Expanding the Yearly Profit of Wind Farm Using Genetic Algorithm with Variable Allocation Method of Possibilities for Crossover and Mutation Procedures

Prasun Bhattacharjee[1], Rabin K. Jana[2], Somenath Bhattacharya[3]

[1]Department of Mechanical Engineering, Jadavpur University,
Kolkata,
prasunbhatta@gmail.com

[2]Operations & Quantitative Methods Area, Indian Institute of Management Raipur,
Raipur,
rkjana1@gmail.com

[3]Department of Mechanical Engineering, Jadavpur University,
Kolkata,
snb_ju@yahoo.com

Abstract*: *With rising surface air temperature, global communities are continually struggling to restrict the production of greenhouse gases through the competent application of renewable resources. Being a proficient alternative to traditional electricity generation technologies, wind energy can facilitate nations to achieve their carbon neutrality goals. This paper aims to enhance the annual profit of wind farms using an enriched genetic algorithm. Innovative dynamic techniques for allotting the chances of crossover and mutation procedures have been employed for the genetic algorithm-based optimization process accompanied by the established static tactic. The evaluation consequences of the projected procedure have been contrasted with the results accomplished by the genetic algorithm with the standard static method of apportioning the crossover and mutation probabilities. The evaluation outcomes authorize the preeminence of the new non-linearly escalating procedure over the static tactic of allotting the crossover and mutation prospects for achieving a more optimal yearly profit.

***Keywords*: Dynamic Allocation, Genetic Algorithm, Wind Farm, Crossover, Mutation Probability.**

(*Article history: Received: 26th February 2022 and accepted 24th June 2022*)

I. INTRODUCTION

The utilization of energy is regarded as one of the several crucial facets of the fiscal expansion of every present-day nation. As the global energy generation expanded from 8794 Mtoe in 1990 to 14410 Mtoe in 2019 with the intensification of economic activities, the conventional energy reserves are exhausting at an unprecedented pace. The share of renewable energy in general energy generation has broadened from 19.75% in 1990 to 26.62% in 2019 which is a rational indication of the international trend towards low-carbon substitutions of energy reserves [1]. Global renewable energy consumption has developed from nearly 941 TWh in 1965 to approximately 7027 TWh in 2019 while Wind Power Generation (WPG) sector has progressed exponentially ever since the preliminary years of the twenty-first century [2].

Worldwide cumulative WPG capacity has expanded from nearly 20 GW in 2000 to 650 GW in 2019 with a forecast of achieving 4042 GW by 2050 [3]. Strangely, throughout the Covid-19 allied restrictions in 2020, the consumption of renewable energy experienced an expansion of 3% where the requirement of all fossil fuels plummeted across the world [4]. WPG market, which remained principally dominated by European nations and the USA till the first decade of the present century, is at present tremendously influenced by Asian countries like the People's Republic of China (Global 1st in WPG) and India (Global 4th in WPG) with 36.3% and 5.8% WPG capacity share respectively [2].

Artificial Intelligence (AI) techniques have been employed extensively to enhance the performance of WPG units [5] [6] [7] [8] [9] [10]. Şişbot et al. have employed Genetic Algorithm (GA) for improving the design of a WPG unit in Gökçeada islet [11]. Saroha and Aggarwal presented a paradigm planned for WPG valuation with GA and Neural Network (NN) [12]. Huang recommended one more NN permitted GA technique for speculating WPG possibility [13]. Khosa et al. suggested a cost-effective dispatch representation for probabilistic WPG using GA [14]. Shin and Lee upgraded the model of a generator for WPG through GA [15]. Viet et al. projected an NN abetted method with swarm intellect and GA for WPG assessing [16].

The existing research aims to maximize the yearly profit of wind farms with an enriched GA. A fresh procedure of dynamically apportioning the possibilities of crossover and mutation has been projected and its comparative effectiveness concerning the established static process of apportioning the crossover and mutation proportions has been estimated.

II. OBJECTIVE FORMULATION

WPG industries can remain efficient by way of expert operating of the WPG cost [11]. The present work is fixated to increase the annual profit of a WPG farm. The objective function has been presented according to (1).

$$Q = [X - Y] \times A_o \tag{1}$$

In (1), Q is the annual profit, X signifies the marketing value of per unit power, Y represents the WPG cost of per unit wind power and A_o indicates the yearly WPG capacity. Y has been calculated using the WPG cost formula provided by Wilson *et al*. [17]. The airflow pattern has been shown in Fig. 1.

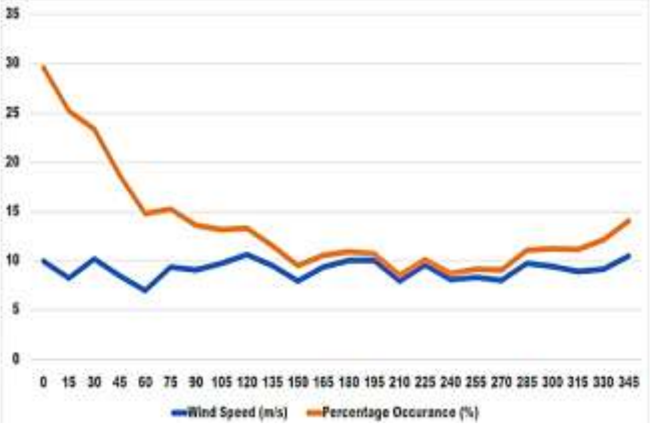

Fig. 1. Considered Airflow Pattern

III. OPTIMIZATION ALGORITHMS

GA has been applied in several engineering arenas for settling decision-constructing challenges [18] [19] [20]. It is a bio-driven metaheuristic exploring practice to recommend results for optimization study by impersonating the progression of natural penchant [21].

The algorithm has been described as follows [18].

1. Establish the essential features such as population scale, recurrence extent, probabilities for crossover, and mutation methods.

2. Instigate the populace randomly.

3. Examine the appropriateness of distinct chromosomes.

4. Commence the crossover technique in the following manner:

    4.1 Choose a numeral arbitrarily between 0 and 1. If it is less than the probability of the crossover technique, recommend the parental unit.

    4.2 Stimulate the crossover activity.

    4.3 Appraise the applicability of the offspring.

    4.4 If the inheritor is suitable, conform it to the up-to-date population.

5. Accomplish the mutation technique in the succeeding means:

    5.1 Choose a numeral randomly in the middle of 0 and 1. If it is less than the possibility of mutation, opt for the unit for the mutation process.

    5.2 Prompt the mutation technique.

    5.3 Confirm the newly mutated entities for their viability.

    5.4 Amalgamate the mutated and possible entities into the current populace.

6. Assess the appropriateness of the fresh units shaped by crossover and mutation approaches.

7. Stipulate the most optimized consequence concerning the choice-maker's zeal.

Supplemented by the recognized arrangement of considering persistent values, this research study has employed an advanced dynamic process for positioning the proportions of crossover and mutation.

The dynamic crossover probability has been calculated through (2).

$$c_d = c_1 + \{(c_2 - c_1)(R_i/R_{max})^8\} \tag{2}$$

Where c_d is the non-linearly growing crossover possibility. c_1 and c_2 are the bounds of the crossover proportion. R_i is the current recurrence count and R_{max} represents the uppermost recurrence count.

The dynamic mutation possibility can be considered by (3).

$$m_d = m_1 + \{(m_2 - m_1)(R_i/R_{max})^8\} \tag{3}$$

Where m_d is the non-linearly growing mutation possibility. m_1 and m_2 are the bounds of the mutation proportion.

IV. RESULTS AND DISCUSSIONS

For the present yearly profit expansion problem for a wind farm. Two designs of dimensions of 3000 m x 3000 m and 3500 m x 3500 m have been taken into account. The purpose of the current work is to make the most of the yearly profit. The marketing charge of wind power in India has been deemed as USD 0.033/kWh [22].

The values of diverse factors connected to the considered optimization problem have been shown in Table 1.

TABLE I. VALUES OF DIFFERENT FACTORS

Parameter	***Considered Value***
c_2	0.6
c_1	0.5
m_2	0.06
m_1	0.05
Populace Size	20

Parameter	*Considered Value*
Maximum Generation Count	50
Tournament Size	4

The optimal placements of WT using the conventional static and the proposed dynamic approach have been shown in Figs. 2-5.

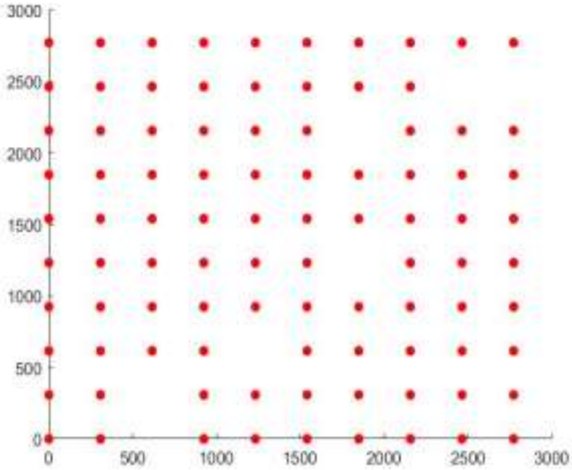

Fig. 2. Optimal Placement of WT for 3000 m x 3000 m Using Static Approach for Assignment of Crossover and Mutation Processes of GA

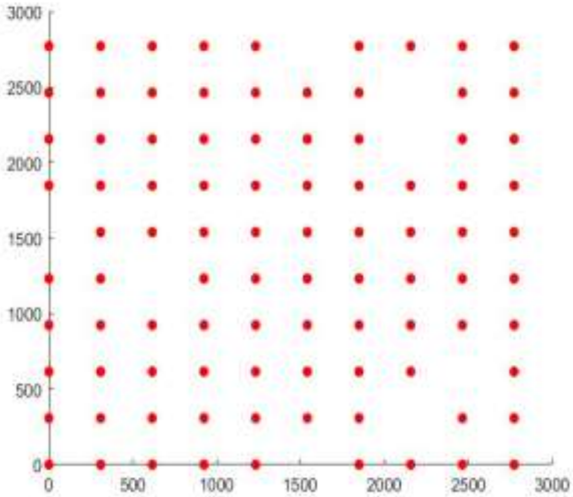

Fig. 3. Optimal Placement of WT for 3000 m x 3000 m Using Proposed Dynamic Approach for Assignment of Crossover and Mutation Processes of GA

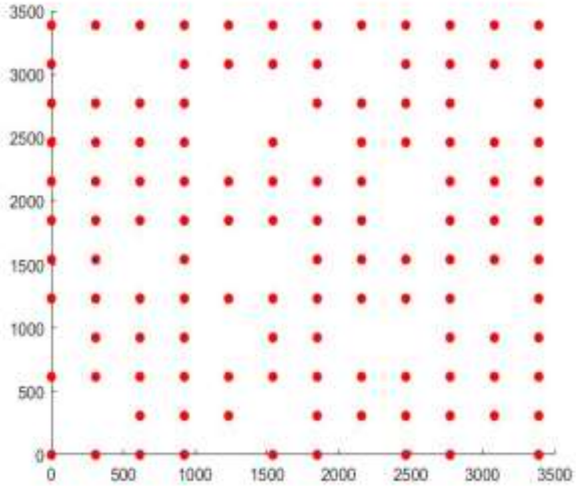

Fig. 4. Optimal Placement of WT for 3500 m x 3500 m Using Static Approach for Assignment of Crossover and Mutation Processes of GA

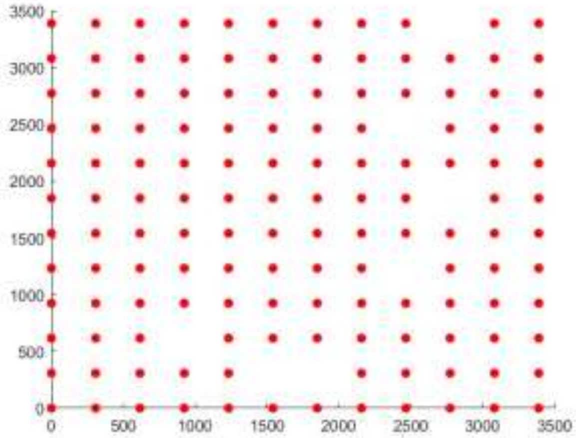

Fig. 5. Optimal Placement of WT for 3500 m x 3500 m Using Proposed Dynamic Approach for Assignment of Crossover and Mutation Processes of GA

A contrast of the optimal yearly profits and number of WTs achieved by all approaches of allocating the chances of crossover and mutation procedures of GA for 3000 m x 3000 m and 3500 m x 3500 m terrain layouts have been shown in Table 2.

TABLE II. THE CONTRAST OF OPTIMAL ANNUAL PROFIT

Approach	*Optimal Annual Profit for 3000 m x 3000 m Layout (in USD)*	*Optimal Number of Wind Turbines for 3000 m x 3000 m Layout*	*Optimal Annual Profit for 3500 m x 3500 m Layout (in USD)*	*Optimal Number of Wind Turbines for 3500 m x 3500 m Layout*
Static	37488	93	49754	120
Proposed Dynamic	38143	92	54803	137

The study results prove the advantage of the projected dynamic approach over the usual static approach for both layouts as it achieved the highest annual profit as designated in Table 2. The consequences also demonstrate that the yearly profit of the projected WPG unit upsurges with the increase of the number of WTs for 3000 m x 3000 m layout. While the annual profit declines with the increase of the number of WTs for 3500 m x 3500 m layout for augmented generation cost.

V. CONCLUSION

Global communities are continually struggling towards the decrease of the carbon tracks by efficient application of renewable resources like wind energy as projected by the Paris treaty and COP-26. Comparative study of conventional static and projected dynamic approaches for appointing the possibilities of crossover and mutation opportunities for the genetic algorithm-based profit expansion for the WPG has been presented in the current work. The optimization consequences verify the improved aptness of the dynamic method over the standard static technique for improving the layouts with the maximum yearly profit. The projected tactic can support the WPG industries to plan a cost-effective wind farm with the realistic contemplation of numerous cost-associated components and variable wind flow conditions. The current study can set off impeccable prospects for wind farm layout optimization and economic sustainability of WPG units which can further aid the worldwide struggle to minimize the discharge of greenhouse gases of the power generation businesses.

ACKNOWLEDGMENT

The first author recognizes the economic assistance offered by the TEQIP section of Jadavpur University.

REFERENCES

[1] Enerdata, "Global Energy Statistical Yearbook," 2020. [Online]. Available: https://yearbook.enerdata.net/. [Accessed 05 September 2020].

[2] "Statistical Review of World Energy," 2020. [Online]. Available: https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html. [Accessed 05 September 2020].

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

[4] International Energy Agency, "The impact of the Covid-19 crisis on clean energy progress," 11 June 2020. [Online]. Available: https://www.iea.org/articles/the-impact-of-the-covid-19-crisis-on-clean-energy-progress. [Accessed 30 July 2021].

[5] 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.

[6] 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.

[7] 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.

[8] 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.

[9] 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.

[10] 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.

[11] S. Şişbot, Ö. Turgut, M. Tunç and Ü. Çamdalı, "Optimal positioning of wind turbines on Gökçeada using multi-objective genetic algorithm," *Wind Energy,* vol. 13, no. 4, pp. 297-306, 2010.

[12] S. Saroha and S. K. Aggarwal, "Multi step ahead forecasting of wind power by genetic algorithm based neural networks," in *2014 6th IEEE Power India International Conference (PIICON)*, 2014.

[13] 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.

[14] F. K. Khosa, M. F. Zia and A. A. Bhatti, "Genetic algorithm based optimization of economic load dispatch constrained by stochastic wind power," in *2015 International Conference on Open Source Systems & Technologies (ICOSST)*, 2015.

[15] H. Shin and K. Lee, "Optimal design of a 1 kW switched reluctance generator for wind power systems using a genetic algorithm," *IET Electric Power Applications,* vol. 10, no. 8, pp. 807-817, 2016.

[16] D. T. Viet, V. V. Phuong, M. Q. Duong and Q. T. Tran, "Models for Short-Term Wind Power Forecasting Based on Improved Artificial Neural Network Using Particle Swarm Optimization and Genetic Algorithms," *Energies,* vol. 13, no. 11, p. 2873, 2020.

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

[18] 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.

[19] 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.

[20] B. Rajeswara Rao and R. Tiwari, "Optimum design of rolling element bearings using genetic algorithms," *Mechanism and Machine Theory,* vol. 42, no. 2, p. 233–250, 2007.

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

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

AUTHOR PROFILE

Prasun Bhattacharjee
Ph.D. Scholar,
Department of Mechanical Engineering,
Jadavpur University.
Work Experience: 3+ years.
Research Experience: 5+ years.
Area of Specialization: Design Optimization, Artificial Intelligence, Renewable Energy Systems.

Rabin K. Jana
Assistant Professor,
Operations & Quantitative Methods Area, Indian Institute of Management Raipur.
Teaching Experience: 13+ years.

Area of Specialization: Optimization,
Artificial Intelligence Techniques,
Machine Learning.

Somenath Bhattacharya
Associate Professor,
Department of Mechanical Engineering,
Jadavpur University.
Teaching Experience: 28+ years.
Area of Specialization: Optimization,
Mechanical System Design, Artificial
Intelligence.