Research on Evaluating Cascading Trip in Power Grid considering the action of backup relay protector

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Abstract. Around the phenomenon of cascading trip in power grid, a method of evaluating it was researched. Firstly, aiming at the backup relay protector of current type, by comprehensive analyzing the action of the relay protector and the power flow distribution in power system, this paper analyzed the relationship between cascading trip and nodal injection power. Base on this, a method of evaluating cascading trip was proposed. This method uses pattern recognition technology and takes the nodal injection power of power grid as the feature input. In order to prove the rationality and effectiveness of this method, some examples with IEEE39 system were shown and the results were satisfactory.

Introduction

In recent years, the problem of cascading failure in power grid receives increasing attention from many scholars. The researchers research the mechanism of cascading failure, the method of simulating the cascading failures, and the effect of the grid structure on the cascading failures, and achieve a lot of research results.

In all modes of cascading failures, cascading trip is the most common case, especially in the early stage of cascading failures.

In generally speaking, in order to prevent cascading trip events from occurring, it should be done as early as possible about evaluating cascading trip events and taking measures. For this purpose, this paper proposes a method to evaluate whether or not the cascading trip event will occur and give some examples with IEEE39 system. This method is based on the neural grid, by using pattern recognition technology to evaluate whether or not the cascading trip events will occur in the power grid.

Basic Analysis on Cascading Trip in the Power Grid.

The common process of cascading trip is: when an initial failure happens on a line, the power flow of the power grid is redistributed. If current of any other line, the line will be cut down by the backup relay.

As to the power flow distribution, a detailed analysis is given here. Before an initial failure happens in the power grid, the power flow distribution can be expressed as equation 1.

$$\boldsymbol{Y}'\dot{\boldsymbol{U}}' = \left(\dot{\boldsymbol{S}}/\dot{\boldsymbol{U}}'\right)^{*} \tag{1}$$

In equation 1, $\boldsymbol{Y}'$ is the node admittance matrix of the power grid, and $\dot{\boldsymbol{U}}'$ is the vector of node voltage, and $\dot{\boldsymbol{S}}$ is vector of the node injection power.

When an initial failure happens in the power grid, if the nodal injection power of the power grid is not adjusted, or its adjustment can be ignored, $\dot{\boldsymbol{S}}$ in equation 1 is kept unchanged. The power flow can be expressed as equation 2.

$$\boldsymbol{Y}\dot{\boldsymbol{U}} = \left(\dot{\boldsymbol{S}}/\dot{\boldsymbol{U}}\right)^{*} \tag{2}$$

In equation 2, $\boldsymbol{Y}$ is the admittance matrix of the power grid excluding the branch with initial failure, and $\dot{\boldsymbol{U}}$ the vector of node voltage. For a specific initial failure, after the branch is shut down, every element of the node admittance matrix $\boldsymbol{Y}$ is fixed. Therefore, from equation 2, it can be concluded that $\dot{\boldsymbol{U}}$ is mainly depended on the nodal injection power of the power grid.

Here, it is assumed that the initial failure happens at branch Lij. Branch Lij is the branch between node i and node j. In this paper, other Branches are expressed in the same way. After branch Lij is shut down, the current of branch Lmk can be simply expressed in equation 3.

$$\dot{I}_{mk} = \left(\dot{U}_m - \dot{U}_k\right) / Z_{mk} \tag{3}$$

In equation 3, $\dot{U}_m$ is the voltage phasor of the m, and $\dot{U}_k$ is the voltage phasor of the k, and Z_{mk} is the impedance of the branch Lmk.

From equation 2, it is known that $\dot{U}_m$ and $\dot{U}_k$ are mainly depended on the nodal injection power of the power grid. Thus, from equation 3, Imk is also mainly depended on the nodal injection power of the power grid.

For branch Lmk, whether cascading trip occurs on branch Lmk can be judged according to equation 4.

$$I_{mk\cdot dist} = \left|I_{mk\cdot lim}\right| - \left|I_{mk}\right| \tag{4}$$

In equation4, Imk·lim is the setting value of backup relay protector of branch Lmk, Imk·dist is the distance between Imk·lim and and Imk. According to eqution 4, when Imk·dist is smaller than 0, the cascading trip event will occur on branch Lmk, and when Imk·dist is equal to 0, the cascading trip event will just occur on branch Lmk, and when Imk·dist is larger than 0, the cascading trip event will not occur on branch Lmk.

Therefore, from equation 2 to equation 4, it can be concluded Imk·dist mainly depends on the nodal injection power. So, whether the cascading trip will occur or not mainly depends on the nodal injection power of the power grid.

For the whole power grid after branch Lij is shut down, the minimum value in all values of Idist of branches can be given by using equation 5.

$$D = \min\left(I_{mk\cdot dist}\right) \tag{5}$$

From equation 5, after the initial failure occurs, when D is smaller than 0, the cascading trip will occur on at least one branch in the power grid, and when D is greater than 0, the cascading trip will not occur on any branch in the power grid, and when D is equal to 0, at least one branch will be involved in the cascading trip.

Furthermore, from equation 2 to equation 5, it can be conclude that the value of D finally and mainly depends on the nodal injection power of the power grid.

Basic Thoughts of Evaluating Cascading Trip of Power Grid.

From above analysis, it can be seen that the nodal injection power includes information whether the cascading trip occurs in the power grid. Therefore, whether the cascading trip occurs in the power grid can be judged by the nodal injection power.

For $\dot{\boldsymbol{S}}$, when all its values are determined, it represents a combination of injection power of all nodes in the power grid. Here, this paper calls the combination as nodal injection power mode.

Because the nodal injection power of the power grid determines the value of *D*, in some nodal injection power modes, the cascading trip will occur, but in other modes, the cascading trip will not occur.

From above analysis, pattern identification technology can be used to evaluate whether the cascading trip event will occur in the power grid. The nodal injection power of the power grid can be used as inputs when pattern identification technology is used. The data format of a sample for using pattern identification technology is expressed in equation 6:

$$S_i = \left[y, P_1, Q_1, \mathbf{L}, P_j, Q_j, \mathbf{L}, P_N, Q_N \right]^T \tag{6}$$

where, Si represents sample i, and Pj represents the active injection of node j, and Qj represents the active power and reactive power of injection of a node j. If the number of nodes in the power grid is N, the dimension of Si is 2N+1. In equation 6, y represents whether the cascading trip occurs, and corresponds to the value of D. if D is smaller than or equal to 0, y is equal to 1; and if D is greater than 1, y is equal to 1.

Therefore, according to the sample format given in equation 6, after a certain number of sample data are obtained, the evaluation on the cascading trip can be carried out by using pattern identification technology. This evaluation method uses the nodal injection power as inputs, and y is the output. Here, the nodal injection power are expressed in equation 7.

$$\boldsymbol{P} = \left[P_1, Q_1, \mathbf{L}, P_j, Q_j, \mathbf{L}, P_n, Q_n \right]^T \tag{7}$$

Where, Pj and Qj are the same as those in equation 6, and P is a column vector with 2N-dimension.

The specific method of pattern identification can be selected according to requirements and actual conditions. The example in this paper adopts a pattern identification method based on the neural network, and gives out main thoughts and the executing process of the algorithm.

Examples.

In this paper, the IEEE39 node system is used to carry out example analysis, and the specific process of evaluation on the cascading trip is demonstrated. In the example, a program based on MATLAB is compiled, and the result is given. The wiring diagram of IEEE39 system is shown in Figure 1.

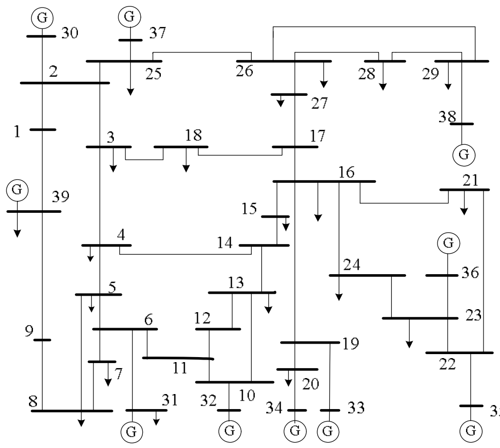

Fig. 1 Wiring diagram of the example system

The process mainly comprises some steps as the following.

A. Form the sample.

In this paper, the sample is gotten by simulation. For the example system shown in Fig. 1, branch circuit L17-18 is assumed as the initial faulted line, and then the following steps are executed.

1) For the example system shown in Fig. 1, except the nodes which are neither power generation nodes nor load nodes, give the injection power of each node randomly, so as to give the vector P. Here P is a column vector with 78-dimension. When each value of vector P is given, an injection power state of the power gird is given.

2) Compute the power flow of the complete power grid corresponding to the injection power state. If the computation is not converged, this sample will be abandoned and the analysis should turn to 7), otherwise, the next step should be taken.

3) Compute the power flow of the power grid without branch L17-18 corresponding to the injection power state. Similarly, If the computation is not converged, this sample will be abandoned and the analysis should turn to 8), and if the computation is converged, the next step should be taken.

4) Compute the current of any branch in the residual system according to equation 3, and then compute each value of Idist of them according to equation 4.

5) Compute the value of D according to equation 5, then judge whether the cascading trip occurs, if D is smaller than or equal to 0, enabling the value of y to be equal to 1, and if D is greater than 0, enabling the value of ye to be equal to 0.

6) Combine vector P and the value of y to form a sample as shown in equation 6.

7) Check whether the samples are sufficient, if it is true, end up the work for forming samples, otherwise, turn to step 1).

B. grouping of the samples

In this paper, 60% of the total samples are used for training, and the rest of the samples are used for testing.

C. initialization and training of the classifier

In this paper, the BP (Back Propagation) neural grid is selected to form classifier. Moreover, some functions in MATLAB toolbox is used in the program. The initialization function of the neural grid is newff, and the parameters in this function are selected as follows:

trainParam.epochs is equal to 1000,

trainParam.lr is equal to 0.1,

trainParam.goal is equal to 0.00000002.

The training function of the neural grid is *train*.

The normalization function of input is *mapminmax*.

The layer number of hidden layers of the integral neural grid is 10.

In this example, the input of the classifier formed by the neural grid is P with 78-dimension, and the output is y whose value is 0 or 1. if the number of the samples for training is N1, the input in function newff and train is an matrix with N1*78-dimesion, and the output in function newff and train is an matrix with N1*1-dimension.

D.Testing of the classifier

Similar with training, in the testing process, the input of samples for testing should be normalized firstly, and the processing method is consistent with that of training samples.

In the testing process, variable p is used to indicate the accuracy of classification. In order to judge whether the classification is rational and effective, variable p1 is used as an threshold and the value of it should be gotten according to experience. In this paper, if p is greater than p1, evaluation is considered to be effective and rational. Otherwise, the analysis should turn to the step C and training should be performed again until the requirement is met.

When the effective and rational classifier is obtained, it is meant that any injection power sate can be judged for whether the cascading trip can occur in that state by inputting P corresponding to that injection power sate into the classifier.

According to above algorithm flow, fig. 2 gives out a case with 200 samples. The testing accuracy under this case is close 100%. This result shows that the classifier is obviously very effective.

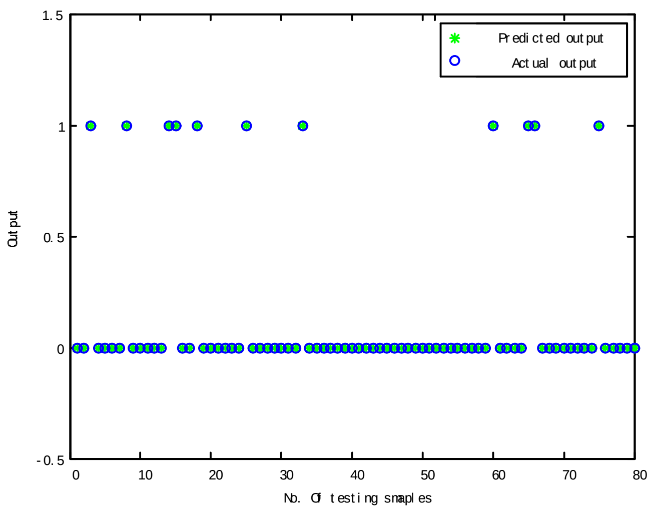

Fig. 2 a case with 200 samples

Actually, in the case of less sample data, when training is performed according to above flow, the testing result is also good. With 90 and 100 samples, this paper also carries out the training and testing process according to above flow, and the testing accuracy also approaches to 100%, which illustrates that the method is very good. Certainly, there is still some spaces of improvement for algorithm. For example, the classifier can be improved by improving the parameters in function *newff* and *train*, and other neural grids and other pattern identification methods also can be selected. These problems need to be further summarized and researched and are not researched in details in this paper.

Through above examples, it can be seen that by the method in this paper, to a given initial fault, different power injection states of the power grid can be evaluated, and once the classifier is formed, this method is very convenient, and is helpful to analyze the power grid.

Conclusion.

The cascading trip phenomenon of the power grid is closely related to the operation state of power grid. When the structure and parameters of the power grid and the setting value of backup protector of each line in the power gird is constant, whether the cascading trip occurs in the power grid mainly depends on the operation state which mainly depends on the nodal injection power of the power grid.

However, the relationship between the nodal injection power of the power grid and the cascading trip is relatively complex, and reconstruction on the relationship between the nodal injection power of the power grid and the cascading trip by using the pattern identification method is relatively a simple and feasible method. This paper, according to the thought, gives out a power grid cascading trip evaluation method based on the mode identification method. By the example, it shows that the method is reasonable and effective and can provide reference for practical application in the power grid and further research.

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