Research Article

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Hybrid optimization strategy for water cooling system: enhancement of photovoltaic panels performance

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Abstract: Solar energy is the most effective substitute for fossil fuels when it comes to Produce electricity among the numerous renewable energy sources. The efficiency may drop as a result of overheating, and the PV cell may also be harmed. Therefore, increasing the output of a solar PV system at a lower cost is essential to improving its efficiency. Additionally, by using cooling methods, the PV cells' lifetime is extended. By lowering the working temperature of a PV panel's surface, you may increase efficiency and slow the thermal deterioration rate. This may be done by module cooling and lowering the heat that the PV cells generate while operating. Hence, an active cooling technology known as optimization-aided water spraying technique is employed to increase efficiency. This method enables the PV panels to provide their maximum output power while taking less time to drop down to a lower surface temperature. Beluga Whale assisted Jellyfish Optimization (BWJO) model is suggested as a means of achieving these goals. Finally, Simulink/MATLAB is used to implement the suggested method and optimize the PV system cooling. The performances of the two components were compared using a variety of metrics.

Keywords: PV; active coolant; water cooling; energy; BWJO

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Nomenclature

PV/T	photovoltaic-thermal
NOCT	normal operating cell temperature
WCP	water-cooled plate
TEG	thermoelectric generator
PV	photovoltaic
PCM	phase change materials
CFD	Computational fluid dynamic
PEG-600	Polyethylene glycol 600
BWO	Beluga Whale Optimization
JFO	Jellyfish Optimization
BES	Bald Eagle Search
HBO	Honey Badger Optimization
WE-HHO	Weighted Exploration based Harris Hawks Optimization
MAT	Maximum Allowable Temperature

1 Introduction

Overconsumption of conventional fossil fuels at an alarming rate caused a shortage of energy and corresponding environmental issues of climate change (Chanphavong et al. 2022; Hadipour et al. 2021), emissions of greenhouse gases, and ozone depletion, which endanger human security and the world's future. Therefore, there is a larger need for renewable and clean energy solutions to lessen our reliance on fossil fuels and the negative environmental effects that follow. Solar energy (Jonas Piotrowski, Godoy Simões, and Farret 2020; Sudhakar et al. 2021) is the most widely used and widely recognized renewable energy source because of its purity, sustainability, ease of accessibility, and limitless potential. Being able to heat and illuminate homes and other buildings (Fakouriyan, Saboohi, and Fathi 2018), the sun is considered the most potent renewable energy source. In addition, several industrial operations like the production of electricity and the heating of water employ solar energy.

Solar energy harvesting techniques (Murtadha and Hussein 2022; Murtadha et al. 2022), such as terrace water heating tubes, solar cells, and mirrors, are always changing and becoming more effective as technology advances. Solar radiation and additional energy sources, such as wave, wind, hydropower, as well as biomass, are credited with producing the majority of the renewable energy used on Earth. It is important to remember that just a small portion of the solar energy (Nabil and Mansour 2022) that enters the planet is used for energy production. Only humans can regulate the usage of solar energy once it has been transformed into electrical energy. The main applications of solar energy (Jafari 2021; Juřcevi et al. 2021) are cooling as well as heating systems in an architectural layout that is based on solar energy exploitation, potable water via disinfection and distillation operation, daylight exploitation, heating of water, solar cooking, as well as the maximum temperature for the industry.

Tiny rooftop or building-based PV systems (Mahmood and Aljubury 2022) can have the capability of a few to multiple tens of kilowatts, while huge utility-scale power plants can have capacities of numerous megawatts. The majority of PV systems currently are connected to the grid, whereas standalone systems only make up a minor percentage of the market. Diverse parameters, including incident solar insolation and running temperature, are needed to increase a PV panel's efficiency (Yesildal et al. 2022). Due to this, when the PV panel is operating, a serious issue known as overheating arises (Madan and Kumar 2020). Therefore, various cooling techniques such as forced air, PCMs, water, thermoelectric cooling, transparent coating, and evaporative cooling are employed to combat the issue of overheating while increasing output power. By using a water tube that is mounted to the back of the PV panel, the MPP minimizes the temperature in a variety of circumstances to its usual operating point. As a result, it becomes highly challenging to regulate the PV surface temperature, necessitating the use of a passive or active cooling approach that eliminates heat transfer and reduces temperature by enhancing the PV cell's effectiveness and performance. Therefore, via spraying water on the surface to decrease overheating, the water spraying cooling technology may offer improved output and efficiency. This paper proposes a novel model water cooling system with the following contributions:

(1) Developed the optimization-aided water spraying technique, an active coolant approach that reduces the operating temperature of a PV panel's surface to maximize output power and shorten the cooling time.
(2) The novel BWJO-based model is compared with the conventional methods with a better convergence rate.

Organization of this proposed technique: Section 1 entails the part of the introduction. Section 2 entails the part of the overview. Section 3 entails the part of the proposed BWJO-aided water spraying technique. Section 4 entails the part of the result and discussion. Section 5 entails the part of the conclusion.

2 Literature review

Yildirim et al. (2022) suggested a thermal collector for the use of PV/T systems. The thermal as well as conversion to electricity efficiencies of the water-assisted PV/T system was achieved by coupling the thermal activity of the solar module with the specified cooling box flow. Under NOCT settings, a range of temperatures and inflow mass flow rates were simulated. The layers of solar modules were examined for the distribution of temperature and average temperature.

Fathi, Mahfoud Abderrezek, and Farid (2019) examined the effectiveness of front-side water cooling and the heating activity of solar panels. A freestanding cooling system was created as a prototype, and the energy calculation of this system aided in the creation of a large-scale implementation methodology. The first situation involved a uniform temperature distribution, whereas the second scenario involved a non-uniform temperature distribution under partial shadowing that produced a hot spot effect.

Liu et al. (2020) constructed a polycrystalline PV cell that was widely accessible and developed a hybrid Bi–Te/TEG system. A multi-layer composite infrastructure was created by incorporating the WCP into the PV/TEG system as a dependable cooling mechanism. As a consequence, power density as well as the efficiency of the composite systems was continuously observed by varying the light intensity and the TEG's use area. It was discovered that the usage rate of residual heat may be raised if the distribution, as well as coverage of thermoelectric devices, were further adjusted.

Sultan et al. (2019) suggested a strategy based on a newly discovered metric known as the temperature-based PV efficiency difference factor that was determined and calculated, for evaluating the PV cooling methods. This element highlighted the pertinent variables that have an impact on efficiency and that result in an evaluation of the total PV cooling method. This metric may have an opportunity to be used as a way for producers and developers of such goods to assess the efficacy of PV coolers. It could show that the cooling method was contributing to a gain, loss, or neutral change in PV efficiency.

Khalili et al. (2023) merged the TEG layer with traditional PVT module layers to better utilise waste heat and boost efficiency. A cooling duct was present in the PVT-TEG unit's base to lower the cell temperature. The system's performance might fluctuate depending on the kind of fluid in the duct and its construction. To create three different cross-section designs, a hybrid nanofluid was used in place of pure water.

Firoozzadeh et al. (2020) centred on the investigation of PV/PCM systems' highest operating temperatures with and without fans. Various melting values of PEG-600 and paraffin have been investigated experimentally as PCM under indoor conditions. Additionally, the impact of employing fns was researched. Since paraffin's melting point was closer to the module temperature at this crucial temperature, the results suggested that employing it would be a superior method for regulating the PV cells temperature.

Wu et al. (2020) conducted a computational model based on CFD to study the impact of solar irradiation, ambient temperature, as well as wind speed on the efficiency as well as mono-crystalline cell temperature. The results of the simulation showed that using the applied cooling strategy for PV cells is more beneficial in maximum solar irradiation as well as hot ambient temperature. Additionally, it is found that using water to cool the cell beneath the investigated circumstances enables the cell's temperature to be maintained within a range that precludes the decrease of its efficiency under high solar irradiation and ambient temperatures.

Belyamin et al. (2021) in order to anticipate distributions of temperature and different PV panel powers, second-degree polynomial algorithms were developed, whilst the linear algorithms were utilized to analyse the relationship between solar power input and different PV panel powers. The findings indicated that the highest electrical, thermal, and power loss values were attained at temperatures near midday. A PV panel research using two distinct cooling water flow rates confirmed the identical PV panel power value measured at two various temperatures.

2.1 Review

One of the primary drawbacks of active air cooling is that it cannot work well at high temperatures since there might not be enough temperature differential between the ambient air as well as panel temperature to provide enough cooling. Some of the problems that researchers had with the available techniques included in the review Table 1 were: Lack of efficient electrical and thermal conversion processes while using a 2-D thermal model (Yildirim et al. 2022). The water flow rate optimization (Fathi, Mahfoud Abderrezek, and Farid 2019) proved difficult. It was difficult to calculate the link between the coverage area of TEG (Liu et al. 2020) and total effectiveness and cost. Increasing the temperature of the solar cell (Sultan, Tso, and Efzan 2019) proved difficult. Influence of inlet velocity on the ideal duct geometry (Khalili, Sheikholeslami, and Momayez 2023). Entropy generation was difficult while using the PV/PCM model (Firoozzadeh, Shiravi, and Shafee 2020). Consumption of fossil fuels in the CFD model (Wu et al. 2020) is on the rise. The second-degree polynomial technique (Belyamin et al. 2021) has an overfitting issue.

3 Active coolant approach: system model

3.1 PV cell temperature effects

The PV cell's equivalent circuit including the current input in parallel having shunt resistance as well as a single diode and also series resistance is shown in Figure 1. In Eq. (1), the single diode PV cell I–V features are determined, in which G_s states solar radiance, I_0 states of diode saturation current, I_{PV} states photovoltaic current, q states electron

Table 1: State-of-the-art methods used by researchers with their features and challenges.

Author [citation]	Methods	Features	Challenges
Yildirim et al. (2022)	2-D thermal model	Huge potential to spread awareness of solar energy and also capture electrical as well as thermal energy	Lack of efficient electrical and thermal conversion processes
Fathi, Mahfoud Abderrezek, and Farid (2019)	PV panel and front side heating behaviour analysis model	Advantageous when employing a PV panels string with at least three panels.	The water flow rate optimization proved difficult.
Liu et al. (2020)	PV-TEG model	The rate of use of leftover heat could be boosted.	It was difficult to calculate the link between coverage area of TEG and total effectiveness and cost.
Sultan et al. (2019)	Temperature assisted PV efficiency difference factor model	Identified the important variables that have an impact on efficiency	Increasing the temperature of the solar cell proved difficult.
Khalili et al. (2023)	PVT-TEG model	Improved electrical efficiency	Influence of inlet velocity on the ideal duct geometry
Firoozzadeh et al. (2020)	PV/PCM model	Improved energy efficiency	Entropy generation was difficult
Wu et al. (2020)	CFD model	Effective in improving cell efficiency	Consumption of fossil fuels was on the rise.
Belyamin et al. (2021)	Second-degree polynomial technique	Gives a new viewpoint on how to handle solar energy for both household and business uses.	Overfitting issue

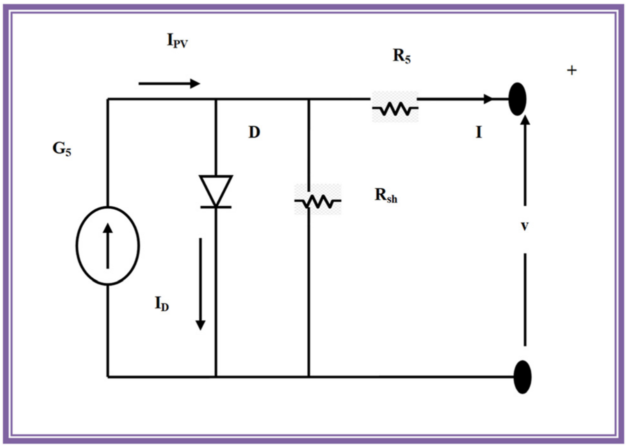

Figure 1: Single diode PV cell: equivalent circuit.

variation, K states Boltzman's constant, a states the diode ideal factor, T states cell temperature, R_s states series resistance (Taqwa et al. 2020) as well as R_{sh} states shunt resistance.

$$I = I_{PV} - I_0\left[\exp\left(\frac{q(V + IR_s)}{aKT}\right) - 1\right] - \left(\frac{V + IR_s}{R_{sh}}\right) \tag{1}$$

KC200GT, a maximum-efficiency Kyocera PV module, is utilized in the suggested system. Physical as well as electrical features of the PV module are represented in Table 2.

Table 2: PV module (Mohamed et al. 2021): physical as well as electrical features.

Electrical features	
Model	KC 200GT
Maximum power current (I_{mp})	7.61 A
Series resistance (R_s)	0.221
Open circuit voltage (V_{oc})	32.9 V
Shunt resistance (R_{sh})	415.405
Maximum power voltage (V_{mp})	26.3 V
Nominal operating cell temperature	47 °C
Maximum system voltage (V_{max})	600 V
Short circuit current (I_{sc})	8.21 A
Power rating (P_{max})	200 W
Temperature coefficients	
Temperature coefficient: I_{sc}	3.18×10^{-3} A/°C
Temperature coefficient: V_{oc}	-1.23×10^{-1} V/°C
Physical features	
PANEL dimension (mm × mm × mm)	1425 × 990 × 36
Cells count per module	54
Weight of panel	18.5 Kg
Type of cell	Multi crystal

3.2 Overheating on PV efficiency: effects

The main problem that must be addressed during the operation of the PV panel is overheating or scalding produced by the excess solar insolation as well as maximized ambient temperature, which in turn affects the efficiency of the panel to a maximum extent (Elnozahy et al. 2015; Moharram et al. 2013). As a PV cell's temperature rises, its highest output power gradually decreases (Tabaei and Ameri 2015). Thus, it is evident that the excessive heat also has an impact on the panel's output.

3.3 Water cooling system

The solar cells on PV panels are cooled using a water-cooling system; as a result, the warm air or water that exits the panels can be used for household services, such as home heating (Makki, Omer, and Sabir 2015; Moharram et al. 2013). Yet, under cooling the temperature of the surface of solar PV panel having water maximize the solar cells output power via 50 percent and it does not allow the rise of floor temperature of sun cells. The solar panel is used with water as a cooling medium to boost efficiency. One of the solar panels is left uncooled during the experiment, while the other is cooled using a pump-powered water spraying approach. Delivering a significant volume of water to the device is the water pump's key function. Additionally, this might be done by pulling water out of the tank and supplying it to the sprinkler (Mohamed et al. 2021; Odeh and Behnia 2009). Additionally, it may provide water by raising the cost of fluid flow from lowest to highest strain heads. As a result, a water distribution in a symmetrical way at the bottom of solar panels is required to properly carry out the cleaning procedure and remove any type of dirt and other deposits (El-Shobokshy and Hussein 1993). It was found that cooled solar panels produce more energy than uncooled solar panels. Thus, by boosting the PV module power, the suggested water-cooling technology may also decrease overheating over the surface of the PV panel. Eq. (2) provides the amount of electricity needed by the pump to cool the panel, in which Q states the rate of water flow as well as P states water pressure.

$$\text{Pumping Power} = Q \times P \tag{2}$$

3.4 Optimization-assisted PV panel cooling by BWJO model

3.4.1 Solution encoding and objective function

In order to achieve a precise cooling effect the proposed work seeks to reduce the time required to cool down the PV panel surface by 2 °C (Moharram et al. 2013).

The main objectives of this study are as follows:

- The first and foremost goal of this work is to raise the current offered by the PV panel,
- The second goal aims to increase the PV panel's output power. The PV panel's output power is increased after cooling, which lowers the cost and lowers the power required by the water spraying mechanism.

3.4.2 The proposed BWJO model

This section provides an overview of BWJO, which draws its inspiration from the beluga whales' swimming, hunting, and whale-falling behaviours. Because of the population-assisted BWJO model, considering beluga whale is the search agent while the candidate solution is considered as the beluga whale which gets updated in the optimization process. The proposed optimization-aided water spraying technique is an active coolant approach that decreases the operating temperature of a PV panel's surface to increase the output power and minimize the cooling time. Besides decreasing the working temperature of the PV panel's surface, the efficiency of the proposed method is increased and the thermal deterioration rate can be lowered. Instead of using the random population in Eq. (3), the proposed logic is used for JFO initialization in the BWO model, in which $\eta \in 4.0$, $i = 1, 2, \ldots, pop$.

$$X_i = Lb + X_i^{\text{Logistic}} \times (ub - lb)\,; X_{i+1}^{\text{Logistic}} = \eta X_i (1 - X_i); X_i^{\text{Logistic}} = \text{rand}(0,1) \quad (3)$$

The balancing factor B^{fac}, defined using Eq. (4), determines whether the BWO algorithm switches from exploration to exploitation, in which T, $T_{\max}$ states current and maximum iteration. Beluga whale swim activity is taken into consideration when establishing the BWO exploring phase. The social-sexual behaviours of beluga whales in caring for people have been observed, and these behaviours can be displayed in a variety of postures, including the pair swim in which two beluga whales move very closely together in a coordinated or mirror image. As a result, the locations of search agents are established by the beluga whale couple swim, and the locations of beluga whales are modified in accordance with Eq. (5).

$$B^{fac} = B_0 (1 - T/T_{\max}()) \quad (4)$$

$$\begin{cases} X_{i,j}^{T+1} = X_{i,pj}^{T} + \left(X_{r,p^1}^{T} - X_{i,p^1}^{T}\right)(1 + r_1)\sin(2\pi r_2); j = \text{even} \\ X_{i,j}^{T+1} = X_{i,pj}^{T} + \left(X_{r,p^1}^{T} - X_{i,p^1}^{T}\right)(1 + r_1)\cos(2\pi r_2); j = \text{odd} \end{cases} \quad (5)$$

The modified position reveals the beluga whales' synchronized or mirror movements while swimming or diving, depending on the dimension determined by odd as well as even numbers. The exploration phase uses two different random numbers, r_1, r_2, to improve the randomized operators. The predatory behaviour of beluga whales serves as inspiration for the BWJO exploitation phase. Depending on the closeness of other beluga whales, beluga whales may move as well as forage together. As a result, beluga whales engage in hunting by discussing job postings with one another and choosing the best candidate. The Levy flying approach is applied to aid convergence during the opportunistic phase of the BWJO. We assumed that they could use the Levy flying method $L_F = 0.05 \times \frac{u \times \sigma}{|v|^{1/\beta}}$ to capture their prey, and the numerical representation is represented as in Eq. (6), in which u, v states normally distributed random value, $C_1 = 2r_4\left(1 - \frac{T}{T_{\max}}()\right)$ states randomized jump strength, and $\beta \in 1.5$ states default constant. According to our proposed model, by hybridizing the JFO (Chou and Truong 2020) and BWO (Zhong and Meng 2022) update equation, we obtain the new exploitation phase position update equation of BWJO expressed as in Eqs. (8)–(12).

$$X_i^{T+1} = r_3 X_{\text{best}}^{T} - r_4 X_i^{T} + C_1 \times L_F \times \left(X_r^{T} - X_i^{T}\right) \quad (6)$$

$$X_i(t+1) = X_i(t) + \text{Ste}\,\overrightarrow{\text{p}} \quad (7)$$

$$X_i(t+1) = r_3 X_{\text{best}}^{T} - r_4\left[X_i(t+1) - \text{Ste}\,\overrightarrow{\text{p}}\right] + C_1 \times L_F \times \left(X_r^{T} - \left[X_i(t+1) - X_i^{T}\text{Ste}\,\overrightarrow{\text{p}}\right]\right) \quad (8)$$

$$X_i(t+1) = r_3 X_{\text{best}}^{T} - r_4 X_i(t+1) + r_4 \text{Ste}\,\overrightarrow{\text{p}} + C_1 \times L_F \times X_r^{T} - C_1 \times L_F \times X_i(t+1) + C_1 \times L_F \times \text{Ste}\,\overrightarrow{\text{p}} \quad (9)$$

$$X_i(t+1) + r_4 X_i(t+1) + C_1 \times L_F \times X_i(t+1) = r_3 X_{\text{best}}^{T} + r_4 \text{Ste}\,\overrightarrow{\text{p}} + C_1 \times L_F \times X_r^{T} + C_1 \times L_F \times \text{Ste}\,\overrightarrow{\text{p}} \quad (10)$$

$$X_i(t+1)\left[1 + r_4 + C_1 \times L_F\right] = r_3 X_{\text{best}}^{T} + r_4 \text{Ste}\,\overrightarrow{\text{p}} + C_1 \times L_F \times \left[X_r^{T} + \text{Ste}\,\overrightarrow{\text{p}}\right] \quad (11)$$

$$X_i(t+1) = \frac{r_3 X_{\text{best}}^{T} + r_4 \text{Ste}\,\overrightarrow{\text{p}} + C_1 \times L_F \times \left[X_r^{T} + \text{Ste}\,\overrightarrow{\text{p}}\right]}{\left[1 + r_4 + C_1 \times L_F\right]} \quad (12)$$

The vast majority of beluga whales are clever, and they can communicate with one another in order to provide information that can assist them escape threats. But some of the beluga whales have perished and are buried beneath the surface of the ocean. The phenomenon referred to as "whale fall" provides food for a wide variety of animals. We presume that those beluga whales are either gone or have been shot at, plunging into the depths of the ocean. To keep the population number consistent, beluga whale locations along with a whale's fall distance are utilized to establish the current position. The mathematical formulation is given in

Eq. (13), in which $C_2 = 2W_f \times n$, $W_f = 0.1 - 0.05\,T/T_{\max}$ states whale fall probability. As per our proposed model, X_{Step} is calculated as time-varying scalar factor (Sharma et al. 2019) in Eq. (14).

$$X_i^{T+1} = r_5 X_i^T - r_6 X_r^T + r_7 X_{\text{Step}};\, X_{\text{Step}} = (ub - lb)\exp(-C_2 T/T_{\max}()) \tag{13}$$

$$X_{\text{Step}} = (ub - lb) \times \frac{(T_{\max}())}{T} \tag{14}$$

Algorithm 1: Pseudocode of proposed BWJO model.

Initialize the population of BWJO using Eq. (3) as per the proposed model
While $T \le T_{\max}$ do
Achieve W_f and achieve B^{fac} using Eq. (4)
for X_i (each beluga whale) do
if $B^{fac}(i) > 0.5$
Create P_j (j = 1, 2, … , d) randomly from the dimension
Select X_r (beluga whale) in a random way
Updating of i^{th} beluga whale novel location using Eq. (5)
else
if $B^{fac}(i) \le 0.5$
Updating C_1 and computing of L_F
Updating i^{th} beluga whale novel location using Eq. (12) in accordance with the proposed model
else if
Identify novel position boundary and calculate fitness
end for
for each X_i do
if $B^{fac}(\text{i}) \le W_f$
Updating of C_1 (step factor)
Calculation of X_{Step} (step size) as per Eq. (14) in accordance with the proposed model
Updating of i^{th} beluga whale novel location using Eq. (13)
Identify novel position boundary and calculate fitness
end if
end for
Identify P^* (present best solution)
$T = T + 1$
end while

4 Results analysis on BWJO for water cooling system

4.1 Experimental setup

The BWJO-based water cooling system was implemented in MATLAB. Moreover, Table 3 shows the system configuration. To demonstrate the effective water-cooling performance of the BWJO, it is compared with the traditional strategies, including, BES, HBO, JS, BWO and WE-HHO (Singh 2022). In addition, the outcome of PV power is calculated for four distinctive scenarios with MAT of 40 °C, 45 °C, 50 °C, and 55 °C. In each scenario, the PV panel is permitted to reach the MAT in an overheated state before being allowed to cool down its surface at a rate of cooling of roughly 2 °C (Moharram et al. 2013). Additionally, it states that the greatest power rises with the water cooling model while the temperature lowers. Further, by employing water as a medium of cooling, the adverse effect of temperature at module output might be lessened. Table 4 shows the experimental parameters.

Table 3: System configuration.

Device specification	
Processor	"11th Gen Intel (IR) core(TM) i5-1135G7 @ 2.40 GHz 2.42 GHz"
Installed RAM	"16.0 GB (15.7 GB usable)"
Software specification	
MATLAB version	2021b

4.2 Assessment of BWJO and conventional schemes: varying MAT

Scenario 1 is a representation of the PV model at 40 °C. The greatest power modification of the PV model before and

Table 4: Experimental parameters.

PV cell parameters	
Ambient temperature	326.15
Nominal short circuit current	8.21
Nominal open-circuit voltage	32.9
Number of solar cells or panels	54
Boltzmann constant	1.38e−23
Elementary charge	1.6e−19
Number of diodes	2
Algorithm parameters	
Honey Badger algorithm	Beta β = 6 C = 2
FireFly	α = 0.5 $\beta_{\min}$ = 0.5 γ gamma = 1
Beluga whale optimization	alpha = 3/2 KD = 0.05
Genetic algorithm	Crossover rate = 0.6 Mutation sigma = 0.1 Elite = 2
Particle swarm optimization	Acceleration constants $c1$ = 2; $c2$ = 2 Maximum weight = 0.9 Minimum weight = 0.1

after 40 °C cooling is illustrated in Table 5. In addition, when cooling a PV panel, the BWJO method offers an average difference of 10 W in comparison to BES, HBO, JS, BWO, and WE-HHO, and its highest possible PV power will be 260 W.

Scenario 2 is a representation of the PV model at 45 °C. The PV module's maximum power modifications before and after cooling at 45 °C are represented in Table 6. In comparison to BES, HBO, JS, BWO, and WE-HHO during PV panel cooling, the BWJO method offers an average difference of 40 W, and the highest PV power output will be 280 W.

Scenario 3 is a representation of the PV model at 50 °C. The greatest power variation of the PV module before and after 50 °C cooling is illustrated in Table 7. In addition, when cooling a PV panel, the BWJO method offers an average difference of 20 W in comparison to BES, HBO, JS, BWO, and WE-HHO, and the highest possible PV power will be 280 W.

Scenario 4 is a representation of the PV model at 55 °C. The PV module's maximum power modifications before and after cooling at 55 °C are represented in Table 8. In addition, when compared to BES, HBO, JS, BWO, and WE-HHO during PV panel cooling, the BWJO method offers an average difference of 40 W, and the highest PV output power will be 300 W.

4.3 Convergence evaluation on BWJO and conventional schemes for water cooling system

Figure 2 explains the convergence analysis on BWJO is contrasted with the BES, HBO, JS, BWO and WE-HHO for the water cooling system. Here, the analysis is carried out for four distinct temperatures, such as 40 °C, 45 °C, 50 °C, and 55 °C. For the efficacious water cooling system, the model should acquire a lower fitness value with quicker convergence. Similarly, at 40 °C, the BWJO converges faster than the BES, HBO, JS, BWO and WE-HHO as well and it obtained a minimal fitness value ranging from −6550 to −6000. In addition, the BWJO accomplished the lowest fitness rate of 0.4128 at 55 °C, though the BES, HBO, JS, BWO and WE-HHO obtained higher fitness values with slower convergence. Similarly, the superiority of the BWJO method is revealed in the respective graphs for the other scenarios too.

Table 5: Scenario 1-PV model's maximum power modification before and after cooling at 40 °C.

Methods	Before cooling	After cooling
BES	135.5100	123.1400
HBO	135.5100	125.7500
JS	135.5100	134.3800
BWO	135.5100	120.8600
WE-HHO	135.5100	144.4300
BWJO	135.5100	144.7800

Table 6: Scenario 2-PV model's maximum power modification before and after cooling to 45 °C.

Methods	Before cooling	After cooling
BES	142.3400	115.5200
HBO	142.3400	129.8600
JS	142.3400	114.5900
BWO	142.3400	110.3900
WE-HHO	142.3400	129.8600
BWJO	142.3400	130.2300

Table 7: Scenario 3-PV model's maximum power modification before and after cooling to 50 °C.

Methods	Before cooling	After cooling
BES	128.8400	115.6700
HBO	128.8400	99.7770
JS	128.8400	118.6500
BWO	128.8400	110.9100
WE-HHO	128.8400	118.6500
BWJO	128.8400	118.9900

4.4 Analysis of optimized results for BWJO and conventional schemes

The evaluation of BWJO strategy and conventional approaches (BES, HBO, JS, BWO and WE-HHO) about average power, best fitness, optimal solution and computational time for distinct scenarios at 40 °C, 45 °C, 50 °C and 55 °C as well as the outcomes are displayed from Tables 9–12. Regarding Table 8, the BWJO acquired the average power of 144.7800, meanwhile, the traditional schemes recorded the least average power rate, notably, BES = 123.1400, HBO = 125.7500, JS = 134.3800,

Table 8: Scenario 4-PV model's maximum power modification before and after cooling to 55 °C.

Methods	Before cooling	After cooling
BES	131.0600	107.5200
HBO	131.0600	84.2980
JS	131.0600	122.3900
BWO	131.0600	84.2980
WE-HHO	131.0600	122.3800
BWJO	131.0600	122.7400

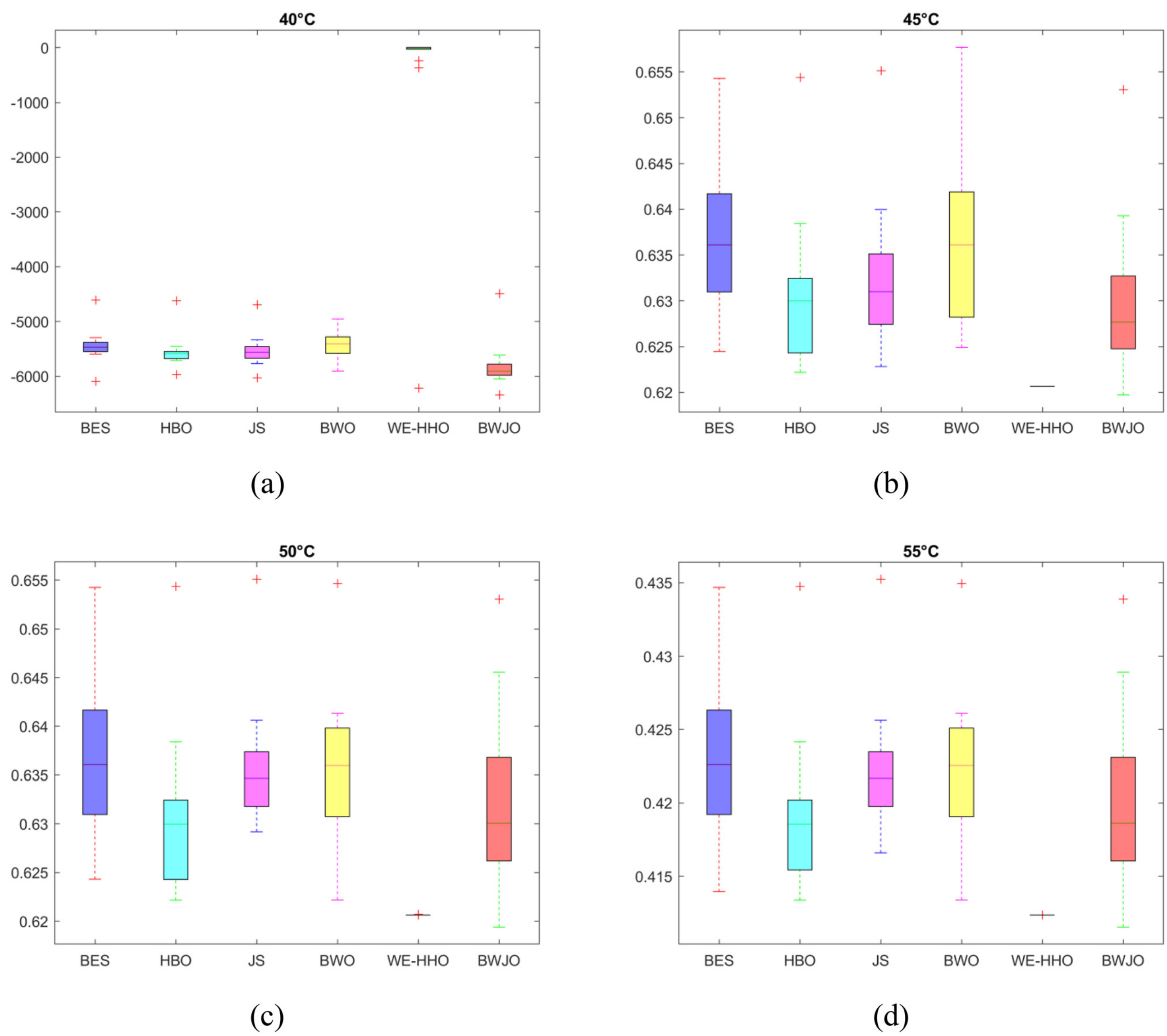

Figure 2: Convergence study on BWJO and conventional schemes for water cooling system at varied allowable temperatures. (a) 40 °C, (b) 45 °C, (c) 50 °C and (d) 55 °C.

Table 9: Optimized results for BWJO and conventional schemes at 40 °C.

Methods	Average power	Best fitness	Optimal solution	Computational time
BES	123.1400	−6091.1000	9.2177	1062.6000
HBO	125.7500	−5966.8000	8.9477	907.3500
JS	134.3800	−6028.9000	8.0476	950.2400
BWO	120.8600	−5904.6000	9.0356	848.4000
WE-HHO	144.4300	−6215.4000	9.2812	706.9900
BWJO	144.7800	−6339.7000	9.2042	467.1400

Table 10: Optimized results for BWJO and conventional schemes at 45 °C.

Methods	Average power	Best fitness	Optimal solution	Computational time
BES	115.5200	0.6245	6.0477	1062.6000
HBO	129.8600	0.6222	6.0477	963.4000
JS	114.5900	0.6277	6.0476	1008.9000
BWO	110.3900	0.6249	6.0356	900.8100
WE-HHO	129.8600	0.6207	6.0512	750.6600
BWJO	130.2300	0.6197	6.0477	467.1400

Table 11: Optimized results for BWJO and conventional schemes at 50 °C.

Methods	Average power	Best fitness	Optimal solution	Computational time
BES	115.6700	0.6243	5.4386	1059.2000
HBO	99.7770	0.6222	5.4386	832.2700
JS	118.6500	0.6300	5.4387	871.6100
BWO	110.9100	0.6222	5.4391	778.2000
WE-HHO	118.6500	0.6206	5.4375	648.4900
BWJO	118.9900	0.6194	5.4386	474.9800

Table 12: Optimized results for BWJO and conventional schemes at 55 °C.

Methods	Average power	Best fitness	Optimal solution	Computational time
BES	107.5200	0.4140	8.9022	2092.0000
HBO	84.2980	0.4134	8.9022	2190.9000
JS	122.3900	0.4166	8.9022	1956.1000
BWO	84.2980	0.4134	8.8895	2054.6000
WE-HHO	122.3800	0.4124	8.9010	1630.0000
BWJO	122.7400	0.4115	8.9021	493.1300

BWO = 120.8600 and WE-HHO = 144.4300, respectively. In addition, for the 55 °C, the BWJO offered the best fitness of 0.4115, whereas the BES is 0.4140, HBO is 0.4134, JS is 0.4166 and WE-HHO is 0.4124, respectively. Moreover, the optimal solution and computation time attained using the BWJO scheme is 6.0477 and 467.1400 for the 45 °C.

5 Conclusions

By using cooling techniques, the PV cell lifetime was extended, boosting the module's output power. By lowering the working temperature of a PV panel's surface, we might maximize efficiency and slow the thermal deterioration rate. This might be done by module cooling and lowering the heat that the PV cells generate while operating. Because of this, an active cooling technology known as an optimization-aided water spraying technique was used to increase efficiency. This technique enabled the PV panels to provide their maximum output power while taking less time to drop down to a lower surface temperature. BWJO was employed as a means of achieving these goals. Finally, Simulink/MATLAB was used to implement the proposed method and optimize the PV system cooling. The performances of the two components were compared using a variety of metrics, including convergence accuracy, solution quality and net power generated after cooling.

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References

Belyamin, Belyamin, Mohamad Ali Fulazzaky, Martin Roestamy, and Rahmat Subarkah. 2021. "Influence of Cooling Water Flow Rate and Temperature on the Photovoltaic Panel Power." *Energy, Ecology and Environment* 1–18, https://doi.org/10.1007/s40974-021-00223-4.

Chanphavong, Lemthong, Vongsavanh Chanthaboune, Southisack Phommachanh, Xayalak Vilaida, and Phetsaphone Bounyanite. 2022. "Enhancement of Performance and Exergy Analysis of a Water-Cooling Solar Photovoltaic Panel." *Total Environment Research Themes* 3–4. https://doi.org/10.1016/j.totert.2022.100018.

Chou, Jui-Sheng, and Dinh-Nhat Truong. 2020. "A Novel Metaheuristic Optimizer Inspired by Behavior of Jellyfish in Ocean." *Applied Mathematics and Computation* 389: 1–47.

Elnozahy, A., A. K. A. Rahman, A. H. H. Ali, M. Abdel-Salam, and S. Ookawara. 2015. "Performance of a PV Module Integrated With Standalone Building in Hot Arid Areas as Enhanced by Surface Cooling and Cleaning." *Energy and Buildings* 88: 100–9.

El-Shobokshy, Mohammad S., and Fahmy M. Hussein. 1993. "Effect of Dust With Different Physical Properties on the Performance of Photovoltaic Cells." *Solar Energy* 51 (6): 505–11.

Fakouriyan, Samaneh, Yadollah Saboohi, and Amorhossein Fathi. 2018. "Experimental Analysis of a Cooling System Effect on Photovoltaic Panels' Efficiency and its Preheating Water Production." *Renewable Energy* 134: 1362–8.

Fathi, Mohamed, Mahfoud Abderrezek, and Djahli Farid. 2019. "Heating behavior of photovoltaic panels and front side water cooling efficiency." *Applied Solar Energy* 55: 327–39.

Firoozzadeh, Mohammad, Amir Hossein Shiravi, and Mojtaba Shafee. 2020. "Thermodynamics Assessment on Cooling Photovoltaic Modules by Phase Change Materials (PCMs) in Critical Operating Temperature." *Journal of Thermal Analysis and Calorimetry* 144: 1239–51.

Hadipour, Amirhosein, Mehran Rajabi Zargarabadi, and Saman Rashidi. 2021. "An Efficient Pulsed-Spray Water Cooling System for Photovoltaic Panels: Experimental Study and Cost Analysis." *Renewable Energy* 164: 867–75.

Jafari, Rahim. 2021. “Optimization and Energy Analysis of a Novel Geothermal Heat Exchanger for Photovoltaic Panel Cooling.” *Solar Energy* 226: 122–33.

Jonas Piotrowski, Leonardo, Marcelo Godoy Simões, and Felix Alberto Farret. 2020. “Feasibility of Water-Cooled Photovoltaic Panels Under the Efficiency and Durability Aspects.” *Solar Energy* 2017: 103–9.

Jur̆cevi, Mĭso, Sandro Nĭzeti, Ivo Maríníc-Kragi, Duje Coko, Müslüm Arıcı, Effrosyni Giama, and Agis Papadopoulos. 2021. “Investigation of Heat Convection for Photovoltaic Panel Towards Efficient Design of Novel Hybrid Cooling Approach With Incorporated Organic Phase Change Material.” *Sustainable Energy Technologies and Assessments* 47: 1–12.

Khalili, Z., M. Sheikholeslami, and Ladan Momayez. 2023. “Hybrid Nanofuid Fow Within Cooling Tube of Photovoltaic-Thermoelectric Solar Unit.” *Scientifc Reports* 13: 1802–7.

Liu, Zekun, Shuang Yuan, Yi Yuan, Guojian Li, and Qiang Wang. 2020. “A Thermoelectric Generator and Water-Cooling Assisted High Conversion Efficiency Polycrystalline Silicon Photovoltaic System.” *Frontiers in Energy* 15: 358–66.

Madan, Charan Jeet, and Naresh Kumar. 2020. “Enhancement of Low Voltage Ride-Through Ability of the Photovoltaic Array Aided by the MPPT Algorithm Connected With Wind Turbine.” *Data Technologies and Applications* 54 (4): 327–38.

Mahmood, Deyaa M. N., and Issam M. Ali Aljubury. 2022. “Experimental Investigation of a Hybrid Photovoltaic Evaporative Cooling (PV/EC) System Performance Under Arid Conditions.” *Results in Engineering* 15. https://doi.org/10.1016/j.rineng.2022.100618.

Makki, A., S. Omer, and H Sabir. 2015. “Advancements in Hybrid Photovoltaic Systems for Enhanced Solar Cells Performance.” *Renewable and Sustainable Energy Reviews* 41: 658–84.

Mohamed, Ahmed T., Mahmoud F. Mahmoud, R. A. Swief, Lobna A. Said, and Ahmed G. Radwan. 2021. “Optimal Fractional-Order PI With DC-DC Converter and PV System.” *Ain Shams Engineering Journal* 12 (2): 1895–906.

Murtadha, Talib K., and Ali Adil Hussein. 2022. “Optimization the Performance of Photovoltaic Panels Using Aluminum-Oxide Nanofluid as Cooling Fluid at Different Concentrations and One-Pass Flow System.” *Results in Engineering* 15. https://doi.org/10.1016/j.rineng.2022.100541.

Moharram, K. A., A.-E. Mohamed, K. Hamdy, and El-S. Hisham. 2013. “Enhancing the Performance of Photovoltaic Panels by Water Cooling.” *Ain Shams Engineering Journal* 4: 869–77.

Murtadha, Talib K., Ali A. dil Hussein, Ahmed A. H. Alalwany, Saad S. Alrwashdeh, and Ala’a M. Al-Falahat. 2022. “Improving the Cooling Performance of Photovoltaic Panels by Using Two Passes Circulation of Titanium Dioxide Nanofluid.” *Case Studies in Thermal Engineering* 36. https://doi.org/10.1016/j.csite.2022.102191.

Nabil, Tamer, and Tamer M. Mansour. 2022. “Augmenting the Performance of Photovoltaic Panel by Decreasing its Temperature Using Various Cooling Techniques.” *Results in Engineering* 15. https://doi.org/10.1016/j.rineng.2022.100564.

Odeh, Saad, and Masud Behnia. 2009. “Improving Photovoltaic Module Efficiency Using Water Cooling.” *Heat Transfer Engineering* 30 (6): 499–505.

Sharma, Prashant, Harish Sharma, Sandeep Kumar, and Jagdish Chand Bansal. 2019. “A Review on Scale Factor Strategies in Differential Evolution Algorithm.” In *Advances in Intelligent Systems and Computing*, 817. Egypt: © Springer Nature Singapore Pte Ltd.

Singh, Vijay Pal. 2022. “An Optimized Water Cooling System for Enhancing the Performance of Photovoltaic Panels.” *Cybernetics and Systems*.

Sudhakar, P., R. Santosh, B. Asthalakshmi, G. Kumaresan, and R. Velraj. 2021. “Performance Augmentation of Solar Photovoltaic Panel through PCM Integrated Natural Water Circulation Cooling Technique.” *Renewable Energy* 172: 1433–48.

Sultan, Sakhr M., C. P. Tso, and M. N. Ervina Efzan. 2019. “A Proposed Temperature-Dependent Photovoltaic Efficiency Difference Factor for Evaluating Photovoltaic Module Cooling Techniques in Natural or Forced Fluid Circulation Mode.” *Arabian Journal for Science and Engineering* 44: 8123–8.

Tabaei, H., and M. Ameri. 2015. “Improving the Effectiveness of a Photovoltaic Water Pumping System by Using Booster Reflector and Cooling Array Surface by a Film of Water.” *Iranian Journal of Science and Technology Transactions of Mechanical Engineering* 39: 51–60.

Taqwa, Ahmad, Tresna Dewi, R. D. Kusumanto, and Carlos R. Sitompul. 2020. “Automatic Cooling of a PV System to Overcome Overheated PV Surface in Palembang.” In *Journal of Physics: Conference Series*, 1500. IOP Publishing.

Wu, Guanghua, Qiang Liu, Jun Wang, and Bohua Sun. 2020. “Thermal Analysis of Water-Cooled Photovoltaic Cell by Applying Computational Fuid Dynamics.” *Journal of Thermal Analysis and Calorimetry* 144: 1741–7.

Yesildal, Faruk, Ahmet Numan Ozakin, and Kenan Yakut. 2022. “Optimization of Operational Parameters for a Photovoltaic Panel Cooled by Spray Cooling.” *Engineering Science and Technology, an International Journal* 25: 1–8.

Yildirim, Mehmet Ali, Artur Cebula, and Maciej Sułowicz. 2022. “A Cooling Design for Photovoltaic Panels E WATER-Based PV/T System.” *Energy* 256.

Zhong, Changting, and Z. Meng. 2022. “Beluga Whale Optimization: A Novel Nature-Inspired Metaheuristic Algorithm.” *Knowledge-Based Systems* 24: 13003–35.