Method and development trend of corrosion state prediction of grounding grid

H Huang1, Y C Liu2*, Y Xing1, J R Wu1, X Y Mao1, X H Ma1 and H B Sun2

1Electric Power Research Institute of Guizhou Power Grid Co., Ltd., Guiyang, China 550002
2College of Electrical and Information Engineering, Hunan University, Changsha, China

Email: 491276835@qq.com

Abstract. With the development of modern power grids to ultra-high voltage, large capacity and long-distance, the grounding short-circuit current of power systems is getting larger and larger, and higher requirements are put forward for the safe and stable operation of grounding systems. The importance of studying the corrosion status of grounding grids is even more prominent. In this paper, from both static and dynamic aspects, the corrosion state prediction methods of the grounding grid are discussed. And the prediction technology is prospected, it is pointed out that the development of a device combining detection and prediction techniques will fill the gap in the international arena. It can not only provide effective guidance for corrosion protection of grounding grids, but also can be applied to other fields.

1. Introduction

Since the grounding grid is in the underground environment for a long time, after a certain period of operation, the conductors and grounding leads of the grounding grid will have different degrees of corrosion, and even break when severe. As a result, the cross section of the grounding body is reduced, the thermal stability is insufficient, and the electrical performance is deteriorated. At this time, in the event of a ground fault, a large safety accident may occur, resulting in immeasurable economic loss and adverse social impact.

At present, some phase results have been achieved in the corrosion detection of grounding grids at home and abroad[1-3], but even if the conductors are found to be corroded and thinned, it is impossible to know when the conductors no longer meet the requirements for the flow. Therefore, in order to grasp the operation of the grounding grid in time, and to provide early warning and maintenance of the equipment, it is necessary to conduct research on the prediction method of the corrosion state of the grounding grid. So far, there have been some theoretical research results on the prediction of corrosion state of grounding grids, but there are no reports on the results of corresponding equipment or instruments.

With the development of modern power grids to ultra-high voltage, large capacity and long-distance, the requirements for grounding systems are becoming higher and higher, and the soil corrosion problem of the grounding grid can not be ignored. Therefore, the importance of the corrosion prediction of the grounding grid is more prominent. It can effectively avoid the occurrence of safety accidents and has important theoretical and practical significance.

According to the different input physical quantities of corrosion rate prediction, the prediction method of corrosion state of grounding grid is introduced from two aspects in this paper. On the one hand, the factors affecting the corrosion rate of grounding grids are analyzed and the static prediction
method is discussed. On the other hand, the dynamic prediction method is introduced based on the historical corrosion rate data. Finally, suggestions and prospects of the corrosion prediction technology are put forward according to the current situation of grounding grid.

2. Static prediction of corrosion state of grounding grid

Since the grounding grid is generally buried underground, the conductors that make up the grounding grid may be corroded by the soil, and soil corrosion factors will directly affect the corrosion state of the grounding grid. The main input for static prediction is soil corrosion.

2.1. Soil corrosion factors

Soil is a very complex system which is composed of three phases of solid, liquid and gas. Its properties and structure are heterogeneous and versatile. When the metal is in contact with different soils, different interface potentials are formed between the metal and the soil cross section, and a loop is formed through the soil, then the corroded battery is formed\(^4\). Therefore, all factors affecting the physical properties, chemical properties, electrochemical properties and macroscopic environment of the soil will have an impact on soil corrosion.

Studies have shown that there are many factors affecting the corrosion of the grounding grid in the soil\(^5-6\), mainly water content, electrical resistivity and salt content.

The corrosion that occurs when the grounding grid is buried in the soil is mainly electrochemical corrosion. Moisture is a prerequisite for causing the soil to become an electrolyte and causing electrochemical corrosion. Therefore, the water content in the soil has a great influence on corrosion. In general, when the soil moisture is not saturated, the more water content, the faster the corrosion rate of the metal.

Soil resistivity is an index of soil conductivity. In most cases, soils with low resistivity are highly corrosive, and soils with high resistivity are weak, that is, soil corrosivity is inversely proportional to soil resistivity.

Salt is the main component of electrolyte, so the conductivity of soil is obviously affected by the soluble salts and their composition. In general, the conductivity increases with the increase of soluble salts, that is, the more soluble salts, the greater the corrosiveness of macroscopic cell corrosion.

In addition, soil porosity, pH, soil type, various anions and cations, redox potential, organic matter content and microbial bacterial activity also affect the corrosion of the grounding grid. These influencing factors are both interconnected and act together to accelerate the corrosion of the grounding grid.

Therefore, it is necessary to consider the corrosion condition of the soil where the grounding grid is located and study the interaction of soil corrosion factors, so as to predict the soil corrosion of the grounding grid and the corresponding anti-corrosion measures can be taken in time.

2.2. Static prediction

Panakaj K. Sen, a scholar at Colorado State University, based on the test data of 44 different soil corrosions in the 12 years of the National Bureau of Standards, proposed an empirical formula for calculating the corrosion rate of steel in soil\(^7\), as in equation (1),

\[
m = 3.36 - 9.63 \times 10^{-5} (P_1) + 0.29 (P_3) + 0.34 (P_4) + 0.012 (P_5)
\]

where \(m\) represents the corrosion rate (mm/a), \(P_1\) represents the soil resistivity (\(\Omega\cdot m\)), \(P_2\) represents the \(PH\) value, \(P_3\) represents the water content (%), and \(P_4\) represents the gas content (%).

According to the specific situation of China, considering the factors of economy and other aspects, most of the grounding grid materials in China use ordinary carbon steel or galvanized steel, which is more corrosive than copper or copper clad steel of foreign grounding grid.

In response to actual needs, Xi’an University of Science and Technology explored the static prediction method of corrosion state of grounding grid. Wang Shaobo selected 13 soil corrosion factors of the grounding grid as indicators. After using the principal component analysis method to
calculate the correlation coefficient between each index and the corrosion rate, the principal component samples were subjected to multiple regression prediction, but the results were not satisfactory. Subsequently, the BP neural network prediction model was proposed. From the experimental results, the expected accuracy requirements were not met\[^8\].

Based on the data of soil corrosion factors in Shanxi Province, Li Na established three different corrosion rate prediction models of the grounding grid through BP neural network progressive optimization algorithm, support vector regression machine and fuzzy analogy method. Among them, the model based on fuzzy analogy method has better prediction effect\[^9\].

Since there are many factors affecting the corrosion of the grounding grid, it is difficult to achieve the desired effect by using a single method for prediction. Du Jingyi proposed “a new method for predicting the corrosion rate of grounding grids”\[^10\]. The prediction process is shown in Figure 1. The corrosion prediction rate of the grounding grid is predicted by the comprehensive prediction method based on vector similarity and Support Vector Regression (SVR). Firstly, the soil corrosion factor is regarded as the feature vector and dimensionless processing. Secondly, the similarity between each measured sample vector and the feature vector is calculated. Finally, the corrosion rate of the grounding grid is predicted according to the similarity.

3. Dynamic prediction of corrosion state of grounding grid

When the dynamic prediction method is used to predict the corrosion state of the grounding grid, the input is generally the historical corrosion rate data, and the output is the predicted value of the corrosion rate.

3.1. Historical measurement data

At present, according to the different principles, three major methods, such as electric network analysis method, electromagnetic field detection method and electrochemical method, are proposed to detect the corrosion of the grounding grid. The electrical network analysis method judges the corrosion of the grounding grid by measuring the magnitude of the grounding resistance. The electromagnetic field detection method uses the measured electric field or magnetic field distribution of the grounding grid and combines the numerical simulation of the grounding network to perform corrosion diagnosis. Electrochemical methods require the application of corrosion electrochemical detection techniques. Three methods have their own advantages and disadvantages. Therefore, the corrosion detection of the grounding grid is mainly realized by measuring the grounding resistance, detecting the grounding network connectivity and combining local excavation in the actual project, and the detection period is long and the sample data amount is small. These sample data can reflect the change of corrosion state in a certain period of time, so they have certain reference value.

Static prediction can not make full use of historical measurement data, but dynamic prediction can dynamically track historical data and reflect the trend of state change in time. Therefore, it is of certain significance to study the dynamic prediction of corrosion state of grounding grid, but it needs to choose appropriate method to deal with the nonlinear data of small samples.
3.2. Dynamic Prediction

The methods applied to corrosion rate prediction include neural network, gray model, support vector machine and combined prediction model of various methods. Each prediction model has its own advantages and disadvantages.

Hunan University has carried out some explorations to realize the dynamic prediction of the corrosion state of the grounding grid. In [11], BP neural network combined with grey prediction theory was used, and the combined forecasting model is constructed as shown in Figure 2. The corrosion rate of the first 3 months was used as input, and the output was predicted as the corrosion rate of the 4th month, and the corrosion rate of the next 9 months was derived. Due to the lack of sample data of the corrosion rate of the grounding grid, the prediction result of the combined model is not very satisfactory, and the longer the prediction time, the larger the error. The neural network method is used for fitting, and all historical data is used for training for each execution, thereby realizing dynamic prediction, but it does not really realize tracking of the innovation data. Because its prediction model will over-fitting the old data, it can't reflect the change of the innovation data in time. Kalman filter algorithm is an efficient algorithm for dynamic tracking of innovation data. It can design the dominant mode of tracking based on prior data information. Jing Jing applies Kalman filter algorithm to the dynamic tracking of corrosion state of grounding grid[12]. It avoids the drawbacks that the traditional corrosion state fitting algorithm can not achieve the tracking of new interest, and can better reflect the latest changes in corrosion state.

In general, the research results on the prediction of corrosion state of the grounding grid are still few, and the existing prediction methods also have some shortcomings. It is also necessary to build a model with a higher prediction accuracy.

4. Conclusion

The corrosion prediction study of the grounding grid plays an important role in the protection and modification of the grounding grid. While saving a lot of manpower, material and financial resources, it can prevent accidents and ensure the safe and stable operation of power system.

In the existing research, both static prediction and dynamic prediction methods have their own advantages and disadvantages, and the applicable conditions are different. The prediction accuracy of existing results still needs to be improved, and no corresponding instruments or equipment are developed.

With the development of modern power grids to ultra-high voltage, large capacity and long-distance, the short-circuit current of the power system is getting larger and larger, which puts higher requirements on the safe and stable operation of the grounding system. It is not difficult to foresee that the combination of corrosion state detection and prediction technology of the grounding grid is a future development trend. It is necessary to develop a corrosion state detection and prediction intelligent system of the grounding grid integrating data acquisition and detection analysis. It can quantitatively evaluate the corrosion state of the grounding grid and predict the development law.

Such a system can be applied not only to the grounding grid, but also to the grounding device of radar, communication and other systems. It can also be extended to corrosion detection and prediction of other underground metal facilities such as water supply, oil transportation, chemical pipelines, etc. It will have significant socioeconomic benefits.
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References
[1] Liu Y G, Meng X, Tian J H and Wang S 2010 Analysis on the method of selecting nodes on the erosion diagnosis of grounding grid Journal of Chongqing University 33 73-77
[2] Liu Y, Cui X, Zhao Z B, Li L and Chen J J 2009 Design and Application of Magnetic Field Detection System for Corrosion Diagnosis of Substation Grounding Grid Journal of Electrotechnics 24 176-82
[3] Zhang X L, Luo P, Mo N, Wang Y G and Li Y L 2008 Development and application of electrochemical detection system for corrosion state of grounding grid Chinese Society for Electrical Engineering 28 152-56
[4] Kong X Y 2005 Analysis of anti-corrosion of buried gas steel pipe Shanxi Chemical Industry 25 61-63.
[5] Li S F, Chen Z Q, Peng M F and Yu D J 2003 Corrosion analysis and anticorrosion technology of grounding grid Inner Mongolia Electric Power Technology 21 11-14
[6] Zhang C Z 1984 Corrosion and Protection of Metals (Beijing: Metallurgical Industry Press) pp 123-25
[7] Sen P K, Malmedal K and Nelson J P 2002 Steel grounding design guide and application notes Int. Rural Electric Power Conference, 2002 (IEEE) pp C2-10
[8] Wang S B 2013 Application Research on Prediction of Corrosion Rate of Grounding Grid Based on Neural Network Xi’an University of Science and Technology pp 15-34
[9] Li N 2014 Research and prediction model of corrosion law of substation grounding grid Xi’an University of Science and Technology pp 32-52
[10] Du J Y, Du B Z, Han J and Yan A J 2015 A new method for predicting the corrosion rate of grounding grids Mathematics Practice and Cognition 45 123-30
[11] Yang T 2011 Detection of corrosion state of grounding grid and its life prediction Hunan University pp 54-67
[12] Jing J 2016 Prediction method for corrosion state of grounding grid Hunan University pp 32-39