Simulation and Analysis of High-Frequency Resistor Sensor for Corona Current Measurement under Ultra High-Voltage Direct-Current Environment

Haiwen Yuan[1], Qinghua Yang[1], Yuanqing Liu[2] and Jiayu Lu[2]
1.School of Automation Science and Electrical Engineering, Beihang university, Beijing 100191,China
(yhw@buaa.edu.cn)
1.School of Automation Science and Electrical Engineering, Beihang university, Beijing 100191,China
(yqh_buaa@asee.buaa.edu.cn)
2. China Electrical Power Research Institute, Beijing 100192, China
(liuyq@epri.sgcc.com.cn)
2. China Electrical Power Research Institute, Beijing 100192, China
(lujy@epri.sgcc.com.cn)

Abstract —in this paper, a design for High-Frequency Resistor Sensor has been presented for accurate measurement of corona current. Based on charge simulation method (CSM) and the finite-element method (FEM), the surface electric field of the high frequency resistor sensor generated from the High-Voltage Direct-Current (HVDC) transmission lines is presented. Simultaneously, Self-capacitance of high frequency resistor sensor has provided reference for optimization of high frequency resistor sensor. The high-frequency resistor has been applied to ± 1000kV HVDC transmission lines to evaluate DC corona characteristics in China.

Index Term-Electric field, high frequency resistor sensor, high-voltage direct-current (HVDC), corona current.

I. INTRODUCTION

Recently, High Voltage Direct-Current (HVDC) system has been dramatically developed due to its advantage. When the conductor surface electric field exceeds the corona onset electric field, a partial electrical breakdown occurs in the surrounding air medium near the conductor surface and is called the corona discharge. One of the important considerations in the design of HVDC transmission line is its corona performance, which is generally defined in terms of corona loss (CL), ratio interference (RI), audible noise (AN) and television interference (TVI), etc. Because the important factor of corona performance is conductor surface voltage gradient, the increase of conductor surface gradient takes change with increase of the increase of supply voltages. Since the charge is moved by a time varying electric field, which is equivalent to a current pulse. Therefore, the corona current due to the corona of transmission lines have to be analyzed in advance.

Many attempts have been made to solve the electric field for bipolar or monopolar transmission lines. Calculations and simulations of electric field and ion flow field and EMI field produced by corona under HVDC transmissions lines have been made by various workers using numerical or analytical solutions and been verified by the corresponding experimental data in [1]-[3], but the experimental data are only acquired by low frequency data acquisition card and the most of experiment conditions are under the low voltage experimental line or corona cage side, the integrity and accuracy of the corona current data not been verified.

Corona current acquisition system was introduced [4], which was only used for the measurements of corona currents in a pin-plane corona generator of the array type. A non-invasive optoelectronic system for measuring of electrostatic discharge induced phenomena was introduced [5], which was not applied into the corona pulse current measurements for getting the completely accurate data, as the signal bandwidth of corona current is more than 10MHz.

Now, the design of sensor for measuring the corona current under HVDC environment is not studied. The present paper reports the simulation and analysis of the high frequency resistor sensor in corona current measurement system. Based on the finite-element method, the surface electric field of the high frequency resistor sensor generated from the High-Voltage Direct-Current (HVDC) transmission lines is analyzed. Simultaneously, Self-capacitance of high frequency resistor sensor has provided reference for optimization of high frequency resistor sensor. And a data acquisition system is described based on the resistor sensor. Finally, acquiring the corresponding corona current data of the variation in the positive corona inception voltage and the negative corona inception voltage, presents the corona V-I characteristics under HVDC transmission line and explains the related measured data.

II. METHOD

DC transmission line corona is equivalent with a nonlinear circuit of the RC basic circuit [17].As is shown in Fig. 1, C_1 is the geometric capacitance of the conductor configuration; C_2 is the additional non-linear capacitance due to corona; C_3 is part of the capacitor representing the charge loss to the air ; R_g is the non-linear conductance representing corona loss. V_0 is the corona onset voltage, the high frequency resistor sensor is assembled between the power generation and the transmission conductor, Below the corona onset voltage V_0, $C_2=0, C_3=0, R_g=0$,there only exists capacitance charging current with the wire-to-ground and a small amount of leakage current. Above corona onset, the R_g increases rapidly , while C_2 , C_3 increases very slowly ,and there appears amounts of corona current with increasing voltage.The corona current on the wire is equal to the current through the resistor minus the leakage current of insulators. Due to leakage current is small enough compared with the corona current, the data measured corona current is the current through the high frequency resistor sensor. The corona current measurement system is designed based on high frequency resistor sensor.

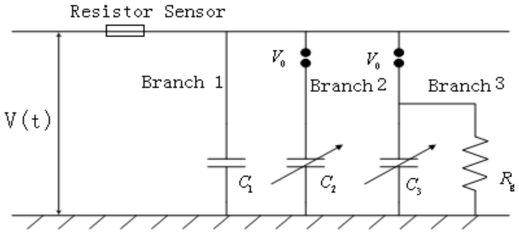

Figure1. The equivalent circuit model of corona discharge

High frequency resistance sensor structure simulation

Making the general assumptions described above, the basic mathematical description of the basic model is as follows:

$$\nabla \cdot E = \frac{\rho}{\varepsilon_0} \quad (5)$$

$$\nabla \cdot J = 0 \quad (6)$$

$$J = k\rho E \quad (7)$$

$$E = -\nabla\Phi \quad (8)$$

Where E and J are the electric field and current density vectors at any point in space, ρ is the space charge density, k is the ionic mobility (assumed to be a constant) and ε_0 is the permittivity of free space. Eliminating the vectors from the above equations yields

$$\nabla^2\varphi = -\rho / \varepsilon_0 \quad (9)$$

$$\nabla \bullet (k\rho\nabla\varphi) = 0 \quad (10)$$

The boundary conditions are

$$\varphi = \begin{cases} V, & \text{at the sensor surface} \\ 0, & \text{at ground level} \end{cases}$$

$$E = E_0, \quad \text{at the sensor surface}$$

where V is the applied voltage, and E_0 is the corona onset field which may be gotten using Kaptzov's assumption and less than 25kV/cm, i.e., the electric field at the sensor surface in corona remains at its corona onset level.

As is shown in Fig. 2, the model of the high frequency resistor sensor is built. The sensor surface voltage gradient is analyzed according to different parameters size mentioned above with FEM and CSM which is shown in Fig. 2(b).

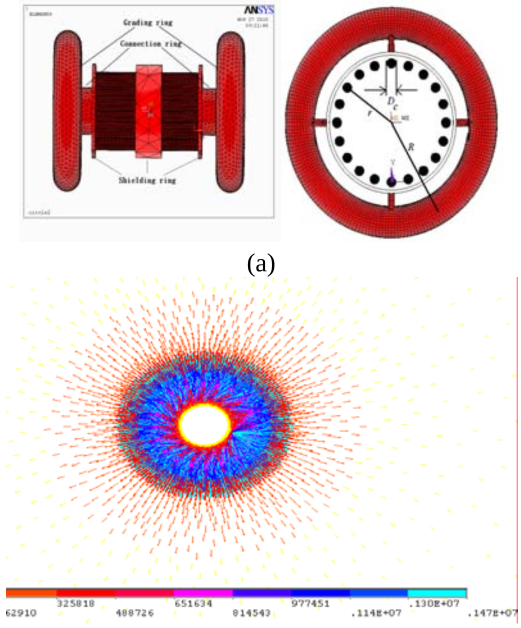

Fig. 2. (a) Sensor structure (b) Sensor surface voltage gradient

III. CONCLUSION

(1)The paper makes a high-frequency resistor senor for corona current measurement and does simulation and analysis of the high frequency resistor sensor in corona current measurement system under HVDC circumstance.

(2) Based on the finite element method and charge simulation method to analyze the surface electric field of the high frequency resistor sensor.

(3)The corona current measurement system, using the high frequency resistor sensor, can be used as an effective tool for evaluating the electromagnetic environment around the HVDC transmission line.

VI. REFERENCES

[1] Tiebing Lu, Han Feng, Zhibin Zhao and Xiang Cui. "Analysis of Electric Field and Ion Current Density under Ultra High-Voltage Direct-Current Transmission Lines Based on Finite Element Method," IEEE Trans. Mag.Vol.43, No.4, pp.1221-1224, Apr. 2007.

[2] M.P.Arma and W.Janischewskyj, "Analysis of corona losses on DC transmission lines: II-bipolar lines," IEEE Trans. Power App. Syst., vol. PAS-88, no. 10, pp. 1476-1490, Oct. 1969.

[3] S.K.Nayak and M.Joy Thomas, "Computation of EMI fields generated due to corona on high voltage over head power transmission lines," Conf. ICEMIC 2001. pp. 15-19.

[4] Z.Kucerovsky W.D.Greason and T.Doyle, "Data acquisition system for the measurement of corona currents,"Industry Applications Conference, 1998. Thirty-Third IAS Annual Meeting. 1998, pp. 2014-2018.

[5] William D.Greason, Zdenek Kucerovsky, Sviatoslav Bulach and Martin W.Flatley, "Non-invasive optoelectronic system for measurement of electrostatic discharge (ESD) induced phenomena," IEEE Int`l 13th Conf. on Ind. App. pp.1264-1270, 1995.

[6] Er-ning li and J.M.K.MacAlpine,"Negative corona in air using a point/cup electrode system," IEEE Trans. DEI, vol. 7, pp. 752-757, 2000.