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A Relative Assessment of Genetic Algorithm and Binary Particle Swarm Optimization Algorithm for Maximizing the Annual Profit of an Indian Offshore Wind Farm

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Abstract

Since climate change is prompting cataclysmic consequences across the world, renewable power generation technologies like wind power recommend fitting substitutes to fossil fuels for dwindling greenhouse gas production. For facilitating the escalating energy requisite of its rising economic structure, India must track down newer cost-effective wind power generation prospects. The current study intends to maximize the annual profit of an offshore wind power generating site in the Gulf of Khambhat exercising artificial intelligence. Genetic algorithm and binary particle swarm optimization algorithm have been applied at the same time to weigh their relative proficiency. The conclusions of the evaluation verify the enhanced competence of genetic algorithm over binary particle swarm optimization in optimizing the deemed purpose.

Keywords: Offshore Wind Power, Genetic Algorithm, Binary Particle Swarm Optimization, Annual Profit, Gulf of Khambhat.

Genetik Algoritma ve İkili Parçacığın Göreceli Bir Değerlendirmesi Yıllık Kârını En Üst Düzeye Çıkarmak için Sürü Optimizasyon Algoritması Hint Açık Deniz Rüzgar Çiftliği

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Özet

İklim değişikliği dünya çapında felaketli sonuçlara yol açtığından, rüzgar enerjisi gibi yenilenebilir enerji üretim teknolojileri, azalan sera gazı üretimi için fosil yakıtların yerine ikamelerin kullanılmasını önermektedir. Yükselen ekonomik yapısının artan enerji ihtiyacını kolaylaştırmak için Hindistan, daha yeni, uygun maliyetli rüzgar enerjisi üretim beklentilerini takip etmelidir. Mevcut çalışma, yapay zeka kullanan Khambhat Körfezi'ndeki bir açık deniz rüzgar enerjisi üretim tesisinin yıllık karını maksimize etmeyi amaçlıyor. Göreceli yeterliliklerini ölçmek için genetik algoritma ve ikili parçacık sürü optimizasyon algoritması aynı anda uygulanmıştır. Değerlendirmenin sonuçları, varsayılan amacı optimize etmede ikili parçacık sürü optimizasyonu üzerinde genetik algoritmanın gelişmiş yeterliliğini doğrulamaktadır.

Anahtar Kelimeler :Açık Deniz Rüzgar Enerjisi, Genetik Algoritma, İkili Parçacık Sürü Optimizasyonu, Yıllık Kar, Khambhat Körfezi.

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1. Introduction

As a consequence of the widespread disquiet for the underprovided stash of fossil fuels and their ruinous impacts on the environment, renewable energy techniques proffer prospering alternates for the power generation industry [1]. Unexpectedly throughout the Covid-19 related restrictions, the consumption of renewable resources underwent an upsurge of 3% whilst the requirement of fossil fuels collapsed unanimously [2]. While India at present supports the second biggest populace on the Earth, it turns out to be remarkably pivotal for its energy supply industry to take advantage of the renewable energy resources for boosting the incipient fiscal structure through nature-receptive techniques [3]. Wind energy, chiefly, is a crucial and efficient renewable energy resource for electricity generation [4]. The expense of generating wind power has dwindled markedly throughout the previous decades globally [5]. The National Institute of Wind Energy (NIWE) has endorsed the wind energy generation competence of the nation as 302 GW at 100 m [6]. Presently, the nation generates 10.3% of its 377260.67 MW full ordained power generation ability from Wind Turbines (WTs) [7]. One of the most favorable attributes of Wind Power Generation (WPG) of India is that it is almost 35% cheaper than the electricity generated from a larger segment of the thermal power plants and another 7% reduction is anticipated by 2022 [8].

Hasager et al. [9] investigated the opportunity of offshore WPG in the southmost portion of inland India was quantified with ENVISAT satellite imageries congregated within 2002 and 2011. Mani Murali et al. [10] explored the feasible sites for offshore WPG and their financial practicability were reviewed. Kota et al. [11] presented a relative scrutiny of several strategy agendas concerning the offshore WPG in the U.K., U.S.A., and India has been discoursed. Nagababu et al. [12] examined the offshore WPG competence of India has been estimated utilizing the OSCAT satellite records. Nagababu et al. [13] applied the Re-examination and bathymetry statistics for assessing the WPG capability in the special economic region in India allowing for the maritime organic circumstances. Singh and Kumar S.M. [14] attempted for the evaluating of the offshore WPG ability and minimizing of the generation expenditure in the Indian coastline range by general algebraic modelling. Kumar et al. [15] evaluated a bigger offshore WPG arrangement for the western shore of Gujrat using the environment analysis and generation expenditure has been prophesied.

The maximization of financial profitability of Indian offshore WPG units necessitates more consideration to aid the green changeover of the Indian power generation industry. While the task of wind farm profit maximization requires enormously intricate computing strength, Artificial Intelligence (AI) is capable of assisting the decision-maker in such a complex setting. AI procedures have been employed in miscellaneous disciplines of technology because of their strength, flexibility, and swiftness with commendable accomplishments [16] - [25]. The central government of India along with the NIWE instituted Light Detection and Ranging (LiDAR) assessment for authenticating the WPG competence at the coasts of Tamil Nadu and Gujarat of India [26]. Comprehensive information concerning the features of offshore wind speed has been procured by a LiDAR placed adjacent to the Gulf of Khambhat [27]. The existing paper purposes for maximizing the annual profit of a wind farm in the Gulf of Khambhat of India employing two bio-stimulated AI procedures known as Genetic Algorithm (GA) and Binary Particle Swarm Optimization Algorithm (BPSOA) to compute their comparative efficacy.

2. Problem Formulation

The kinetic energy engrossed by a WT can be determined as per Equation 1.

$$P = \frac{1}{2}\rho\vartheta^3 C_p cos\theta \tag{1}$$

In Equation 1, *P* stands for the kinetic energy, *ρ* denotes the air density, *A* signifies the wheel area, *v* stands for the windspeed, C_p is the power coefficient and *θ* denotes the yaw inaccuracy [28]. WPG units can stay profitable by skilled controlling of the generation cost [19]. The current research work focused on maximizing the annual profit of a wind farm [29]. The objective function has been mentioned in Equation 2.

$$Profit = (SP - CoE) \times P_{total} \tag{2}$$

In Equation 2, *SP* stands for the selling price of the 1 kWh generated electricity, *CoE* denotes the generation cost per unit of electricity and P_{total} is the annual generated power [29]. *CoE* function considered by Bhattacharjee et al. [19] has been taken into account for the present study. The location and the wind-stream form noticed in the Gulf of Khambhat have been presented in Figures 1 and 2 correspondingly.

Figure 1. Location of the Gulf of Khambhat [30]

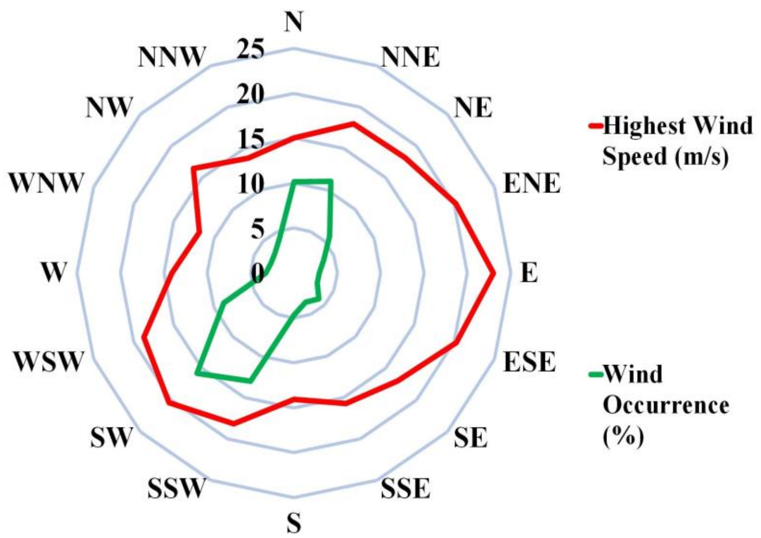

Figure 2. Wind-Flow Configuration for the Gulf of Khambhat

3. Optimization Algorithms

GA and BPSO have been applied for maximizing the annual profit of a probable wind farm in the Gulf of Khambhat of India. The optimization algorithms have been sketchily depicted in the succeeding segments.

3.1. Genetic Algorithm (GA)

GA can be defined as a bio-stirred exploration method to acclaim solutions for optimization trials mimicking the evolvement of organic preference as envisioned by Turing [31]. GA has been exercised in numerous technical realms for unravelling specific and compound criteria decision-rendering challenges [16]. The algorithm has been defined as follows.

1. Coordinate the parameters such as populace range, repetition count, possibilities for crossover, and mutation.
2. Process the fittingness of every chromosome.
3. Appoint the populace unsystematically.
4. Analyse the properness of every chromosome.
5. Initiate the arithmetic crossover technique.
    (a) Elect a numeral indiscriminately inside 0 and 1. If it is not as much of the possibility of the crossover, indicate the chromosome for the crossover scheme.
    (b) Complete crossover between the paternities.
    (c) Scrutinize the possibility of the descendants.
    (d) combine the viable descendants into the populace.

6. Kick off the mutation activity.
    (a) Elect a numeral indiscriminately inside 0 and 1. If it is not as much of the possibility of mutation, elect the chromosome for mutating.
    (b) Mutate the individuals.
    (c) Justify the immaculate individuals.
    (d) If the originated chromosome is practicable, incorporate it into the latest populace.
7. Assess the properness of the novel beings shaped using crossover and mutation approaches.
8. Identify the most outstanding outcome pursuing the choice maker's liking.

3.2. Binary Particle Swarm Optimization Algorithm (BPSOA)

Particle swarm intelligence mimics the shared deeds of a group of bees through relating the communication allied to the all-embracing and delimited optimal outcomes [17]. The BPSOA is an adapted arrangement of particle swarm optimization algorithm that sums all elements as strings of bits [19]. The spot of a particle can be revised by the velocity [32]. The BPSOA can be defined as follows.

1. Indiscriminately fabricate a basic population.
2. Randomly construct the fundamental velocities inside the confines.
3. Assign the initial values for local and global best locations.
4. Compute the weights required for velocity formation.
5. Alter the velocities of the particles accordingly.
6. Change the locations of the particles following the velocities.
7. Conclude if the final conditions are realized, else return to step 3.

4. Results and Discussions

For evaluating the comparative operation of GA and BPSOA, a comparable goal for maximizing the yearly profit of a probable wind farm in the Gulf of Khambhat has been deemed. Annual profit has been measured in USD. GA and BPSOA have been reiterated 50 epochs. Populace magnitude has been deemed as 20 for GA and BPSOA. 1.5 MW turbine of diameter 77 m has been exercised for the existing study. To decrease the wake deficit consequence, the space between two nearby turbines has been reserved as 4 times the turbine diameter. The cut-in and cut-off speeds have been considered as 12.6 km/hr and 72 km/hr correspondingly. Three layouts of dimensions 2000 m x 2000 m, 2500 m x 2500 m, and 3000 m x 3000 m have been considered for the study. The selling price of wind power has been considered as USD 0.033/kWh [33]. The optimal positions of turbines achieved through GA and BPSOA have been presented in Figures 3-5 and 6-8 respectively.

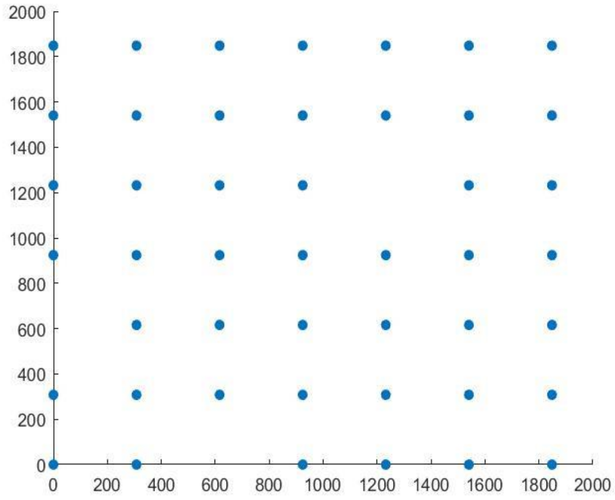

Figure 3. GA Optimized Layout of 2000 m x 2000 m

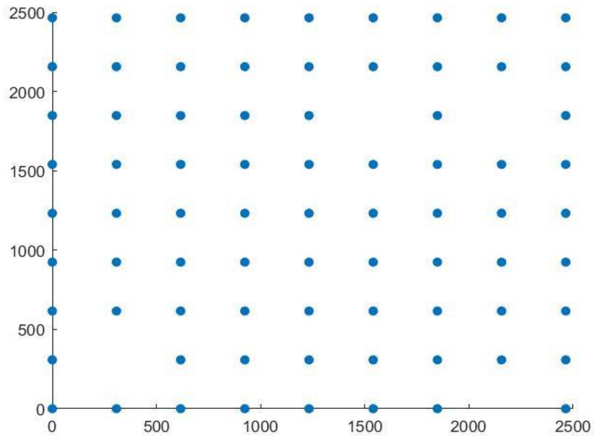

Figure 4. GA Optimized Layout of 2500 m x 2500 m

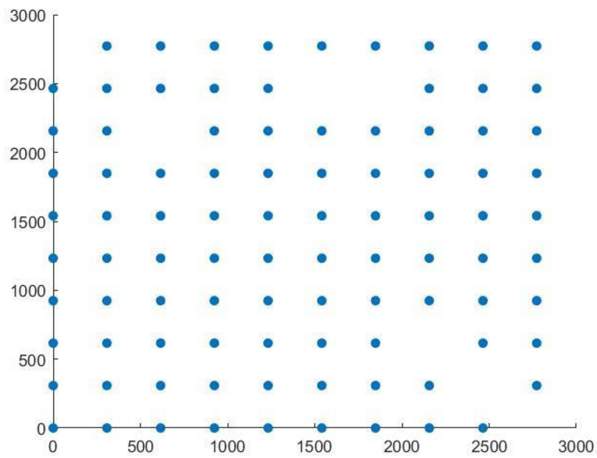

Figure 5. GA Optimized Layout of 3000 m x 3000 m

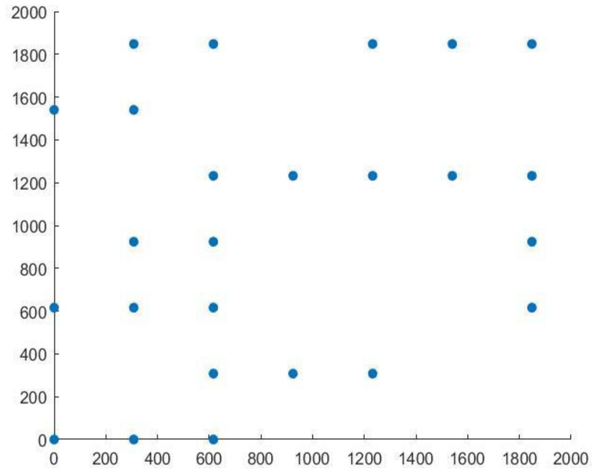

Figure 6. BPSOA Optimized Layout of 2000 m x 2000 m

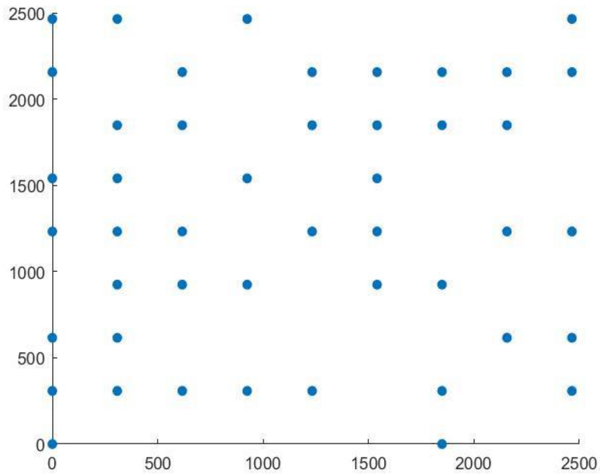

Figure 7. BPSOA Optimized Layout of 2500 m x 2500 m

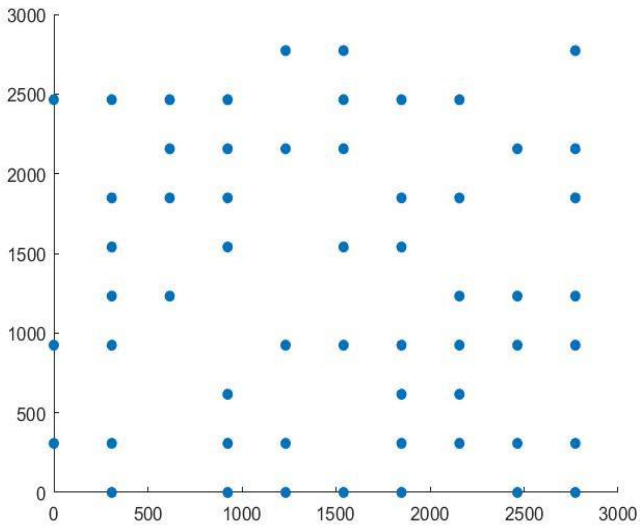

Figure 8. BPSOA Optimized Layout of 3000 m x 3000 m

The annual profit of the possible offshore WPG unit in the Gulf of Khambhat computed using GA and BPSOA has been presented in Table 1.

Table 1. Comparison of Optimized Annual Profit Attained by GA and BPSOA

Layout Dimension	GA Optimized Annual Profit (in USD)	BPSOA Optimized Annual Profit (in USD)
2000 m x 2000 m	12438	7867.1
2500 m x 2500 m	20444	13148
3000 m x 3000 m	25419	16353

The analysis outcomes prove the superior ability of GA over BPSOA in optimizing the annual profit of the WPG unit for every layout dimension. Moreover, the power outputs of the layouts optimized by GA are higher than those optimized by BPSOA.

Better profitability for similar layouts can enable the offshore WPG units to gain more economic sustainability and assist the electricity generation industry to restrain the emission of greenhouse gases.

5. Conclusion

As the Paris accord of 2015 directs the member nations to curb the release of greenhouse gases for diminishing the repercussions triggered by global climate change, it turns out to be enormously important for a coal-reliant nation like India to utilize more renewable energy resources for fulfilling its energy requirement.

This current paper focuses on maximizing the annual profit of a possible offshore WPG unit in the Gulf of Khambhat of India. Two well-recognized AI-driven techniques identified as GA and BPSOA have been employed to optimize the layouts for better economic viability. The optimization solutions demonstrate the better applicability of GA over BPSOA for three considered layout scenarios.

This study can instigate novel prospects of WPG layout optimization for both onshore and offshore settings. In the future, WTs with higher generation capacity and wheel area can be attempted for a better understanding of the resolution makers.

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6. References

[1] B. Obama, "The irreversible momentum of clean energy," *Science,* vol. 355, no. 6321, pp. 126-129, 2017.

[2] International Energy Agency, "Global Energy Review 2021," [Online]. Available: https://www.iea.org/reports/global-energy-review-2021/renewables. [Accessed 30 July 2021].

[3] M. B. H. Kumar, S. Balasubramaniyan, S. Padmanaban 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,* vol. 12, no. 11, p. 2158, 2019.

[4] J. Cousse, R. Wüstenhagen and N. Schneider, "Mixed feelings on wind energy: Affective imagery and local concern driving social acceptance in Switzerland," *Energy Research & Social Science,* vol. 70, p. 101676, December 2020.

[5] R. Sitharthan, J. N. Swaminathan and T. Parthasarathy, "Exploration of Wind Energy in India: A Short Review," in *2018 National Power Engineering Conference (NPEC)*, 2018.

[6] Wikipedia, "Wind power in India," [Online]. Available: https://en.wikipedia.org/wiki/Wind_power_in_India. [Accessed 10 August 2021].

[7] Ministry of Power, Government of India, "Renewable Generation Report," 2020. [Online]. Available: https://cea.nic.in/renewable-generation-report/?lang=en. [Accessed 23 July 2021].

[8] 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].

[9] C. B. Hasager, F. Bingöl, M. Badger, I. Karagali 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.

[10] R. Mani Murali, P. Vidya, P. Modi and S. Jaya Kumar, "Site selection for offshore wind farms along the Indian coast," *Indian Journal of Geo-Marine Sciences,* vol. 43, no. 7, pp. 1401-1406, 2014.

[11] S. Kota, S. B. Bayne and S. Nimmagadda, "Offshore wind energy: A comparative analysis of UK, USA and India," *Renewable and Sustainable Energy Reviews,* vol. 41, p. 685–694, 2015.

[12] G. Nagababu, R. Simha R, N. K. Naidu, S. S. Kachhwaha and V. Savsani, "Application of OSCAT satellite data for offshore wind power," in *5th International Conference on Advances in Energy Research, ICAER 2015*, Mumbai, India, 2016.

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

[14] R. Singh 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 *2018 International Conference on Current Trends Towards Converging Technologies (ICCTCT),* 2018.

[15] R. Kumar, T. Stallard 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,* vol. 24, no. 2, p. 174–192, 2020.

[16] R. K. Jana and P. Bhattacharjee, "A multi-objective genetic algorithm for design optimisation of simple and double harmonic motion cams," *International Journal of Design Engineering,* vol. 7, no. 2, pp. 77-91, 2017.

[17] A. Duggirala, R. K. Jana, R. V. Shesu and P. Bhattacharjee, "Design optimization of deep groove ball bearings using crowding distance particle swarm optimization," *Sādhanā,* vol. 43, no. 1, 2018.

[18] P. Bhattacharjee, R. K. Jana and S. Bhattacharya, "A Comparative Analysis of Genetic Algorithm and Moth Flame Optimization Algorithm for Multi-Criteria Design Optimization of Wind Turbine Generator Bearing," *ADBU Journal of Engineering Technology,* vol. 10, 2021.

[19] P. Bhattacharjee, R. K. Jana and S. Bhattacharya, "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," *ITM Web of Conferences,* p. 03016, 2021.

[20] P. Bhattacharjee, R. K. Jana and S. Bhattacharya, "An Enhanced Genetic Algorithm for Annual Profit Maximization of Wind Farm," in *Applied Informatics in Economy and Information Technology: "e-Society 2021 - Knowledge and Innovation: the Online Era"*, Bucharest, Romania, 2021.

[21] P. Bhattacharjee, R. K. Jana and S. Bhattacharya, "An Improved Genetic Algorithm for Yearly Profit Maximization of Wind Power Generation System," in *The 31st ACM SIGDA University Demonstration*, 2021.

[22] P. Bhattacharjee, R. K. Jana and S. Bhattacharya, "Design Optimization of Cam in Computer-Aided Simulation Applications using Taguchi's Experimentation Method," *International Journal of Electrical and Computer System Design,* 2021.

[23] P. Bhattacharjee, R. K. Jana and S. Bhattacharya, "Multi-Objective Design Optimization of Wind Turbine Blade Bearing," *Invertis Journal of Science & Technology,* vol. 14, no. 3, pp. 114-121, 2021.

[24] P. Bhattacharjee, R. K. Jana and S. Bhattacharya, "Optimizing Offshore Wind Power Generation Cost in India," in *Third New England Chapter of AIS (NEAIS) Conference*, Boston, Massachusetts, 2021.

[25] P. Bhattacharjee, R. K. Jana and S. Bhattacharya, "Realizing The Optimal Wind Power Generation Cost in Kayathar Region of India," in *International Conference on Information, Communication and Multimedia Technology - 2021 (ICICMT - 2021)*, Madurai, 2021.

[26] J. Charles Rajesh Kumar, D. Vinod Kumar, D. Baskar, B. Mary Arunsi, R. Jenova and M. Majid, "Offshore wind energy status, challenges, opportunities, environmental impacts, occupational health, and safety management in India," *Energy & Environment*, p. 0958305X2094648, 2020.

[27] C. B. Hasager, A. Pena, M. B. Christiansen, P. Astrup, M. Nielsen, F. Monaldo, D. Thompson and P. Nielsen, "Remote Sensing Observation Used in Offshore Wind Energy," *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing,* vol. 1, no. 1, p. 67–79, 2008.

[28] Z. Wu and H. Wang, "Research on Active Yaw Mechanism of Small Wind Turbines," *Energy Procedia,* vol. 16, p. 53–57, 2012.

[29] H. S. Huang, "Distributed Genetic Algorithm for Optimization of Wind Farm Annual Profits," in *The 14th International Conference on Intelligent System Applications to Power Systems, ISAP 2007,* Kaohsiung, Taiwan, 2007.

[30] Google, "[Google Earth Map of Gulf of Khambhat]," [Online]. Available: https://earth.google.com/web/@21.25810683,72.56091163,-102.31051105a,1055553.15311864d,35y,-0h,0t,0r. [Accessed 22 July 2021].

[31] A. Turing, "Computing Machinery and Intelligence (1950)," in *The Essential Turing*, Oxford University Press, 2004.

[32] J. Liu, Y. Mei and X. Li, "An Analysis of the Inertia Weight Parameter for Binary Particle Swarm Optimization," *IEEE Transactions on Evolutionary Computation,* vol. 20, no. 5, p. 666–681, 2016.

[33] U. Bhaskar, "Adani Renewable places lowest bid in SECI's wind auction," Mint, 2021.

[34] P. Bhattacharjee, R. K. Jana and S. Bhattacharya, "Design Optimization of Simple Harmonic and Cycloidal Motion Cams," in *1st National Conference on Applied Science and Advanced Materials*, 2021.