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Investigating and Improving the Effect of Distributed Generation on Reliability in Wind Systems by ARMA Method

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Abstract

The increasing development of the use of new energies has led to the widespread use of power electronics, so that electronic power converters play an important role in extracting power from renewable sources. Power electronics can convert raw energy produced from new energy into the desired power with controlled current, voltage and frequency to be used in the power grid. Restructuring of power systems has led to an increasing number of scattered products in these systems. Distributed generation units, depending on the specifications, operating conditions and installation location, can be the source of positive effects such as improving the reliability of distribution networks. In this paper, the effect of distributed generation on reliability in wind systems is modeled. With the presence of DG, the distances of power infrastructure equipment are reduced, and as a result, system losses are reduced and ultimately network safety is improved. Proper design of these systems from the point of view of proper selection of active and inactive elements and proper design of ventilation system will have a direct impact on the reliability of these systems. It is also important to study the methods that do not lose the total output power of the converter after an error occurs in electronic converters.

Keywords Scattered production, reliability, wind systems
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1. Introduction

Today, increasing the reliability of power systems is one of the important goals in its various planning. Among these, the study of reliability from the point of view of production is of particular importance. With the increasing entry of renewable energy sources into the energy production cycle on the one hand and increasing energy consumption on the other hand, reliability indicators have become particularly important. Meanwhile, the use of wind farms has become more important due to the production of energy in higher volumes and being cheaper. For any system and in any project, the first step in assurance engineering is to determine its assurance requirements. Assurance engineering should specify the requirements of the tasks performed to ensure system assurance, document system design and development steps, tests, production and performance. Assurance tasks include a variety of analyzes, scheduling, and failure reports. The choice of the type of tasks and the level of work to be done depends entirely on the importance of the system, its type of operation and the defined costs. Important systems need formal reporting failures to be used in later stages of development. While less important systems can suffice with final test reports[1].

There are various definitions and interpretations of the concept of distributed generation. DG can be defined as "the generation of electrical power in distribution networks on the part of the consumer of the network" [2] or "the use of small-scale power generation units to generate power near load locations" [3]. These units are connected both directly to the distribution network and to the meter consumer [2]. This dramatically reduces distribution costs. DG is also able to supply electricity to buildings, companies and surplus electricity to the grid. In general, DG refers to units that produce less than 10 MW of power [3].

With the increase of production and distribution power plants in a large geographical area, the transmission distance is reduced, followed by less energy losses and lower pressure on the power system. Scattered generation is able to increase the security of energy supply between several load sources while reducing the probability of failure due to a single energy source [2]. Other studies showing cost-effective reasons include reduced transmission lines due to direct connection of DG to the distribution network, high investment costs and short construction time of small power plants, and uncertainty of load growth [4,5].

Some factors are involved in the design of the distribution system in order to determine the optimal development strategies taking into account the growth of the load and the provision of services with high reliability and economic efficiency for consumers. The liberalization of the power sector has prompted designers to use economically and technically economical equipment with new energy sources, such as distributed generation. In addition, the advantages of DG technology make it a safe and attractive option for designers. Also, the use of clean and renewable technologies has brought many environmental benefits. In recent years, the influence of DG in distribution systems around the world has increased.

Thera are two types of scattered production:

A) Microturbines [6]

Micro-turbines are small combustion turbine machines. Existing models produce power between 25 and 500 kW. Microturbine technology is primarily used as auxiliary power units in aircraft and large trucks. The main components of a turbine are: compressor, combustion chamber, turbine section, alternator and generator. Most microturbines have a single-stage radial distribution design.

B) Reciprocating machines

DG reciprocating machines are based on the same technology that can be seen in small machines or small home generators. The output of a reciprocating generator is less than one kilowatt for use in large five-megawatt units.

2. Wind systems and Reliability assessment methods

With wind energy, they generate electricity by investing in wind passing through the turbine blades, similar to a propeller-driven aircraft. WTs are an early alternative energy solution in many parts of the world, including Europe and the United States. The main structure of an air turbine consists of a system of blades connected to a generator or a set of generators and mounted on a tower. In most cases, gears are needed to transmit rotor speeds, low to generators, to generate electricity. There is a two percent drop in efficiency for each stage of the gear.

The probability of success, or the probability that the system will perform certain tasks with certain design constraints (such as time and space of system operation) without failure [2]. There are Four key elements of the theory of reliability:

– Reliability is the reduction of the probability of error. This means that failure is a function of a series of random phenomena. That is, it is not possible to provide complete information about the type of failures, the reasons for failure, and the relationship between failures, except that the overall probability of failure can be predicted based on probability functions over a period of time.
– Reliability is predicted based on "expected performance" and expected performance means performance without system failure. It should be noted that if each of the individual components and subsystems do not fail, there will be no reason for the failure of the entire system.
– Reliability is defined for a specific period of time. This means that the system has a definite opportunity to operate without failure before time t. Reliability engineering must ensure that components and subsystems will comply with defined requirements over a period of time. Of course, other parameters may be used instead of the time unit, for example, in the automotive industry, the number of kilometers traveled, in the military industry, the number of fire units fired, and in some moving mechanical parts, the number of operating cycles.
– Reliability is limited to specific environmental and operational conditions, and these constraints are necessary to achieve a potential for reliability because it is generally not possible to design a system to operate under unlimited conditions. For example, the Mars rover will definitely have different operating conditions and restrictions than a personal vehicle [3].

Therefore to have Reliability in wind systems , below assessment methods are required:

A) Controller design

There are various and extensive control models to control a wind energy converter system, such as adaptive control [9], fuzzy logic control [10], slip mode control [11], PI control [12], point tracking the maximum power and etc. noted.

Wind turbines with permanent magnet synchronous generators (PMSG) are an efficient configuration for variable speed applications. The advantages of using these settings include removal of dc excitation, less need for repair and high power over weight. These combinations require a full-fledged converter to connect to the grid, which makes it possible to obtain wind power over a wide range of wind speeds. Various control methods are used to obtain the maximum power and track the maximum power point related to the maximum power (MPPT) at the variable speed of the wind turbine [13].

B) Modeling the effect of scattered production on reliability

Modeling the DFIG system for wind turbine use is the main reference challenge [14]. The PSCAD / EMTDC software is used to prove the superiority of the proposed model and the dynamic response to voltage drops with the behavior of one is discussed. An analysis for wind-based DFIG for operation under unbalanced voltage conditions is presented in [15]. The DFIG system models the positive synchronous reference framework. The behavior and operation of the generator system and the converter on the network side under unbalanced conditions are shown by defining the expressions of oscillation power in the synchronous reference framework. This model enables control of active and reactive power generation using direct power control technique. It has been shown that the exchange of power expressions is simplified by considering the DFIG model in the synchronous reference jar. In addition, using the proposed model, the output power fluctuation of the stator is calibrated using GSC.

C) System risk modeling

The general model of the production system, which was calculated from the combination of traditional production units and wind power, is finally combined with the load model to determine the system risk and energy indicators. The amount of load in the Egyptian power system changes with time, and these changes can be modeled by the load model. Figure 1 shows the load curve model.

3. Method evaluation

The evaluation model of the expressed wind power system consists of three stages [16]:

A) Wind speed modeling

The wind power produced is directly related to the existing wind speed cube. This means that accurate wind speed modeling is essential to study the effect of wind power on reliability and cost. As the time and geographical position change, the wind speed changes continuously. Thus, wind model simulation simulates wind speed for a specific region over a specified period of time. To simulate the hourly wind speed for the selected wind farm, the ARMA time series is used, which is mathematically formulated as follows [16]:

$$y_t = \varepsilon_t + \sum^{p} \varphi_i \, y_{t-i} + \sum^{q} \theta_i \varepsilon_{t-j} \tag{1}$$

In this relation yt are the time series values at time t, φi and θj are recursive and kinetic parameters. εi is normal white noise with a mean of zero. The simulated wind speed SWt at t hour can be calculated according to Equation (2) using the mean velocity μt and the standard deviation σt and the value calculated in the time series yt as follows:

$$SW_t = \mu_t + \sigma_t \times y_t \tag{2}$$

Hourly average wind speed and standard deviation information for the Zafarana area has been collected by NREA and a computer program has been written to use the wind speed information to determine the exact ARMA model (p, q) from which to simulate Use wind speed. This model represents the first step in modeling a wind system.

B) WTG system modeling

Zafarna wind farm consists of three types of units and has an installed capacity of 425.82MW. WTG modeling of the system requires the integration of the wind speed model mentioned above with the WTG power generation specifications for all types of WTG.

4. Wind power modeling

The main features that affect the amount of power produced by WTG are the low cut-off speed Vci, the high cut-off speed Vco, the rated speed Vr and the rated power Pr. The generated wind power changes non-linearly with changes in wind speed and can be determined by the WTG power curve, which is mathematically formulated as follows:

$$P_t = \begin{cases} 0 \quad 0 \le SW_t \le V_{ci} \\ A + B \times SW_t + C \times SW_t^2 \quad V_{ci} \le SW_t \le V_r \\ P_r \quad V_r \le SW_t \le V_{co} \\ 0 \quad V_{co} \le SW_t \end{cases} \tag{3}$$

In this regard, Pt is the output power at hour t and the coefficients A, B, C are determined by the high and low cut-off speed.

Wind farm production capacity consists of a number of different modes of production capacity and the corresponding probabilities of each of them. The probability of availability of simulated Pwi power at wind speed SWi is calculated by the following equation:

$$P_{wi} = \frac{N_i}{(N \times 8760)} \tag{4}$$

In this regard, N is the number of simulated years and Ni is the number of occurrences of wind speed in the range (SWj ,, SWj + 1) which:

$$SW_i = \frac{(SW_j + SW_{j+1})}{2} \tag{5}$$

The Pi power generated by each WTG in the wind farm is calculated by Equation (4) and then added together to determine the wind farm power generation model, which consists of the WPi wind farm power generation and the probability of their occurrence pi. The value of WPi corresponding to the wind speed SWi is calculated from Equation (6):

$$WP_i = \sum_n P_i \tag{6}$$

In this regard, n is the number of wind turbines (WTG) in the wind farm.

EPO is defined as the average long-term output power and is an indicator for evaluating the useful power of a wind farm. This index is calculated from the following equation:

$$EPO = \sum_{i=1}^{m} WP_i \times p_i \tag{7}$$

In this regard, m expresses the number of production modes.

The number of model modes obtained is large. Therefore, a suitable method has been used to present a reduced equivalent model of the wind farm. The average wind speed for this geographical area is between 9 and 9.7m / s and the hourly standard deviation index is in the range of 3.5 to 3.6m / s. The values of low cut-off speed, rated speed and high cut-off speed of each wind turbine (WTG) are in the range of 2.5, 4 and 4m / s, 13, 13 and 17m / s, 25, 19 and 25m / s, respectively. The 5-state model obtained for the wind farm is shown in Table 1 [16].

Table.1.
Production wind power model

Probability of any case	$\boldsymbol{WP_t}$(%)
0.070210	0
0.059460	25
0. 116850	50
0.244460	75
0.509020	100

The next step in the evaluation process is to determine the wind farm production capacity model at the point of connection to the network. In this model, the transmission line model is also considered, which includes power transmission capacity and the possibility of out-of-service lines, which are included as constraints in the wind farm production power model. As stated in Equation (8), the amount of wind power available at the point of connection to the network (WPGi) is limited by the capacity of the Tcap transmission lines:

$$\begin{aligned} WP_{Gi} &= WP_i, \quad for \;\; WP_i < T_{cap} \\ WP_{Gi} &= T_{cap}, \quad for \;\; WP_i \geq T_{cap} \end{aligned} \tag{8}$$

Also, the probability of pGi to produce the WPGi mode is calculated from Equation (9):

$$\begin{aligned} p_{Gi} &= U_T + (1 - U_T) \times p_i \quad for \;\; WP_{Gi} = 0 \\ p_{Gi} &= (1 - U_T) \times p_i \quad for \;\; WP_{Gi} < T_{cap} \\ p_{Gi} &= (1 - U_T) \times \textstyle\sum_{j=1}^{s} p_j \;\; for \;\; WP_{Gi} = T_{cap} \end{aligned} \tag{9}$$

In this regard, UT is the probability of the transmission line leaving the network and s is the total number of j production modes which is limited by the transmission capacity of the lines.

In this research, the transmission system failure rate (λ) and the average repair time (r) are extracted from the information of the Egyptian Electricity Company. The probability of non-availability of the transmission system is calculated to be 0.066. The combined wind power generation model with the unavailability of the transmission system has 2 to 5 modes, which depending on the capacity of the transmission lines and the capacity of the installed wind farm. These models, which are calculated from computer execution, are shown in Table 2.

Table.2.
Constrained model of generated wind power

Probability of any case	***Produced wind power modes*** $\boldsymbol{WP_t}$***(MW)***
Two-mode model	
0.1843	0
0.8057	100
Three-mode model	
0.1943	0
0.4554	130
0.3503	250
Four-mode model	
0.1943	0
0.4554	130
0.3117	260
0.0386	350
Five-mode model	
0.1943	0
0.4554	130
0.3117	260
0.0375	390
0.0012	520

Thus, Equations (6) to (9) have been used to determine the different states of wind power generation and the probability of occurrence of each state. This model is used to calculate the EPO according to Equation 10.

$$EPO = \sum_{i=1}^{m} WP_{Gi} \times p_{Gi} \quad (10)$$

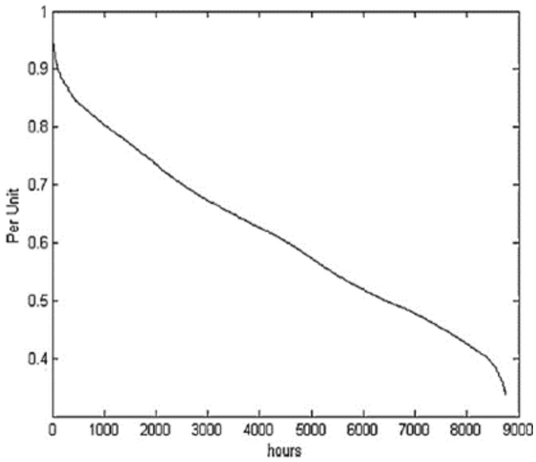

Fig. 1. Load change curve

Figure 2 shows the general software process used to evaluate system adequacy. This program calculates system reliability indicators such as the amount of expected unfulfilled load (LOLE) as well as energy indicators such as the amount of expected wasted energy (LOEE) and the amount of expected supplied energy (EES) for each production unit. he does. These indicators are used to assess the reliability and cost of combining wind units with traditional production units and transmission systems [16].

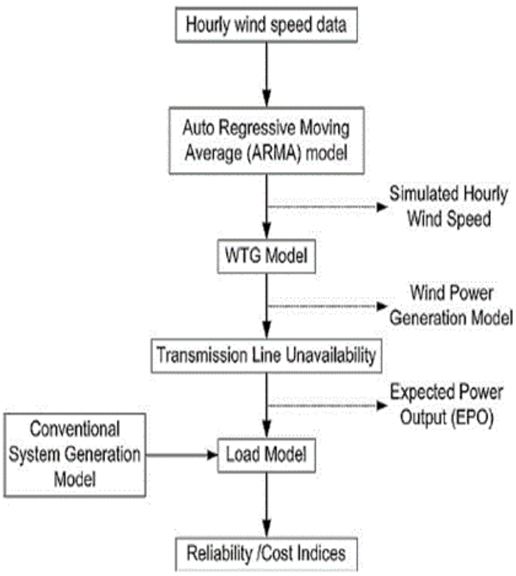

Fig. 2. Flowchart of the evaluation process used

Adding wind power to a traditional system can be beneficial by providing additional energy to the system and reducing the cost of paying subscribers (ECOST). The simplest way to estimate ECOST is stated in Equation (11) [16]:

$$ECOST = LOEF \times IEAR \quad (11)$$

The IEAR represents the rate of cut-off energy and is estimated at $ 3.63 / kWh equal to the un feed energy. LOEE is also defined as the amount of energy not supplied by production sources (EENS). Adding wind power to the power system has improved the overall performance of the system and increased the reliability of the system. This sentence can be calculated numerically by reducing the LOEE value obtained from Equation (12):

$$\Delta LOEE = EENS - EENS_w \quad (12)$$

In this regard, ΔLOEE is the amount of reduction in the LOEE of the system as a result of wind use, EENS is the amount of energy not supplied before adding wind and EENSw is the amount of energy not supplied after adding wind power.

The amount of cost reduction for subscribers or the amount of profit available from ECOST reserve can be calculated according to Equation (15):

$$BOC = IEAR \times \Delta LOEE \quad (13)$$

BOC is the amount of profit earned from ECOST savings in dollars. Thus the total gain (Bw) from wind power is calculated using Equation (14) as follows:

$$B_w = EES_w(FC + WPPI) + IEAR \times \Delta LOEE \quad (14)$$

5. Simulation results

The Egyptian power system consists of 165 common production units with a production capacity of 21516MW. The annual peak load for this country is equal to 19700MW. System information and the necessary information about the reliability of the units of this system are given in Table 5 1. Zafarana wind farm constitutes 1.979% of this capacity.

According to the method presented in Figure 3, this chapter uses reliability assessment to find the best transmission system capacity. For this study, EPO, LOLE, LOEE and EES indices were used to study reliability.

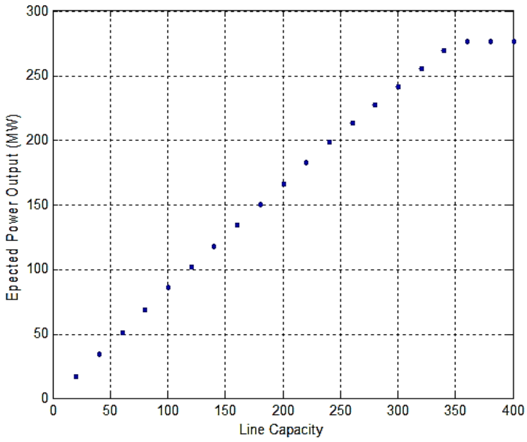

Fig. 3. Expected output power (MW)

6. Conclusion

Due to the growing need for energy and the depletion of fossil fuels and concerns about greenhouse gas emissions, energy saving and the use of renewable energy has become more important. Production through new energies such as the sun and wind is the main way out of the energy crisis. The total installed solar capacity in 2012 reached 100 gigawatts. This value for wind energy has reached 283 GW at the same time. The increasing use of new energy sources has led to the widespread use of power electronics, so that electronic power converters play an important role in extracting power from renewable sources. Power electronics can convert raw energy produced from new energy into desired power with controlled current, voltage and frequency to be used in the power grid. For wind systems, the electronic power converter is the intermediary between the wind turbine and the power grid and can convert the raw power generated by the turbine into compatible power to the grid, along with tasks such as improving grid power quality, extracting maximum Power from the grid and control the active and reactive power.

For solar systems, too, the electronic power converter is responsible for converting the dc output power of the panels to the desired ac power of the grid. Of course, it also has tasks such as extracting maximum power. Due to the expansion of renewable resources in the network, the reliability of these resources is very important because the departure of these resources, which are usually installed near load centers, will cause blackouts and reduce the reliability of the entire network. Proper design of these systems from the point of view of proper selection of active and inactive elements and proper design of ventilation system will have a direct impact on the reliability of these systems. It is also important to study the methods that do not lose the total output power of the converter after an error occurs in electronic converters. This field of research needs further studies in the future.

References

[1] Campbell D.B. (1990) Electric Power Distribution Systems Operations, Alexandria, Virginia

[2] T. Ackermann, G. Andersson, and L. Soder, "Distributed generation: A definition," Electric Power Systems Research, vol. 57, pp. 195-204, 2001.

[3] A.-M. Borbely and J. F. Kreider, Distributed Generation - The Power Paradigm for the New Millennium. CRC Press, 2001.

[4] Mohamed El Chehaly, Power System Stability Analysis with a High Penetration of Distributed Generation, Thesis of Master, Department of Electrical and Computer Engineering, McGill University, Montréal, Québec, Canada February 2010.

[5] M. Rabinowitz, “Power systems of the future. 4,” IEEE Power Eng. Review, vol .20 ,2000 ,pp. 4-9 .

[6] Fiala D.D. M. (2009) Cost analysis of electric grid enhancement utilizing distributed generation in post-war reconstruction, Thesis of Master, Naval Postgraduate School.

[7] A. Von Meier, Electric Power Systems. Wiley Online Library, .

[8] J.D. Glover and M.S. Sarma, Power System Analysis and Design, Brooks/Cole ,2001 .

[9] A.M.L. Da Silva, S. Leandro, L.S. Rezende, L.A.F. Manso, G.J. Anders, Transmission expansion planning: a discussion on reliability and “N−1” security criteria, in: Proceedings of the 110th International Conference (PMAPS’11), Probabilistic Methods Applied to Power Systems (PMAPS’11), 14–17 June, 2010, pp. 244–251.

[10] L. Wang, C. Singh, Adequacy-based design of a hybrid generating system including intermittent sources using constrained particle swarm optimization, in: Power Engineering Society General Meeting 2007 IEEE, 24–28 June, 2007.

[11] M. Hand, N. Blair, M. Bolinger, R. Wiser, R. O’Connell, Power system modeling of 20% wind-generated electricity by 2030, in: Power Engineering Society, 2008 General Meeting, Pittsburgh, Pennsylvania, July 20–24, 2008.

[12] J. Matevosyan, T. Ackermann, S.M. Bolik, Comparison of international regulations for connection of wind turbines to the network, in: Proceedings of Nordic Wind Power Conference (NWPC’04), GÄoteborg, Sweden, March, 2004, pp. 1–2.

[13] J. Sveca, L. SÄoder, Wind power in areas with limited export capabilities, in: Proceedings of the World Wind Energy Conference and Exhibition, Berlin, Germany, July 2–6, 2002

[14] Alejandro Rolán, Joaquín Pedra , Felipe Córcoles, Detailed study of DFIG-based wind turbines to overcome the most severe grid faults, International Journal of Electrical Power & Energy Systems,Volume 62, November 2014, Pages 868–878

[15] Asit Mohanty, Meera Viswavandya, Prakash K. Ray, Sandipan Patra, Stability analysis and reactive power compensation issue in a microgrid with a DFIG based WECS, International Journal of Electrical Power & Energy Systems, Volume 62, November 2014, Pages 753–762

[16] Arjang Yousefi-Talouki, Edris Pouresmaeil, Bo Nørregaard Jørgensen, Active and reactive power ripple minimization in direct power control of matrix converter-fed DFIG, International Journal of Electrical Power & Energy Systems, Volume 63, December 2014, Pages 600–608.