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Research article

Using Arithmetic Optimization Algorithm to Allocate and SizeWind Energy Systems in RDSs

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Recent years have seen a marked increase in the world's energy needs. Numerous studies have been conducted to examine distributed generation (DG) utilizing renewable energy sources (RESs) in order to address this need. The number of environmental problems that are raised by the usage of traditional power plants is also decreased by these renewable sources. The ideal position and size of the RESs-DG significantly influence the bus voltage profile, power quality, and efficiency of Radial Distribution Systems (RDS) because of power losses. In this study, the use of wind energy systems as a DG source in RDS is investigated. One of the most common RESs used as DG sources, the ideal location and size for wind system, was chosen to demonstrate this enquiry. The goal of this optimization work, which used the Arithmetic Optimization Algorithm (AOA), was to increase system efficiency by minimizing power losses and improving the voltage profile and power quality. Two widely used RDS, including the IEEE 31 and 69 bus systems, have been used to evaluate how well the recommended technique has been implemented. Genetic Algorithm (GA) is offered to examine the efficacy of the recommended AOA. The findings show that the used AOA approach can pinpoint the appropriate size and positioning of a wind farm in order to reduce power loss, enhance voltage profile, and outperform other existing tactics with superiority over GA.

I. INTRODUCTION

In sparsely populated areas, radial distribution systems (RDSs) are often used since they are cheap and simple to build. The systems discussed above use a single power source to provide energy to a number of users, however it's crucial to remember that these systems do have certain restrictions.[1] One of the RDSs's drawbacks is the possibility of power blackouts, short circuits, or broken power lines, which may cause failure in the supply of electricity to the consumers. The resolution of the fundamental problems is a need for the restoration of power system.[2-4] An effective approach to overcoming the difficulties of situating energy production systems near to the demand is using distributed generators (DGs), especially based-renewable energy sources (RESs).[5-8] DGs are technologies that are distributed, flexible, and more adaptable and located near to the load. Reducing the power supplied via the transmission lines increases efficiency by reducing the amount of power lost in the lines and current. One of the key benefits of using DG-RESs is that customers will get reliable, affordable, and environmentally friendly power.[9,10] They may also reduce feeder congestion, increase network reliability, and increase security in addition to reducing power losses and improving voltage profiles and stability.[11,12]

Over the past few years, numerous research works have been carried out to find the DG's optimal location for minimizing the aforementioned objectives by using various optimization techniques, such as mixed-integer linear programming (MILP),[13] analytical methods,[14] Genetic algorithms (GA)[15] and Particle swarm optimization (PSO).[16] Optimal location for wind energy conversion systems as DG in IEEE 30bus system using PSO was presented in.[17]

Diversifying the sources of electricity production is facilitated by the use of wind energy into power networks. This lessens reliance on conventional fossil fuels and increases the electricity grid's robustness.[18] A clean and eco-friendly energy source is wind power. Wind energy contributes to energy security by offering a domestic and locally accessible source of power, reducing carbon dioxide and other greenhouse gas emissions, and reducing the effects of climate change. The size of wind-generating facilities may range from modest, dispersed setups to enormous utility-scale wind farms.[19] The flexibility of integration into power systems depending on local demands and resource availability is made possible by this scalability. The manufacturing, installation, and maintenance industries are all supported by the wind energy industry. In addition, wind projects often stimulate local economies in areas where wind farms are built. Increased energy collection and cost-effectiveness are benefits of ongoing improvements in wind turbine technology, such as the development of bigger, more efficient tur-

List of abbreviations

AOA	Arithmetic Optimization Algorithm
C_{Iter}	Current iteration between 0 and 1
DG	Distributed Generation
GA	Genetic Approach
LBj	Lower bounds of the jth place.
VSI	Voltage Stability Index
⌦	Little integer
MOA	Math Optimizer Accelerated
MILP	Mixed-integer linear programming
UBj	Upper limits of the jth position
μ	Control variable with a value of 0.5
PSO	Particle swarm optimization
RDSs	Radial distribution systems
RES	Renewable energy sources
V_i	Voltage magnitude at each bus
$V_{i,ref}$	Reference voltage magnitude at each bus
V_{min}	Min acceptable voltage magnitude
V_{max}	Max acceptable voltage magnitude
Ps	Main generator real power
P_{loss}	Total Power losses
P_{L_loss}	Power losses at each line
P_L	Load demand real power
Qs	Main generator reactive power
Q_L	Load reactive power

bines. Storage technology advancements further increase the dependability of wind energy.[20]

One of the most effective renewable energy sources, wind, has a relatively large capacity and generating costs that are comparable to those of conventional energy sources.[21] Due to its technological, financial, and environmental advantages, distributed renewable generation is widely deployed. Efficiency, grid strengthening, dependability, power loss reduction, and improved voltage profile are some of the technical benefits.[18-21] In the past, the performance of wind systems as DG was assessed using the chronological simulation approach.[22] These methods need a lot of time series data on wind speed, but such data is rarely accessible. In order to estimate wind turbine and load, a probabilistic technique was created[23] by treating wind speed and load as random variables. To find the best capacity and placement of DG units based on renewable resources in the distribution system and reduce yearly energy loss, a MILP-based technique was elaborated on.[24] These techniques, however,[25,26] did not take into account the relationship between load and renewable resources. To demonstrate the efficiency of this technique, it was put to use on a standard 70-bus test system. In order to position DG units for the best power loss reduction and voltage stability enhancement of the distribution network, Kayal et al. suggested a multi-objective restricted PSO based solution.[27] In this study, radial distribution networks of 12 buses, 15 buses, 33 buses, and 69 buses were used to test the DG placement strategy. To demonstrate how different kinds of wind turbine generating units may be employed as DGs for load flow analysis of radial distribution systems, Divya et al. created a model.[28] This method was used on a 33-bus radial distribution system with supplies from wind system and DG.

Using PV and wind turbine systems as a DG was presented and discussed in.[29] This study presents an approach for determining the ideal position in a RDS on a newly developed voltage stability index (VSI) using PSO and GA. Another investigation of the optila location of RES-Dg with three types Type I, II and III was elaborated in.[30] An improved whale optimization approach for restructuring RDS that chooses the best switch combination under system operational restrictions was presented in.[31] The mine blast technique is used to deduce the appropriate sizes and placements of capacitors from the chosen busses in RDSs in.[32] Additionally, this approach has been introduced for determining the ideal location and size of renewable energy sources.[33]

In the study conducted by,[34] the goal function of minimizing power loss was used to determine the optimal DG in a RDS using GA. However, the analysis primarily focused on reducing power loss, without considering additional goals such as voltage level enhancement or system stability. This research study also did not compare the findings with other optimization techniques. PSO algorithm was used to determine the optimal placement of DG in a RDS.[35] This work focused on DG types rather than RES methods. The primary purpose was to minimize losses, without considering other objectives. The Ant Colony Algorithm was presented in a RDS to find the best location for conventional DGs.[36] DGs-RES was not used for environmental issues, nor were the criteria for system reliability taken into account.

The aforementioned algorithms exhibit many limitations, notably the prevalence of local optimality and the need for substantial computational resources during simulation. These drive the author of the current study to develop a novel, simple, effective, and quick population-based optimization approach to address the best placement of wind energy systems as A DG in RDS. To the author, the implementation of the AOA has not been previously explored to determine the optimal placement and sizes of wind energy systems (as a DG source) in RDSs. AOA is attributed to its efficacy using this new optimization technique, demonstrated by surpassing the performance of twelve other optimization techniques over twenty-three test functions and five engineering design issues, as reported in.[37]

To reduce the energy loss in RDS, the author of this research utilized the AOA technique for IEEE 30 bus RDS. The results show that the AOA algorithm is effective, quick to converge, and competent to manage complex power system networks when compared to GA. In addition, the VSI has been conducted for all RDS in this study.

II. OPTIMAL ALLOCATION PROBLEM FORMULATION

Utilizing the created objective charge function, power losses are decreased while voltage profiles and the voltage stability index are improved. The objective charge function may be solved by integrating three objectives, namely F_1, F_2, *and* F_3, leading to the best identification of wind system sites and their corresponding capabilities.[3] Actual losses, voltage profiles, and VSI are correlated with F_1, F_2, *and* F_3, respectively. These three functions are added together to form the objective function.

$$F_1 = \frac{\sum_{n=1}^{k} P_{loss}(n)_{with\,WT}}{\sum_{n=1}^{k} P_{loss}(n)_{without\,WT}} \quad (1)$$

F2 may be derived as such and allows for voltage profile improvement.

$$F_2 = \frac{\sum_{n=1}^{N} |V_i - V_{i,ref}|_{with\,WT}}{\sum_{i=1}^{N} |V_i - V_{i,ref}|_{without\,WT}} \quad (2)$$

This study examines the enhancements made to the voltage stability index (VSI), which may also be referred to as:

$$F_3 = \frac{1}{VSI_{with\,WT}} \quad (3)$$

The primary aim of this study is to minimize the objective function Ft, which is defined as the summation of three distinct functions, each multiplied by their respective weighting factors $\propto_1$, $\propto_1$ *and* $\propto_3$.

$$F_t = \propto_1 F_1 + \propto_1 F_2 w_2 + \propto_3 F_3 \quad (4)$$

According to reference,[3] it is possible for the cumulative weight values given to each individual effect to be equivalent to one. Numerous attempts were undertaken to establish the criteria above. The optimal values of three weighted parameters were examined and analyzed, considering several configurations of these parameters. It was determined that $\propto_1$ should have a higher value compared to the other two parameters $\propto_2$ and $\propto_3$namely 0.5, 0.1, and 0.4 as mentioned and reported in.[3,38]

The objective function given in (4) is optimized and the optimization should fulfill the following equality and inequality constrains:

- The total input and output real and reactive powers flow across the RDS may be equal that can be expressed as:

$$P_S + \sum_{i=1}^{N_{DG}} P_{DG}(i) = \sum_{i=1}^{L} P_{L_loss}(i) + \sum_{q=1}^{N} PL(q) \quad (5)$$

$$Q_S + \sum_{i=1}^{N_{DG}} Q_{DG}(i) = \sum_{i=1}^{L} Q_{L_loss}(i) + \sum_{q=1}^{N} QL(q) \quad (6)$$

- The voltage at every node must range in the standard acceptable limits as:

$$V_{\min} \le |V_i| \le V_{\max} \quad (7)$$

To prohibit inverse power flow, the installed size of the DG in the grid has been restricted so as not to overtake the power provided by the substation.[3,10]

The present investigation presents the Application of AOA as a strategy for reducing the objective function. The achievement of this objective involves considering many limitations, including the balance of power between the generated power and the power requested by the load, acceptable limits for voltage, and restrictions on the rating of the wind.

III. OPTIMIZATION ALGORITHMS

1. ARITHMETIC OPTIMIZATION ALGORITHM

The main source of inspiration for the proposed AOA is using arithmetic operators to resolve arithmetic problems, as shown by previous studies.[39,40] The AOA optimization process consists of two distinct stages, namely exploration and exploitation. To mitigate the occurrence of localized solutions, the search agents of an algorithm engage in exploration throughout a substantial region of the search space. Exploitation refers to the process of enhancing the precision of solutions discovered during the discovery phase. This study will examine the behaviors and consequences associated with arithmetic operators, including multiplication, division, addition, and subtraction.

Prior to the initiation of the AOA, it is essential to choose the appropriate search phase, which involves making a decision between exploration and exploitation. The Math Optimizer Accelerated (MOA) function is a coefficient that is derived from:

$$MOA\,(C_{Iter}) = Min + C_{Iter} * \left(\frac{Max - Min}{M_{Iter}}\right) \quad (8)$$

Subsequently, MOA is used in the subsequent phases of the search process.

The formula MOA represents the function value at iteration t, calculated by equation (4).

The variable C_{Iter} represents the current iteration, which may take on any integer value between 1 and the maximum allowable value. The terms “Min” and “Max” are used to represent the minimum and maximum values of the accelerated function, as shown in references.[39,40]

$$xi, j\,(C_{Iter} + 1) = \begin{Bmatrix} \frac{best(xj)}{MOP + \epsilon} * ((UBj - LBj) * \mu + LBj) \\ best(xj) * MOP * ((UBj - LBj) * \mu + LBj),\ otherwise \end{Bmatrix} \quad (9)$$

The symbol $xi, j\,(C_{Iter} + 1)$ represents the jth element of the ith solution in the current iteration. Furthermore, the symbol *best(x j)* represents the jth position in the solution that has been identified as the most optimal so far. The control parameter μ is given a value of 0.5 in order to adjust the search method.

The numerical representation of the MOP (C_{Iter}) is equivalent to the integer value of 1. The above statement may be reformulated as the quotient obtained by raising C_{Iter} to a certain exponent.

The sensitive parameter α, which plays a crucial role in determining the degree of accuracy in the process of exploitation throughout several iterations, has been assigned a value of 5 in this particular scenario. The operators of AOA, namely Subtraction and Addition, are used to systematically investigate the search area at many densely populated locations and using various techniques, with the aim of discovering an enhanced answer. The operators are

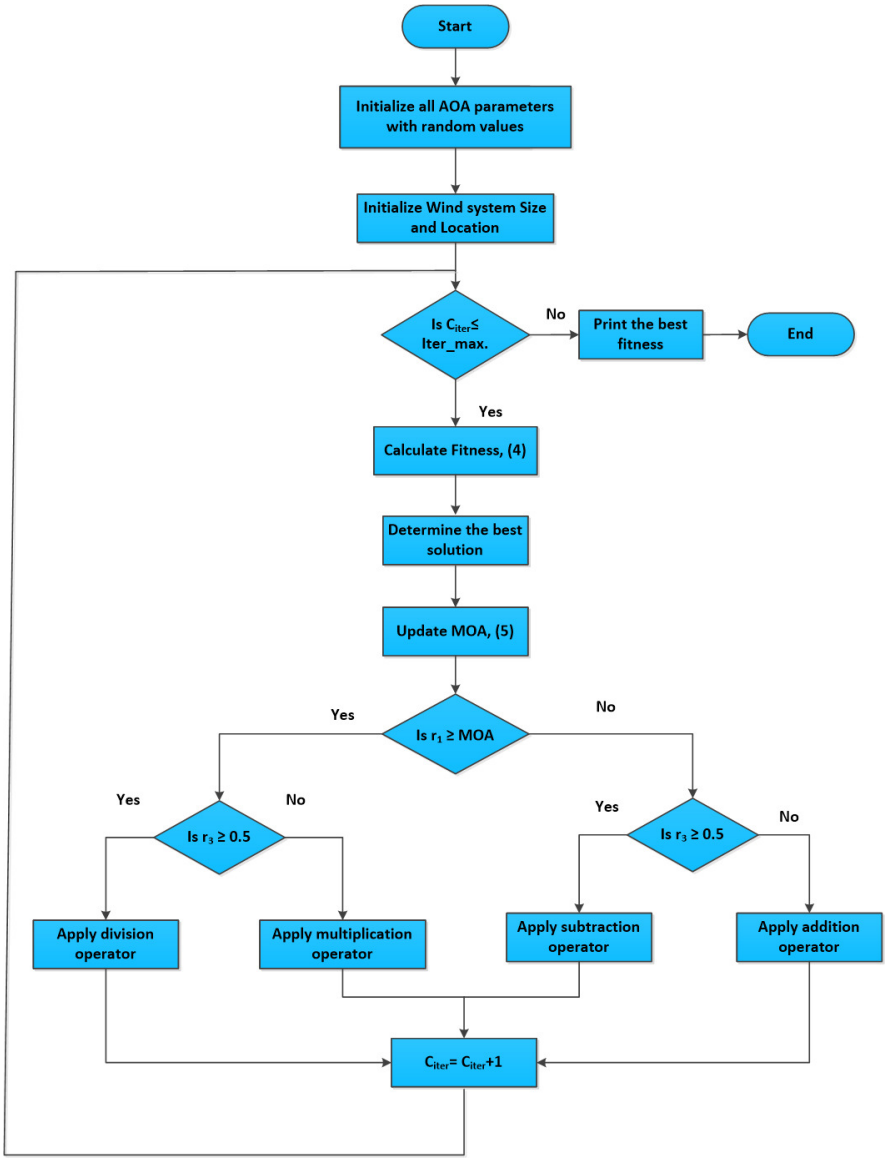

Fig. 1. Flow chart of AOA

shown using two fundamental search strategies. Figure 1 presents a flow chart that depicts the recommended strategy of the AOA for the optimization of the multi-objective function Ft.

The particular features and specifications of the current optimization problem determine the selection of the suitable representation, fitness function, and operators. In this work, GA is used to compare and assess the efficiency of the AOA approach in resolving the relevant multi-objective optimization problem.[41,42]

2. GENETIC ALGORITHM OPTIMIZATION

GA is a widely utilized optimization technique that draws inspiration from the principles of natural selection. The technique is employed to identify approximate solutions to optimization and search problems. GA started by setting the initial values or conditions for a system. The initial step involves generating a population of potential solutions, which can be achieved by a random selection process or by employing a heuristic method. Every member of the population serves as a potential solution to the optimization problem. Assessing the physical condition of every member inside the population is then performed through determining the fitness function. A person's degree of fitness is taken into account when selecting them from the current population. Greater physical fitness increases a person's likelihood of selection or favoritism. Various selection methods commonly employed in evolutionary algorithms include roulette wheel selection, tournament selection, and rank-based selection. The Pseudocode code of GA is shown in Figure 2,[43] [44].

In this work, GA is used to compare and assess the efficiency of the AOA approach in resolving the relevant multi-objective optimization problem.[41]

The GA is a commonly employed optimization tool that is derived from the principles of natural selection. It is well recognized in numerous engineering applications and re-

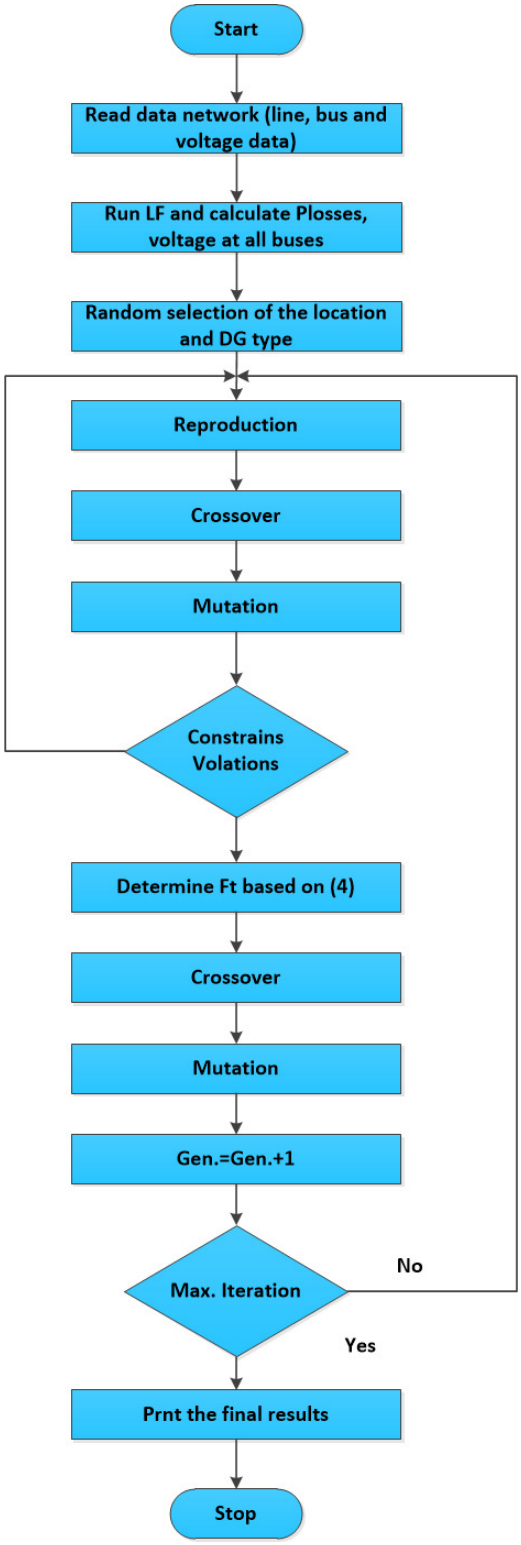

Fig. 2. GA Flow chart

garded as the standard for evaluating optimization techniques.

IV. RESULTS AND DISCUSSIONS

This study examines the effectiveness of the AOA method in identifying the most suitable placement and capacity of wind energy systems as DG units. The investigation is conducted using the IEEE 31 and 69 RDSs. The technique was devised via the MATLAB software.

A. CASE STUDY 1 IEEE 31 BUS SYSTEM

This work aims to thoroughly study the results associated with IEEE 31 bus RDSs shown in Figure 3. This study aims to implement a singular wind system while ascertaining the optimal dimensions and placement for its installation. The determination is achieved by minimizing the multi-objective function, denoted as equation (4).

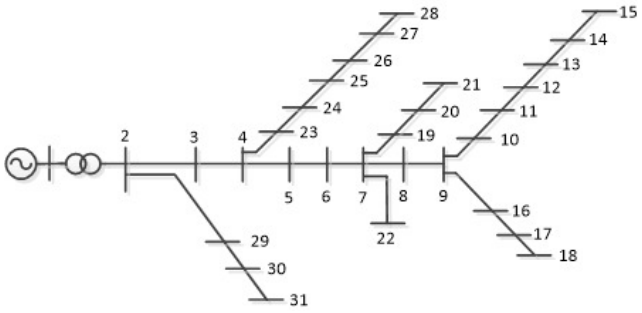

Figure 3. IEEE 31 bus system

The consequences found for the basic case scenario without adopting wind system are shown in Figure 4, which is spitted into two figures to clearly show the voltage profile. The recorded lowest voltage value was seen at bus 31, a phenomenon that may be reasonably ascribed to its relative distance from the main feeder.

The voltage profile was improved by integrating the DG unit into the system, following the goal function described in equation (4). This improvement was achieved by the use of two optimization approaches, namely GA and AOA). Significantly, the AOA exhibited a more prominent enhancement in the voltage profile, as seen in Figure 4.

The optimal placement of the DG unit in the IEEE 31 bus system was determined to be at buses 7 and 8, respectively while using GA and AOA techniques. Notably, AOA exhibited lower DG ratings in comparison to GA. Although the rating is lower, the voltage profile is enhanced compared to the GA, although with a decrease in the total power losses. Table 1 displays the findings obtained for the IEEE 31-bus system. The power losses were recorded at 26.36 kW when the wind system was not integrated. However, after the wind system was integrated utilizing AOA and GA optimization approaches, the power losses were reduced to 8.7 kW and 12.6 kW, respectively. The ideal placement of the wind system was determined to be at bus 7, with a power rating of 355 kW, when employing the GA approach. In contrast, while considering AOA a power rating of 400 kW, the optimal site was at bus 8.

B. CASE STUDY 2: IEEE 69 NODE

Another testing method is used to assess the effectiveness of AOA in accurately determining the size and position of the DG unit. The IEEE 69 bus system, shown in Figure 5, is utilized for this purpose.

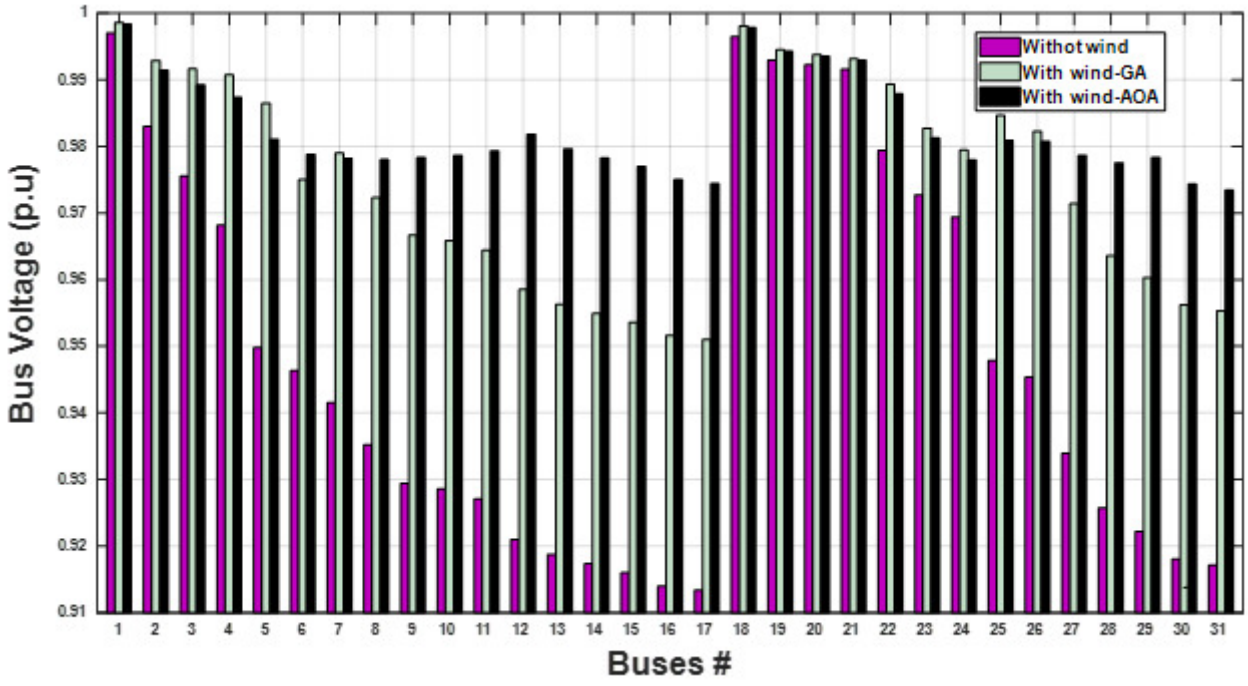

Fig. 4. Bus voltage with and without wind for 31 bus system

Table 1. Outcomes for IEEE 31-bus system.

Parameter	Without Wind	With Wind	
		PSO	AOA
Losses (kW)	26.36	12.6	8.7
Loss mitigation (%)	---	52	67
Wind energy (DG) location	--	Bus #7	Bus #8
Wind energy (DG) ratings kW	--	335	400
VSI	25.6	28.2	31

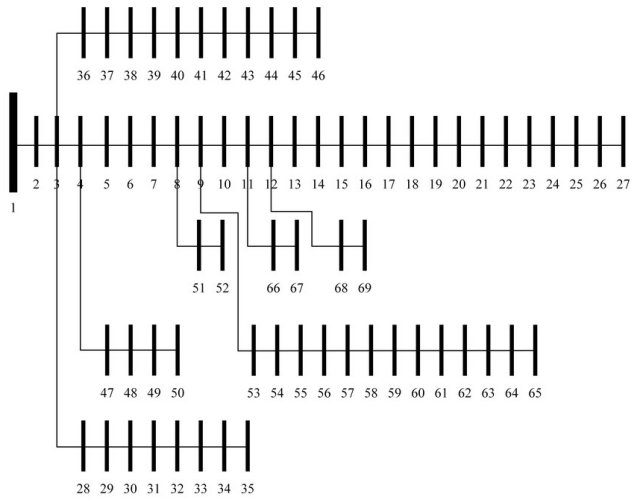

Fig. 5. IEEE 69 bus system

By including the DG unit in the system and using the objective function shown in equation (4), the voltage profile was improved. The use of two optimization techniques, namely GA and AOA, led to this improvement. Importantly, the voltage profile showed a much-pronounced elevation in the AOA, as seen in Figure 6.

Using the GA technique, it was found that bus 61, with a wind power rating of 1920 kW, was the best location for the wind system in the IEEE 69-bus system. On the other hand, bus 55 was identified as the ideal location when the wind power rating of 1887 kW was taken into account using the AOA algorithm. When the wind system was not integrated, 62.4 kW of electricity was lost. Nevertheless, the power losses decreased to 31.5 kW and 28.2 kW, respectively, once the wind system was incorporated using GA and AOA optimization techniques. The findings are given in table 2.

V. CONCLUSIONS

This article showcases the effective use of the AOA in the process of selecting suitable locations and determining ratings for a wind system as a DG unit within different RDSs. The formulation of the process design has been approached as an optimization issue, whereby the calculations of power losses, voltage profiles, and VSI have been included. The outcomes derived from the AOA methodology have been juxtaposed with those achieved via the use of the GA technique. The analysis demonstrates that the developed method significantly benefits bus voltage profile, power losses, and yearly cost reductions. The AOA was assessed using two commonly used systems, namely the IEEE-33 and 69 bus systems. The AOA was able to determine the optimal size and position for the wind system, resulting in a de-

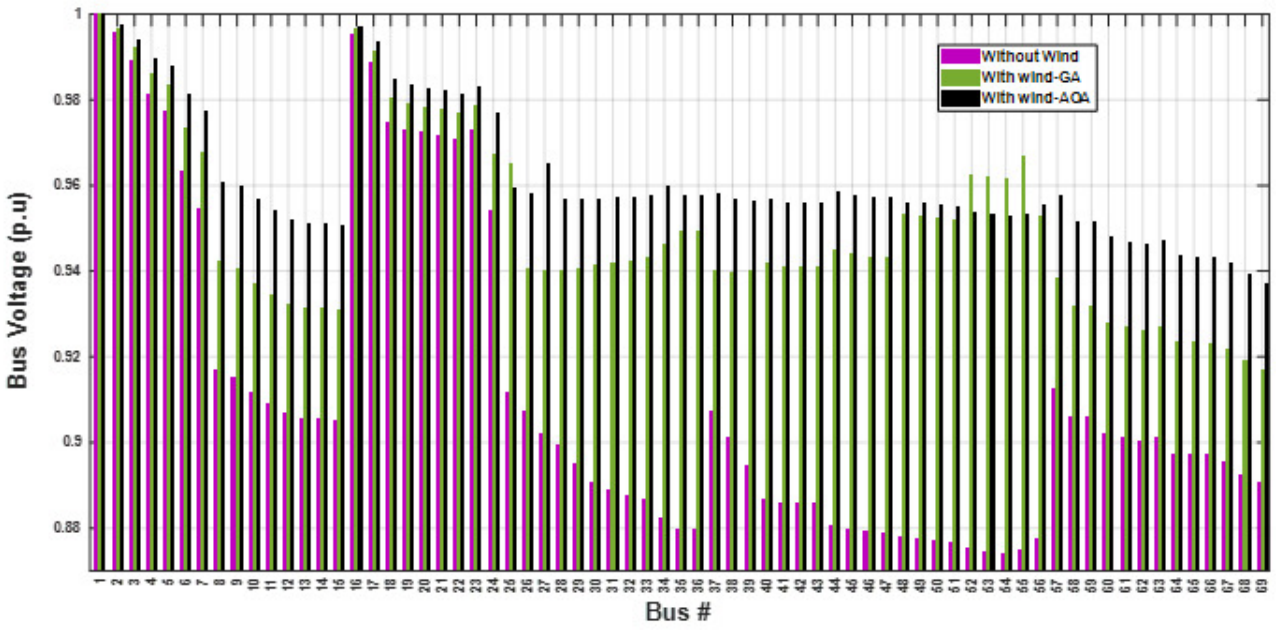

Fig. 6. Bus voltage with and without wind for 69 bus system

Table 2. Outcomes for IEEE 69-bus system.

Parameter	Without Wind	With Wind	
		GA	AOA
Losses (kW)	62.4	31.5	28.2
Loss mitigation (%)	---	49	55
Wind location	--	**Bus #61**	**Bus #55**
Wind ratings kW	--	1920	1887
VSI	36.2	42	44

crease in losses by 67% and 55% when compared to the GA approach, which achieved reductions of 52% and 49% in the IEEE 33 and 69 systems, respectively. The AOA has the potential to provide superior VSI compared to GA .

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Appendix: AOA and GA intial parameters

	Initial parameters	Value
AOA	Arithmetic min accelerating value	0.2
	Arithmetic max accelerating value	1
	sensitive parameter α	5
	control parameter μ	0.5
	Parameter r1	[0,1]
GA	Population size	50
	Number of generations	100
	Crossover rate	0.8
	Mutation rate	0.01