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Numerical study on flow and dynamic characteristics around multiple vertical axis turbines for practical use of ocean current power generation

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After the industrial revolution, mankind has achieved rapid development, and the development of industry and economy including the developing countries has not stopped. On the other hand, the energy consumption of the world continues has increased at the annual average of 2.5%, and the problems of the finiteness of fossil fuel which is a main resource and the environmental effect in the energy production become large serious problems in the global scale. Though the positive utilization of the renewable energy is also attempted, there are still many problems on them, and the new energy source is required in addition to the conventional systems such as wind power generation, photovoltaic power generation, biomass power generation. Ocean energy is attracting attention as such new energy in recent years. Among them, a system to convert kinetic energy of sea water flow such as ocean current and tidal current into electric energy has an advantage of easy prediction of electric power generation quantity since it is not influenced by weather in addition to its high energy potential. Furthermore, one of the features in comparison with wind power which is a similar power generation system is the difference in the density of the medium. Since the density of seawater is about 800 times that of air, it is easy to obtain a large power in the downstream, even if seawater passes through the turbine and the flow velocity decreases somewhat. Therefore, unlike wind power generation, it seems to be possible to install a lot of turbines in a comparatively narrow region, and verification of the interaction of each turbine at that time is one of the important themes. Generally, when analyzing the flow around a rotating object, a rotating coordinate system which rotates with the object is often used. However, when there are multiple rotating bodies, it is highly difficult because a special contrivance is required and the calculation amount becomes enormous.

In order to solve this problem, in this study, a new algorithm "Partially overlapping grid of rotating and stationary coordinate systems" is proposed to reduce calculation amounts while keeping precision objecting at three-dimensional simulation using 2 vertical axis S-shaped turbines rotating synchronously. In addition, the proposed method is used to change the distance of turbines and the direction of the stream to confirm their basic interaction and to verify the applicability of the method to the situation where there are more turbines. Details are described below.

In the case that the value of the physical quantity of the lattice point on one region boundary is decided from the other lattice which has different lattice, for example, the case that a lattice including a rotating object overlaps the other lattice of the whole region, interpolation from adjacent 8 points (4 points for 2D) is required in the three-dimensional case. Since the error cannot be avoided in the interpolation, the smaller the interpolation, the better. This method "Partially overlapping grid of rotating and stationary coordinate systems" can be said to be more accurate than the usual method, because only the interpolation in one direction in the circumferential direction is sufficient. Moreover, although the calculation load for searching adjacent points is usually large since it is necessary to interpolate every time the coordinates of grid points change, in this method, the calculation time can be reduced because it is easy to search adjacent points in interpolation. Also, this method is advantageous in that the rotating region can be made small. It is because generally the absolute values of X and Y coordinates become large when the region is large and it makes calculation difficult in the case that only the rotational coordinate system is used. These advantages suggest that the use of "Partially overlapping grid of rotating and stationary coordinate systems" makes it possible to perform calculations even when there are a lot of turbines.

Using the proposed grid system, the incompressible Navier-Stokes equations are solved in each domain by the fractional step method. The validity of the simulation program prepared using "Partially overlapping grid of rotating and stationary coordinate systems" was verified by comparing the behavior of a single turbine and the behavior of 2 turbines in two dimensions with the results of a previous study conducted by another method.

The following verification was carried out using the proposed technique.

First, the vertical-axis S-shaped turbine adopted in this study was verified with and without end plates on the upper and lower sides. There is the Savonius type windmill as a windmill similar to this

shape, and generally the Savonius windmill has top and bottom end plates for efficiency improvement. Therefore, it was confirmed whether there is also a difference in the efficiency by the existence of end plates in the mechanism which is the object of this study. The calculation was carried out using the program made by the above proposed method, and as a result, it was clarified that the efficiency was improved by attaching end plates at the top and bottom.

Second, when two pairs of turbines were arranged, it was demonstrated how the efficiency changed by the distance. The calculation was made for the case where the distance between the rotating shafts of the turbines is 4R, 5R, and 6R, where the length of the radius of the turbine is R. As a result, it was verified that the efficiency was improved by the interaction when the distance between both turbines approached 4R.

Third, the torque coefficients of two turbines were compared with each other depending on the direction of flow when two pairs of turbines were arranged. The calculation was carried out in 3 cases: the case where the flow hits perpendicular to the line segment connecting the axes of 2 pairs of turbines (0 deg.), the case where the flow hits oblique (45 deg.), and the case where the flow hits parallel (90 deg.). As a result, no difference was observed in the case of 0 degrees, and in the case of 45 degrees, the torque coefficient of the turbine located in the downstream side exceeded that of the upstream side, and in the case of 90 degrees, the torque coefficient of the turbine in the downstream side remarkably decreased. From this result, it was indicated that the performance of the downstream turbine might be improved by bending the mainstream and generating the vortex by the turbine in the upstream.

Fourth, the effects of phase differences between 2 pairs of turbines of 0, 45 and 90 degrees on the torque coefficients were investigated. When the flow direction was 0 degrees, the torque coefficient became the largest at the phase difference of 0 degrees, and it became small as the deviation from 45 degrees to 90 degrees. Also, it was clarified that when the flow direction was 45 degrees, the torque coefficient of the turbine located at the downstream side decreased at the phase difference of 45 degrees. These results suggest that the solution to optimize phase difference exists for each flow direction.

Fifth, the calculation in the case of installing four turbines was carried out, and the expandability to the calculation in the case of installing lots of turbines was verified,

In this study, proposal and basic examination of the calculation technique which became a forerunner on development and installation of the equipment in the ocean current power generation were carried out. In particular, it is suggested from the second, third and fourth results that there exists an optimum arrangement considering the interaction between the turbines. Therefore, this study is expected to greatly contribute to the future development of ocean current power generation by further expanding this method and conducting large-scale simulations.