CURRENT MUTATION AND PHASE DIFFERENTIAL FAULT IDENTIFICATION ALGORITHM BASED ON SUPPLY AREA SAMPLING CALIBRATION METHOD FOR ACTIVE DISTRIBUTION NETWORK

Jiaming WENG
Shanghai Jiao Tong University, China
Jimmywjm007@gmail.com

Dong LIU
Shanghai Jiao Tong University, China
liudong@ieee.org

Qingming ZHAO
Guizhou Power Grid Co., Ltd, China
qingmingzhao@eyou.com

ABSTRACT

More distributed energy resource (DER), regarded as clean energy source, become accessed into the distribution power system. However, it brings different influence on the judgement of protection act and fault location as before. This paper mainly focus on how to use these clean energy sources more effectively and to ensure safe operation of power system without the introducing of other facility.

This paper proposes unified-sampling calibration method in which data of all the interconnected feeders in supply area is collected. Without changing the original network topology, the concept of "directed graph" is introduced to carry out of current direction calibration. With the results of such sampling calibration method, current mutation is to be the start-up condition to locate the fault precisely. Through local communication in distributed FA and GPS time synchronization, current wave data is transferred between adjacent FA controllers. Fault identification algorithm based on current mutation and phase differential is proposed.

INTRODUCTION

Active Distribution Network (ADN) not only accepts DER into the distribution network, but also actively manages the system operation, which may alter the one-way power flow in traditional distribution network. Such operation management brings fundamental alteration of primary system as well as secondary system of distribution network, and requires better operation in ADN. Feeder Automation (FA), as one of the key techniques in the operation of distribution network, also needs improvement on its traditional concept in secondary system to meet the demand of technology enhancement brought by ADN.

The protection coordination with DG isolation protection has to be considered due to isolate operation is allowed in active distribution network. There is many research has work on these. By studying the relay based on the rate of frequency change and mismatch rate of load and DG to analyze the sensitivity and reliability of protection is proposed in [1]. An active distribution grid protection scheme combined over-current protection and voltage protection is proposed in [2]. An active distribution grid fault location solution that only use current signal to identify the fault line by artificial intelligence algorithms is proposed in [3]. A radial active distribution network protection scheme is proposed in [4] by using directional over-current protection as a primary feeder protection and setting the appropriate current threshold with the appropriate trip time. An active management and protection coordination concept is proposed in [5] based on flexible active distribution network topology and adjustable over-current protection method. This method can provide more flexible and efficient mode of operation, and it is also applicable to islanding operation. It is first proposed in [6] that how to introduce the operation and protection of active distribution network in UK. But at that time, distributed generation is the major consideration. Once a fault is detected, protection action to protect distributed generation. An index called the maximum level of fault transient voltage shock is proposed in [7]. It is found that the index has linear correlation with fault distance. So it is very useful to fault location in single fault of micro-grid. A new method of impedance-based fault location by matching the voltage of substation bus and the voltage of each DG is proposed in [8]. It can be used in unbalanced three-phase distribution network. The influence of synchronized phasor measurement and the sensitivity of fault location based on the voltage drop with distributed generation is proposed in [9]. The main problems affecting the distribution network fault location accuracy is: too many branch lines, load changes too fast, the system imbalance, unbalance three-phase system, the presence of branch line and load tap. So the four main issues of active distribution network protection is [10]: (1) It is need to replace the switch due to the increased level of fault currents; (2) Decrease the sensitivity of protection equipment and the normal operation of the feeder will be malfunction due the failure; (3) It is need to introduce new protection device, in particular islanding protection (loss of mains protection); (4) It is need to introduce new protection concept to meet in some islanding operation cases that may be achieved.

The operation in traditional topology of secondary system mainly takes consideration of forward mode in which power is applied only by substation. However, it neglects the two-way power flow in ADN, which cannot take one-way flow for granted to set one single current direction as forward direction. This paper proposes unified-sampling calibration method in which data of all the interconnected feeders in supply area is collected. Without changing the original network topology, the concept of "directed graph" is introduced to carry out of current direction calibration. With the results of such sampling calibration method, current mutation is to be the start-up condition to locate the fault precisely. Through local communication in distributed FA and GPS time synchronization, current wave data is transferred between adjacent FA controllers. Fault identification algorithm based on current mutation and phase differential is proposed. The method presented in this paper is verified by fault location simulation in China's 863 Project. This method is able to solve the efficiency problem in the operation of ADN with mass DER asserted, and to enhance economic performance by reduce the facility number as much as possible.

SUPPLY AREA SAMPLING CALIBRATION METHOD FOR ACTIVE DISTRIBUTION NETWORK

The traditional distribution system topology is radial network, so it can be interpreted as a multi-tree structure. Multi-tree structure changes only in the case of changing the operating mode through changing tie-switch status with the other one multi-tree or more multi-trees. However, in this case the new grid structure must still be a multi-tree structure. The conversion is shown in Fig.1:

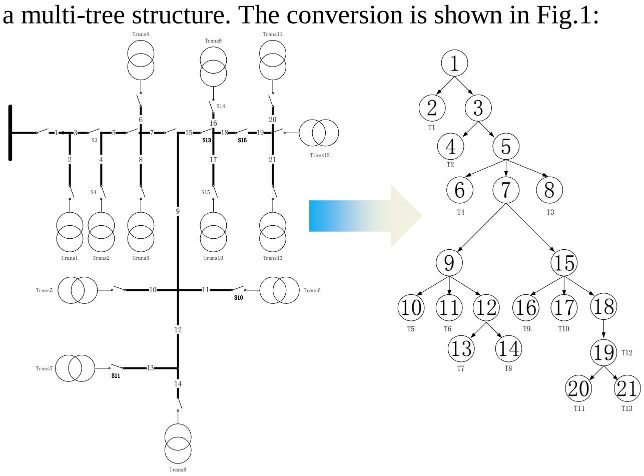

Fig.1: Schematic diagram of conversion

In the same way, this paper choose two or more multi-trees interconnect with each other through tie-switch as the study area, also called as interconnect power supply area. Although distribution network structure doesn't change when the tie-switch status is changed, the structure of multi-trees has been changed. Under radial distribution network circumstance, each tree roots will not change. Therefore only the end of the tree can be change which is the structure and number of branches. As shown in Fig.2:

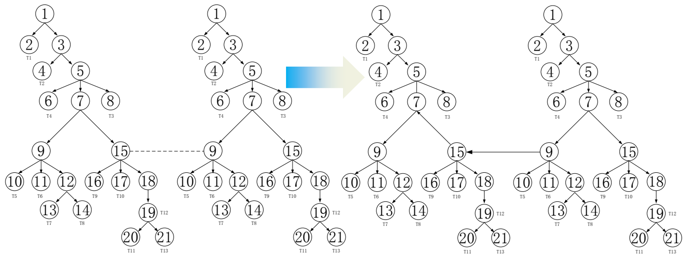

Fig.2: Tree changes caused by changes in the status of tie-switch

From the above figure can be drawn the main body of multi-tree I and multi-tree II has not changed, but power flow of node 15 to node 7 has changed of multi-tree II.

In the same way, not only in the number of multi-tree roots change, but also in creating multi-tree branches and changing the operating mode that required calibrate with the actual operation conditions of DG when distributed generation interconnect with distribution network. So it brings many fundamental changes to active distribution network protection and automation systems. Therefore, this paper proposes unified-sampling calibration method in which data of all the interconnected feeders in supply area is collected. Without changing the original network topology, the concept of "directed graph" is introduced to carry out of current direction calibration.

Based on the above analysis, this paper proposed an active distribution network power supply area as a smallest research unit, which may contain two or more feeders interconnect with each other through tie-switch and also interconnect with DG. Within this study unit, first select any one of feeder outlet switch sampling direction as a reference direction, that power flow from substation which this feeder belongs to into this feeder is positive, power flow from this feeder into substation which this feeder belongs to is negative. So choose this feeder outlet switch is a multi-tree root and build the directed graph based on the root and the reference direction with topology. The process is shown as follows:

①Defined root node direction as positive direction. Start depth traversal algorithm from the root to the leaves;

② All remaining feeder outlet switches, loads and distributed generations define as the end leaf node of multi-tree.

③After traverse a node during depth traversal process, define direction which the node connect to root node is positive and the other direction is negative. If the node is a tie-switch, then put this node to the last place of this layer for depth traversal;

④If a new found node has been traversed or is a child node of the upper layer node during depth traversal process, then do nothing to this node and continue until depth traversal is finished.

SUPPLY AREA SAMPLING CALIBRATION METHOD FOR ACTIVE DISTRIBUTION NETWORK

FA is active by feeder outlet switch in substation is over-current during the fault is happen. Judge the current go through the switches is over-current or normal current or non-current as classification standard. The algorithm proposed unified-sampling calibration method to define positive direction in whole area, then the algorithm compare the current phase angle at the same time by using distributed communication and GPS. Current mutation and phase differential method is used to fault identification. The algorithm is shown as follows:

① According to the current amplitude mutation, determined the switch is over-current status (whether positive current mutation is large), or normal operating status (whether positive current mutation is small), or non-current status (whether negative current mutation is large or current is almost equal to 0)

②Start distributed communication sequentially from the feeder outlet switch to an adjacent switch until to the end node. Each switch and its downstream neighbor switch is defined as belonging to the same region. When all the switches in the same region is non-current status, it can be determined that the region isn't fault area.

③When there is only one switch is over-current status in one area, and the remaining switches in this area are non-current status, it can be determined that this area is fault area.

④In all other cases, the region has at least one switch is over-current status and at least one switch is over-current status or normal current status and also N($N \geq 0$) switches is non-current status. First take any two switch is over-current status or the operating status. If their adjacent ends direction based on supply area sampling calibration method are one positive and one negative, then calculate the current phase angle difference between two switches. If their adjacent ends direction based on supply area sampling calibration method are two positives or two negatives, then set one current waveform multiplied by a factor -1 before calculate the current phase angle difference between two switches. If the current phase angle difference is equal to $0^{\circ} \pm \delta$, it can be determined that the region isn't fault area. Where δ refers to the actual error coefficient, set δ as 25 ° in consideration of the errors of GPS and other factors. Otherwise, when any two switches is over-current status or normal operation status does not meet the above requirements, it is judged that the region is fault area.

CASE STUDY

Based on the foregoing chapters, the algorithm proposed in this paper is applied to a practical application in China national demonstration area. The demonstration area is an interconnection power region formed by the five feeders. The basic frame of demonstration area using the sampling calibration method is as follows:

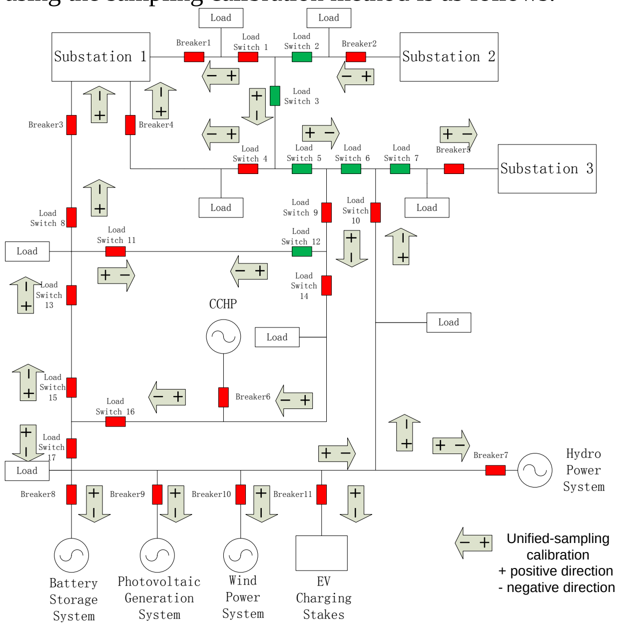

Fig.3: Unified-sampling calibration method used in the schematic diagram of the National demonstration zone in the 863 Program

In this paper, RTDS software is used in simulation for the example. Since the simulation software node limit, the above example can be simplified only retained 11 key switch nodes with using the proposed algorithm combination of current mutation and phase differential. Brk1, Brk2 and Brk10 are feeder outlet switches. Point of fault is in the middle of three distributed generations, also known as the line which between Brk4, Brk6, Brk7, Brk11. The schematic diagram and the results are as follows:

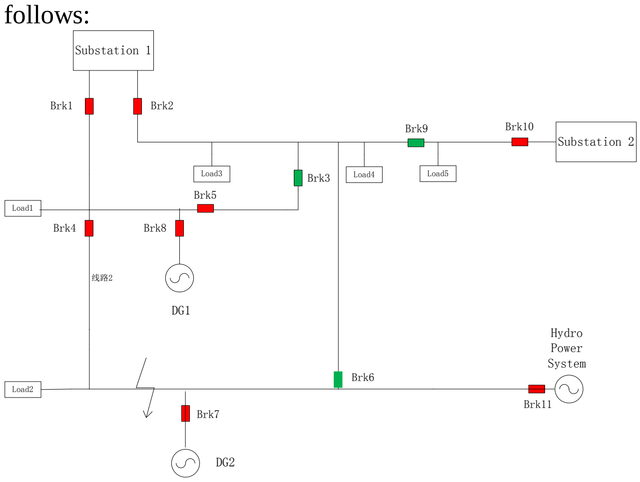

Fig.4: Simplified schematic diagram of the National demonstration zone in the 863 Program

According RTDS simulation results, when the fault occurs, three distributed generations and the main power supply from the substation convey the current to the point of failure. That causes Brk1, Brk4, Brk11 over-current. So Brk1, the outlet switch, starts FA. Each switch will transmit the fault current waveform at the same time through GPS to each other by the way of distributed communication according to the proposed algorithm. Finally, Brk4, Brk7 and Brk11 will be switch off at 1.455s, 1.053s and 1.126s to isolate the fault. Therefore, the proposed algorithm can correctly solve the actual distribution network fault isolation process.

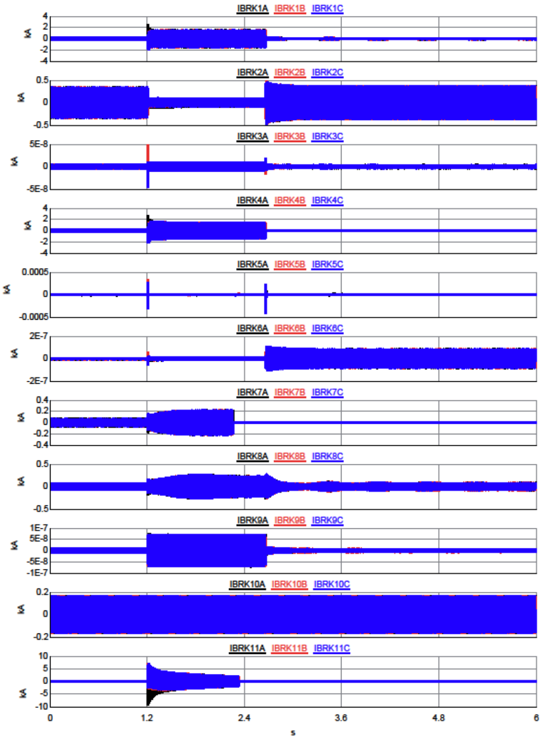

Fig.5: Switch current waveform in RTDS

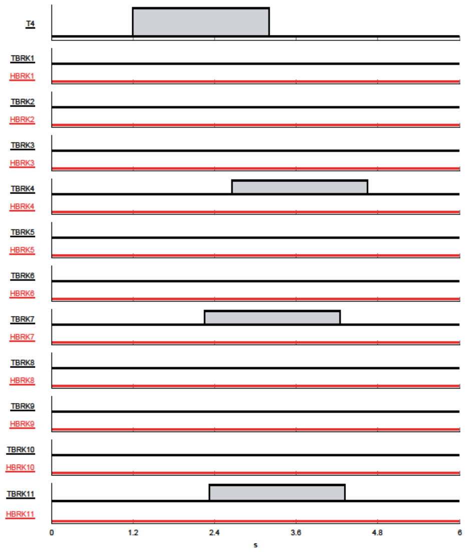

Fig.6: Switch tripping time result in RTDS

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