Available online at www.dergipark.org.tr/en

INTERNATIONAL ADVANCED RESEARCHES
and
ENGINEERING JOURNAL

Journal homepage: www.dergipark.org.tr/en/pub/iarej

e-ISSN: 2618-575X

International Open Access

Volume 07
Issue 01

April, 2023

Research Article

Optimizing the wind power generation cost in the Tirumala Region of India

Prasun Bhattacharjee [a,*], ***Somenath Bhattacharya*** [a]

[a]*Jadavpur University, Raja Subodh Chandra Mallick Rd, Kolkata 700032, India*

ARTICLE INFO

Article history:
Received 29 June 2022
Accepted 25 March 2023
Published 15 April 2023

Keywords:
Artificial intelligence
Generation cost
Genetic algorithm
Particle swarm optimization
Wind farm

ABSTRACT

Global warming is impacting almost every nation of the world and causing excessive socioeconomic damage to human civilization. India is presently the second most inhabited country on the planet and possesses the noteworthy potential to curb global greenhouse gas emissions. Most of the stakeholders of the global communities have signed the Paris treaty of 2015 to curtail the surface temperature rise. As the central government of India has announced its target to attain net zero-emission by the end of 2070, the electricity generation sector of the country needs to utilize renewable resources like wind energy rapidly. This paper focuses to optimize the wind energy generation cost in the Tirumala region of the country using the Genetic Algorithm and Particle Swarm intelligence concurrently. Tirumala is located in the area of Tirupati in the southern state of Andhra Pradesh. A relative analysis of the optimization outcomes validates the superiority of the Genetic Algorithm over the Binary Particle Swarm Optimization Algorithm for minimizing the wind energy generation cost. The application of the Genetic Algorithm has been proven to cut down the generation cost by up to 7.56% as compared to the usage of Binary Particle Swarm Optimization for similar terrain conditions and wind flow conditions in the Tirumala Area.

1. Introduction

Climate change is impacting human communities across the continents of the world and devastating economies extensively [1]. Because of the universal concern for the restricted reserve of non-renewable fuels and their life-threatening after-effects on the ecosystem, renewable energy resources expound rich substitutes for global scientific society [2]. International renewable energy utilization has advanced rapidly in the current century [3]. Worldwide collective Wind Power Generation (WPG) competence has increased by more than 32 times in the past 20 years [4]. Worldwide wind energy utilization per capita augmented by 230 times in the past 30 years. Currently, India generates around 10% of its combined electricity generation capability from WPG systems [5]. The expenditure of WPG has been economical for the previous few decades and is anticipated to shrink by 7% in 2022 [6].

Hasager et al. [7] dealt with the probability of Indian offshore WPG with ENVISAT information. Nagababu et al. [8] scrutinized the Indian offshore WPG capacity with the OSCAT evidence. Singh and Kumar S.M. [9] evaluated the Indian offshore WPG competence and strived for minimizing the generation expenditure. the WPG capacity in the Tirumala district of India has been explored with Artificial Intelligence (AI) methods [10]. In another study, the reevaluation and bathymetry information have been employed for gauging the WPG fitness in the special commercial parts in India, formulating lenience for the prevalent salt-water biotic conditions [11]. Investigators have calculated a larger offshore WPG proposal in the western seashore of Gujarat state of India with the biological examination, and generation expense has been projected [12]. The lightning search algorithm was involved in multi-objective WPG farm layout improvement with more than a few airflow settings for upgraded efficiency regarding energy generation and venture expenditures [13]. The wind farm design proposal has been improved for a Spanish WPG farm with the coral reefs' optimization procedure counting the substrate level [14]. Gradient-centered optimization method has been directed for WPG farm layout enhancement, and the scrutiny conclusions have been juxtaposed with the same accomplished through large-eddy simulation [15].

This research aims for recognizing the optimum charge of WPG for the Tirumala zone in India. Due to the

* Corresponding author. Tel.: +91-990-356-5278;
E-mail addresses: prasunb.mecheng.rs@jadavpuruniversity.in (P. Bhattacharjee), sbhattacharya.mech@jadavpuruniversity.in (S. Bhattacharya)
ORCID: 0000-0001-9493-5883 (P. Bhattacharjee), 0000-0002-3286-5450 (S. Bhattacharya)
DOI: 10.35860/iarej.1137173

computing might of AI systems have been employed in quite a lot of engineering disciplines [16][17]. That is why the Genetic Algorithm (GA) and Binary Particle Swarm Optimization Algorithm (BPSOA) were applied concurrently to optimize the WPG cost in the Tirumala area to assess the relative efficiency of the two AI methods for optimizing the generation cost and improving the design of WPG farm accordingly due to their ability to deal with the binary values ('1' for presence and '0' for the absence of turbine in a layout). Moreover, this study can aid concerned researchers and businesses to measure the effect of AI in the planning of WPG systems.

2. Problem Formulation

WPG systems are expected to remain economically worthwhile by competently controlling the generation cost (G_c). The generation cost has been evaluated using Eqs. (1)-(4) suggested in the 22nd Genetic and Evolutionary Computation Conference [18].

$$G_c = \frac{\{A\}+(B)}{(1-(1+r)^{-y})/r} * \frac{1}{8760 * P} + \frac{0.1}{N} \tag{1}$$

$$A = C\left(\frac{2}{3} + \frac{1}{3} e^{-0.00174N^2}\right) \tag{2}$$

$$B = C_{om} N \tag{3}$$

$$C = \left\{C_t N + C_s floor\left(\frac{N}{m}\right)\right\} \tag{4}$$

where C_t represents the expenditure of a Wind Turbine (WT). C_s signifies the expenditure for a sub-station. N designates the sum of WTs in a WPG farm and m is WT per sub-station. C_{om} designates the yearly operative and upkeep charge. P symbolizes the energy harvest of the whole WPG farm. r denotes the fraction of interest. y shows the lifetime of the WPG farm. The directional wind-flow pattern in the Tirumala region has been shown in Fig. 1.

The contemplated terrain settings for this research are displayed in Figs. 2 and 3. Layout 1 is of 2000 m x 2000 m dimension and lacks any obstruction. Layout 2 is 2000 m x 2000 m with an internal obstruction of 1000 m x 1000 m. The internal obstruction has been marked in red and the available area for turbine placement has been shown in green in Figs. 2 and 3.

AI algorithms have been utilized in the current work to optimize the generation cost in the Tirumala area of India. The algorithms considered randomly generated locations (with horizontal and vertical distances) of WT inside the limitations of the considered terrain setting. Subsequently, the generation cost of wind power has been computed by applying Eqs. (1)-(4). The minimal WPG cost has been found after iterating the above-mentioned optimization process up to the maximum generation number and the optimal locations of WT for each considered terrain condition in the present study.

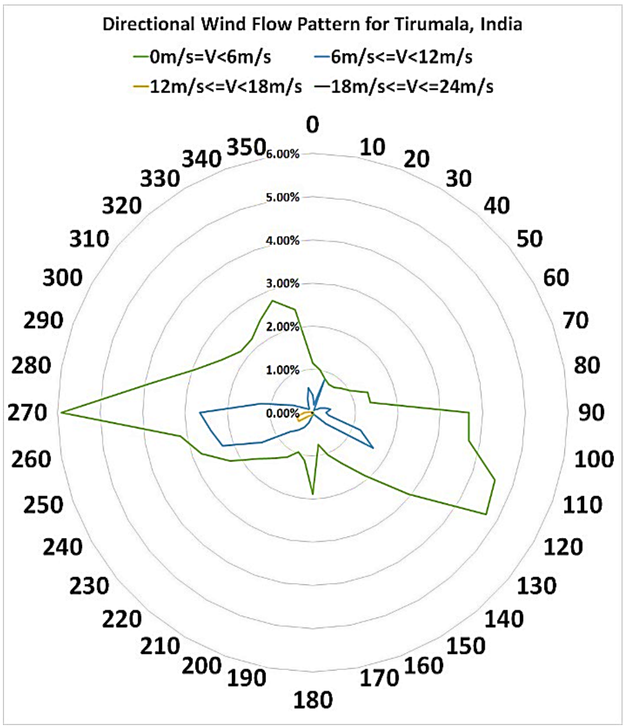

Figure 1. Wind-Flow Form in Tirumala, India

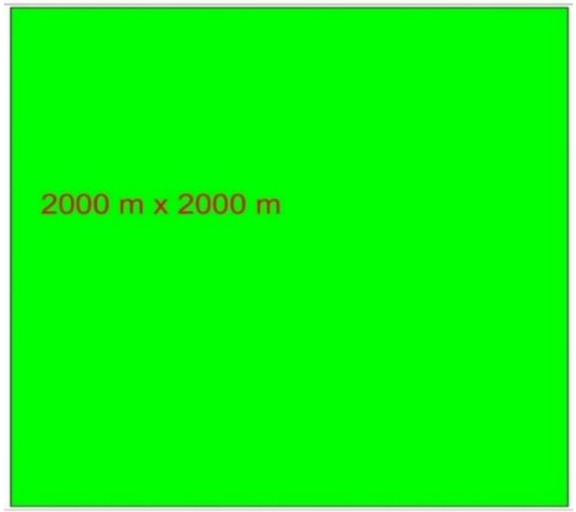

Figure 2. Layout 1

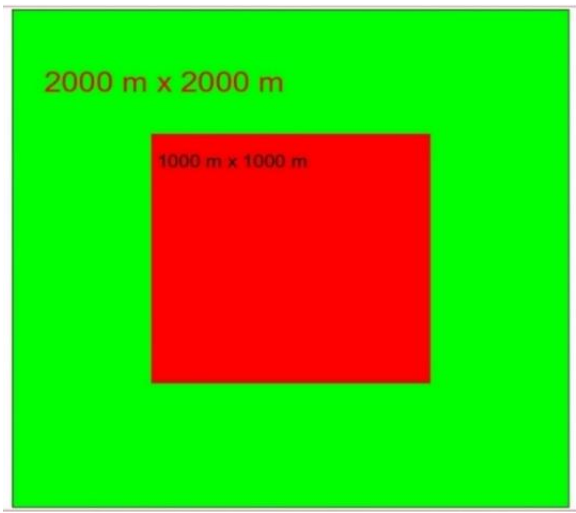

Figure 3. Layout 2

3. Optimization Algorithm

3.1 Genetic Algorithm (GA)

GA can be termed as a bio-enthused metaheuristic scheme to suggest resolutions for optimization trials representing the evolvement of natural preference as projected by Turing [19][20]. The algorithm has been described as follows [16].

1. Organize the parameters such as population span, replication tally, potentials for crossover, and mutation.
2. Administer the suitability of every chromosome.
3. Engage the population unsystematically.
4. Scrutinize the suitability of every chromosome.
5. Launch the arithmetic crossover procedure.
6. Initiate the mutation action.
7. Measure the properness of the renewed beings.
8. Classify the most remarkable consequence by tracking the choice maker's penchant.

3.2 Binary Particle Swarm Optimization Algorithm (BPSOA)

The BPSOA is an altered preparation of particle swarm optimization algorithm that considers all constituents as strings of bits [21]. The BPSOA can be described as follows.

1. Comprehensively construct a basic population.
2. Arbitrarily form the essential velocities inside the restrictions.
3. Allot the opening values for local and global finest sites.
4. Calculate the weights obligatory for velocity development.
5. Adjust the velocities of the particles consequently.
6. Swap the positions of the particles.
7. Settle if the ultimate conditions are grasped, else revert to stage 3.

4. Results and Discussion

AI algorithms like Genetic Algorithm and Binary Particle Swarm Optimization have been employed for optimizing the WPG cost in the Tirumala area in India. Two dissimilar terrain settings have been considered and the AI algorithms utilized numerous randomly created positioning of WTs in each terrain setting for computing the WPG cost up to the extreme generation count. After ranking the calculated WPG costs, the most optimal value of generation charge has been found for both terrain conditions. Later, the optimal values of WPG costs computed using GA and BPSOA have been compared to select the most efficient AI algorithm for the considered optimization scenario.

The values of vital factors associated with WT and optimization processes have been displayed in Table 1. They have been deemed as per Wilson et al. (2018). The WPG cost has been calculated using Eqs. (1)-(4). The optimum locations of WTs for both layouts utilizing both optimization processes have been shown in Figs. 4-7. The vertical and horizontal axes symbolize the length and breadth of the proposed terrains for WPG systems. The red dot indicates the placement of a WT within the layout.

Table 1. Values of Vital Factors

Factor	Value
Populace Range	20
Utmost Generation number	50
Turbine Output	1.5 MW
Blade Diameter	77 m
Inter-Turbine Space	308 m
Lowest Allowable Wind Velocity	12 km/hr.
Supreme Allowable Wind Velocity	72 km/hr.
Capital Charge per WT	$ 750,000
Sub-Station Cost per Sub-Station	$ 8,000,000
Total WTs per Sub-Station	30
Proportion of Interest	3%
Annual Maneuver and Upkeep Expenditure	$ 20,000
Possible Working Time	20 Years

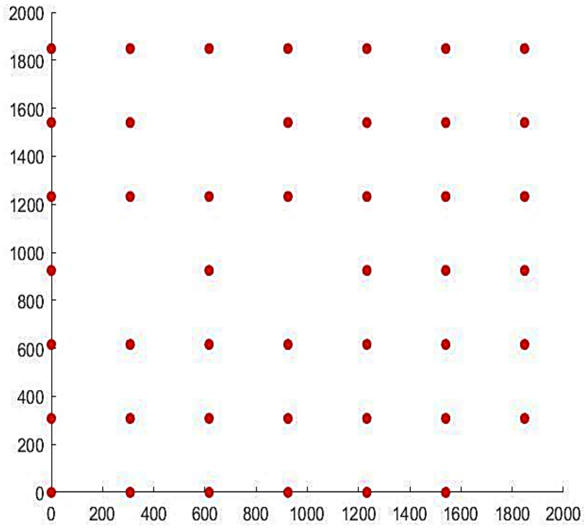

Figure 4. Optimal Placement of WTs for Layout 1 Using GA

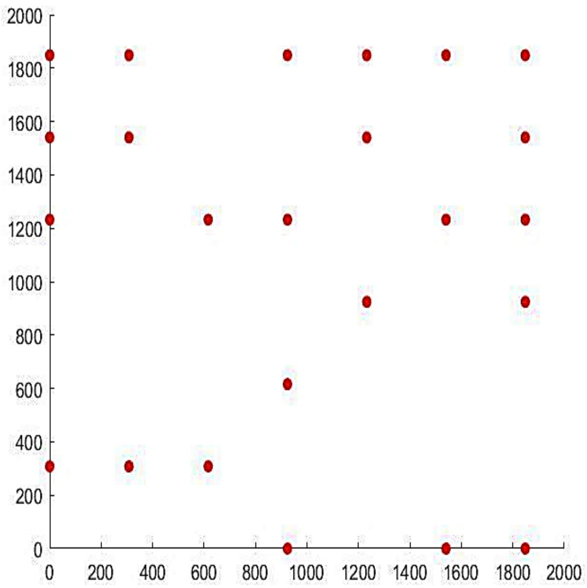

Figure 5. Optimal Placement of WTs for Layout 1 Using BPSOA

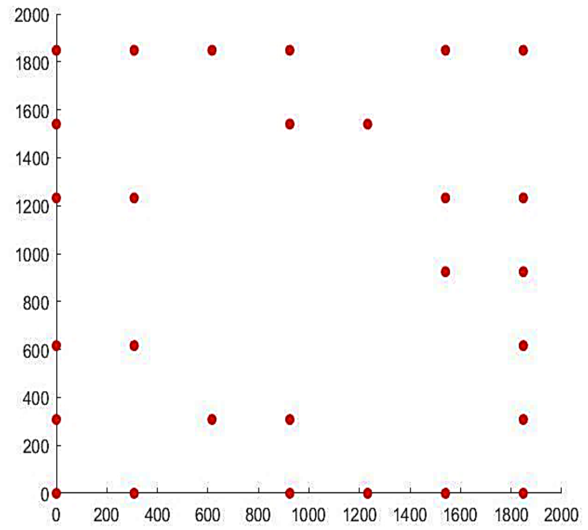

Figure 6. Optimal Placement of WTs for Layout 2 Using GA

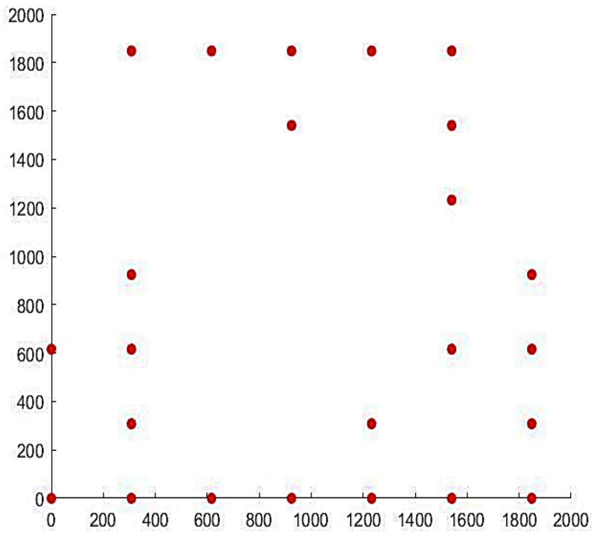

Figure 7. Optimal Placement of WTs for Layout 2 Using BPSOA

Table 2. Assessment of Optimized WPG Cost Achieved by GA and BPSOA

Layout	GA Optimized Generation Cost (in USD/kWh)	BPSOA Optimized Generation Cost (in USD/kWh)
Layout 1	0.0110	0.0111
Layout 2	0.0110	0.0119

The generation costs of the WPG in the Tirumala area calculated employing GA and BPSOA have been offered in Table 2. The results show that the optimal generation costs attained for both the layouts by GA are more financially viable than the same achieved by BPSOA. The WPG costs achieved by GA are 0.90 % and 7.56% more optimal than the same attained by BPSOA. The optimization consequences authenticate the pre-eminence of GA over BPSOA for optimizing the WPG cost in the Tirumala area in India. The improved generation cost can assist the WPG businesses to stay economical and feasible for practical implementation.

5. Conclusions

The Paris agreement of 2015 guides the associated countries to control the emancipation of greenhouse gases for lessening the penalties caused by global climate change. The resourceful management of renewable energy generation expertise can abet countries realize their carbon neutrality ambitions. Wind power can play a crucial role in limiting the carbon footprint of electricity businesses.

This present research aims for minimizing the WPG cost in the Tirumala area of India. GA and BPSOA have been exercised to optimize the layouts for better financial feasibility. The outcomes validate the supremacy of GA over BPSOA for minimizing the WPG cost. This work can prompt innovative prospects for WPG layout optimization. In the forthcoming works, WTs with advanced generation capability and wheel area can be tried. As the current study has been conducted considering the cost function provided by Wilson et al. (2018), the results need to be verified using other similar functions in future studies.

Declaration

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. The authors also declare that this article is original and was prepared in accordance with international publication and research ethics, and ethical committee permission or any special permission is not required.

Author Contributions

Prasun Bhattacharjee developed the methodology and wrote the article. Somenath Bhattacharya scrutinized the research work.

Acknowledgment

The first author admits the economic support of the TEQIP department of Jadavpur University.

References

1. Obama, B., *The irreversible momentum of clean energy*. Science, 2017. **355**(6321): pp. 126-129.
2. Chaurasiya, P. K., Warudka, V., and S. Ahmed, *Wind energy development and policy in India: A review*. Energy Strategy Reviews, 2019. **24**: pp. 342-357.
3. BP, *BP Statistical Review of World Energy*. 2022. [Online]. Available: https://www.bp.com/en/corporate/energy-economics/statistical-review-of-world-energy.html. [Accessed 19 April 2022].

4. Global Wind Energy Council, *Global Wind Energy Outlook.* 2014. [Online]. Available: http://www.gwec.net/wp-content/uploads/2014/10/GWEO2014_WEB.pdf. [Accessed 06 September 2020].

5. Ministry of Power of Government of India, *Renewable Generation Report.* 2021. [Online]. Available: https://cea.nic.in/renewable-generation-report/?lang=en. [Accessed 23 July 2021].

6. Global Wind Energy Council, *India Wind Outlook Towards 2022: Looking beyond headwinds.* 2020. [Online]. Available: https://gwec.net/india-wind-outlook-towards-2022-looking-beyond-headwinds/. [Accessed 23 July 2021].

7. Hasager, C. B., Bingöl, F., Badger, M., Karagali, I. and E. Sreevalsan, *Offshore Wind Potential in South India from Synthetic Aperture Radar*. Information Service Department Risø National Laboratory for Sustainable Energy Technical University of Denmark, 2011.

8. Nagababu, G., Simha R, R., Naidu, N. K., Kachhwaha, S. S., and V. Savsani, *Application of OSCAT satellite data for offshore wind power.* In 5th International Conference on Advances in Energy Research, 2015, Mumbai, India.

9. Singh, R., and A. Kumar S.M., *Estimation of Off Shore Wind Power Potential and Cost Optimization of Wind Farm in Indian Coastal Region by Using GAMS*, In International Conference on Current Trends Towards Converging Technologies (ICCTCT), 2018.

10. Kumar, M. B. H., Balasubramaniyan, S., Padmanaban, S., and J. B. Holm-Nielsen, *Wind energy potential assessment by weibull parameter estimation using multiverse optimization method: A case study of Tirumala region in India*. Energies, 2019. **12**(11): pp. 2158.

11. Nagababu, G., Kachhwaha, S.S., Naidu, N. K., and V. Savsani, *Application of reanalysis data to estimate offshore wind potential in EEZ of India based on marine* ecosystem *considerations.* Energy, 2017. **118:** pp. 622–631.

12. Kumar, R., Stallard, T., and P. K. Stansby, *Large-scale offshore wind energy installation in northwest India: Assessment of wind resource using Weather Research and Forecasting and levelized cost of energy*. Wind Energy, 2020. **24**(2): pp. 174–192.

13. Moreno, S. R., Pierezan, J., Coelho, L. dos S., and V. C. Mariani, *Multi-objective lightning search algorithm applied to wind farm layout optimization*. Energy, 2021. **216:** p. 119214.

14. Pérez-Aracil, J., Casillas-Pérez, D., Jiménez-Fernández, S., Prieto-Godino, L., and S. Salcedo-Sanz, *A versatile multi-method ensemble for wind farm layout optimization*. Journal of Wind Engineering and Industrial Aerodynamics, 2022. **225**: p. 104991.

15. Thomas, J. J., Bay, C. J., Stanley, A. P., and A. Ning, *Gradient-Based Wind Farm Layout Optimization Results Compared with Large-Eddy Simulations*. Wind Energy Science Discussions, 2022. pp. 1-28.

16. Jana, R. K., and P. Bhattacharjee, *A multi-objective genetic algorithm for design optimisation of simple and double harmonic motion cams.* International Journal of Design Engineering, 2017. **7**(2): pp. 77-91.

17. Turkoglu, B., and E. Kaya, *Training multi-layer perceptron with artificial algae algorithm.* Engineering Science and Technology, an International Journal, 2020. **23**(6): pp. 1342-1350.

18. Wilson, D., Rodrigues, S., Segura, C., Loshchilov, I., Hutter, F., Buenfil, G. L., Kheiri, A., Keedwell, E., Ocampo-Pineda, M., Özcan, E., Peña, S. I. V., Goldman, B., Rionda, S. B., Hernández-Aguirre, A., Veeramachaneni, K., and S. Cussat-Blanc, *Evolutionary computation for wind farm layout optimization*. Renewable Energy, 2018. **126**: pp. 681-691.

19. Turing, A., *Computing Machinery and Intelligence (1950)*. In The Essential Turing, Oxford University Press, 2004.

20. Akarsu, C. H., and Küçükdeniz, T., *Job shop scheduling with genetic algorithm-based hyperheuristic approach*. International Advanced Researches and Engineering Journal, 2022. **6**(1): pp. 16-25.

21. Bhattacharjee, P., Jana, R. K., and S. Bhattacharya, S. (2021). *A Relative Analysis of Genetic Algorithm and Binary Particle Swarm Optimization for Finding the Optimal Cost of Wind Power Generation in Tirumala Area of India*. In ITM Web of Conferences, 2021. **40**: p. 03016.

.