An Intelligent Fault Detection and Service Restoration Scheme for Ungrounded Distribution Systems

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Abstract – Electric load components have different characteristics according to the variation of voltage and frequency. This paper presents the load modeling of an electric locomotive by the parameter identification method. The proposed method for load modeling is very simple and easy for application. The proposed load model of the electric locomotive is represented by the combination of the loads that have static and dynamic characteristics. This load modeling is applied to the KTX in Korea to verify the effectiveness of the proposed method. The results of proposed load modeling by the parameter identification follow the field measurements very exactly.

Keywords: Load modeling, Parameter, Traction power supply system

1. Introduction

Public safety and service quality are the main objectives of a responsible distribution system [1]. As the industry develops, the request for power is increasing, and the need for high quality and reliable power supplies is also on the rise [2]. If the chosen method is not effective when the fault occurs, it would greatly affect the society and significantly inconvenience the customers. In order to minimize the bad affections of a fault, the fault section must be located and isolated, and the service must be restored as quickly as possible.

Nowadays, the Distribution Automation System (DAS) is widely used because it has greater speed and efficiency in handling faults. Recently, many methods are being developed to deal with single phase to ground faults occurring in ungrounded distribution systems [3]. There is an approach contrasting the differences between high-impedance fault detections for ungrounded systems and multigrounded systems [4]. Also, some methods using the latest communication technology have been developed in order to accelerate the restoration [5]. The ungrounded system is used throughout most parts of China, and there are many valid methods that can handle a fault. A signal injection method is developed for fault line selection and fault section detection [6, 7]. This method uses a specialized frequency signal which can be distinguished from system harmonics. This signal can be injected from the second device of the system, such as PT, and then tracked. The fault point is at the location where the signal disappeared. This method has no interrupt with the first device of the system, but it needs many manual operations which cannot satisfy the automation requests.

After studying and comparing many methods which have already been developed, an intelligent and efficient scheme for fault section detection and service restoration for single phase to ground fault in ungrounded distribution systems is proposed in this paper. Part two mainly introduces how to judge whether a fault occurs in the ungrounded distribution system and how to use communication and the controlling of the switches in single-tie and multi-tie distribution systems. It also gives the solution of handling the single phase to ground fault. In part three, a demo system is also built and some case studies are done to prove the method. Finally, the conclusion is presented.

2. Proposed Method

2.1 Problems of Single Phase to Ground Fault in Ungrounded Systems

In ungrounded distribution systems, when single phase to ground fault happens, the fault current will be much smaller than it is in grounded distribution systems, so the fault section detection scheme used in the grounded system is not valid in the ungrounded system. In the conventional method, fault section is isolated by using a

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sequential time-out control scheme. The conventional method requires the cooperation of the reclosing and re-reclosing devices to detect and isolate the fault section, and then service can be restored based on restoration rules. However, the conventional method leads to many blackout areas and costs much time. So even though the ungrounded system can operate without interruption within 1 or 2 hours after a fault happens, the system may have hidden failure because the voltage of two healthy phases will increase and the high voltage might enlarge the fault area. This paper proposes a method for fault section detection and service restoration in an ungrounded distribution system. This scheme is developed to deal with permanent single phase to ground fault in single-tie and multi-tie ungrounded distribution systems. Communication technology is used to realize the automation during the fault section detection and the service restoration process.

As shown in Fig. 1, when single phase to ground fault occurs in an ungrounded system, the fault current can only form a loop with the capacitor between line and ground, and because the capacitance is small, the fault current is also very small. The voltage of the fault phase will decrease to zero. However, the voltage of a healthy phase will increase to line voltage. The unbalance of the system will cause zero sequence voltage and zero sequence current. So whether or not the fault occurs can be generally judged by detecting zero sequence voltage.

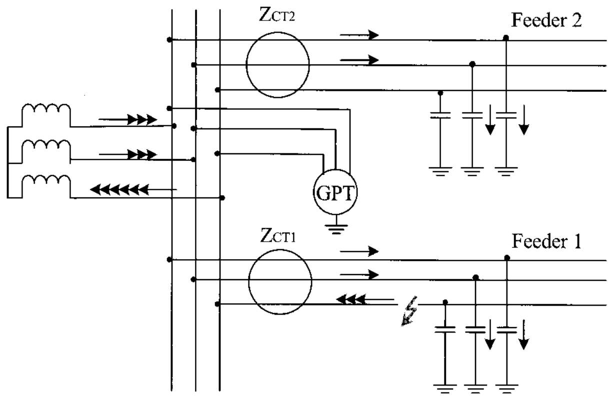

Fig. 1. Single phase to ground fault in ungrounded system

2.2 Proposed Communication based Fault Detection

The DAS has a communication channel and can obtain all the needed information concerning the system from FRTUs located in the system. In the proposed method, the control of the switch moving which can be realized by communication technology is a core of the whole algorithm.

There is a two terminal single-tie distribution system,

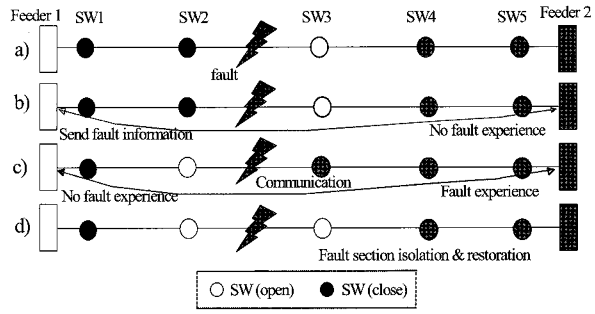

Fig. 2. Single-tie distribution system

which contains 5 switches and SW3 is the tie switch between Feeder 1 and Feeder 2. We can assume fault occurs between switch SW2 and SW3.

Fig. 2 shows the operation procedure using the proposed method and it can explain how the communication works.

a) In Fig. 2-a), single phase to ground fault occurs between switch SW2 and SW3.

b) In Fig. 2-b), Feeder 1 detects the fault and then communicates with Feeder 2 in order to send the fault information and request whether Feeder 2 can detect the fault. If Feeder 2 does not experience fault, then it moves the tie switch from switch SW3 to SW2.

c) In Fig. 2-c), when the tie switch is moved to switch SW2, Feeder 2 experiences fault. At the same time, after communicating with Feeder 1, it can be known that Feeder 1 does not experience fault which means the fault occurs in the section between switch SW2 and SW3.

d) In Fig. 2-d), Open both switch SW2 and SW3, isolate the fault section, and the restoration is done at the same time.

The above discussion shows that using the proposed method, the fault section detection and the service restoration can conclude simultaneously, meaning that the proposed method can save much time, thereby affecting the customers only slightly. We know that the real distribution system always has the radial configuration, so we should pay more attention to the multi-tie distribution system. The proposed method works well not only in single-tie distribution systems but also in multi-tie distribution systems.

In the multi-tie system, especially the system containing a loop, whenever a fault occurs, feeders connected with the loop will experience zero sequence voltage, and the fault feeder cannot be distinguished from healthy feeders, so we should add another criterion: the direction of zero sequence current, which is shown in Fig. 3 for a simple multi-tie ungrounded distribution system. DAS can control the open or close status of the switches easily, and our proposed method is based on the switch moving, while the tie switch moves across the fault section, the

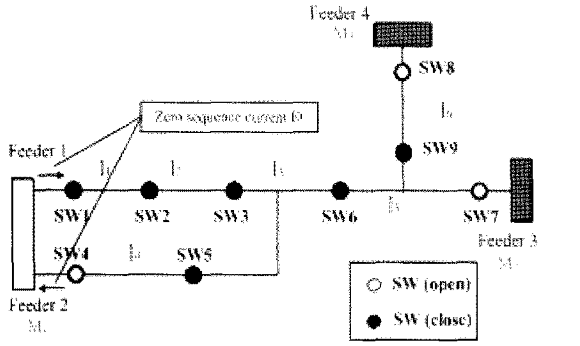

Fig. 3. A simple multi-tie ungrounded distribution system

healthy feeder will exchange with the fault feeder, so the direction of zero sequence current should change 180 degrees [8].

Therefore, depending on zero sequence voltage and the direction of zero sequence current, whether there is a fault or not can be judged.

In Fig. 3, assume the margin of each feeder is M_2, M_3 and M_4, and the load of each line is L_1, L_2, L_3, L_4, L_5, and $L6$.

Only one open switch should be moved at a time, because this method depends on the system information available each time the open switch moves. So choosing the moving switch is very important while the method is used in the multi-tie distribution system. As we already know, during the movement of the open switch, the load is transforming at the same time. The margin of the tie switch stands for the restoration ability of each feeder, so we choose the moving switch based on the margin of each tie switch.

The margin of the tie switch equals feeder margin minus the load of restored lines:

$$M\_SW_i = M_p - L_j \tag{1}$$

where, M_SW_i: Remain margin of SWi;
M_p: Margin of Feeder p;
L_j: Load of line j.

For example, tie switch between Feeder 1 and Feeder 4 moves to SW9, the remaining margin of SW9 equals the margin of Feeder 4 minus the load of SW8.

2.3 Fault Section Detection and Service Restoration Scheme

A more detailed description about the proposed method is presented. And we will also take the system shown in Fig. 3 as an example. When the backup feeders receive the fault information, they will start the restoration process based on the method of the flow chart. The flow chart showing the restoration procedure is shown in Fig. 4.

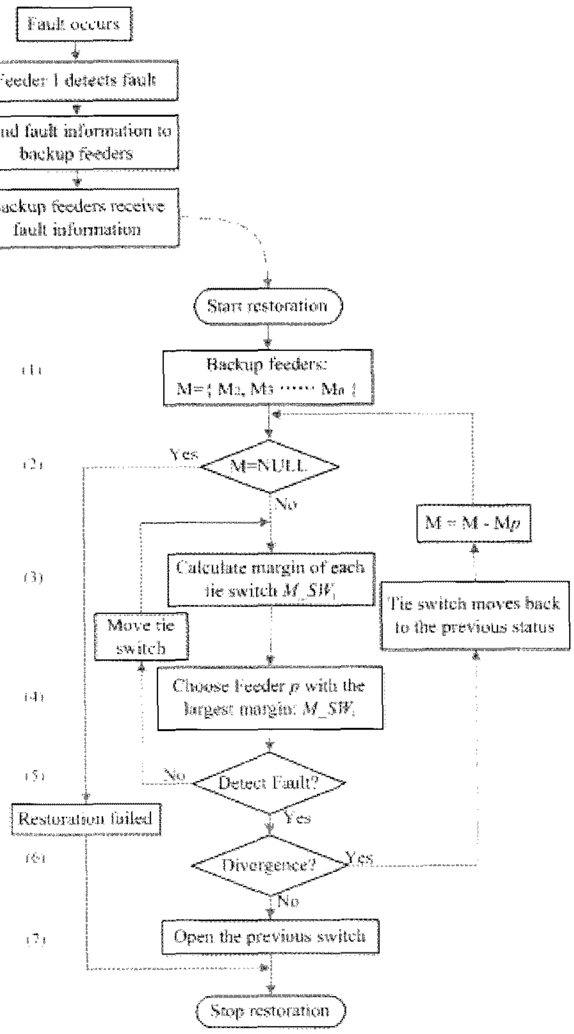

Fig. 4. The flow chart of the proposed scheme

When a fault occurs, Feeder 1 detects the fault and sends fault information to the backup feeders to request whether they can restore the fault or not. Backup feeders receive fault information and then the restoration process begins.

1) Assume the aggregate M is made up of all the backup feeders.
2) Check whether M is NULL or not, If M is NULL, the restoration is failed and the process should stop, or else proceed to step 3.
3) Calculate the margin of each tie switch.
4) Choose Feeder p which has the largest margin to do the restoration.

5) Check whether Feeder p can detect the fault or not. If it detects no fault, the tie switch between Feeder 1 and Feeder p will move, at which point step 3 should be performed again and the flow chart followed. If Feeder p detects the fault, go to step 6.
6) Check whether there is a divergence behind the current open switch or not. If there is a divergence, then go back to the previous status, close the current open switch and open the previous switch. Let $M=M-M_p$, then go to Step 2. If there is no divergence while detecting the fault, go to Step 7.
   Here, the divergence is specially defined as a section which connects two, or more than two, closed switches.
7) Feeder p detects the fault and there is no divergence behind the current open switch. This situation means the fault section is between the current open switch and the previous open switch. Open the previous switch, and then the fault section can be isolated and the service restoration can be completed at the same time. The whole process will stop.

3. Case Study

A 10kV 50Hz ungrounded multi-tie distribution system is built using Matlab Simulink. Fig. 5 shows the structure of the demo system. This multi-tie distribution system has 9 switches and 4 feeders and there is a loop between Feeder 1 and Feeder 2. The margin of the feeders and load value of the lines are also indicated in Fig. 5.

In order to put the method into application for an ungrounded distribution system, we build a demo system which uses computers to simulate each switch and FRTU.

Assume the fault occurs at 0.1s, the switches will move every 0.1s. We can get zero sequence voltage and zero sequence current's value from the FRTU of each feeder.

As indicated in Fig. 5, this multi-tie system has 6 sections, and the fault has a chance to occur in any section. Here we choose Section 5 which has the most steps to finish the whole fault detection and service restoration procedure.

When a fault occurs in Section 5, the procedure using the proposed method to finish the fault detection and the service restoration includes 10 steps which are shown as follows:

1) Fault occurs among SW6, SW7, and SW9.
2) Feeder 1 experiences fault, so it sends fault information to other feeders to exchange information and start the restoration. Calculate the margin of each tie switch to find the feeder which has the largest margin. At this step, Feeder 2 has the largest margin, so choose Feeder 2 to restore the service.
3) Move the tie switch from SW4 to SW5, Feeder 2, Feeder 3, and Feeder 4 cannot experience fault, and the margin of SW5 equals the margin of Feeder 2 minus the load of Section 4, and it is larger than zero, so the tie switch moves.
4) The tie switch moves from SW5 to SW3, at this time, the direction of zero sequence current changes. Feeder 2 detects fault, but Feeder 3 and Feeder 4 cannot experience fault. However, there is a divergence behind SW3, so go back to the previous status.
5) Open SW5 and close SW3. Then compare the margin of the other two feeders to choose which one has the larger margin. At this time, Feeder 3 has the larger margin, so choose Feeder 3 to continue the restoration.
6) Move the tie switch from SW7 to SW6. Feeder 3 can experience fault but Feeder 1, Feeder 2, and Feeder 4 cannot. However, there is also a divergence behind SW6, so move back to the previous status again.
7) Open SW7 and close SW6. Next, choose the last feeder, Feeder 4, to continue the restoration.
8) Move the tie switch from SW8 to SW9. All the feeders cannot experience fault, so move the tie switch.
9) Move the tie switch from SW9 to SW6. At this step, Feeder 4 can experience fault but Feeder 1, Feeder 2, and Feeder 3 cannot, and there is no divergence behind

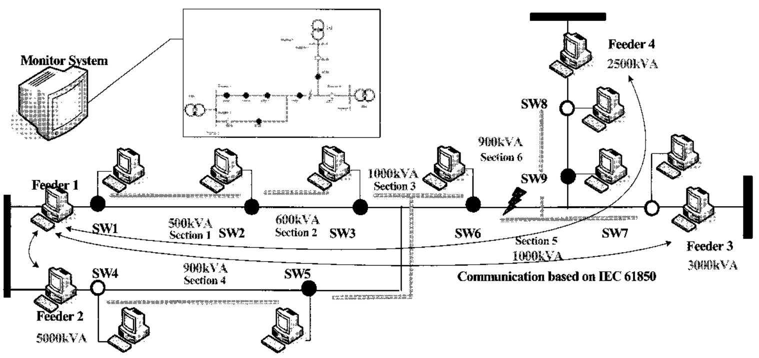

Fig. 5. Case study system

SW6 (SW7 is open, so in this section, only SW9 is closed, as we defined, there is no divergence behind SW6). Depending on these evidences, it can be decided that the fault occurs in Section 5.

10) Open SW9. The fault section is detected and the service restoration is completed all together.

The stable value during each step is shown in Table 1 and the final result can be gotten from the monitor system shown in Fig. 6.

Communication plays an important role in the proposed method, and in order for this method to be widely used, an IEC61850 based FRTU development scheme is used. Then a new logic node is defined named FRTU in IEC61850 configuration which has both client mode and server mode. The communication function which is based on IEC61850 standard [9] is used in two parts. One is among feeders and the other is while FRTUs send open or closed command to the switches.

Table 1. Stable value of each step

Steps	Feeder1		Feeder2		Feeder3		Feeder4	
	V0 (mag)	I0 (ang)	V0 (mag)	I0 (ang)	V0 (mag)	I0 (ang)	V0 (mag)	I0 (ang)
1	0	----	0	----	0	----	0	----
2	8113	-150	8113	30	0	----	0	----
3	8152	-150	8152	30	0	----	0	----
4	8130	30	8130	-150	0	----	0	----
5	8130	-150	8130	30	0	----	0	----
6	0	----	0	----	8165	30	0	----
7	8130	-150	8130	30	0	----	0	----
8	8130	-150	8130	30	0	----	0	----
9	0	----	0	----	0	----	8160	30
10	0	----	0	----	0	----	0	----

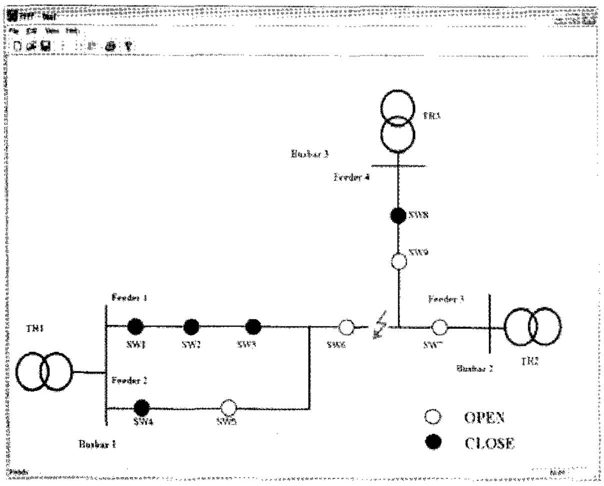

Fig. 6. The final result

4. Conclusion

In this paper, an intelligent scheme is developed to deal with the fault section detection and service restoration in ungrounded distribution systems. It uses communication to minimize the outage time. And a case study system whose communication part is programmed based on IEC61850 standard has already been built. The result of case studies can prove the proposed method is valid not only in single-tie systems but that it is also effective in multi-tie systems.

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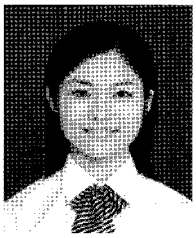

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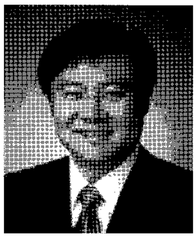

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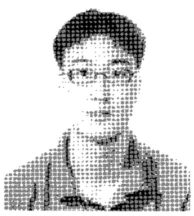

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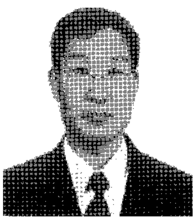

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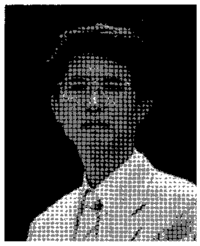

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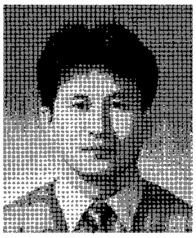

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