Improved Method of Local Feeder Automation Considering Small Hydro-power Connection

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Abstract. With the access of small hydro-power stations (SHS), the distribution system presents a multiple power supply pattern, which has a negative impact on the original local feeder automation (LFA) which is suitable for single side power supply system. In view of this effect, the phase to phase short-circuit fault (PPF) and single-phase grounding fault (SPGF) are treated differently, and an improved LFA method (IMLFA) considering SHS’s access based on low-frequency load shedding (LFLS) and high-frequency generator tripping (HFGT) is proposed. In case of SPGF, the section switch (SSW) and the outgoing circuit breaker of the substation shall be opened in sequence, and the isolated network (IN) generated in the process can be operated stably by cooperating with LFLS or HFGT while the fault is preliminary isolated. The SSW and the breaker are added with the function of no-voltage detection and synchronization detection. In case of instantaneous fault, the power supply in the fault area can be restored after a series of operations, and the IN can be connected to the grid. If it is a permanent fault, the section switches (SSWs) around the fault area will be locked to close in order to isolate the fault effectively, and the IN, not separated by the fault area from the grid, can be connected to the grid. Analysis and simulation show that the method is correct and feasible.

Keywords: Small hydro-power; Distributed generation; Feeder automation.

1. Introduction

LFA is widely used in the construction of distribution network automation because it does not rely on communication with the master station and can realize fault isolation locally, with short fault processing time, low cost and reliable action. When SHS is connected, if it is not reliably disconnected after fault, it will cause breaker’s re-closing failure [1,2].

In case of fault of feeder with SHS, the current treatment method is to cut off all SHS before re-closing the breaker, and then implement LFA for single side power supply system. This method does not distinguish the severity between PPF and SPGF. For PPF, the fault should be isolated as soon as possible, while for SPGF the feeder can continue to operate with fault within a certain period of time; when SPGF occurs, it does not consider the ability of SHS to operate in an IN with load after disconnection from the main network, and the method is suitable for SHS access system with no or only weak frequency-voltage automatic regulation ability.

Small hydro-power unit (SHU) belongs to a kind of distributed generation (DG) with better generation regulation performance[3,4], but the adjustable capacity of SHU changes greatly[5]. The stable control of frequency can be realized through the control measures such as LFLS and HFGT[6], which can overcome the shortcomings of large changes in the adjustable capacity of SHU.
From the above, considering the characteristics of SPGF and the increase of the proportion of SHU with self-control ability, LFA not only needs to isolate the fault, but also let SHS operate in an IN with load, instead of cutting off all SHS before the re-closing of the breaker in the substation. Reference[7] proposed that if the IN can operate stably, it is necessary to adjust the voltage and frequency of which to connect with the main network, otherwise all the SHS will be disconnected, and according to the characteristics of SHS in wet and dry seasons in reference[8], the re-closing mode is adaptive selected, but the two methods are not combined with feeder automation; references [9,10] use anti-island protection for inverted DG connected to feeders; Reference[11] studies the fault handling method of adaptive LFA based on regional serial number, reference[12] distributed feeder automation, reference[13] security solutions for smart grid feeder automation data communication while reference[14] optimal implementation of feeder automation in medium voltage distribution networks and all the above literature do not study LFA with SHS access based on LFLS and HFGT.

Based on the existing LFA, in order to protect the rights and interests of users and hydro-power owners, and make more use of clean energy, considering the different effects of different fault types in small current grounding system, this paper proposes to treat PPF and SPGF differently. The PPF remains unchanged according to the existing method, IMLFA considering SHS access is proposed with the increase of the proportion of SHS with automatic regulation ability considered when SPGF occurs. The method is divided into two stages. The first stage is to generate the IN in the process of preliminary fault isolation, and the second is to restore the power supply in the fault area (transient fault) and the feeder is connected to the main network, or in the process of effectively isolating the fault (permanent fault), the adjacent isolated networks (if any) outside the fault area are connected, and the IN at the grid side of the fault area is incorporated into the main network. Analysis and simulation show that the method is correct and feasible.

2. Feeder Model

In figure 1, QF1 is the breaker on the feeder numbering 1 in the substation, which is equipped with the function of checking no-voltage and checking synchronization. QS11, QS12 and QS13 are the main line SSW, the first digit $x_1$ of the number $x$ is $1$ indicating feeder’s number, the second digit $x_2$ is the sequence number according to the distance from the substation with QS11 the nearest SSW. S1111, S1112, S1211 are the branch line SSW. Taking S1111 as an example, the first part of the number is the first two digits (11), which means that the branch is connected to the load side of QS11 (the side close to QF1 is called the grid side, and the other side is called the load side); the second part (the third digit, 1) refers to the first branch on which the SSW is, and the third part (the fourth digit, 1) is numbered in sequence according to the distance from QS11.

![Figure 1. Components connection diagram on feeder 1.](image1)

DG1 and DG2 are equivalent units of SHS, which are not on the same line with load. SDG1 is a splitting switch to disconnect DG1, and so is SDG2 to DG2. LD0, LD1, LD2 and LD3 are equivalent loads. QIN1211 contains SHU and load, and it can operate stably if its source and load is balanced after it is separated from the main network. In this paper, it is called quasi isolated network (QIN). In figure 1, in addition to the marked QIN, it can also be composed of different components. For example, all the components on the load side of QS11 constitute QIN11. When QS11 is switched off, QIN11 can operate stably with its source load balanced. Those between QS11 and QS12 can form QIN11-2. To facilitate the description, a quasi power balanced switch (QPBS) is defined. Reactive power is considered to balance locally, so it is not considered when defining QPBS. When $P_{SP} = 1$ and $P_{SP}$ is less
than the allowable value $P_{\text{ YunP}}$, or when $P_{S_1} = 1$ and the absolute value of $P_{\text{ YunP}}$ is less than the allowable value $P_{\text{ YunP}}$, the SSW is called QPBS in this paper. $P_{S_1} = 1$ indicates that the direction of active power $P_2$ flowing through the SSW is from the grid side to the load side; when $P_{S_1} = 1$ it is from the load side to the grid side. $P_{\text{ YunP}}$ is the loads, which are in the QIN on the load side of the SSW, connected to LFLS control, and $P_{\text{ YunP}}$ is all SHU’s capacity connected to high frequency splitting control in the same QIN. The magnitude and direction of active power are stored instantaneously before fault. In the paper, some or all SHU have the ability of automatic frequency and voltage regulation; when SHU is connected to the grid stably, it is controlled by fixed active power and reactive power, while in the IN which is under constant active power and constant voltage control.

3. Improved Method of Local Feeder Automation

3.1. The First Stage

3.1.1. Logic design principle with SSW closed. The logic design principles of SSW at closed position are as follows: 1. Opens with power loss; 2. For SPGF: (1) QPBS shall be judged before SSW’s opening; (2) Important loads shall be supplied continuously, while LFLS is required to maintain the balance between source and load, the sequence of load shedding shall be determined according to the degree of load’s importance, and the sequence of generator tripping shall be determined according to the regulating ability when SHU is required to be cut off; (3) Disconnecting spots shall be reduced in order to be easy to recover, so it is necessary to isolate the fault in a large area and then in a small area, that is, the sequence of trunk line first and then branch line.

3.1.2. Opening logic of SSW. See figure 2 for the work flow when the SSW is closed.

![Figure 2. Work flow with SSW closed.](image)

In figure 2, $U_L$ is the effective value of line voltage at the SSW, $|\Delta f|$ the frequency variation, $t_{\text{pro}}$ the longest possible opening time of QF1 for small current grounding line selection, and $U_0$ is the zero sequence voltage. When $U_L$ is less than the setting value, power loss is judged and the SSW opens; if the SSW is with power during SPGF on feeder, which is QPBS or not will be judged after delay $t_{\text{det}}$ after the opening of breaker; if the SSW is QPBS and $U_0$ greater than the setting value, the SSW will be opened; if not, after the delay $t_{\text{det}}$ when $U_0$ is greater than the setting value, it opens, with which is to avoid the delay of QPBS’s opening and give priority to the action of QPBS, and to prevent the failure of isolating fault in case of non QPBS for one SSW. For main line SSW there is
There are two situations of QF1 opening: if the active power flowing through QF1 before opening is small enough and so $|\Delta f|$ less than the setting value after opening, the IN at QF1’s load side can operate stably without LFLS or HFGT, then the delay is $t_{\text{del}} = t_{\text{pro}} + t_{\text{det}}$, for main line SSW $t_{\text{det}} = 0.5x_y$ and for branch line SSW $t_{\text{det}} = \max(0.5x_x + 0.5x_y);$ if the power is large, $|\Delta f|$ will be larger than the setting value after opening, and the detection of this change can be regarded as the instant of QF1 opening and the delay is $t_{\text{del}}$.

3.1.3. Access load to low frequency load shedding. When the load of the IN is greater than the generating capacity and $|\Delta f|$ greater than the setting value, LFLS is required to achieve the active power balance. The maximum power deficit is calculated according to the large load in the dry season[15], and then the frequency regulation effect of the load is considered to obtain the load $\Delta P_{\text{max},x}$ that should be connected to the LFLS[16]. When the power generation in the calculation area is 0, all loads in the area should be connected to LFLS. The calculation area is between two adjacent SSW or at the load side of line end SSW. When the actual access value of each area is greater than or equal to the $\Delta P_{\text{max},x}$, it is not necessary to detect whether $P_{\text{Sx}}$ with $P_{\text{Sx}} = 1$, is less than $P_{\text{yun},x}$ or not when judging QPBS. When the actual access value of load connected to LFLS is less than the sum of $\Delta P_{\text{max},x}$ in each calculation area on the load side of the SSW, $P_{\text{yun},x}$ is equal to the actual value, and the power with $P_{\text{Sx}} = 1$ is taken to judge whether the SSW is QPBS or not.

3.1.4. Splitting of small hydro-power stations. For the disconnection logic without considering the different treatment of fault types, refer to reference [2]. In this paper, it is proposed that PPF and SPGF should be treated differently in SHU’s splitting. In case of PPF, all units need to be connected to the splitting control and be disconnected in the IN. In case of SPGF, there is no need to split all SHU when the active power of the IN is surplus, the surplus can be balanced by the generating capacity controlled by splitting control, the reduced active power output by primary frequency regulation of SHS, and the increased load with load frequency regulation effect. When the active power of the IN is insufficient, and LFLS cannot restrain the frequency drop, so the SHS should cut off the generator at low frequency, and the starting frequency should be lower than the last level starting frequency of LFLS.

In order to unify the requirements of PPF and SPGF, splitting control should be installed in all SHS. The active power through switch is always less than that of SHU connected into splitting control with $P_{\text{Sx}} = 1$, it is not necessary to consider the situation when judging QPBS. For high frequency cut-off, the unit without automatic frequency regulation capability shall be cut off first. The SHU are classified according to the frequency regulation ability from no to strong, and the splitting starting frequency is set from low to high (all higher than the rated frequency).

3.2. The Second Stage

3.2.1. Logic design principle with SSW opened. In case of SPGF, due to the existence of IN, the SSW shall have the function of no voltage detection and synchronous re-closing detection. For transient fault, the power supply in fault area can be restored and paralleling operation with the main network can be realized. For permanent fault, the area of grid side from the fault and the power grid shall be operated in parallel, and the non grid side shall be supplied by SHS or the other grid source by closing connect-switch.

3.2.2. Closing logic of SSW. Figure 3 shows the logic when the SSW is opened. X is the closing time of SSW being with power after opening, and Y is the SSW closing confirmation time [17]. According
to the IMLFA in this paper, either side of the opened SSW can be electrified, as shown for QS12 and QS13 in figure 1, in some cases, both of them may be closed at the same time with checking no-voltage for QS12’s load side and QS13’s grid side and so to cause impact. Therefore, the X cannot be taken as the same value. In this paper, the method of correlating X with switch number, in reference [11], is adopted. The value of X is $T_x = T_{ab} + T_\alpha$ and the base value $T_{ab}$ are determined according to the principle of X coordination of single side power supply system in reference [17], seen in figure 4. $T_\alpha$ is related to SSW number, in this paper, $T_\alpha = x_2$ for the main line SSW and $T_\alpha = x_3$ for the branch line, and X is shown in figure 5. The time unit is second ‘s’ in figure 4 and 5. The coordination is also applicable to single side power system.

Figure 4. X coordination of single side power supply system.

As shown in figure 3, when there is no fault and the SSW is at the opened position, if either side has power supply ($U_{i1}$) shows one side $U_{i1}$ is greater than the setting value) and lasts for X (if less than X, it will be locked to close), and when the voltage on the other side $U_{i2}$ is greater than the setting value ($U_{i2}$), if not, check no-voltage to close), after $t_{de3}$ the SSW will check synchronization to close. If a fault is detected within Y time limit (PPF is with voltage loss and SPGF is with $U_0$ greater than the setting value), the SSW will be opened and locked to close. Paralleling operation of adjacent isolated power networks can be realized by checking no voltage or checking synchronization (secondary frequency regulation can be used to make SHS tend to the same angular frequency). In order to avoid the synchronous closing of two SSWs at the same time, the time delay $t_{de3}$ is set. Here, $t_{de3} = 20x_2$ for the main SSW, and $t_{de3} = 20x_3 + \max(20x_1)$ for the branch SSW.

4. Simulation and Analysis

Feeder 1 is as shown in figure 1, on which is a permanent SPGF point.

In figure 1, the first re-closing time of QF1 is 2s. QIN1211 contains a small hydro-power equivalent unit and an equivalent load. LD0 is 2.1MW (not connected with LFLS), LD3 is 0.91MW (fully connected with LFLS); LD1 is 6.01MW, LD2 is 2.71MW, load is 3.61MW in QIN1211, and for the three loads that connected to LFLS all are 0.91MW. The terminal voltage of SHS is 0.4kV, and it is connected to 10kV feeder through step-up transformer. The rated capacity of each equivalent unit is 5MVA. The active power controlling target is 1pu and the reactive power is 0pu. After simple calculation, except for S1111 and S1211, all SSWs are QPBS.

The simulating results are shown in figure 6, figure 7 and figure 8 with the horizontal coordinate-axis time and the unit second ‘s’. Figure 6 is Sequence diagram of opening and closing of breaker and SSWs. Figure 7 is zero sequence voltage, with unit kV, at load side of each SSW. Figure 8 is angular frequency of each small hydro-power unit with per-unit value.

QF1 opens at 310s, and closes at 312.5s checking no voltage (QS11 is 310.5s opening, QF1 first re-closing time is 2s) in figure 6; QS11 opens at 310.5s, and its closing is at 357.4s with checking synchronization in figure 6. In the figure 8, wDG2 starts to oscillate, and QIN1111 where DG2 is located is connected to the main network; QS12 opens at 311s (S1111 and S1112 do not open with isolating fault by QS12’s opening zero sequence voltages, U011FR, U01111FR, U01112FR on the load side of QS11, S1111 and S1112 in the figure 7, are reduced to 0), and checks for no-voltage closing at 320s;
S1211 opens at 312s (U01211FR drops to 0 in figure 7), and check synchronization closing at 405s, w1211 starts to oscillate in the figure 8, QIN1211 is connected to the main network. QS13 opens at 314s (zero sequence voltage U012FR of QS12 load side drops to 0 in figure 7). After QS12 is switched on at 320s, QS13 delays for 10s, checks no voltage closing at 330s, and opens immediately when closing to fault. Voltage pulse is generated except U01211FR in figure 7. SDG1 opens at 318s by HFGT with wDG1 increasing shown in figure 8 and then QS13 load side zero sequence voltage U013FR drops to 0.

From the above analysis, IMLFA advanced in the paper is correct and feasible.

Figure 6. Sequence diagram of opening and closing of breaker and SSWs.

Figure 7. Zero sequence voltage at load side of each SSW.

Figure 8. Angular frequency of each small hydro-power unit.

5. Conclusion
Aiming at the small current grounding system with SHS access, this paper proposes to treat the PPF and SPGF separately, and gives the work logic of opening and closing of SSW comprehensively considering different fault types, and puts forward that SHU should be separated step by step according to the regulation ability corresponding to different starting frequency with power’s surplus while done at the lower one than that of LFLS with insufficient power, and IMLFA with cooperation of outgoing circuit breaker, SSW, LFLS and HFGT, is given. The analysis process shows that the method has strong adaptability to feeder connection mode, and to different distribution of SHS and loads. It can solve the problems of single-phase grounding fault isolation and keep power of load to some extent in IN after breaker’s opening while all the loads will lose power and all the SHS be
disconnected for a short or a longer term because of PPF or SPGF for the current method. IMLFA protects the rights and interests of users and hydro-power owners better and make more use of clean energy while its shortcoming is to add the complexity of control of breaker and SSWs to some extent. The simulation results show that IMLFA is correct and feasible.

References

[1] SONG Xiaodong. Research on the Effect and Countermeasures of Inverter Distributed Power Supply on Feeder Automation(D). Shandong: Shandong University of Technology, 2018

[2] CHEN Zhifeng, XU Xingfa, etc., Research on a new type of auto-disconnection safety for small hydro electric power system[J]. Power System Protection and Control, 2016, 44(1): 144-148

[3] ZHANG Qiaohui, DENG Xiaogang, YANG Chunxia, etc. Present situation and analysis of rural small hydro power automation control technology[J]. Mechanical & Electrical Technique of Hydro power Station, 2012, 35(3): 22-24

[4] YIN Kun. Technical status analysis of small hydro power integrated automation system[J]. Big technology, 2017, 15: 138-139

[5] YU Tao, LIANG Haihua, ZHOU Bin, Smart power generation control for micro grids islanded operation based on R (λ) learning[J]. Power System Protection and Control, 2019, 25(4): 1-6

[6] HE Ting, YANG Ping, XU Zhirong, Frequency Control Strategy of the Islanded Microgrid[J]. Modern Electric Power, 2017, 34(6): 28-32

[7] LI Wen, YANG Jindong, XIAO Qi. A New Control Method for Regional Self Commissioning of Large Number of Small Hydropower Stations[J], Power System and Clean Energy, 2018, 34(1): 144-148

[8] WU Yong, CHENG Zhifeng, JIN Dianqian, etc. Self-adaptive re-closer suitable for small hydroelectric power system in mountainous area[J]. Electric Power Automation Equipment, 2009, 29(9): 145-150

[9] ZHAO Yonghua, FANG Yongyi, WANG Na, Research on the impacts on feeder automation by inverter-based distribution generation connected to the distribution network[J]. Power System Protection and Control, 2013, 41(24): 117-122

[10] ZHEN Chenglin, ZHU Gelan, LAN Jincheng, Research on the effect of inverter interfaced distributed generation on voltage-time feeder automation[J]. Power System Protection and Control, 2020, 48(1): 112-116

[11] LI Zhaotuo, JIN Songmao, ZHANG Hua. Adaptive Fault Processing Method for Local Type Feeder Automation Based on Region Sequence Numbers[J]. Automation of Electric Power Systems, 2019, 43(19): 179-184

[12] WANG Zhonghui, CHEN Yu, XU Bingyin, etc. Logical Node Based Topology Identification of Distributed Feeder Automation[J]. Automation of Electric Power Systems, 2020, 44(12):124-130

[13] Jafary Peyman, Repo Sami, Koivisto Hannu, etc. Security solutions for smart grid feeder automation data communication[C]. Proceedings of the IEEE International Conference on Industrial Technology, 2016:551-557

[14] Koozehkanani Sanaz, Salemi, Saeid, Sadr shahab, etc. Optimal implementation of feeder automation in medium voltage distribution networks[C]. 20th Electrical Power Distribution Conference, 2015: 16-21

[15] LIANG Yali, QIN Keyuan, YU Jiaoshan, Study on voltage regulation strategy of distribution network considering small hydropower[J], China Rural Water and Hydropower, 2019, 5:184-190

[16] YANG Guancheng. Principle of power system automation device[M]. Beijing: China Electric Power Press, 2012

[17] KANG Wenwen, ZHONG Hao, etc. Application of Voltage-Time Mode of Feeder Automation in 10kV Overhead Transmission Line[J]. Shan Dong Dian Li Ji Shu, 2013, 5: 33-36