Voltage Deviation of Wind Power Generation due to Wind Velocity Change

J. Arai, R. Yokoyama, K. Iba, Y. Zhou, Y. Nakanishi

Abstract— The present paper treats an induction machine as a wind power generator, and voltage deviation due to wind velocity change is simulated by a dynamic stability calculation program. The ac bus voltage connected to the wind generator depends strongly on the wind velocity variation. The wind velocity, which is used for the simulation, was measured. The present paper shows that one-second sampling data of the wind velocity is needed for evaluation of voltage deviation.

Keywords— Wind power generation, Voltage deviation, Wind velocity, Induction generator, Simulation.

I. Introduction

THE largest renewable energy source is provided by the wind and an increasing number of wind power generation plants are being installed worldwide. The generation is highly dependent on the wind velocity, and the active power output fluctuates with the change in wind velocity. Since wind power generation is normally undertaken with the intention of selling electrical power, estimation of the amount of electric power generation is very important. For this estimation, as a simple method, available wind velocity data, such as a ten-minute mean value, is used. This ten-minute mean value is reported by the Meteorological Agency. A number of studies [1] have discussed the prediction of ten-minute mean wind velocity data in a stochastic manner, such as a Rayleigh distribution, to determine the total output power of a wind farm.

The voltage deviation will also be an important evaluation item for planning new wind power generation or wind farms. If the wind power generation is installed at a weak ac system connection point, the ac voltage deviation will be large and will strongly depend on wind velocity change. Problems of power quality [2], such as voltage flicker or voltage drops, will arise. The voltage deviation is important, but few studies have examined this phenomenon. One study [3] treated the voltage control for stand-alone wind power generation. Another study [4] presented a simulation result for voltage change in a wind generator connected to an ac network using wind velocity data, but no information on the wind data was presented. Few studies have examined wind velocity data with respect to voltage deviation. Therefore, we focused on voltage deviation due to wind velocity change for a wind generator connected to an ac network.

An induction generator with a squirrel winding, which is the simplest configuration and is widely used, is assumed herein. When the wind velocity increases, the active power output increases and the lagging reactive power output increases in the induction generator. The lagging reactive power increase induces a voltage drop in the ac system.

The present paper reports the measurement of wind velocity with a one-second sample, simulation results of voltage deviation inducing wind velocity data as a mechanical input for induction generator, and evaluation of voltage deviation. In addition, the need for a standard data type for wind velocity change is proposed.

II. Measurement of Wind Velocity

The wind velocity of a one-second sample was measured by a wind gauge, and the characteristics are show in Table 1. The wind gauge is a cup type gauge, and the minimum sample time is one second.

The requirement for the one-second sample is clarified later herein, which means that a longer time average value such as 10 minutes has no meaning for evaluation of voltage deviation.

TABLE I
WIND VELOCITY GAUGE

Items	Specification
Type	A-702
Manufacturer	Yokokawa Elec.
Method	Cup
Range	2 m/s – 50 m/s
Precision	+/- 5% of full scale
Minimum velocity	2 m/s
Minimum sample	1 s

The measurement was carried out on the roof of 20-m-tall building located on top of a small hill on the campus of Kogakuin University. The university is located in the suburbs

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of Tokyo where high wind velocities are rare.

One set of measured data, time (s) VS wind velocity (m/s), is shown in Fig. 1. This data was collected over 3 hour and 17 minutes on September 27, 2006.

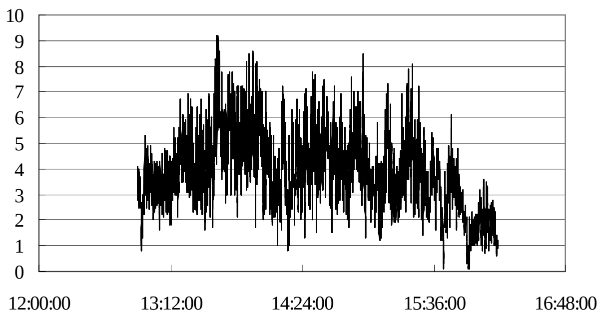

Fig. 1 Measured wind velocity with a one-second sampling

From Fig. 1, we selected a 120-second period of data, including the highest wind velocity, for voltage deviation analysis. These 120 data points are for a relatively high wind velocity, and the peak velocity reaches 9 m/s. The normal wind power generator has a rating power at a velocity of approximately 12 m/s. Therefore, these measured wind velocity data are not sufficient for voltage analysis at the equipment rating operation condition.

III. Modeling of the Wind Power System

A. Wind Power System

A model of a wind power system is shown in Fig. 2. The configuration is assumed to be simple. One squirrel cage type induction generator is connected through its step-up transformer to the ac system, which consists of one reactance and an infinite bus. The stall type is assumed for the control of the wind turbine.

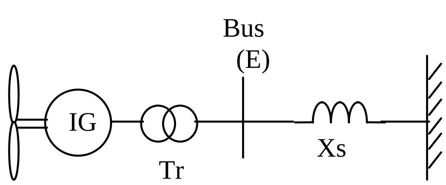

Fig. 2 Wind power system model

The rating of the wind generation is assumed to be 1,000 kW. The parameters of this system are listed in Table 2. The equivalent circuit of the induction machine used in this simulation is shown in Fig. 3 [5].

The slip s is calculated from the following motion equation:

$$\frac{d}{dt}\omega = \frac{1}{2H}(Pm - Pe) \qquad (1)$$

where ω is the angle velocity, Pm is the mechanical input, and Pe is the electrical output.

TABLE II
Parameters of the System

Items	Parameters
Generator rating	1,176 kVA
Generator output	1,000 kW
Voltage	660 V
Armature resistance, R1	0.0061 pu
Armature leakage reactance, X1	0.0645 pu
Rotor resistance, R2	0.009 pu
Rotor leakage reactance, X2	0.102 pu
Magnetizing reactance, Xm	3.25 pu
Inertia, H	6 s
Capacitor at 660V	250 kvar
Transformer rating	1,000 kVA, 6%Z

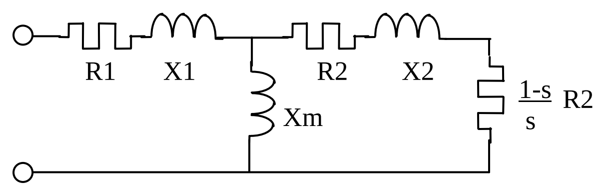

Fig. 3 Equivalent circuit of the induction machine

B. Wind Velocity

The 120 selected wind velocity data points are shown in Fig. 4, which shows an expansion of the data selected in Fig. 1.

The wind velocity data shown in Fig. 4 starts from 5 m/s. However, we assumed this velocity to be 9 m/s, which means that all wind velocity data are shifted to +4 to assume a 0.5 pu generator output at 9 m/s as a starting operation point.

The dynamic stability program [6] is used for this analysis. The wind velocity data are prepared as a text data file that was used for calculation.

The mechanical input of the shaft is calculated as follows:

$$Pm = \frac{1}{2}\rho ACV^3 \qquad (2)$$

The typical value [7] of the coefficient is used here. V [m/s] is the wind velocity.

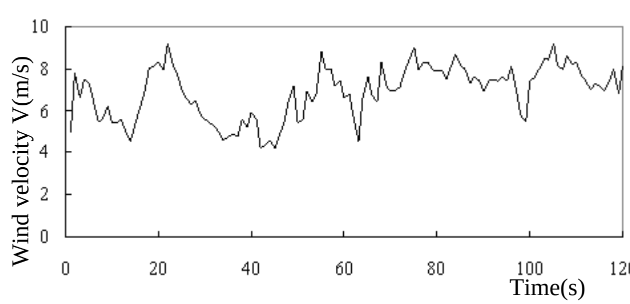

Fig. 4 Wind velocity data used for simulation

IV. Voltage Deviation

A. Short Circuit Ratio and Voltage Deviation

The simulation result is shown in Fig. 5. The short circuit ratio is assumed to be 10, i.e., 10 times the generator capacity. Fig. 5 shows the wind velocity V (m/s), the bus voltage E (pu), the active power on the line side P (pu/1,000 kVA base), the reactive power Q (pu), and the slip s (%) of the induction generator.

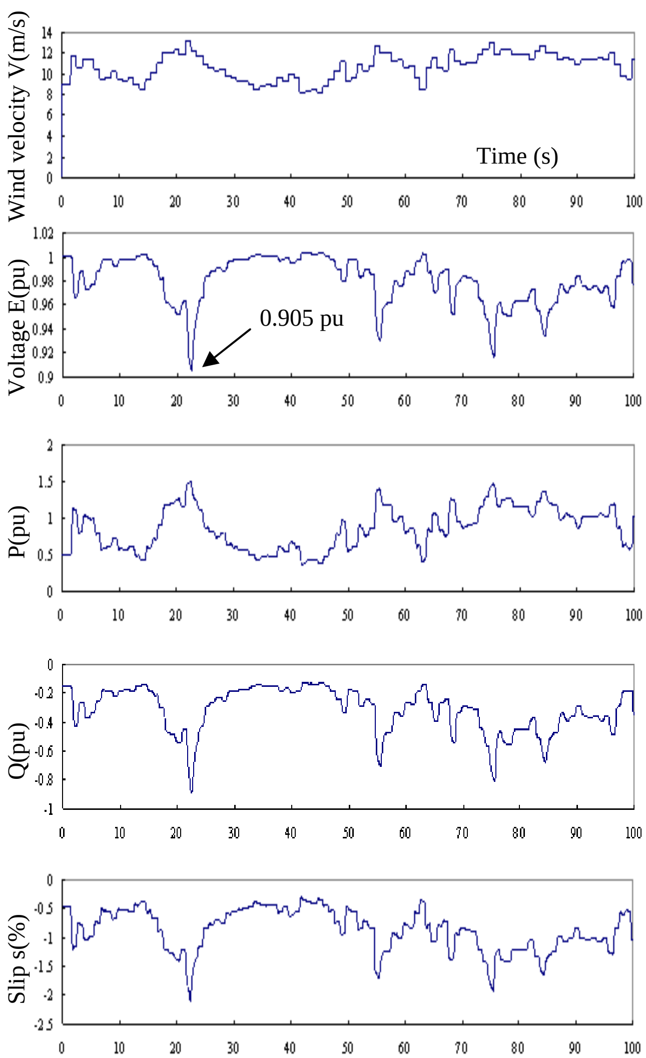

Fig. 5 Simulation results

From Fig. 5, the initial operating condition is as follows: wind velocity V = 9 m/s, bus voltage E = 1.0 pu, active power P = 0.5 pu, and reactive power Q = 0.15 pu lag. At t = 22.5 s, the wind velocity increased. In addition, P increases with the generation direction, and Q increases with the lagging direction. As a result, the voltage E drops from 1 pu to 0.905 pu. This voltage drop is very large and is due to the large reactive power consumption [8].

This voltage drop is shown in Fig. 6, in which the short circuit ratio is the parameter of interest. Fig. 5 and Fig. 6 show that this detailed simulation is able to show the precise voltage deviation related to the ac system condition. If a wind power generator is to be connected to a weak ac system, a detailed analysis is necessary.

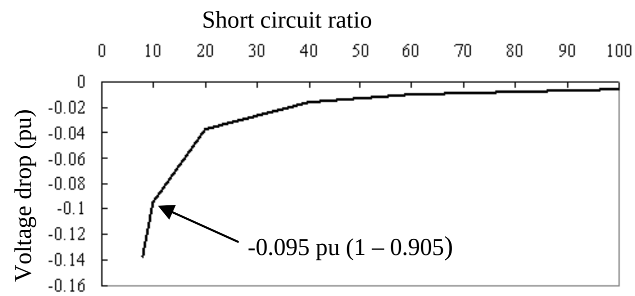

Fig. 6 Voltage drop vs. short circuit ratio

B. Average wind velocity and voltage deviation

The wind velocity is given as a ten-minute mean, usually of announced data. Therefore, we attempt simulation using average wind velocity data and compare voltage deviation. The average wind data are calculated from the data in Fig. 5, and the two-second mean data, the four-second mean data, and ten-second mean data are prepared. The same simulation is carried out, and voltages are shown in Fig. 7.

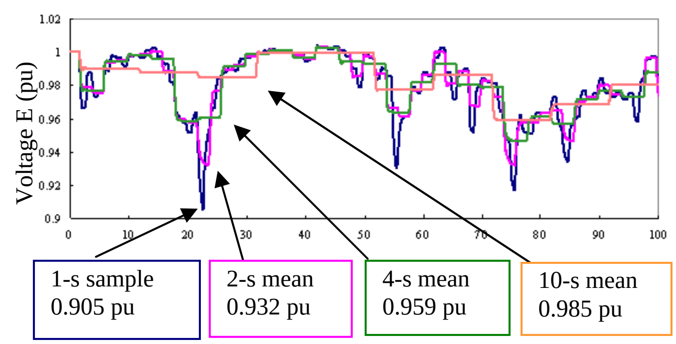

Fig. 7 Average wind velocity and voltage deviation

The maximum voltage drops are shown and compared in Fig. 8. From Fig. 7 and Fig. 8, the voltage deviation is highly dependent on the sampling time of the wind velocity. It is shown that only a one-second sampling is necessary for the evaluation of voltage deviation, and longer sampling data is not useful for evaluation.

C. Consideration for assumption

The measured wind velocity was biased to simulate the rating output operation of the induction generator. The validity of this assumption should be discussed for more detail evaluation.

The measured wind velocity is used directly as the mechanical input of the generator, but the wind direction usually changes. This simulation will yield the worst results with respect to voltage deviation because no change in wind direction was assumed. This corresponds to the condition in the ideal response of a yaw control.

The ac system is assumed as the reactance network in this simulation for the sake of simplicity. If the ac system is a low-voltage distribution network such as a 6.6-kV system, the resistance of the network will be large and the voltage deviation will be more complex.

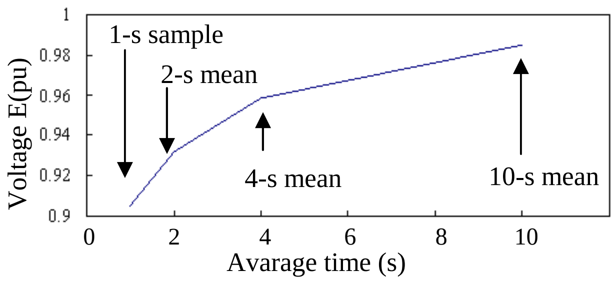

Fig. 8 Maximum voltage drop

For simplicity, only one generator is treated in the present study. However, if a wind farm is assumed, the average effect due to several generators will be obtained. This is another topic that will be analyzed.

We assumed a simple induction generator. If another type of generator, such as a dc link type generator, is assumed, the inverter in the dc link can control the ac voltage [9] within its capacity. However, the induction machine will be applied continuously due to its robustness and ease of maintenance.

Since the voltage deviation is not so small, a more detailed discussion should be performed for additional wind power generation applications. A standard wind velocity model for voltage evaluation that depends on location, area, and land should be developed.

V. Conclusion

The present paper describes the voltage deviation as being highly affected by the wind velocity change, and a one-second sample data is required rather than ten minutes of available data for reasonable evaluation.

Many considerations will be examined in the future, but the present paper reveals that voltage deviation can be estimated through detailed ac system dynamic simulation.

In addition, the requirement for a standard data type for wind velocity was proposed.

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