Research on New Scheme Based on Secondary Reclosing Distribution Network Protection

Yong Wang¹, Anning Wang¹ and Xia Lin²

ABSTRACT

The research on the rapid secondary reclosing technology proposed by Shandong Electric Power Grid (short delay primary reclosing + long delay secondary reclosing) and boundary switch reclosing and fixed value matching system within the framework of the grid is introduced in this paper. The different distribution network structure identifies the selection of relevant matching principle and secondary reclosing scheme, which changes the current mode which puts emphasis on the safe operation of the system side. The secondary reclosing shortens the user power outage time, achieves the reliability of the user's power supply, improves the quality of power, and provides a high quality distribution network for the users. By continuously optimizing the reclosing strategy and the corresponding protection configuration setting principles, the system to respond to the actual user needs is fully coordinated to improve the reliability of power supply of distribution network.

Keywords: secondary reclosing technology; boundary switch reclosing; fixed value matching system; power supply reliability; coordination system response

INTRODUCTION

Reclosing is an effective way to improve the reliability of distribution network. When the line fault occurs, the rapid reclosing of the line is of great significance for shortening the users’ power outage time. At present, the rapid secondary reclosing technology put forward by Shandong Electric Power Grid (short delay time primary reclosing + long delay time secondary reclosing) hasn’t had other relevant research and application in China. For the provincial network companies under the jurisdiction of national companies, in accordance with technical requirements of Q/GDW 766-2012 "10kV ~ 110kV line protection and auxiliary

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device standardized design specifications", 10 (35) kV line protection should include three-phase reclosing function, which does not make technical requirements for the secondary reclosing, so most of the companies use a three-phase reclosing technology[1-4]. For the provincial companies under the jurisdiction of China Southern Power Grid, according to the technical requirements of Q / CSG -2011 "China Southern Power Grid 10 kV - 110 kV line protection technical specifications": 35kV and below line protection devices should have primary reclosing and secondary reclosing function, and can input primary or secondary reclosing by the control word selection. The secondary reclosing technology mainly uses the feeder circuit breaker in the distribution system and the movement coordination of the switch on the column to locate and isolate the fault, and rapid recover power supply, which is suitable for voltage-time distribution automation lines, and is quite different from the secondary reclosing technology proposed by our province [5-6].

The reason why there are the above current states is as follows: one is determined by the operation idea of power grid all the time, namely, the safe and stable operation of power grid is the primary consideration, and there is not enough knowledge about the quality of power supply in distribution network. The other is determined by the priority of the construction of the distribution network in the earlier stage, namely, grid operators have also been fully aware of the importance of users’ power reliability. So vigorous development of the power distribution automation intends to quickly isolate the mining efficiency; and the distribution network closely related to the power distribution automation also takes the function of cooperating with it, for instance, the secondary reclosing strategy in the previous China Southern Power Grid is based on this idea. And in fact, the main protection of the distribution network should play its leading role regardless of its protection of the principle of configuration or reclosing strategy. From this aspect, the guidance and the protection of the power supply recovery strategy can change globally and increase substantially, rather than being passive to coordinate power distribution automation strategy in turn. The essential relationship should be: the primary grid structure determines the protection configuration and automatic control strategy, and then creates space for the efficient operation of distribution automation.

The Topology Based on the Primary Reclosing Determines the Protection Configuration and the Coordination Hierarchical Division

In order to solve the protection configuration and coordination determined by the network topology, the first level, as shown in the diagram: what has been bothering the distribution network is that the local grid obeys the requirements of the higher power grid, general substation outlet switches are configured with no delay transient protection I section, the advantage of this is to reduce the distribution network coordination level, and ensure the rapid isolation of the upper power grid fault. But for the distribution network with short outlet and simple topological structure, this kind of protection cooperation mode has been used all the time. Also, since all are equipped with load switches or fuses (user transformer) except the outlet switch, it is reasonable to not consider the stage difference coordination. But with the continuous development of the distribution network, this operation mode has gradually shown its limitations.
Figure 1. The protection scheme and the protection action logic of the extended border method.

(1) When the line is longer, for example, when it exceeds 10kM, if only the instantaneous speed segment exists, and over-current protection is greatly influenced by the operation mode, it is difficult to take the protection into account in the maximum, or minimum mode; At the same time, the sensitivity of the line caused II segment overcurrent value too small. That is, if the line is too long, the performance of this protection configuration is worse.

(2) When the user’s inlet side or transformer is side-installed with a circuit breaker to protect the fault of the subsequent scope, no protection grading causes simultaneous tripping, which is a kind of cognition of jump tripping for users.

(3) Since the primary three-phase reclosing of the outlet switch is adopted, all the faults are dependent on the reclosing measure. For the distribution network with many outlets, complex branch structure, on one hand, because the primary reclosing does not subdivide the breakdown fault area, on the other hand, the opportunity of reclosing is limited; therefore, this strategy is clearly irrational for low-voltage distribution network.

It can be seen from the above analyses: for the longer line, more branch lines, this pressure level difference is no longer applicable. On the contrary, it is needed to take a more sophisticated, layered, targeted protection and reclosing measure. The following measures should be taken:
(1) When the line is longer, for example, when the line exceeds 10kM, it should be installed with sub-circuit breaker and equipped with the relevant protection; For the complex branch network, it is needed to be installed with controller in the boundary switch, and equipped with the relevant protection and primary reclosing function, which is shown in the figure.

(2) The outlet switch of substation should cancel instantaneous quick-motion segment, and add a short delay of the I-section protection, correspondingly give a protection match gradation to the relevant circuit breaker at the downstream of distribution network or controller, as shown in the figure.

(3) The outlet switch adopts a short time and a long time secondary reclosing mode, and matches with the pre-closing reclosing, as shown in the figure.

In short, at this point, the angle of protection cannot always look up to the system side, but to re-locate the distribution network protection downward, through continuous segmentation, on the basis of ensuring the safe and stable operation of the system side, the system side is allowed to transfer part of the protection coordination space to the downstream side, and the protective cooperation boundary continues to expand to the downstream boundary switch. At the same time the fault isolation region is further subdivided through the boundary switch and section switch, the outlet secondary reclosing and boundary primary reclosing refinement are used under favorable conditions to accurately locate the fault area and achieve the purpose of more intensive load recovery measures. Therefore, the distribution automation will be locked in the smaller areas of the fault location end for self-healing. The specific coordination relation and protection action logic are shown in the Figure 2.

![Diagram of protection configuration and reclose](image)

<table>
<thead>
<tr>
<th>Protection configuration</th>
<th>Reclose</th>
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<tbody>
<tr>
<td>CB1</td>
<td>OCBR - Section overcurrent protection</td>
</tr>
<tr>
<td>CB</td>
<td>OCBR - Section overcurrent protection</td>
</tr>
<tr>
<td>CB2</td>
<td>OCBR - Section overcurrent protection</td>
</tr>
<tr>
<td>QF</td>
<td>OC/Number lock/load switch</td>
</tr>
</tbody>
</table>

Figure 2. The Specific Coordination Relation and Protection Action Logic.
A SECONDARY RECLOSES SCHEME BASED ON IMPROVING POWER SUPPLY RELIABILITY

The drawbacks of the primary reclosing: First, the reclosing time of primary reclosing is 1S; the equipment fault protection setting time is generally 0.5S, even the line transient fault reclosing succeeds, which will lead to a large number of load to be off the line, the voltage switch will recover power transmission after 21S +7 nS. And the use of secondary reclosing strategy is to solve a large number of loads off the network through the primary rapid reclosing, and replace the manual delivery through the secondary long delay time to ensure a substantial increase in power distribution reliability.

Application Analysis of Secondary Reclosing Based On Current Concentration

ANALYSIS OF THE FIRST RAPID RECLOSES SCHEME

Transient fault of the power distribution line, the switch within the station trips at 0.14S (fixed value 0.08S), recloses at 0.2S (The motor continues to operate, the setting time of the motor voltage loss protection is generally 0.5S; if digital clock, VCR, microwave equipment can pass the 0.5S interrupt, and therefore it helps to reduce housing complaints.). The line recovers power supply, which is 0.8S faster than the original scheduled 1S.

The advantage of fast reclosing is that the voltage of the motor does not fall to zero immediately even if its circuit breaker (or automatic switch) is switched on. The residual voltage of the motor is attenuated by time and magnitude. When reclosing happens, if there is angular difference between the system side voltage and the residual voltage of the motor, which will seriously affect the motor winding and shaft and its driving load. And the decay time of the motor is a function of the size of the motor, the inertia of the motor and its load. The open circuit time constant of 150KW-1500KW motor usually is 0.5 to 2 seconds. In the time constant, the residual voltage is 36.8% of the initial value after the motor is attenuated. However, there is no such problem by using 0.1S fast reclosing. Because most of the distribution circuits generally do not load a single motor with more than 370KW. Even the non-dynamic load of a large industrial customer feeder will be large enough to reduce the voltage to an unsafe level, the time taken is (0.4 to 0.6 seconds), and the secondary reclosing is only 0.1S. It is precisely because of the time of 0.15S-0.2S, it is enough to re-reclose and ensure the normal load of the motor supply, so the first and second class motor loads within the power plant within use 0.1-0.2 fast cutting device to quickly transfer the motor load without losing its power output, therefore, the use of fast reclosing can guarantee the continuous output of power equipment shown in the Figure 3.

Figure 3. The Voltage Drop Trend Chart of the Distribution Network During Fault.
It can be seen from the above analysis that the shorter primary fast reclosing time is more conducive to the recovery of motor load. And at the same time, it is needed to consider the time for switch arc breaking and deionization.

The time is a function of voltage and structural spacing. 
\[ t = 10.5 + \frac{V}{35} \]  

wherein, \( t \) is the minimum de-ionization cycle number, 60 Hz period (\( t = 1 / 60t \))  
\[ V = \text{rated line voltage kV} \]

Therefore, the higher the voltage level, the longer the required de-ionization time is. 35 kv is substituted into the formula, which may be switched on again for 11 cycles. The time is 11 cycles with the time of 0.18 seconds, for the fastest moving device (vacuum or SF6 device), 35KV class instantaneous reclosing time is recommended for 0.2 seconds. And 10kV can take 0.15 seconds according to the calculation result.

ANALYSIS OF CURRENT BLOCKING OF FAST RECLOSING

Since each fault will bring mechanical and thermal stress to the transformer, the use of secondary reclosing needs to assess the short-circuit impact on the transformer, so as not damage transformer by passing through the fault. Because the thermal stress is cumulative, the secondary reclosing does not cause thermal stress damage to the transformer. Through the Electrical Power Research Institute (EPRI) analysis of 220KV transformer mechanical stress bearing capacity, the domestic transformer is of weak short-circuit resistance, leading to winding deformation, decreased insulation performance. Therefore, it is necessary to install a protective locking device on the switch within the station, when the fault current value reaches this value; the lock secondary reclosing measures are taken.

For the transformer which meets the short circuit requirements, it is necessary to verify the obtained short-circuit safety margin, that is, the ratio of the critical buckling strength \( F_b \) to the force \( F_c \) (\( F_b / F_c \)) of the inner coil is less than 1.8.

Statistical analysis shows that the safety margin of 179 low-voltage side windings in the 248 transformers with short-circuit capability is less than 1.8, with an average of 0.14. For a particular transformer, the relationship between the short-circuit capability safety margin and short-circuit current \( ISC \) through the transformer winding is:

\[ F_b / F_c \propto ISC^{-2} \]

According to the transformer’s ability to withdraw short-circuit capability safety margin (\( F_b / F_c \)) and short-circuit current \( ISC \) through the transformer winding, the maximum short-circuit current withdrawn by the transformer can be calculated. Supposing that the three-phase short-circuit current of a transformer at the low voltage side is 30kA (the maximum short-circuit current can be obtained according to the short-circuit impedance value of the transformer), if the safety margin is selected the average value of 0.1; the maximum short-circuit current \( ISC \) is:

\[ ISC = 30 \times (1.8/0.1)^{-1/2} = 7.07 \text{kA} \]

This is a conclusion drawn from the domestic transformer test, but considering the practical engineering application, a more intuitive result is needed. That is, from the scope of protection, is there practical engineering value for the setting of the two reclosing? According to the setting principle, the transformer's low voltage fast break protection is the main protection of the low voltage side bus, that is, the short-circuit current has a sensitivity of 1.5 times in the minimum mode. And it can be known through estimation, this value is 8000-10000A, and through sensitivity verification, as well as with the 10kV line matching system taking 1.1, the general set value of 6000-7000 is taken as the transformer low voltage breaking speed value. Therefore, the protection range of the outlet fast breaking
protection can be selected, and the upper limit of the rated value of the outlet speed breaking protection can be further selected as the latching current value.

Assuming that the limiting current is 7000A, the regional grid 10kV to be the maximum mode, the impedance in minimum mode is generally 0.2-1.0pu, and the universal distribution interval is 0.2-0.5pu, then:

For 10kV, there is, according to Table 4-3 of “Electrical Engineering Electrical Design Manual (Electrical Part)”, the overhead line positive sequence impedance is \(0.4\Omega/km\), 10kV cable takes \(0.08\Omega/km\),

The impedance of the overhead line in the maximum mode is:

\[
\frac{\frac{\sqrt{3}}{2}}{0.22 = 0.4X_X} = 7(kA)
\]

The line protection length is obtained to be 1.41 km.

The impedance of the overhead line in the minimum mode is::

\[
\frac{\frac{\sqrt{3}}{2} = 0.4X_X}{0.5 = 0.4X_X} = 7(kA)
\]

The line protection length is obtained to be 0.71 km.

The cable is:

\[
\frac{\frac{\sqrt{3}}{2}}{0.5 = 0.08X_X} = 7(kA)
\]

The line protection length is obtained to be 3.57 km.

It can be know from the above analysis that when at the maximum mode of operation, in the 1.46 km three-phase fault needs to close secondary reclosing, taking into account the general fault is developed from two-phase fault, it can be considered at about \(1.46 \times 0.67 = 1\ km\), the fault locks the secondary reclosing. And for cable lines, especially the longer export cable line, it is not suitable for secondary reclosing.

In summary, the latching current can be set to 7000A, when the protection monitors the fault current over 7000A, indicating a fault occurs nearby, and the secondary reclosing locks.

It can be seen from the red mark in the Figure 4, it can be seen that the coordination of the protection is divided into three levels. And the reclosing coordination is divided into the two layers. That is, outlet switch reclosing and the boundary switch reclosing, segment switch (branch switch) over current latching logic.

- For the boundary switch, when it is the circuit breaker, it implements the protection coordination relationship shown in the diagram, to implement a fast reclosing. The time selection is the same as the fast cycle of the outlet switch within the station. When the fault is at the downstream of the boundary switch and the primary reclosing fails, no reclosing anymore. This will improve the success rate of the secondary reclosing of the switch within the station.

- For the automatic segment switch (branch switch), when it is the load switch, then after the secondary over current and the current disappears, the outlet switch trips to wait for the tripping of secondary reclosing, the latch is no longer reclosing, as shown in the figure. In this way, the success rate of the secondary reclosing of the outlet switch can be improved. If it is the sub-automatic re-closer for segmented fault judgment function, the outlet switch will need to carry out the second round of the slow reclosing, because the first automatic fast reclosing is done by the outlet switch, mainly to eliminate the instantaneous fault. This round of fast segment switch is not involved. In the first round of the slow reclosing, the segment switch uses the sequential reclosing to determine the fault segment and the second round of the slow reclosing is isolated by the segment switch to identify the fault segment, the action sequence is as shown. This idea is fully embodied in the voltage distribution automation system.
Application Analysis of Secondary Reclosing Based On Voltage Distribution Automation

This is a voltage distribution automation system of the original secondary reclosing for fault location and isolation. Obviously, this is the action cycle to be done before the completion of the traditional reclosing function. In order to reflect the newly defined secondary reclosing function, it is necessary go through two rounds to achieve the function.

The characteristics of time voltage distribution switch:170V with pressure reclosing, 80V without pressure gate (10kV / 220V, assuming AB interphase voltage), A \ B \ C phase large current blocking function, mechanical delay 0.6-0.9S trip.

The instantaneous fault near the distribution line, the switch within the station fast trips for protection at about 0.14S, recloses at 0.2S (the motor continues to keep running, the setting time of the motor voltage loss protection is generally 0.5S), the line recovers power supply, which is 21S+7nS faster than the original scheduled.

For permanent faults, the following logic exists:
For the primary reclosing: after 2 shocks, it can isolate the fault.
For the secondary reclosing, after 4 shocks, it can isolate the fault shown in the Figure 5.
Figure 5. The Action Diagram of the Voltage Type Segment Being Coordinated With The Three-Fold Reclosing Method.

For the distribution line fault, the switch within the station, reclosing occurs at 0.2S, the voltage switch does not reclose (no voltage trips after 600-900ms), the reclosing fails, reclosing for the second time after 15S, the switch of line voltage will be switched on and then tripped again until it reaches the fault branch. At this time, the fault interval of main distribution station is "full line fault" (FA specifications: master receives three trips, it is judged "full line fault"), the judgment of fault interval is mistaken; this problem can be solved by modifying the program; At the same time, the switch on the side of the network
will carry out the second round of reclosing, and it trips after 0.2S until the 15S reclosing successfully.

In order to prevent the 4th tripping, the charge time of reclosing can be adjusted to 2 minutes (the procedure needs to be modified by the factory), and the remote execution is carried out by the distribution network automation.

Because the voltage distribution network switch is basically used in the suburbs, the transient fault is over 80%, so the fault isolation time can be greatly shortened shown in the Figure 6,7.

<table>
<thead>
<tr>
<th>1. Transient fault</th>
<th>2. DL reclose 1s after</th>
<th>Voltage is presented at A &amp; B 2s reclose in 15s</th>
<th>Voltage is presented at B &amp; C 2s reclose in 15s</th>
<th>Voltage is presented at C &amp; D 2s reclose in 15s</th>
<th>Voltage is presented at D &amp; E 2s reclose in 15s</th>
<th>Remark: restore power supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. DL trip</td>
<td>A trip</td>
<td>B trip</td>
<td>C trip</td>
<td>D trip</td>
<td>Remark: restore power supply</td>
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<th>3. DL reclose 1s after</th>
<th>Voltage is presented at A &amp; B 2s reclose in 15s</th>
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</table>

Figure 6. The Action Diagram for The Voltage Segment Being Coordinated With The One-Fold Reclosing Method.

Figure 7. The Action Diagram for The Voltage Segment Being Coordinated With The Three-Fold Reclosing Method.
IMPLEMENTATION METHOD AND CASE ANALYSIS

After the secondary reclose strategy is put into the actual 10kV line (current concentration type), the original motor can recover quickly after a rapid reclose, and improve the reliability of the power supply.

The specific parameters are as follows: 10kV system impedance: 0.36/0.76, line length: yjv22-8.7/15kv3 *300 cable is with the length of 60 meters, jklyj-10kv 240 is with 610 meters, yjv-8.7/15kv3 *95 is with the 135 meters.

Three 10 kV asynchronous motors: two 1600 kw ac asynchronous motor, being with the 10000 v voltage, 115.4 A current, 992 r/min rotational speed, the 1545 v rotor voltage, the729 A rotor current is, 50 hz frequency is, 3 phase, Y/Y winding connection, 0.84 the power factor. A 500kw ac asynchronous motor, being with 10000V voltage, 36.2 A current, 980r/min RPM, 0.84 power factor, Y winding grafting.

After the fault, two asynchronous motors returned to operation. The frequency converter failed to recover because of the low voltage of the frequency converter. The fault is transient, and the fault current is 296A, and 151A after trip.

As shown in Figure 8 the load falling and recovery, when a transient fault adopting the original 1.5 S three-phase reclosing strategy, figure b is load falling and recovery when the first time short time of 0.2 S reclose using the new secondary reclose. It can be seen from the figure that rapid reclose shot can reduce load loss significantly and greatly reduce load recovery time, which is an effective means to improve the reliability of power supply.

CONCLUSIONS

This paper mainly aims at the equipment configuration of increasingly mature segment switch of distribution network (current type and voltage type) in order to improve the reliability of power supply. Through analyzing the disadvantages of the primary reclosing in widely used in the current power grid in the new situation, the author proposed the
protection secondary reclosing configuration in line with distribution automation. This paper mainly introduces the principle and configuration method of secondary reclosing, and the necessity and idea of the three reclosing configurations are put forward on the basis of the action characteristics of the current and voltage type segment switch, which further provides the reliability of power supply and new measures to meet the needs of important industrial load continuous power supply.

REFERENCES