and the mathematical calculation of power is:

$$P=V*I \tag{18}$$

From array, there are five PV panel connected in series in each string and six strings connected in parallel therefore, V=273.5V and I=368.2A. So, the power P=100.72kW.

The power value appeared similar to the obtained by simulation.

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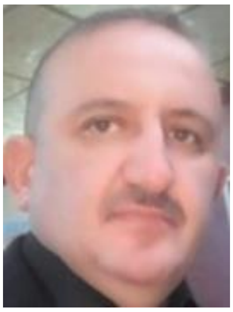

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