No. O-051

Effect of Wind Turbines on Reliability of Distribution Power Systems

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Abstract

Using wind turbines as energy sources change the reliability of distribution power systems. This paper studies the effects of wind turbines on the reliability of a distribution power system. The method is based on the value-based method for a wind farms located in Iran. The obtained results show that when the wind turbines number changes, then the reliability of the power system varies non-linear. Therefore, the optimal number of the wind turbines for maximum reliability can be obtained by using value-based method.

Keywords: Wind Turbines, Reliability, Distributed Power Generation, Distribution Power System.

1. INTRODUCTION

In general, Wind turbines (WTs) are used in distribution power systems as alternative energy sources beside existing fossil power plants. The positive impacts of WTs such as reduction of greenhouse gases increase the attention on the development of using WTs in distribution networks. In last decay, the use of WTs around the world increased by 30% [1, 2].

Despite their rapid growth, WTs output power varies when the wind speed varies, therefore a reliable output power can not be produced only by WTs. In this case, the reliability of the power system changes and it is necessary to use some techniques for investigating the reliability of the power system [3, 4].

The value-based method is one of the popular techniques for dealing with the power systems reliability. There have been proposed many studies associated with the value-based techniques, but most of them deal with radial topologies. When WTs are connected to a radial distribution power system, then the network changes to non-radial system. Because, in this case, the distribution power systems are fed from two sides, on one side there are WTs and on the other side there are conventional generation (CG) sources [5].

In this paper the value-based technique based on the cost/worth concept is used for evaluating the effects of adding WTs on the reliability of power systems. The indices such as EENS (Expected Energy Not Supplied), Ecost (Expected Interruption Cost), WGIEB (Wind Generation Interrupted Energy Benefit), WGICB (Wind Generation Interrupted Cost Benefit), ENCG (Equivalent Number of Generators) and ECGC (Equivalent Conventional Generation Cost) are used. In addition, the optimal number of WTs based on the value of WGIEB will be obtained. The method will be applied for a wind farm where located in Manjil site in the north of Iran.

2. VALUE-BASED METHOD INDICES

The value-based method evaluates the reliability cost associated with different power system configurations. The reliability cost is the capital cost of the utility invested to improve reliability for consumers. It is usually difficult to evaluate the reliability cost directly; hence it is obtained by calculating some indices [4].

The most popular using indices are explained as fallow [6]:

$$WGIEB \frac{EENS_{bw} - EENS_{aw}}{Incremental\ WTG\ Capacity} \tag{1}$$

$$WGICB = \frac{ECOST_{bw} - ECOST_{aw}}{Incrementa\,l\ WTG\ capacity} \tag{2}$$

$$ENCG = \frac{RNCG}{RNWTG} \tag{3}$$

$$ECGC = \frac{RCCG}{RCWTG} \tag{4}$$

Where:

- $EENS_{bw}$: Expected Energy Not Supplied before adding WTs
- $EENS_{aw}$: Expected Energy Not Supplied after adding WTs
- $ECOST_{bw}$: Expected Interrupted Cost before adding WTs
- $ECOST_{aw}$: Expected Interrupted Cost after adding WTs
- WGIEB: Wind Generation Interrupted Energy Benefit
- WGICB: Wind Generation Interrupted Cost Benefit
- ENCG: Equivalent Number of Conventional Generation Unit
- ECGC: Equivalent Conventional Generation Capacity
- RNCG: Required Number of Conventional Generation Unit
- RCCG: Required Capacity of Conventional Generation Unit
- RNWTG: Required Number of WT Generation Unit
- RCWTG: Required Capacity of WT Generation Unit

In this paper, the indices EENS, Ecost, WGIEB, RNCG, RNWTG and ENCG are only used for evaluating the reliability of the distribution power systems.

3. SYSTEM MODEL

The system under consideration is the part of a distribution power system in Manjil site in Iran as shown in Figure 1.

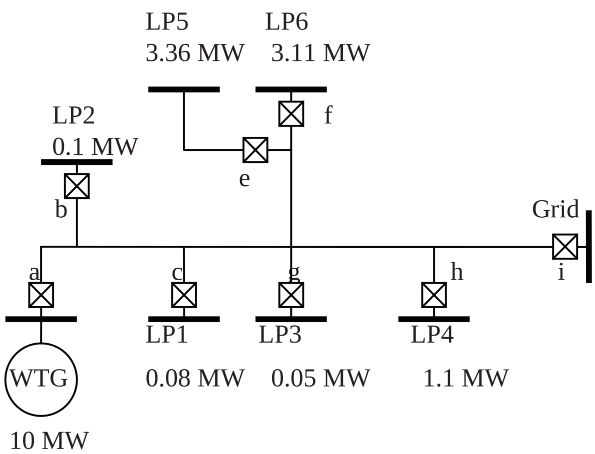

Figure 1. Power System under Consideration

As can be seen, the network is supplied by CG units on the grid side and WTs on the opposite side of the network. The size of WTs is more than the total loads and therefore, some part of generated energy by WTs could be exported to the grid.

The load points are indicated by LP1 to LP6 with the total amount of 8.4 MW. LP1 to LP3 are commercial load points and LP4 to LP5 are industrial loads.

The output power of WTs is as a function of wind velocity, humidity and other environmental circumstances; therefore the output power varies when the environmental conditions change. The annual output power of WTs under consideration is shown in Figure 2.

Figure 2 shows that the output power of WTs varies from very small amount of power nearly zero to a large amount up to 10 MW. The maximum power output will be produced during August and the minimum energy output will be generated during April and March. Therefore, sometimes power flows from WTs side to the grid side, but in most of the time the loads gets power from both sides, the grid and WTs. Hence, the network does not behave like a radial distribution network.

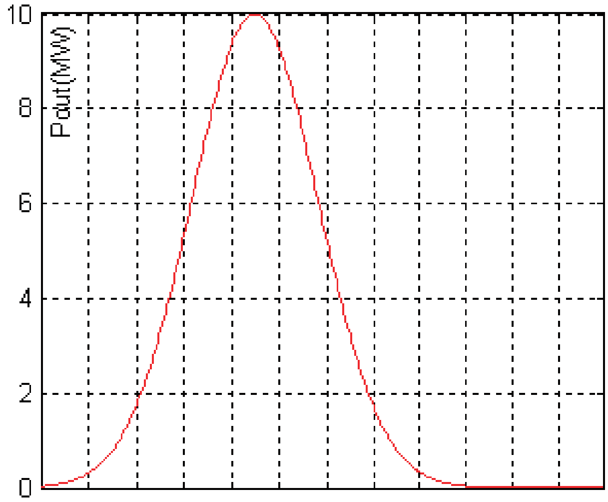

Figure 2 Output Power of WTs

Each section of the network can be disconnected by eight designated circuit breakers in Figure 1, a to i. The reliability of each circuit breaker is considered 0.98%.

The priority of load points is LP1 to LP6 for the wind farm and the load priority for the grid is LP6 to LP1 sequentially.

The average of annual maintenance of each line is also assumed 2 hours per year.

4. CASE STUDY

Three different cases have been selected for analysing the reliability of the network.

Case 1

No WTs are connected to the network.

- Case 2

  10 MW WTs are connected to the network.
- Case 3

  10 MW Conventional Generation unit is used instead of 10 MW WTs.

In each case, the reliability of the network is obtained by calculating the introduce indices. For this purpose, the fallowing procedures have been used.

- Determination of fail operation probability of each section of the network and WTs.

  (The probability of fail operation of WTs are given 4%)
- Determination of loss of power cost for each load.

  (10 $ per MW is considered as the penalty for commercial consumers and 50$ per MW is used as the penalty for industrial consumers. The load points 1, 2 and 3 are considered as the commercial consumers and the load points 4, 5 and 6 are industrial consumers).
- Determination of EENS for each load points before and after adding WTs.
- Determination of Ecost before and after adding WTs.
- Determination of indices values.

5. SIMULATION RESULTS

The MATLAB software is used for obtained results. The Figure 3 and Figure 4 show the simulation results for each three cases introduced in section V.

Figure 3 shows that the EENS value for the case 1 is higher than the values for other cases. When 10 MW WTs are added to the network, then the value of EENS reduces. The minimum of EENS will be obtained when a 10 MW conventional energy source is used instead of the WTs. Furthermore, the EENS values have linear relation with the load points' power. For example, the EENS value of LP5 is higher than the EENS value of LP6.

Figure 4 shows the Ecost values for each load points. As can be seen, the variations of Ecost values are similar to the EENS values in Figure 3. Because, the relation between Ecost and EENS is:

$$E\,cost_i = EENS_i \times COST_i \qquad (5)$$

Where

$COST_i$: The loss of power cost of the load point i.

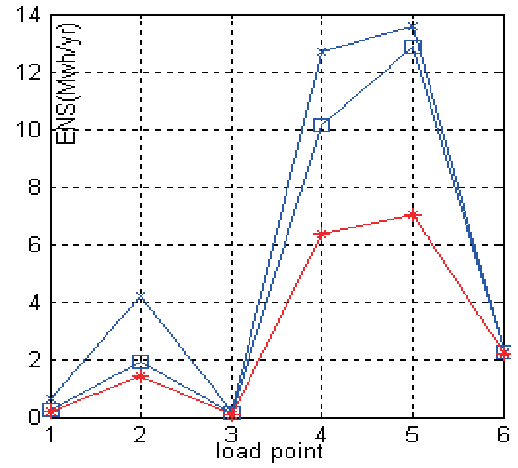

Figure 3 EENS values for each load points

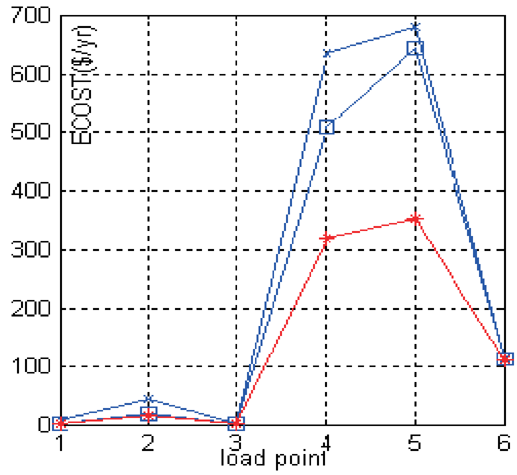

Figure 4 Ecost values for each load points

As stated before, it is considered that 10 $ per MW is the loss of power cost for load points 1, 2, 3 and 50$ per is assumed for load points 4, 5 and 6.

Figure 3 and Figure 4 show that the reliability of the power system will be changed. For obtaining the reliability of the network, it is necessary to calculate the EENS and Ecost of the network. The expressions (6) and (7) explain the EENS and Ecost relations.

$$EENS = \sum_{i=1}^{6} EENS_i \qquad (6)$$

$$E\,cost = \sum_{i=1}^{6} E\,cost_i \qquad (7)$$

The values of EENS and Ecost for the entire network in each three cases are shown in Table 1.

Table 1. ENNS and Ecost of the Network

Index \ Case	1	2	3
EENS(MWh/yr)	33.54	27.49	17.43
ECOST($/yr)	1475.6	1284.8	796.69

Table 1 shows that the EENS value decreases when WTs and conventional energy source are added to the network. By adding WTs, the EENS value reduces by 18% percent, while adding conventional energy source decreases the EENS by 48%. It is evident that adding conventional energy sources has better effect than WTs on the reliability of the power system.

The value Ecost also reduces when WTs are added to the network. For example, the difference of Ecost value between the case 1 and the case 2 is about 13%.

In addition, the annual outage of load points in three cases are studied and shown in Table 2.

Table 2 Calculated Annual Outage of Load Points (Hours/Years)

Load Point	Case 1	Case 2	Case 3
Lp1	0.62	0.22	0.21
Lp2	4.3	1.85	1.45
Lp3	0.2	0.12	0.1
Lp4	12.7	10.15	6.35
Lp5	13.6	12.85	7
Lp6	2.24	2.24	2.2

As the third column of Table 2 shows, the annual outage of load points where are near WTs have been decreased, but the related values for load points are far from WTs have less variations. For example, the annual outage of LP1 has decreased from 0.62 to 0.22, but the value of LP6 has remained at 2.24.

Better figure of the reliability will be obtained if the WGIEB index is calculated. Figure 5 shows the variations of WGIEB when the number of WT changes. In this case, each WT has 1 MW capacity.

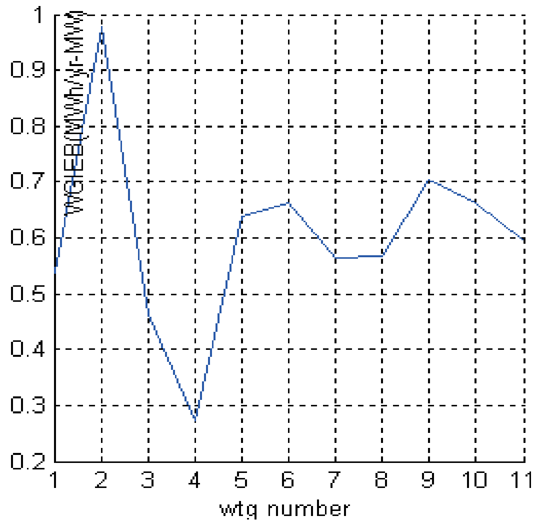

Figure 5 WGIEB variations

Figure 5 shows that better benefit obtained when the number of WTs is 2.

For calculating ENCG, it is required to calculate the Ecost variation of the network when the number of WTs and conventional generation unit change. The variation of Ecost has been shown in Figure 6.

Figure 6 shows that for a specific Ecost, for example near 1300 $/Year, The require number of WT is 10 (RNWTG=10) and for the same Ecost the required number of conventional generation unit is 3.6. Therefore, ENCG is 0.36.

$$ENCG = \frac{RNCG}{RNWTG} = \frac{3.6}{10} = 0.36$$

In other words, the Ecost of 10 unit of WT is equal with the Ecost of 3.6 conventional generation unit.

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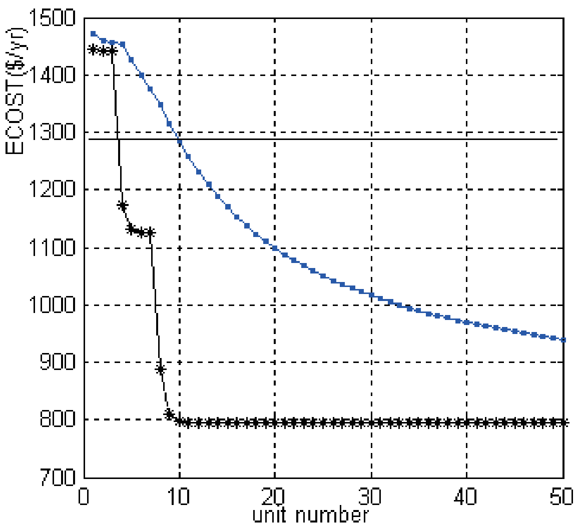

* Conventional Generation Unit

• WT

Figure 6 Ecost Variations when WTs or Conventional Generation Unit Varies

6. CONCLUSION

This paper showed that the effects of WTs on the reliability of the network had a different affect in compare with conventional generation unit. The reliability of the network changed when the velocity and output production of WTs varied. This feature of WTs is the main factor for reducing the reliability of the network in comparison with the conventional generation units, although adding WTs to the network increases the reliability of the entire network.

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8. BIOGRAPHIES

Hossein Kazemi Kargar was born in Tehran, Iran in 1969. He received the B.Sc. and M.SC. degree in electrical engineering in 1993 and 1996, respectively, from Sharif and IUST University in iran. He recieived phd degree in electrical engineering in 2002 from Amir Kabir University of Technology in Iran. He is now as Professor Assistance of Electrical and Computer Engineering in Department of Shahid Beheshti University (SBU), Iran. His research of interests is power system protection and power quality.

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