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ASSESSMENT OF PROBABILITY DISTRIBUTION SEQUENCE FOR VOLTAGE STABILITY IN A POWER SYSTEM WITH A LARGE SHARE OF RENEWABLE SOURCES INTEGRATION WITH VARIABLE POWER

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Abstract- The traditional energy infrastructure has been gradually modernized with renewable energy and microgrid technologies, leading to widespread generation. However, renewable energy sources cannot produce large amounts of inertia, requiring more sophisticated stability considerations. To study voltage stability in renewable-dominated power networks with wind turbines, PV panels, and distributed energy sources, appropriate explanatory approaches are necessary. This article proposes a probabilistic approach to determine voltage stability limits in a power system incorporating distributed generation systems with renewable sources and variable generation. The method involves repeatedly solving constant regime equations for a range of wind power capacities corresponding to average wind speed fluctuations. The sequential loading method determines the limit of initial data of power generation through the P-V function, which corresponds to the maximum power transfer through the controlled part of the power system network. Modelling on IEEE test diagrams and a real power system showed that this strategy can address issues in operational control during characteristic hours of power generation. The stress limit values estimated for wind speed fluctuations relative to each average wind speed value can assess risks of voltage stability violations in the system, depending on its state (normal circuit, shutdown of main elements - generators, lines) and wind speed.

Keywords: Wind Power, Variable Generation, Voltage Stability.

1. INTRODUCTION

The development of renewable sources with variable generation, such as wind and solar power plants, creates problems in the central energy system due to the stochastic power generation [1], [2]. These changes in the system require the use of new approaches in managing the power system mode, assessing its normal and critical states. Right now, different approaches are being utilized for the stability analysis of the electric power system, which are widely used in power systems with traditional sources.

In studies to determine the limiting regimes, equations are proposed to estimate these regimes by classical methods for identification of the limits of static stability. A large number of works are devoted, including [3], [4] the authors consider the issues of forecasting the stability of a system with a huge share of integrated wind generation. In association with the transformation of the electric power industry, which involves the integration into the power system of a significant proportion of wind and solar PV stations implemented both through distribution PV microsystems and individual PV microsystems, the problem of estimating the stability limit of the system becomes the most relevant. In this regard, the challenge of creating digital models for quick margin determination of static stability of an electric power system with distributed generation networks designed for the dominant use of renewable sources is of great importance. This paper presents one of the possible approaches for stochastic estimation of the limits of voltage stability in a system with developed power generation from wind farms.

This paper's goal is to carry out a voltage stability analysis using an iterative control framework package, to assess the effect of deliberately set wind generators on dispersion frameworks with regard to the basic voltage varieties and collapse edges. This paper concludes with the discussion about criticality points change based on different wind speed and wind power generation.

2. METHODOLOGY

The power flow, voltage profile, and control quality for consumers and power suppliers can all be significantly impacted by wind generators. Recently, there has been a rapid global advancement in the production of wind energy. A significant amount of wind power is entering the power system as wind farms and turbine estimates are growing quickly. The impact of wind turbines on the control quality and voltage stability is becoming more and more important as wind power penetration into the network increases quickly. Because of the erratic nature of the wind and the characteristics of wind turbines, it is widely recognized that a significant increase in the amount of wind power entering a power system may result in serious problems [3].

Power quality problems can become a major concern in smaller facilities connected to flimsy electric grids like medium voltage distribution networks because of the proximity of the generators to the loads. One of the most important power quality issues in distribution networks is the existence of voltage dips. According to estimates, between 75 and 95 percent of industrial sector claims to electric distribution firms in developed nations are connected to issues brought on by this kind of disturbance. Many electrical loads are not built to continue functioning normally after a voltage drop, which causes several problems [3].

Method of Continuation Load Flow study was carried out using the *P-V* and *V-Q* Curves. By continuously updating the load flow equation and computing the load flow equation, the convergence issue close to the stable operation limit point can be resolved, and the voltage stability limit may be attained. Additionally, the estimated voltage breakdown point is rounded by the continual prediction and correction procedure. A series of load flow results can be obtained by running the microgrids while altering the load value *P* or *Q* of the chosen bus while maintaining the other parameter values. The voltage collapse point, or the boundary between stable and unstable conditions, is the point at which the load flow algorithm fails to converge. In order to conduct the simulation ETAP Software version 19.5.0 has been used.

2.1. Study Area

As a reasonably windy and sunny country with abundant hydro, biomass, and geothermal resources, Azerbaijan offers a considerable untapped potential for renewable energy. The Khizi district in Azerbaijan is chosen in order to use the collected data that are relevant to that location in the proposed method. It is in the country's east and is a part of the Absheron-Khizi Economic Region. The Khizi were selected due to the wind potential at these areas and possible construction and operations synergies. According to the information collected from GWA platform, the average annual wind speed in the area reaches 6 m/s.

2.2. Test Scheme

For this study IEEE-30 bus test scheme has been used. The scheme has been selected based on its structural similarities with the selected area electric power system network. The IEEE 30-bus test system has 30 buses, 6 generators, and 6 transformers and 300 MW total demand. The 30-bus test scenario does not have line restrictions, which is important to note. The model places these buses at either 132 or 33 kV. To conduct the study the microgrid with 4 number of wind turbines has been integrated to the scheme.

2.3. Wind Turbine Parameters

The characteristics of the wind turbines selected for installation in the scheme are shown in Table 1. The link between wind speed and the electrical output generated by the selected wind turbine is also shown in Figure 1. There are three stages that need to be discussed, it is obvious. When the wind speed is between 4 and 13.5 m/s, stage 1 begins. When the wind speed fluctuates between the rated (13.5 m/s) and the cutoff speed (25 m/s), stage 2 is reached. When the wind speed reaches the (25 m/s) cut off speed or higher, stage 3 is finally reached.

Table 1. Wind Turbine general specifications

Category	Specification
Rated Power	2 MW
Number of Blades	3
Rotor Diameter	54.4 m
Cut-in Wind Speed	4 m/s
Rated Wind Speed	13.5 m/s
Hub Height	70 m
Cut-out Wind Speed	25 m/s

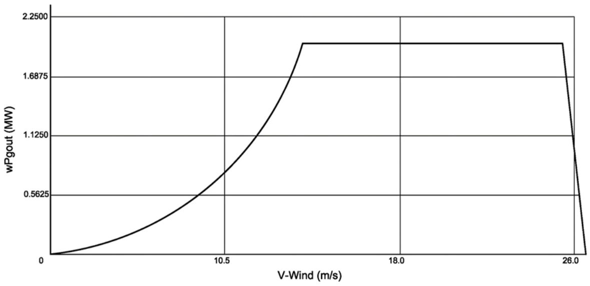

Figure 1. Wind turbine power curve

3. WIND SPEED DATA

The collection and visualization of important wind data was completed after the scheme was structured. For each time step of the year, a one-year time series of average wind speed in meters per second serves as the baseline data. The monthly averages, hourly data, and real data per 100 minutes are displayed in Figures 2, 3, and 4. For more precise wind generation modeling, high resolution (200 meter) data inputs can be found in the Typical Year Virtual Met Mast (TY-VMM) data set.

During the study it has been also investigated the method of generating data for the modeling when the real data is not available. It has been identified that the best method to do this is to use Monte-Carlo modeling to generate the numbers close to the possible wind speed data [4]. Monte Carlo simulation is a powerful statistical analysis tool that is widely used in engineering fields to assess the likelihood of energy system failure.

This simulation uses random sampling and a large number of computer experiments to display the statistical characteristics of the model outputs to their distributions [5].

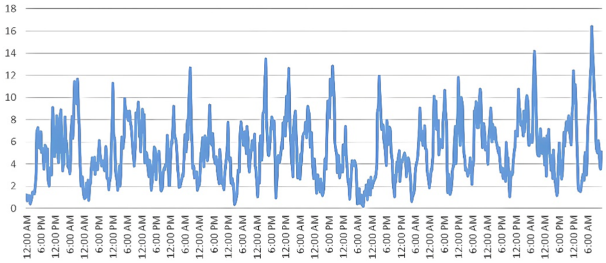

Figure 2. Hourly wind data per month (April)

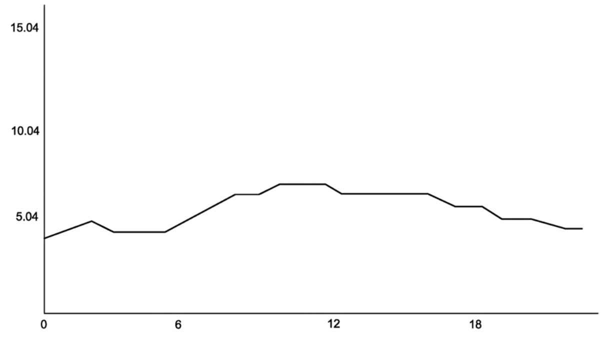

Figure 3. Monthly average wind speed (April)

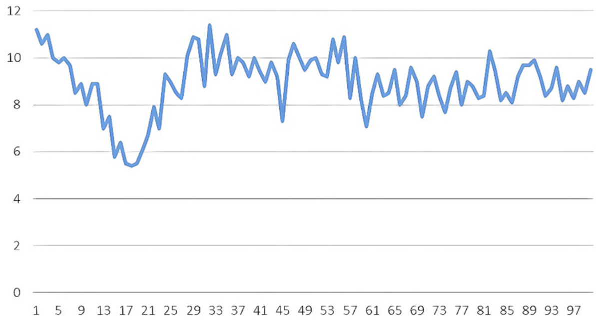

Figure 4. Real data for 100 minutes for a curtain period

$$x_i = F_x^{-1}\left(u_i\right)\frac{\partial^2\Omega}{\partial v^2} \tag{1}$$

$$\ln x = \lambda_x + \zeta_x\phi^{-1}\left(u_i\right) \tag{2}$$

$$u_i = \phi\left(\frac{\ln\left(X_i - \lambda_x\right)}{\zeta_x}\right) \tag{3}$$

$$x_i = \exp\left(\lambda_x + \zeta_x\phi^{-1}\left(u_i\right)\right) \tag{4}$$

where, u_i is random number (0 and 1), and where λ_x and ζ_x are the two parameters of the lognormal distribution. Any random number distribution can be produced by a computer program. In fact, there are numerous computer programs that can produce random numbers for frequently used distributions. The Equations given from (1) to (4) can be used to produce a specific distribution if the computer is unable to do so [5].

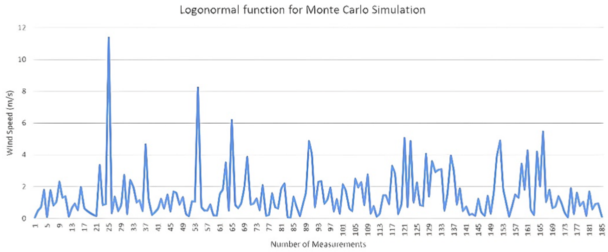

Figure 5. Lognormal variables for Monte-Carlo simulation

4. ALGORITHM OF CALCULATION

Below is the calculation algorithm of the study:

- For real minute measurements of wind speed in a certain period, build the probability distribution. Figure 6 shows the probability density functions for the sample variable from 1 to 25. The function applied to the 100 minutes real data measurements.

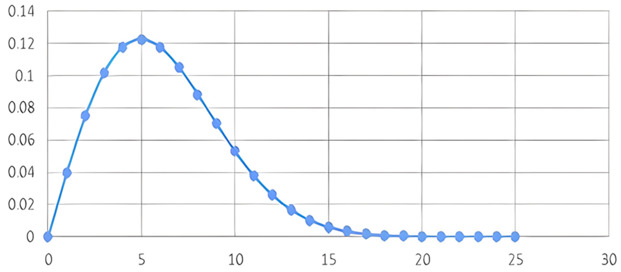

Figure 6. Probability density function (shape factor *k*=2)

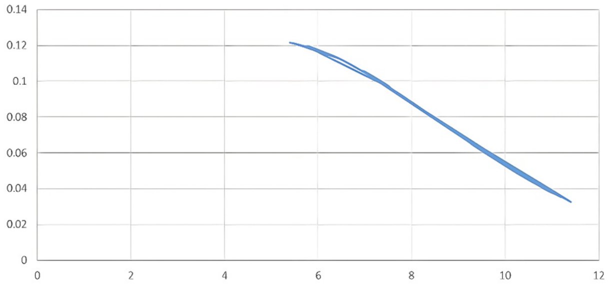

Figure 7. Probability density function for real data

By applying Weibull formula on the data, the most probable wind speed data has been identified. Figure 7, shows that the 5.5 m/s and 6 m/s is the mostly repeated wind speed of the area. The 8-10 m/s is also characteristic to the area, more than 12 m/s is less probable between these 100 minutes of data.

The quantity known as the Weibull k value, also known as the Weibull form factor, represents the width of a distribution of wind speeds. Lower *k* values are associated with wider distributions of wind speed, demonstrating that winds typically vary over a large speed range. The *k* number refers to the shape of that distribution. As, *k* values rise, wind speeds tend to remain within a small range. As a result, a region with strong winds may have a Weibull k value as low as 1.5, whereas a site with strong winds that are relatively constant (such tropical trade wind conditions) may have a *k* value as high as 3 or 4. We utilize a default Weibull *k* value of 2, which is typical for many

– In the absence of sufficient data on wind speed measurements, they can be simulated using the Monte Carlo method.

– For the most probable interval of repetition of wind speeds, construct the distribution of power generation of wind farms. Figure 8 corresponds to the Figure 6, whereas Figure 8 corresponds to Figure 7 probability function.

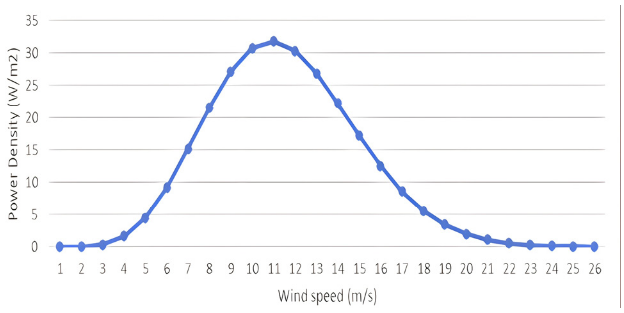

Figure 8. Power density curve based of Figure 6 variables

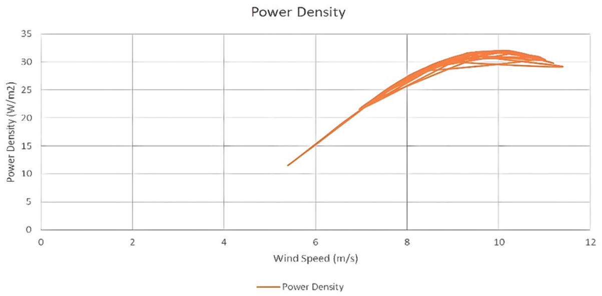

Figure 9. Power density function curve of Figure 7 variables

– For the values of wind speed on 5, 10 and 14 m/s and corresponding power generation, we carry out calculations of the limit of static voltage stability. Several number of wind speed values are considered around the shown numbers. This is due to intermittent and fluctuating character of the wind speed.

– We use the method of maximum network load limit according to the Continuation load flow

– The power of the wind farm is set by the value of the highest output

– A series of calculations of the power load flow is carried out for the load values in the system from the one specified from the daily schedule to those values at which *P* in one of the transmission lines does not reach the maximum.

– Generate curves *P-V* and *Q-V* curves.

5. RESULTS AND DISCUSSIONS

Several load flow analyses were performed beginning with the operational point to obtain the *P-V* curve and *Q-V* curves for wind speeds of 5, 10, and 14 m/s at the power distribution system's common bus. We obtained a steady-state stability analysis of the system using these simulations. To show each plot, the results were summarized in Figure 10.

It is important to note that as the wind speed and active power of the load increase, so does the current, resulting in higher voltage drops at the cables and an increase in the critical point of the curves (where the system becomes unstable). It can be seen that when the load demand increases, the voltage drops rapidly at the “knee” of the PV curve. Beyond this point, load flow solutions do not converge, indicating that the system has become unstable [6]. When the wind speed reaches 5 m/s, the system reaches a tipping point, with an additional 178 MW load demand and a 26% voltage drop. When the wind speed reaches 10 m/s, the system reaches a critical point, with an additional 175 MW load demand and a 30% voltage drop. When the wind speed reaches 14 m/s, the system reaches a critical point, with an additional 106 MW load demand and a 52% voltage drop. The critical point varies within the area shown in elliptic form. If we combine the critical points with one line, we can get the trend of critical points. To show its difference for each wind speed and wind power generation accordingly.

When the wind speed is 14 m/s, the system is less stable in terms of reactive power variation Figure 11 this wind speed is less likely in the study area. Wind speeds of 5-10 m/s, on the other hand, are very typical for the area. Voltage stability is determined by how changes in *Q* and *P* affect the voltages at the load buses. The influence of a device's reactive power characteristics is more obvious in a *Q-V* connection. It illustrates how bus voltages are sensitive to reactive power injections or absorptions and how they might vary. In typical operation, a rise in *Q* leads to a rise in voltage. Therefore, if the operating point is on the right side of the curve, the system is said to be stable. On the other hand, the functioning points on the left of the graph are thought to be unstable [4, 5].

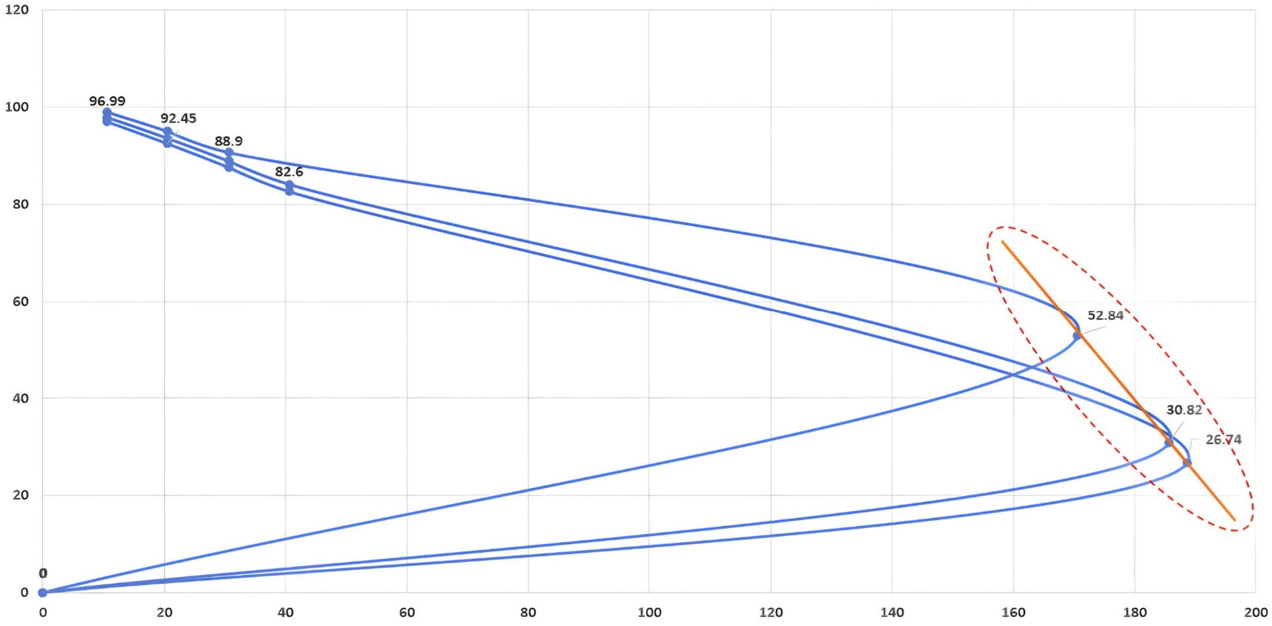

Figure 10. *P-V* curves for 5, 10 and 14 m/s wind speeds

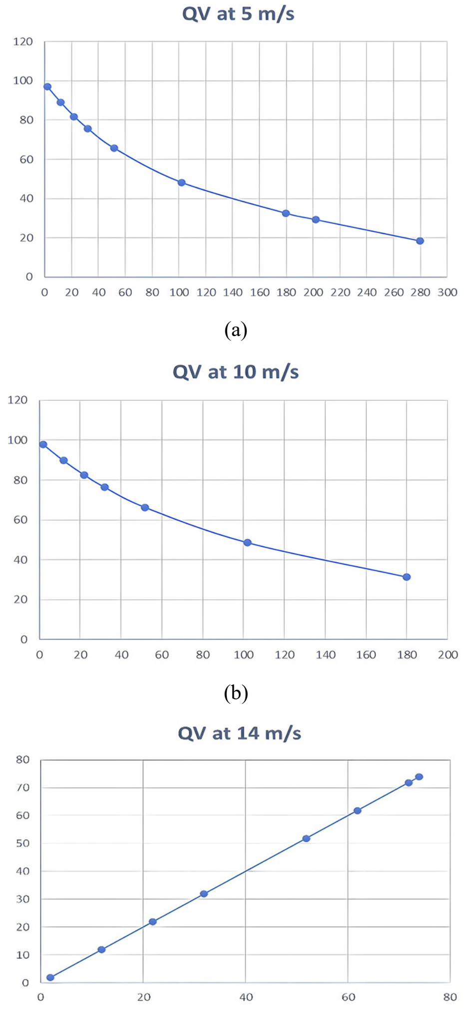

Figure 11. *V*-*Q* Curves for 5, 10 and 14 m/s wind speeds, (a) Wind speed 5 m/s, (b) Wind speed 10 m/s, (c) Wind speed 14 m/s

6. CONCLUSION

The paper presented a method for determining the maximum permissible load in a distribution power system's common bus. The presence of wind power is taken into account in order to assess the impact of this generation on voltage operation and voltage stability limits. For each wind speed and power generation, the voltage stability limit region and a sub-region in which the voltages at the bus are within acceptable ranges are defined. In actual use, the *PQ* curves can be used to identify a system bus's ability to handle an increase in load demand. Of course, the safe voltage limitations must be established in order to satisfy the new demand.

The study concept or design, data collection, analysis, or interpretation for the article, critical revision of the article for significant intellectual content, and approval of the final version for publication have all been significantly influenced by the authors. The authors also contribute in the idea and design of the analysis, data gathering and visualization, resource inquiry, and data curation and then performed the simulation, produced insightful research reports, and contributed to the intellectual and visual aspects of the work.

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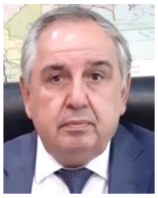
BIOGRAPHIES



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