Study on A Fault Isolation Device in Low-voltage Network

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Abstract. A fault isolation device was designed in order to overcome the shortage of the traditional protective system. The corresponding circuit model was established and the character was analyzed when leakage occurred. Simulation study was carried out in this paper. The results show that a coupling voltage can be gotten which can drive the control system when leakage occurred. The adjustable capacity can be input reasonable by compare the supply voltage and voltage drop of the isolation device, thus the resonance parameters can be adjusted online and the electrical fault can be isolated effectively.

1. Introduction
In low-voltage distribution network, Leakage protective device was usually installed for single-phase leakage. When leakage occurred, the protective device can operate quickly which shut off the power immediately[1].Yet some protective devices often trip out and delay because of the rusting and node melt, thus the leakage current will be great and it is prone to two-phase leakage[2]. A new theory of leakage protection was presented for the low-voltage power system in document[3] in order to reduce the leakage current, document[4]analyzed the operating characteristics of a novel residual current protective device in low-voltage grid, and then discussed general design principles of protector in low-voltage power supply system under different wiring systems. From document[5] [6]and [7],it can be obtained the leakage current can be greatly reduced with the suitable resonance params, However, the leakage protective device can not work in perfect in the actury grounding fault. The aim is tend to design a new type of grounding fault isolation device to overcome the present’s disadvantages, which can isolate the grounding fault effectively.

2. The grounding fault isolation device structure
The structure of the grounding fault isolation device is shown in Fig.1, it is made of adjustable capacity, fixed capacity, impedor, control system and coupling power supply. As an important part of the grounding fault isolation device, the structure of the impedor is a three resonance circuit, which is made of iron core and inductance loop. The inductance winds round the same iron core, and the self-induction is equal to the mutual inductance [8].The coupling power supply can be gotten though the winds round the impedor, which is the supply of the control system. The parameters in resonance point can be gotten by compare the supply voltage and voltage between isolation device in and out with control system.
3. Operational principle analysis on the grounding fault isolation device

3.1. Analysis the electric power system in normally.
The function that contacts the isolation device with cable in low voltage network is equal to neutral point resonant grounding[9]. The three-phase current is symmetry in the impedor when the circuit operates normally. The three-voltage is dropped on the load totally. No leakage voltage is detected by coupling supply and the control system do not operate. Therefore, the grounding fault isolation device has no influence on the power system.

3.2. Analysis the leakage circuit in stability when single-phase grounding fault occurred.
Analysis the low voltage supply system in different wiring in stability, the leakage current \( I_R \) is given by equation(1).

\[
I_R = (1 - N\omega^2 LC) I_L
\]  

(1)

Where \( I_L \) is the inductance current through impedor, \( \omega \) is angular frequency, \( N \) is the wiring of the low voltage, \( L \), \( C \) is the parameters of the impedor in resonance point. The grounding fault can be isolated effectively when the parameters are satisfied with equation(2).

\[
LC = \frac{1}{N\omega^2}
\]  

(2)

3.3. Analysis the leakage circuit in transient when single-phase grounding fault occurred.
Analysis the low voltage supply system with different wiring in transient, the leakage current \( i_R \) is given by equation(3).

\[
i_R(t) = Ke^{-\frac{1}{2NRC}} [NLC(\frac{1}{4N^2R^2C^2} \sin \frac{\sqrt{4NR^2C-L}}{\sqrt{L2NRC}} t - \frac{\sqrt{4NR^2C-L}}{6N\sqrt{LR^2C^2}} \cos \frac{\sqrt{4NR^2C-L}}{\sqrt{L2NRC}} t) - \frac{4NR^2C-L}{4N^2LR^2C^2} \sin \frac{\sqrt{4NR^2C-L}}{\sqrt{L2NRC}} t + \sin \frac{\sqrt{4NR^2C-L}}{\sqrt{L2NRC}} t] \]

\[
= Ke^{-\frac{1}{2NRC}} [NLC(\frac{1}{4N^2R^2C^2} \sin \frac{\sqrt{4NR^2C-L}}{\sqrt{L2NRC}} t - \frac{\sqrt{4NR^2C-L}}{6N\sqrt{LR^2C^2}} \cos \frac{\sqrt{4NR^2C-L}}{\sqrt{L2NRC}} t) - \frac{4NR^2C-L}{4N^2LR^2C^2} \sin \frac{\sqrt{4NR^2C-L}}{\sqrt{L2NRC}} t + \sin \frac{\sqrt{4NR^2C-L}}{\sqrt{L2NRC}} t] \]

(3)

where \( R \) is the direct-current resistance of inductor. From equation (3), it can be seen whatever the coefficient \( K \) is, the amplitude of the leakage current is damped.

3.4. Analysis the loads operation when single-phase grounding fault occurred in different wiring.
The operational circuit was given in document[3] when the single phase grounding fault occured in three wiring system, the loads operation can be gotten in equation(4).

\[
U_{UV} + U_{VW} + U_{WE} = 0
\]  

(4)
where \(U_{UV}, U_{VW}, U_{WU}\) denotes the load line voltage.

The operational circuit was given in document[10] when the single phase grounding fault occurred in four wiring system, the loads operation can be gotten in equation (5).

\[
U_A + U_B + U_C = U_U + U_V + U_W
\]

where \(U_A, U_B, U_C\) denotes the three phase supply voltage, \(U_U, U_V, U_W\) denotes the three phase load voltage.

From equation (4) and (5) it can be seen: there is a balance between the load’s voltage and the source voltage, and the load can operate normally when single-phase grounding fault occurred. Thus the power supply can not switch off which keeps the power supply in reliable.

4. Simulation research

4.1. Simulation circuit and parameters.

The simulation circuit is in Fig 2, three-phase power supply is obtained, the inductance parameter of the impedor is \(4.67H\), the direct-current resistance parameter of the inductance is \(2\Omega\), the adjustable capacity parameter is varied among \(0.01\mu F\) to \(0.33\mu F\), the load is \(100H\), the test resistance is \(1k\Omega\).

4.2. Simulation in normal operation.

Turn on the switch, Shut off the adjustable capacity, the simulation results are shown in Fig.3. It can be seen from Fig.3: in normal operation, the voltage difference between the grounding fault isolation device in and out is very small which has no influence on the electric power system.

![Figure 3. Simulation in normal operation](image)

(a) The isolation device voltage
(b) The leakage detecting voltage

4.3. Simulation when single-phase grounding fault occurred.

Turn on the switch and make the adjustable capacity in appropriate, the simulation results are shown in Fig.4.

![Figure 4. Simulation when grounding fault occurred](image)

(a) The leakage detecting voltage
(b) Grounding fault current

It can be seen from Fig.4: The electrical source voltage is almost equal to the voltage difference of the isolation device when single-phase leakage occurred. The leakage detecting voltage was detected.
which is the power supply of the control system. And a good compensate point of the isolation device is found through alter adjustable capacity, and the grounding fault leakage current is in minimum when the adjustable capacity is to $0.33 \mu F$.

5. Experimental research

Power supply voltage in Figure 2 is $U_A = 247 V$, $U_B = 244 V$, $U_C = 247 V$, The load is an electric motor with $10 kW$. Switch $S$ Closed in Figure 2, change the adjustable capacitance value, test the operation of isolation device in case of single phase failure of distribution network, Test results are shown in Table 1.

| Adjustable capacitance $C_0$ (uF) | Voltage drop in isolation device $U_{L1}$ | $U_{L2}$ | $U_{L3}$ | Load Voltage $U_a$ | $U_b$ | $U_c$ | Leakage current $I_R$ (mA) | Coupling Voltage $U_k$ (V) |
|---------------------------------|------------------------------------------|---------|---------|------------------|------|------|--------------------------|-------------------|
| 0.47                            | 178                                      | 178     | 179     | 80               | 344  | 378  | 80                       | 6.5               |
| 0.48                            | 178                                      | 179     | 179     | 77.4             | 342  | 380  | 75                       | 6.5               |
| 0.538                           | 179                                      | 180     | 181     | 68.8             | 351  | 380  | 67.25                    | 6.5               |
| 0.62                            | 183                                      | 183     | 184     | 62.5             | 362  | 361  | 61                       | 6.5               |
| 0.69                            | 182                                      | 182     | 183     | 58.5             | 355  | 371  | 57.75                    | 6.5               |
| 0.80                            | 182                                      | 182     | 183     | 53.8             | 373  | 363  | 52.5                     | 6.5               |
| 0.847                           | 180                                      | 181     | 182     | 57.7             | 360  | 362  | 60                       | 6.5               |
| 0.94                            | 179                                      | 180     | 180     | 69.7             | 348  | 345  | 68.5                     | 6.5               |

It can be seen from Table 1, in case of failure, adjust the adjustable capacitance value by comparing the voltage of the power supply and the voltage of the isolation device, make the isolation device work near the resonance point, The leakage can be controlled in a safe range.

Because of the randomness of ground fault in distribution network, causes ground resistance can change among one thousands. Next, test the effect of isolation under different ground resistors. Under the above test conditions, Test resistance $R$ for 4Ω and 500Ω. Testing of isolation device operation, the test results are shown in Table 2.

| Leakage current $I_R$ (mA) | $R=4 \Omega$ | $R=500 \Omega$ | $R=1k \Omega$ |
|---------------------------|--------------|----------------|--------------|
| 0.47                      | 106          | 91             | 80           |
| 0.48                      | 98           | 86             | 75           |
| 0.538                     | 85           | 76             | 67.25        |
| 0.62                      | 79           | 69.25          | 61           |
| 0.69                      | 60           | 60             | 57.75        |
| 0.80                      | 52           | 52             | 52.5         |
| 0.847                     | 54           | 57             | 60           |
| 0.94                      | 57           | 64             | 68.5         |

From the Table 2 it can be seen: When the ground resistance changes among one thousands, if Control capacitance deliver at $0.80 \mu F$, The leakage current can be controlled in a safe range. This test result indicates that the isolation device can effectively isolate the fault points when a single phase failure occurs at any point in the distribution network.

6. Conclusions

A grounding fault isolation device was designed in this paper with parallel the fixed capacity and the adjustable capacity. The parameters of the adjustable capacity can be changed accurately by compare the power supply voltage and voltage difference between the isolation device in and out by the control system. The coupling power supply can be obtained through the winds round the impedor when the grounding fault occurred in low voltage power network, and that is the supply of the control system which can control the parameters of the adjustable capacity immediately and accurately. With the grounding fault isolation device the leakage current will be limited in safety when grounding fault occurred in anyway.
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References
[1] Chen Jia-bin. Grounding Technology and Device. Beijing:China Electric Power Press,2002
[2] Chen Shi-zhong. The Residual Current Protection Device. Beijing:China Electric Power Press,2002
[3] Zhang xiu-hua, Fu zhou-xing. Journal of China Coal Society. 2008 (7): 837-840. In Chinese
[4] Zhang xiu-hua. Industry and Mine Automation,2014(5):27-29. In Chinese
[5] Zhang xiu-hua, Fu zhou-xing. Low Voltage Apparatus.2008(5):12-15. In Chinese
[6] Zhang xiu-hua. Mining Research and Development,2010(3):75-77. In Chinese
[7] Jiang jun, Dong feng-bin, Huang jin-feng. Low Voltage Apparatus.2007(7):48-51. In Chinese
[8] Yao huan-nian, Cao mei-yue. Resonant grounded power system[M]. Beijing:China Electric Power Press,2004.
[9] Zhang xiu-hua. Electrical & Energy Management Technology.2014(13): 11-13. In Chinese
[10] Jing dong, Zhang xiu-hua, Sun hong-liang. Industry and mine Automation,2016(10):56-59. In Chinese