Journal of Applied Sciences

ISSN 1812-5654

science alert

ANSInet
an open access publisher
http://ansinet.com

Journal of Applied Sciences 12 (20): 2107-2114, 2012
ISSN 1812-5654 / DOI: 10.3923/jas.2012.2107.2114

Optimal Capacity and Placement of Wind Power Generation System Under Wind Speed Uncertainties: A Review

Ruhaizad Ishak, Azah Mohamed and Mohd Zamri Che Wanik
Department of Electrical, Electronic and Systems Engineering, Universiti Kebangsaan Malaysia,
Bangi, 43600, Selangor, Malaysia

Abstract: A large move towards renewable energy generation is anticipated to inevitably take place in the coming decades as the world faces the depletion of fossil energy reserves. The trend in the current global scenario presents the potential of the wind power industry into becoming one of the major contributors for alternative energy generation. Since the number of wind power generators connected to a grid continuously increases, providing subtle attention on issues confronting this technology is vital. Weather condition significantly influences the performance of wind power generators and thus, the wind power generator technology is vulnerable to generation uncertainties. Uncertainties in generated outputs are often relevant the outputs of traditional deterministic models, easily resulting in uneconomical and unreliable solutions. Thus, the accurate assessment of the potential location and size of wind power generators under the uncertainties of the element of wind speed is important. Improper allocations may further degrade the performance of an entire power system. The current study provides a review on the popular and distinct techniques developed by researchers to optimize wind power capacity and location and maximally harvest the targeted benefits from wind energy resources. Moreover, different techniques for predicting wind speed, particularly for long-term prediction, are discussed to show the correlation between wind speed prediction and the planning process for creating a wind power generator.

Key words: Wind power generation, optimization, uncertainties, probabilistic, Rayleigh distribution, Weibull distribution, wind speed prediction, numerical weather prediction

INTRODUCTION

The growth of renewable energy resources into electric power systems continues to hike around the world. In the year 2010 despite world economy crisis more than $200 billion investment in renewable energy resources was commenced (REN21, 2011). Global issues such as climate change, green house gas effect and atmospheric pollution have deepened many countries interest on greater provision of safe and clean generation plants. A research backtrack suggested that a serious move on renewable energy generation has already begun as early 2004, amounting to an average of 10-60% of capacity installed for a number of renewable technologies annually (REN21, 2010). For instance, 60 and 27% capacity was installed for solar photovoltaic and wind power, respectively. Photovoltaics is globally considered as a feasible option for alternative energy especially for countries with bright and long hours of sunlight exposure. Nonetheless, the deployment of wind-based energy is an exceptional achievement, particularly in certain regions of Europe. Many European countries are able to meet their energy demands through renewable resources from wind energy. It is reported that the cost for generating electricity from wind has fallen almost 90% since 1980s (Hosseinpour *et al*., 2008). As reported in the WWEA, (2011) the total amount of world capacity generation for wind power was 196.6 GW for that year. Figure 1 shows the 15-year growth record for the global wind power industry.

Across Indian subcontinent, the wind power industry is growing rapidly. The utilization of wind power also shows promising potential in Asian regions. Surprisingly, more wind farms have been deployed in developing countries when the idea was initially scrapped due to high installation costs. Iran has the largest wind power capacity in the Middle East; Germany and Spain amongst the world's front runners along with China and the Unites States (GWEC, 2011). Such scenario on global wind power interest dictates that the wind power industry

---

Corresponding Author: Ruhaizad Ishak, Department of Electrical, Electronic and Systems Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan, Malaysia, Bangi, 43600, Selangor, Malaysia

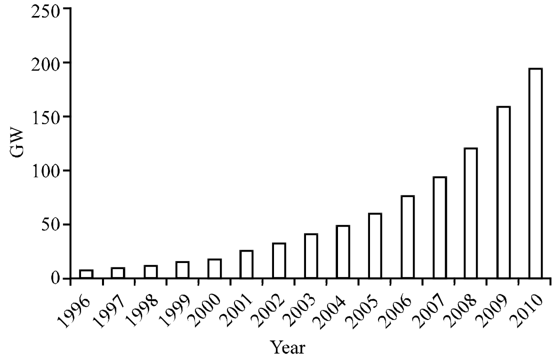

Fig. 1: World wind power installed capacity

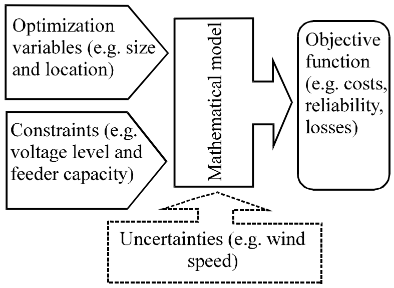

Fig. 2: Optimization model

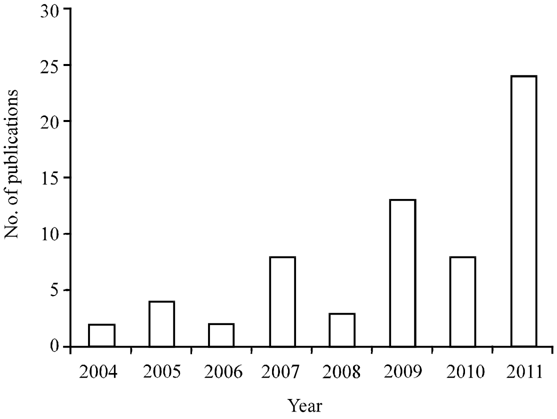

Fig. 3: Wind power publications

has the ability to remain the fastest growing market as alternative energy. However, major problems and issues concerning wind power technology need to be fairly observed and resolved. Although wind power generation offers many attractive benefits, the wind power industry continues to face suppressing challenges. The dispatch ability of wind power generation, including its effect on the entire power system is of great concern. A cliché remark on wind energy generation is "what will happen when there is no wind blowing?" In modern operation of a power system, the balance between the load demand and power generation is possibly supported by the renewable energy generators (Haron *et al.*, 2012). However, electrical power from wind turbines varies with wind speed variation which in turn varies a lot by nature. Thus, strong concerns due to wind speed variation include the ability of wind power to meet load demands during peak hours.

Determination of the right location and size for new site installations is another challenging issue. Studies on the placement and sizing of wind power generators have long been around. Many methods have been developed to evaluate the proper placement and sizing of wind turbines (Wang and Nehrir, 2004; Atwa *et al.*, 2009; Ghosh *et al.*, 2010; Liu *et al.*, 2011). Strategic allocations of wind power units brings lucrative benefits, including reduction in power losses, improvement in voltage stability, increase in load factors and deferral of system upgrades (Rau and Wan, 1994; Hadjsaid *et al.*, 1999). A multi-objective optimization problem with multiple governing constraints is generally used as a model for determining the optimal location and size of a wind power unit. Nevertheless, the fluctuating nature of wind resource is frequently left unaccounted for, generating different effects on the reliability assessment of a generation system (Singh and Kim, 1998). Thus, the inclusion of uncertainties into an optimization model is important to produce more accurate and reliable results (Atwa *et al.*, 2010; Liu *et al.*, 2011), as shown in Fig. 2. Generally, a basic optimization model consists of a group of variables that are optimized to their best values to minimize the objective function. The uncertainties component is added to further improve the optimization model.

A thorough search on a well-known database for electrical engineering with keywords 'wind power generation uncertainties' yielded fluctuating results, as shown in Fig. 3. Encouragingly, in 2011, the number of results grew tenfold of that in 2004. Although, the data presented is neither definite nor conclusive because of the different keywords that easily produced different results, trend are revealed from the data gathered, indicating a new breeze in wind energy research interest. Moreover, given the current wind power penetration scenario, it is time that the issue on uncertainties receives more attention.

The current study provides a review on the popular optimization studies on wind power generation in terms of placement and sizing with the consideration of wind speed variation. Since this study aims to emphasize the importance of wind speed uncertainties, discussing the optimization studies without covering wind speed prediction techniques would seem incomplete. This study is divided into two main parts. The first part covers wind speed prediction and the second part covers wind power optimization techniques. The optimization part is subsequently divided into two namely the sizing and location of wind power.

WIND SPEED PREDICTION

Wind speed forms from the differences in air pressure, resulting in wind blows from the high to low pressure areas to balance out the differences. The extractable amount of wind power completely depends on wind speed and thus, improving the wind speed prediction technique is important in wind energy research (Thor and Weis-Taylor, 2003). Wind speed prediction is a time-dependent function, i.e., different time scales are assigned for different applications. For instance, the definition of scales suggested by Jun and Hao (2010) categorized wind speed prediction into three categories in accordance to the relation between research aims and time intervals. Moreover, Zhang *et al.* (2008) suggested that the purpose of forecasting from a few seconds to a few minutes is appropriate for controlling wind power generator operation. Additionally, creating predictions in a few minutes to a few hours is used for scheduling wind power unit operation to assist power systems (Cai *et al.*, 2008; Contaxis and Kabouris, 1991).

Eventually forecasting in days or weeks, or even longer periods will become desirable to estimate medium- and long-term generation planning and the reserved generation capacity (Jun and Hao, 2010; Scott and Peter, 2003). Recent developments on medium-and long-term wind speed forecasting (Firat *et al.*, 2010) continue to attract interests from academic and industrial circles. Accordingly, the sub-focus of the current study is to look at the long-term wind speed prediction as electricity supply should always meet the demand of consumers. Thus, network operators need an advanced tool to foresee wind speed variations in order to maintain the reliability of power system.

LONG TERM WIND SPEED FORECAST

Various techniques are used for long-term wind speed forecasting. However, for discussion purposes, these techniques are downscaled into two, namely physical and statistical methods (Landberg, 1999). The physical methods require large measurement data for estimating future wind speed. In the current study, the combination of meteorological and terrain data is used to estimate future weather parameters, such as wind speed, temperature, pressure and humidity. A set of future time series weather data can easily be determined

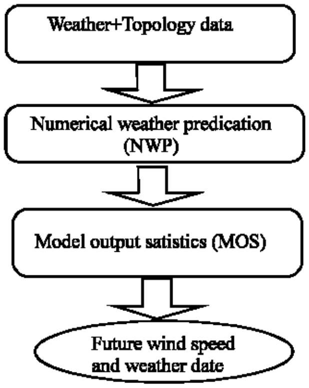

Fig. 4: Physical method for predicting wind speed

NWP numerically approximates future weather data by manipulating present weather values (Fig. 4). The initial prediction produced by NWP usually contains calculation errors that are corrected using model output statistics (Landberg and Joensen, 1998; Watson *et al.*, 1999). On the other hand, the time series statistical method has a different approach. The time series statistical method purely utilizes statistical models for estimating wind speed distribution. Probabilities for each wind speed state are estimated using the Probability Density Function (PDF). The Weibull and Rayleigh methods are among the popularly used models for PDF (Gupta, 1986; Rehman *et al.*, 1994; Sideratos and Hatziargyriou, 2007). Feijoo *et al.* (1999) proposed two other methods aside from the methods above. The first method is based on conditional probabilities, whereas the second method is a combination of the Monte Carlo Simulation (MCS) and Rayleigh distribution function. A brief description of each distribution function is given to provide further insights.

NORMAL DISTRIBUTION

Normal distribution has a bell shape and is considered as the most widely used PDF in many applications. Two main parameters, namely mean, μ (or peak location) and variance, σ^2 (width of distribution), are keys for determining the shape of the distribution. Figure 5 shows the curve shape under different means and variances.

WEIBULL DISTRIBUTION

Weibull distribution usually provides a good fit to wind speed data. The general form of the Weibull PDF is mathematically expressed as follows (Walker and Jenkins, 1997):

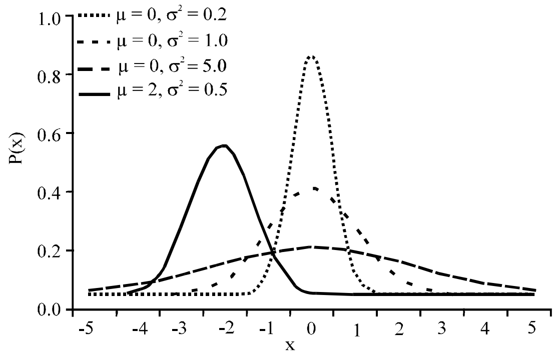

Fig. 5: Normal PDF curves

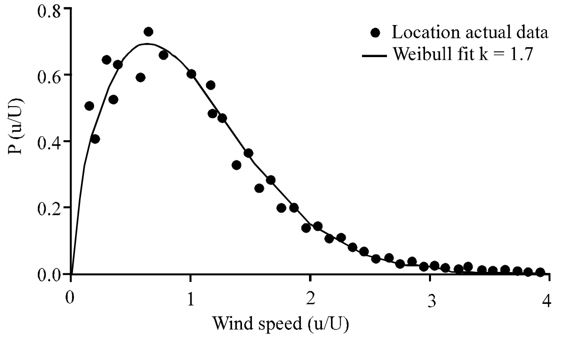

Fig. 6: Weibull PDF curve

$$f(v)=\left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} e^{-}\left(\frac{v}{c}\right)^{k} \qquad (1)$$

where, v, k and c are greater than zero. The function of f (v) is the probability of having a wind speed of v. Similar to the normal distribution, the Weibull function also has two controlling variables, namely, the parameter k which is called the dimensionless shape factor and the parameter *c*, which is the scale factor of speed. The value k should be carefully selected to accurately fit actual data to the Weibull PDF. Figure 6 shows an example of a site wind speed data that fits into the Weibull distribution curve, where the Weibull curve is skewed from a normal curve.

RAYLEIGH DISTRIBUTION

Rayleigh distribution is a special case of the Weibull distribution, where the shape parameter, k, is equal to 2. Substituting k = 2 into Eq. 1 yields the following mathematical expression for the Rayleigh distribution (Feijoo *et al.*, 1999):

$$g(v)=2\frac{v}{c^{2}} e^{-}\left(\frac{v}{c}\right)^{2} \qquad (2)$$

where, v is the wind speed and *c* is the scale factor. The curve line in Fig. 5 proportionally spreads out as the value of *c* increases. The Weibull and Rayleigh distributions are usually suitable for describing the randomness of wind speed over a long period. These models are usually employed for annual wind speed forecasting because of their simplicity and acceptable precision.

On the other hand, the physical methods are preferred for applications that require higher precision and consistency. The NWP is included in a physical method, but it may not be necessary for a statistical one. NWP models take long computational time and thus, recent studies have proposed a combination of both physical and statistical methods to overcome this limitation (Salcedo-Sanz *et al.*, 2009; Barbounis *et al.*, 2006; Liu *et al.*, 2010; Giebel *et al.*, 2003).

OPTIMIZATION OF WIND POWER CAPACITY

The integration of wind power generators into a power system raises significant concerns on supply adequacy. In simple definition, power adequacy is a kind of assessment that checks whether the installed capacity in a power system is sufficient to meet the load demand (Billinton and Allan, 1996). Keane *et al.* (2011) defined the capacity as the amount of additional load that can be served with the addition of a generator while maintaining the existing level of reliability. In matters concerning supply adequacy, Billinton *et al.* (1997) and Karki and Billinton (2001) introduced a novel probabilistic method called the system well-being index as a practical solution to the problems encountered in Small Isolated Power Systems (SIPS). They suggested that conventional capacity assessment using the deterministic method is not sufficient for wind power generation with highly fluctuating values. Thus, they suggested that assessment should be based on the probabilistic method, which optimizes the reliability and cost criteria, to determine the right amount of wind capacity penetration.

The reliability of the power grid is another issue that often alarms network operators concerning with the integration of renewable energy resources (An and Singh, 2011). In response to the dwelling issues on reliability caused by intermittency in wind resources, the novel work of Billinton *et al.* (2010) examined the capacity credit of wind power using a joint probabilistic-deterministic method. They extended the deterministic criterion N-1, which has been used for traditional diesel generator expansion planning, to the wind power generation plan. Moreover, they also included some probabilistic elements into the model to characterize wind power output. The optimization algorithm tool has been used for determining the appropriate size of the wind power that would support peak load carrying capacity in a power system.

Zhang *et al*. (2011) did a great work that focused on the impact of integrating large amounts of wind power into electric power systems. Zhang *et al*. (2011) stated that probabilistic models are required for determining the capacity limit of wind power in a system reliability assessment. They used a probabilistic model to represent the stochastic nature of wind resources. Moreover, they developed a probabilistic framework of reliability modeling for wind power to optimize the cost of wind power integration with the power system for maintaining system adequacy and reliability. Atwa and Saadany (2011) and Atwa *et al*. (2010) undertook another probabilistic method. They developed a probabilistic generation-load model with the consideration of uncertainties from renewable supply resources. They aimed to determine the optimum combination capacity of wind power and photovoltaic that would minimize power losses in a distribution system. Their optimization model also imposed several limitations, such as voltage limits, feeder capacity and the maximum penetration limits.

Studies have shown that wind power generators could provide great benefits, such as enhancing reliability and deferring system investment. Nevertheless, deploying wind power generators without considering network reinforcements may cause unavoidable restrictions on interconnecting capacity. Su *et al*. (2011) proposed a new method for the interconnection of wind power generators. Their new method calculated maximum allowable capacity at a connection node in a distribution system. Moreover, they used a stochastic technique to simulate uncertainties in wind power generators and loads and then they optimized these uncertainties using a binary particle swarm optimization tool. Ekren and Ekren (2010) conducted another optimal capacity study at the GSM base station in Turkey. They aimed to develop a stand-alone hybrid energy comprising wind, solar and battery storage systems. The overall system relied on wind power generators and photovoltaics as primary power sources assisted with batteries to support the stochastic characteristics of wind speed and solar insolation. The simulated annealing algorithm is used to solve the optimization problem. The size of wind power generators, photovoltaics and battery storage are optimized when the total cost of the hybrid system is minimal. Yang *et al*. (2007) investigated a comparably similar problem but with the aim of achieving system reliability. The Loss of Power Supply Probability index (LPSP) is chosen as the component sizing criterion. They used the LPSP as the objective function to deliberately optimize the appropriate size of each component in the hybrid system that meets the reliability requirement.

Among ancillary services, spinning reserve plays a significant role to support system reliability (Bazardeh and Rashidi-Nejad, 2009). Under normal operation, a power system requires spinning reserve to compensate sudden imbalances between load and generation (Shahidehpour and Alomoush, 2001). The accurate prediction of the amount of power injected by all generators into the power system becomes increasingly difficult as the amount of power produced by the wind power generator increases. Concerning uncertainty in wind power generation, Ortega-Vazquez and Kirschen (2009) designed a model that included the uncertainty factor in spinning the reserve planning. They successfully searched for the optimal capacity when the total cost of system operation was at its minimum.

OPTIMIZATION OF WIND POWER PLACEMENT AND CAPACITY

A number of techniques have been used for the placement of distributed generation units in power systems (Mithulananthan *et al*., 2004; Acharya *et al*., 2006; Prommee and Ongsakul, 2008). The technique from the famous work of Rau and Wan (1994) has been continuously referred to by many researchers. However, most of the studies above based their assumptions on the constant power output from wind power generators. A work initiated by Hedayati *et al*. (2008) considered the uncertainty factor for finding the optimal placement for wind power generators. Their objectives were to improve voltage profiles and reduce active power losses through sensitivity analysis search. The identification of the weak/weakest bus or also termed as sensitive bus is a major concern in voltage stability study (Nagendra *et al*., 2010; Nizam *et al*., 2006). They concluded that most sensitive buses that face voltage collapse or maximum loading are candidate buses for wind power installation. Hadian and Haghifam (2010) attempted an advanced study using a multi-objective optimization model that consisted of power system reliability, losses and investment cost. Their formulated model became more complex after they incorporated the time varying load, stochastic power generation and equipment failure rate. They aimed to reduce power losses and improve system reliability and they used a Genetic Algorithm (GA) optimization tool to search for the optimal locations.

The search for the optimal placement of a wind power generation unit continued with different targeted objectives. Jayaweera and Islam (2010) performed a research on the placement of distributed generation to enhance supply security. They aimed to seek solutions to balance the improved security of energy supply within the technical and economic constraints of wind energy generators. Apart from the technical benefits, the placement of wind power generation units can also be performed to address socio and economic values (Gautam and Mithulananthan, 2007). Their study aims at maximizing social welfare and company profits. Social welfare is defined as the difference between the total benefit to consumers and the total cost of energy production (Rothwell and Gomez, 2003). Welfare maximization is the profit to society and holds the maximum value when the market price becomes equal to the marginal cost of electricity production while the profit maximization was taken from the distributed generator owners' perspective and the DG placement was based on locational marginal price value that maximizes the owners' profit.

Compared with either choosing only the sizing method or the placement optimization method, the combination of the two methods involves heavy mathematical models with higher difficulty, consequently increasing the degree of optimization complexity. The sizing or placement optimization methods have a surplus advantage of either enhancing system reliability or reducing power losses, respectively. Nevertheless, the combination of sizing and placement methods is desired for some cases. For instance, Carpinelli *et al.* (2001) conducted a study on the uncertainties aspect of power produced by distributed generators. They aimed for medium-to-long term planning and to find optimal location and size that will minimize the overall network costs, including maintenance, losses and interruption costs. Liu *et al.* (2011) recently considered the optimal location and sizing of wind turbines under various factors of uncertainties. They aimed to minimize various types of costs, such as investment, operating, maintenance, network loss and capacity adequacy costs. The optimization work was performed using the combination of analytic hierarchy process and GA to determine the optimal weighting coefficients for each objective.

Finally, Novoa and Jin (2011) formulated a new planning framework for wind power generator with load uncertainty. They employed the moment-based method introduced by Jin and Tian (2010) to exhibit volatilities in wind power output. The planning problems were divided into three stages. Instead of solving the probabilistic problems individually, they transformed the first problem into an optimization model with the deterministic objective function known as the second problem. Then, an additional constraint was added to the second problem, resulting in the final optimization problem. The problem was finally optimized using GA for the appropriate type, location and size of the wind power generators.

CONCLUSION

The current study reviewed previous studies on the optimization techniques for wind power placement and sizing with advanced techniques employed in wind speed prediction. Each study presented uniquely different in solution techniques, problem definition, or study goals covering unlimited perspectives. Different optimization approaches standing from single to multi-objective goals with varying constraints and limits were literally put across to give a better view on diversity of optimization work. In addition, the current study also discussed wind speed prediction practice techniques, particularly those adopted for long-term application to predict wind power generation uncertainties.

REFERENCES

Acharya, N., P. Mahat and N. Mithulananthan, 2006. An analytical approach for DG allocation in primary distribution network. Int. J. Electrical Power Energy Syst., 28: 669-678.

An, Y.D. and B.S.M. Singh, 2011. Sustainable Solar-wind Hybrid Power Plant for Implementation in Malaysia J. Applied Sci., 11: 1121-1128.

Atwa, Y.M., E.F. El-Saadany, M. Salama and R. Seethapathy, 2009. Distribution system loss minimization using optimal DG mix. Proceedings of the IEEE Power and Energy Society General Meeting, July 26-30, 2009, Calgary, Canada, pp: 1-6.

Atwa, Y.M., E.F. El-Saadany, M.M.A. Salama and R. Seethapathy, 2010. Optimal renewable resources mix for distribution system energy loss minimization. IEEE Trans. Power Syst., 25: 360-370.

Atwa, Y.M. and E.F.E Saadany, 2011. Probabilistic approach for optimal allocation of wind-based distributed generation in distribution systems. IET Renew. Power Gener., 5: 79-88.

Barbounis, T.G., J.B. Theocharis, M.C. Alexiadis and P.S. Dokopoulos, 2006. Long-term wind speed and power forecasting using local recurrent neural network models. IEEE Trans. Energy Convers., 21: 273-284.

Bazardeh, M.A. and M. Rashidi-Nejad, 2009. Dynamical joint energy and spinning reserve dispatch considering transmission network constraint. J. Applied Sci., 9: 1248-1257.

Billinton, R. and R. Allan, 1996. Reliability Evaluation of Power Systems. 2nd Edn., Plenum Press, New York,.

Billinton, R., R. Karki and M. Fotuhi-Firuzabad, 1997. Probabilistic methods applied to small isolated power generating systems. Proceedings of the 5th PMAPS International Conference, September 1997, Vancouver, Canada, pp: 457-462.

Billinton, R., Y. Gao and R. Karki, 2010. Application of a joint deterministic-probabilistic criterion to wind integrated bulk power system planning. IEEE Trans. Power Syst., 25: 1384-1392.

Cai, K., L. Tan, C. Li and X. Tao, 2008. Short-term wind speed forecasting combining time series and neural network method. Power Syst. Technol., 32: 82-85.

Carpinelli, G., G. Celli, F. Pilo and A. Russo, 2001. Distributed generation siting and sizing under uncertainty. IEEE Porto Power Tech Proc., 4: 7-7.

Contaxis, G.C. and J. Kabouris, 1991. Short-term scheduling in wind/diesel autonomous system. IEEE Trans. Power Syst., 6: 1161-1167.

Ekren, O. and B.Y. Ekren, 2010. Size optimization of a pv/wind hybrid energy conversion system with battery storage using simulated annealing. J. Applied Energy, 87: 592-598.

Feijoo, A.E., J. Cidras and J.L.G. Dornelas, 1999. Wind speed simulation in wind farms for steady state security assessment of electrical power systems. IEEE Trans. Energy Conversion, 14: 1582-1588.

Firat, U., S.N. Engin, M. Saraclar and A.B. Ertuzun, 2010. Wind speed forecasting based on second order blind identification and autoregressive model. Proceedings of the 9th International Conference on Machine Learning and Applications, December 12-14, 2010, Washington DC., USA., pp: 686-691.

GWEC, 2011. Global wind report annual market update. GWEC.net.

Gautam, D. and N. Mithulananthan, 2007. Optimal DG placement in deregulated electricity market. Electric Power Syst. Res., 77: 1627-1636.

Ghosh, S., S.P. Ghoshal and S. Ghosh, 2010. Optimal sizing and placement of distributed generation in a network system. Int. J. Electr. Power Energy Syst., 32: 849-856.

Giebel, G., L. Landberg, G. Kariniotakis and R. Brownsword, 2003. State-of-the-art on methods and software tools for short-term prediction of wind energy production. Proceedings of the European Wind Energy Conference and Exhibition, June 16-19, 2003, Madrid, Spain.

Gupta, B.K., 1986. Weibull parameters for annual and monthly wind speed distributions for five locations in India. J. Solar Energy, 37: 469-471.

Hadian, A. and M.R. Haghifam, 2010. Placement of DG with stochastic generation. Proceedings of the IEEE Power Engineering Society Transmission and Distribution, April 19-22, 2010, Minneapolis, Minnesota USA., pp: 1-7.

Hadjsaid, N., J.F. Canard and F. Dumas, 1999. Dispersed generation impact on distribution networks. IEEE Comput. Appl. Power, 12: 22-28.

Haron, A.R., A. Mohamed and H. Shareef, 2012. A review on protection schemes and coordination techniques in microgrid system. J. Applied Sci., 12: 101-112.

Hedayati, H., S.A. Nabaviniaki and A. Akbarimajd, 2008. A method for placement of DG units in distribution networks. IEEE Trans. Power Delivery, 2B620-1628.

Hosseinpour, M., A. Yazdian, M. Mohamadian and J. Kazempour, 2008. Design and simulation of UPQC to improve power quality and transfer wind energy to grid. J. Applied Sci., 8: 3770-3782.

Jayaweera, D. and S. Islam, 2010. Value based strategic integration of distributed generation. Proceedings of the 20th Australasian Universities Power Engineering Conference, December 5-8, 2010, Christchurch, New Zealand, pp: 1-6.

Jin, T. and Z. Tian, 2010. Uncertainty analysis for wind energy production with dynamic power curves. Proceedings of the International Conference on Probabilistic Methods Applied to Power Systems (PMAPS), June 14-17, 2010, Singapore, pp: 745-750.

Jun, J.T. and Y.M. Hao, 2010. Equivalent wind speed model of wind generation. Proceedings of the IEEE PES Transmission and Distribution Conference and Exposition, April 19-22, 2010, New Orleans, LA, USA., pp: 1-5.

Karki, R. and R. Billinton, 2001. Reliability/cost implications of PV and wind energy utilization in small isolated power systems. IEEETrans. Energy Convers., 16: 368-373.

Keane, A., M. Milligan, C. Dent, B. Hasche and C. D'Annunzio *et al*., 2011. Capacity value of wind power. IEEE Trans. Power Syst., 26: 564-572.

Landberg, L. and A. Joensen, 1998. A model to predict the output from wind farms-An update. Proceedings of the Annual Conference on British Wind Energy Association, September 2-4, 1998, Cardiff, UK..

Landberg, L., 1999. Short-term prediction of the power production from wind farms. J. Wind Eng. Indus. Aerodyn., 80: 207-220.

Liu, H., H.Q. Tian, C. Chen and Y. Li, 2010. A hybrid statistical method to predict wind speed and wind power. Renewable Energy, 35: 1857-1861.

Liu, Z., F. Wen and G. Ledwich, 2011. Optimal siting and sizing of distributed generatorsin distribution systems considering uncertainties. IEEE Trans. Power Delivery, 26: 2541-2551.

Mithulananthan, N., T. Oo and L. van Phu, 2004. Than Oo and Le Van Phu, distributed generator placement in power distribution system using genetic algorithm to reduce losses. Thammasat Int. J. Sci . Technol., 9: 55-62.

Nagendra, P., T. Datta, S. Halder and S. Paul, 2010. Power system voltage stability assessment using network equivalents-a review. J. Applied Sci., 10: 2147- 2153.

Nizam, M., A. Mohamed and A. Hussain, 2006. Performance evaluation of voltage stability indices for dynamic voltage collapse prediction. J. Applied Sci., 6: 1104-1113.

Novoa, C. and T. Jin, 2011. Reliability centered planning for distributed generation considering wind power volatility. Electric Power Syst. Res., 81: 1654-1661.

Ortega-Vazquez, M.A. and D.S. Kirschen, 2009. Estimating the spinning reserve requirements in systems with significant wind power generation penetration. IEEE Trans. Power Syst., 24: 114-124.

Prommee, W. and W. Ongsakul, 2008. Optimal multi-distributed generation placement by adaptive weight particle swarm optimization. Proceedings of the International Conference on Control, Automation and Systems (ICCAS), October 14-17, 2008, Seoul, Korea, pp: 1663-1668.

REN21, 2010. Renewable energy policy network for 21st century Renewables 2010 Global Status Report, http://www.ren21.net/REN21Activities/Publications/GlobalStatusReport/GSR2010/tabid/5824/Default.aspx.

REN21, 2011. Renewable energy policy network for 21st century. Renewables 2011 Global Status Report, http://www.ren21.net/Portals/97/documents/GSR/REN21_GSR2011.pdf

Rau, N.S. and Y.H. Wan, 1994. Optimum location of resources in distributed planning. IEEE Trans. Power Syst., 9: 2014-2020.

Rehman, S., T.O. Halawani and T. Husain, 1994. Weibull parameters for wind speed distribution in Saudi Arabia. Solar Energy, 53: 473-479.

Rothwell, G. and T. Gomez, 2003. Electricity Economics Regulation and Reregulation. John Wiley and Sons, Hoboken, NJ, USA.

Salcedo-Sanz, S., A.M. Perez-Bellido, E.G. Ortiz-Garcya, A. Portilla-Figueras, L. Prieto and D. Paredes, 2009. Hybridizing the fifth generation meso scale model with artificial neural networks for short-term wind speed prediction. Renewable Energy, 34: 1451-1457.

Scott, K. and R. Peter, 2003. A probabilistic model for simulating long-term wind power output. J. Wind Eng., 27: 167-181.

Shahidehpour, M. and M. Alomoush, 2001. Restructured Electrical Power Systems: Operation, Trading and Volatility. CRC Press, UK., ISBN: 13-9780824706203, Pages: 510.

Sideratos, G. and N.D. Hatziargyriou, 2007. An advanced statistical method for wind power forecasting. IEEE Trans. Power Syst., 22: 258-265.

Singh, C. and Y. Kim, 1998. An efficient technique for reliability analysis of power systems including time dependent sources. IEEE Trans. Power Syst., 3: 1090-1096.

Su, S.Y., C.N. Lu, R.F. Chang and G. Gutierrez-Alcaraz, 2011. Distributed generation interconnection planning: A wind power case study. IEEE Trans. Smart Grid, 2: 181-189.

Thor, S.E. and P. Weis-Taylor, 2003. Long term research and development needs for wind energy for the time frame 2000-2020. Wind Energy, 5: 73-75.

WWEA, 2011. World wind energy report, 2010. Proceedings of the 10th World Wind Energy Conference and Renewable Energy Exhibition, October 31-November 2, 2011, Cairo, Egypt, pp: 1-23.

Walker, J.F. and N. Jenkins, 1997. Wind Energy Technology. John Wiley and Sons, Chichester, ISBN: 13-9780471960447, Pages: 161.

Wang, C. and M.H. Nehrir, 2004. Analytical approaches for optimal placement of distributed generation sources in power systems. IEEE Trans. Power Syst., 19: 2068-2076.

Watson, S.J., G. Giebel and A. Joensen, 1999. The economic value of accurate wind power forecasting to utilities. Proceedings of European Wind Energy Conference (EWEC), March 1-5, 1999, Nice, France, pp: 1109-1012.

Yang, H., L. Lu and W. Zhu, 2007. A novel optimization sizing model for hybrid solar-wind power generation system. Solar Energy, 81: 76-84.

Zhang, Y., A.A. Chowdhury and D.O. Koval, 2011. Probabilistic wind energy modeling in electric generation system reliability assessment. IEEE Trans. Indust. Appl., 47: 1507-1514.

Zhang, Y., L. Kang, S. Zhou and B. Cao, 2008. Wavelet analysis applied to wind speed prediction in predicate control system of wind turbine. Taiyangneng XuebaoActa Energiae Solaris Sinica, 29: 520-524.