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Optimal placement of wind generation units in order to increase revenues and reduce the imposed costs in the distribution system considering uncertainty

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ABSTRACT

Recent advances in the field of new energies such as wind turbines, solar power plants, fuel cells, micro-turbines, etc., and also the great benefits of these power plants for the power network, attract the attention of distribution companies towards them. As, today, many distribution companies are examining options for changing the distribution network structure in order to exploit new energies. In the meantime, wind energy is one of the most widely used types of distributed generation in the power network. In addition, wind power generation has the most changes to other types of renewable energy. Distribution network planning is one of the major concerns of system designers, especially when wind generation units by their random and variable nature are in system development. Since the proper placement of wind units in the network plays an essential role in improving the performance of the distribution network, providing a comprehensive and appropriate solution for placement of these units in the network is important. In this paper, a method has been presented that by considering the uncertainty in generation and consumption and the network constraints, the placement of wind units in the network is done with the aim of increasing revenues and reducing the imposed costs in the distribution system, taking into account the uncertainity. The algorithm used in this paper is a genetic algorithm with improved operators.

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1. INTRODUCTION

In the structured electricity industry, once in a while, we need to change and re-formulate the system, although our main destination may still remain unchanged. In a power system, variety of targets must be met at the same time in order to exploit a system optimally and efficiently. Today, factors such as the need for higher flexibility of power systems, changes in the economic contexts and structures of the electricity industry, the need to save and manage energy consumption, and environmental issues, have created a greater incentive to foster and develop Distributed Generation. For this reason, distributed generation will play a major role in the development of power systems in the near future. One of the most widely used types of distributed generation is wind energy, due to its lower cost than other types of renewable energy plants, as well as its many advantages over the last few decades. Given the high potential of our country to exploit this energy and in order to use these resources efficiently, we need to understand the conditions of the power network.

Mainly the configuration of distributed networks is radial, that is, power is flowing in one direction, and the last users of low or medium voltage networks are fed using simple security models that provide a reliable and acceptable level of performance for such networks. By expanding the dimensions of using distributed generation in a continuous network and changing the network templates from passive to active mode, the conditions are gradually changing. For example, the need for a new control algorithm to quickly re-configure the network and the use of secure communication systems to implement such a goal seems necessary.

It should also be noted that if wind units are correctly programmed, they will bring many benefits to the power network, including reducing losses, improving the voltage profile, increasing system reliability, reducing environmental pollution along with economic justification and cost reduction. If the distribution company is allowed to use its products, then the use of wind units can be an appropriate option to save costs and improve the quality of service to customers. If only the private generation units are allowed to be produced, the distribution company can determine the system planning for load forecasting to identify existing capacities and allocate them to investors who want to install the unit in the right places on the network. In this way, distribution companies with achievements such as improving the voltage profile or reducing network losses will allow network development with the least cost.

In case of the justified use of wind power plants in order to respond to load growth in the network, these units must be installed in such a way that they can be more economical and functional. There are factors such as selecting the location of installing distributed generation units, the capacity of installing units, investigating the anemometry statistics of the region and etc. In this way, the first and most fundamental factor that will attract the attention of engineers and designers after the feasibility of the installation of wind units in the network is the locating problem of these units and determining the optimal capacity of their installation in the network to meet the maximum network needs, and enjoy the economical benefit of the same projects.

So far, various studies have been proposed to address the problem of placement in different situations and by identifying the different goals in the problem situations, each of which can be classified according to the used algorithm or the considered goals in the problem. The proper location of DG units in existing distribution systems plays an important role in improving system performance. Therefore DG's optimal placement is one of the most important aspects for DG planning.

In [1], the placement of the wind unit on the distribution network is based on the proposed load distribution and PSO methodology. The placement is only for one of the network buses and in order to reduce losses. The uncertainty of generation and consumption is also not addressed in the problem solving.

In [2], the placement is solved with the aim of reducing the losses and relying on the method of sensitivity coefficients. Placement is made for one of the network busses. It should also be noted that the method of sensitivity coefficients is not sufficiently precise as the problem becomes larger and more complicated, and in practice it will lose its effectiveness compared to other methods.

In [3], the placement of generation units is made in order to reduce losses and with the clustering of buses in the network. Although the bus clustering in the network decreases the accuracy of the problem but helps in faster resolution and convergence by reducing the problem size in smaller categories. The uncertainty in the generation of wind units has been partially achieved by obtaining the parameter c in the Rail function and assigning a probability vector to the wind speed. The numerical solution method is the problem of genetic algorithm method.

In [4], the placement of generation units has been solved by considering several goals and mentioning them in terms of the network's imposed and useful costs. The overall goal is to increase the benefits of installing wind units on the network. In this regard, taking into account the cost of building and supporting wind units as the imposed costs and the benefits of reducing losses and reducing the greenhouse effect, and also the profit from not purchasing energy from the power network is intended to increase the profits of installing the relevant units. Uncertainty in the generation of units in this problem is modeled using the capacity coefficient of sample wind units. Uncertainty in consumption is not considered in this paper. The PSO is also the optimization algorithm to obtain answers, and generation planning has been made for different time periods.

Under the limitations of the total power penetration of DG, Kim et al. [5] and Gandomkar et al. [6] used the Hereford Ranch algorithm to reduce system losses. For the same purpose, Griffin et al. [7] provided an iterative technique for determining the optimal placement of DG units in the power network. Nara et al. [8] introduced Tabu's search method to determine the DG unit location in the distribution system to minimize system losses. In [9, 10], an iterative method has been used to locate DG units in the distribution system. They used the voltage sensitivity and loss sensitivity analysis of power distribution equations to identify the best places to locate DG units in the distribution system. In [11] an exploratory approach is proposed for investment planning scheduling of DG capacity in the field of competitive power market.

The optimal location of DG units is obtained from the perspective of a distribution company using cost-benefit analysis. In order to minimize system losses, Rahman et al. [12] provided evolutionary techniques for determining the optimum DG power.

Therefore, the investigations show that there is considerable work in the placement of DG units in the distribution system; however, many of the presented work assume that DG outputs are dispatch able and controllable. The proposed methods cannot model the disconnecting nature of the output power. Only a small number of sources [13-16] considered uncertainty as the output of DG units. However, in [13], authors only determine the optimal placement of DG units and DG size is not optimized. In [14, 15], some technical limitations such as the size of DG units and the maximum level of DG penetration have been ignored. Hence, the issue of optimizing the placement of renewable DG units in the distribution system still needs attention. In [13], an analytical method is proposed for optimal DG placement in radial distribution systems in order to minimize power losses. The proposed technique considers different types of load profiles with time variable and DG output. Due to technical limitations such as feeder capacity limitation and feeder profile, in [17] the genetic algorithm (GA) has been used for optimal placement of DG units in the distribution system. To investigate, the impact of the uncertainties related to the penetration and protection of DG, Celli and Pilo in [14] and Carpinelli et al. in [15] have used decision theory based on heuristic optimization algorithms. In [16], the problem of placement has been solved with the aim of reducing losses in the distribution system. Uncertainty in generation and consumption is considered. The problem is solved by nonlinear programming method.

The analysis of generation units is not merely an economical method to reduce the cost of casualties. Since, besides its advantages over the period that have been considered for the return of capital to wind units, it should reduce the total imposed costs on the distribution company. In this paper, this Profitability is done in a moment and only in the form of load distribution. In addition, the nonlinear programming method is low on speed, which by increasing the network size will be more likely to be found.

In this paper, we try to provide a comprehensive approach to solve the problem of placement and determining the capacity of wind units in the network. The proposed methodology is expected to address the proposed method will address the shortcomings in other methods ranging from consideration of uncertainties in generation and consumption, taking into account the prospects of environmental development and expression of the elements contributing to problem solving in the form of economic quantities. The used algorithm in this paper is a genetic algorithm, which is used by optimized operators to improve its convergence speed.

In the second part of this paper, modeling of uncertainties has been studied. The objective function and problem constraints are expressed in the third part. In Section 4, optimization algorithm for problem solving is described briefly. The simulation results are presented in the fifth section and the responses are compared with other references and its superiority over other references is presented. Finally, at the end of this article results are presented in Section 6.

2. UNCERTAINTIES MODELING

2.1. Generation uncertainty

The primary requirement for wind power units to generate energy is the blowing of wind to extract the power it has. Since the wind and its intensity are not precisely predictable, the output of wind turbines cannot be expressed conclusively and continuously. Therefore, the output power of the generation units in a one-year period is estimated based on the statistical information obtained from the weather forecast and the anemometer statistics of the region.

Wind statistic data are usually estimated using the Weibull probability distribution function. In this way, the multi-year statistics related to the anemometer of the given region are adapted to the Weibull function, thus extracting the corresponding coefficients. The formula for the Weibull function is as follows [18]:

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{1}$$

Where k is the edge parameter and c is the scale parameter. By using this function, the probability of wind blow at a certain speed has been continuously available at a given interval.

The function curve for k = 2 is a good option for wind turbine installation. So that in a wider range has a wind speeds with a proper power and within an acceptable range has low speeds. In fact, such a rule is the norm for choosing the places that are prone to install wind turbines.

By choosing k = 2, the Weibull function is simplified as follows, which is known as the Riley probability distribution function, and this function forms the basis of the annual energy generation of a wind unit.

$$f(v) = \frac{2v}{c^2}\exp\left[-\left(\frac{v}{c}\right)^2\right] \quad (2)$$

The only adjustable parameter in this probability function is the parameter c in order to adapt to the environmental characteristics of the wind.

The increase in c in the Riley function causes the curve to move toward higher wind speeds, and thus, the average speed becomes higher. In fact, there is a direct relationship between c and the wind velocity, which can be obtained in the form of (3):

$$\bar{v} = \int_0^\infty v\,.f(v)dv = \int_0^\infty \frac{2v^2}{c^2}\exp\left[-\left(\frac{v}{c}\right)^2\right]dv = \frac{\sqrt{\pi}}{2}c \cong 0.886c \quad (3)$$

Or can be written in another form:

$$c = \frac{2}{\sqrt{\pi}}\bar{v} \cong 1.128\,\bar{v} \quad (4)$$

Therefore, we can show Riley's function as follows:

$$f(v) = \frac{\pi v}{2\bar{v}^2}\exp\left[-\frac{\pi}{4}\left(\frac{v}{\bar{v}}\right)^2\right] \quad (5)$$

Average wind speed in the region can be achieved statistically by means of cheap anemometer tool and during a particular period. Given the average velocity and the assumption that the atmospheric profile is compatible with the Riley function, we can calculate the power produced by the wind turbine. First, the average cube of wind speed was calculated as follows, and then, given the equation c and wind speed, the average generation power was obtained.

$$(v^3)_{avg} = \int_0^\infty v^3\,.f(v)dv = \int_0^\infty v^3\,.\frac{2v}{c^2}\exp\left[-\left(\frac{v}{c}\right)^2\right]dv = \frac{3}{4}c^3\sqrt{\pi} \quad (6)$$

$$\bar{P} = \frac{6}{\pi}\,.\frac{1}{2}\,\rho A\bar{v}^3 \quad (7)$$

In some articles, this value is used as the continuous capacity of a wind unit [19]. Some of the references provide a more realistic form of generation by randomly determining the C coefficient in the Riley function through the mean wind speed information and taking into account some uncertainty. In reference [3], the C coefficient of the Riley function is obtained using the mean wind speed. Then, the wind speed is given by the formula and the probability distribution vector H, which is randomly assigned.

$$v = c_m\left[\ln\left(\frac{1}{1-H}\right)\right]^{0.5} \quad (8)$$

In this way, the power output of the wind turbine in terms of nominal power and the upper and lower wind speeds are obtained as follows:

$$P_s = \begin{cases} 0 & 0 \le v_{ave,s} \le v_{ci} \\ P_r \times \frac{v_{ave,s}-v_{ci}}{v_r-v_{ci}} & v_{ci} \le v_{ave,s} \le v_r \\ P_r & v_{ci} \le v_{ave,s} \le v_r \\ 0 & v_{co} \le v_{ave,s} \end{cases} \quad (9)$$

P_s is the power of the turbine output in s state.
$v_{ave,s}$ is the average wind speed in s state.

P_r is the nominal power of the turbine that can be delivered at the nominal speed range of v_r and the maximum tolerable speed of turbine v_{co}. v_{ci} is the minimum required wind speed of turbine for power generation. Of course, it should be noted that the use of this method does not provide a sufficient guarantee of close proximity to the actual generation capacity of a turbine over a year.

In most articles, the capacity coefficient is used to estimate the continuous generation of wind turbines [4]. Capacity coefficient is obtained using the annual wind power generation statistics and its formula is as follows:

$$CF = \frac{\text{Total energy produced by an air unit during one year in terms o}f\ MWh}{nominal\ power\ of\ turbine \times 8760} \tag{10}$$

Or, in other words:

$$CF = \frac{mean\ powe}{\text{nominal powe}} \tag{11}$$

The use of capacity coefficients based on the statistics of the turbine and wind characteristics of the region gives the system planner a more accurate estimate of the generation capacity of the wind unit. But the most accurate method of estimating the generation of wind units is the traditional method, relying on the anemometer statistics of the site where the power plant is located, which provides information about the wind at different speeds over the year, and the same statistics or results can be used to estimate wind specifications in the coming years.

In this method, wind speed data are divided into different categories in different intervals, and the contribution of each of the intervals throughout the year is estimated according to the previous information. Finally in [17, 20], the turbine power generation is presented as the function of wind speed. The formula shows the wind turbine generation power in terms of wind speed and fixed parameters of minimum speed and maximum speed of turbine performance and its nominal power [21].

$$G_W = \begin{cases} 0 & v \le v_i\,, v \ge v_0 \\ \frac{v-v_i}{v_r-v_i} G_{Wr} & v_i \le v \le v_r \\ G_{Wr}\,, & v_r \le v \le v_0 \end{cases} \tag{12}$$

Uncertainty in the generation of wind power units in this issue is achieved by relying on multi-year anemometer statistics in the surveyed network. Although the use of this method is more complicated and requires more computations, but gives more accurate data to the designer. To solve the problem by the use of this method, we divide the various wind speeds into arbitrary intervals and denote the share of each interval over the year in terms of hour. Table 1 shows an example of this segmentation. Assuming the minimum wind turbine speed at 4 m/s and its maximum speed at 24 m/s, he average wind speed and the probability of each of the conditions is extracted in Table 2. Given the nominal speed of the turbine at 16 m/s, for above mentioned example, the power generation is carried out in different situations and with the corresponding probabilities in Table 3.

Table 1. Different wind speed intervals

Status number	Wind speed(m/s)	Flow hour measure
1	0-4	1370
2	4-8	1011
3	8-12	1482
4	12-16	1752
5	16-20	1394
6	20-24	990
7	>24	761

Table 2. Related probabilities to Table 1

Status number	1	2	3	4	5	6	7
Average speed	-	6	10	14	18	22	-
Probability	0.156	0.115	0.17	0.2	0.159	0.113	0.087

Table 3. Generation power of Turbins by related probabilites

Status number	Wind speed (m/s)	Turbine generation power	The probability
1	0-4	0	0.156
2	4-8	$0.167 \times P_r$	0.115
3	8-12	$0.5 \times P_r$	0.17
4	12-16	$0.83 \times P_r$	0.2
5	16-20	P_r	0.159
6	20-24	P_r	0.113
7	>24	0	0.087

2.2. Uncertainty in consumption

The amount of electrical energy consumption in a power system is not always fixed. The amount of this variable is always dependent on many factors, such as consumer type, day and night hours, atmospheric conditions, power network status, and many other factors. Usually in most papers due to the complexity of the problem, the load consumption uncertainty is ignored and peak load is considered as a constant load [4, 20]. Also, in addition, some authorities consider the network load as a factor of peak load by considering the annual consumption of the network [3]. Relies on this method to plan the placement of generating units provides more realistic value, but in the case of network sensitivity and dependence of consumption on generation units is problematic.

In some sources, the system designer's formula is used to model the loads in the network. In the [22], the active and reactive power consumption of the system is modeled as:

$$P_i = P_{oi} V_i^{\alpha} \tag{13}$$

$$Q_i = Q_{oi} V_i^{\beta} \tag{14}$$

Table 4 shows the values of α - β parameters for different consumers. As observed, if α and β be zero, the same peak load is considered.

Table 4. Related coefficient to sample load [22]

Load type	α	β
Constant	0	0
Industrial load	0.18	6
Residential load	0.92	4.04
Commercial load	1.51	3.4

Another method is to provide statistics of the amount of load consumption in the last years and classify the load at different levels and allocate a share of the one - year period. Usually this classification is performed in three categories as light loads, medium loads, and peak loads, which provide a more accurate estimate to the designer [23].

The uncertainty of load in this paper is estimated based on the annual statistics of the distribution company. In the load classification, several situations are considered as a percentage of the peak load and their share is expressed in terms of consumption hours over the year. The simplest classification is the three categories of load as light, medium and peak load. We extend our classification to more situations in order to increase accuracy. An example of this classification is illustrated in the Table 5 with the consumption hours and the corresponding probability of each situation.

To investigate the problem in terms of uncertainty in generation and consumption, all relevant conditions must be included in system analysis. Therefore, the general analysis of the system in K different situation is examined by a different percentage of the loads and the nominal power coefficients, which is the multiplication of the number of generation uncertainty in the number of load uncertainty.

$$K = N_w \times N_L \tag{15}$$

Table 5. Different statuse of load during a year

Status number	Peak load percentage	Consume hours	Corresponding probability of situation
1	100%	87	0.01
2	85%	438	0.05
3	75%	2190	0.25
4	65%	1314	0.15
5	50%	3942	0.45
6	30%	789	0.09

Also, the probability of each of the system states is equal to multiplication of the probability of the uncertainty in generation in the probability of the load uncertainty. In the following formula, P_t, P_w, and P_L are the probability of the whole system, the probability of generation and the probability of peak consumption percentage, respectively.

$$P_t = P_W \times P_L \quad (16)$$

$$\sum_{t=1}^{K} P_t = 1 \quad (17)$$

2.3. Times the load

Over time, loads are added to the distribution system. This increase can be due to the increased demand of each consumer, the addition of a new consumer or network expansion. The load forecast for a power network, takes a long discussion that depends on a large number of factors. For this reason, we briefly describe load growth as a percentage of the system peak load annually.

$$P_{L,T} = \sum_{i=1}^{T} P_L \times (1+\alpha) \quad (18)$$

$P_{L,T}$ is total consumption of the system after T year
P_L is system consumption in the first year
α is the growth rate of the load in percent

3. THE OBJECTIVE FUNCTION OF THE PROBLEM

In this section, we describe the constraints of the problem solving, the hypotheses and the objectives. The expression of the objective function in an economic form and comprehensive coverage of the constraints and conditions of the problem will make it more real, which will be very useful in solving the problems.

3.1. Problem objectives

To accurately estimate the objective function of the problem, all the objectives and conditions of the problem are expressed identical and in the form of the imposed costs on the system or the benefits of the system. In this way, the objective function of the problem will be one-sided and directs us to the correct answer. The review of the system in this paper has been done over a Perennial period, mainly adapted from the normal range of capital return for a wind unit. For one of these networks, network load growth has also been studied over this period. Such an analysis leads us to the actual simulation of a true placement problem and an understanding of costs.

a. Cost of the construction of wind units

The cost of the construction of wind units is expressed as, where m represents the wind and the Costi representing the cost of constructing the unit m.

$$C_{inv} = \sum_{i=1}^{m} Cost_i \quad (19)$$

b. The repair and maintenance cost

The cost of maintenance and repair of wind units in the term of MWh can be calculated as follows:

$$C_{o\&m} = \sum_{i=1}^{m} \sum_{j=1}^{n_w} G_{w\,i,j} \times P_j \times C_{m,i} \times 8760 \quad (20)$$

$C_{o\,\&\,m}$ is the cost of maintenance of all wind units over a year.

$C_{m,i}$ is the cost of repairing the i-th unit
n_w is the number of power generation states with different wind flow probabilities.
m The number of installed wind units on the network.
$G_{w\,i,j}$ is the i-th generation unit in j-th mode.
P_j is the probability of power generation in j-th mode.

In order to obtain the current value of the total cost of maintenance and repair of units during the period of the last few years, the following formula is used:

$$NPV(C_{o\&m}) = C_{o\&m} \times \sum_{t=1}^{T} \left(\frac{1+inf}{1+int}\right)^t \tag{21}$$

NPV ($C_{o\&m}$) is the current cost of repair and maintenance during T year.
inf is the constant rate of inflation calculated as a percentage.
int is the fixed profit rate calculated as a percentage.

c. Income from loss reduction

By adding distributed generation to the network and injecting current into different parts of the network, the level of current pass through the lines decreases, thus reducing system losses. To calculate the profit from system losses, we calculate the difference in network losses before installing wind units and after installing them. System losses before installation of wind units and during the perennial period specified in term of MWh are obtained from the following:

$$E_{loss\,nWT} = \sum_{t=1}^{T} \sum_{s=1}^{n_L} \sum_{i=1}^{n} \sum_{j=1}^{n} G_{i,j} \times \left(V_{i,s}^2 + V_{j,s}^2 - 2 \times V_{i,s}^2 \times V_{j,s}^2 \times \cos(\delta_{i,s} - \delta_{j,s})\right) \times P_s \times 8760 \tag{22}$$

$E_{loss\,nWT}$ is the total system losses during the T year before the installation of wind units
n_L is the number of load models modes
n number of system bases
$G_{i,j}$ is line resistance between the i and j buses
P_s is the related probability to the s mode of the load model
System losses after installation of wind units are obtained as follows.

$$E_{loss\,WT} = \sum_{t=1}^{T} \sum_{f=1}^{n_K} \sum_{i=1}^{n} \sum_{j=1}^{n} G_{i,j} \times \left(V_{i,f}^2 + V_{j,f}^2 - 2 \times V_{i,f}^2 \times V_{j,f}^2 \times \cos(\delta_{i,f} - \delta_{j,f})\right) \times P_f \times 8760 \tag{23}$$

$E_{loss\,WT}$ is the total system losses during the T year after the installation of wind units
n_K is the total number of modes of load models and generation levels
P_f is the probability of the f mode
The difference in system losses before and after installation of wind units is given as follows:

$$E_{loss} = E_{loss\,nWT} - E_{loss\,WT} \tag{24}$$

Therefore, the profit from the loss reduction can be calculated as follows:

$$C_{loss} = E_{loss} \times C_e \tag{25}$$

Where Ce is the price of energy sales to the distribution company. Finally, the present value of the loss-making benefit is expressed as follows.

$$NPV(C_{loss}) = C_{loss} \times \sum_{t=1}^{T} \left(\frac{1+inf}{1+int}\right)^t \tag{26}$$

d. Profit from energy sales

The total produced energy and the Profits from the sales power of wind units to the network can be calculated as follows:

$$E_{WT} = \sum_{i=1}^{m} \sum_{j=1}^{n_w} G_{w\,i,j} \times P_j \times 8760 \tag{27}$$

$$C_{sale} = E_{WT} \times C_e \tag{28}$$

E_{WT} is the total energy produced by wind units during a year
C_{sale} is the profits from energy sales to the network over a year
C_e is the price of energy sales to the distribution network
n_w The number of power generation mode with different wind flow probabilities
m The number of installed units in the network
$G_{w\,i,\,j}$ is the i-th unit generation in j-th mode
P_j is the probability of power generation in j-th mode
The current value of this amount is also calculated as follows.

$$NPV(C_{sale}) = C_{sale} \times \sum_{t=1}^{T} \left(\frac{1+inf}{1+int}\right)^t \quad (29)$$

e. Benefits from reducing greenhouse gases

Wind energy is clean and the generation of electricity by it can eliminates the need to use fossil fuel resources. If no wind units are used, the needed energy must be supplied through the network and connected power plants. Fossil fuel plants are required for filtering and reducing greenhouse gas emissions, such as CO2, which will be met by the presence of wind turbines. So the benefits of reducing the CO2 effect can be calculated as follows.

$$C_{co2} = (E_{loss} + E_{WT}) \times \varphi \times C_{ems} \quad (30)$$

C_{co2} is benefits from reducing greenhouse gases over a year
φ is greenhouse gas emission rate in kg / MWh
C_{ems} is Profits from the reduction of greenhouse gases per kilogram
The current value of this amount is obtained as follows.

$$NPV(C_{CO2}) = C_{CO2} \times \sum_{t=1}^{T} \left(\frac{1+inf}{1+int}\right)^t \quad (31)$$

Therefore, the general objective function of the problem is obtained as follows. Our goal is to maximize this objective function. Also, if the distribution company exploit the turbines, the objective function should always be greater than zero to have an advantage over the non-winding mode.

$$C_{Total} = NPV(C_{loss} + C_{sale} + C_{CO2}) - NPV(C_{o\&m}) - C_{inv} \quad (32)$$
$$C_{Total} > 0$$

3.2. Constraints of the problem

a. Load transfer equations

$$P_{Gg,1} + \sum_{t=1}^{m} \boldsymbol{C}(g,t) \times P_{DGt,i} - \boldsymbol{C}(g,m+1) \times P_{Di} = \sum_{j=1}^{n} V_{g,i} \times V_{g,j} \times Y_{ij} \times \cos(\theta_{ij} + \delta_{g,j} + \delta_{g,i}) \ \forall i,g \quad (33)$$

$$Q_{Gg,1} - \boldsymbol{C}(g,m+1) \times Q_{Di} = -\sum_{j=1}^{n} V_{g,i} \times V_{g,j} \times Y_{ij} \times \sin(\theta_{ij} + \delta_{g,j} - \delta_{g,i}) \ \forall i,g \quad (34)$$

Where:
P_{DGt}, i: *t*-th nominal power of DG based on wind connected on bus *i*
P_{Gg}, 1: Active power of the side post injected at the bus *i*
Q_{Gg}, 1: Reactive power of the side post injected at the bus *i*
P_{Di}: Maximum active power in bus *i*
Q_{Di}: Maximum reactive power at the bus *i*
$V_{g,\,i}$: Voltage at bus *i* during *g* mode
n: Total number of bases in the system

b. Power loss equations:

$$P_{loss,g} = 0.5 \times \sum_{i=1}^{n} \sum_{j=1}^{n} G_{ij} \times [(V_{g,i})^2 + (V_{g,j})^2 - 2 \times V_{g,i} \times V_{g,j} \cos(\delta_{g,j} - \delta_{g,i})] \ \forall i,j,g \quad (35)$$

c. Branch flow equations

This represents the maximum tolerable flow by network feeders. Placement problem must be done in such a way that the feeder current does not exceed the permitted limits.

$$I_{g,ij} = |Y_{ij}| \times \sqrt{V_{g,i}^2 + V_{g,j}^2 - 2 \times V_{g,i}^2 \times V_{g,j}^2 \times \cos(\delta_{g,i} - \delta_{g,j})} \quad (36)$$

$I_{g,\,ij}$ is the current passing through the line between the bus *i* and *j* during *g*'s mode and Y_{ij} is its admittance.

d. Voltage Limit

The bus voltage should be within the standard range. The addition of generating units to the network will improve the voltage profile of the weak networks.

$$V_{min} \leq V_{g,i} \leq V_{max} \; i = 1,2,\dots,n \quad (37)$$

e. Feeder capacity limit:

$$0 \leq I_{g,ij} \leq I_{ij_{max}} \quad (38)$$

f. Maximum installed power on the bus

Which indicates the maximum capacity or number of wind units that a bus can accept.

$$P_{wind\ j} < P_{\max j} \quad (39)$$

j is the number at which the wind unit is installed.

4. THE METHOD OF PROBLEM SOLVING

In order to solve the placement problem with the help of the proposed algorithm, at first we examine the data, constraints and objectives of the problem and make the main form of the problem. Then, given the number of permissible wind units on the network, we determine the length of the chromosomes and, by filling the chromosomes with the permitted values, we form the initial population.

The problem solving chromosome consists of two categories of genes. The initialization of the chromosome is carried out in such a way that the first group of genes in the chromosome contains the number of candidate buses for the purpose of installing the wind units. The second part of the chromosome is composed of a number of genes that is equal to the first genes, which represents the size of the generation power appropriate to the unit. The resulting chromosome is shown in Figure 1.

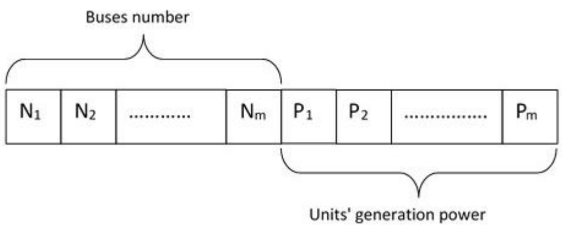

Figure 1. Setting of the problem of chromosomes

m indicates the number of candidate buses for installing wind units.
The following operations are performed on the system without the presence of wind generations:

- The load distribution for the system without the presence of wind resources is done for all of the years and considering different load models.
- The system losses without wind turbines are measured and accumulated in all years.
- Voltage measures are stored in all buses.

Next, to find the highest value of the target function, the initial population is randomly generated. For each of the chromosomes, the following actions are performed:
- Assign power output to the selected bus in the network
- Estimation of all load models and power generation solutions and related probabilities
- Run the load distribution for each of the scenarios, considering the associated probability
- Measurement of system losses in the presence of wind units
- Allocation of profit function from loss reduction
- Allocation of the profit from the sale of energy to the network
- Allocation of the profit function of reducing polluting gases
- Determine the cost of units building and the cost of maintenance by determining the amount of units generation
- Determine the size of the objective function using the amounts of profit and obtained cost

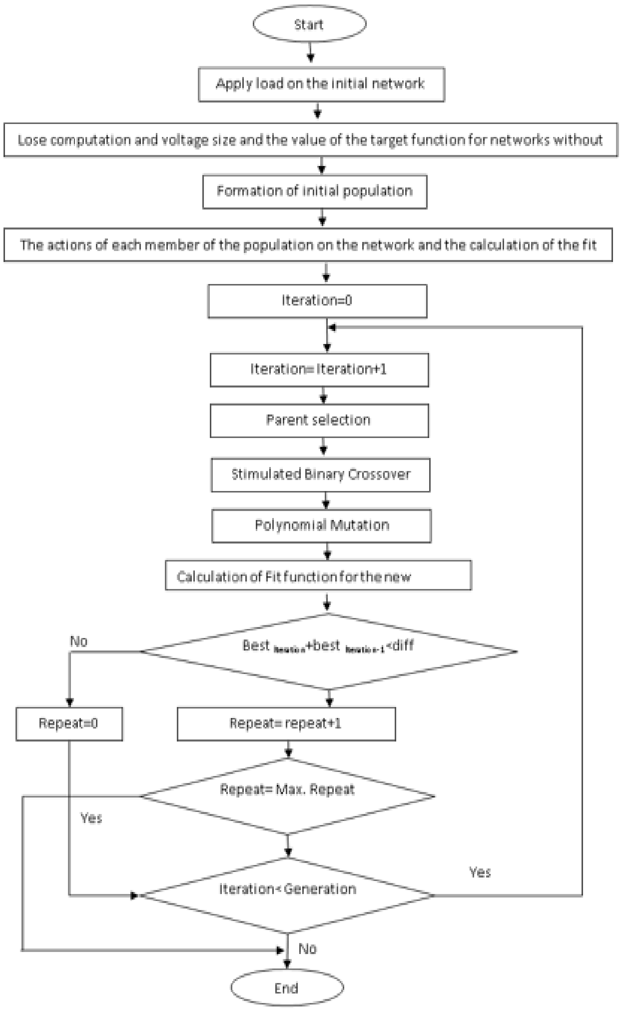

Figure 2. The flowchart of problem solving

Thus, the values of the fit function for the initial population are obtained. We apply operators of the genetic algorithm to the initial population. The algorithm continues with the number of repetitions set. The condition of the completion of the algorithm is to achieve the number of repetitions defined or the difference between the best replies of two replicates of the defined value after a certain number of steps. Finally, the optimal response is determined by the maximum value of the target function. The problem solving flowchart is shown in Figure 2.

5. SIMULATION RESULTS

The test system of the feeder is IEEE 69 standard bus. Consumption of the network is 2.95 MVA. The growth rate is estimated at 3% per annum in the network. The specifications of the selected generation units for installation in the network and other economic considerations are discussed below. The site is designed to justify the economic installation of wind units and maximize the profits from installing the units in the network. Table 6 shows the anemometer information of the area in question. This information is required to determine the uncertainty of the wind units.

Table 6. Anemometer information of 69 bus testing system [4]

Status number	Wind speed(m/s)	Flow hour measure (h)
1	0-4	1189
2	4-6	1533
3	6-8	1346
4	8-10	1429
5	10-12	1264
6	12-13	792
7	13-25	1207

The minimum required speed for wind turbine is 4 m/s and its maximum speed is 25 m/s. The nominal speed of the turbine is 13 m/s and the turbine capacity coefficient is approximately 0.5. With this information, we can extract the turbine outputs and their corresponding probabilities as Table 7. Table 8 shows the load models in the network and their corresponding probabilities. All scenarios involving generation and consumption uncertainty are shown in Table 9.

Table 7. Products corresponding to different wind probabilities of 69 bus test system

Status number	Wind speed (m/s)	Turbine generation power	The probability
1	0-4	0	0.136
2	4-6	$0.11\times P_r$	0.175
3	6-8	$0.33 \times P_r$	0.154
4	8-10	$0.56 \times P_r$	0.163
5	10-12	$0.78 \times P_r$	0.144
6	12-13	$0.94 \times P_r$	0.09
7	13-25	P_r	0.138

Table 8. Load models of the 69-bus test system

Status number	Peak load percentage	Consumption hours	The probability corresponds to the situation
1	%100	88	0.01
2	%85.3	491	0.056
3	%77.4	926	0.1057
4	%71.3	1449	0.1654
5	%65	1449	0.1654
6	%58.5	1428	0.163
7	%51	1428	0.163
8	%45.1	799	0.0912
9	%40.6	414	0.0473
10	%35.1	289	0.033

The generation capacity of each wind turbine installed in the network is 100 KW and its capacity coefficient is 0.5. There is no limit to the number of units in the buses. The economic conditions governing the problem and the prices are as follows [4, 23].

- The cost of constructing each unit of the wind plant to a capacity of 1 MW: \$ 4.8 × 107
- Maintenance and repair costs: \$ 42.8 / MWh
- CO_2 emissions per kilowatt-hour: 0.612 kg / kWh
- Costs for CO_2 disposal: \$ 30.8 / ton
- Average annual interest rate: 12.5%
- Average annual inflation rate: 9%
- Annual rate of load growth: 3%
- Duration of system analysis: 20 years

By performing the simulation, the optimal location and capacity of the wind units in the network is as Table 10. Table 11 shows the comparison of the results obtained from the implementation of the proposed algorithm on the problem and the algorithm used in reference [4]. Prices are calculated at the current value.

Table 9. Probabilities related to the uncertainty of test systems 69 bus

Status	Turbine rated power factor	Load coefficient	Probability	Status	Turbine rated power factor	Load coefficient	Probability
1	0	1	0.0014	36	0	1	0.0222
2	0.11	0.853	0.0098	37	0.11	0.853	0.0285
3	0.33	0.774	0.0163	38	0.33	0.774	0.014
4	0.56	0.713	0.027	39	0.56	0.713	0.0077
5	0.78	0.65	0.0238	40	0.78	0.65	0.0048
6	0.94	0.585	0.0147	41	0.94	0.585	0.0009
7	1	0.51	0.0225	42	1	0.51	0.0077
8	0	0.451	0.0124	43	0	0.451	0.0144
9	0.11	0.406	0.0083	44	0.11	0.406	0.0289
10	0.33	0.351	0.0051	45	0.33	0.351	0.0255
11	0.56	1	0.0016	46	0.56	1	0.0266
12	0.78	0.853	0.0081	47	0.78	0.853	0.0235
13	0.94	0.774	0.0095	48	0.94	0.774	0.0082
14	1	0.713	0.0228	49	1	0.713	0.0065
15	0	0.65	0.0225	50	0	0.65	0.0045
16	0.11	0.585	0.0285	51	0.11	0.585	0.0018
17	0.33	0.51	0.0251	52	0.33	0.51	0.0086
18	0.56	0.451	0.0149	53	0.56	0.451	0.0172
19	0.78	0.406	0.0068	54	0.78	0.406	0.0238
20	0.94	0.351	0.003	55	0.94	0.351	0.0149
21	1	1	0.0014	56	1	1	0.0225
22	0	0.853	0.0076	57	0	0.853	0.0222
23	0.11	0.774	0.0185	58	0.11	0.774	0.016
24	0.33	0.713	0.0255	59	0.33	0.713	0.0073
25	0.56	0.65	0.027	60	0.56	0.65	0.0054
26	0.78	0.585	0.0235	61	0.78	0.585	0.0014
27	0.94	0.51	0.0147	62	0.94	0.51	0.005
28	1	0.451	0.0126	63	1	0.451	0.0146
29	0	0.406	0.0064	64	0	0.406	0.0225
30	0.11	0.351	0.0058	65	0.11	0.351	0.0289
31	0.33	1	0.0015	66	0.33	1	0.0251
32	0.56	0.853	0.0091	67	0.56	0.853	0.0266
33	0.78	0.774	0.0152	68	0.78	0.774	0.0131
34	0.94	0.713	0.0149	69	0.94	0.713	0.0043
35	1	0.65	0.0228	70	1	0.65	0.0046

Table 10. Simulation results on 69 bus test system

Selected buses with generation capacity (kW)		Total waste of energy before units installation (MWh)	Total waste of energy after units installation (MWh)
61 1800 Kw	63 600 kW	53,935	32,128

Table 11. Compare the simulation results of the 69 bus test system

		Proposed Algorithm	Reference [4]
Total system losses (MWh)	Before installing wind units	53,935	53,935
	After installing wind units	32,128	32,729
System costs over the whole period ($)	Construction of wind units	144,000,000	1,008,000,000
	Repair and Maintenance	131,036,950	68,7943,990
The benefits of installing wind units on the network ($)	Reduction of casualties	28,636,788	27,847,983
	Energy sales	274,263,385	1,439,882,769
	Reducing greenhouse gases	63,439,412	307,401,529
	Total income	91,302,635	79,188,292
Selected bus to install units		61,63	5,6,7,11,12,14,16, 17,19,53,57,58,59,61, 62,63,64,65,67,68,69

As shown in Table 11, the profit from installing wind units based on the proposed algorithm is more than the proposed method in reference [4]. In addition, the required time to install the units is much lower than the method presented in [4]. In fact, the reference [4] has achieved a disproportionate response to the needs of the network by ignoring the uncertainties of the load and generation and only reliance on the capacity coefficient. The correct placement of wind units in the proposed method of this paper has led to an increase in the main factors related to the profitability of the network, taking into account the minimum imposed costs on the system. The placement of the units in reference [4] with theoretical reliance to reduce losses and increase system benefit as well as uncertainties lead to the benefits from the system, lose its balance to the costs incurred on the system.

The placement of generation units for a large number of buses separately has led to a significant difference in the cost of power plants construction with the proposed method. But with careful maintenance costs, we notice that it's more in the proposed algorithm. This indicates more energy generation by generation units in MWh in the proposed method, which is accomplished by the correct understanding and formulation of the uncertainties in the network.

Similarly, according to the preferred placement of the proposed method, in contrast to reference [4] it can be found that the system losses are reduced further, which, in turn, will increase the profit from sales. The greater the profit from reducing greenhouse gas emissions and selling energy in the proposed method of reference [4] is more, which is natural due to the large volume of wind unit generation. However, in the end, the profit from placement is higher by the proposed method than the reference [4]. The average size of the voltage in the network before and after the placement of generation units is shown in Table 12.

Table 12. The average voltage of the 69-bus test system before and after the installation of wind units

	Before placement of generation units	After placement of generation units
Average voltage size (p.u.)	0.983	1.00

Figure 3 shows the size of the voltage in the bus system before and after the installation of the wind units. As it can be seen, before the installation of wind units, the voltages of bus 61-65 of network were lower than the permitted range, with considerable improvement in the placement of wind units, the voltage profile improved significantly. Figure 4 shows the process of approaching the problem using genetic algorithm. As we can see, the use of the introduced operators in the process of solving the genetic algorithm results in a faster response to optimized response.

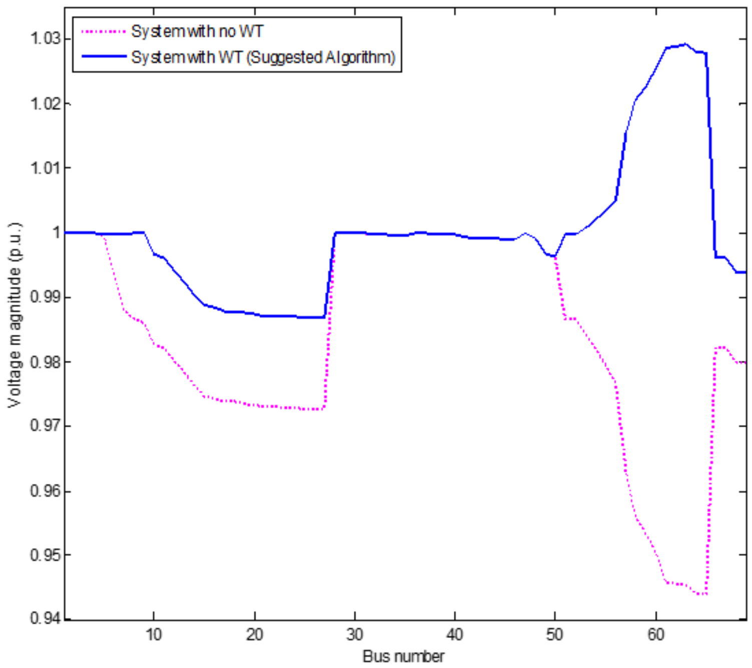

Figure 3. Voltage measurement of the 69-bus test system before and after the installation of wind units

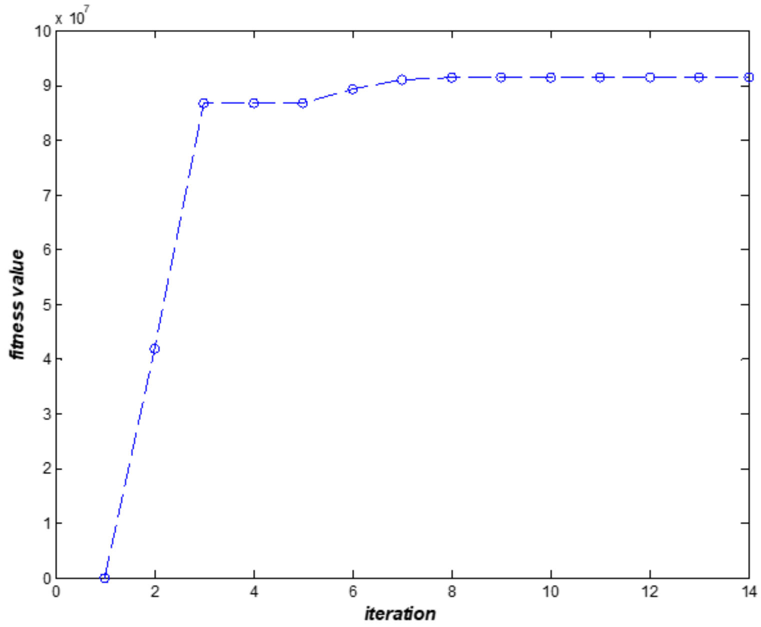

Figure 4. The genetic algorithm solution procedure for the 69 - bus test system

6. CONCLUSION

In this paper, the placement problem of the wind units in the power network was investigated. Placement is one of the most important issues that have always been raised in the power system. It has been more and more widely considered in the network over the past few decades with the presence of distributed generation in the network. In addition to the assumptions of the problem situation, wind units in distributed generation, also require their particular considerations. The dependence of wind power units that is not predictable is one of the requirements that need to be addressed, which is usually based on the region's statistical records and turbine characteristics in response. But this also has different levels that add to the complexity and precision of problem solving, respectively. Using accurate statistical estimates can lead the system designer toward more profitability and lower system costs. Another hypothesis in the placement problem solving framework is the reliance on peak load capacity in load calculations, which causes distance from the actual situation. In this paper, it has been tried to make a more accurate decision about the location of generation units using the annual statistics on network consumption and consumption forecast. Also, the statement of the problem objectives in the form of the imposed costs on the system and the resulting revenues for the distribution company has made it easier to integrate the objective function and analyze it. This allows the designer to analyze the considered plan within the desired time frame, which will greatly contribute to the future development goals of the network. At the end, the use of genetic algorithm method using optimized operators, cause the problem to be solved faster by optimizing absolute responses. Here are some essential points.

Although the placement with the aim of reducing the losses has a major contribution to the network operator's decision making, but solving the problem considering network losses reduction due to the initial cost of wind units has not necessarily economic justification, and this goal must be taken into account considering the economic conditions. Considering peak load as a fixed load of the system cause deviation from the main system requirement, and because of lower construction of generation units and the placement with less precision, the cost of purchasing energy from the network will be higher for the distribution company.

The use of wind turbines capacity coefficient to model the uncertainty in the network does not provide an accurate estimate of the generation power required by the designer and may cause additional or less estimation of generation units Due to the high cost of wind farms, the mere susceptibility of a part of the network to install these units cannot justify the use of them. For this reason, their placement in the moment and regardless of time domain is theoretical and is not applicable.

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