Local feeder automation under mode of customer power supply priority

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Abstract. The local feeder automation method (LFA) is applied in the single side power distribution system. The protection and re-closing of substation outgoing line are used to coordinate with the time limit characteristics of voltage-time type switch to isolate fault and recover power supply automatically. The access of small hydro-power (SH) makes the distribution system present multi power pattern. In this paper, based on LFA considering SH access, in order to achieve the goal that SH can operate in isolated network with load after fault, LFA under the mode of customer power supply priority (LFAUP) with adaptive opening time for switch is proposed. When the fault point is located on the grid side of the quasi power balance switch (QPBS) and the isolated network is on its load side, the switch can automatically isolate all types of short circuit fault from the load side without residual voltage locking (also known as X locking). When the power of the isolated network is balanced, the loads in which will not get power failure. Simulation results show LFAUP advanced in the paper is correct and feasible.

1. Introduction
LFA can improve power supply reliability, reduce blackout area and be of significance to shorten the outage time [1,2]. Due to the advantages of simple and reliable logic, independent of communication and low construction cost, LFA has been widely used in the domestic overhead-line distribution automation. However, when the distributed power supply such as SH is connected, LFA will be affected [3], for which, the current treatment method is that the voltage and frequency protection will act to cut off the SH after the fault occurs, and then the system outside the SH will be isolated from the fault and restored to power supply according to LFA.

In reference [4], an adaptive re-closing feeder automation (FA) method considering single-phase to ground fault processing is proposed, but the access of SH is not considered. In reference [5], aiming at the difficulty of fault section location in distribution network with distributed generation (DG), a fault section location algorithm based on sub network partition is proposed. In reference [6], aiming at the fault location and isolation technology of FA with high-density DG, a fault location scheme based on distributed intelligent FA system is constructed. Reference [7] studies the fault handling method of adaptive LFA based on regional serial number, references [8,9] use anti islanding protection for inverter DG connected to feeders; while reference [10] studies distributed feeder automation. It can be seen that there is no literature that combines fault isolation of FA with isolated network operation with SH with load.
Based on the existing LFA, in order to achieve the goal that SH keeps running in isolated network with load after fault, LFAUP is proposed in this paper. When the fault occurs at some position, the fault can be isolated automatically from the load side of the fault spot (the side close to CB1 is called the grid side, and the other side is called the load side) by using the delay time adaptive to the switch number to open switch, without need of residual voltage locking. When the power of the load side is balanced, the SH in this side can operate in an isolated network with load, and users would not lose power.

2. Introduction of existing LFA methods considering SH access

Figure 1 shows the connection diagram of feeder numbering 1 of 10kV small current grounding system substation. CB1 is the circuit breaker of substation, FS11, FS12, FS13, FS14 line section switches (FS represents the section switch in the paper), LD11, LD12, LD13, LD14 equivalent loads, and FSDG is disconnecting switch installed at low-voltage side of SH step-up transformer, DG is small hydro-power equivalent synchronous generator. In this paper, FS and FSDG both use circuit breakers, which can break the short-circuit current.

Taking the permanent phase-phase short circuit fault as an example, the existing LFA with SH’s access is illustrated. In case of the fault in Figure 1, the current fast-tripping protection of substation acts on switching off CB1, and voltage-frequency protection to open FSDG, and then each section switch opens with loss of power. With CB1 re-closed the first time, FS11 is closed after X delay time getting voltage with CB1’s re-closing, the same way FS12 closed, then current fast-tripping protection operates again within FS12’s Y time limit, next FS11 and FS12 open, and for FS12 the closing, with getting power from the substation side, is locked. FS13 detects residual voltage within X time limit to block closing with getting the reverse incoming power. So the fault is isolated by FS12 and FS13. The CB1’s second re-closing restores the power supply at the FS12’s power grid side; the FS13’s load side may be powered on by the contact switch (if any); SH is re-integrated into the grid at the appropriate time.

By the foregoing, this present method does not consider that SH can operate in isolated network with load after fault isolation, so it is suitable for the system without SH or with weak ability of frequency regulation and voltage regulation, and voltage frequency protection is not utilized effectively for FSDG to reflect the power balance of isolated network operation, the section switch can cut off the short-circuit current used in the paper, which is consistent with the site conditions of power grid in some district; the actual capacity of frequency regulation and voltage regulation of SH stations is gradually improved. Considering the shortcomings of the present LFA with SH access and the feasibility of its improvement, the paper puts forward LFAUP.

3. Action logic of FS and FSDG’s controller

Multi power distribution system is formed with SH connected to feeder. In case of feeder fault, in order to realize the principle of power supply priority for users, LFA should be able to isolate the fault after the substation outgoing circuit breaker trips, so that SH with voltage and frequency regulating ability can power load to form an isolated network; when SH does not have the ability or the ability is weak, it should be automatically converted to the current LFA.

This part gives the action logic of FS and FSDG’s controller for LFAUP, and explains the logic by single-phase grounding fault and phase to phase fault. On the premise of local reactive power balanced
and voltage regulation capability possessed by SH, there is not need for FS to detect the magnitude and direction of reactive power.

3.1. Action logic of FS and FSDG’s controller

FS’s logic is shown in Figure 2 and FSDG’s Figure 3.

In Figure 2 and Figure 3, \( U_0 \) is to detect whether the zero sequence voltage is greater than the setting value; \( i_\phi \) is to detect whether the phase current is greater than the setting value; \( Q_{FS} = 1 \) indicates that the reactive power direction points from the line points to the bus bar of the substation; \( P_{FS} = 1 \) shows the active direction is from the bus bar to the line and \( P_{FS} = 1 \) reversed; \( P_{FS} \) is that the active power \( P_{FS} \) passing through FS is less than the allowable value \( P_{ym} \), with \( P_{FS} = 1 \); \( |P_{FS}| \) is that the absolute value of the active power \( P_{FS} \) is less than \( P_{ym} \), with \( P_{FS} = 1 \). When FS is with \( P_{FS} = 1 \) or \( P_{FS} = -1 \), it is called quasi power balance switch (QPBS). The time \( t \) refers to the sum of action time of small current line selection device and CB1 tripping time or the sum of current quick break protection and CB1 tripping time. 0.1\( x_{i,2} \) is a delay with adaptive change of section switch added on the basis of \( T \), with \( x_{i,2} \) the second part of a feeder switch number. In this paper, FS’s number is required to be represented by two parts. The first part is the number of the feeder, and the second is numbered by sequence beginning from the grid side, for FS adjacent to CB1 which is 1. According to the delay related to the number, FS11 will delay \( (t + 0.1) \) s to open and FS12 to delay \( (t + 0.2) \) s to open; \( U_0 \) is to detect whether the zero sequence voltage is less than the setting value; \( i_\rho \) is to detect whether the phase voltage is greater than the setting value; \( f \) or \( f' \) is whether the detection frequency is greater than or less than the setting value; \( x_{j,2} \) is the second part of the number of FS which is at the grid side of SH’s access point on the feeder.

**Figure 2.** Action logic of FS’s controller.

**Figure 3.** Action logic of FSDG’s controller.
3.2. Single phase ground fault

In Figure 2, the switch is to open with some delay when the switch is closed, with the zero sequence voltage greater than the setting value and \( P_{FS} \) less than the allowable value \( P_{yun} \) with \( P_{FS} = 1 \), or the absolute value of \( P_{FS} \) is less than the allowable value \( P_{yun} \) with \( P_{FS} = 1 \). The magnitude and direction of active power are stored instantaneously before fault.

The opening of FS is equivalent to the sudden increase of load at SH’s side in the case with \( P_{FS} = 1 \), and SH shall increase its output. If the increased load is within the reserve capacity of SH (if any), the active power output will increase after the primary frequency regulation of SH’s governor (without considering the frequency regulation effect of load), and the frequency drop will be within the allowable range. The simulated load model uses constant power model without the effect of active power frequency regulation with which the qualitative analysis of the improved method will not be affected, because the actual comprehensive load regulation effect is relatively small. In this paper, \( P_{yun} \) is taken as 0.1 times of the rated capacity and \( \delta = 0.05 \), with \( \delta \) adjustment coefficient of SH governor. According to the primary frequency regulation effect \( \Delta f = \delta \cdot \Delta P \cdot 50 \), so is \( \Delta f = -0.25Hz \), then the protection in Figure 3 at FSDG does not act.

When the absolute value of \( P_{FS} \) is less than \( P_{yun} \) with \( P_{FS} = 1 \), the protection at FSDG will not act with FS opened. This situation is equivalent to the sudden reduction of the load for SH side, and SH should reduce the output. If the reduced load is within the adjustable capacity of SH, the active power output will be reduced and the frequency rise will be within the allowable range after the primary frequency regulation of the SH governor. Here, the frequency protection is allowed to offset up to 1Hz, with SH rated capacity \( S_G = 2MVA \) and \( \Delta P = (\delta / \Delta f) \cdot S_G \) according to the primary frequency modulation effect, so \( P_{yun} = 0.8MVA \).

The delay opening time of FS should match with \( t \). The line selection device acts on the outgoing circuit breaker to jump off the fault line and the zero sequence voltage of the line under the action of SH is still greater than the setting value, indicating that it is a fault line, then FS can be opened with some condition. If FS’s opening does not cooperate with \( t \), FS on the non-fault line may also be opened, which will expand the fault range. There may be more QPBS than one on the fault line. As shown in Figure 1, LD11 and LD12 will lose power, and the isolated network will suffer the impact of losing two comprehensive loads at the same time when FS11, FS12 and FS13 all are QPBS with the same time delay. In order to avoid the similar adverse situation, a delay with adaptive change for FS is added on the basis of \( t \) to avoid the simultaneous opening.

After FS13 is opened, the zero sequence voltage on the load side of FS13 is reduced to below the setting value, and the reverse incoming power blocking closing is carried out, and the SH side is isolated from the fault point so SH can operate in an isolated network with the voltage and frequency protection does not act in Figure 3.

The improved method is applicable to the case that the fault point is located on the grid side of QPBS while the SH is on its load side. If the switches fail to meet the applicable conditions, According to Figure 3, FSDG will be opened with delay and the improved method advanced in the paper automatically changes to the existing feeder automation method.

3.3. Phase to phase short circuit fault

In Figure 2, the setting value of \( I_p \) current protection should reliably avoid the maximum current through FS provided by SH, which corresponds to that the load on the feeder connected to SH is 0, and all output of SH is sent to the power grid except the loss of lines and transformers.

The judgment of active power and direction is the same as that of single-phase grounding fault. Here \( t \) refers to the time for the current protection action of substation to trip the outgoing circuit breaker, which is different from the action of line selection device in case of single-phase ground fault.
After FS’s opening, if the voltage on the load side of FS returns to normal, its closing will be locked with the reverse power coming. With voltage frequency protection in Figure 3 not operating, SH can operate in isolated network with load.

4. Simulation and analysis

4.1. Single phase ground fault

In Figure 1, SH’s rated capacity is 2MVA, power generated is 1.7MW, total load of feeder 1 is 2MW, LD11 = 0.3MW, LD12 = 0.1MW, LD13 = 1MW, LD14 = 0.6MW, and reactive power of each load is taken as 0.1Mvar. FS12 and FS13 are QPBS.

Figure 4, CB1 is opened after 0.1s delay (in fact, this time is much longer than 0.1s) after fault; FS12 is opened after 0.2ms delay after CB1 is opened; FS13 is opened after FS12 is opened with 0.1ms delay, then fault is isolated from FS13’s load side, SH keeps running in isolated network mode with load not losing power and FSDG not opened.

Figure 5, after FS12 is opened, zero sequence voltage on load side of FS11, 3U0_FS11, disappears; after FS13 is opened, zero sequence voltage on load side of FS12, FS13 and FS14, 3U0_FS11, 3U0_FS13, 3U0_FS14 disappears.

Figure 6 shows that the frequency will be stabilized at a value slightly lower than the rated frequency, about 49.964 Hz; from Figure 7, it can be seen that the output active power of SH is about 1.73MW. The frequency decreases, the output active power increases, and the primary frequency modulation is realized. The load model is a fixed power model, which is independent of frequency in static state. Most of the actual system load is asynchronous motor, which can participate in frequency regulation, and the actual frequency drop will be slightly less than the value in Figure 6.

Figure 4. Action sequence diagram of FS on feeder 1.

Figure 5. Zero sequence voltage at load side of FS.
4.2. Phase to phase short circuit fault

Similar to 5.1 fault conditions, FS12 and FS13 all are QPBS. Only FS13 can meet the requirements that the phase current is greater than the setting value and the reactive power direction is from the line to the bus. According to Figure 8, after CB1 is opened, FS13 will delay 0.3s to open, isolating the fault from the load side, and SH will operate in an isolated network with load.

According to Figure 9, after CB1 is opened, FS11 and FS12 currents decrease significantly, and the fault current through FS13 supplied by SH decreases significantly after FS13 is opened.

The fault is isolated from the load side with FS13 opened, and SH operates in an isolated network with load. After the isolated network frequency and SH output active power are stable, they are the same as those in Figure 6 and Figure 7, which are not listed here.

Figure 8. Action sequence diagram of FS on feeder 1.

Figure 9. Three phase current of FS.
4.3. Summary
It can be seen from 5.1 and 5.2 that the logic in Figure 2 and Figure 3 is applicable to various fault types. When the fault point is located at the side of QPBS’s power grid and the isolated network is on its load side, the fault can be isolated from the load side, so that the isolated network can operate stably after being separated from the main network, and the load in the isolated network will continue to get power, and SH will maintain power supplying.

5. Conclusion
Against the deficiency of existing LFA after SH access and in view of available conditions, this paper proposes LFAUP to improve the action logic of FS and FSDG, and advances that the time delay of switch action should match with the time with which the substation small current line selection device or current quick break protection trips the outgoing circuit breaker, and the delay of FS is adaptive to its number, while the time delay of FSDG is coordinated with the delay of FS adjacent to the grid side of feeder’s point at which SH is joined. Simulation results show that the improved method is correct and effective.

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