Realizing The Optimal Wind Power Generation Cost in Kayathar Region of India

Prasun Bhattacharjee
Department of Mechanical Engineering,
Jadavpur University, Kolkata-700032, West Bengal, India.
Email: prasunbhatta@gmail.com
Rabin K. Jana
Operations and Quantitative Methods Area,
Indian Institute of Management Raipur, Raipur-492015, Chhattisgarh, India.
Email: rkjana1@gmail.com
Somenath Bhattacharya
Department of Mechanical Engineering,
Jadavpur University, Kolkata-700032, West Bengal, India.
Email: snbofju@gmail.com

ABSTRACT

To restrain the increase of worldwide mean surface temperature well below 2^{o}C as proposed by the Paris agreement of 2016, non-fossil fuel resources like wind power have to stay economically practicable for empowering the green energy changeover. Even though Indian Wind Power Generation (WPG) market at present claims the worldwide fourth-largest instated competence, it requires to expand more quickly to satiate the mounting energy exigency of its progressing financial system while limiting the resulting emission-related impacts leading to climate change. For realizing 140 GW WPG ability by 2030 as projected by the Central Government of India, a greater number of fiscally practical wind farms are needed to operate throughout the nation right away. This paper aims to understand the optimum cost of WPG in the Kayathar region of Tamil Nadu. Genetic Algorithm and Binary Particle Swarm Intelligence have been engaged simultaneously with four randomly chosen terrain conditions. The experimentation results confirm the higher competence of Genetic Algorithm for realizing the most optimum WPG cost.

Keywords: *Wind Power, Cost Optimization, Genetic Algorithm, Binary Particle Swarm Optimization, Kayathar.*

1. INTRODUCTION

The continual emission of greenhouse gases as a result of miscellaneous societal events is escalating the average air temperature and deviant meteorological conditions leading to worldwide climate change (Obama, 2017). Renewable energy techniques recommend well-off substitutes amidst the swelling intercontinental trepidation for the constrained stash of non-renewable resources and their perilous consequences on the environment (Chaurasiya, Warudka, & Ahmed, 2019). Even throughout the Covid-19 lockdowns in 2020, the usage of renewable energy experienced an increase of 3% while the exigence of every other fuel fell universally (International Energy Agency, 2020).

As India is the second most inhabited country on the planet, it becomes tremendously decisive for the nation to exploit renewable energy to drive its emerging financial system in an environmental-friendlier mode (Kumar, Balasubramaniyan, Padmanaban, & Holm-Nielsen, 2019). Universally, the cost of Wind Power Generation (WPG) has contracted steeply over the past few decades (Sitharthan, Swaminathan, & Parthasarathy, 2018).

The National Institute of Wind Energy has validated the Indian WPG capability as 302 GW at 100 m (Wikipedia, n.d.). Up to the end of January 2021, India holds 10.3% of its 377260.67 MW entire instated electricity generation competence from WPG farms (Ministry of Power, Government of India). The levelized cost of WPG is nearly 35% lesser than that from a major section of the coal-fired plants and this is expected to decline by 7% in 2022 (Global Wind Energy Council). This paper aims to recognize the optimum cost of WPG for the Kayathar region of Tamil Nadu of India. As the task of optimizing the WPG cost involves complex and extensive computation, Artificial Intelligence (AI) procedures have been exercised owing to their capability to deal with multifaceted problems of diverse engineering domains (Jana & Bhattacharjee, 2017) (Duggirala, Jana, Shesu, & Bhattacharjee, 2018). Due to the randomness of the wind flow over any space, the optimum location of turbines in a WPG farm necessitates massive arithmetical determination to maintain equilibrium between the total power yield and the cost. Genetic Algorithm (GA) and Binary Particle Swarm Optimization Algorithm (BPSOA) were involved concurrently to minimalize the optimum Cost of Energy (CoE).

2. Problem Presentation

As stated by the law of aerodynamics, the kinetic energy engrossed by a Wind Turbine (WT) can be estimated as per Eq. (1) (Bhattacharjee, Jana, & Bhattacharya, 2021).

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

where *P* is the wind energy extracted by WT, ρ stands for the density of the airstream, *A* represents WT wheel area, *v* stands for the wind speed, C_p is the power coefficient and θ represents the yaw error.

2.1 Objective Function

Wind farms remain commercially worthwhile by capably managing the CoE. The present research work considered the CoE function employed by Bhattacharjee et al. (Bhattacharjee, Jana, & Bhattacharya, 2021). The concerned CoE function has been illustrated in Eq. (2).

$$CoE = \frac{c_t N + c_s floor\left(\frac{N}{M}\right)\left(\frac{2}{3} + \frac{1}{3} e^{-i0.00174N^2}\right) + (\, C_{om} N)}{(1-(1+r)^{-y}) \,/\, r} * \frac{1}{18760 * P} + \frac{0.1}{N} \tag{2}$$

where C_t indicates the expenditure owing to a WT. C_s symbolizes the spending attributable to one sub-station. *N* designates the total number of WTs and *m* specifies the amount of WT per sub-station. C_{om} represents the annual operational and maintenance cost. *r* designates the interest rate. *y* specifies the probable active lifespan of the farm. The final term (*0.1/N*) compensates the layouts with a superior WT count to expand the windfarm's power yield.

2.2 Airstream Flow Pattern and Terrain Condition

In the present study, Kayathar (08°57′N 77°48′E) zone of Tamil Nadu has been nominated for realizing the optimum CoE. The wind flow pattern has been shown in Fig. 1 (R, K, Raju, Madurai Elavarasan, & Mihet-Popa, 2020). Three terrain layouts of 1000 m x 1000 m, 2000 m x 2000 m and 3000 m x 3000 m have been considered for the present study.

3. Optimization Algorithms

GA and BPSOA have been involved at the same time to attain the optimum CoE for the formerly stated terrain situations. GA has been concisely discussed as follows (Jana & Bhattacharjee, 2017).

1. Organize the parameters like population magnitude, iteration number, chances for crossover, and mutation.
2. Arrange the population arbitrarily.
3. Compute the aptness of all individual chromosomes.
4. Complete the arithmetic crossover procedure as follows.

4.1 Pick a number randomly within 0 and 1. If it is not as much of the chance of crossover, elect the parental chromosome for the crossover process.

4.2 Initiate the crossover process. 4.3 Scrutinize the practicality of the offspring.

4.4 If the descendants are reasonable, then incorporate them into the pool.

5. Accomplish the mutation process as follows.

5.1 Pick a number randomly within 0 and 1. If it is not as much of the possibility of mutation, elect the chromosome for the mutation process. 5.2 Institute the mutation procedure.

5.3 Authenticate the new chromosomes.

5.4 If the formed chromosomes are feasible, amalgamate them into the fresh population.

6. Assess the suitability of the new entities formed by crossover and mutation approaches.

7. Pull out the most outstanding outcome comprehending the decision maker's fondness.

Particle Swarm Optimization (PSO) is an AI-empowered probing procedure that matches the communal movements of bees by collaborating the data associated with the general and restricted optimum solutions (Duggirala, Jana, Shesu, & Bhattacharjee, 2018). The BPSOA is a modified form of PSO that deliberates each element as a bit string (Liu, Mei, & Li, 2016). For the m^{th} bit of nth element, the velocity v_{mn} is represented using Eq. (3).

$$v_{mn} = wv_{mn} + c_1r_{1n}(p_{mn} - x_{mn}) + c_2r_{2n}(g_n - x_{mn}) \tag{3}$$

where w designates the inertia weight and is ascertained as per Eq. (4).

$$w = w_1 - (w_1 - w_2)\frac{l}{l_{high}} \tag{4}$$

where w_1 and w_2 are the uppermost and lowermost confines of inertia weight correspondingly. l is the present count of repetition and l_{high} is the peak count of repetitions. c_1 and c_2 are acceleration factors. r_{1n} and r_{2n} are arbitrary variables oscillating between 0 and 1. p_{mn} identifies the n^{th} bit of the dissimilar most exceptional location of the m^{th} particle. g_n denotes the n^{th} bit of the combined best site.

The transfer function which is operated to review the bit value can be expressed using Eq. (5).

$$S(v_{mn}) = \frac{1}{1+e^{-v^{mn}}} \tag{5}$$

The location of the particle is updated according to Eq. (6).

$$x_{mn} = \begin{cases} 1, if\ rand() \leq s(v^{mn}) \\ 0, otherwise \end{cases} \tag{6}$$

where *rand ()* represents a function that randomly picks a number following the uniform distribution (Liu, Mei, & Li, 2016).

4. Results and Discussion

For evaluating the comparative implementation of GA and BPSOA, a comparable objective function for optimizing of CoE has been deliberated. CoE is computed in USD/kW. Both the optimization procedures have been repeated for 50 periods. Population magnitude has been contemplated as 20.

1.5 MW turbine of diameter 77 m has been engaged. To decrease the wake deficit influence, the space between two in line WTs has been reserved as 4 times the WT diameter. The cut-in and cut-off speeds were 3.5 m/s and 20 m/s correspondingly. The experimentation results have been presented in Fig. 2.

The graph showed in Fig. 2 validates that GA is more efficient than BPSOA for locating the optimum CoE for all three terrain layouts for WPG in Kayathar, Tamil Nadu. The GA is competent of locating CoE as low as USD 0.0019/kW while the lowest possible CoE attained using BPSOA is USD 0.0023/kW.

5. Conclusion

In the present work, AI-enabled competent methods have been offered to locate the optimum CoE for WPG in the Kayathar zone of Tamil Nadu. GA and BPSOA have been applied simultaneously to measure their comparative efficiency. The study results demonstrate the better aptness of GA in discovering the optimum CoE for three arbitrarily selected terrain circumstances.

The current study will open fresh chances for examining the economic feasibility of WPG for diverse geographical sites global. More AI-enabled techniques can be utilized to analyze the efficiency of other search algorithms.

List of Figures

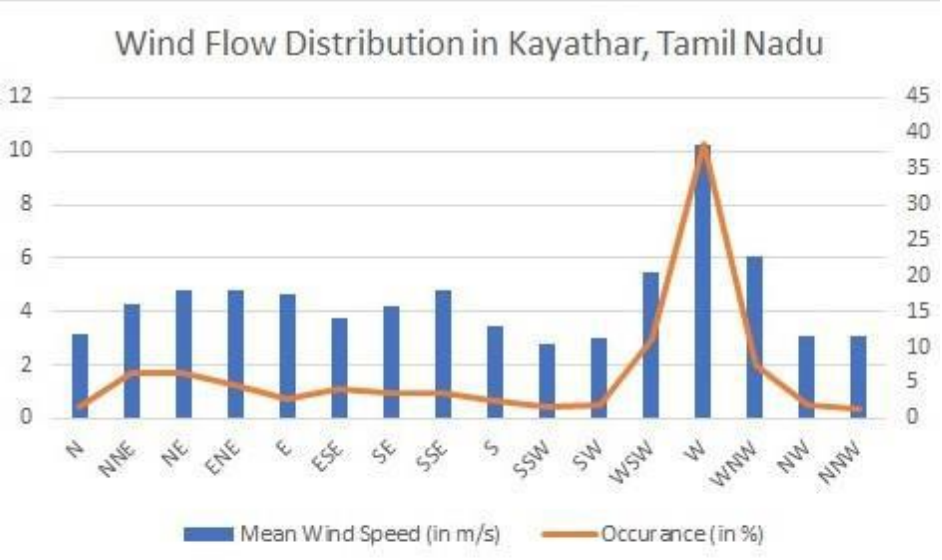

Fig. 1. Wind Flow Pattern of Kayathar, Tamil Nadu

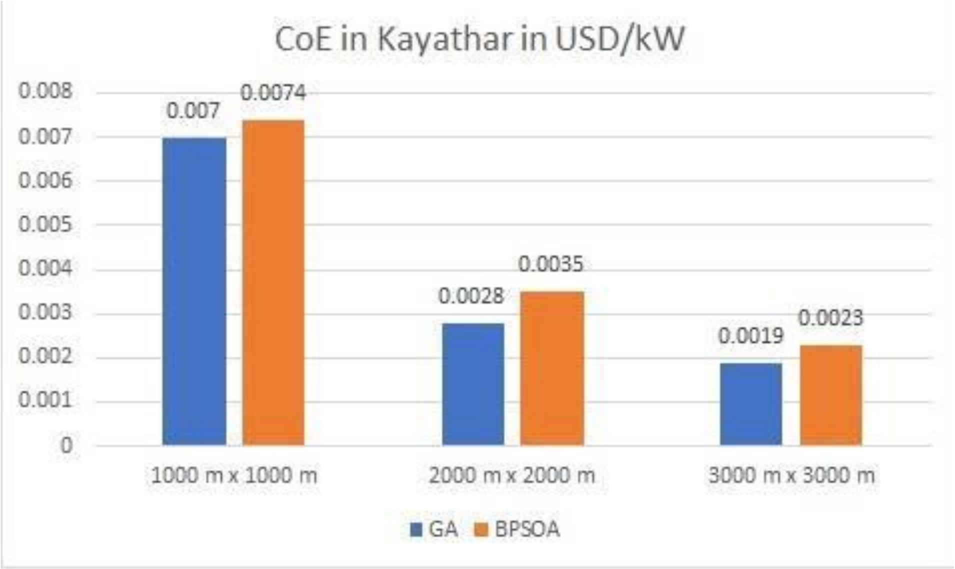

Fig. 2. Comparison of CoE for Different Layouts

References

[1] Bhattacharjee, P., Jana, R., & 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. ITM Web of Conferences, 03016. doi:10.1051/itmconf/20214003016

[2] Chaurasiya, P. K., Warudka, V., & Ahmed, S. (2019). Wind energy development and policy in India: A review. Energy Strategy Reviews, 24, 342-357. doi:10.1016/j.esr.2019.04.010

[3] Duggirala, A., Jana, R., Shesu, R., & Bhattacharjee, P. (2018). Design optimization of deep groove ball bearings using crowding distance particle swarm optimization. Sādhanā, 43(1). doi:10.1007/s12046-017-0775-9

[4] Global Wind Energy Council. (n.d.). India Wind Outlook Towards 2022: Looking beyond headwinds. Retrieved July 23, 2021, from GWEC: https://gwec.net/india-wind-outlook-towards-2022-looking-beyond-headwinds/

[5] International Energy Agency. (2020, June 11). The impact of the Covid-19 crisis on clean energy progress. Retrieved July 30, 2021, from https://www.iea.org/articles/the-impact-of-the-covid-19-crisis-on-clean-energy-progress

[6] Jana, R., & Bhattacharjee, P. (2017). A multi-objective genetic algorithm for design optimisation of simple and double harmonic motion cams. International Journal of Design Engineering, 7(2), 77-91. doi:10.1504/ijde.2017.089639

[7] Kumar, M. B., Balasubramaniyan, S., Padmanaban, S., & Holm-Nielsen, J. B. (2019). Wind Energy Potential Assessment by Weibull Parameter Estimation Using Multiverse Optimization Method: A Case Study of Tirumala Region in India. Energies, 12(11), 2158. doi:10.3390/en12112158

[8] Liu, J., Mei, Y., & Li, X. (2016). An Analysis of the Inertia Weight Parameter for Binary Particle Swarm Optimization. IEEE Transactions on Evolutionary Computation, 20(5), 666–681. doi:10.1109/tevc.2015.2503422

[9] Ministry of Power, Government of India. (n.d.). Renewable Generation Report. Retrieved July 23, 2021, from Central Electricity Authority: https://cea.nic.in/renewable-generation-report/?lang=en

[10] Obama, B. (2017). The irreversible momentum of clean energy. Science, 355(6321), 126-129. doi:https:// doi.org/10.1126/science.aam6284

[11] R, K., K, U., Raju, K., Madurai Elavarasan, R., & Mihet-Popa, L. (2020). An Assessment of Onshore and Offshore Wind Energy Potential in India Using Moth Flame Optimization. Energies, 13(12), 3063. doi:10.3390/en13123063

[12] Sitharthan, R., Swaminathan, J., & Parthasarathy, T. (2018). Exploration of Wind Energy in India: A Short Review. 2018 National Power Engineering Conference (NPEC). IEEE. doi:10.1109/npec.2018.8476733

[13] Wikipedia. (n.d.). Wind power in India. Retrieved August 10, 2021, from https://en.wikipedia.org/wiki/Wind_power_in_India