Analysis of Voltage Dependence of Standard High-Voltage Compressed Gas Capacitor

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Abstract — As the high-voltage compressed gas capacitors are usually employed as standards, their accuracy and stability characteristics and the factors affecting the characteristics should be predicted, such as the temperature, gas pressure and voltage dependence. The value variation of the capacitors caused by the voltage or the electric field force is investigated by the finite element analysis in this paper. By analyzing a 300kV high-voltage compressed gas capacitor, the relationship between the value variation and the shape change caused by the electric field force is obtained. The variation of the capacitance is less than 3 ppm, as long as the eccentricity of the electrodes is not greater than 5 mm.

I. Introduction

The high-voltage compressed gas capacitors are usually used for the standards in the bridge circuits for the dissipation factor measurement of other capacitors[1]. Therefore, they must have high accuracy. However, there are some factors that make the value of capacitance vary during long term operation. One of the factors is the high voltage, which produces high electric field force to make the capacitor distort. This phenomenon is called voltage dependence of capacitors, which is the most important factors influence the stability of high-voltage compressed gas capacitors.

II. Structure of The Capacitor

The high-voltage compressed gas capacitors are usually constructed using the design of Schering/Vieweg [1]. This kind of capacitor consists of a cylindrical low voltage electrode surrounded by a high voltage electrode, which are both mounted on the upside of the capacitor. The structure has the merits of eliminating the influence on the capacitance by the outside electric field. The typical structure is shown in Fig. 1.

III. Distortion and Value Variation of Capacitance

The geometry of electrodes would be influenced by the attracting electric field force. If the position of electrodes is perfectly coaxial, the force only causes slightly axial-symmetric shape change. The capacitance will change to a little bit larger with the increase of the applied voltage. If the position of the electrodes is not coaxial, the electric force may cause larger distortion and value variation of capacitance [2].

The question is that how much the value variation of the capacitor is caused by a certain dimension of distortion. This problem could be solved approximately by means of several established formula for the cylindrical capacitor[3]. For the capacitance of an eccentric cylindrical capacitor, suppose the distance of two axes of cylindrical electrodes is a, the length of electrodes is l, and the permittivity of dielectric is ε, the variation of the capacitance can be calculated by

$$C_E = \frac{2\pi\varepsilon l}{\ln\left[\frac{r_1^2 + r_2^2 - a^2}{2r_1 r_2} + \sqrt{\left(\frac{r_1^2 + r_2^2 - a^2}{2r_1 r_2}\right)^2 - 1}\right]} \quad (1)$$

where, r_1 and r_2 are the radius of the electrodes.

However, (1) only applies to the normal cylindrical capacitor with infinite length of electrodes. In order to acquire precise results for specifically high-voltage compressed gas capacitor, the numerical simulation should be employed. Software ANSYS/EMAG was used to calculate the capacitance. The model is shown in Fig. 2. The electric field of the simulation result with a =1 mm is shown in Fig. 3. The FEM results of capacitance changing along with the variation of eccentricity of the electrodes are shown in Fig. 4.

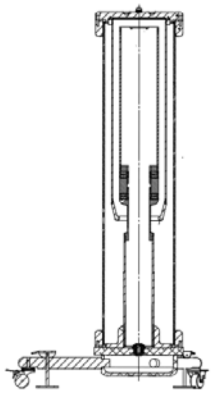

Fig. 1. Structure of the high-voltage compressed gas capacitor.

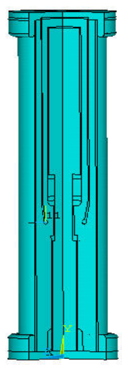

Fig. 2. Simulation model of a high-voltage compressed gas capacitor by ANSYS/EMAG.

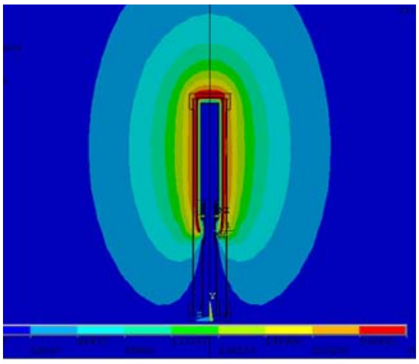

Fig. 3. Electric field of the simulation results (a=1mm).

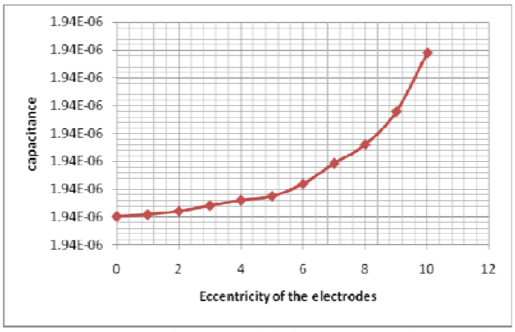

Fig. 4. Capacitance changing with the variation of eccentricity

IV. Elastic Bending of Electrodes by Electric Force

The eccentric electrode would move towards the direction of F1 (as shown in Fig. 5) fatherly by the electric force which is conducted by the alternating voltages applying on the capacitor, making the eccentricity larger[4]. But the eccentricity will not grow without limits, which is related to the hardness, the toughness of the electrode. Due to the difficulty in computing and many unknown factors, qualitative analyses are usually made [5].

The electric force could be calculated through the energy as shown in the formula 2.

$$F = \frac{\partial W}{\partial D} = \frac{U^2}{2}\frac{\partial C}{\partial D} \approx \frac{C_0 U^2 a}{(r_1^2 - r_2^2)\ln\dfrac{r_1}{r_2}} \qquad (2)$$

Due to the electric force on the eccentric electrode is in proportion to the distance a, the voltage dependence of a high-voltage compressed gas capacitor should be positive and is not in proportion to the voltage variation[6][7].

The simulation for the elastic bending of the electrodes is shown in Fig. 6 and the relationship curve (at 300kV) is drawn in Fig. 7.

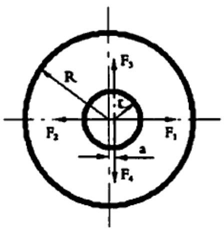

Fig. 5. Eccentricity of the electrodes

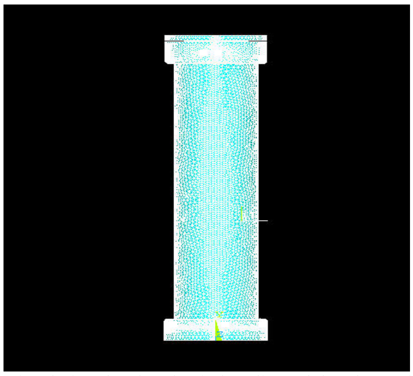

Fig. 6. Simulation for the elastic bending of the electrodes

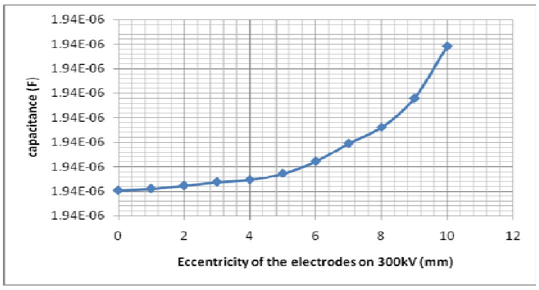

Fig. 7. Relationship between capacitance and the variation of eccentricity (300kV)

V. Conclusion

This paper explores the relationship between the alternating voltage applying on the capacitor and the changing of the capacitance under different eccentricity of the electrodes through simulation experiments on a 300kV commercial high-voltage compressed gas capacitor. Conclusions are drawn from simulation experiments is that the error of the high-voltage compressed gas capacitor could be less than 3 ppm related to the rated value of capacitance, as long as the eccentricity of the electrodes less than 5 mm.

The traditional methods analysis on the voltage dependence of high-voltage compressed gas capacitors are mainly through physical experiments. Numerical calculation and simulation using on this problem shows the advantages of this method. But only comparing with much more contrastive physical experiments, the results of the simulation could be much persuasive.

VI. References

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