Voltage Deviation of Wind Power Generation due to Wind Velocity Change

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Abstract: - This 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 highly depends on the wind velocity variation. Then author actually measured the wind velocity which is used for the simulation. This paper shows 1 second sampling data of the wind velocity is needed for evaluation of voltage deviation.

Key-Words: - Wind power generation, Voltage deviation, Wind velocity, Induction generator, Dynamic stability, Simulation

1 Introduction

The largest renewable energy source is the wind power generation and many plants will be installed further through the world. The generation is highly dependent on the wind velocity and the active power output fluctuates along with the wind velocity change. The wind power generation is planned normally for selling electrical power, so estimation of amount of electric power generation is very important. For this estimation, as simple way, available wind velocity data like a 10 minute mean value is used. This 10 minute mean value is announced from the Meteorological Agency for example. Some reports [1] are discussed on prediction of 10 minutes mean wind velocity data by stochastic manner, like Reyleih distribution, to get total output power of wind farm.

The voltage deviation also will be one of important evaluation items for planning new wind power generation or wind farm. If the wind power generation will be installed at weak ac system connection point, the ac voltage deviation will be large and highly depend on wind velocity change. The problem of power quality [2] as voltage flicker or voltage drop will arise. The voltage deviation is important but few papers are published. A paper [3] treat voltage control for a stand alone wind power generation. A paper [4] presented a simulation result of voltage change on wind generator connecting to an ac network using wind velocity data, but no information on the wind data was described. We can find few papers discussing about wind velocity data in view point of voltage deviation. Therefore we focused on voltage deviation due to wind velocity change for wind generator connecting to ac network.

The induction generator with squirrel winding is assumed in this paper that is the simplest configuration and used wildly. When wind velocity increased, active power output increased and lagging reactive power output increased in the induction generator. The lagging reactive power increase induces voltage drop in the ac system.

This paper reports actual measurement of wind velocity with 1-second sample, simulation results of voltage deviation inducing wind velocity data to mechanical input for induction generator, and evaluation of voltage deviation. Furthermore need of a kind of standard of wind velocity change is proposed.

2 Measurement of wind velocity

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

The reason why the 1 second sample is required is cleared later in this paper, that means longer time average value like 10 minute has no meaning for evaluation of voltage deviation.

Table 1 Wind velocity gauge

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

The measurement was carried out at a roof of 20m height building located at top of small hill in the university. This area is the suburbs of Tokyo, and no high wind velocity is obtained normally.

One set of measured data is shown in Figure 1. This is data during 3 hour and 17 minutes on September 27, 2006.

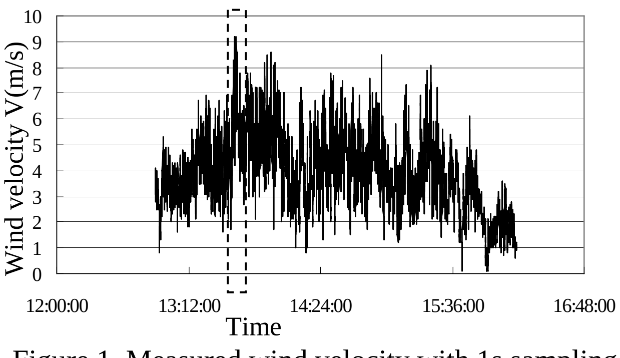

Figure 1 Measured wind velocity with 1s sampling

From Figure 1, we selected 120 seconds data shown in dotted rectangular for voltage deviation analysis. These 120 points (2 minutes) data are relatively high wind velocity and peak velocity reaches 9m/s. Normal wind power generator has the rating power at velocity of around 12m/s, so these measured wind velocity data are not enough to use for voltage analysis at equipment rating operation condition.

3 Modeling of wind power system

3.1 Wind power system

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

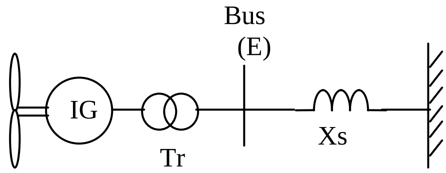

Figure 2 Wind power system model

The rating of the wind generation is assumed as 1000kW. Parameters of this study system are listed in Table 2. The equivalent circuit of the induction machine used in this simulation is shown in Figure 3 [5].

Table 2 Parameters of the system

Item	Parameters
Generator rating	1176kVA
Generator output	1000kW
Voltage	660V
Armature resistance, R1	0.0061pu
Armature leakage reactance, X1	0.0645pu
Rotor resistance, R2	0.009pu
Rotor leakage reactance, X2	0.102pu
Magnetizing reactance, Xm	3.25pu
Inertia, H	6s
Capacitor at 660V	250kvar
Transformer rating	1000kVA, 6%Z

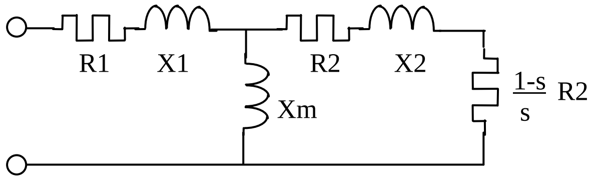

Figure 3 Equivalent circuit of induction machine

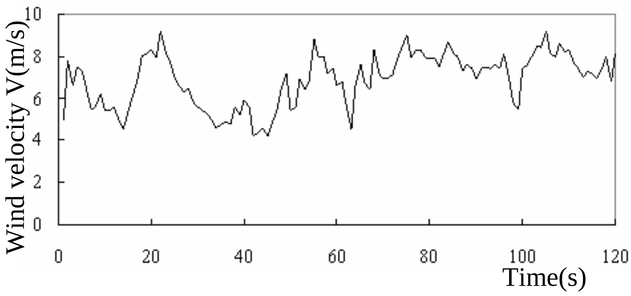

Figure 4 Wind velocity data used for simulation

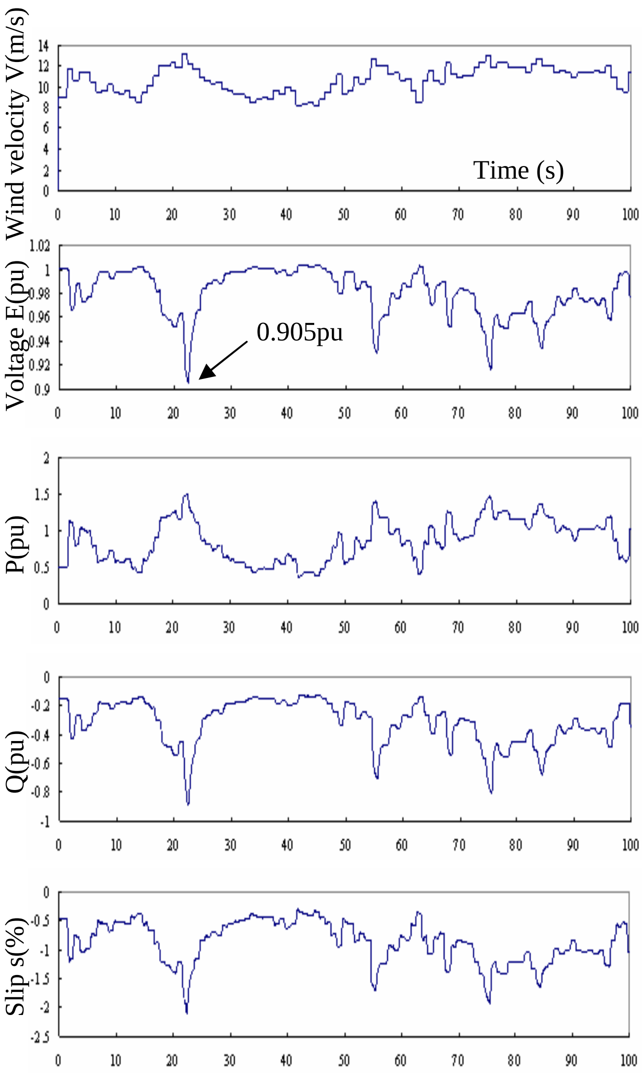

Figure 5 Simulation results

The slip s is calculated from the motion equation (1), where ω is angle velocity, Pm is mechanical input and Pe is electrical output.

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

3.2 Wind velocity

The selected wind velocity data containing 120 points is shown in Figure 4, this is the same as a part of Figure 1.

The wind velocity data shown in Figure 4 starts from 5m/s, however we assumed this velocity as 9m/s, that means all wind velocity data are shifted to +4 to assume 0.5pu generator output at 9m/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 and it was read and taken into calculation.

The mechanical input of the shaft is calculated by the equation (2).

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

The typical value [7] of coefficient $1/2\rho AC$ is used here. V[m/s] is the wind velocity.

4 Voltage deviation

4.1 Short circuit ratio and voltage deviation

The simulation result is shown in Figure 5. The short circuit ratio is assumed as 10, that is 10 times of generator capacity. The Figure 5 shows the wind velocity V(m/s), the bus voltage E(pu), the active power at line side P(pu/1000kVA base), the reactive power Q(pu), and the slip s(%) of the induction generator.

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

This voltage drop is shown in Figure 6 in which the short circuit ratio is taken as parameter study. Figure 5 and 6 show this detailed simulation is able to present precise voltage deviation relating to ac system condition. If a wind power generator is planned to connecting to a week ac system, detailed analysis should be necessary.

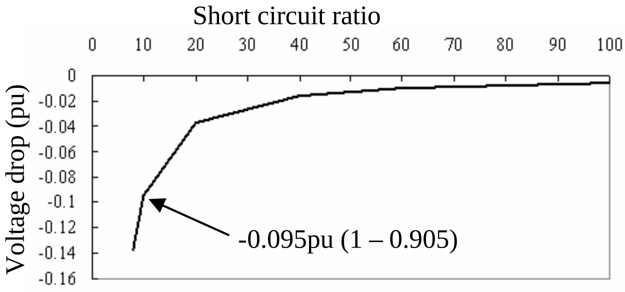

Figure 6 Voltage drop vs short circuit ratio

4.2 Averaged wind velocity and voltage deviation

The wind velocity is offered by 10 minute mean usually in announced data. So we try to make a simulation by using averaged wind velocity data and compare voltage deviation. The averaged wind data are calculated from data used in Figure 5, and the 2-second mean data, the 4-second mean data, and 10-second mean data are prepared. The same simulation is carried out and voltages are shown in Figure 7.

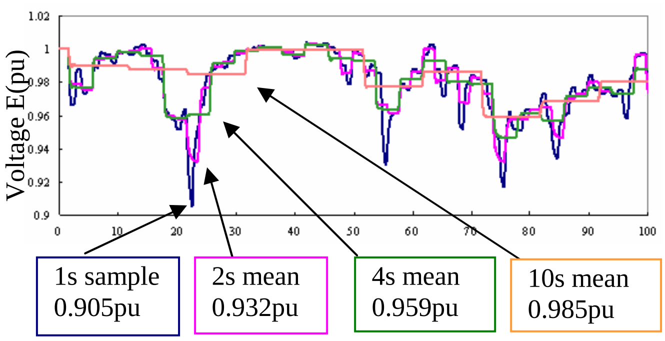

Figure 7 Averaged wind velocity and voltage deviation

The maximum voltage drops are compared in Figure 8. From Figure 7 and 8, the voltage deviation is highly dependent on sampling time of the wind velocity, and it is clear that 1 second sampling is necessary for evaluation of voltage deviation and longer sampling data has no meaning.

4.3 Consideration for assumption

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

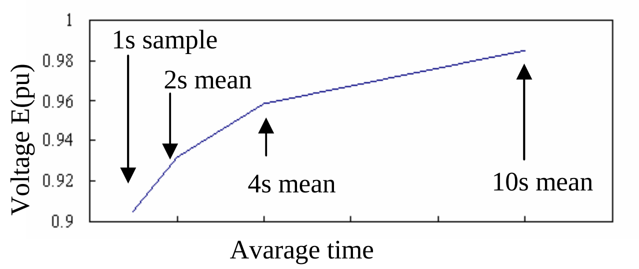

Figure 8 Maximum voltage drop

The measured wind velocity is used directly to mechanical input of the generator, but the wind direction usually changes. This simulation will give worst results in viewpoint of voltage deviation because the no wind direction change was assumed. It is corresponding to condition in ideal response of a yew control.

The ac system is assumed as reactance network in this simulation for simple study. If the ac system is low voltage distribution network like 6.6kV, the resistance of the network will be large and voltage deviation will be more complex.

One generator is treated here for simplicity, however, if wind farm is assumed, averaging effect due to many generators will be obtained.

We assumed a simple induction generator. If another type generator like a dc link type, an inverter in the dc link can control ac voltage [9] within its capacity. But the induction machine will be applied continuously due to its robustness and easy maintenance.

The voltage deviation is not so small, then more detailed discussion should be done for more wind power generation application. We would like to propose a kind of standard wind velocity model for voltage evaluation. That should be depending on location, area, and land.

5 Conclusion

This paper presents the voltage deviation is highly affected by the wind velocity change, and 1-second sample data is necessary instead of 10-minute available data for reasonable evaluation.

Many considerations will be examined further, but this paper shows voltage deviation can be estimated through detailed ac system dynamic simulation.

Need of a kind of standard data of wind velocity is proposed in this paper.

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