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Review Article

PRESENTING A METHOD FOR THE ANALYSIS OF WIND POWER PLANT IMPACT ON RELIABILITY INDEXES AS WELL AS FORECASTING THEM BASED ON WIND REPETITION PATTERNS

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ABSTRACT

Presented in this article, is a method for calculating two important reliability indexes which are LOLE and LOEE based on wind velocity static information. In order to achieve this goal, 6-bus test network of RBTS and connection of the modeled wind power plant to one of its turbines are used. Information of production, the network load curve, and statistic information of Yazd winds velocities obtained during 10 years are used. After that, Seasonal calculations of reliability indexes are used which leads the computational accuracy to be heightened compared with annual computations. Furthermore, a novel method is given for wind plants production and subsequently, for LOLE and LOEE indexes to be forecasted. Later, in order to assimilate the behavior of surveying test network with Iran power network, the load durability curve of this network has been moved. The results furnished, show a significant impact of using seasonal patterns on reliability indexes values.

Keywords: *Wind Repetition Pattern, Wind Seasonal Pattern, Random Production, Reliability Index, Wind Power Plant*

INTRODUCTION

As power consumption and industrial development increase, the need to intensify energy production and production units expanding have been dramatically increased compared to the past. Nowadays, due to diversity in energy production, being clean and bringing less damage to the environment, the extent of resources, no need to carry, and increasing the price of fossil fuels, utilizing renewable energies is on the way to be increased. Among all these, using wind energy and power plants has higher importance since it is cheaper, producing greater amount of energy, and vastly available concerning the geographical level. Production rate of these power plants is random because the wind itself has random and unpredictable characteristics.

In addition, the arguments related to network security and load-providing reliability have been taken into account after entering some discussions such as electrical power market to the area of electrical engineering particularly, in recent years. Therefore, we are having trouble planning and estimating the production of the networks containing wind turbines. Two conventional methods are available for analyzing the effect of random production on networks' production and their judging which power plants are included. These methods are: 1- Monte Carlo method, 2- Using COPT table which is based on the analysis of each power plant's output probability.

First in this article, we will examine wind turbines and their production characteristics. Then, reliability indexes and the test network used will be introduced. It should be mentioned that in this survey, COPT method and a proposed method are used as a conventional method and a method based on Yazd's real wind speed information in various years, respectively. Consequently, the impact of these power plants on networks reliability indexes and the effect of power plant region's wind speed pattern adaptation on network load profile will be furnished. Finally, the conventional and proposed method will be compared.

Wind Velocity Pattern

Information used in this article is based on 10-year statistics of the Yazd city obtained from Meteorological Organization. The average wind speed in this region was 5 m/s during this period. Probable distribution curve of wind speed obtained by distribution abundance is brought in figure 1.

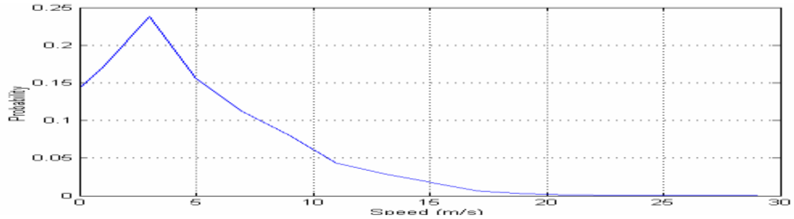

Figure 1: The graph of Yazd wind speed

The standard altitude to analyze the wind velocity is 10 meter. The turbines used in this study are placed on the towers at the height of 50 and 70 meter from the ground thus, in order to use this information they should be converted to more appropriate values. Concerning the height of 50 meters for wind turbines and taking into account that there is no significant increase in wind velocity after the altitude of 50m, a suitable ratio will be obtained for converting the information related to wind velocity using equation 1 (One of the most common relations presented by ASCEF-93 regulation in the year 1993, is the regulation of loading the masts (Billinton, 2000).

$$\mathbf{V_T = V_0 \left(\frac{h_T}{h_0}\right)^{\frac{1}{7}}} \qquad \mathbf{(1)}$$

In this equation V_T, V_0, h_T, and h_0 are wind speed at the height of turbine (m/s), wind speed at the height of 10m (m/s), installing height of the blades from the ground, and anemometer height which is at altitude of 10m, receptively (Billinton, 2000).
Concerning the 60m height for wind turbines and with bearing in mind that wind velocity does not increase significantly after the altitude of 50m, an appropriate ratio for conversion of wind velocity information can be furnished using equation 2.

$$\mathbf{V_T = V_0 \left(\frac{50}{10}\right)^{\frac{1}{7}} = 1/26\ V_0} \qquad \mathbf{(2)}$$

Wind Power Plant Modeling
Wind power plants consist of several wind turbines. These turbines can be whether from a same type or diverse. The output power of these power plants is equal to sum of the all wind turbines' output powers. If all the turbine are of a same kind and have the output power of X, the output rate of power plant can be obtained using equation 3 (Hung, 2011).

$$P=\beta X \qquad \mathbf{(3)}$$

In this equation $\boldsymbol{\beta}$ is equal to the number of turbines existed in the power plant. Furthermore, a correlation ratio will be placed in this equation which depends on the wind power plant arrangement. The value to this ratio is considered 0.95. As a result, equation 4 is as follows:

$$P=0/95\beta X \qquad (4)$$

Wind Turbines Characteristics
Wind turbines have different traits compared to conventional generators. The output of wind turbines is a function of wind velocity and there is a linear relation between the wind speed and its output. The relation of wind turbines output produced by wind is able to be calculated using velocity-power curve. Figure 2 shows a sample of this attribute (Dobakhshari, 2009).

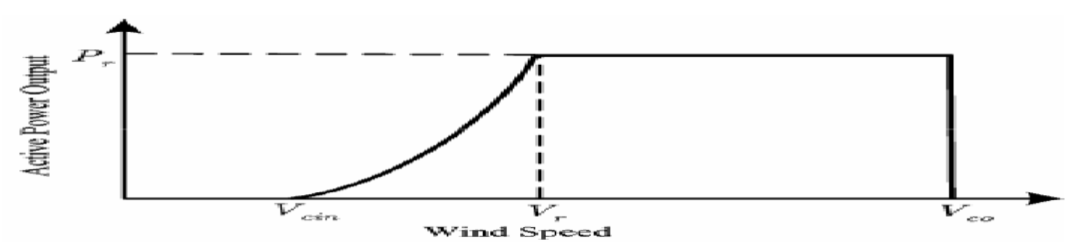

Figure 2: Velocity-power curve

AS shown in this figure, when wind speed reaches to V_{Cin} value, wind turbines start their production and they reach their nominal production in the speed of V_r. If the wind speed continues to increase, turbines output will be fixed at p_r value as long as the wind speed reaches the value of V_{co}. In the case that wind speed continued to increase more than V_{co}, turbines will be locked to avoid mechanical damages and thus, the output would be zero. The mathematical equation related to power-velocity curve is brought in relation 5 (Zani, 2009).

$$P_{wt} = \begin{cases} 0 & X < V_{cin} \\ P_r \times (A + BX + CX^2) & V_{cin} < X < V_r \\ p_r & V_r < X < V_{co} \\ 0 & X \geq V_{co} \end{cases}$$

Which A, B, and C are fixed values that they are depending on turbine attributes and their relations are given in reference (Chowdhury, 2012). Turbines used in the research, have the values of V_{cin} = 4 m/s, V_r = 15 m/s, V_{co} = 30 m/s, P_r = 2.5 MW, and they are made in Denmark (Haghifam, 2010).
Number of turbines used in this article is 8. As a result, the wind power plant output power should be 20 MW. After the turbines concurrency index considered 0.95 is entered, the nominal power of wind power plant will be 19 MW (Chowdhury, 2012).

The Analysis of Wind Power Plants Probability Pattern

The conventional method to add information into COPT table is grading the wind power plants output power. In other words, wind power plant is considered like conventional power plants with several outputs. It is clear that the more the number of levels is, the more the computation accuracy will be. In this study, output power of each turbine is divided into 6 different levels. According to the output power of 2.5 MW for each turbine, these levels are 0, 0.5, 1, 1.5, 2, and 2.5 MW.

Table 1: Ranges of occurrence probability assessment at each power level

Output Power	Occurrence Probability
P (P_W = **0**)	P(P_W <**0/2**)
P (P_W = **0/5**)	P (**./2** ≤ P_W <**0/6**)
P (P_W =**1**)	P (**./6**≤ P_W<**1**)
P (P_W = **1**)	P(**1** ≤ P_W <**1/4**)
P (P_W = **2**)	P(**1/4** ≤ P_W <**1/8**)
P (P_W = **2/5**)	P(**1/8** ≤ P_W)

Power occurrence probability at each level will be obtained based on their abundance after converting the wind 10-year information to output power. Evaluating ranges are shown in table 1. P and P_w show the occurrence probability and output power, respectively.

Computing the Reliability Indexes of Rbts

Reliability Indexes

There are numerous indexes to analyze power networks' reliability which each one brings a different issue for the matter of reliability.
However, two indexes of LOLE and LOEE are of the most important indexes. LOLE is shorted for Loss of Load Expectation and LOEE stands for Loss of Energy Expectation. Their mathematical equations are as in relation of 6 and 7.

$$\text{LOLE} = \sum_{i=1}^{2^n} p_i \times t_i \quad (6)$$

In this equation, n, P_i and t_i are the number of network's power plants, the probability of event occurrence out of the power plant or concurrence exiting of several power plants from the circuit, and the period of inactivity as the result of this event without concerning the blackout extent, respectively.
In other words, LOLE analyze that how much blackout we have in a corner of the network due to lack of production annually.

$$\text{LOEE} = \sum_{i=1}^{2^n} P_i \times E_i \quad (7)$$

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In this relation, n, P_i, and E_i are the number of power plants in the network, probability of a production capacity exiting, and the amount of unsupplied energy due to this exit, respectively. The E_i amount is gained by crossing the curve of production rate after each event from the load durability curve (LDC) which is relating to the surveying time interval.

Test Network of RBTS

Roy Billinton Test System is a 6-bus system. This network has generator efficiency and its load peak is 185 MW. Its load curve is similar to load curve of RTS system. The load durability curve can be obtained from the load curve as well. The information relating to generators capacity and forced output rate (F.O.R) is given in table 2 (Billinton, 2011). Furthermore, one-line diagram of this system is drawn in figure 3.

Table 2: Capacity and the forced output rate of RBTS generators

G_i	P_r(mw)	F.O.R
G_1 , G_2	**40**mw	**0/03**
G_3	**10**mw	**0/02**
G_4	**20**mw	**0/025**
G_5 , G_6	**5**mw	**0/01**
G_7	**40**mw	**0/02**
G_8 ,G_9, G_{10},G_{11}	**20**mw	**0/015**

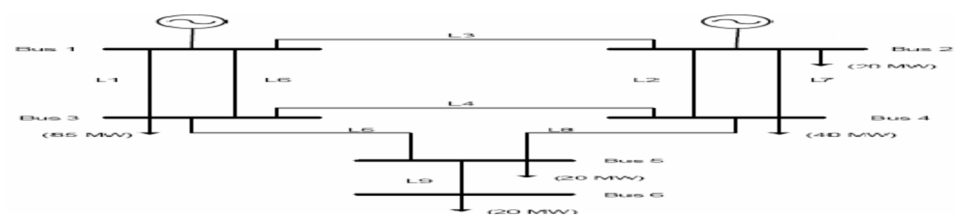

Figure 3: RBTS test network

As mentioned earlier, the method of COPT table has been used in this article to calculate the reliability indexes. Based on this, after obtaining the load durability curve (Figure 4) according to what mentioned in the previous part, first each of the generators and then various combinations of their n-ary states in each row of COPT table with probabilities computed by generators damage rate will be obliterated. Analyzing these states based on the sum of breakout hours and lost load amount, LOLE and LOEE will be furnished. The LOLE and LOEE of RBTS networks are 1.0919 hour/year and 9.8613 mwh/year, respectively.

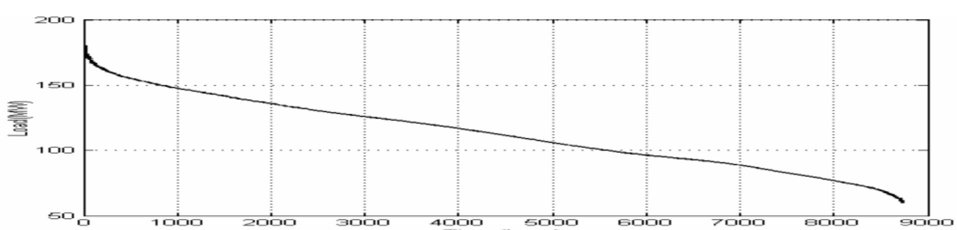

Figure 4: Load durability curve

Adding Wind Power Plant

As stated in the previous section, turbines used in this study have the capacity of 2.5 MW. The number of these turbines is 8 in the wind power plant. Using equation 8 we will have:

$$P=0/95\times8\times2/5 = 19 \text{ mw} \tag{8}$$

Thus, nominal power of the wind power plant is 19 MW. We divide this power into 6 levels which are 0, .8, 7.6, 11.4, 15.2 and 19 MW.

The results of this feasible matrix and the feasibilities analysis intervals based on abundance are given in table 3.

Table 3: The evaluation of occurrence feasibility in each level of power

Output Power	Occurrence Feasibility
P(PW=**0**)	P(PW≤ **1/8**)=**0/46712**
P(PW=**3/8**)	P(**1/8**< PW ≤ **5/6**) =**0/18921**
P(PW=**7/6**)	P**5/6**< PW ≤ **9/4**) =**0/04521**
P(PW=**11/4**)	P(**9/4**< PW ≤ **13/3**) =**0/046675**
P(PW=**15/2**)	P(**13/3**< PW < **17**) =**0/057612**
P(PW=**19**)	P(**17**≤ P_W)=**0/1479**

Feasibility occurrence of each production level for the power plant installed in Yazd will be achieved based on abundance of table 2. LOLE and LOEE values are 0.6687 hr/yr and 5.9721 mwh/yr, respectively. Concerning the numbers of production power levels, turbines in the power plant and with assumption of no concurrence of two or more turbine failures, the forced output rate (F.O.R) of wind power plants are omitted in this study.

Computing the Indexes Based on Monthly Patterns

In the previous section, annual wind speed information was used for reliability computations taking into account that wind speed does not follow a specified pattern throughout the year. However, concerning wind velocity statistics in the city of Yazd, the wind has higher speed in early months of the second half of the year. Shown in figure 5, is the curve of daily wind velocity average during the surveying time.

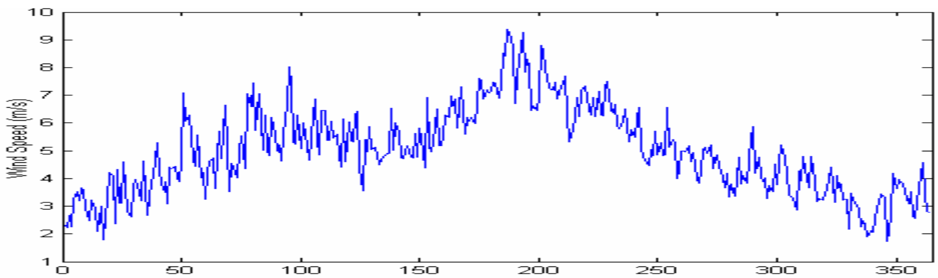

Figure 5: Daily average of wind velocity

In this section with separate analysis of information related to wind speed in each month, we calculate the indexes of that month. As an example, figure 6 shows the information of RBTS system's load durability curve in the months of fall season.

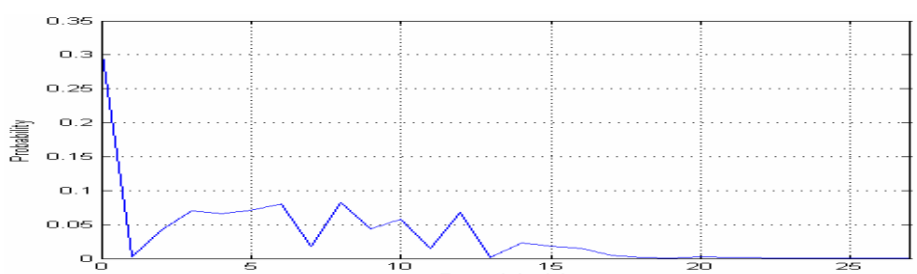

Figure 6: Load durability curve of RBTS system for the fall season.

Based on this matter, COPT table should be formed each month and subsequently, indexes values should be furnished for that. Consequently, annual values will be extracted using equations 9 and 10.

$$\text{LOLE} = \sum_{i=1}^{12} LOLE_i \quad (9)$$

$$\text{LOEE}= \sum_{i=1}^{12} LOEE_i \quad (10)$$

In these relations, **I** shows the number of months. Calculated values of monthly reliability indexes are presented in table 4.

Table 4: Monthly reliability indexes

Month	LOLE $^{hr}/_{month}$	LOEE $^{mwh}/_{month}$
January	**0/07068**	**0/66812**
February	**0/02169**	**0/22817**
March	**0/00517**	**0/0417**
April	**0/00819**	**0/071101**
May	**0/03471**	**0/41512**
June	**0/046217**	**0/38977**
July	**0/01101**	**0/089518**
August	**0/00398**	**0/035712**
September	**0/00312**	0/02767
October	**0/01689**	0/15193
November	**0/15717**	1/34715
December	**0/45912**	4/17916

Using equation 9 and 10, we can calculate the annual LOLE and LOEE which are 0.807 hr/yr and 7.325 mwh/yr, respectively. It should be said that the difference between annual indexes computed with annual pattern and annual values obtained from monthly calculation in the state of wind power plant presence, is due to increasing computation accuracy and using monthly behavioral patterns.

Indexes Computation Based on Seasonal Information

In this part with separate analysis of information related to wind speed in each month, we compute the indexes of that month. Similar to the previous part, RTS 79 system information is used in this section. As a result, every year contains 52 weeks which every 13 weeks is assigned to each season. The first, second, third, and fourth 13 weeks are related to winter, spring, summer, and fall, respectively. Presented in figure 7, is the load durability curve information of RBTS system for each season separately. In addition, output power occurrence feasibility related to wind power plant in each level is considered, the power for each season is noticed separately, and they are brought in table 5.

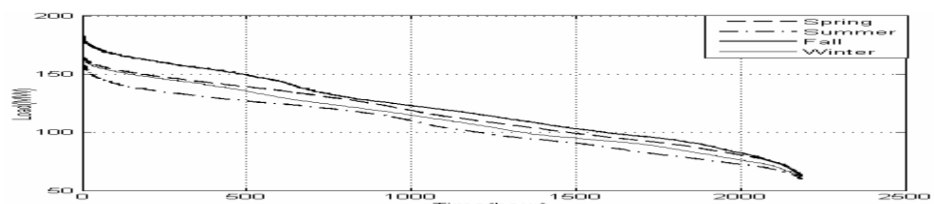

Figure 7: Load durability curve of RBTS system for every season

Table 5: Occurrence feasibility for each power level in different seasons

Season pw	Winter	Spring	Summer	Fall
0 mw	0/4082	0/2066	0/1893	0/4533
3/8 mw	0/4104	0/5174	0/4519	0/4310
7/6 mw	0/0583	0/1042	0/1111	0/0438
11/4 mw	0/0378	0/0633	0/0854	0/0255
15/2 mw	0/0096	0/0168	0/0269	0/0084
19 mw	0/0657	0/0917	0/1353	0/0380

Calculated values related to reliability indexes in this phase as well as the values related to RBTS system without the presence of wind power plants are brought in table 6 and 7.

Table 6: Seasonal indexes without the presence of wind power plant

Season	LOLE $^{hr}/_{Season}$	LOEE $^{mwh}/_{S}$
Winter	0/1267	1/1532
Spring	0/1674	1/4606
Summer	0/0519	0/4359
Fall	0/7458	6/7924

Table 7: Seasonal indexes in presence of wind power plants

Season	LOLE $^{hr}/_{Season}$	LOEE $^{mwh}/_{S}$
Winter	0/0894	0/8129
Spring	0/0983	0/8714
Summer	0/0273	0/2386
Fall	0/5595	5/0231

Using the equations 11 and 12, annual LOLE and LOEE can be furnished as well. These values are 0.7265 hr/yr and 6.672 mwh/yr, respectively. The difference between annual indexes values computed previously, annual pattern and this annual value obtained from seasonal computations is because of wind current behavior pattern and calculating accuracy increase.

$$LOLE = LOLE_{Winter} + LOLE_{Spring} + LOLE_{summer} + LOLE_{fall} \quad (11)$$

$$LOEE = LOEE_{Winter} + LOEE_{Spring} + LOLEE_{summer} + LOEE_{fall} \quad (12)$$

Indexes Comparison Based on Monthly Division and Iran Network Consumption Pattern

In this section, concerning Iran's consumption pattern which is a completely different pattern compared to RTBS system, computations will be repeated and results will be analyzed. Figure 8 shows Iran's 12-month profile for analyzing load durability curve.

Iran's load peak is higher in warm seasons compared to cold ones. If the load profile related to various months of the year which its sample is given figure 6 changes like what has been brought in figure 8, RTBS modified load profile will we changed to Iran power network's load profile.

Table 8: The comparison of monthly maximum load in seasons' order between the RTBS system and Iran network

Maximum load order	RTBS load pattern	Iran network load pattern
1	December	August
2	November	July
3	June	June
4	January	October
5	May	May
6	October	September
7	July	January
8	February	November
9	April	April
10	August	February
11	September	March
12	March	December

It should be noticed that the only difference between the computations of this section and the previous one is related to replacement of LDC curve thus, feasibility matrixes of power level will not be changed.
It is worth mentioning that we experienced a significant decrease in indexes values and a remarkable increase in feasibility as well. This diminishing is in relation with wind velocity traits in Yazd. For instance, wind high speed in months of July and August meaning the consumption peak and subsequently, higher feasibility in wind power plant more production leads to lack of power feasibility decrease which is because of other power plants' outputs.

Table 9: Feasibility indexes for modified RTBS network based on monthly patterns

Month	LOLE $^{hr}/_{month}$	LOEE $^{mwh}/_{month}$
January	**0/02591**	**0/197677**
February	**0/008642**	**0/064178**
March	**0/004894**	**0/035926**
April	**0/011254**	**0/110251**
May	**0/031476**	**0/212760**
June	**0/042966**	**0/314269**
July	**0/061009**	**0/49786**
August	**0/202134**	**1/67892**
September	**0/010078**	**0/076297**
October	**0/059735**	**0/499917**
November	**0/025833**	**0/197813**
December	**0/004446**	**0/027878**

Using equations 9 and 10, LOLE and LOEE can be obtained 0.4224 hr/yr and 4.1927 mwh/yr, respectively. As it can be seen, we have 27% and 37% of decrease in terms of the previous relating values based on wind velocity pattern and annual load profile, and in terms of the previous values which there was no adaptation between wind speed behavior and load peak, respectively.
Indexes Calculation Based on Seasonal Division and the Consumption Pattern of Iran Network
This part is brought to complete the previous one. Concerning Iran consumption pattern, computations and analyses will be started. Brought in table 10, is Iran four seasons' load profile for evaluating the load durability curve. Load peak is higher in the warm seasons compared to the cold ones.
If we change the load profile of winter, summer, and fall presented in figure 7 with seasons of fall, winter and summer, respectively, RTBS modified profile will be changed to Iran power network load profile.

Table 10: The comparison of the seasonal maximum load between RBTS system and Iran network

Maximum load order	RTBS network load pattern	Iran network load pattern
1	Fall	Summer
2	Spring	Spring
3	Winter	Fall
4	Summer	Winter

It is interesting to know that with assimilation in this phase, we were able to see a significant reduce in indexes and an increase in feasibility.
This reduce is due to Yazd wind speed attributes. In addition, we have these traits in most of the desert parts of Iran.

Table 11: Indexes based on seasonal pattern for modified RBTS network

	Season	LOLE $hr/_{season}$	LOEE $mwh/_{yr}$
Modified RTBS in presence of wind power plant	Winter	**0/0385**	**0/3148**
	Spring	**0/0976**	**0/7978**
	Summer	**0/4721**	**3/8792**
	Fall	**0/0899**	**0/7876**

It should be noticed that the only difference between the computations of this section and the previous one is related to replacement of LDC curve therefore, feasibility matrixes of power level will not be varied. Results are shown in table 11. Utilizing equation 9 and 10, yearly feasibility indexes are able to be gained. Table 12 shows these measurements which are computed in four different stages.

Table 12: Computation indexes during 5-step stages

Computations stages	LOLE $hr/_{yr}$	LOEE $mwh/_{yr}$
RTBS without the presence of wind power plant	**1/0876**	**9/7112**
Annual computations of RBTS network in presence of wind power plant	**0/6989**	**6/128**
Seasonal computations of RTBS network in presence of wind power plant	**0/7452**	**6/715**
Sesonal computations of modified RTBS network in presence of wind power plant	**0/6417**	**5/3417**

Indexes Forecasting Based on Seasonal Repetition Pattern of Wind Velocity

In this part, we use statistical information and wind repetition pattern to predict the production amount of the network using feasibility indexes. Concerning daily, monthly and seasonal average speed of various weather stations including Yazd's station, it can be concluded that these indexes follow an approximately predictable and repeatable frequency. In other words, using monthly and then seasonal average wind speed in a specific year, we can achieve an acceptable estimation of average wind speed of that season in the next year. Although computations related to feasibility indexes are based on daily and hourly wind speeds, concerning the extent amplitude of monthly and seasonal speeds which its difference for a specific season in various years in one place is approximately 8 times more, accepting the seasonal wind speed as a criterion for the amount of daily and monthly velocities, and noticing regional relative stability of each region, wind seasonal repetition pattern can be exploited to prognosticate the production of wind power plants.

In an innovative design used in this study, following step are suggested in order and separately to compute reliability indexes.

1. Grouping the i^{th} season of various years based on seasonal average wind speed.
2. Forming the power feasibility matrix using all the daily wind speed information for each group.
3. Using power feasibility matrix related to the i^{th} season group in order to calculate feasibility indexes of the next year's i^{th} season.

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CONCLUSION

It is tried in this article to present a new method for computing the reliability indexes and a better analysis of wind power plant place. The city of Yazd was chosen in this study. The average wind speed was 5 m/s during the study. However, in addition to the acceptable wind speed in the region, wind behavior pattern is the thing that justifies the installation of wind power plant in this area. Analyzing the results relating to advantages of installing a power plant in Yazd came into the point that noticing the wind velocity pattern of Yazd which shows the high velocity of wind in some seasons adapted to the load peak season, establishing wind power plants in this region was pretty suitable for production increase and improvement of feasibility indexes. Therefore, installing wind power plants in this region is completely legitimate. Furthermore, towards increasing the computation accuracy, these indexes are computed separately for each month and each season. In the next step in order to create a similarity between Iran load pattern and RTBS, modified RTBS network was analyzed. Results obtained showed the considerable impact of monthly and seasonal adaption of wind speed with load profile, which this amount was roughly 27% for the city of Yazd. Finally, a creative method was presented for forecasting feasibility indexes according to grouping based on seasonal wind speed average and using daily information of group wind velocity which the correspondent season of the previous year was existed in that group.

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