Intelligent Wind Turbine Generator with Tandem Rotors
(Acoustic Noise of Tandem Wind Rotors)

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Abstract: The authors had invented the unique wind turbine generator composed of the large-sized front wind rotor, the small-sized rear wind rotor and the peculiar generator with the inner and the outer rotational armatures. The front and the rear wind rotors drive respectively the inner and the outer armatures of the generator, and the rotational speed and the direction of both armatures/wind rotors are adjusted automatically in response to the wind circumstances.

The effects of the axial distance and the diameter ratio between both wind rotors on the turbine characteristics are discussed experimentally. The rear wind rotor runs in the counter direction against the front wind rotor at the lower wind speed and runs in the same direction at the higher wind speed, where the diameter ratio \( D = \frac{\text{rear wind rotor diameter}}{\text{front wind rotor diameter}} \) is less than 0.84. This rotational behavior is acceptable to get the superior operation of this wind turbine generator. Besides, the rear wind rotor should be set close to the front wind rotor as possible, irrespective of the diameter ratio \( D \).

To prepare the prototype, this paper also investigates preliminarily the acoustic noise from the wind rotors in accompanying with the flow conditions. The acoustic noise is larger with the decrease of the axial distance and/or the increase of the rear wind rotor diameter.

Keywords: Wind energy, Wind turbine, Tandem wind rotors, Generator, Acoustic noise

1. INTRODUCTION

Wind is clean, renewable and homegrown energy source of electric power generation, and has been positively/effectively utilized to cope with the warming global environment. The traditional wind turbines with the large-sized wind rotor generate higher output at moderate wind. The power generation of the small-sized wind rotor is lower but is suitable for the weak wind. That is, the size of the wind rotor must be correctly/appropriately selected in conformity with the wind circumstances. Moreover, the turbines must be equipped with the brake and/or the pitch control mechanisms, in general, to suppress the abnormal rotation and the overload generated at the stronger wind, and to keep good quality of the electric power. To overcome above weak points, the authors had invented the superior wind turbine generator [1, 2], as shown in Fig. 1. This unit was called “Intelligent Wind Turbine Generator” by the authors, as the rotational speeds of the tandem wind rotors are adjusted pretty well in cooperation with the double rotational armatures of the generator in response to the wind speed. This unit is composed of the large–sized wind rotor, the small-sized wind rotor and the peculiar generator with the inner and the outer rotational armatures without the traditional stator. The front and the rear wind rotors drive the inner and the outer armatures, respectively. The rotational torque is counter-balanced between the inner and the outer armatures of the generator. The rotational direction and the speed of both wind rotors/armatures are free, and these are automatically determined in response to the wind circumstances. The superior power generation of the proposed wind turbine generator was verified in the previous papers [1, 2, 3], and the characteristics of the double rotational armature type doubly fed induction generator was presented [4]. Continuously, this paper discusses preliminarily the effects of the axial distance between both wind rotors and the rear wind rotor diameter on the acoustic noise, after investigating the desirable arrangements of the tandem wind rotors.

Fig. 1 Intelligent wind turbine generator

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2. SUPERIOR OPERATION OF TANDEM WIND ROTORS

The superior operation of the tandem wind rotors has been presented [1], but is represented briefly for helping the discussions in this paper. The operation shown in Fig. 2 is in cooperation with the double rotational armature type generator. The rotational torque is counter-balanced between the inner and the outer armatures of the generator in response to the electric load. Then, the rotational direction and the speed of the wind rotor/armature are automatically adjusted in response to the wind speed. Both wind rotors start to rotate at the low wind speed, but the rear wind rotor counter-rotates against the front wind rotor. The rear wind rotor reaches the maximum rotational speed at the rated wind speed. With more increment of the wind speed, the rear wind rotor speed decelerates gradually and begins to rotate in the same direction as the front wind rotor, so as to coincide with the rotational torque of the front wind rotor. The reason of such behavior is that the small-sized rear wind rotor must work at the blowing mode against the attacking wind, because the rear wind rotor can not generate the same rotational torque as the large-sized front wind rotor in the turbine mode. Resultantly, the above operating conditions enable successfully to guarantee the quality of the electric power in the rated operating mode without the traditional brake and/or pitch control mechanisms. Moreover, the counter-rotation makes the output higher at poor wind circumstances, which is a remarkable advantage for the area having unacceptable wind circumstance to the power generation.

3. ARRANGEMENTS OF TANDEM WIND ROTORS
3.1. Experimental apparatus and model wind rotors

The model wind rotors were set at the outlet of the wind tunnel (the nozzle diameter is 600mm), as shown in Fig. 3. The wind rotors were connected directly and respectively to the isolated motor with the inverter, in place of the peculiar generator. The rotational torques of the front and the rear wind rotors were counter-balanced by the rotational speed control. The model blade profiles, which have no camber and are two dimensional, are shown in Fig. 4(a). The diameter of the front wind rotor is $d_F=500\,\text{mm}$, and one of the rear wind rotor $d_R$ is changed from 260 to 560mm. The front and the rear blade numbers are $Z_F=3$ and $Z_R=5$, and the front and the rear blade setting angles are $\beta_F=\beta_R=11.3$ degrees (see Fig. 4(b)). These values have been optimized in the previous papers [1~3].

3.2. Effect of axial distances

Figure 5 shows the effect of the axial distance between the front and the rear wind rotors on the output and the wind rotor speeds, where $C_{p_{\text{max}}}$ is the maximum
output coefficient at each distance \[CP = \frac{P}{\rho AV^{3/2}}, \]
where \(A\): area of the larger wind rotor, \(V\): wind speed\] and \(\lambda_{opt}\) is the tip speed ratio \(=\) (rotor tip speed)/(wind speed), subscripts \(T\), \(F\) and \(R\) means the relative, the front and the rear rotational speeds\] giving \(CP_{max}\), the diameter of the rear wind rotor is \(d_R = 355\) mm, and \(L\) is a dimensionless axial distance between both wind rotors divided by the front wind rotor diameter \(d_F\). The output \(CP_{max}\) and the relative tip speed ratio \(\lambda_{optT}\) are larger at the smaller distance. It was confirmed that such tendencies do not depend on the blade profiles. These data may suggest that the rear wind rotor should be set close to the front wind rotor as possible when both wind rotor profiles are optimized.

### 3.3. Effects of wind rotor diameters

Figure 6 shows the effect of the rear wind rotor diameter on \(CP_{max}\) and \(\lambda_{opt} \), where \(L=0.08\) and \(D\) is the diameter ratio of the wind rotor \(=\) (diameter of the rear wind rotor)/(diameter of the front wind rotor)\]. The coefficient \(CP_{max}\) shows the maximum values at \(D=1\), but this diameter ratio is not acceptable as follows.

Figure 7 shows the rotational behavior of the tandem wind rotors against the relative rotational speed \(N_T\) \(=\) \(N_F - N_R\), the rotational direction of the front wind rotor \(N_F\) is positive). The rotational behavior of the front and the rear wind rotors changes obviously at \(D=0.84\). That is, the rear wind rotor comes to run in the same direction as the front wind rotor at slower \(N_T\), when \(D\) is less than 0.84. This behavior is acceptable to get the superior operation described before. On the contrary, at the diameter ratio larger than \(D=0.84\), the front wind rotor runs in the same direction as the rear wind rotor. Such behavior is not acceptable because the rear wind rotor with larger diameter does not work effectively in the rated operation due to the disturbance of the front wind rotor in blowing mode. Then, the most suitable diameter ratio \(D\) between both wind rotors may be near 0.84. It was also confirmed that the suitable diameter ratio does not depend on the blade profiles.
4. ACOUSTIC NOISE

4.1. Preparation of the experiments

To reduce the background noises as possible, the new wind tunnel with the nozzle diameter 265 mm was prepared. Then, the diameter of the front wind rotor discussed in the previous chapters was shortened to \(d_F = 200\) mm, and the rear wind rotor diameter \(d_R\) was also changed from 105~225 mm. The axial distance \(l\) between the front and the rear wind rotors can be changed from 30 to 60mm. The wind rotors were set on the test stand reducing the dimensions of Fig.1, and surrounded with the anechoic box to intercept the background noises, as shown in Fig. 8.

The microphone of the sound-level meter, namely phonometer, was set at the position of 300 mm in the radial direction measured from the front wind rotor. The output signal form the meter was accumulated in the personal computer, and analyzed by a FFT analyzer. The level and the frequency of the wind rotors were evaluated without the background noises. The rotational speed of the front wind rotor was kept constant at \(N_F = 1800\) min\(^{-1}\), while the rotation speed of the rear wind rotor was \(N_R = 1800\) min\(^{-1}\).

The noise level from such measurements may be effective as for the preliminary evaluation, though the Reynolds number is very small as compared with one of the prototype and the blade profiles have not been optimized.

4.2. Effect of axial distance between both wind rotors

Figure 9 shows the effect of the axial distance between the front and the rear wind rotors on the equivalent continuous A-weighted sound pressure level \(L_{Aeq,T}\), and the dash line gives the level for the single wind rotor (front wind rotor). The sound pressure levels \(L_{Aeq,T}\) of the tandem wind rotors are higher than one of the single wind rotor, and become higher with the decrease of the axial distance with 4dB increment at \(L=0.15\) as compared with the value at \(L=0.30\). That is, the tandem wind rotor generates unacceptable noise owing to the flow interaction. The longer distance is acceptable as for the acoustic noise, but the shorter distance is acceptable for the output as recognized before.

Figure 10 shows the spectrum distributions of the acoustic noise at \(L=0.15\) and 0.30. The spectrum level at \(L=0.30\) is synthetically lower than the level at \(L=0.15\). The peculiar frequencies concerning to the blade rotation (\(NZ_F=90\) Hz for the front rotor, \(NZ_R=150\) Hz for the rear wind rotor, \(NZ_T=900\) Hz for the tandem wind rotors) scarcely observed and the level is high irrespective of the frequency. That is, the levels are induced from the turbulent noises due to the flow separation because the two dimensional blade has large attack angle (18.3degrees~63.9degrees for the front blade, 27.7degrees~62.0degrees for the rear blade). Then, it is possible to reduce the turbulent noise by optimizing the blade profiles.
4.3. Effect of rear wind rotor diameter

Figure 11 shows the effect of the diameter ratio $D$ on the sound pressure levels $L_{Aeq,T}$ at $L=0.15$. The level at the smaller $D$ is almost the same as one of the single wind rotor given by the dash line in Fig. 9. The level, however, is larger with the increase of the rear wind rotor diameter, because the larger rear wind rotor catches the tip vortex from the front wind rotor and generates itself the noise owing to the faster tip speed.

5. CONCLUDING REMARKS

To prepare the prototype of the intelligent wind turbine generator, the effects of the axial distance between both wind rotors and the rear wind rotor diameter on the acoustic noise were known roughly, after investigating the desirable arrangements of the tandem wind rotors. The acoustic noise is larger with the decrease of the axial distance and/or the increase of the rear wind rotor diameter.

The acoustic noise will be discussed in detail after the tandem wind rotor profiles are optimized taking account of the output, in the near future.

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7. REFERENCES