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Enhancing the Yearly Profit of a Wind Farm Using a Novel Transfer Function for Binary Particle Swarm Optimization Algorithm

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R E S E A R C H A R T I C L E

A B S T R A C T

While governments of quite a lot of nations and international alliances like the United Nations are perpetually striving for curtailing the emission of greenhouse gases for limiting the dangerous aftermaths of climate change, renewable energy resources like wind power can be utilized to realize an environment-friendly switchover of electricity generation projects. In this paper, Binary Particle Swarm Optimization Algorithm has been employed to enhance the yearly profit of a wind farm in Kayathar town of India with a novel transfer function. The optimization trial outcomes validate the superiority of the proposed transfer function when compared with similar 'S'-type transfer functions.

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1. Introduction

Due to the undependable provision and harmful influence of hydrocarbon-based fuels, renewable energy resources are desired to be applied competently to constrain the destructive penalties of climate change [1]. Wind power is a pronounced renewable energy resource and is aiding nations to generate electricity economically [2, 3].

India is presently the second-most peopled country in the world and necessitates operating its Wind Power Generation (WPG) competence for fulfilling the carbon neutrality goals [4]. At the moment, India generates approximately 10% of its collective power generation capacity from WPG farms [5]. The expense of WPG has been reasonable for the past few decades and is expected to decrease by 7% in 2022 [6].

Hasager et al. [7] explored the chance of offshore WPG in India with ENVISAT data. Mani Murali et al. [8] surveyed the practicable locations for offshore WPG and their economic operability was reviewed. Nagababu et al. [9] inspected the offshore WPG ability of India exploiting the OSCAT testimonies. Singh and Kumar S.M. [10] made an effort for assessing the offshore WPG capability and lessening of the generation outlay on the Indian oceanfront.

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The current paper aims to augment the yearly profit of a WPG farm in the Kayathar region of India using the Binary Particle Swarm Optimization Algorithm (BPSOA). A novel transfer function has been applied to enhance the efficiency of BPSOA. Similar four 'S'-type of transfer functions have been employed to evaluate the relative efficiency of the proposed transfer function.

2. Problem Statement

The yearly profit of a WPG farm can be evaluated using Eq. (1).

$$V_{annual} = (M - G) \times E_{annual} \tag{1}$$

where V_{annual} is the annual profit of the wind farm, M denotes the marketing price of per unit wind power, G signifies the generation charge of per unit wind power and E_{annual} symbolizes the yearly generated wind power. The wind flow pattern of Kayathar has been shown in Figure 1. The considered layouts have been displayed in Figure 2 and 3.

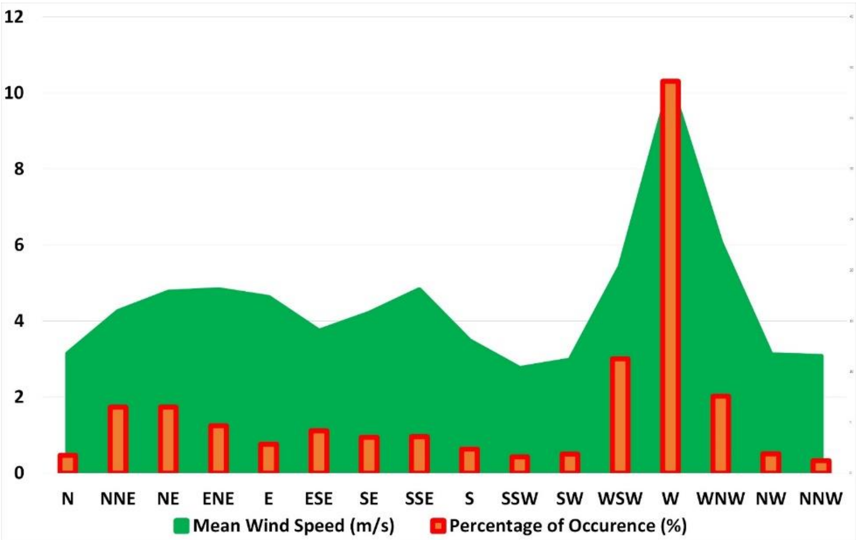

Figure 1. Wind flow pattern of Kayathar, India

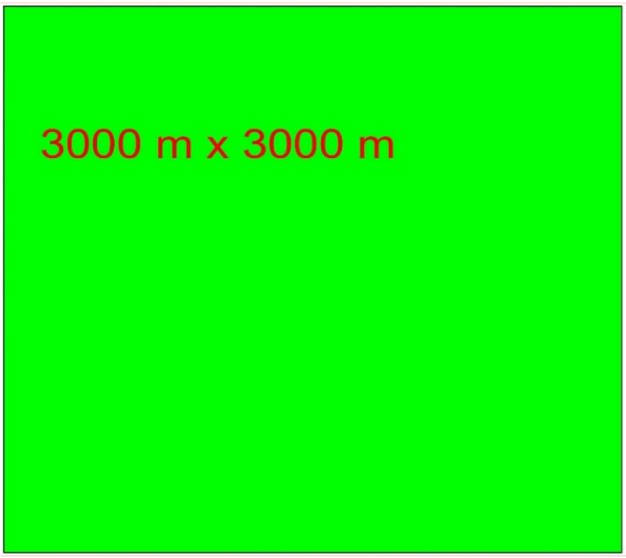

Figure 2. Layout 1

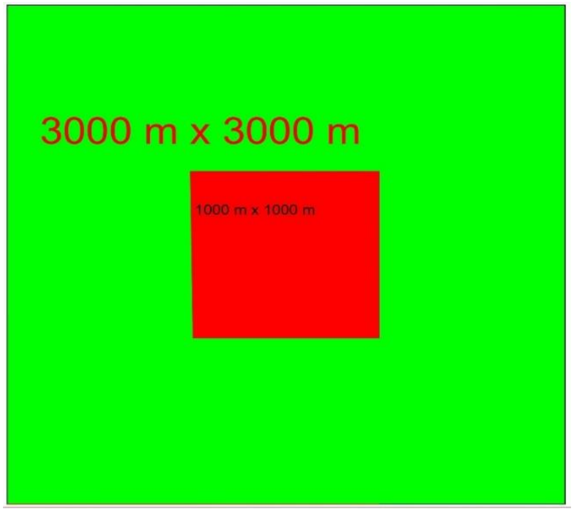

Figure 3. Layout 2 with obstruction of 1000 m x 1000 m

3. Optimization Algorithm

Artificial intelligence-based metaheuristic techniques have been engaged in several engineering fields for enhancing their effectiveness [11] - [24]. BPSOA is a bio-motivated metaheuristic technique and has been used for finding solutions in several scientific fields [13]. The algorithm has been briefly discussed in the following manner.

1. Unevenly construct a rudimentary populace.
2. Erratically create the elementary velocities surrounded by the boundary values.
3. Allot the preliminary values for local and global preeminent sites.
4. Calculate the inertia weights essential for velocity establishment.
5. Modify the velocities of the particles consequently.
6. Swap the locations of the particles adhering to the velocities.
7. Settle if the concluding situations are fulfilled, otherwise go back to stage 3.

In BPSOA, a transfer function is usually employed to modify the value of the bit and it has been mathematically shown in Eq. (2).

$$S(V_{mn}) = \frac{1}{1+e^{-V_{mn}}} \quad (2)$$

where $S(V_{mn})$ indicates the transfer function, V_{mn} denotes the velocity of the n^{th} bit of m^{th} particle. The value of the bit is altered as per Eq. (3).

$$x_{mn} = \begin{cases} 1, & rand() \leq S(V_{mn}) \\ 0, & rand() > S(V_{mn}) \end{cases} \quad (3)$$

Four recognized 'S' type transfer functions have been shown in Table 1.

Table 1. Recognized 'S' type transfer functions [25]

Transfer Function Number	Function Description
S_1	$S(T) = \frac{1}{1+e^{-2T}}$
S_2	$S(T) = \frac{1}{1+e^{-T}}$
S_3	$S(T) = \frac{1}{1+e^{-\frac{T}{2}}}$
S_4	$S(T) = \frac{1}{1+e^{-\frac{T}{3}}}$

Apart from the above-mentioned 'S' type transfer functions, this study proposes a novel 'S' type transfer function and the function has been mathematically shown as per Eq. (4).

$$S_5 = S(x) = \frac{1}{1+e^{-\frac{x}{4}}} \quad (4)$$

where x is a variable. The proposed transfer function has been employed along with four 'S' type transfer functions mentioned in Table 1.

4. Results and Discussion

For measuring the fitness of the proposed transfer function for the BPSOA-based WPG farm design optimization process, the selling price of wind energy in India has been considered as USD 0.033/kWh [26].

The values of essential parameters related to Wind Turbine (WT) and the BPSOA essential for calculating the considered objectives have been exhibited in Table 2.

Table 2. Values of essential parameters

Parameter	Considered Value
Population Extent	20
Greatest Generation number	50
Turbine Output	1500 kW
Blade radius	38.5 m
Inter-Turbine Gap	308 m
Least Permissible Wind Speed	12 km/hr.
Extreme Permissible Wind Speed	72 km/hr.
Capital Cost	USD 750,000 per Turbine
Sub-Station Charge	USD 8,000,000 per Sub-Station
Number of WTs per Sub-Station	30
Rate of Interest	3%
Yearly Operation and Maintenance Expense	USD 20,000
Expected Operational Time	20 Years

The optimal placements of wind turbines for both layouts using all transfer functions have been displayed in Figure 4-13.

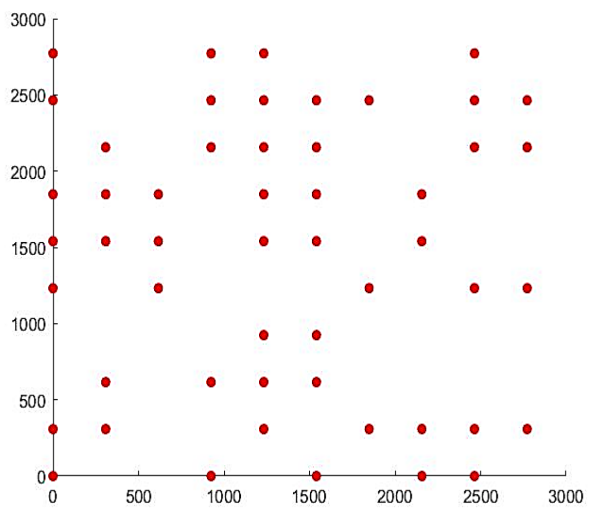

Figure 4. Optimal placement of WTs for layout 1 using S_1

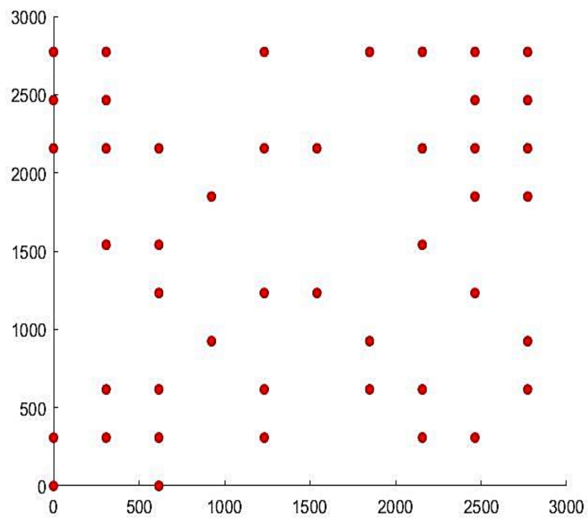

Figure 5. Optimal placement of WTs for layout 1 using S_2

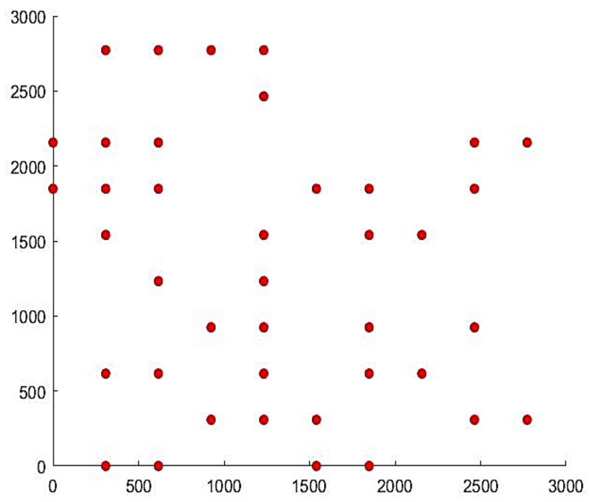

Figure 6. Optimal placement of WTs for layout 1 using S_3

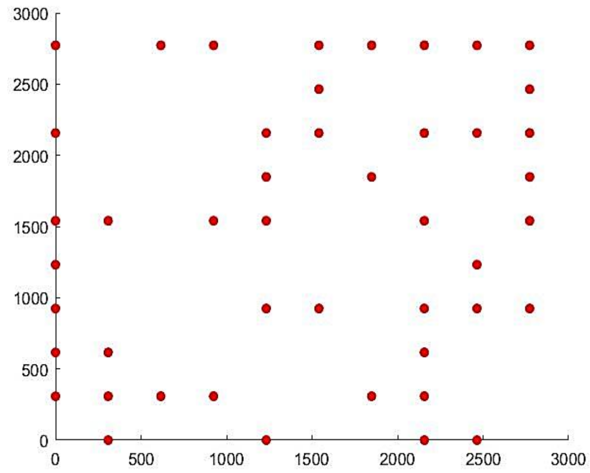

Figure 7. Optimal placement of WTs for layout 1 using S_4

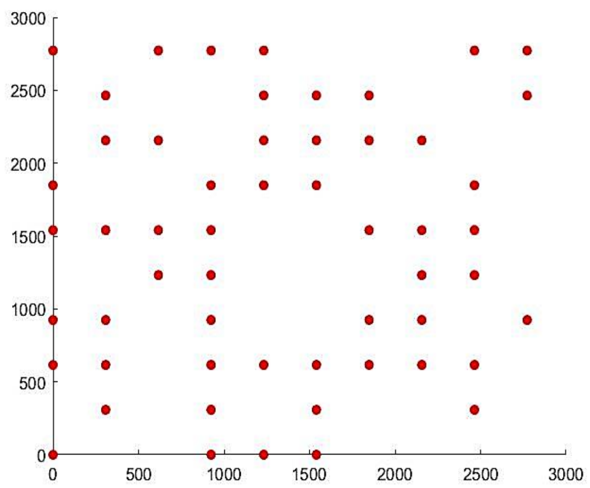

Figure 8. Optimal placement of WTs for layout 1 using S_5

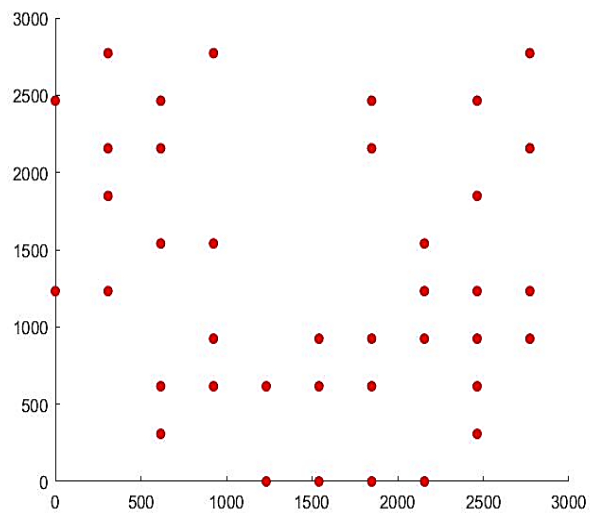

Figure 9. Optimal placement of WTs for layout 2 using S_1

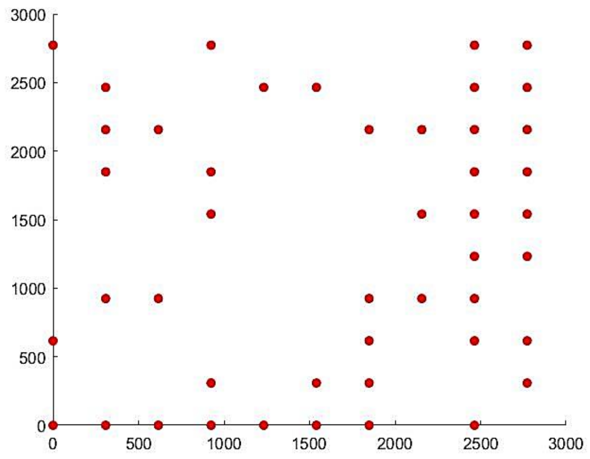

Figure 10. Optimal placement of WTs for layout 2 using S_2

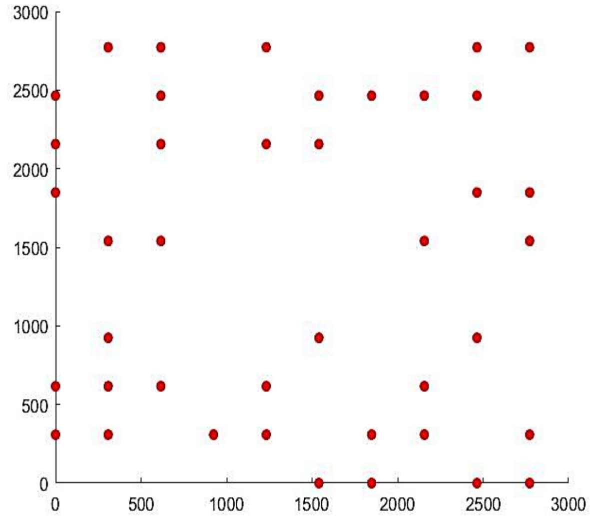

Figure 11. Optimal placement of WTs for layout 2 using S_3

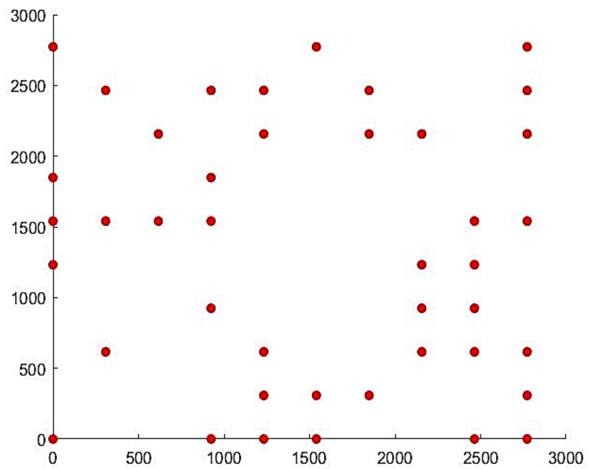

Figure 12. Optimal placement of WTs for layout 2 using S_4

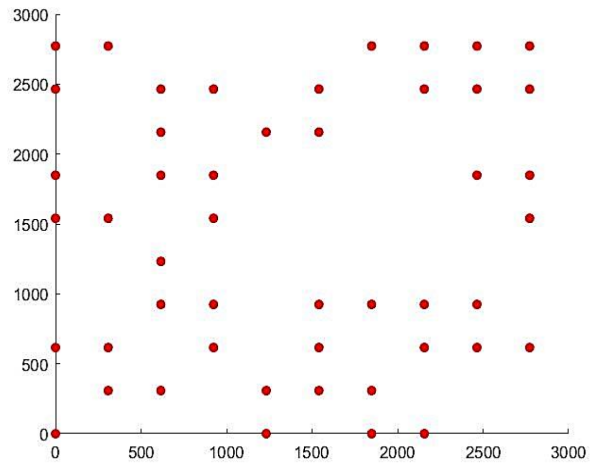

Figure 13. Optimal placement of WTs for layout 2 using S_5

The optimal yearly profits and the corresponding count of turbines for both layouts using all transfer functions have been presented in Table 3.

Table 3. Optimal annual profit and count of wind turbines

Transfer Function	Optimal Annual Profit for Layout 1	Optimal Count of Wind Turbines for Layout 1	Optimal Annual Profit for Layout 2	Optimal Count of Wind Turbines for Layout 2
S_1	13409	52	10911	39
S_2	12800	46	12034	46
S_3	13502	40	11334	41
S_4	12520	46	12096	42
S_5	13639	55	12475	48

The optimization outcomes validate the superiority of the proposed transfer function of BPSOA for optimizing the annual profit of both WPG site layouts at Kayathar, India.

5. Conclusion

For curtailing the emission of greenhouse gases, renewable energy resources like wind energy must be efficiently utilized to minimalize the catastrophic consequences of climate change throughout the world. The current paper aims to augment the yearly profit of a WPG farm in Kayathar of India by engaging BPSOA. A novel transfer function has been proposed to enhance the efficiency of the optimization algorithm. Optimization solutions confirm the pre-eminence of the proposed transfer function for enhancing the financial sustainability of both the layout designs. This research can initiate fresh opportunities for the WPG farm design process.

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