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Study on coalface stray current safety early warning based on ANFIS

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Abstract

By analyzing the DC traction supply system in coal mine, we confirmed the following four parameters to be the characteristic parameters of workface stray current safe early warning, that is, the leakage current of contacting line, resistance of insulating splint, the distance between workface and subtraction substation and the stray voltage of contacting line. After that, we developed a safety early warning model of coal mining workface stray current danger grade with ANFIS as its core, choosing data sets measured online to do the training and early warning of safe early warning model. Results indicate that the model can be able to complete safety early warning of workface stray current. Besides, a monitoring and early warning system of stray current was introduced.

Keywords: coal mining; stray current; early warning; ANFIS

1. Introduction

Coal mine DC traction supply system uses steel rail as current return line. For certain insulation level, there must be some current leakage into the ground or workface, which is called the stray current. Stray current going into workface may cause many dangers such as electric detonator explosion, gas explosion, bunker ignition, electronic shock, relay protection misoperation and so on. As the improvement of management automation level for coal mining, it needs to predict the stray current on workface and confirm its dangerous degree, in addition, warn the workers in certain pre-safe time range so as to control the danger of stray current by taking effective measures in time. On one hand, there are many factors affecting stray current level on workface, and it is difficult to perform reliable measurement of all the parameters. On the other hand, the measurement of workface relational parameters will affect the coal production. As a result, it is desired to take feasible measures to safety early warning to stray current on workface. In this work, the authors developed a safety early-warning model of workface stray current based on Adaptive Network-based Fuzzy Inference System (ANFIS). According to the distribution rule of stray current, the characteristic parameters affecting stray current level of workface were confirmed. Besides, the authors also did training and early warning to the safety early warning model according to the selected on line measured

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data sets and developed the monitoring and early warning system to stray current. The above work made the prevention level of stray current in coal mining improved furthermore.

2. Characteristic parameters of stray current safety early warning on workface

Fig. 1 shows the DC traction supply system of coal mine. The traction substation supply to the locomotive through feeder and contact line, and the load current of locomotive flows back to subtraction substation through the rail and return line. As the insulation level is limited, some current (I_S) will leak to the roadway floor and return to the subtraction substation through the pipeline; and some current (I_Z) will go to workface through some medium such as the insulating splint and pipeline. There is also some current (I_X) goes to workface by insulating terminal of contact line and metal false proof of the workface. I_S, I_Z and I_X are all stray currents. A part of stray current (I_Z and I_X) goes to workface causing sever threat to safe production.

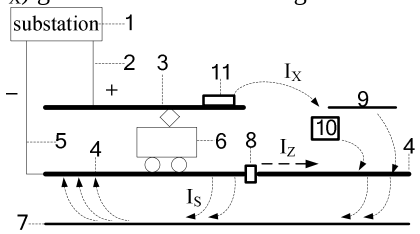

Fig. 1. Diagram of underground DC carrying system
1-traction substation; 2-feeder; 3-contacting line; 4-steel rail; 5-return line; 6-locomotive; 7-pipeline; 8-insulating splint; 9-metal false proof; 10-bunker of mining; 11-contact line insulating terminal

In order to analyze the stray current of workface, we assume that the locomotive locates at the terminal position of stringing, the longitude resistance of the rail distributes equally along the line and the rail-to-ground transition resistance between the rail and pipeline distributes equally. Neglecting the leakage current of system to the outside, we can get the resistance distribution net of the system shown as Fig. 2:

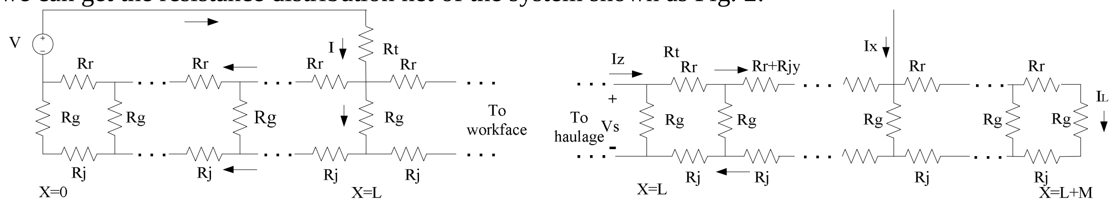

Fig. 2. Resistance distribution network of steel rail to haulage bottom of for underground DC locomotive carrying system
I-current of locomotive; Rr-longitude resistance of the rail; Rg-rail-to-ground transition resistance; L-length of supply area; M-distance between workface and the terminal of contacting line; Rj-resistance of pipeline; Rjy-resistance of insulating splint

We can see from Fig. 2 that the following factors jointly determine the stray current of workface at M position [1]. They are the subtraction supply voltage V, the resistance of the rail Rr, rail-to-ground transition resistance Rg, resistance of insulating splint Rjy, resistance of pipeline Rj, length of supply area L, distance between workface and the terminal of contacting line. Building current balance equation to all the nodes in Fig. 2, the farther analysis indicates that the workface stray current decreases linearly with the increasing of the distance M between workface and stringing terminal, and declines with the increasing of insulating splint resistance value, which is shown in Fig. 3.

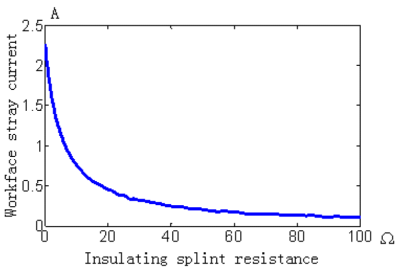

Fig. 3. Relationship curve between resistor value of insulating splint and stray current of workface

We can see from Fig. 2(b) that the rail to ground voltage at L position of stringing terminal is equal to a source to the resistance distribution network of workface; and the voltage change will cause the fluctuation of workface stray current. Farther analysis also indicates that the rail to ground voltage of stringing terminal L changes correspondingly with increasing rail resistance Rr inside the haulage and workface, rail-to-ground longitude resistor and resistance Rj of pipeline. Because the measurement of the above three parameters are difficult, it is an effective method to describe the variation of the above three parameters by measuring the rail to ground voltage. We can see from Fig. 2 that the rail-to-ground of stringing terminal at L position is equal to a power supply for the equivalent network of workface part; the voltage variation will cause fluctuation of workface stray current.

In addition, we can know that the stray current generated by leakage current I_L on workface is directly proportional to I_X, and the parameter can be obtained by measuring the leakage current of contacting line insulator. As a result, the leakage current of contacting line, resistance of insulating splint, the distance between workface and subtraction substation and the stray voltage of contacting line are the most easily detected and processed parameters among all the characteristic parameters of workface stray current, and they are also characteristic parameters with very obvious effects.

3. Safety early warning system of workface stray current based on ANFIS

3.1. System structure

The environment in underground coal mine is very complex such as that the damp laneway will cause the rail to ground longitude resistance distributed unequally and the high rail joint resistance will cause the increment of stray current. Therefore, it is difficult to build analytical relationship between working-surface stray current and each parameter. ANFIS can be used to build the mapping based on human knowledge and input and output data set. Therefore, it can be used to learn every parameter of the current of an hour and the complex mapping relationship among working-surface stray current of the next hour, thereby safely predicts working-surface stray current. The paper uses multi-input and single-output ANFIS [2-4] to do the safety early warning system of workface stray current. The input is an eigenvector built by the four parameters as contacting line leakage current, insulating splint resistance, distance between working surface, and traction subjection and stray voltage of contacting line terminal. The output is the early warning result. Considering the practical situation of stray current security, and in order to dispose the evaluated result of ANFIS furthermore, we do fuzzy decision making to the output result of ANFIS to make it approximate to the expected output, and so it is easy to observe the evaluated result. The computing formula is as follows:

$$J = \begin{cases} +1 & z \geq 0 \\ -1 & z < 0 \end{cases} \tag{1}$$

where J is the working-surface stray current prediction result; stray current natural expected output is -1 and the practically required output range is Z<0; stray current exceeding standard expected output is 1 and the practically required output range is Z≥0.

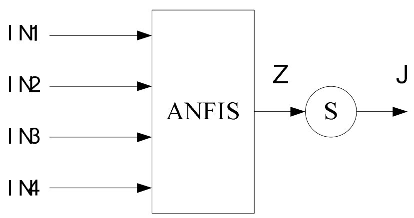

Fig. 4. Workface stray current safety early warning system structure based on ANFIS

3.2. ANFIS initialization

The 440 sets of training and testing data for ANFIS come from field measurement. Choose the number of membership function as 2 and their types as Gauss, which is shown as formula (2)

$$f(x;\sigma,c) = e^{\frac{-(x-c)^2}{2\sigma^2}} \tag{2}$$

Building initial fuzzy inference system by genfis1 [5] function, its input membership function and If-then rules are shown as Fig. 5 and Fig. 6, respectively.

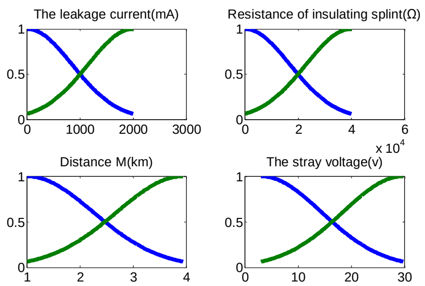

Fig. 5. Input membership functions for initialize ANFIS

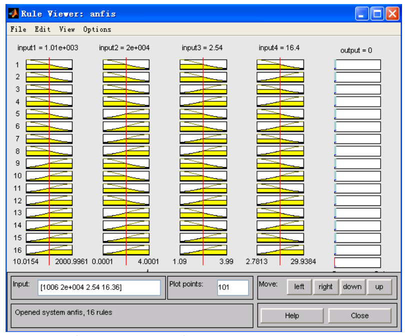

Fig. 6. If–then rules for initialize ANFIS

3.3. Optimizing ANFIS

ANFIS uses reverse transmission mixed with least squares method to do parameters optimizing to initial fuzzy inference system in order to get feat number of rules and higher recognition accuracy for T-S fuzzy model. Fig. 7 and Fig. 8 show the membership function and If-then rule after 50 times of iterative training, respectively. We can see by comparing that after the learning process, the number and shade of membership function are modified, besides the rule parameters are also optimized.

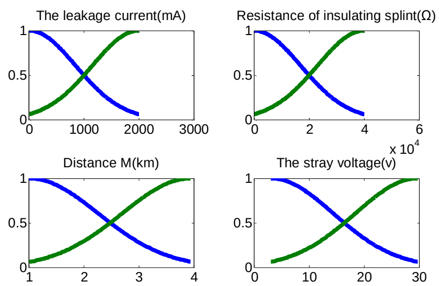

Fig. 7. Input membership function for optimizing ANFIS

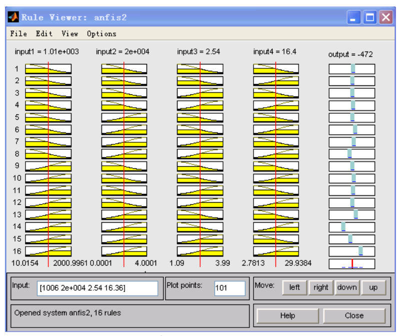

Fig. 8. IF-THEN for optimizing ANFIS

3.4. Discussion

The simulations show that there are 16 rules, 55 nodes, 80 linear parameters and 16 nonlinear parameters in ANFIS. Among the 110 sets of unsafety testing data, 84 sets prediction results are right, and there are 103 sets right among the 110 sets safety testing data, and the evaluation accuracy is 85.00%. The input parameters of ANFIS are four easy detected parameters. In order to obtain higher prediction accuracy, we can increase the number of characteristic parameters properly. Meanwhile, we can know it is very necessary to do online measurement to the parameters such as rail resistance, rail-to-ground longitude resistance, pipeline resistance and so on. The study on this question is undertaking.

4. Monitoring and early warning system for stray current of coal mining

In order to realize safety early warning of stray current on line, the authors developed a monitoring and early warning system for stray current of coal mining. The system is made up of stray current monitoring equipment and computer monitoring centre. It uses the monitoring substation and communication channel of coal mining safety monitoring system for communication, which is shown as Fig. 9.

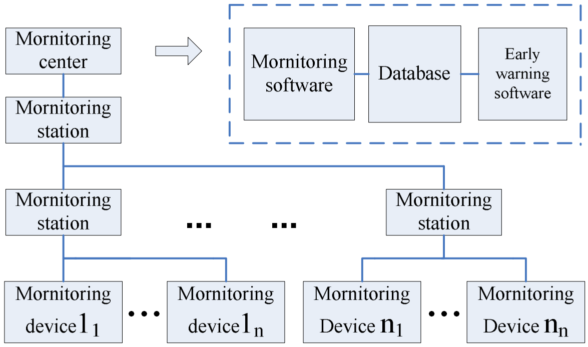

Fig. 9. Safety monitoring and early warning system of stray current in coal mining

The equipment installed at the entrance of workface can monitor two parameters, that is, the insulating splint resistance value and stray voltage of contacting line terminal. The monitoring equipment installed in rectifier chamber can monitor the leakage current of contacting line. The monitoring equipment can realize the in-situ collection and processing performance to the relational parameters and pass the monitoring data to the computer in monitoring centre by the nearby monitoring substation. The stray current monitoring software installed in the computer sends control order and status query instruction to monitoring equipment so as to obtain monitoring data and complete the collection, displaying and warning performance of stray current monitoring data, meanwhile, saving the data into database. Stray current safety early warning software real-timely calls the data in database and does safety early warning according to the established algorithm.

The safety early warning system software of stray current in coal mine is developed on Labview, including the training and assessing two parts. The ANFIS training part can automatically call the data document in the corresponding file and call ANFIS safety early warning document based on Matlab according to the set training data number and testing data set number to train and display the training progress and accuracy rate. Stray current safety early warning part uses the successfully trained ANFIS to do intrinsic safety assessment to the circuit according to the parameter information of input circuit and the built discharging model of all kinds of circuits. It can also display the assessment results.

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