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Solving surface potential of DC grounding electrode by Chebyshev polynomial

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Abstract. The operation experiences have shown that the large-scale DC magnetic bias caused by DC grounding electrode can be attributed to the uneven surface potential distribution. Here, the Chebyshev polynomial is used to fit the Hankel transform kernel function in order to solve the surface potential distribution for the complex earth model of wide area depth stratification. The adaptive order fitting method of Chebyshev polynomial for kernel function is obtained via shift operation, coefficient expansion and truncation error determination, which greatly reduces the calculation difficulty of surface potential distribution in a large area caused by DC grounding electrode. Compared with the standard grounding calculation software CDEGS, the proposed Chebyshev polynomial approach achieves less than 1 V of earth surface potential deviation in range of 1-100 km when the DC grounding current is 5 000 A. Moreover, the order of the Chebyshev polynomial has influence on the solution results, and it is confirmed that the 20th-order Chebyshev polynomial can meet the accuracy requirements for general DC bias risk assessment. The proposed surface potential assessment method based on shifted Chebyshev polynomial provides a basic technical means for the risk assessment of DC bias, which is helpful to reduce the difficulty of DC bias risk assessment for power grid.

AMS subject classifications: 41A50, 76B07

Key words: DC grounding electrode, Surface potential, Chebyshev polynomial, Hankel integral, DC bias.

1 Introduction

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Dc power transmission in the unipolar earth return operation mode, high amplitude direct current will flow into the earth through the DC ground pole. Due to the poor conduction of the ground and the simultaneous action of the wide-area power grid, part of the DC current will invade the AC system, resulting in an adverse effect on the transformer, that is, the DC magnetic bias hazard. Dc magnetic bias seriously endangers the safe operation of power system. The DC bias tolerance characteristics of transformers are very complex [1-3], and the control of DC bias also requires a lot of manpower and material resources [4-7].

Operation experience shows that the root cause of DC magnetic bias hazard of power grid is the uneven distribution of surface potential caused by DC grounding electrode [8-11], which is manifested as follows: transmission lines are connected to many substations that are far apart, and the neutral points of high-voltage transformers in substations are mostly directly grounded. A parallel current channel is formed between the ground and the power network. Due to the difference of surface potential between substations, part of the incoming current of the DC transmission is "extracted" from the ground to the power system. Dc current flows through the transformer winding, the transformer core is saturated and the excitation half-cycle saturation phenomenon is generated, thus forming the DC bias hazard. Dc bias hazards are mainly transformer vibration and abnormal sound, as well as local temperature rise and harmonics.

The field-circuit coupling model of DC current intrusion is adopted in the simulation evaluation of power grid magnetic bias [10], that is, the coupling between the above-ground circuit model and the underground current field. The coupling is directly manifested as the surface potential of the power station, and the greater the difference of the surface potential between the power stations, the more serious the magnetic bias. The method of solving the surface potential is related to the selected earth model. Since the earth model used for DC magnetic bias problem is the actual geoelectrical structure model, the existing grounding analysis and evaluation methods may not be applicable [11-12]. Literature [13-15] systematically uses finite element method to solve the geodetic parameters of complex structures; literature [16-17] proposes a calculation method of surface potential considering the relief of terrain; Literature [18-19] focuses on the study of surface potential under the distribution of middle-earth fault zones. These studies mainly rely on commercial finite element software, which cannot be applied to the risk assessment of power grid magnetic bias for the time being. Geng Shan et al. [20] used the mirror image method to study the surface potential distribution around the DC grounding electrode in the complex geological environment of Xinjiang, and Ma [21] conducted the sensitivity analysis of the model parameters. However, the mirror image