비접지 배전계통에서 영상전류 위상 비교에 의한 고장구간 검출 방법

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A Fault Section Detection Method for Ungrounded System Based on Phase Angle Comparison of Zero-Sequence Current

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Abstract – In this paper, a fault section detection method is proposed for ungrounded system in the case of a single line-to-ground fault. A conventional method is used for faulted feeder selection according to the angular relationship between zero-sequence currents of the feeders and zero-sequence voltage of the system. Fault section detection is based on the comparison of phase angle of zero-sequence current. Proposed method has been testified in a demo system by Matlab/Simulink simulations. Based on Distribution Automation System(DAS), Feeder Remote Terminal Unit(FRTU) is used to collect those necessary data, at present a demo system is under developing using Manufacturing Message Specification (MMS) in IEC61850 standard.

1. Introduction

The ungrounded system can be defined as a system having no intentional ground connection between the phase conductors and ground. In reality, the "so-called" ungrounded system is actually capacitively grounded as a result of the capacitance coupling between the energized components of the distribution system and ground [1]. Its major advantage is that when one phase shorts to ground, there is no solid return path through which current may flow. Due to the capacitive coupling, there is usually only the very small current flow especially in low voltage systems. The absence of any significant current during a ground fault means the power system can remain energized and the process can continue to operate.

However, SLG faults are 80% of all faults in it, and the amplitude of fault current is small, which makes fault detection difficult [2]. So far many experts have carried out deep and abroad study of this problem and put forward many algorithms for it [2]-[6].

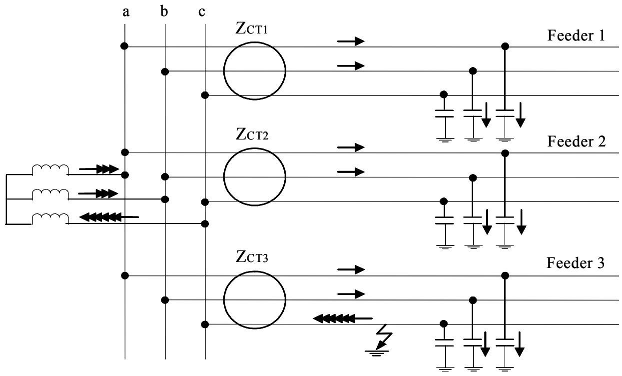
In this paper, a new fault section detection method is proposed based on the comparison of phase angle of zero-sequence current. In practice, based on DAS, FRTU is utilized to collect those measured data such as zero-sequence current and voltage, or phase-to-phase voltage. In addition, based on MMS communication in IEC61850 standard, an intelligent demo system is under developing with also considering other fault types such as open-circuit fault and phase-to-phase fault diagnosis.

2. Proposed Algorithm

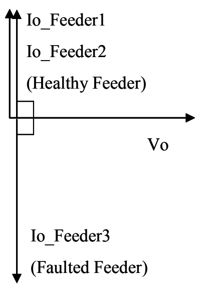
2.1 Faulted Feeder Selection

So far many techniques have been done for faulted line selection, such as wavelet transform [3]-[4]. In this paper, a conventional method is introduced for faulted feeder selection [6]. Fig.1 shows an ungrounded power system with a solid c phase-to-ground fault on Feeder 3. During a ground fault, the phase-to-neutral voltage increases to a phase-to-phase voltage. Zero-sequence voltage of the system is equal to the phase-neutral voltage in the normal conditions. If phase angle of zero-sequence current at each feeder is in phase, that means fault occurs in the busbar; if phase angles of zero-sequence currents at the feeders are opposite in polarity, that means fault occurs at a feeder. Zero-sequence current of faulted feeder is equivalent to the sum of capacitance current of the whole network excluding faulted feeder, while zero-sequence current of the healthy feeder is the sum of its own three-phase currents. Zero-sequence current of the faulted feeder flows from fault point to busbar, while that of the healthy feeder flows from busbar to the feeder. Hence zero-sequence current of the faulted feeder is higher than that of the healthy feeder in amplitude.

Based on the angular relationship between zero-sequence currents of the feeders and zero-sequence voltage of the system, a rule can be achieved: zero-sequence current of the healthy feeder leads zero-sequence voltage of the system by 90 degrees, while zero-sequence current of the faulted feeder lags zero-sequence voltage of the system by 90 degrees. Fig.2 depicts the corresponding phasor diagram of zero-sequence current and voltage for the multi-feeder ungrounded system shown in Fig.1. According to this rule, the faulted feeder can be found out.



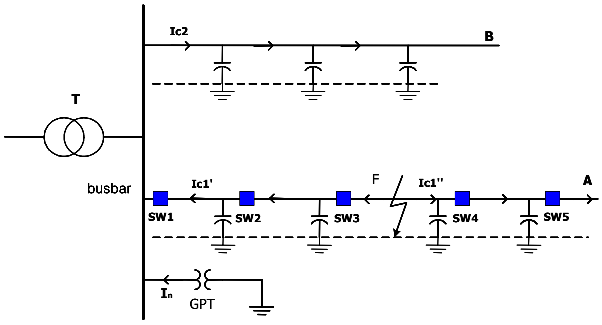
<Fig.1> A multi-feeder ungrounded system



<Fig.2> Phasor diagram of zero-sequence current and voltage in ungrounded system

2.2 Fault Section Detection

Faulted feeder selection is using the zero-sequence voltage at the busbar and the zero-sequence current at each feeder. A new faulted section detection method is proposed using the phase-to-phase voltage and zero-sequence current. Zero-sequence voltage can be measured by GPT(Grounding Potential Transformer) in the substation. Zero-sequence current can be measured by FRTU. But the problem is that those measured data should be obtained synchronously in the network. As long as the issue can be overcome, the faulted section would be easily detected through the information of the voltage and current. Fig.3 shows the flowing direction of zero-sequence current in the feeders. In the faulted feeder, zero-sequence current direction is opposite in the section before the fault point and the section behind the fault point.



<Fig.3> Direction of Zero-sequence current in the feeders

In ungrounded system, In the pre-fault or post-fault condition, both the amplitude and phase angle of the phase-to-phase voltages are not changed. So one of the phase-to-phase voltage can be chosen as a standard reference value, which is used to compare with the phase angle of zero-sequence current. If it is 180 degree for the phase angle difference between the kth switch before the fault point and the (k+1)th switch behind the fault point, that means fault section is between kth switch and (k+1)th switch.

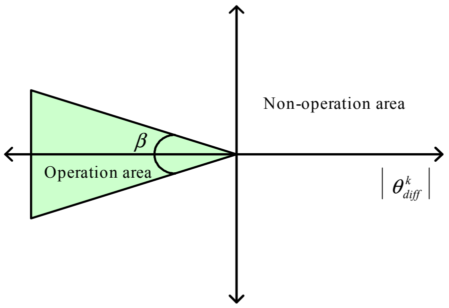
Θ_{Diff}^{k} is the difference of phase angle between the (k-1)th FRTU and kth FRTU. It means

$$\Theta_{Diff}^{k} = \Theta^{k-1} - \Theta^{k} \tag{1}$$

Θ^{k} is the difference of phase angle between phase-to-phase voltage and zero-sequence current. That is

$$\Theta^{k} = \angle V_{LL}^{k} - \angle I_{0}^{k} \tag{2}$$

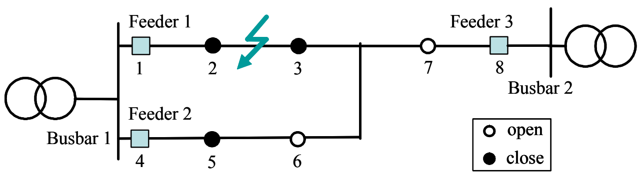
Taking account of the measurement error of phase-to-phase voltage and zero-sequence current, if the phase angle between two FRTUs is about $180° \pm \beta$, the section between those two FRTUs is fault section. Fig.4 shows the criterion for the operation area and non-operation area.



<Fig.4> Criterion of fault section detection

3. Case Study

Fig.5 shows the demo system which consists of two feeders, 3 circuit breakers such as CB1, CB4 and CB8, 5 switches. The voltage level is 10kV, and the frequency is 50 Hz. Those CBs and the switches are with FRTUs, respectively. When a single phase-to-ground fault occurs between SW2 and SW3, the proposed method has been testified in Matlab/Simulink based on this demo system.



<Fig.5> The demo system

As shown in Table 1, the amplitude of zero-sequence voltage Vo at Busbar 1 is 8114.3; its phase angle is -150.3°. While the phasor of zero-sequence voltage at Busbar 2 is almost 0. That means fault occurs in the system with Busbar 1. There are two feeders at Busbar 1. Then according to the proposed faulted feeder selection method, zero-sequence current of Feeder 2 leads zero-sequence voltage at Busbar 1 by 89.943 degrees, while zero-sequence current of Feeder 1 lags zero-sequence voltage at Busbar 1 by 90.06 degrees. So the faulted feeder is Feeder 1.

<TABLE 1> Results for Faulted Feeder Selection

	Amplitude	Phase Angle
Vo (Busbar 1)	8114.3	-150.3°
Vo (Busbar 2)	7.652e-10	-
Io_SW1(Feeder 1)	0.061315	119.64°
Io_SW4(Feeder 2)	0.061315	-60.357°

As shown in Table 2, due to the proposed fault section detection method, Θ_{Diff}^{k} is 179.82 degrees between SW2 and SW3. That means fault section is between SW2 and SW3.

<TABLE 2> Results for Faulted Section Detection

Switch Phase angle	SW1	SW2	SW3
Vab	60°	59.824°	59.506°
Io	119.64°	119.68°	-60.454°
Θ^{k}=Vab-Io	-59.64°	-59.856°	119.96°
Θ_{Diff}^{k}	-	-0.216°	179.82°

4. Conclusion

A fault section detection method is proposed for ungrounded system in the case of a single line-to-ground fault based on the comparison of phase angle of zero-sequence current. The simulation results demonstrate that the effectiveness of the faulted feeder selection method and fault section detection method. Based on DAS, FRTU is used to collect data. At present, an intelligent communication-based demo system is under developing with the application of MMS in IEC61850 standard.

5. Acknowledgment

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