

Evaluating the Cascading Trip in a Power Grid Considering the Action of Backup Relay Protector

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Abstract—This research investigated the phenomenon of cascading trip in a power grid. First, aiming at assessing the backup relay protector of the current type, this paper investigated the relationship between cascading trip and nodal injection power by comprehensively analyzing the action of the relay protector and the power flow distribution in the power system. Then, the pattern recognition technology is adopted, using the nodal injection power of power grid as the feature input. Some examples with the IEEE39 system were presented in order to prove the rationality and effectiveness of this method, and the results were satisfactory.

Keywords—power system; blackout; cascading failure; cascade trip; power flow transfer

I. INTRODUCTION

In recent years, many researchers have focused on the cascading failure problems in a power grid. The investigators usually investigate the mechanism of cascading failure, the technique of simulating the cascading disappointments, and the effect of the grid structure on the flowing fiascoes. A cascading trip is the most common case for all mode failures, particularly in the beginning period of falling disappointments.

In order to prevent the occurrence of cascading trip events, these should be examined in depth and measures must be completed as early as possible. This paper proposes the technique of evaluating the likelihood of a cascading trip event using examples from the IEEE39 system. This technique is based on the neural grid and also uses pattern recognition technology to determine the probability of a cascading trip event occurring in a power grid.

II. BASIC ANALYSIS OF THE CASCADING TRIP EVENT IN A POWER GRID

Process of the occurrence of cascading trips can be expressed as: redistribution of power flow takes place initially due to problem initiated at any one of the transmission system line. As a result backup relay cutoff the line supply without knowing the cause of problem but due to the excessive load demand. This redistribution of power flows has been discussed in details, in this section. Expression of the power flow redistribution could be written as:

$$Y \dot{U}' = (\tilde{S} / \dot{U}')^* \quad (1)$$

In this equation we have node admittance matrix as Y' and node voltages have been presented in vector form

as \dot{U}' , the third term \tilde{S} represents the note injection power vector. By ignoring the nodal injection power or by not considering its adjustment, there is no effect on the equation one eq-1. So, we can write the equation of power as shown in eq-2

$$Y \dot{U}' = (\tilde{S} / \dot{U}')^* \quad (2)$$

Where Y is the admittance matrix of the power grid excluding the branch with initial failure, and \dot{U}' is the vector of the node voltage. For a specific initial failure, after the branch is shut down, every element of the node admittance matrix Y is fixed. Therefore, from Eq. 2, we can determine that the cascading trip mainly depends on the nodal injection power of the power grid. We assumed that the initial failure happens at branch L_{ij} . Branch L_{ij} is the branch between node i and node j . In this paper, other branches are expressed in the same way. After branch L_{ij} is shut down, the current of branch L_{mk} can be simply expressed as

$$i_{mk} = (\dot{U}_m - \dot{U}_k) / Z_{mk} \quad (3)$$

In the above equation (2), we have excluded the branch where power failure has occurred and is shown by Y , and the node voltage vector is presented as \dot{U}' . When any of the branch is shut down due to initial failure, each element of the node admittance matrix Y is fixed. This can be influenced from the eq-2 that nodal injection power is the main factor at which cascading trip strongly depend. Let suppose that initial failure has happened between nodes i and j at branch L_{ij} , which is the branch between these nodes. Similar method has been adopted for presenting other branches in this study. When the branch L_{ij} is shut down, we can express the current in the branch L_{mk} as given in the equation 3 below.

$$I_{mk \cdot dist} = |I_{mk \cdot lim}| - |I_{mk}| \quad (4)$$

Where $I_{mk \cdot lim}$ is the set value of backup relay protector of branch L_{mk} , and $I_{mk \cdot dist}$ is the distance between $I_{mk \cdot lim}$ and

I_{mk} . As stated in Eq. 4, when $I_{mk-dist}$ is less than 0, the cascading trip event will occur on branch L_{mk} , and when $I_{mk-dist}$ is come to 0, the cascading trip event will just appear on branch L_{mk} . Further, when $I_{mk-dist}$ is larger than 0, the cascading trip event will not appear on branch L_{mk} . Therefore, from Equations 2 to 4, we can conclude that $I_{mk-dist}$ primarily depends on the nodal injection power. Hence, certainly the cascading trip will appear depends on the nodal injection power

of the power grid. For the whole power grid, after branch L_{ij} is shut down, the minimum value in all values of I_{dist} of branches can obtained using Eq. 5

$$D = \min(I_{mk-dist}) \quad (5)$$

As can be seen in Eq. 5, after the initial failure occurs, when D is less than 0, the cascading trip will appear on at least one branch in the power grid, and when D is greater than 0, the cascading trip will not appear on any branch in the power grid. In addition, when D is equal to 0, at least one branch will be involved in the cascading trip. Furthermore, from Equations 2 to 5, it can be concluded that the value of D finally and primarily depends on the nodal injection power of the power grid.

III. BASIC THOUGHTS ON EVALUATING THE CASCADING TRIP IN A POWER GRID

From the above analysis, it can be seen that the nodal injection power includes information on whether a cascading trip will occur in a power grid, which can be determined based on the nodal injection power. When all its values are determined, it represents a combination of the injection power of all nodes in the power grid. In this paper, we call such a combination as the "nodal injection power mode." Given that 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.

On the basis of the above analysis, pattern identification technology can be used to evaluate whether a cascading trip event will occur in a power grid. The nodal injection power of a 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 as

$$S_i = [y, P_1, Q_1, \dots, P_j, Q_j, \dots, P_N, Q_N]^T \quad (6)$$

Where S_i represents sample i , P_i represents the active injection of node j , and Q_j 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 S_i is $2N+1$. In Eq. 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 Eq. 6, after a certain number of sample data are obtained, the evaluation of the cascading trip can be carried out by using pattern identification technology. This evaluation method uses y as the output and the nodal injection power as inputs. The nodal injection power is expressed as

$$P = [P_1, Q_1, \dots, P_j, Q_j, \dots, P_n, Q_n]^T \quad (7)$$

Where P_j and Q_j are the same as those in Eq. 6, and P is a column vector with $2N$ -dimension. The specific method of pattern identification can be selected according to the requirements and actual conditions. The example in this paper adopts a pattern identification method based on the neural network. Insights on the executing process of the algorithm are also provided.

IV. EXAMPLES

In this paper, the IEEE-39 node system was used to carry out case analysis. Then, the specific process of evaluating the cascading trip is demonstrated. A program based on MATLAB is compiled, and the result is provided. The wiring diagram of the IEEE-39 system is shown in Fig. 1.

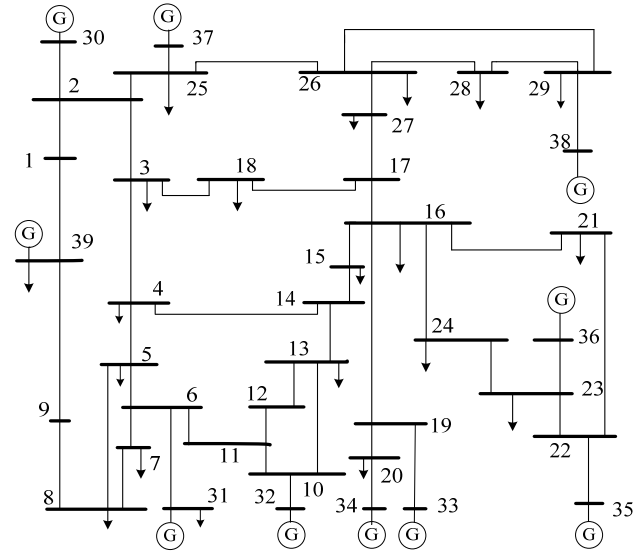


FIGURE I. WIRING DIAGRAM OF THE SAMPLE SYSTEM

The process includes different steps described below.

A. Form the Sample

This sample was obtained by simulation. For the sample system shown in Fig. 1, branch circuit L_{17-18} was assumed as the initial faulted line, and then the following steps were executed.

a. In Fig. 1, we provide the injection power of each node randomly as a vector P , except nodes that are neither power generation nodes nor load nodes. P is a column vector with 78-dimension. When each value of vector P is given, an injection power state of the power grid is confirmed.

b. Compute the power flow of the complete power grid matching the injection power state. If the computation is not converged, this sample is abandoned and the analysis skips to Step d; otherwise, the next step is taken.

c. Compute the power flow of the power grid without the branch L_{17-18} corresponding to the injection power state. Similarly, if the computation is not converged, the sample will be abandoned and the analysis skips to Step g; otherwise, if the computation is converged, the next step should be taken.

d. Compute the current of any branch in the residual system according to Eq. 3, and then compute each value of I_{dist} given in Eq. 4.

e. Compute the value of D according to Eq. 5, and then determine whether the cascading trip will occur. If D is smaller than or equal to 0, the value of y will be equal to 1, but if D is greater than 0, then the value is equal to 0.

f. Collect the P and y values to form a sample, as shown in Eq. 6.

g. Check the samples. If it is true, end the forming samples; otherwise, go back to Step a.

B. Grouping of the Samples

In this research, 60% of the samples were used for training and the rest were used for testing.

C. Initialization and Training of the Classifier

In this paper, the back propagation (BP) neural grid was selected to form the classifier. Moreover, specific functions in MATLAB toolbox were used in the program. The initialization function of the neural grid is newff, and the parameters selected are 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 the input is mapminmax.

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

Here, the input of the classifier formed by the neural grid is P with 78-dimension, and the output is y , which has a value of 0 or 1. If the number of the training samples is $N1$, the input of the function newff and train is the $N1 \times 78$ -dimension matrix, and the output in the function newff and train is the $N1 \times 1$ -dimension matrix.

D. Testing of the Classifier

As in the case of network training, the sample used for testing was also normalized, and the processing method was consistent with the training sample. The correct rate of classification was given in the test. If a threshold value of P_1 is given according to experience, as long as it satisfies $P > P_1$, then the evaluation is valid, and the classifier is considered to have been trained. If $P > P_1$ is not satisfied, then in this paper, the evaluation is considered effective and rational when P is greater than P_1 . Otherwise, the analysis must go to step C and training should be contacted again until the requirements are met.

When the effective and rational classifier is obtained, this means that any injection power state can be judged, the power state is injected into any node, and the correct rate of the chain tripping is evaluated under the given initial failure. If the classifier meets the requirements, the evaluation is considered valid.

According to the flow algorithm discussed above, we present Fig. 2, which shows a case with 200 samples. The testing accuracy under this case is closer to 100%, indicating that the classifier is obviously very effective.

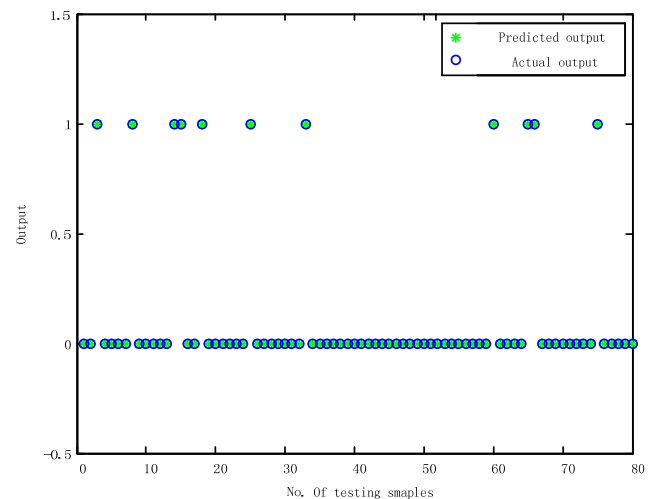


FIGURE II. A CASE WITH 200 SAMPLES

Actually, in the case with less sample data, when training is performed according to the flow above, the testing result is good. For 90 and 100 samples carried out according to the above flow, the test accuracy approaches 100%, which illustrates that the method is very good. Certainly, there are some spaces of improvement for algorithm. For example, the classifier can be developed by improving the parameters in the function newff and train. Other neural grids and pattern identification methods can also be selected.

For a specific initial error, different energy injection cases can be evaluated for a power grid. Once the classifier is formed, this method is very convenient and useful for power grid analysis.

V. SUMMARY

The efficiency of the power grid is closely related to the state of grid power operation. When the structure and parameters of the power grid and the value of backup protector setting for each line in the power grid is constant, the occurrence of the cascading trip in the power grid depends mainly on the state of operation. In turn, this depends on the nodal injection strength of the power grid.

However, the relationship between the nodal injection power for the power grid and the cascading trip is relatively complex, yet rebuilding the relationship using the pattern identification method involves a relatively a simple and feasible method. In this paper, we propose a power grid cascading trip evaluation method based on the mode identification method. By using this example, we demonstrate that the method is reasonable and effective. The results of our work can also provide reference for future research and for the method's further practical application in power grid operation.

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