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Research Article

Increasing Annual Profit of Wind Farm Using Improved Genetic Algorithm

Prasun Bhattacharjee*[1] and Somenath Bhattacharya[2]

[1]*Department of Mechanical Engineering, Ramakrishna Mission Shilpapitha, India*
[2]*Department of Mechanical Engineering, Jadavpur University, India*

**(prasunbhatta@gmail.com)*

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Abstract – Wind energy, a prominent renewable source of energy, has expanded rapidly in the past few decades. This paper focuses on raising the yearly profit of a possible wind farm in the Kayathar area of India using an enhanced genetic algorithm. Novel dynamic techniques for assigning the probabilities of crossover and mutation operations have been applied for the genetic algorithm-based optimization method along with the conventional static approach. Non-linear functions have been applied for dynamically allocating the crossover and mutation factors for the genetic algorithm-based optimization process. The analysis outcomes of the proposed technique have been compared with the solutions attained by the genetic algorithm with the standard static approach of allocating the crossover and mutation factors. The evaluation outcomes confirm the superiority of the novel non-linearly incrementing methodology over the non-linearly decrementing and static approach of allocating the crossover and mutation probabilities for attaining a more optimal annual profit.

Keywords – Annual Profit, Dynamic Allocation, Genetic Algorithm, Profit Maximization, Windfarm.

I. Introduction

The unceasing release of greenhouse gases is accelerating climate change and bringing about colossal human torment universally [1]. Renewable resources commend abounding alternates for the energy generation industry in the middle of the augmenting transnational fretfulness for the hindered hoard of conventional hydrocarbon-based fuels [2].

Considering the massive populace of India, it turns out to be exceedingly pivotal to make the most of the renewable resources to manipulate its promising economic structure in a nature-affable way [3]. Right now, India sustains 10.3% of its 377.26 GW all-inclusive established electricity generation competency from wind energy [4]. Wind power is closely 35% cheaper to generate in India while compared to a larger portion of the thermal power generation units and is prospective to encounter an added 7% expense decline by 2022 [5].

The prospect of offshore wind power in southern India was quantified with ENVISAT satellite information collected between 2002 and 2011 [6]. Some feasible sites for offshore Wind Power

Generation (WPG) and their fiscal sustainability have been discussed in a research work conducted in 2014 [7]. In the subsequent year, one more analysis was performed to measure the offshore WPG scope in India utilizing the OSCAT satellite records [8]. Estimation of the offshore WPG potential and minimization of the generation cost in the Indian shoreline zone was undertaken [9]. Wilson et al. [10] applied evolutionary computing methodology for optimizing the WPG expenditure. The WPG site layout has been optimized with the sustenance vector regression directed Genetic Algorithm (GA) and contemplation of involvement among property-owners [11]. In another study, both aground and seaward WPG abilities of India have been explored using a bio-inspired algorithm [12]. A sizeable offshore WPG arrangement for the western coastline of Gujrat was evaluated applying the weather analysis and generation cost was estimated [13]. A binary form of the most valuable player algorithm has been applied for WPG site design for finding the optimal WPG cost [14]. Due to the complexity of the computational procedure, Artificial Intelligence (AI) algorithms have been utilized for wind farm layout optimization problems [15-19]. Although quite a few AI-assisted algorithms have been applied for WPG cost minimization, more novel modifications of the algorithms are yet to be explored for refinement of the optimization process.

The present study aims to maximize the yearly profit of a possible WPG unit in the Kayathar region of Tamil Nadu, India using an improved GA-based optimization tactic. Profit maximization is a vital method to enhance the commercial practicability of WPG projects and aid the green evolution of the electricity generation business in India and abroad. An innovative modification for allocating the probabilities of crossover and mutation has been attempted to optimize the concerned objective. The analysis results have been compared with the same achieved employing standard GA to evaluate its comparative effectiveness.

II. Problem Formulation

The kinetic energy acquired by a Wind Turbine (WT) can be determined as per (1).

$$P = 0.5\rho A\vartheta^3 C_p cos\theta \qquad (1)$$

Where P stands for the engrossed energy, ρ signifies the air density, A denotes the swept area, v symbolizes the inbound wind speed, Cp signifies the Betz limit and θ is the angular yaw fault [20]. WPG businesses can remain economical through consummate manipulating of the generation cost [21]. The existing study is focused to expand the yearly profit of a WPG unit [22]. The objective function has been shown as per (2).

$$f = [S - C] \times P_{overall} \qquad (2)$$

Where f is the annual profit, S denotes the selling price of per unit electricity, C symbolizes the generation cost of per unit wind power and Poverall signifies the wind power generated annually. The WPG cost function mentioned by Wilson et al. [10] for computing the yearly profit and has been presented as per (3).

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

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

$$B = \frac{2}{3} + \frac{1}{3}e^{-0.00174N^2} \qquad (3)$$

Where C_t indicates the primary expenditure of WT. C_s symbolizes the spending for a sub-station. N designates the WT count of the WPG unit and m specifies the number of WT for each sub-station. Com is the annual operative and upkeep price. r designates the rate of interest. y shows the anticipated working lifespan [10]. The airflow pattern of Kayathar has been shown in Fig. 1.

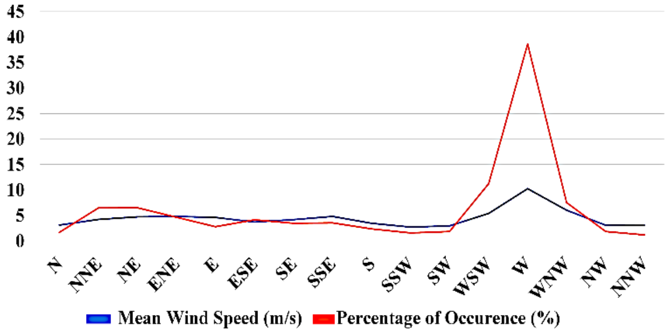

Fig. 1 Airflow Pattern in Kayathar, India

III. Proposed Optimization Algorithm

GA has been exercised in numerous technical fields for resolving decision-constructing conundrums [23-36]. It is a bio-motivated metaheuristic investigating technique to suggest outcomes for optimization analysis by mimicking the advancement of natural preference [37]. The algorithm has been presented as follows [10].

1. Ascertain the fundamental factors such as populace scale, repetition extent, possibilities for crossover, and mutation techniques.
2. Originate the populace unsystematically.

3. Scan the properness of distinct chromosomes.

4. Undertake the crossover procedure in the following manner:

4.1 Pick a numeral arbitrarily between 0 and 1. If it is less than the chance of the crossover method, nominate the parental entity.

4.2 Prompt the crossover activity.

4.3 Review the applicability of the offspring.4.4 If the successor is acceptable, assimilate it into the up-to-date populace.

5. Attain the mutation procedure in the subsequent means:

5.1 Pick a numeral erratically in the middle of 0 and 1. If it is less than the chance of mutation, opt for the entity for the mutation method.

5.2 Begin the mutation method.

5.3 Verify the freshly mutated entities for their viability.

5.4 Unite the mutated and feasible entities into the present populace.

6. Appraise the properness of the novel entities fashioned by crossover and mutation strategies.

7. Specify the most optimized outcome regarding the choice-maker's keenness.

Accompanied by the established scheme of deeming constant values, this research work has applied an innovative dynamic procedure for arranging the ratios of crossover and mutation.

For the Non-Linearly Incrementing Crossover and Mutation Probabilities (NLICMP) procedure, the dynamic crossover probability has been computed using (4).

For the NLICMP technique, the dynamic mutation probability can be calculated by (5).

$$m_{in} = m_{lo} + \{((m_{hi} - m_{lo})/2)(R_{cu}/R_{hi})^2\} \quad (5)$$

Where m_{in} stands for the non-linearly increasing mutation probability. m_{lo} and m_{hi} are the limits of the mutation ratio.

For Non-Linearly Decrementing Crossover and Mutation Probabilities (NLDCMP) technique, the dynamic crossover probability has been computed using (6).

$$c_{de} = c_{hi} - \{((c_{hi} - c_{lo})/2)(R_{cu}/R_{hi})^2\} \quad (6)$$

Where c_{de} signifies the non-linearly decreasing crossover probability.

For the NLDCMP procedure, the dynamic mutation probability has been calculated as per (7).

$$m_{de} = m_{hi} - \{((m_{hi} - m_{lo})/2)(R_{cu}/R_{hi})^2\} \quad (7)$$

Where m_{de} indicates the non-linearly decreasing mutation probability.

The stationary probability of crossover (c_s) has been calculated using (8).

$$c_s = (c_{hi} + c_{lo})/2 \quad (8)$$

The stationary probability of mutation (m_s) has been considered as per (9).

$$m_s = (m_{hi} + m_{lo})/2 \quad (9)$$

IV. RESULTS

GAs have been employed numerous times in the wind farm layout optimization field. They propose a recognizable and accepted standard compared to other optimization algorithms from the domain of evolutionary computing. For the current research work, GA has been utilized to optimize a binary chromosome that chooses to locate a WT in every single grid of the layout. For the current annual profit maximization problem for a proposed WPG site in the Kayathar area of India, two layouts of dimensions of 3000 m x 3000 m and 4000 m x 4000 m have been considered.

The objective of the present study is to maximize the annual profit at the proposed WPG site. In India, the generation price of wind power has remained financially viable and the selling price of wind power in India has been considered as USD 0.033/kWh [38]. Along with the consideration of the conventional static approach, the present study has deemed novel non-linearly varying approaches for allocating the ratios of crossover and mutation methods of GA-based wind farm layout optimization. The values of different parameters related to the considered optimization problem have been shown in Table 1.

Table 1. Values of Parameters Considered for Proposed GA

Parameter	Considered Value
c_{hi}	0.6
c_{lo}	0.4
m_{hi}	0.06
m_{lo}	0.04
Populace Size	20
Maximum Generation Count	50
Tournament Size	4

The specifications of the WT have been presented in Table 2.

Table 2. Turbine Specification

Parameter	Considered Value
Turbine Rated Output	1500 kW
Turbine Blade Radius	38.5 m
Inter-Turbine Space	308 m
Minimum Operating Speed	12 km/hr.
Maximum Operating Speed	72 km/hr.

The wake loss effect is an influential factor for generating the electricity from WT as it degrades the obtainable kinetic energy of the air-stream of the adjacent WTs. To minimalize the detrimental consequence of wake loss, a definite gap is required to be maintained between two adjacent WTs for wind farm layout optimization. The generation cost of wind power has been computed following Wilson et al. [10] for maximizing the annual profit of the wind farm as per (2). The values of the corresponding parameters for calculating the WPG cost have been shown in Table 3.

Table 3. Values of Generation Cost Related Parameters

Parameter	Considered Value
Turbine Cost	USD 750,000 per Turbine
Electrical Sub-Station Cost	USD 8,000,000 per Sub-Station
Number of Turbines per Sub-Station	30
Rate of Interest	3%
Annual Operation and Maintenance Cost	USD 20,000
Expected Operation Life	20 Years

In the current study, terrain layouts of 3000 m x 3000 m and 4000 m x 4000 m dimensions with no obstacles have been considered. The optimal placement of turbines for 3000 m x 3000 m and 4000 m x 4000 m layouts attained by NLICMP, NLDCM, and static approaches for genetic algorithm-based optimization of yearly profit of the proposed wind farm at Kayathar have been shown in Figs. 2-4 and 5-7 respectively.

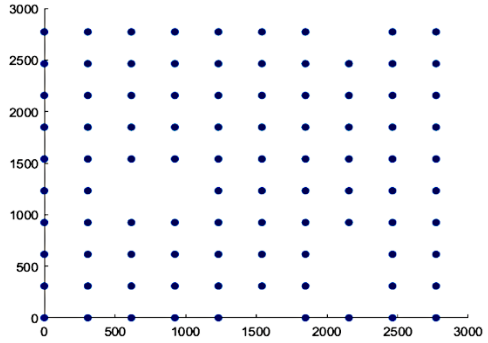

Fig. 2. Optimal Placement of Wind Turbines for 3000 m x 3000 m Layout Using NLICMP Approach

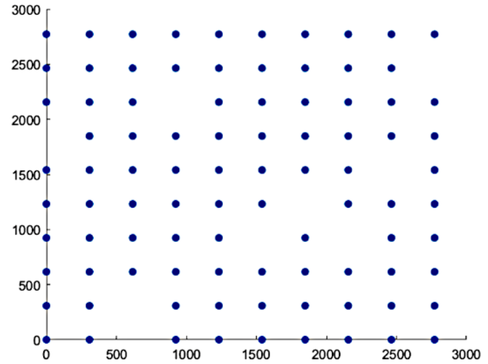

Fig. 3. Optimal Placement of Wind Turbines for 3000 m x 3000 m Layout Using NLDCMP Approach

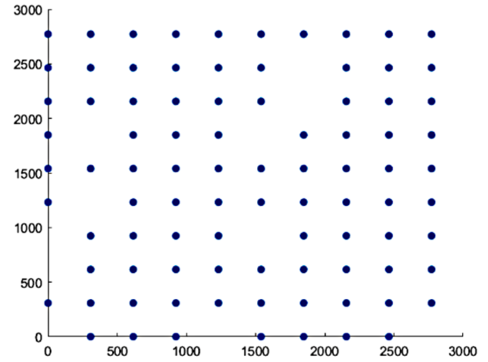

Fig. 4. Optimal Placement of Wind Turbines for 3000 m x 3000 m Layout Using Static Approach

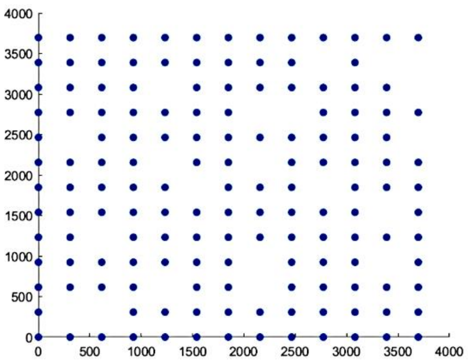

Fig. 5. Optimal Placement of Wind Turbines for 4000 m x 4000 m Layout Using NLICMP Approach

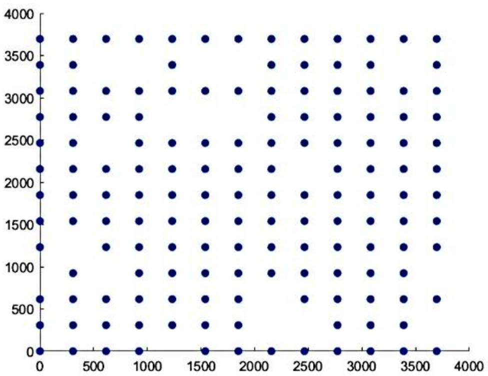

Fig. 6. Optimal Placement of Wind Turbines for 4000 m x 4000 m Layout Using NLDCMP Approach

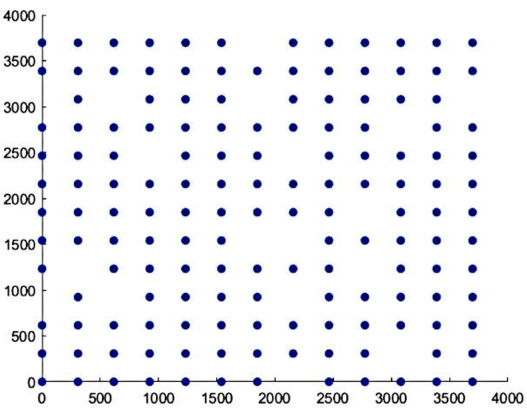

Fig. 7. Optimal Placement of Wind Turbines for 4000 m x 4000 m Layout Using Static Approach

In Figs. 2-7, the optimized locations of the turbines obtained by all considered algorithms have been shown graphically with blue-painted dots.

V. DISCUSSION

The annual profits of the WPG units have been calculated using (2) and (3) with the considered values of Tables 2 and 3. A comparison of the optimal annual profits and number of WTs attained by all approaches of allocating the probabilities of crossover and mutation methods of GA for 3000 m x 3000 m and 4000 m x 4000 m terrain layouts have been presented in Table 4.

Table 4. Comparison of Annual Profits

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 4000 m x 4000 m Layout (in USD)	Optimal Number of Wind Turbines for 4000 m x 4000 m Layout
NLICMP	19257	94	31996	148
NLDCMP	19029	91	31982	150
Static	19074	89	31753	151

The analysis outcomes demonstrate the superiority of the proposed NLICMP approach over the conventional static and NLDCMP approaches for both layouts as it accomplished the uppermost yearly profit as indicated in Table 4. The results also demonstrate that the annual profit of the proposed WPG site increases with the increment of the number of WTs for 3000 m x 3000 m layout. Whereas, the annual profit decreases with the increment of the number of WTs for 4000 m x 4000 m layout for increased generation cost. The expanded profitability of the wind farm permits the improved sustainability of the WPG projects and supports the course of emission regulation for the electricity generation trades. Proficient positioning of WTs through the projected NLICMP tactic can help the WPG businesses to achieve higher financial paybacks without expanding the layout area and avoiding further investment in land resources.

In a GA-based WPG site layout optimization problem for an offshore location in India, the interest in investments and the maximization of annual profit have been disregarded. Whereas the present research considered both crucial financial aspects for better understandability of WPG methodology. Similarly, a major portion of the studies conducted for the WPG site design optimization process focused on either generation cost minimization or annual energy yield and overlooked the financial viability of the WPG farms [39][40]. Even though, Huang [22] applied GA for maximizing the yearly profit of a wind farm, the time-dependent nature of the WPG cost has been overlooked for calculating the yearly profit of the wind farm. Whereas, the current work considered the time-reliant aspect of every component of the investment cost and presented a more reasonable representation of the WPG businesses. Moreover, the realistic consideration of airflow conditions causes a more accurate calculation of the annual profit of the probable WPG farm and contributes to the effectuality of the proposed optimization procedure.

VI. CONCLUSION

International communities are constantly striving towards diminution of the carbon footprints through effective utilization of renewable resources like wind energy as proposed by the Paris agreement and COP-26. This research work focuses on maximizing the annual profit of a proposed WPG unit in the Kayathar area of India for supporting the green changeover of power generation businesses and reducing the carbon footprint. Relative research of conventional static and two proposed dynamic strategies for assigning the probabilities of crossover and mutation proportions for the genetic algorithm-based profit maximization for the WPG has been offered in the existing work. The optimization consequences verify the improved aptness of the NLICMP method over the standard static and NLDCMP techniques for optimizing the layouts with the maximum annual profit. The proposed approach can assist the WPG businesses to design an economically viable wind farm with the pragmatic consideration of various cost-associated components and variable wind flow conditions. The current study can set off immaculate prospects for wind farm layout optimization and fiscal sustainability of WPG units which can further help the international effort to minimalize the release of greenhouse gases of the electricity generation businesses.

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