Scientific Bulletin of the „Petru Maior" University of Tîrgu Mureş
Vol. 10 (XXVII) no. 2, 2013
ISSN-L 1841-9267 (Print), ISSN 2285-438X (Online), ISSN 2286-3184 (CD-ROM)

DETERMINING OPTIMAL CAPACITY OF WIND GENERATION IN A CONVENTIONAL POWER SYSTEM

Shahrokh SHOJAEIAN[1], Hadi AKRAMI[2]
[1,2] *Electrical Engineering Department, Islamic Azad University, Khomeinishahr Branch, P.O.Box:84175-119, Isfahan, IRAN*
[1]shojaeian@iaukhsh.ac.ir
[2]Hadi.Akrami@iaukhsh.ac.ir

Abstract

This paper investigates the effect of adding different capacities of wind power to the reliability of power systems using Monte Carlo method in order to obtain an optimum limit for that. At first, wind speed of the Swift Carnet Region in Canada, as a typical test area, is simulated and the amount of wind power output of the wind turbine generator is measured. Then, using the Monte Carlo Sequential Method, a model that involves energy generated by conventional and wind power generators is made. The power generated in Monte Carlo Sequence was compared with the system load in order to calculate risk indices. Then values of the 'loss of load expectation' and 'loss of energy expectation' indices are presented in the adequacy evaluation of the electric power system including the wind power generators.

Keywords: wind generator, reliability, Monte Carlo, loss of load expectation (LOLE), loss of energy expectation (LOEE).

1. Introduction

Environmental concerns due to the generation of energy from conventional sources and restrictions of the fossil fuels including coal, oil and natural gas, as well as the emission problem, provide enough reason for the development and booming of the use of the renewable sources of energy in power systems [1].

Among renewable sources of energy, wind has had the fastest growth rate and has been recognized as the most successful renewable energy source. Different countries of the world have policies towards the increased use of the wind power to enhancement penetration of wind power in power systems. Increased penetration of wind power in Electrical systems, therefore, widespread application and calculation of reliability indices find importance due to the variable nature of wind power.

Wind turbine generators (WTG) have a high degree of fluctuation due to wind speed variation at the wind farm location, and cannot produce constant rate of power outputs. Therefore it is necessary to develop reliability evaluation techniques for the power systems including wind power.

In order to carry out useful studies regarding wind power, we need precise models of forecasting wind speed variation at the wind farms location, to obtain suitable models for WTGs.

Extensive studies [2-4] have been made for modelling wind speed behavior to performance, planning and reliability of wind energy conversion systems (WECS) or mixed power systems containing wind energy. In the past, Weibull distribution method [5] was used to estimate the speed of the wind speed data in wind power studies. Though these techniques could not recognize the chronology in wind speed variation at a specific location, and for this reason can't make the right model for the simulation of the wind speed. In the statistical analysis with time series, auto regressive moving average (ARMA) model with considering the chronology of the wind speed, is an appropriate model to simulate the wind speed. Reference [2] uses this method. Correspondence between wind speed and turbine generators power output is expressed as wind power curve with a non-linear equation [6].

Reliability evaluation of the power generation systems such as WTGs generators is carried out with different techniques. In [5-10] analytical techniques have been used in modelling for the purpose of evaluating the reliability of power systems with WTGs. Analytical methods are suitable for evaluating conventional power generators, but they are not reliable in evaluating power systems with WTGs due to the necessity of temporal continuity for this purpose and intermittent nature of WTG output. Sequential Monte Carlo simulation (SMCS) is a powerful method for evaluating these systems because of the consideration of the temporal and random nature of wind speed in simulation [18]. Reference [7] presents an algorithm which has been presented for deriving a probability based model for wind power generators. Reference [8] presents a technique to obtain multi-state power output models of WTG units for reliability evaluation. A simple WTG model which has been provided for the evaluation of reliability with acceptable accuracy is present in [9].

The ARMA model has been used with SMCS method in the reliability evaluation of power systems including wind energy in [11-16].

In this paper, IEEE-RTS and RBTS test systems which are widely used in reliability studies are used for simulations. It has been assumed that RBTS is the generation test system and the IEEE-RTS is the load test system with 185MW load peak as shown in Fig.1. ARMA time series and SMCS techniques have been used for wind speed simulation and reliability indices evaluation respectively.

To begin with, loss of load expectation (LOLE) and loss of energy expectation (LOEE) are calculated in the absence of wind power, and then the best added capacity of wind power with due regard to the reliability indices is figured out by adding WTGs with various capacities to the system. All simulations have been carried out at HL1 level with MATLAB.

2. Statement of the problem

Evaluation of the capacity of the generation facilities in answering to the whole system load is a main concern in adequacy evaluation at the HL1 level. This important outcome can be achieved by developing power generation models, load models and using the two-state model (Markov Model).

In general, there are two methods for the evaluation of the reliability: deterministic method and probabilistic method.

The deterministic method estimates the reserve capacity through experience and information on load growth. In the deterministic approach, forecasting the amount of reserve is equal to: a percentage of the entire load or system's output, the biggest generation unit or a combination of the two ways. Whereas the probabilistic method, used a combination of the load and generation model to obtain the system's risk model and uses the result to forecast the capacity needed. Adequacy evaluation in the probabilistic model goes through the following three steps:

1- Construct a generation model based on the operating characteristics of all the generating units in the system.

2- Build a suitable load model

3- Obtain the right risk model by combining the load and generation models.

A. Generation model

A generator unit in power systems can be shown by a two-state or a multi-state Markov model. The two-state model represents a generator unit in either of the two states: full working (Up) state or out of service (Down) state. The generation unit alternates between the two states as shown in Fig. 2. In this figure, λ is the failure rate and μ is the repair rate of the generator unit. In the two-state model, the derating is not there and derating only goes back to multi-state models. Generator units considered in this paper conform to the generator units of RBTS test system.

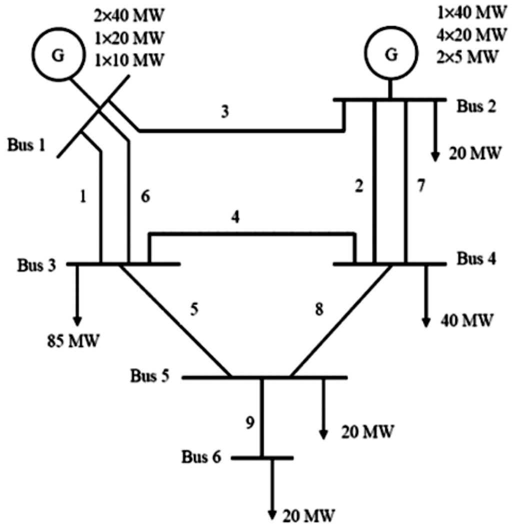

Fig. 1: Roy Billinton test system

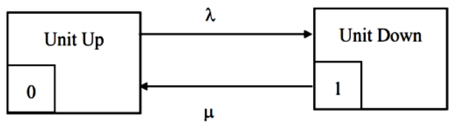

Fig. 2: Two state model for generating unit

In order to model the wind energy Conversion systems, simulate the wind speed data and WECS power generation model derivation are required.

A.1. Wind Speed Model

Wind speed varies in time and by site, and at a certain time, depends on the wind speed in the past hours. Therefore, for modeling the wind speed, we need a comprehensive model that consider all continuity chronological and wind speed variations in the past, present, and future.

Making use of the wind speed measurements at a certain location and use the ARMA time series, it is possible to artificially produce the wind speed.

Simulation takes place by ARMA time series of the speed of wind (SW_t) for a special site using the mathematical equation (1).

$$SW_t = \mu_t + \sigma_t . y_t \tag{1}$$

where μ_t is the historical hourly mean wind speed, σ_t is the standard deviation of the wind speed, and y_t is the value of the time series at time t. In [17] y_t has been discussed extensively and the value of ARMA time series for Canadian Swift Current area (which is our test case area) has been obtained as follows:

$$y_t = 0.8782y_{t\text{-}1} - 0.0061y_{t\text{-}2} + 0.0265y_{t\text{-}3} \\ +\alpha_t - 0.2162\alpha_{t\text{-}1} + 0.0091\alpha_{t\text{-}2} \\ \alpha_t \in NID(0, 0.55792^2) \quad (2)$$

where α_t is the white noise process with zero mean and a variance of 0.55792^2. Using the above mentioned equations, the wind speed for one year has been simulated and used in later stages in the generation of wind power.

A.2. WTG model

Contrary to conventional generators, WTG are not able to generate a constant rate of power output. The power generated by a WTG is highly influenced by the wind speed. The relation between a WTG power output and the speed of the wind is described by a nonlinear equation known as the power curve as shows in Fig. 3.

In this curve, cut-in, rate and cut-out wind speed are the most important parameters. A wind generator turbine at the wind speed of $V_{cut\text{-}in}$ starts to generate and is turned off as soon as the speed of $V_{cut\text{-}out}$ is reached due to safety precautions. The wind generator turbine is capable of power generation within the range of $V_{cut\text{-}in}$ and $V_{cut\text{-}out}$. The generation power of the wind turbine at different speeds is depicted using the equation (3).

$$P(\mathrm{SW}_t) = \begin{cases} 0 & , 0 < SW_t \le V_{ci} \\ (A + B.SW_t + C.SW_t^2)P_r & , V_{ci} < SW_t \le V_r \\ P_r & , V_r < SW_t \le V_{co} \\ 0 & , V_{co} < SW_t \le 0 \end{cases} \quad (3)$$

where P_r is the rated output power and V_{ci} , V_r , V_{co} are the cut-in wind speed, the rated wind speed, and the cut-out wind speed respectively.

Constants of A, B and C are calculated by V_{ci} and V_r [10]. The V_{ci} , V_r , V_{co} values used in the paper are 14.4, 36, and 80 km/hour respectively [18]. Using these values, constants A, B and C are calculated as 0.0311, -0.0215 and 0.0013. Power generated by each unit, (P_r) is 1MW and units of WTGs have been assumed to be the same for wind farms.

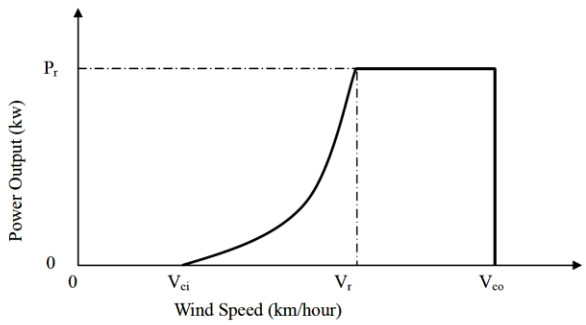

Fig. 3. Wind power curve

Using the relations expressed in this section, the output power of the WTGs and output power from the conventional generator produced in Monte Carlo method are added up in order to obtain the total power production. Given the goal of this paper which is to compare the modes of reliability in the added wind power capacity, the added wind powers taken for comparison are: 5, 10, 15, 20, 25 and 30 MW. These values account for 2.0833, 4.1667, 6.2500, 8.3333, 10.457, and 12.500 per cent of the overall conventional generation respectively.

B. Load model

Different kinds of load models can be presented for the energy demand of the system within a given period of time. The simplest model that can be considered for the load is the use of a fixed load for the entire period of the research. Normally, in such conditions, maximum load of the system is considered to be the constant load. Daily peak load variations curve (DPLVC), and load duration curve (LDC) are extensively used as load models in the adequacy evaluation of the power generation systems.

A suitable load model using the mathematical relations of the load model can be achieved using the information on the hourly load of the IEEE-RTS test system and the amount of the load peak of the RBTS.

C. System risk model

System risk model is achieved by combining the generation and load models. Using the risk model, one can calculate the system risk indices such as LOLE and LOEE. Generally, two basic approaches are available for the calculation of the risk indices in adequacy evaluation models. The analytic model uses statistical and mathematical models for the description of the direct elements of the system and the risk indices are obtained using mathematical models. This method is mostly used in the reliability evaluation of the conventional generators and related equipment. SMCS simulates actual values of processes and random behaviors of the system, too. In SMCS, various methods are used in evaluating indices through the simulation of real processes and random behavior of the system. SMCS is a practical method for the evaluation of the power systems, including wind power plants. Monte Carlo simulation techniques comprise sequential and non-sequential methods [1].

In sequential simulation technique, simulation takes place on the basis of time series from the actual states of the system in consideration of the conditions in the future and in the past. In non-sequential simulation time series are not considered during simulation. Therefore, system's behaviors are available at various points in time in a discrete manner.

The sequential MCS approach simulates the basic intervals in chronological or sequential order, recognizing the fact that the system state in a given time interval is correlated with that in the previous, and the subsequent time intervals. In non-sequential simulation chronological order is not considered during simulation and the system behavior at each time interval is considered to be independent.

This paper uses SMCS for the evaluation of the risk indices. In this method, a random number between [0, 1] with uniform distribution is generated. This number is compared with the forcing out rate (FOR) of the generator. If the random number is greater than FOR, the generator is in the 'Up' state, and the generating power of the unit is at the capacity included in the total generation capacity. Otherwise, the unit is in the 'Down' state and zero generation power is considered for the unit.

This step is carried out for all of the 11 generation units and the total generation power of the whole generators is calculated. The total generation power of the conventional generators (C_c) is calculated by adding up all generation powers of the units at this stage. In the next stage, for the demonstration of the effect of wind power with different capacities, C_c obtained at each stage is added to different capacities of wind power (C_w) and total generation obtained at each stage ($C_{total}=C_c+C_w$) are compared with the system load at the relevant point in time.

If the load is greater than the total generation, the system will have failures (loss of the load) and loses energy. This goes ahead for a long period of time until the right convergence has been achieved in LOEE index, because LOEE is converged later than the other index and the convergence of this index entails the convergence of other indexes. In the end, values of LOLE and LOEE are presented for various modes and shown on a bar diagram for better comparison. Title of the Article

3. Simulation and results

Simulation of the system indices such as LOLE and LOEE are needed for the reliability evaluation of the system. At first, LOLE indices are simulated for the probabilistic generation of the conventional generation units in the presence of the simulated load, and then the generation capacities of 5, 10, 15, 20, 25, 30 MW of the wind power is added to the generation of the conventional generators and then LOLE is calculated for these indices. Fig. 4 shows the system at the above modes in full. It should be pointed out that the added capacity of the wind power at each mode has been mentioned at the top of the figure.

Fig. 4 compares different modes of wind power added from 0 to 30MW. LOEE index is also simulated for the calculation of probabilistic the loss of energy expectation. Also, the right convergence trend is simulated and the results appear in Fig. 6 and Fig.7.

As seen in the figures, adding the wind power to the system, significantly increases the reliability of the system, however, this increase depends greatly on the capacity of the added wind power.

Table 1 shows the impact of the wind powers added on the LOLE and LOEE indexes of system reliability. Therefore, given the significance of the system reliability and investment power, the best mode will be chosen.

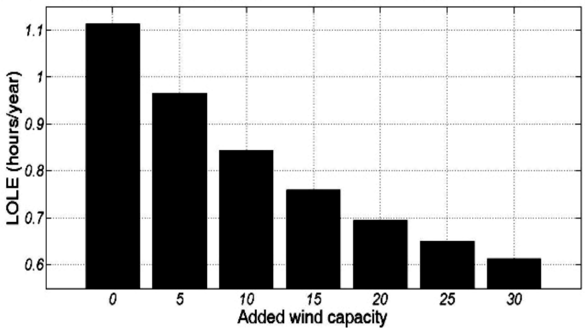

Fig. 4. LOLE versus wind energy penetration.

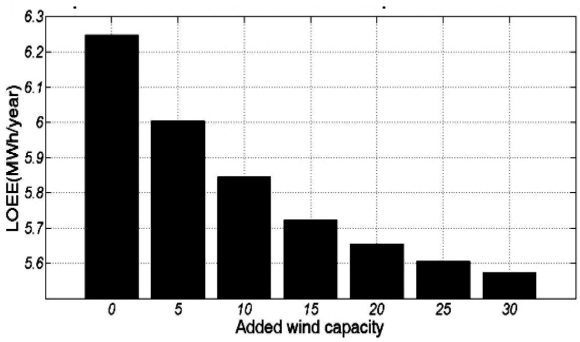

Fig. 5. LOEE versus wind energy penetration.

Table 1: The final value of the reliability indices

Added wind capacity(MW)	LOLE	LOEE
0	1.1130	6.2470
5	0.9660	6.0028
10	0.8443	5.8438
15	0.7597	5.7223
20	0.6950	5.6552
25	0.6497	5.6046
30	0.6127	5.5729

4. Conclusion

In this paper, the optimal contribution level of wind power plants in a typical conventional power system is determined using a proposed algorithm based on Sequential Monte Carlo Method. The proposed method uses the risk and energy indices LOLE and LOEE to find the best contribution level. The proposed method is examined for two well-known reliability test systems and its validity is shown.

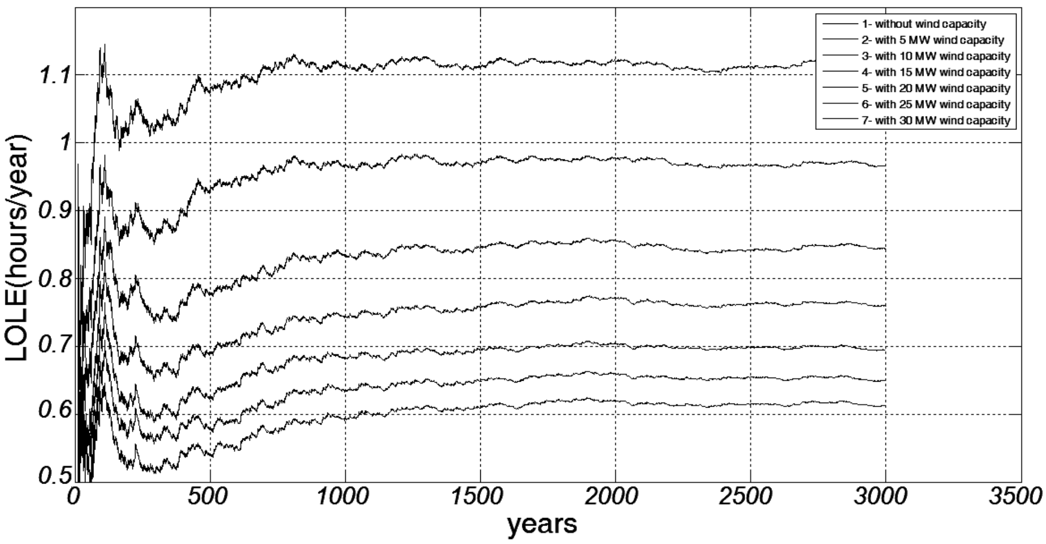

Fig. 6. Comparison of LOLE for all of states

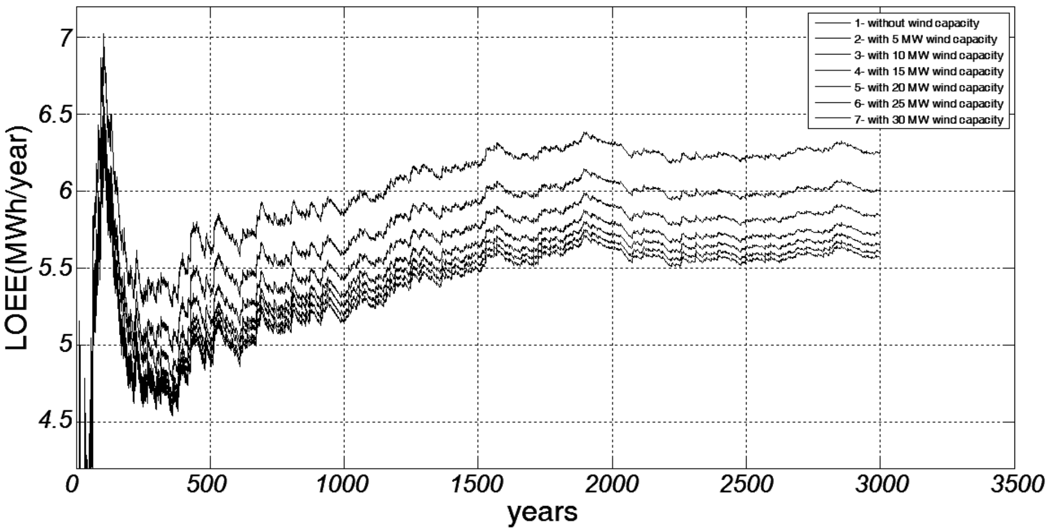

Fig. 7. Comparison of LOEE for all of states

References

[1] Billinton, R. and Allan, R.N. (1996), *Reliability Evaluation of Power Systems*, 2nd ed, New York: Plenum Press.

[2] Billinton, R., Chen, H. and Ghajar, R. (1996), Time-series models for reliability evaluation of power systems including wind energy, *Microelectronics Reliability*, vol. 36, pp. 1253-1261.

[3] Chou, K.C. and Corotis, R.B. (1981), Simulation of hourly wind speed and array wind power, *Solar Energy*, vol. 26, pp.199-212.

[4] Blanchard, M. and Desrochers, G. (1981), Generation of auto-correlated wind speeds for wind energy conversion system studies, *Solar Energy*, vol. 33, pp.571-579.

[5] Abouzahr, I. and Ramakumar, R. (1991), An approach to assess the performance of utility-interactive wind electric conversion systems, *IEEE Transactions on Energy Conversion*, vol. 6, pp. 627-638.

[6] Giorsetto, P. and Utsurogi, K.F. (1983) Development of a new procedure for reliability modeling of wind turbine generators, *IEEE Transactions on Power Apparatus and Systems*, vol. 102, pp. 134-143.

[7] Wang, X., Dai, H. and Thomas, R.J. (1984) Reliability modeling of large wind farms and electric utility interface systems, *IEEE Transactions on Power Apparatus and Systems*, vol. 103, pp. 569-575.

[8] Karki, R. and Hu, P. (2005), Wind power simulation model for reliability evaluation,

Proceedings of the IEEE Canadian Conference on Electrical and Computer Engineering, Saskatoon, pp. 541-544.

[9] Karki, R., Hu, P. and Billinton, R. (2006), A simplified wind power generation model for reliability evaluation, *IEEE Transactions on Energy Conversion*, vol. 21, pp.533 – 540.

[10] Karki, R., Hu, P. and Billinton, R. (2006), Reliability evaluation of a wind power delivery system using an approximate wind model, *41st International Universities Power Engineering Conference*, Newcastle, UK.

[11] Wangdee, W. (2005), *Bulk electric system reliability simulation and application*, Ph. D. thesis, University of Saskatchewan.

[12] Karki, R. and Billinton, R. (2001), Maintaining supply reliability of small isolated power systems using renewable energy, *IEE Proceedings Generation, Transmission and Distribution*, vol. 148, pp.530 - 534.

[13] Karki, R. and Billinton, R. (2004), Cost-effective wind energy utilization for reliable power supply, *IEEE Transactions on Energy Conversion*, vol. 19, pp. 435-440.

[14] Billinton, R. and Bai, G. (2004), Generating capacity adequacy associated with wind energy, *IEEE Transactions on Energy Conversion*, vol.19, pp. 641-646.

[15] Billinton, R. Chen, H. and Ghajar, R. (1996), A sequential simulation technique for adequacy evaluation of generating systems including wind energy, *IEEE Transactions on Energy Conversion*, vol. 11, pp. 728-734.

[16] Karki, R. and Billinton, R. (2001), Reliability/cost implications of PV and wind energy utilization in small isolated power systems, *IEEE Transactions on Energy Conversion*, vol. 16, pp. 368-373.

[17] Pandit, S.M. and Wu, S.M. (1983), *Time Series and System Analysis with Application*, John Wiley & Sons Inc.

[18] Gao, Y. (2006), *Adequacy assessment of electric power systems incorporating wind and solar energy*, M. Sc. Thesis, University of Saskatchewan.