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Research Paper

Optimal Placement of Wind Turbines for Reducing Losses and Improving Loadability and Voltage Profile in Distribution Networks by Data Clustering and NSGA-II Algorithm

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Abstract

In recent years, by considering problems such as environmental pollution and energy crisis, using renewable distributed generation resources as a clean energy for supplying load in distribution network is growing. On the other hand, wind energy as a free and renewable energy has been always considered. So, in this paper, by using NSGA-II multi-objective optimization algorithm, placement of wind turbines for reducing losses and improving Loadability margin and voltage profile of distribution network has been investigated. Productivity generated power of these resources on the base of environmental situation has a probabilistic nature so using probabilistic methods is essential. However, for reducing calculations and speeding up time for solving these probabilistic problems, methods which are on the base of variable data classification are used. In this paper, by using K-means classification, wind turbines data and network Load are divided into the several clusters and then network for these clusters is analyzed. Results of running this algorithm in network show fastness and accuracy of this method.

Keywords: Wind Turbine, Loadability, Power Losses, Voltage Profile, NSGA-II.

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1. Introduction

By increasing electricity consumption and industrial development, there is a need for increasing energy generation and extension of power stations. According to the several reasons, using renewable resources for generating power is expending. Some reasons are as follow:

- Diversification of energy generation portfolio.
- Cleanness and less harm of environment.
- No need for fuel.
- Increasing price of fossil fuel and economic justification of using these power stations by free fuel.

Beside mentioned benefits, there are also disadvantages in using these resources such as probabilistic generation because generation amount of these units is depending on environmental condition. Various studies for placement of probabilistic distributed generation resources had been done up to now. These studies had different goals and evaluating these goals is possible by knowing network load and generation of probabilistic distributed generation resources and load amount and generation of these resources by using different methods had been modeling in articles. In 2013, Abri et al studied the method for determining place and optimum size of probabilistic renewable resources (photovoltaic & wind turbine) for increasing Loadability is

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presented. In this article by using new index, the improvement of Loadability is measured and wind turbine and photovoltaic had been modeled in order by Weibull and Beta distribution function. In 2013, Kayal and Chando studied the placement of wind turbine and photovoltaic had been done by PSO method in order to optimizing voltage stability margin and reducing losses and load had been analyzed in three separate assessments as most of the peak, peak load and less than peak [2]. The uncertainty of parameters is reduced by means of probabilistic methods and effect of conditions on the estimated values for engineering models is thoroughly investigated by Adeli et al. [3-5]. Gilani et al (2012) studied the optimum placement of wind turbine for decreasing losses and increasing trust ability (Energy not supplied power) and amount of generation had been clustered by Fuzzy C-Means (FCM) and uncertainty of load and generation had been mentioned [6]. Sadeghi and Kalantar (1892) uses of wind turbine in order to decreasing annual costs which are including energy losses and cost of not provided energy and energy which is bought from private investors of wind turbine and the upstream network, certainty for wind turbine generation had been mentioned by using Weibull distribution function.

In this article, optimum placement of wind turbines with three objectives of improving Loadability, decreasing network losses and enhancing voltage profile is done. In most of methods, objective functions are placed in a weighted objective function or fuzzy methods are used for solving multi-objective problems but in NSGA-II multi-objective optimization method, problem is examined in the form of three separate objective function and finally, in contrast of single-objective methods, it present set of answers to the designer which is make objective functions closer to the optimum points. On the other hand, because network load and wind turbine output are not constant and have a probabilistic characteristic, it is necessary to locate wind turbines during the year. But using enumeration methods is very time consuming. So in this paper, data of wind turbine generation and network load are clustered by K-means and network is analyzed for these clusters.

1.1 Uncertain parameters modeling

Wind Turbine: In this article, for improving network parameters, wind turbine has been used. So, firstly behavior of wind turbines should examine. Wind energy always considered as renewable and free energy but beside this, using this energy has several disadvantages, such as impossibility of forecasting wind speed and as a result, variability of output power of these units which is make its programming difficult. In this article, output power of wind turbines had been modeled as equation 1.

$$P_{WT}(t)=\begin{cases}0 & V<V_{cin}\\ P_r\times\frac{(V-V_{ci})}{(V_r-V_{ci})} & V_{cin}<V<V_r\\ P_r & V_r<V<V_{co}\\ 0 & V>V_{co}\end{cases} \quad (1)$$

According to figure1, wind plant start to work in wind speed equivalent to V_{cin}, in V_r it reaches its rated power and continue its rated power generation until V_{co} speed and if wind speed is higher than V_{co}, amount of turbine generation will be zero for protection of equipment.

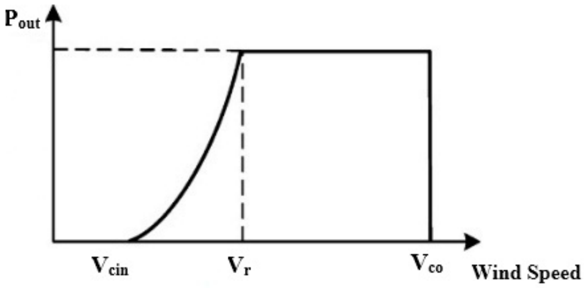

Figure 1. Wind turbine power curve.

For calculating amount of turbine generation, by considering penetration coefficient and load rate, we can use equations 2, 3 and 4 [5].

$$S_{DG}=S_{Load}\times WT_{PL} \quad (1)$$

$$P_{DG}=S_{DG}\times PF \quad (2)$$

$$Q_{DG}=\sqrt{S_{DG}^2-P_{DG}^2} \quad (3)$$

S_{DG} : DG power generation
S_{Load} : Total apparent load
WT_{PL} : Wind turbine penetration level
P_{DG} : Active power produced by DG
PF : Power Factor
Q_{DG} : Reactive power produced by DG

Load modeling: In this article, data of RTS-IEEE network has been used [6], which are determined for each hour as a ratio of peak load and by considering modeling of wind turbine and load, we obtained for each hour one data for wind turbine generation and one data for determining amount of load in order to network analyzing. Considering variation of generation and load causes proposed place for wind turbine will be optimum during one year(in this condition, both peak and non-peak moments will be effective in choosing wind turbine place by considering number of hours).

Data clustering by K-means method: In data clustering which is done by different methods and on the base of similarities or their distance to each other, investigated data are clustered into the different clusters, so as data of one cluster have the most similarity and closeness to each other and have the most differences and distance with data of other clusters. By using clustering, instead of examining so much information, only limited number of clusters is analyzed. Up to now, various methods have been proposed for clustering data. This method uses kind of correlation or relationship between data. In this research, K-means method has been used and its algorithm is as follow [7]:

1. Determining number of clusters (K)
2. Choosing K row data by random and assigning those as a representative of ai cluster if i=1, 2, 3…
3. Allocating other data to the formed clusters on the base of minimum distance to the cluster representative.
4. Calculating the average of each cluster members and choosing it as a representative of each cluster for next reparation.
5. Repeating steps 3 and 4 until the slightest change in the value of each cluster representative will be created.

Finally, output of K-means clustering algorithm will be the average (representative) of clusters and their probability. Probability of each cluster is resulted from dividing number of that clusters members on the total number of data. Here, for evaluating network in different operating works resulted from change in load and wind plant power, method which is on the base of data clustering, is proposed and its process is as follow:
Step1: wind plant output power being calculated on the base of variation in wind speed in the period under study.
Step2: by using K-means clustering method, system load and output power of wind plant are clustered simultaneously and each cluster determined by its probability and representative (the average load of system and average output power of wind plants).
Step3: counter of clusters chosen as i and adopted 1 and start to rise in one loop.
Step4: by considering values of cluster representative, buses load and output power of wind plant will be adjusted.
Step5: by using continuous power flow and forward backward sweep, network condition will be evaluated in relation to the cluster representative.
Step6: if all clusters do not examine, one added to the counter and step4 again will be calculated.

1.2 Mathematical formulation of problem
Finding suitable place for diffused generation resource in distributing network for obtaining maximum advantage is still a critical problem. The main part of losses in power network is occurring in distribution part. On the other hand, after restructuring power networks, distribution networks are operating close to the Loadability margin. If wind turbines are located in suitable place, in addition to the load supplying, they can help to decrease losses and improving voltage profile and Loadability margin (voltage consistency) in network significantly. In placement problem of diffused generation resources. Three objectives are followed simultaneously. First objective is improving voltage profile of network, second one is decreasing energy losses and the third one is improving voltage stability or system Loadability margin and all these three objectives are very important in supplying electricity safely.

A) Voltage Profile
Because wind turbines are supplying part of active and reactive power of local load, this issue can cause decreasing in current power of diffused network lines and reinforcing consumer range and as a result, improving voltage profile.

$$F_{1,V_{profile}} = \sum_{j=1}^{N} \left(\sum_{i=1}^{N_b} (1-V_i)^2\right) \times P_j$$

N : Number of cluster
N_b : Number of buses
V_i : Voltage magnitude at bus i
P_j : Probability of each cluster

B) Network losses
Because the main part of network losses are because of power transition in lines, using wind turbines has a significant effect on decreasing power transition and accordingly, losses will be decrease.

$$F_{2,P_{loss}} = \sum_{j=1}^{N} \left(\sum_{i=1}^{N_L} 3\times R_i \times I_{L_i}^{2}\right) \times P_j$$

N : Number of cluster
N_L : The number of lines distribution network
R : Line resistance
I_{L_i} : Current magnitude at line i
P_j : Probability of each cluster

maximizing objective function number 3 (Loadability margin).

C) Loadability margin

One of the main benefits of wind turbines is supplying local load and because of that, construction of newlines and plants will be postponed, however this cause increasing in network Loadability margin. One criterion for evaluating voltage consistency is determining voltage consistency margin as a distance of current operating point to the system uploading maximum point (critical points). This distance is calculated by increasing in bus loads and also in power of productive bus. Precise calculation of voltage consistency margin is possible by continuous power flow method. Also, P-V curve is calculated by this load distribution. In this curve, critical point means system Loadability which is show in below figure by λparameter. As we can see in figure 2, if diffused generation units are located in suitable place, it causes increasing of network Loadability from λmax 1 to λmax2. Objective function which is evaluated in article, defined as below:

$$F_{3,Loadability} = Min\,\lambda_i\,,\; i=1,\; 2\ldots\; N$$

λ : Loadability margin

N : Number of cluster

It should be noted that the minimum amount of Loadability for all clusters is the maximum Loadability margin in network. In this paper, wind turbine had been used for minimizing objective function number 1 (voltage profile) and objective function number 2 (network losses) and maximizing objective function number 3 (Loadability margin).

1.3 NSGA-II Algorithm

For optimum placement of wind turbines, designers mention various parameters. NSGA-II algorithm is one of the most common multi-objective algorithms which are providing optimization of multi-objective problems. Process of this algorithm is as follow [8]:

a) First P_0 population with N size created randomly or purposely given to the algorithm, counter t being used for differentiating between generations. In this stage t=0.

b) By applying crossover and mutation, Q_0 population of N size being generated.

c) R population with 2N size created by aggregation of P and Q populations.

d) By using non-dominated sorting genetic algorithm, all members of population are placed in fronts $F_1, F_2, \ldots, F_k$ and for all members of fronts, crowding distance values being calculated.

e) Population of $P_{t+1}$is calculated by starting with F1 front members if Fi front members added to P_{t+1}population. If some members of Fi which have more crowding distance, are added to P_{t+1}, size of P_{t+1}population become equal to N.

f) After formation of a new population, crossover and mutation should be applied on new samples and this process should continue until it reaches to the stop condition of algorithm.

Figure 3 shows how to do the process well.

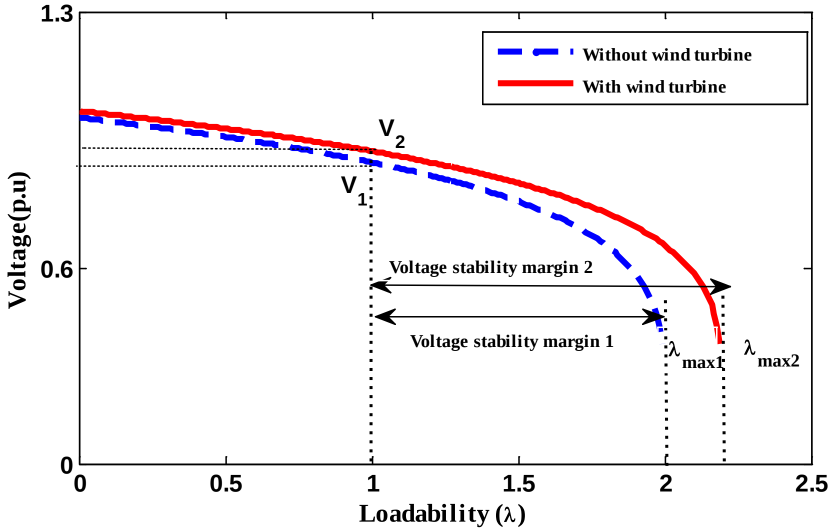

Figure 2. Impact of wind turbine on maximum Loadability margin.

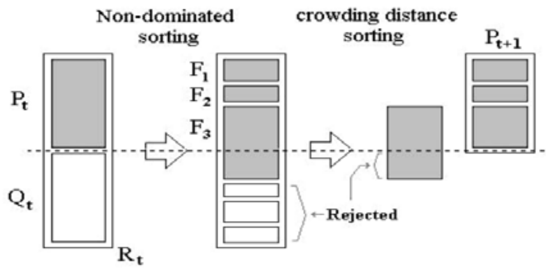

Figure 3. The NSGA-II Algorithm.

2. Results and discussion

For efficiency of mentioned method, IEEE 33-bus distribution network had been used [9]. Figure 4 shows single-line diagram of network.

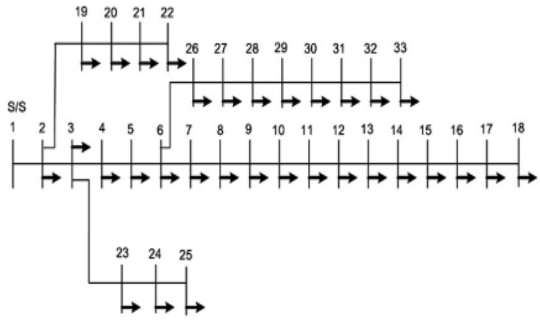

Figure 4. IEEE 33-bus distribution network.

Amount of external load of whole network is 4369KVA which is consists of 2300 KW reactive power and 3715 KW active power. In this article, RTS-IEEE network had been used and its load curve being shown in figure 5.

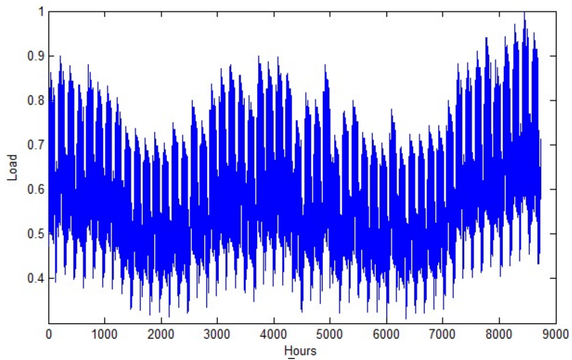

Figure 5. Load variation curve.

For simulation of wind turbine, a wind regime which is shown in figure 6 and consists of 8736 data of wind per hour speed was used and by equation (1) generation power could be calculated for each hour.

Characteristics of used turbine in this section are $V_{cin} = 4$,$V_r = 10$,$V_{co} = 22$.

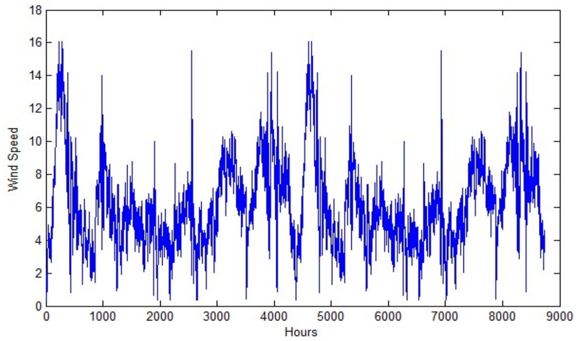

Figure 6. Wind speed curve sampled within a year.

By considering equation 2 to 4, we can calculate generation of wind turbine by desired penetration coefficient in table 1, generation of wind turbine was calculated with 0.95 power factor and 10% penetration coefficient.

Table 1. Power generate of wind turbines.

S_{Load}	WT_{PL}	PF	S_{DG}	P_{DG}	Q_{DG}
4369.35	10%	0.95	436.935	415.088	133.682

In normal condition and absence of wind turbine, network has amounts of table 2.

As we can see, if network being investigated in peak, results will be different from real condition and network will be operated in limited number of hours in peak load. In simulation of this article, each wind turbine with 55KVA external power is including 0.10 of load had been used?

First, by considering section3, we will clustering output power of wind turbine and network load by K-means method, then by using NSGA-II multi-objective optimization algorithm, optimum place of wind turbine will being located for decreasing losses and improving loadability and voltage profile of network . Results of optimum placement in order to improving above parameters are shown in table3.

Table 2. 33-bus test system parameters before placement of wind turbine.

Condition	Voltage Profile	Loadability margin	System losses
Peak load	0.1338	3.41	211 KW
Average all hours of the year	0.0504	3.41	80.009 KW

Table 3. 33-bus test system parameters after placement of wind turbine.

Name of point on fig 7	Wind turbine locations	Voltage Profile	Loadability margin	System losses (KW)
F1	12,15,3233,17,15,31,18	0.0245	5.1888	47.294
F2	18,15,18,8,17,17,16,18	0.0223	4.7841	50.681
F3	12,15,32,33,17,30,31,18	0.0257	5.3138	47.392
F4	18,15,32,33,17,17,16,18	0.0228	5.1197	48.054
F5	18,15,32,33,17,17,15,18	0.0229	5.0172	47.992
F6	18,15,32,33,17,11,10,18	0.0239	5.1529	47.892
F7	12,15,32,33,17,11,31,18	0.0250	5.2886	47.477
F8	18,15,32,33,17,11,31,18	0.0244	5.2458	47.372

Losses between answers and if designer give more attention to the losses parameter, he can choose these places for installing units. On the other hand, if improving Loadability of network is more important for designer, he can uses F3 point of wind turbine location and if improving voltage profile is more important for him, he can use F2 for installing units. It should be noted that the other answers are improving all parameters on average, as none of answers cannot dominate other answers.

Because placement of wind turbines had been done for 3 objectives which are decreasing losses, improving Loadability and enhancing voltage, the result should show by 3-dimension diagrams but for better presentation of parameters results in relation to each other, 2-dimension diagrams are presented (Figure 7 and 8).

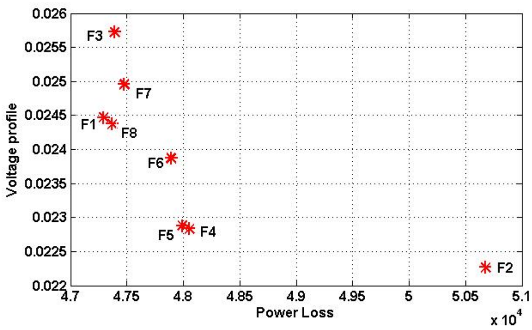

Figure 7. Pareto front NSGA-II Algorithm, Voltage Profile- losses.

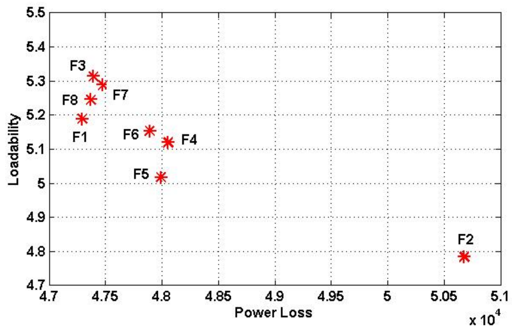

Figure 8. Pareto front NSGA-II Algorithm, Loadability-losses.

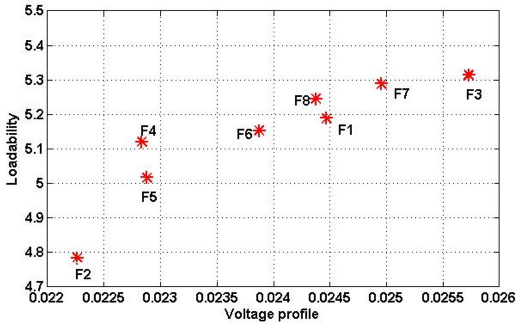

Figure 9. Pareto front NSGA-II Algorithm, Loadability-Voltage Profile.

3. Conclusion

In multi-objective condition, optimization of objective functions is farther than their optimization in single-objective condition, because objectives are in conflict with each other and need a multi-lateral interchange for reaching an equivalent answer. But, as this method tries to optimize technical parameters of problem simultaneously, resulted answers are more precise and practical and designer does not just have one answer but he has set of answers (Pareto front) which gives him power of decision making in flexible environment (figure 9). On the other hand, if units are being located for special objective, other parameters may become weakened because of these units presence and make network condition critical. So, it is necessary to mention presence of these units in network in terms of several parameters, so the answers of problem are close to the real optimum.

References

1. Abri R, El-Saadany EF, Atwa YM. Optimal placement and sizing method to improve the voltage stability margin in a distribution system using distributed generation. *IEEE Transactions on Power Systems*. 2013; 28: 326-334.

2. Kayal P, Chanda C. Placement of wind and solar based DGs in distribution system for power loss minimization and voltage stability improvement.

International Journal of Electrical Power & Energy Systems; 2013. 53: 795-809.
3. E. Adeli, B. V. Rosić, H. G. Matthies and S. Reinstädler. Bayesian parameter identification in plasticity. XIV International Conference on Computational Plasticity. Fundamentals and Applications COMPLAS XIV E. õnate, D.R.J. Owen, D. Peric and M. Chiumenti (Eds), 2017.
4. E. Adeli, B. V. Rosić, H. G. Matthies and S. Reinstädler. Effect of Load Path on Parameter Identification for Plasticity Models using Bayesian Methods. Lecture Notes in Computational Science and Engineering, Springer 2018, \url{http://arxiv.org/abs/1906.07246}, 2018.
5. E. Adeli. Viscoplastic-Damage Model Parameter Identification via Bayesian Methods. Ph.D. Dissertation, Institut fűr Wissenschaftliches Rechnen, Technische Universität Braunschweig, 2019.
6. Gilani SH, Afrakhte H, Ghadi MJ. Probabilistic method for optimal placement of wind-based distributed generation with considering reliability improvement and power loss reduction. In Thermal Power Plants (CTPP), 4th Conference; 2012. p. 1-6.
7. Sadeghi M, Kalantar M. 1892. Probabilistic analysis of wind turbine planning in distribution systems," in Electrical Power Distribution Networks (EPDC), 2014 19th Conference on. Clerk Maxwell, A Treatise on Electricity and Magnetism; 1892. 3rd ed., 2: 68-73.
8. Aman M, Jasmon G, Bakar A, Mokhlis H. A new approach for optimum simultaneous multi-DG distributed generation Units placement and sizing based on maximization of system Load ability using HPSO (hybrid particle swarm optimization) algorithm. *Energy*; 2014. 66: 202-215.
9. Subcommittee P. IEEE reliability test system. *IEEE Transactions on Power Apparatus and Systems*; 1979. No.6.
10. Fernandes PO, Ferreira AP. Pattern Aggregation of Wind Energy Conversion Technologies Using Clustering Analysis. In Computational Science and Its Applications (ICCSA), 14th International Conference on; 2014. pp. 105-110.
11. Dehghani-Arani A, Maddahi R. Introduction a multi-objective function in unbalanced and unsymmetrical distribution networks for optimal placement and sizing of distributed generation units using NSGA-II. In Electrical Power Distribution Networks (EPDC); 2013. pp. 1-9.
12. Baran ME, Wu FF. Network reconfiguration in distribution systems for loss reduction and load balancing. *Power Delivery, IEEE Transactions*; 1989. 4: 1401-1407.