Research to Improve the Fault Indicator Malfunction using Current Direction in Distribution Automation System

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SUMMARY

In this paper, an improved method for generation of fault indicator in FRTUs is proposed for the Distribution Automation System. It is found that the upper side fault current direction is different from the down side fault current direction. Therefore, in order to prevent the generation of wrong fault indication information for FRTU at the down side of the fault, an improved fault indication generation method is developed. It not only the basic conditions, but also the directions from the angle difference between zero and positive sequence currents is considered to generate the fault indication information. In case study, the proposed method has shown the reliability in generating the correct fault indication information for many kinds of faults according to conditions.

KEYWORDS

Distribution Automation System(DAS), Fault Indicator(FI), Feeder Remote Terminal Unit(FRTU)
1. Introduction

Domestic distribution automation system (DAS) is a comprehensive control system, which comprises IT-technic, operating power system technic. ALTS and FRTUs. FRTU is connected to ALTS and receive many information such as voltage, current, signal of fault so that DAS can work efficiently. The reliability of the power supply is one of the most important aspects because distribution system is directly connected to the consumer. When equipment trouble occurs, fast exploration and repair of equipment are very important factor because it reduces the time of power outage. Therefore, from a position of consumer, outage restoration function is the most useful function among many functions of DAS. Distribution system using ground neutral system use the algorithm of ‘Yes-No’ method. This logic is that devices at upper side of a fault experience the fault current whereas devices at the down side of the fault not experience it. In other words, if a relay is operated by fault, DAS gathers information of voltage, current and decides that the fault is located between two devices, one of the device experiences fault current while the other does not. And restoration of distribution system is processed according to this result. So the decision of fault location is very important. But the existing algorithm of fault indication generation of ‘Yes-No’ method assume that the distribution system can be analyzed by single-phase analysis but the distribution system in practice is unbalanced three-phase power system and has distributed generators and large load of motors. Therefore, if a fault occurs, the reverse current can flow from the load or distributed generator without power converter devices. In fact, the many errors that devices at the down side of the fault experience the fault current are discovered in the real DAS operation. Actually, when single line-to-ground fault occurs in heavy load power system, reverse power or large reverse current can be made by distributed generators or motors connected to a transformer of wye-delta type. Recovering power outage is very important, so many papers have been published such as experiential detection method, expert system, G-net, Fuzzy logic, Petri net method and so on. But most of those have researched about algorithms of restoration after fault area is decided. This paper analyzes errors of algorithm of ‘Yes-No’ method in detail and propose new algorithm considering not only magnitude of current but also angle of current so that we can acquire correct FI information. This paper is organized as follows. Section 2 describes how to detect fault section and problem of existing algorithm considering magnitude of current only. Section 3 propose new algorithm considering not only magnitude of current but also angle of current. In Section 4, results of computer simulation are presented to verify the usefulness of new algorithm.

2. Protection principle of distribution system, recovery method and problems

Improving reliability of distribution system is that fast isolation of faults and detecting fault area, separating the fault area from power system and recovering area without fault by connecting another distribution system.

2-1. Protection of Distribution system

CB(Circuit Breaker) and Recloser are typical protection device of distribution system. These devices have OCR(Over Current Relay) which protect each phase from fault current and OCGR(Over Current Ground Relay) which protect each phase from ground fault current. OCR’s tap value is set for line-to-line fault; OCGR’s tap value is set for line-to-ground fault. Commonly OCR works in case of line-to-line fault and OCR and OCGR works in case of ground-fault. Therefore double protection is worked in case of normal ground-fault. OCR’s minimum operation current is larger than that of OCGR so OCGR have to operate in case of high impedance ground-fault. In addition devices at upper side of fault should be cooperated with each other to prevent operating at same time. So power outage area can be minimized in case of fault.

Fig.1 is typical single line diagram in Korea’s distribution system. This is radial system where power flows only in one direction from CB1. If a fault occurs among 2,3,6 district, devices at the upper side of a fault experience fault current and Recloser of districe2(Recloser2) blocked fault current coordinatind with CB1. In other words, Recloser2 operates faster than CB1 because Recloser2’s setting time is smaller than it of CB1. Therefore minimized power outage area appears into fig.1’s rectangular box. Unless the speed and reliability is guaranteed, protection of distribution system not uses communication technique because it is necessary for fast speed and reliability. After protection devices operate, all devices at the upper side of the fault except for CB1 experience zero voltage and send FI(Fault Indication) to DAS; whereas devices at down side of the fault don’t send FI.
2-2. Restoration in distribution system.

Restoration service is minimized power outage area by recovering unnecessary outage area so it is very important. Existing restoration service decides fault area and restoration area by analyzing information acquired from devices. Operator or system separates fault area and calculate restoration equation and make restoration by connecting restoration area to another system. In addition, it is important to get a combination of switch operation order considering capability margin of another system. In order to operate this work, we have to accurately detect fault area. Existing system gather fault indication information for detecting fault area, but if we don’t trust fault indication information, it is impossible to do fast restoration in distribution automation system.

2-3. Existing distribution system device’s method of generating fault indication information and problems.

Devices at the upper side of the fault should generate fault indication information whereas devices at the down side of the fault shouldn’t generate it. As mentioned before, existing distribution system uses the algorithm of ‘Yes-No’ method. This logic is that devices at upper side of a fault experience fault current but devices at the down side of fault not experience it. Besides, this logic assumes that the distribution system can be analyzed by single-phase analysis but the distribution system in practice is unbalanced three-phase power system and has the distributed generator and big load of motor. For example, Fig2 is zero-sequence circuit diagram in ground fault case. If the generator and load are three-phase balance, zero-sequence voltage is not generated. But if unbalanced 3-phase is occur by ground fault, zero-sequence voltage is generated at the fault point. And it causes that zero-sequence fault current flows from generator area and load area and it resulted in errors generating FI information at the down side of the fault.

Figure 2 The zero-sequence circuit in ground fault

Figure 3 The zero-sequence circuit of wye-delta transformer at the load area

Another drawback of the algorithm is that does not take account of the large load of motors. The large load of motors work normal load in normal state but it can work like generator in fault state because of inertia. So it can supply fault current to fault spot during very short time. Also distributed generators without power converter devices can supply fault current to fault spot. Errors based on wrong assumptions have been problem in distribution system. Therefore N-phase-FI information without phase-FI information is ignored in current DAS operation. But OCGR can cover the fault area that OCR can’t cover. At the time, FI information is N-phase FI. So if we ignore N-phase FI information, we can’t do restoration of ground fault. In order to solve it, not only magnitude of the fault current but also fault current angle should be considered.

3. An improved method of fault indication generation

This paper analyzes two cases, the first is that the load area supply fault current to fault point in ‘wye-delta’ transformer and the second is that distributed generators supply fault current to the fault point. This paper proposes two principles that can prevent a wrong fault indication information generation.

3-1. An improved FI information generation considering direction of zero-sequence current

The first principle is comparing zero sequence phase and positive sequence phase. Therefore we need the direction standard in order to determine whether the upper side of the fault or the down side of the fault. The positive and zero sequence current direction can be obtained from the three-phase current measured by FRTU, and then we can know the upper side of the fault and the down side of the fault by comparing the positive-sequence current and the zero-sequence current.

Figure 4 Three-phase current measured at the upper side of the fault in phase A-to-ground fault
Fig. 4 is three-phase current measured at the upper side of the fault in phase A-to-Ground fault case. In this case, the A-phase current increases because A-phase is fault phase. The direction of the positive-sequence is equal to the direction of the A-phase current. But healthy-phase voltage at the down side of the fault increases and zero-sequence current is supplied from the load area. Therefore the healthy-phase current increases. The smaller fault impedance and zero-sequence impedance at the load area there is, the more zero-sequence current can flow. According to this, the zero-sequence current is increased and the positive-sequence current is increased in the reverse direction before the fault.

Figure 5(a) Three-phase current measured at the down side of the fault in small zero-sequence current and A-to-ground fault
Figure 5(b) Three-phase current measured at the down side of the fault in large zero-sequence current and A-to-ground fault

Fig. 5(a) and Fig. 5(b) are three-phase current measured at the down side of the fault in phase A-to-Ground fault case. Fig. 5(a) is case where the small zero-sequence current is flowed from the down side of the fault. But Fig. 5(b) is case where the big zero-sequence current is flowed from the down side of the fault. In this case, the angle difference between positive-sequence and zero-sequence current is approximately 180 degree regardless of magnitude of current. The deference between zero-sequence current phase and positive-sequence current phase is 0degree at the upper side of the fault and 180degree at the down side of the fault. So we can prevent a wrong fault indication information generation by using this principle. But there are some cases that the positive-sequence current phase at the upper side of the fault is equal to the positive-sequence current phase at the down side of the fault. This problem is can be solved by using the second principle. Similarly, B-to-ground fault and C-to-ground fault can be analyzed by this method. In B-to-ground fault case, difference of the positive and zero sequence current angles is 120 degree at the upper side of the fault and difference of the positive and zero sequence current angles is -60 degree at the down side of the fault. In C-to-ground fault case, difference of the positive and zero sequence current angles is -120 degree at the upper side of the fault and difference of the positive and zero sequence current angles is 60 degree at the down side of the fault.

Figure 6 Three-phase current measured at the upper side of the fault in phase BC-to-ground fault

Fig. 6 is three-phase current measured at the upper side of the fault in phase BC-to-Ground fault case. In this case, the B-phase and C-phase both current increase because B-phase and C-phase are fault phase. The direction of the positive-sequence is same as the direction of the A-phase current. Therefore zero-sequence and positive-sequence current direction is in opposite.

Figure 7(a) Three-phase current measured at the down side of the fault in small zero-sequence current and phase BC-to-ground fault
Figure 7(b) Three-phase current measured at the down side of the fault in large zero-sequence current and phase BC-to-ground fault

Healthy-phase current increase in case of BC-to-ground fault because of not only the increase of phase voltage but also the supply of the zero-sequence current from load area. But the fault current increase in the opposite direction of the current direction before the fault. Similarly, AB-to-ground fault and CA-to-ground fault can be
analyzed by this method. In AB-to-ground fault case, difference of the positive and zero sequence current angles is 60 degree at the upper side of the fault and difference of the positive and zero sequence current angles is -120 degree at the down side of the fault. In CA-to-ground fault case, difference of the positive and zero sequence current angles is -60 degree at the upper side of the fault and difference of the positive and zero sequence current angle is 120 degree at the down side of the fault. By the way, the magnitude of three-phase current in A-to-ground fault is similar to the magnitude of three-phase current in BC-to-ground fault. Also, the difference between positive and zero sequence is same in two cases. Therefore the two cases should be distinguished because devices at the down side of the fault can generate incorrect FI information. Also, BC-to-ground fault measured at the upper side of the fault and A-to-ground fault measured at the down side of the fault should be distinguished. First, Fig.4 and Fig.7(a) are same in vector diagram but fault-phase current is lower than the current before the fault because Fig.7(a)’s zero-sequence current is low. Therefore, if we can know that any phase-current after the fault is lower than current before the fault, we can decide that the area is down side of the fault. And, comparing Fig.4 and Fig.7(b), the information show that all phase-current are larger than current before the fault. In this case, the biggest phase current is deemed fault phase and the others are deemed healthy. Based on this standard, the sum of difference between healthy and fault phase is over 180 degree in Fig.4 and under 180 degree in Fig.7(b). In summary, Table.1 and Table.2 present how to distinguish the area whether the upper side of the fault or the down side of the fault.

Table 1 The difference between the upper side of the fault and the down side of the fault

<table>
<thead>
<tr>
<th>Kind of the fault</th>
<th>The upper side of the fault</th>
<th>The down side of the fault</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>After fault, all phase current become larger than current before fault</td>
<td>After fault, some phase current may become smaller than pre-fault current</td>
</tr>
</tbody>
</table>

Table 2 The difference between the upper side of the fault and the down side of the fault (kinds of the fault)

<table>
<thead>
<tr>
<th>Kind of the fault</th>
<th>A difference between the zero/positive sequence current phase (degree)</th>
<th>A sum of differences between healthy/fault phase (degree)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-to-ground</td>
<td>between 60±90</td>
<td>between 120±90</td>
</tr>
<tr>
<td>B-to-ground</td>
<td>between 120±90</td>
<td>between 60±90</td>
</tr>
<tr>
<td>C-to-ground</td>
<td>between -60±90</td>
<td>between 120±90</td>
</tr>
<tr>
<td>BC-to-ground</td>
<td>between 120±90</td>
<td>between 60±90</td>
</tr>
<tr>
<td>CI-to-ground</td>
<td>between 60±90</td>
<td>between -60±90</td>
</tr>
</tbody>
</table>

3-1. An improved FI information generation considering direction of zero-sequence current

The second principle is using the difference between the positive-sequence voltage phase and positive-sequence current phase. If there are large motor loads or the distributed generator without power converters at the down side of the fault, the fault current can be flowed to the fault point. In this case, the difference between the positive-sequence voltage phase and positive-sequence current phase is over ±90 at the down side of the fault. Therefore if the difference between the positive-sequence voltage phase and positive-sequence current phase is over ±90, fault indication information shouldn’t be generated.

4. Case study

In this paper, in order to verify the feasibility of the proposed algorithm, the simulations are conducted considering single line-to-ground fault and double line-to-ground fault in existing distribution system by using the proposed algorithm. Fig.9 is the simulation system that applies the proposed algorithm.

Figure 8 The simulation model
Figure 9 The key diagram of the simulation model

Table 3 presents the difference between the upper side of the fault and the down side of the fault in ground fault. In Table 3, B device decides that the fault is A-to-ground by comparing the magnitude of current. And then, it does not generate FI information because the difference of positive-sequence voltage and current is more than 90 degree and the sum of difference between healthy and fault phase is less than 180 degree. Likewise C device decides that the fault is BC-to-ground by comparing the magnitude of current. And then it does not generate FI information because the difference of positive-sequence voltage and current is less than 90 degree. In case of BC-to-ground fault, C device decides that the fault is A-to-ground by comparing the magnitude of current but it does not generate FI information because the sum of difference between healthy and fault phase is less than 180 degree.

Device B does not generate FI information about any kind of the fault because it does not meet both the fault condition, angle difference between positive-sequence voltage and current and the sum of difference between healthy and fault phase.

Table 3 The result of the simulation (fault impedance [1Ω] / The difference of each devices)

<table>
<thead>
<tr>
<th>Fault type</th>
<th>A device (upper side of the fault)</th>
<th>B device (down side of the fault)</th>
<th>C device (down side of the fault)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ph-to-f</td>
<td>The same sequence current [1]</td>
<td>The same sequence voltage and current [degree]</td>
<td>The same sequence voltage and current [degree]</td>
</tr>
<tr>
<td>Ph-to-f</td>
<td>539</td>
<td>-12</td>
<td>12</td>
</tr>
<tr>
<td>Ph-to-f</td>
<td>542</td>
<td>-13</td>
<td>13</td>
</tr>
<tr>
<td>C-to-f</td>
<td>541</td>
<td>-12</td>
<td>12</td>
</tr>
<tr>
<td>BC-to-f</td>
<td>444</td>
<td>-12</td>
<td>12</td>
</tr>
<tr>
<td>Ab-to-f</td>
<td>447</td>
<td>-12</td>
<td>12</td>
</tr>
<tr>
<td>Mb-to-f</td>
<td>445</td>
<td>-12</td>
<td>12</td>
</tr>
</tbody>
</table>

5. Conclusion

The algorithm in existing distribution system is based on wrong assumptions so FI information errors are generated at the down side of the fault and these errors make a trouble in restoration. In this paper, we analyzed the error of fault indication generated from the FRTU and developed an algorithm which generates fault indication in an improved way to avoid the errors by using not only the magnitude of the fault current but also its phase. To avoid errors of the terminal devices that are dispersedly installed in the distribution system, we can upgrade the software by applying the proposed algorithm in this paper. Therefore, it is believed that the proposed method in this paper can be applied in the field easily.

6. References