pp.85:90

Reliability Assessment of Power Generation Systems in Presence of Wind Farms Using Fuzzy Logic Method

Shohreh Monshizadeh[1], Mahmoud Reza Haghifam[2], Ali Akhavein[3]

[1] Electrical Engineering Department, Islamic Azad University-South Tehran Branch, Tehran, Iran, Email: Bargh257@yahoo.com
[2] Electrical Engineering Department, Islamic Azad University- South Tehran Branch, Tehran, Iran, Email: haghifam@ieee.org
[3]Electrical Engineering Department, Islamic Azad University- South Tehran Branch, Tehran, Iran, Email: a-akhavein@azad.ac.ir

Abstract

A wind farm is a collection of wind turbines built in an area to provide electricity. Wind power is a renewable energy resource and an alternative to non-renewable fossil fuels. In this paper impact of wind farms in power system reliability is investigate and a new procedure for reliability assessment of wind farms in HL1 level is proposed. In proposed procedure, application of Fuzzy – Markov for wind speed modelling and calculating reliability indices by probabilities of generation units by calculating state transition matrix is proposed. Fuzzy logic for this method will be possible to calculate the reliability in accordance with the existing uncertainties.
Fuzzy-Markov approach is appropriate for wind farms that have insufficient data of wind speed. In this theory, by state transition probability matrix solution can be obtained probabilities of states of fuzzy- Markov model, by solving state- space differential equation. Finally, the authenticity of approach is shown with some simulation.

Keywords: Wind farm, Fuzzy logic, Markov model, Reliability indices.

1. Introduction

Large wind farms consist of hundreds of individual wind turbines which are connected to the electric power transmission network. For new constructions, wind generation is an inexpensive source of electricity, competitive with or in many places cheaper than fossil fuel plants therefore Wind generation is one of the best sources of renewable energy for production of electrical energy in the recent years [1]. Wind power, as an alternative to fossil fuels, is plentiful, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation and uses little land. The effects on the environment are generally less problematic than those from other power sources. Wind generation has become competitive with other power generation sources then it is as useful substitute for conventional generation especially electrical energy derived from fossil resources [3].

Due to variation of wind speed in time, wind generation sources have different behaviour Therefore reliability evaluation of power system including wind farms is not easy and it needs to use of a new approach for reliability calculation. Application of wind power in power systems has created the most challenge in system planning and operations [6, 8].

Reliability of power system is defined as the ability of power system. In reliability studying, power system can be divided into three sections including generation, translation and distribution. Based on this categorization, reliability calculation will also be divided into three levels that are defined HL1, HL2, and HL3. The first level (HL1) is considered for load and generation system. In the second level (HL2), the reliability calculation is performed considering both generation and transmission and in the third level (HL3), distribution network is considered [4]. According to these levels, there are many methods for reliability calculation of power system, especially in presence of wind farms.

Some of these methods need long terms data of wind speed for modelling but in many areas that is a suitable location for using of wind farms, may not exist sufficient data of wind speed for modelling then insufficient data of wind speed can be used for modelling wind farm. In this paper, will be used of a new approach for wind farms modelling in power system by insufficient data of wind speed based on fuzzy logic and Markov model.

This paper proposes a method for reliability evaluation of wind farm in the level of production. State-space diagram is used to represent the changes wind speed and also it can be use for representation transition rates in fuzzy-Markov model. Because of used of insufficient wind speed data in this paper is calculated states transition matrix in Markov model by fuzzy method. Fuzzy transition matrix based on wind speed data in period time is considered then by using of non-fuzzy method; exact values of probability states of fuzzy-Markov model are calculated then reliability indices can be calculated of wind farms. Loss of load expectation (LOLE) and loss of energy (LOEE) are considered as reliability indices.

Fuzzy-Markov approach is appropriate for wind farms that have insufficient data of wind speed. The fuzzy- Markov approach models wind speed with Markov chain and departure rates of each states are fuzzy probabilities.

2. Fuzzy Sets

A non-fuzzy set we can define a characteristic function in the following form [9].

$$X_A(x) = \begin{cases} 1, x \in X \\ 0, x \notin X \end{cases} \quad (1)$$

The ordinary sets can be stated in form of fuzzy sets theory. As the idea is extended to fuzzy sets, characteristic function is generalized to a membership function in which each member corresponds to a value in the interval [1,0] instead of corresponding to either the values {1,0} only. Membership degree of 1 demonstrates the fact that a given member entirely belongs to the fuzzy set. On the other hand, the membership degree of 0 implies that a given member is not tied up with the specified set. Membership function of the fuzzy set is represented by μ_f and is defined using the following relation [10].

$$\mu_f : X \to [0,1]$$
$$F = \left\{\left(x, \mu_f(x)\right) \middle| x \in X \text{ and } 0 \le \mu_f \le 1\right\} \quad (2)$$

Mathematical Operators in fuzzy sets theory can be operated on fuzzy numbers calculation, such as summation $(+)$, subtraction$(-)$, multiplication $(*)$ or division$(/)$. Assume $(*)$ is a mathematical operator using generalized concept, $\tilde{A}(*)\tilde{B}$ is defined as:

$$\mu\big(\tilde{A}(*)\tilde{B}\big)(Z) = SUP_{Z=x*y} min\{\mu\tilde{A}(x), \mu\tilde{B}(x)\} \quad (3)$$

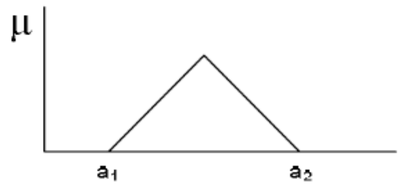

Fig.1. Fuzzy number A

Fig.1 shows the representation of triangular fuzzy number. If A and B are triangular fuzzy numbers, principal fuzzy operations are defined as fallowing [3, 9].

$$A(+)B = [a_1 + b_1, a_2 + b_2]$$
$$A(-)B = [a_1 - b_1, a_2 - b_2] \quad (4)$$
$$A(.)B = \left[min\left(a_i . b_j\right), max\left(a_i . b_j\right)\right]$$
$$A(/)B = \left[min\left(a_i / b_j\right), max\left(a_i / b_j\right)\right]: 0 \notin B$$
$$I, j = 1, 2$$

3. WPG Power Output Model

The wind turbine generator system operation is permanently determined by the variation of wind speed. This relationship between the output power of a WTG and wind speed is shown in Fig 2. The vertical axis is the value of power output of the wind turbine $P(SW_i)$ and the horizontal axis is the wind speed. A mathematical model for the power output of WPG is given as 5 .The power, P_i generated by wind speed band SW_t can be formulated as 5. Where, 'I 'is the number of wind speed band.

At very low wind speeds, there is insufficient torque exerted by the wind on the turbine blades to make them rotate. However, as the speed increases, the wind turbine will begin to rotate and generate electrical power. The speed at which the turbine first starts to rotate and generate power is called the ***cut-in speed***. As the wind speed rises above the cut-in speed, the level of electrical output power rises rapidly as shown. The power output reaches the limit that the electrical generator is capable of. This limit to the generator output is called the rated ***power output*** and the wind speed at which it is reached is called the ***rated output wind speed.*** At higher wind speeds, the design of the turbine is arranged to limit the power to this maximum level and there is no further rise in the output power.

As the speed increases above the rate output wind speed, the forces on the turbine structure continue to rise and, at some point, there is a risk of damage to the rotor. As a result, a braking system is employed to bring the rotor to a standstill. This is called the ***cut-out speed***

In this following, four basic states of wind speed variation are represented.

Where,

$V_{ci}: the\ cut-in\ speed\ [m/sec]$.

$V_R: the\ rated\ speed\ [m/sec]$.

$V_{CO}: the\ cut-out\ speed\ [m/sec]$.

$P_R: The\ rated\ power[MW]$.

$$P(SW_i) = \begin{cases} 0 & ,0 \leq SW_t < V_{ci} \\ (A + B.SW_t + C.SW_t^2).P_r & ,V_{ci} \leq SW_t < V_r \\ P_r & ,V_R \leq SW_t < V_{CO} \\ 0 & ,\ SW_T \geq V_{CO} \end{cases} \quad (5)$$

Constants A, B and C as expressed in [7].

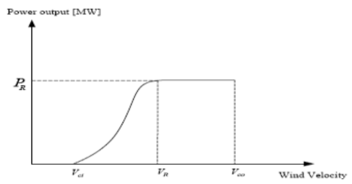

Fig.2. Power curve of wind turbine

4. RBTS Model

The RBTS is utilized to model of wind farm that has reasonable generation system adequacy [1].

In this paper, will be considered Duplex states of the generator outage and reliability data for the RBTS are shown in table1. Structure of the RBTS is shown in fig3. Load model is in basis of IEEE-RTS chronological load profile with annual peak load is 185 MW. Load duration curve is illustrated in fig.4.

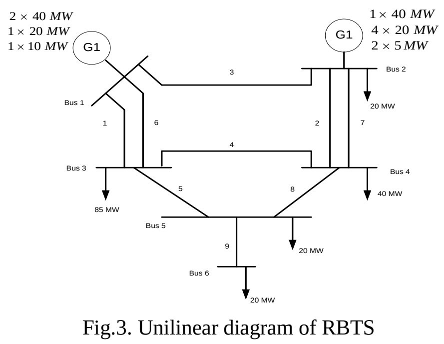

Fig.3. Unilinear diagram of RBTS

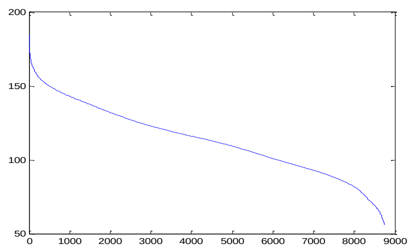

Fig.4. Load model RBTS

Table.1
COPT Table for RBTS

Outages units	Outages capacity	E_i	t_i (hours)	P_t
0	240	0	0	0.81286
$G_1 + G_2$	160	929.6971	146	0.00077753
$G_1 + G_4$	180	9.45	3	0.00064462
$G_1 + G_7$	160	929.6971	146	0.00051306
$G_1 + G_8$	180	9.45	3	0.00038284
$G_1 + G_9$	180	9.45	3	0.00038284
$G_1 + G_{10}$	180	9.45	3	0.00038284
$G_1 + G_{11}$	180	9.45	3	0.00038284
$G_2 + G_4$	180	9.45	3	0.00064462
$G_2 + G_7$	160	929.6971	146	0.00051306
$G_2 + G_8$	180	9.45	3	0.00038284
$G_2 + G_9$	180	9.45	3	0.00038284
$G_2 + G_{10}$	180	9.45	3	0.00038284
$G_2 + G_{11}$	180	9.45	3	0.00038284
$G_4 + G_7$	180	9.45	3	0.00042536
$G_7 + G_8$	180	9.45	3	0.00025263
$G_7 + G_9$	180	9.45	3	0.00025262
$G_7 + G_{10}$	180	9.45	3	0.00025262
$G_7 + G_{11}$	180	9.45	3	0.00025262

In the table.1 values of E_i and t_i are obtained from the load duration curve (LDC) in fig.4 and values of P_t are obtained of forced outage rates (FOR) generators.

5. Modeling

In fuzzy-Markov model, the state-space method is used for the system reliability analysis. A state-space diagram is used to representation states of power system and transition rates in Markov model [11]. The state- space method is not limited to just possible two conditions 1, 0 but components can have different states such as operation, derated and fully faulted or maintenance [9].

This paper proposed a method to evaluate reliability of wind farms. In this technique state–space diagram is used to representation wind speed data within a short time such as one year.

Due to use of insufficient data of wind speed in this paper, we can use of fuzzy logic method for calculating state transition matrix in Markov model. If transitions rate are fuzzy number, will be represented the membership function in fig. 5.

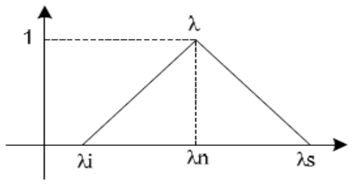

Fig.5. Membership function

State- space diagram of Markov model for wind speed is depicted in fig.6.

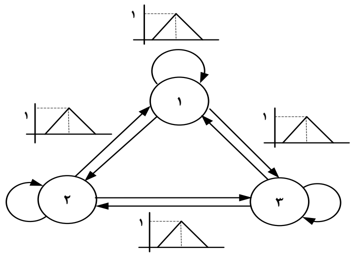
Fig.6. model Markov – fuzzy wind speed

We can describe the above model by A transition probability matrix [9], [11]. State transition matrix is presented in 6.

(6)

$$[\widetilde{P_1} \quad \widetilde{P_2} \quad \widetilde{P_3}]\begin{bmatrix} 1-(\tilde{a}_1+\tilde{a}_2) & \tilde{a}_1 & \tilde{a}_2 \\ \tilde{b}_1 & 1-(\tilde{b}_1+\tilde{b}_2) & \tilde{b}_2 \\ \tilde{c}_1 & \tilde{c}_2 & 1-(\tilde{c}_1+\tilde{c}_2) \end{bmatrix} = [\tilde{P}_1 \quad \tilde{P}_2 \quad \tilde{P}_3]$$

$$\tilde{P}_1+\tilde{P}_2+\tilde{P}_3=1$$

By calculation state transition matrix, can be calculated fuzzy states probabilities of fuzzy-Markov model, defuzzification method can obtain the accurate values of probability of states in model [4]. In defuzzification, the fuzzy results of probabilities are converted to exact values so that they can be used in the reliability calculation. There are some methods which can be used based on some criteria such as expected accuracy and the amount of acceptable computation time to select proper non- fuzzy.

Such as mean of maximum defuzzification is one of the defuzzification method for reliability calculation. Mean of maximum (mom) defuzzification method can be describe according to7.

$$X_{MOM}=\frac{\sum_{i=1}^{n} w_i}{l} \quad (7)$$

The general scheme of data analysing system is represented in fig. 7.

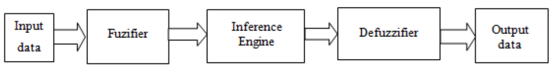

Fig.7. General Structure of fuzzy block

Solution steps for calculating reliability indices for proposed method as following:

(1) Definition fuzzy-Markov model of wind speed data.
(2) Obtaining the fuzzy transition matrix, equation (4).
(3) Calculation fuzzy transition matrix and obtained states probability of model Mark ov
(4) Defuzzification of step (3) and obtained accurate values of states probability.
(5) Obtained reliability indices for RBTS.
(6) Adding wind farm to power system.
(7) Calculation reliability indices for step (6).

In this technique, it is assumed that the failure rates of generating units are known. Then according to outage power of wind farm and probabilities of states in Markov-fuzzy model, can be calculated reliability indices of wind farm in power system [11]. Loss of Load Expectation (LOLE) and Loss of energy Expectation (LOEE) ar e considered reliability indices. Their method calculation is expressed in [8].

6. Case Study

In order to exhibition a practical sample study, two wind farms in Iran, Zabol and Manjil are modelled. Rated capacity of each turbine utilized in one of them is 3MW. Turbines are structured of company VESTAS of Denmark. In characteristic turbine, V_{ci} is equal 4 m/s and V_o is equal 15 m/s and V_{co} is equal 25m/s. The basic system model is considered for the study that is shown in fig.8 [8].

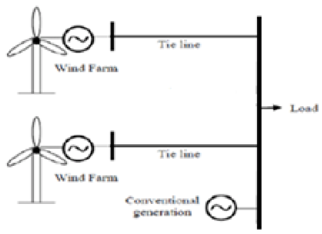

Fig.8. Basic system model

6.1. Results of simulation

With method proposed in this paper for modeling wind farm, at first should be modeled wind speed based on Markov model for one of wind farms such as fig.3.

Electricity generated from wind power can be highly variable at several different timescales: hourly, daily, or seasonally. Annual variation also exists, but is not as significant [8]. In this paper, used of daily variation in during one year of wind speed that wind speed sequential curve for Manjil is shown in fig.9.

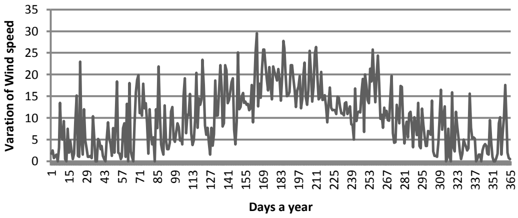

Fig.9. Daily sequential wind speed variation curve in Manjil

Wind speed sequential curve Zabol is shown in fig10.

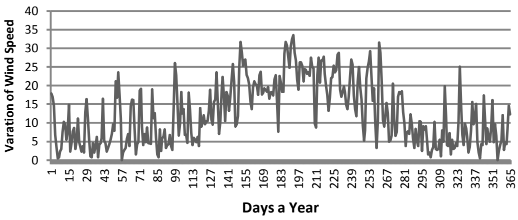

Fig.10.Daily sequential wind speed variation curve in Zabol

Due to use of insufficient data of wind speed, can be calculated failure rates and repair rates based on fuzzy number. In fuzzy-Markov model, probabilities of states are calculated by fuzzy logic. By defuzzification method; we can calculate exact value of probabilities of states in fuzzy-Markov model. Table2 probability of non-fuzzy states based on non-fuzzy different three–phase method for fuzzy-Markov model for Manjil wind speed is shown.

Table.2
Non-fuzzy Probabilities of states in Manjil fuzzy-Markov model

Probability states of model Markov Manjil	Centred	Som	mom
P_1	0.2469	0.2492	0.2484
P_2	0.4690	0.4691	0.4726
P_3	0.2840	0.28164	0.27883

Table3 is shown accurate probabilities of states with three non-fuzzy approach for the construction of fuzzy- Markov model of Zabol.

Table.3
Non-fuzzy Probabilities of states in Zabol fuzzy-Markov model

Probability states of model Markov Zabol	Center	Som	mom
P_1	0.3428	0.3429	0.3420
P_2	0.27197	0.28076	0.2730
P_3	0.3834	0.376253	0.3847

Based on these values of probabilities of states Markov model and wind farm output, reliability indices can be calculated in level HLI. Before adding wind farms to generation system, LOLE and LOEE of original RBTS are calculated that LOLE is equal to 0.280696, LOEE is equal to 1.731543. By adding wind farms to production system of original RBTS, reliability indices are decrease. The value for LOLE in presence manjil wind farm is equal to 0.074379 and for LOEE is equal to 0.441152. The results are shown in fig 11 and fig 12.

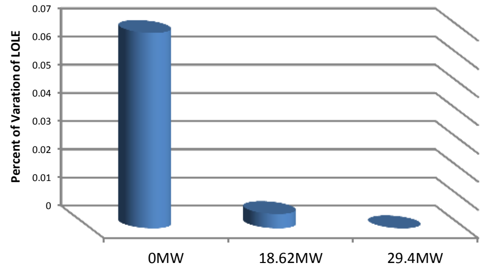

Fig.11. Percentage reduction of LOLE with respect to original RBTS by adding Manjil wind farm to generation system

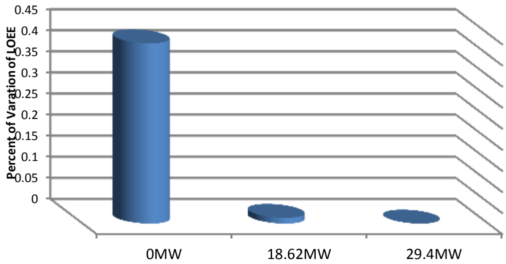

Fig.12. Percentage reduction of LOEE with respect to original RBTS by adding Manjil wind farm to generation system

By adding Zabol wind farm and Manjil wind farm to generation system of original RBTS, reliability indices are decrease. These values of reliability indices in presence two wind farms are calculated that LOLE is equal to 0.026224 and LOEE is equal to 0.153172. With states comparison before and after adding wind farm into power system, LOLE and LOEE will decrease. The results are shown in fig.13 and 14.

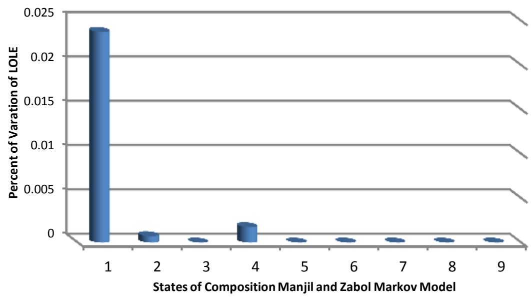

Fig.13. Percentage reduction of LOLE with respect to original RBTS by adding Zabol and Manjil wind farms to generation system.

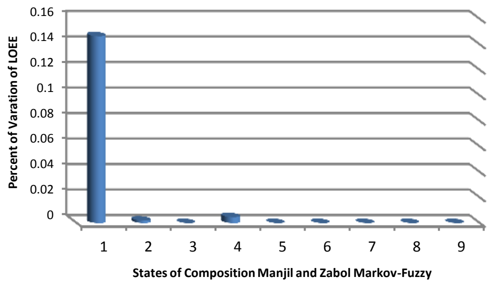

Fig.14. Percentage reduction of LOEE with respect to original RBTS by adding Zabol and Manjil wind farms to generation system.

As shown in fig13 and 14 by adding two wind farms to generation system of original RBTS, LOLE and LOEE will significantly decrease.

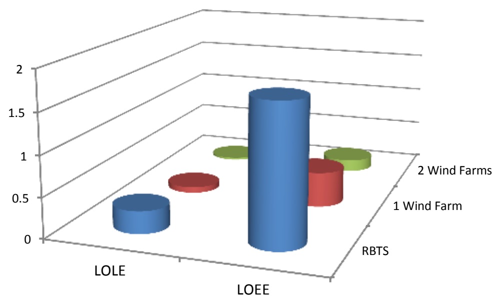

Fig.15. Percentage of reduction in reliability indices by adding wind farms to generation system

As results represented in Fig 15, after adding wind farms to power system, reliability indices will decrease. These results are shown in Table 4.

Table4. Comparison of reliability indices by adding wind farms in power system

States	LOLE	LOEE
RBTS	0.280696	1.731543
By adding Manjil wind farm	0.074379	0.441152
By adding Zabol wind farm	0.026224	0.153172

In this research, it has been tired with limited weather data allow the calculation of risk and reasonable results are obtained. The other result, the rated power of wind farm is going to be determined by the percentage of drop in LOLE and LOEE indices, due to addition wind farms to existing generation system.

7. Conclusion

The fuzzy-Markov model is an effective instrument for calculating the reliability indices with uncertain data. In this paper suggests the new approach based on fuzzy logic for modeling wind speed.

The fuzzy-Markov approach models wind speed with Markov chain and departure rates of each states are fuzzy probabilities.

In this method by insufficient data of wind speed and power output of wind farm are used to study the effects of adding wind farms in the power system. These results are shown, by adding wind farm to power system, reliability indices will decrease that results were shown in fig 15. Therefore calculation of risk and reasonable results are obtained finally, the authenticity of approach is shown with some simulation.

References

[1] R.Billinton, S.Kumar, N.Chowdhury and K.Chu, "A Reliability Test System For Educational Purposes-Basic Data", IEEE Transaction on Power System, , Vol.4, No.3, pp.1238–1244, 1989.

[2] R.Billinton and R.Allan,"Reliability Evalution of Power Systems", 2nded, New York; Plenum, 1996.

[3] B.EUA-Approrn, A.Karunanoon,"Reliability Evaluation in Electrical Power Generation With Uncertainty Modeling by Fuzzy Number", IEEE Conference on Power Engineering Society Summer Meeting, Vol.4, pp.2051–2056, 2000.

[4] M.Fotuhi, A.Ghafouri, "Uncertainty Consideration in Power System Reliability Indices Assessment Using Fuzzy Logic Method ", IEEE Conference on Large Engineering System, pp.305-309, 2007.

[5] R.Billinton, M.S.Grover," Reliability Assessment of Trans and Distribution Schemes", IEEE Trans on Power Apparatus and Systems, Vol.94, Iss.3, pp.724-732, 1975.

[6] Wook-Won.Kim, Jin-O.Kim, "Reliability Cost of Battery With Wind Farm", 10th IEEE Conference on TENCON, Bali, pp.981–985, 2011.

[7] C.Nemes, F.Munteanu," Reliability Consideration on Wind Farms Energy Production", 13th International Conference on OPTM, Brasov, pp.183–187, 2012.

[8] J.Nikukar, " Modeling of Wind Farms in Raliability Study by Means of Mont Carlo Simulation", 12th WSEAS international conference on Mathematical methods and computational techniques in electrical engineering, pp.140-144, 2010.

[9] M.Tanrioven, Q.H.Wu, D.R.Turner, C.Kocatepe and J.Wang, "A New Approach to Real- Time Reliability Analysis of Transmition System Using Fuzzy Marvov Model",International Journal of Electrical Power & Energy Systems, ELSEVIER, Vol.26, No.10, pp.821–832, 2004.

[10] H.J. Zimermann," Fuzzy Set Theory and it's Applications",4th ed Springer, pp.514, 2001.

[11] A.Ghaderi, M.R.Haghifam,"Wind power Modelling Using Fuzzy-Markov Approach in Power System Reliability", Scientific Information Database (SID), pp.101-106, 2011.