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Research for a New Optimization Model of Electric Distribution Network with Wind Power

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Abstract: In the distribution network with wind power, due to the different costs of different power tariff from different power source, the minimum power loss of the distribution networks does not always correspond to the largest economic efficiency. In the most cases, to ensure the distribution network power quality at the same time get the most economic efficiency is an important goal of the enterprise. The new improved distribution network optimization model is an economic optimization model that has important theoretical and economic value. This new model can solve some problems of economic optimization of Chinese current distribution network with distributed power.

Key words: Wind power, minimum loss, economic optimization

INTRODUCTION

With the maturity of wind power generation technology, as well as the growing concern for environmental protection and sustainable development issues (Daly and Morrison, 2001; Iyer *et al*., 2006), the distributed small-capacity wind power generation equipment near the electricity load centers, most connect to distribution networks. Distributed Generation (DG) access to the distribution network will affect voltage and power loss of the distribution network and the distribution network operates for optimization more and more complex (Zhu and Tomsovic, 2002; Tapia *et al*., 2004; Niknam *et al*., 2010). In the case of certain single power supply, minimum network power loss corresponds to the maximum economic value of the optimization target. In some case, the different multi-power supply, the different power tariff. From different power source, the minimum network power loss is not the corresponding to maximum economic value consistent with the optimization objective. Considering of voltage and power in the distribution network run in normal condition, the new improved optimal model of a distribution network with distributed source, it better reflect the actual costs of supply price and obtain the best economic goals in the comprehensive running conditions.

OPTIMIZATION MODEL OF THE DISTRIBUTION NETWORK WITH WIND POWER

The objective optimization of distribution network with wind power is a multi-variable, multi-constrained nonlinear integer optimization problem. The mathematical model consists of the objective function, constraint conditions. The mathematical model consists of the objective function, constraint conditions. In the distribution network with wind power case, operation optimization objectives are: to meet the multi-constraint conditions, to improve the economic costs to a minimum value, to meet the operating range of the node voltage, to improve voltage quality, to meet the safe and reliable distribution network systems operation, to improve power capacity of wind power accepted by the distribution network. The following formula is a mathematical model of optimization of distribution network with wind power.

In Eq. 1:

- F = The objective function of economic optimization for the distribution network
- C_1 = Power tariff from traditional power generation companies
- λ_1 = Weighting factor relate to C_1
- C_2 = Power tariff from wind power companies
- λ_2 = Weighting factor relate to C_2
- P_{loss} = Power loss of the distribution network
- P_{DG} = Total power from wind turbines
- P_i = Injected active power of node i
- Q_i = Injected active power of node i
- V_i, V_j = Voltage of i, j node
- G_{ij} = Conductance connecting i node to j
- $B_{ij:}$ = Susceptance connecting i node to j node
- θ = The phase difference between i, j node voltage
- I_{ij} = The branch current between i node and j node

Subscript min and max represent the upper and lower limits of the variables. The value of λ_1 and λ_2 are defined

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in accordance with each load power of the proportion of the total power. The higher power source has higher line losses, the:

$$
\begin{cases}
F = \min(C_1\lambda_1 + C_2\lambda_2)P_{loss} \\
\qquad + (C_2 - C_1)P_{DG} - C_1\mu P_{DG} \\
\text{Sub} \\
P_i = V_i \sum\limits_{i\in N, j\in N_j} V_j(G_{ij}\cos\theta_{ij} + B_{ij}\sin\theta_{ij}) \\
Q_i = V_i \sum\limits_{i\in N, j\in N_j} V_j(G_{ij}\sin\theta_{ij} - B_{ij}\cos\theta_{ij}) \\
V_{i.min} < V_i < V_{i.max} \\
Q_{i.min} < Q_i < Q_{i.max} \\
I_{ij.min} < I_{ij} < I_{ij.max}
\end{cases}
\tag{1}
$$

lower power source has lower line losses in distribution network. Have been simplified λ_1 and λ_2 make the model equation easy to solve. In order to better solve the complex optimization model of the distribution network, the distribution network system is idealized, assume the following conditions be true (1) The load of the distribution network can be considered as the constant load in a period of time and little changes over time, (2) The admittance and susceptance of the branches are constant, (3) Wind power in a constant power input and the cast and the changes of reactive power can be quickly compensated by reactive power devices, such as capacitor banks, etc. and (4) Distribution network in the stable operation, the allowable value of the line current is greater than the operating current in the circuit. In many literatures (Venkatesh *et al*., 2000; Goswami and Basu, 1992; Lin and Chin, 1998 and Zhang *et al*., 2008), a lot of the traditional distribution network optimization objective function can be summed up as Eq. 2, as follows:

$$F = \min P_{loss} \tag{2}$$

We discuss the differences between the objective function model 1 and 2 in two cases. First case, from equation 1, when there is no wind turbine input, we can see, P_{DG} value is equal to 0, λ_1 value is equal to1 and λ_2 value is equal to 0, assume C_1 value is equal to 1, the objective function of Eq. 1 and equation is the same. When C_1 value is not equal to 1, the difference between the objective function of Eq. 1 and that of 2 is a constant. So the amplitude trends of Eq. 1-2 are the same. We can conclude that Eq. 2 is the special case of Eq. 1. In the second case, the wind turbine input the distribution network. When the C_1, C_2, ì and P_{load} in Eq. 1 is the given fixed constant, the λ_1 and λ_2 are variables related to P_{load} and P_{DG}, so the fundamental variables of Eq. 1 are P_{load} and P_{DG}. In general, the power flow in the distribution network changes in term of position and input power of the wind turbine, the distribution network loss also change simultaneously. From the Eq. 1, we can apparently see the equation 1 is not the simple objective function only determined by P_{loss}, so the minimum P_{loss} does not guarantee the minimum economic value of Eq. 1, so it has certain limitations to take Eq. 2 as norm to assess economic costs of the distribution network. The C_1 and C_2 have a great impact on the objective function of Eq. 1. The magnitude relationship between the C_1 and C_2 determine the best economic costs in the distribution network with wind power. From Eq. 1, we can easily deduce Eq. 3:

$$F = \min C_1P_{loss} + [(C_2 - C_1)(1 - \frac{P_{loss}}{P_{load}}) - C_1\mu]P_{DG} \tag{3}$$

From Eq. 3: When inequality:

$$(C_2 - C_1)(1 - \frac{P_{loss}}{P_{load}}) - C_1\mu < 0$$

holds, to improve the power of wind turbines that input the distribution network can get the best economic costs of Eq. 1. When inequality:

$$(C_2 - C_1)(1 - \frac{P_{loss}}{P_{load}}) - C_1\mu = 0$$

holds, the P_{loss} determine the best economic costs of Eq. 1. When inequality:

$$(C_2 - C_1)(1 - \frac{P_{loss}}{P_{load}}) - C_1\mu > 0$$

holds, the fitted power of wind turbines that input distribution network can get the economic costs of the Eq. 1. Based on the above discussion, we can conclude that Eq. 1 has some advantages than Eq. 2 in range of application. It has important economic significance.

ANALYSIS AND CALCULATION OF THE OPTIMIZATION EXAMPLE FOR THE DISTRIBUTION NETWORK WITH WIND POWER

In this study, the distribution network topology map is from IEEE 14 nodes power system topology, the relevant line parameters adopt typical distribution network parameters. The distribution network data is shown in Table 1. The distribution network topology map is shown in Fig. 1. In the nodes of 2, 3, 6 and 8 number of positions where are placed wind turbines whose total power capacity is 10MW. In study, we may instead symbol D_1,

Table 1: Fourteen nodes distribution data

First node	End node	Resistance (Ω)	Reactance (Ω)	Node	Node load (MW)
1	2	0.0893	0.1191	1	-
1	5	0.0840	0.1230	2	13.7
2	3	0.0409	0.0479	3	17.2
2	4	0.0581	0.0563	4	-3.9
2	5	0.0569	0.1738	5	1.6
3	4	0.0670	0.1710	6	7.5
4	5	0.0133	0.0421	7	-
4	7	0.0000	0.2091	8	-
4	9	0.0000	0.5561	9	16.6
5	6	0.0000	0.2520	10	5.8
6	11	0.0950	0.0000	11	1.8
6	12	0.1229	0.2551	12	1.6
6	13	0.0661	0.1302	13	5.8
7	8	0.1100	0.1761	14	5.0
7	9	0.0800	0.1100		
9	10	0.0318	0.0445		
9	14	0.1171	0.1103		
10	11	0.0820	0.1220		
12	13	0.2209	0.1998		
13	14	0.1709	0.3480		

Table 2: Operation data by optimization in the distribution network with wind turbines

Each wind turbine input power (MW)	Total power (P_{Total}) MW	Total power from wind turbines (P_{DG}) (MW)	Active power of load (P_{load}) (MW)	Loss of the distribution network (P_{loss}) (MW)	$C_2 = 1.1C_1$; $C_1 = 0.1$ \$; economic cost unit^{-1} of time (EC) \$ h^{-1}	$C_2 = 1.5C_1$; $C_1 = 0.1$ \$; Economic cost unit^{-1} of time (EC) \$ h^{-1}	$C_2 = 2.0\ C_1$; $C_1 = 0.1$ \$; Economic cost unit^{-1} of time (EC) \$ h^{-1}
$P_{D1} = 0$, $P_{D2} = 0$ $P_{D3} = 0$, $P_{D4} = 0$	80.95	0	77.2	3.750	375.00	375.00	375.0
$P_{D1} = 0$, $P_{D2} = 5$ $P_{D3} = 5$, $P_{D4} = 0$	80.16	10	77.2	2.956	371.77	756.45	1237.3
$P_{D1} = 0$, $P_{D2} = 5$ $P_{D3} = 5$, $P_{D4} = 5$	79.88	15	77.2	2.679	382.69	961.87	1685.8
$P_{D1} = 5$, $P_{D2} = 5$ $P_{D3} = 5$, $P_{D4} = 5$	79.56	20	77.2	2.358	389.69	1165.30	2134. 7
$P_{D1} = 5$, $P_{D2} = 10$ $P_{D3} = 5$, $P_{D4} = 5$	79.28	25	77.2	2.082	401.45	1374.50	2590.8
$P_{D1} = 5$, $P_{D2} = 10$ $P_{D3} = 10$, $P_{D4} = 5$	79.05	30	77.2	1.848	417.61	1588.90	3053.0
$P_{D1} = 5$, $P_{D2} = 10$, $P_{D3} = 10$,$P_{D4} = 10$	78.97	35	77.2	1.770	448.97	1816.90	3526.8
$P_{D1} = 10$, $P_{D2} = 10$ $P_{D3} = 10$, $P_{D4} = 10$	78.78	40	77.2	1.577	469.53	2036.80	3996.0

D_2, D_3 and D_4 of wind turbines. Each group of wind turbines can afford power capacity of 0, 5 and 10 MW. When C_2 is equal to 1.1 times C_1, C_2 is equal to 1.5 times C_1, C_2 is equal to 2 times C_1. To analyze the relationship between the best economic cost in the distribution network, minimum power loss and the position and power capacity of wind turbines. The economic costs and power loss in the distribution network are calculated by MATLAB programming language.

It is obvious from Table 2 that when the price of wind power is higher than that of ordinary power plant, the loss will apparently reduce with the distribution network inputted wind turbines, but in many conditions, the economic costs of operation will increase. The fitted position and power capacity of the wind turbines input the distribution network will acquire the best economic cost, decrease power loss and improve quality of the electric energy. Figure 2 is drawn based on data form

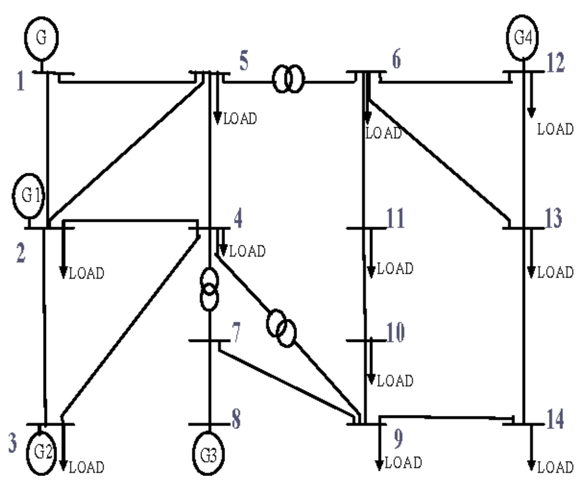

Fig. 1: Topology structure of the IEEE 14 nodes distribution network

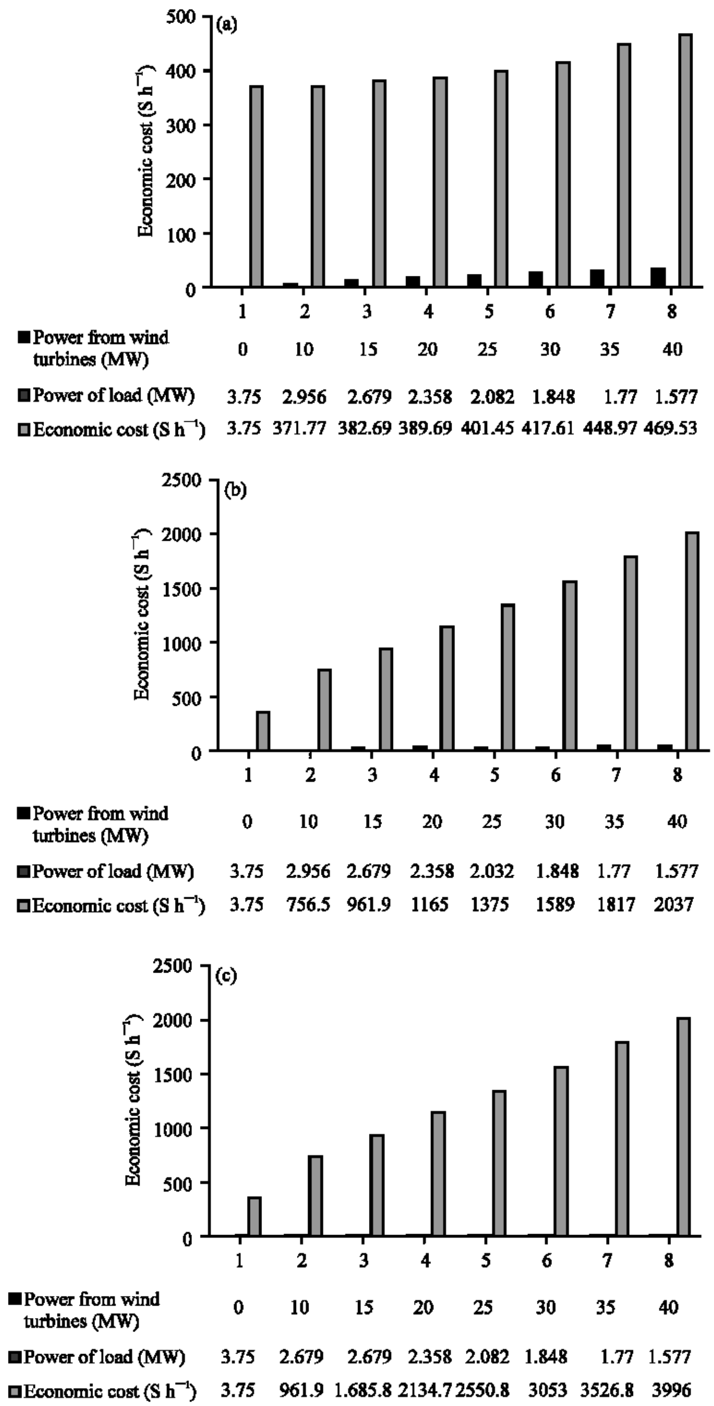

Fig. 2: Economic optimization value responds to power loss and varied price of wind power (a) $C_1 = 1.1\ C_2$, (b) $C_1 = 1.5\ C_2$ and (c) $C_1 = 2.0C_2$

Table 2. Figure 2 shows the value of economic optimization great influenced by not only network loss but also price of wind power. The price of wind power is an important factor in the economic optimization process of distribution network. When the price of wind power is clearly greater than that of conventional power plants, lower the economic cost and reduce network loss are contradictory by inputting a certain amount wind power.

In the above case, the optional value of economic cost can be obtained by inputting too slight amount or zero wind power. When the price of wind power is close to that of conventional power plants, the optional value of economic cost can be easy obtained. As discussed above, Eq. 1 is correct and reasonable that applying distribution network with wind turbines. We can get optional value of economic cost of distribution network with wind turbines. Above mentioned methods can bring power companies huge economic benefits.

CONCLUSION

The power flow will be great affected when the wind turbines input the distribution network. When the wind turbines capacity is less than total load in the distribution, in general the power loss will gradually decrease with ascent of power capacity of wind turbines. There is a great relationship between the economic costs in the distribution network and power tariffs from different power plants. When the electricity price from wind farms is no more than that of ordinary power plants, the economic costs in the distribution network will gradually decrease with ascent of power capacity of wind turbines. When the electricity price from wind farms is more than that of ordinary power plants, the best economic costs in the distribution network will be got with fitted power capacity of wind turbines. In wide range of the global, the economic costs will gradually increase with ascent of power capacity of wind turbines. This is consistent with the actual operation in the distribution network with wind turbines. Therefore, the cost optimization model in the distribution network with wind turbines has significant practical value.

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