A fault recovery scheme cooperating with reclosing and LVRT for active distribution network

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Abstract. The integration of distributed generation brings great change to the operation mode of the distribution network, and higher requirements have also been set for the fault recovery scheme. Analysing the relationship between fault reclosing and voltage variation of the distributed generation in distribution network and considering the influence of reclosing on LVRT of DG, this paper proposes a new fault recovery scheme cooperating with reclosing and LVRT (low voltage ride through) for active distribution network. The planned isolated island area is divided in advance for each DG, and different fault recovery methods are implemented according to the different fault conditions of the fault location, the isolated island area and the voltage variation of the distributed generation. The feasibility and effectiveness of the proposed scheme are verified by simulation in PSCAD.

Keywords: active distribution network, fault recovery, pre-planned islanding, DG, voltage drop.

1. Preface
Power supply restoration is an important part of active distribution network fault handling, and it is also an important condition for realizing the self-healing of the distribution network [1]. In the context of a large number of distributed power sources, the distribution network puts forward higher requirements for power supply restoration [2-3]. At present, domestic and foreign researches have been carried out on the failure recovery of active distribution networks, and some solutions have been proposed. Literature [4] proposed a distributed protection scheme for active distribution network that combines anti-islanding protection, low voltage ride through and distributed feeder protection, but the scheme did not consider the failure of reclosing to cause DG to withdraw from operation. Literature [5] proposed a coordination scheme of photovoltaic power plant LVRT and front acceleration automatic reclosing. This scheme effectively avoids the failure of reclosing caused by DG providing fault current to the short-circuit point by setting the reclosing time. However, this method believes that the photovoltaic power station must be out of operation after a fault, and cannot play the positive role of DG's access to the system voltage support when the distribution network fails, and the reclosure time is too long, which affects the speed of fault recovery. Literature [6] divides the active distribution network into several regions that can operate in isolated islands. After the fault is isolated, the reclosing and islanding re-connection control schemes are designed, but the failure recovery scheme is not specifically analyzed.
and the reclosing pair is not considered. The influence of DG low voltage ride through. Literature [7] proposed a distributed feeder automatic protection scheme realized by a new network topology identification method. Literature [8-9] all proposed a fault recovery strategy combining distribution network reconstruction and islanding, but its reconstruction method generally considers limited conditions, and its practicability is limited. Literature [10] considers the operating characteristics of distributed power sources and proposes a distribution network protection scheme suitable for multi-DG access. However, the realization of its fault algorithm relies on PMU online calculation and needs to transmit a large amount of real-time information, so it requires data communication technology Higher.

The continuous development of communication technology and the continuous upgrading and transformation of the distribution network provide technical conditions for proposing new fault recovery methods [11]. According to the capacity of distributed power supply, this paper divides and plans the island area of DG in advance. When a fault occurs and is isolated, the smart terminal unit (STU) at the point of common coupling (PCC) detects the problem. Whether the DG still has a complete planned islanding area and the extent of the first reduction of the fault voltage, and chooses different power supply restoration schemes according to different situations, to realize the rapid power supply restoration of the active distribution network. Finally, PSCAD model simulation is used to verify the feasibility of the proposed scheme.

2. The impact of reclosing on low voltage ride through of distributed power sources

2.1. Low voltage ride through

In the early days when distributed power sources were connected to the distribution network, in order to eliminate the adverse effects of DG on the protection of the distribution network, the control device took the initiative to withdraw all DGs from operation when a fault occurred, so that the distribution network could restore the original passive radial network, so that the original protection can operate normally. However, as the penetration rate of DG increases, all removal of DG will not only fail to play the role of DG in voltage support during faults, but also may further aggravate the power imbalance of the power grid and affect the stable operation of the power grid [12-16]. Therefore, considering the safety and stability of the active distribution network, the power grid requires that after a fault occurs, if the voltage at the PCC drops within a certain range, that is, the conditions for low voltage ride through are met, the DG should be kept connected to the grid for a period of time. Time and continue to provide reactive support [17-18]. The requirements for low voltage ride through conditions are shown in Figure 1. Generally, for photovoltaic power plants or wind farms, T1 is 0.625s, and T2 is 2s [19-20].

![Figure 1. Requirements for LVRT conditions](image)

As shown in Figure 1, if the voltage at the PCC of the distributed power supply remains above the solid line, the DG will remain connected to the grid. Once the voltage at the PCC drops below the solid line, the protection will cut off the DG and exit operation.

For the fault recovery of the active distribution network, the current relevant research schemes focus on the optimization of the network reconstruction algorithm, and seldom consider the impact of
reclosing on the low voltage ride through of distributed power generation. When the fault occurrence area is determined, the corresponding switch trips to isolate the fault, and after a period of time, the switch near the power supply side performs reclosing operation. Generally speaking, during the reclosing period, some distributed power sources are also in the process of low voltage ride through. If the reclosing is due to a permanent fault, the voltage at the PCC of some distributed power sources will dip a second time and fall below the low voltage ride through requirement curve shown in Figure 1, these distributed power sources will be out of operation, which will affect the power distribution network. Stable operation has a great impact. It should be noted that not all the low voltage ride through process of distributed power sources will be affected by the reclosing operation. The different fault occurrence locations have different effects on the low voltage ride through of distributed power sources, the following will introduce the impact of reclosing on DG under different fault sections.

2.2. The impact of reclosing on DG under different fault sections

2.2.1. The fault occurred in the feeder connected to the distributed power supply. The premise of the analysis in this paper is that all feeder switches in the active distribution network are circuit breakers, each switch is equipped with STUs, and the STUs are connected to the network through EPON (Ethernet Passive Optical Network). Realize peer-to-peer communication, and STU itself can complete information processing and control decisions. As shown in Figure 2, under normal operation, the tie switch KLL is in the open state, and the circuit breakers on the other feeders are in the closed state. When a fault occurs at F2, buses 1, 2, 3, 4, 5, and 6 feel the voltage drop for the first time. The STU at switches K5 and K6 detects that the fault is located in this area and sends a "trip" command to switch K5, K6 trips to isolate the fault. After about 0.8s, the switch K5 closes to the power side and recloses. If the fault is a transient fault, the recloser is successful and the switch K6 is notified to close. The tie switch always maintains the "open" state, and the line returns to normal run. If the fault is a permanent fault, the switch K5 will fail to reclose, and the voltage of buses 1, 2, 3, 4 will drop twice.

![Figure 2. System structure diagram of active distribution network](image)

For DG1, the fault occurs on its downstream side. If a permanent fault occurs, the bus 4 connected to DG1 has two voltage drops. If the fault is serious, the voltage of the bus 4 may not meet DG1 during the second drop. Under the low voltage ride-through condition, switch K9 trips and exits DG1 operation.

For DG2, the fault occurs on the upstream side. Since the remote power side switch K6 is in the "open" state, the success of the recloser of the near power side switch K5 does not affect the voltage of the busbar at DG2, so there will be no reclosure failure. DG exits from operation.

2.2.2. The fault occurred in the adjacent feeder of the distributed power generation. As shown in Figure 2, when a fault occurs at F1, buses 1, 2, 3, 4, 5, and 6 feel the voltage drop for the first time, switches
K1 and K2 trip to isolate the fault, and then close to the power side switch K1 to reclose. If the fault is a transient fault, the reclosing is successful, the switch K2 is notified to close, the tie switch always maintains the "open" state, and the line resumes normal operation; if a permanent fault occurs, the reclosing fails, and the switch K1 trips again. Open, the voltage of bus 1, 3, 4, 5, 6 drops twice. For DG1 and DG2, the faults occur in the adjacent feeder, here only the influence of the fault on DG1 is analysed. Since DG1 is adjacent to the faulty line, the coincidence of switch K1 on the fault causes another shock to the voltage at the bus bar connected to DG1, causing the voltage to drop twice. If the line distance between fault F1 and DG1 is short or faulty If the situation is serious, the voltage at DG1 may not meet the low voltage ride through condition and DG1 will be removed.

To sum up, in the active distribution network, when the recloser is in a permanent fault, the positional relationship between the fault occurrence section and the distributed power supply and the extent to which the voltage drops at the bus bar connected to the distributed power supply will be affected by the fault. It has a great impact on the low voltage ride through of distributed power sources. At present, in the related research of active distribution network fault recovery scheme, few consider the impact of reclosing on the low voltage ride through of distributed power generation. However, reclosing may cause the low voltage ride-through failure of distributed power generation, which will cause DG to exit operation and reduce the efficiency of DG power generation. This article considers this impact and combines the anti-islanding protection to propose different power supply restoration schemes for different fault situations.

3. Power restoration plan

3.1. Island division

For each distributed power source in the active distribution network, this article divides it into a number of appropriate planned island areas according to the capacity of the distributed power source and feeder load. The so-called planning island refers to that after the fault is isolated, if the power-loss load in the non-faulty area is not connected to the main power source, but there is a path connected to the distributed power source, and the distributed power source has stable output capacity, the plan can be considered at this time the island realizes power restoration.

Taking DG1 in Figure 2 as an example, it can be divided into planned island areas as shown by the dashed box in Figure 3 according to load capacity. It is known that the load capacity of buses 2, 4, 5, and 6 in Fig. 3 are all 2MW, and the power of distributed power sources DG1 and DG2 are both 2MW. When a permanent fault occurs in F2, switches K5 and K6 are tripped to isolate the fault. In order to prevent DG1 from exiting operation due to the reclose of switch K5, actively disconnecting switches K3 and K4 can make DG1 run in islands as planned. DG1 is in bus 4 Load power supply. In the same way, when F1 has a permanent failure, when the planned islanding condition is established, the switches K3, K4, K5 and K6 are actively disconnected to make DG1 islanding operation as planned.

![Figure 3. The planned island area of DG1](image-url)
3.2. Voltage detection

When a fault occurs, the voltage at the PCC of the distributed power supply will decrease, and the voltage at the PCC will gradually increase as the distributed power supply outputs reactive power. If there is a complete path between the distributed power supply and the switch near the power supply side of the faulted section, reclosing to a permanent fault will cause a secondary voltage drop. As shown in Figure 1, take T1 as 0.625s and T2 as 2s, then the coordinates of point M are (0.625,0.2), the coordinates of point N are (2,0.9), the slope of the straight-line MN is 0.509, when the reclosing time is 0.8 At s, the point coordinates on the corresponding line segment MN are (0.8, 0.41). Assuming that the two voltage drops have the same depth, considering leaving a certain margin, the calculated critical value is changed from 41% of the rated voltage to 50%. If the first voltage drops below 50% of the rated voltage, the second voltage drop will cause the distributed power supply to exit operation due to low voltage ride through failure; if the voltage at the PCC drops to more than 50% of the rated voltage, it is considered the first the secondary voltage drop will not cause the low voltage ride through failure.

3.3. Scheme process

This paper divides different planned island areas for each DG according to the distributed power and load capacity in advance. When a fault occurs, the fault section is determined by comparing the current amplitudes on both sides of the line. If the fault section is on the downstream side of the DG or on the adjacent feeder, the network topology obtained by the information exchange between the STU at the PCC of the distributed power supply and other STUs on the feeder is used to detect whether each DG still has a complete Plan the island area. Based on the above detection results, different failure recovery schemes were designed according to the following two situations.

If the fault section is on the downstream side of the DG or on the adjacent feeder, and the planned islanding area of the related DG is not damaged due to the feeder switch tripping, that is, there is still a complete planned islanding area, the voltage change at the PCC is detected. If the voltage drops for the first time When the rated voltage is less than 50%, the corresponding circuit breaker will be actively disconnected to achieve planned island operation. After the contact switch is closed, the power supply will be restored in the non-faulty power loss area, and the DG will be connected to the grid at the same time to restore the normal operation of the entire distribution network. If the voltage at the PCC drops to more than 50% of the rated voltage for the first time, the traditional reclosing operation is performed. As shown in Figure 3, if a permanent fault occurs in F2, switches K5 and K6 are tripped to isolate the fault. Since the fault section is on the downstream side of DG1 and the planned islanding area is complete, if it is detected that the voltage at PCC1 drops to the rated value for the first time If the voltage is below 50%, the switches K3 and K4 are actively disconnected, so that DG1 is islanded as planned, and the switch K5 no longer performs reclosing operation, which effectively saves the fault recovery time. Then the tie switch is closed, the feeder power supply is restored, and DG1 is connected to the grid at the same time to restore the normal operation of the active distribution network. If the voltage at the PCC drops to more than 50% of the rated voltage for the first time, the power supply to the non-faulty power-loss section is restored by closing the tie switch KLL.

If the faulted section is on the upstream side of the DG or the DG does not have a complete planned islanding area, follow the traditional reclosing operation for fault recovery. The specific failure recovery program flowchart is shown in Figure 4.
Pre-division of planned island areas

Detect fault occurrence section

Does the fault occur on the downstream side of the DG or on the adjacent feeder?

Yes

Is there a complete island area?

No

The voltage at PCC drops below 50% for the first time \( U_n \)?

No

Follow the traditional reclosing procedure to restore power supply

Yes

Actively disconnect the corresponding switch, realize planned island operation

Close the tie switch to restore the feeder fault

Grid-connected DG planned for island operation at the same time

Distribution network failure recovery completed

Figure 4. Flow diagram of the fault recovery scheme

4. Organization of the Text

4.1. Model establishment

| Table 1. System parameters |
|-----------------------------|
| element | project parameter |
| System power | Voltage 10kV |
| | impedance \( 1\angle 80^\circ \) |
| DG 1,2 | Types Inverter type |
| | Control Strategy PQcontrol |
| | power 2MW |
| | capacity 2MW |
| Load 1,2,3,4 | Power factor 0.9 |
This paper builds an active distribution network system model in PSCAD software [21], the system diagram is shown in Figure 2, and the model parameters are shown in Table 1 and Table 2.

### Table 2. Line parameters

| Impedance parameter      | Parameter                          |
|--------------------------|------------------------------------|
| Positive sequence impedance | $(0.17+0.34j)\Omega$              |
| Negative sequence impedance | $(0.17+0.34j)\Omega$              |
| Zero sequence impedance  | $(0.42+1.51j)\Omega$              |

| Line length | Section(①, ②, ③, ④) | 2km |

\[
c_2 = a_2 + b_2
\] (1)

### 4.2. Simulation verification of the impact of reclosing on DG

In order to verify the impact of reclosing on DG low voltage ride-through, this paper simulates the short-circuit fault and the fault recovery process in different locations of the distribution network. Compared with the motor type DG, the inverter type DG cannot provide voltage support after a fault, so the voltage drop at the grid connection point is greater. In order to simulate the most serious fault of voltage drop in the distribution network, the DG type selected in the simulation of this paper is the inverter type DG, and the fault type is a three-phase short-circuit fault.

As shown in Figure 2, a permanent fault occurs at F1. The fault occurs on the adjacent feeder of the feeder where DG1 is located. The solid line in Figure 5 represents the line voltage at PCC1 before and after the fault, and the dashed line is the low voltage ride through condition.

![Figure 5. Voltage change at PCC1 when permanent fault occurs at F1](image)

When a permanent fault occurs at F2, for DG1, the fault occurs on its downstream side. The solid line in Figure 6 represents the line voltage change curve at PCC1.

![Figure 6. Voltage change at PCC1 when permanent fault occurs at F2](image)

When a permanent fault occurs at F3, for DG1, the fault occurs on its upstream side. The solid line in Figure 7 represents the line voltage change curve at PCC1.
As shown in Figure 5, Figure 6 and Figure 7, the fault occurred at 0.3s, and the reclosing operation was performed after 0.8s. Comparing the above three figures, it can be found that when the fault occurs on the upstream side of DG1, the reclosing has little effect on the voltage at PCC1, and there will be no phenomenon that the voltage does not meet the low voltage ride through conditions. However, when the fault occurs on the downstream side of DG1 or the adjacent feeder, the failure of reclosing will cause the voltage at PCC1 to drop twice, which may cause the DG to be removed without satisfying the low voltage ride-through. Therefore, when a fault occurs on the downstream side of the distributed power source or adjacent feeders, and the voltage at the PCC drops below 50% of the rated voltage due to the fault for the first time, it is considered that the failure of reclosing will cause the DG to exit operation, so it is actively disconnected. The circuit breakers are operated on islands according to the pre-divided plan, and after the feeder fault is restored, they will be connected to the grid at the same time.

4.3. Simulation verification of failure recovery scheme

In order to verify that DG may exit operation when the fault is more serious, this paper simulates a permanent fault 100m downstream of DG1 in section ③. The fault type is a three-phase short circuit. The voltage change at the PCC of DG1 is shown in Figure 8. And shown in Figure 9.

As shown by the solid line in Figure 8, a fault occurs at 0.3s, and the voltage drops below 50% of the rated voltage. At about 1.1s, the switch on the near-power side performs reclosing operation according to the traditional reclosing strategy. Because it is a permanent fault, the reclosing fails, the voltage drops twice, and the low voltage ride through condition requirements are no longer met, the circuit breaker K9 at PCC1 trips, and DG1 exits operation.

The fault section of the above fault conditions is on the downstream side of DG1. For DG1, there is a complete planned islanding area, and the voltage at the PCC of DG1 drops below 50% of the rated voltage for the first time. According to the solution proposed in this article, after the fault is isolated, switches K3 and K4 should be opened to form a planned island area. When the contact switch is closed, the power supply is restored in the non-faulty power-loss section ④, and DG1 is connected to the grid.
again. According to the above power recovery strategy, the voltage change at PCC1 is shown in Figure 9.

![Figure 9](image)

**Figure 9.** Voltage changes at PCC1 in the proposed scheme simulation

Comparing Figure 8 and Figure 9, it is found that in the new fault recovery scheme proposed in this article, the voltage is no longer lowered twice, and DG1 maintains grid-connected operation. Therefore, the proposed fault recovery scheme is effective and feasible.

5. Conclusion

By analyzing the low voltage ride-through conditions of distributed power sources and the influence of reclosing on the voltage at PCC, this paper proposes a new active distribution network fault recovery scheme. This plan divides the distributed power generation plan into island areas in advance. After a fault occurs, if the voltage at the PCC of a DG drops below 50% of the rated voltage for the first time, and the fault zone is located on the downstream side of the DG or the feeder connected to the DG, adjacent feeders enable the DG to operate according to the planned island area, avoiding the DG exiting operation due to reclosing during the fault recovery process, and improving the utilization efficiency of distributed power. Through the simulation test in PSCAD software, this paper verifies the feasibility of the proposed scheme.

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