Research on the shape coefficient of disc insulator strings for UHV transmission lines

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Abstract. Following continuous lengthening of the ultra-high voltage disc shaped insulator strings, wind load plays a more important role in controlling of the disc insulator string. It is necessary to carry out deep study about the shape coefficient of disc insulator strings, learn the concrete wind pressure distribution, and wake flow condition of the insulator string in detail. To this end, we used the SST turbulence model to operate value simulation for the three-dimensional flow field of disc insulator strings. Results showed that value simulation could clearly simulate surface pressure of the insulator and distribution of tail flow; the fitness of calculation results for nonstructural grid and structural grid was very high; the structural grid could control every part of the grid well, but classification was complicated; the structure adaptability of the nonstructural grid was stronger compared with structural grid.

1. Foreword

In the ultra-high voltage line which is put into operation at present, length of the insulator string can reach 10m and more. Increment of length can cause reduction of rigidity at lateral resistance side, as a result, control function of wind load about the insulator string is more obvious. The windage yaw and wind vibration phenomenon have been observed for several times in the built-up ultra-high voltage power transmission line.

Wind load of the traditional insulator is generally obtained through approximate calculation, using the product of average wind pressure in 10 min and wind area of the insulator. With the increasing of type, length and connection number for insulator string, its forcing condition becomes more complicated. Therefore, it is necessary to carry out deep research about its shape coefficient, so as to learn concrete distribution of surface wind pressure and tail flow field of the insulator string.

Study of the shape coefficient generally consists of three methods: actual measurement at site, wind tunnel test and simulation of computational fluid dynamic (Computational Fluid Dynamic, CFD). Actual measurement at site is the most direct and effective method, but it also has more limitation. The cost of actual measurement is high and it is limited by meteorologic conditions, what’s more, it is hard to obtain data under most adverse operation condition. Because wind tunnel test need a large quantity of model fabrication and repeated test with different operation conditions, test period is long. At the same time, it is difficult to make the Reynolds number similar to the actual situation. In recent years, with the development of computer technology, CFD is characterized with the advantages of low cost, short period, good repeatability and easy control. Congzhen Xie[1] etc took advantage of CFD to study the accumulated
filth of the composite insulator and the characteristic of air flow field; Xingliang Jiang\textsuperscript{[2]} etc studied the application of CFD in accumulated filth characteristic of the insulator in the line; Limin Wang\textsuperscript{[3]} etc took advantage of CFD to study accumulated filth characteristic of the pillar insulator and obtained good simulation effect.

2. Value analysis

2.1 Turbulence model
Because study about the shape coefficient of the insulator string belongs to the separated bluff body streaming issue generating from gradient of inverse pressure. This paper applied shearing stress conveying $k$-$\omega$ model, which is abbreviated as the SST turbulence model. The SST model was forwarded by Menter\textsuperscript{[4]}, taking into consideration transfer of turbulence shearing stress. It can well forecast the starting and quantity for fluid separation under inverse pressure gradient, and simulate flow phenomenon of pure air dynamic with high accuracy. The model applied $k$-$\epsilon$ model in far wall area, and $k$-$\omega$ model forwarded by Wilcox in wall surface area. We used one blending function for transition between two models. It will fully play advantage of the $k$-$\omega$ model in calculation of high Reynolds number, also it can avoid characteristic that $k$-$\omega$ is sensitive to incoming flow.

2.2 Geometrical modeling
As the insulator string is a composite structure of several insulator strings which are connected at end to end, difference between the shape coefficient of the section model and the shape coefficient of the whole isn’t great. Therefore, in order to reduce number of the grid, this paper applied 5 discs of the insulator to build up the ANSYS model. In order to ensure the quality of grids, we carried out polishing treatment at local sharp location, and made its minimum curvature radius above 0.003m. The disc diameter was 0.425m, length was 0.775m and calculation flowing field applied 10m×10m×10m, the insulator string model is located in the middle of the fluid field, and blockage rate is less than 2%.

2.3 Division of grid
The ICEM fluid grid division tool is applied. In order to investigate application of different grid division way in this subject, the structural grid and nonstructural grid were applied in this paper to divide the fluid field.

Advantage of the $k$-$\omega$ model is that solution expression formula about $\omega$ in the viscosity layer is known, $\omega$ value of near wall surface must be large enough to obtain correct result\textsuperscript{[5]}. According to
requirement of document\cite{6}, the dimensionless height $y^+$ value at wall surface is located near 1. For every part of the insulator being different in thickness, in order to obtain the shape coefficient of every part accurately, height of first layer grids of the structural grid and nonstructural grid took 0.00001, taking the 10 layers boundary layer.

For the structural grid, we unified the applicable structural hexahedron grid, and the O grid was applied to directly divide the fluid field. This method could control every part of the grid well, but it had a disadvantage that the division of the grid was complicated. Total number of the structural grid was approximately 3.8 millions, and minimum grid quality was 0.2.

\begin{figure}
\centering
\includegraphics[width=0.5\textwidth]{fig3}
\caption{Local structure grid on insulator surface}
\end{figure}

For nonstructural grid, we established one square calculation subdomain within 0.1m scope around the insulator string. The nonstructural tetrahedron grid was applied in the subdomain to fully fit the complicated geometrical boundary, and the blocked structural hexagonal grid was applied out of the subdomain to obtain incoming flow condition accurately. The contact surfaces of two grids applied Interface way to couple. The assembled grid was 5.6 million in total, and minimum grid quality was 0.31. Advantage of the nonstructural grid is that the division is simple and the structural adaptability is strong. While the disadvantage is that the quantity of the grid is more.

\begin{figure}
\centering
\includegraphics[width=0.5\textwidth]{fig4}
\caption{Method of unstructured grid}
\end{figure}

\begin{figure}
\centering
\includegraphics[width=0.5\textwidth]{fig5}
\caption{Unstructured grid in the subdomain}
\end{figure}

2.4 Setting of boundary condition

The inlet applied boundary condition of speed (Velocity inlet), with the tangential speed being zero, and there was only vertical speed. The outlet applied the outlet boundary condition, with the relative pressure being zero. The side wall surface applied the free slip (Free slip) wall surface conditions. The upper and lower wall surfaces applied the symmetrical boundary condition (Symmetry), while the column surface applied the no slip (No slip) wall surface boundary condition. We applied the separation type solver with 3D single accuracy, chose the constant density air model which was not compressed, and used the SIMPLE algorithm to disperse the flowing item.
2.5 Analysis of calculation result

It is found that the results of structural grid are similar with the results of nonstructural grid in Fig. 6, and in Fig. 7, the value simulation can accurately simulate shape coefficient of every part of the insulator body surface. The shape coefficients of the umbrella cap at upwind location, as well as the shape coefficients of connection location between the umbrella cap and the umbrella skirt are maximum. Connection rigidity at this location can be suitably strengthened during design. Fig. 9 is the distribution of wake flow around the umbrella cap, while Fig. 8 is the distribution at the umbrella skirt. It is also found that the shape of the insulator isn’t regular. As a result, the tail flow shows obvious three dimension characteristic. The tail flow speed of the umbrella cap is very high, and the speed gradient is very great, while tail flow of the umbrella skirt is very smooth.

![Figure 6. Curves of the shape coefficient changing with wind speed](image)

![Figure 7. Distribution of shape coefficient on the upper surface of the insulator strings](image)

![Figure 8. The flow field velocity distribution around the umbrella skirt](image)

![Figure 9. The flow field velocity distribution around the umbrella cup](image)

3. Conclusion

The following conclusions were obtained through calculation results.

The value simulation could clearly simulate surface pressure of the insulator and distribution of tail flow.

The fitness of calculation results for nonstructural grid and structural grid was very high. The structural grid could control every part of the grid well, but classification was complicated; the structure adaptability of the nonstructural grid was stronger compared with structural grid.

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