Study on Fault Line Detection of Non-Effective Earthed Power System Based on A Novel Method

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Abstract. In the neutral point ineffectively grounded systems, the single-phase-to-earth faults frequently occur. When single-phase-to-earth faults occur, the fault features are inconspicuous and complex for the different grid running situations. Although varieties of fault line detection methods have been presented, the results of line detection were unsatisfactory. In order to improve the reliable and accuracy line detection method, a plenty of mathematical calculations to find fault feature values, simulation experiments based on Matlab/Simulink and laboratory tests have been conducted, then a novel line detection method based on zero-sequence admittance has been put forward. The research results show this method is satisfactory.

1. Introduction
In neutral point ineffectively grounded system, the single-phase-to-earth fault often occurs. As this system can still keep the symmetrical line voltage and the fault current is small, it isn’t needed to switch off the fault immediately [1, 2]. The power system can continue to run 1~2 hours [3]. At the same time, the healthy line’s phase voltage will rise to $\sqrt{3}$ times than the normal value, which is a potential risk to the power grid’s insulation system. So the fault must be detected and cut off as soon as possible. The single-phase-to-earth faults account for more than 80% of all power system faults [4]. But the steady-state earthed current value is extremely small [5, 6]. The single-phase-to-earth fault detection is more difficult than the other faults [7]. This paper presents a new line detection method which not only demonstrates the optimized principle of line detection, also constructs a simulation module and repeats a serial of simulations to verify its accuracy and reliable. The main simulation includes single-phase-to-earth fault though 1000Ω earth resistance and single-phase-to-earth fault though 10Ω earth resistance. In addition, a serial of actual tests of this novel theory were conducted in laboratory. Finally, the accuracy and reliable of this line detection method based on zero-sequence admittance were confirmed.

2. The optimized principle of line detection based on zero-sequence admittance
The value of zero-sequence admittance of fault feeder equals the sum of zero-sequence admittance of non-fault feeders for non-effective earthed power system. In addition, zero-sequence admittance of fault feeder has opposite phase to others. After optimizing principle of line detection, the fault’s judgment criterion is as follows:
Where $A_i$ is the judgment criterion of feeder $i$. It is also the sum of absolute value of dividing zero-sequence current of feeder $i$ by zero-sequence voltage of bus within one period. $A_k$ is the maximum of $A_i$ and $k$ is fault feeder.

3. Simulations and analysis

3.1. Simulation model
There are six feeders in non-effective earthed power system. Suppose there are two transformers and an opened bus-tie switch in this substation. The whole simulation model is shown in Figure 1. The distribute network module is shown in Figure 2.

![Figure 1. The whole simulation model](image-url)
3.2. The simulation analysis of single-phase-to-earth fault though 1000Ω earth resistance

Suppose there is a single-phase-to-earth fault in line 6’s phase A during 0.05s~0.16s. The fault waveforms of zero-sequence admittance in lines 1~6 have been obtained. The simulation results are shown in Figure 3. It can be seen that the zero-sequence admittance of line 6 has opposite phase to others when the fault occurs in the 2nd bus. The line 6’s zero-sequence admittance amplitude is the sum of line 4~5’s value. Meanwhile, the zero-sequence admittances of line 1~3 are close to 0. In other words, the line 6’s zero-sequence admittance is maximum, which is shown in table 1. According to the formula (1) and (2), line 6 is fault line, which is consistent with our assumption.
Table 1. Every line’s data after processing in single-phase-to-earth fault through 1000Ω earth resistance

| Sequence numbers | Line1/2/3 | Line4   | Line5   | Line6   |
|------------------|-----------|---------|---------|---------|
| The average value of zero-sequence admittance/S | 0         | -8.929e-7 | -8.2204e-7 | 1.6949e-6 |
| The effective value of zero-sequence current/A | 0         | 0.1740  | 0.1741  | 0.3841  |
| The average value of zero-sequence current/A | 0         | 0.001890 | 0.001890 | -0.003781 |
| The effective value of zero-sequence voltage/V | 0         | 4115.55 | 4115.55 | 4115.55 |

3.3. The simulation analysis of single-phase-to-earth fault through 10Ω earth resistance

Suppose the single-phase-to-earth fault occurs in the A phase of the line 3 during 0.05s–0.16s. The fault wave-forms of zero-sequence admittance in lines 1–6 have been obtained. The simulation results are shown in Figure 4.

![Figure 4. Every line’s zero-sequence admittance wave-forms in single-phase-to-earth fault though 10Ω](image)

It can be seen that the zero-sequence admittance of line 3 has opposite phase to others when the fault line occurs in 1st bus and it is the sum of line 1’s and 2’s values. Meanwhile, the zero-sequence admittance of line 4–6 are close to 0. Line 3’s zero-sequence admittance is maximum, which is shown in table 2. According to judgment criterion of line detection i.e. formula (1) and (2), the line 3 is fault line. This result is consistent with our assumption.

Table 2. Every line’s data after processing in single-phase-to-earth fault through 10Ω earth resistance

| Sequence numbers | Line1   | Line2   | Line3   | Line4/5/6 |
|------------------|---------|---------|---------|-----------|
| The average value of zero-sequence admittance/S | -2.2267e-5 | -2.2067e-5 | 4.4304e-5 | 0         |
| The effective value of zero-sequence current/A | 2.8914  | 2.8915  | 5.7829  | 0         |
| The average value of zero-sequence current/A | 0.002862 | 0.002862 | -0.005723 | 0         |
| The effective value of zero-sequence voltage/V | 2324.05 | 2324.05 | 2324.05 | 0         |

4. Laboratory tests

In order to verify the accuracy of this method based on zero-sequence admittance, a serial of laboratory tests have been designed. The structures of test circuits are shown in Figure 5.
After three experiments were carried out, we obtained the test results, as followed in table 3. The results showed that the actual fault feeder was same with the fault line we set. This result verified the accuracy of this line detection method based on zero-sequence admittance.

| The fault feeder | zero-sequence current(A) | zero-sequence Voltage(V) | computational zero-sequence admittance | experimental zero-sequence admittance | experimental result |
|------------------|--------------------------|--------------------------|----------------------------------------|--------------------------------------|---------------------|
| Line 1           | 0.0167                   | 2.5                      | 0.00668                                | 0.00724                              | Line 1              |
|                  | 0.0075                   |                          | 0.003                                 | 0.00296                              |
|                  | 0.0158                   |                          | 0.00632                                | 0.00663                              |
| Line 2           | 0.00415                  | 2.5                      | 0.00166                                | 0.00168                              | Line 2              |
|                  | 0.0104                   |                          | 0.00416                                | 0.00434                              |
|                  | 0.00625                  |                          | 0.0025                                | 0.0025                               |
| Line 3           | 0.005                    | 2.5                      | 0.002                                 | 0.0021                               |
|                  | 0.0104                   |                          | 0.00417                                | 0.00398                              |
|                  | 0.0208                   |                          | 0.00883                                | 0.00830                              |

5. Conclusion
In this paper, the single-phase-to-earth fault was selected as the research subject, and a novel line detection method based on zero-sequence admittance was designed. After a serial of simulations and laboratory tests were carried out, the accuracy and reliable of this method has been proved. In two transformer substation, this method can identify the fault in bus, and also can detect fault feeder in this bus. The theory is the infant stage of fault line detection in non-effective earthed power system. In order to improve the reliable of the whole power system, the device of line detection should be designed in our further work.

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