A Novel Fault Location Algorithm in Distribution Network Based on Power-on Signal and Power-off Signal

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Abstract. In recent years, with the continuous promotion of clean and low-carbon energy strategy, power system’s operation mode has been transformed gradually. Consequently, the extended time of fault location when it occurs will jeopardize the fault restoration of distribution system and reduce the grid resilience. Hence, this paper proposes a novel fault location algorithm based on the combination of power-on signal and power-off signal, which can improve the efficiency of the fault location. First, the principle of numbering node is presented, making it convenient for computer to identify the relationship between device in the distribution network. Then, some assumptions and principles of the algorithm are shown, together with the termination condition of the proposed algorithm. Finally, case study involving an actual distribution network is carried out. Results show that the proposed algorithm is able to achieve accurate fault location meanwhile improve the efficiency of fault location.

1. Introduction
With the progress of smart power distribution grids, fault location (FL) techniques are playing an important role in repairing work expedition, outage time reduction, and economic loss mitigation[1]. In recent years, many researchers have been focused on this problem. One way to deal with this is via current information. A new differential current-based fast fault location scheme for multiple Photovoltaic-based dc microgrid is proposed in [2]. In [3], an intelligent fault detection scheme for microgrid is proposed, with branch current measurements sampled by protective relays being pre-processed by discrete wavelet transform to extract statistical features. Reference [4] propose a scheme for DC microgrid which uses superimposed currents of both ends of a line segment. Similarly, reference [5] presents a new method for locating faults in multi-terminal direct current networks incorporating hybrid transmission media. Meanwhile, voltage information is also used in fault location. In [6], a novel method is presented for wide-area fault location incorporating both synchronized and unsynchronized voltage measurements. In [7], a voltage-based protection scheme is proposed that detects, classifies, and locates string-to-ground, string-to-string, and open-circuit faults in utility-scale PV arrays. Besides, other researchers pay attention to the placement of measuring device itself to improve the performance of fault location. In [8][9], mathematical models to optimally place automation system devices within distribution networks are introduced, the problem is formulated in mixed integer programming, which guarantees global optimum solution achieved in an effective runtime. Reference [10] presents a model to integrate sectionalizing switches(SS) malfunction probability into SS placement problem. However,
none of the above methods are based on the power-on signals and power-off signals uploaded at each device after the fault occurs. Hence, this paper aims to propose a novel fault location algorithm. And our major contributions can be summarized below: 1) The principle of numbering nodes are established to clarify the relationship between upper and lower levels of each device in the network. 2) the principle of fault location through power-on signal and power-off signal is proposed. In particular, power-on signal has not been used in fault location before. 3) an actual distribution network is used to validate the effectiveness of the proposed algorithm.

2. Principle of numbering nodes
The purpose of numbering node is to clarify the relationship between the upper and lower levels of each device in the network, so that the computer can handle it and directly use it to realize fault location. Specific rules are as follows:
- The node number of 110kv substation (acting as a power source) is set to 10.
- The line directly connected to the power source is called the trunk line, on which the nodes (the intersection of trunk line and branch line) are numbered in increasing order from near to far according to the distance from the power source, and set to 11, 12, and 13 etc.
- The node on the branch line (the intersection points of the branch line and the lower-level line) adds two numbers to the number of the intersection point of the branch line and the trunk line, and increases in turn according to the distance between the node and the head node of the branch line. Set to 1100, 1101... Or 1200, 1201, etc.

3. Principle and assumptions of the algorithm
This section illustrate some rules and assumptions used in fault location based on the principle of numbering nodes.

3.1. Assumption
- It is impossible for three or more faults to occur simultaneously in the network.
- All signals received are correct.
- Do not consider the possibility of load transfer at the moment of fault occurring.

3.2. Principle
- When the power-off signal is received, it is determined that the fault has occurred on the line where the power-off signal is located or the superior line of it.
- When the power-on signal is received, it is determined that the fault has occurred on the subordinate line or other branch line.
- When two power-off signals are received on a certain line at the same time, it isn’t determined until other signals upload.
- When three or more power-off signals are received on a certain line, it is determined that the fault has occurred on this line or the superior line.
- When power-off signal and power-on signal from the same line are received simultaneously, it is directly determined that the branch line that uploads the power-off signal is faulty.

3.3. Termination condition
- Time to reach 90s
- All devices upload signals
- The scope of the fault is located to a certain area
If any of the above three conditions are met, the fault location algorithm can terminate.
The complete procedure of the proposed algorithm can be abstracted as below:
Table 1. Algorithm flow of the fault location

| Algorithm | Start |
|-----------|-------|
| Step 1    | Input the abstracted topology of a certain network |
| Step 2    | Numbering the nodes in the network according to section 2 |
| Step 3    | When 2 power-off signals are uploaded, start to locate fault |
| Step 4    | Reduce the range of the fault position according to section 3 |
| Step 5    | Output the fault location |

End

4. Case study
Take the actual topological diagram of a certain distribution network as an example for analysis, the specific topology the number of every node in the network is as Fig 1 shows. Obviously, the number of nodes is in accordance with the principle shown in section 2.

Supposing that the fault occurs between 16 and 17 and the order of signal upload is 170405 → 170100 → 170400 → 170101 → 1702 → 1500 → 1700 → 1600. In such case, all devices whose first two digits are 17 should upload power-off signals, and all devices whose first two digits are less than 17 should upload power-on signals. It is noticeable that the number in red in the figure represents that the device has uploaded its status (either power-on or power-off), while number in blue has not uploaded its status. Also, the red lines mean the possible location of fault occurs.
Figure 2. When 170400 and 170101’s signal is received

Figure 3. When 1702 and 1500’s signal is received
After receiving power-off signals at 170405 and 170100, the operation centre immediately starts the fault location algorithm and recruit signals from all devices on all lines. First, judge the positional relationship of the device where power-off signal has been uploaded. Comparing number 170405 and 170100, it can be found that their lengths are equal. Therefore, the two devices are of the same level. However, the middle two digits of the two devices are different, which means their superior lines (1704 and 1701) are connected to the same feeder line 17. It is determined to deal with the signal until other device uploading signals. Using the same method to determine the fault location

- If the power-off signal uploaded by 170400 is received, the range of the fault position will be reduced to 10~17, 17~1704.
- If the power-off signal uploaded by 170101 is received, since there are only two power-off signals on line 1701, the range of the fault position remains the same as above, see Fig 2.
- If the power-off signal uploaded by 1702 is received, the range of the fault position will be reduced to 10~17, 17~1702.
- If the power-off signal uploaded by 1500 is received, it is determined that there no fault between 10~15, then the range of fault position is reduced to 15~17, 17~1702, see Fig 3.
- If the power-off signal uploaded by 1700 is received, it is determined that the fault position is in upper line of 17, then the range of fault position is reduced to 15~17.
- If the power-off signal uploaded by 1600 is received, it is determined that there is no fault between 15~16. Hence, the fault is located in 16~17, see Fig 4. Since it meets the termination condition, the procedure of fault location is over.

5. Conclusion
According to the case study above, it is not difficult to find that the proposed fault location algorithm greatly reduces the number of devices that need to call for signals. There are a total of 21 devices in the case, and only 8 devices’ signals are used. Although the number of equipment required for fault location in the same scenario is affected by the sequence of equipment upload signals (for example, if the power-off signals of 3 devices in the same level is received first, the range of the fault location can be quickly reduced into the upper line. Meanwhile, no more attention should be paid to other device of the lower level line or the same level line, and if the equipment signal of the lower level line is received first, although it is of no use for fault location to narrow the fault range, it still increases the equipment signal used). Therefore, fault location through the combination of power-off signals and power-on signals in
the upper- and lower-line device can indeed eliminate the signal demand of irrelevant equipment and shorten the time for fault location. In addition, the effective use of this method for the power-on signal also speeds up the research and judgment time in a certain procedure. Refer to case above, after receiving the power-on signal uploaded by 1600, the possibility of line 10-16 failure is immediately eliminated, there is no need to recruit the signal of the device on lines 10~16. Otherwise, the possibility of fault on line 10~16 cannot be ruled out immediately, increasing the time for fault location.

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