An Adaptive Reclosing Switch Based on Shunt Resistance

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Abstract. In order to solve problems that the low coincidence success rate of the automatic reclosure of distribution network and short-circuit current has a large impact on the system when it coincides with the permanent fault, a shunt resistance type of adaptive reclosing switch is proposed. In order to improve the success rate of reconfiguration of the distribution network. By selecting the appropriate shunt resistance, the switch can not only suppress the magnetizing inrush current, limit the short-circuit current, reduce the system impact, but also use the current characteristics flowing through the shunt resistance to determine whether there is a permanent fault in the downstream, and realize the adaptive reclosing. The shunt resistance type adaptive reclosing switch can be separately applied to the power distribution switch to replace the original reclosing mode, and as a switch with protection function, the safety of the fault handling process is improved.

1. Introduction
The distribution network (especially overhead lines) often has transient faults, and the application of automatic reclosing can improve the reliability of line work. In recent years, with the increase in the proportion of cable used in distribution networks, the success rate of reclosing has gradually decreased. In order to solve the problem of blind coincidence of automatic reclosing, it is proposed to use adaptive reclosing in the distribution line.

Single-phase adaptive reclosing is widely used in transmission lines, which judges whether there is a fault downstream of the line according to residual electrical characteristics in the line after tripping, such as recovery voltage, arc characteristics of transient faults, etc[1-5]. However, after the short-circuit fault occurs in the distribution line, the three-phase trips at the same time. For the distribution network with complete power loss, the residual electric quantity is very weak. Therefore, the research on single-phase adaptive reclosing is not applicable to the domestic medium-voltage distribution network. At present, the three-phase adaptive reclosing of the distribution network mainly adopts the active method, and the transient voltage and current characteristics are obtained by injecting signals into the blackout line to analyze whether a permanent fault occurs in the blackout line [6-9]. The drawback of this method is that it is easy to impact the upstream system and requires a special excitation signal injection device, which is costly.

Aiming at the above problems, this paper proposes a shunt resistance type adaptive recloser switch. The input of the shunt resistance can better suppress the short circuit current and reduce the impact of the system during the reclosing process. At the same time, the current characteristic flowing through
the shunt resistance is used to determine whether the downstream fault is a permanent fault, and the reclosing is adaptive.

2. The structure of shunt resistance type of adaptive reclosing switch

The structure of the shunt resistance type of adaptive reclosing switch comprises two parts: a main circuit breaker and a parallel auxiliary closing circuit. The structure is shown in Figure 1. The main circuit breaker K_1 adopts a 10kV vacuum circuit breaker, and the parallel auxiliary closing circuit is a series connection of the resistance R and the switch K_2 (a load switch or a contactor can be used). The specific action logic is:

1) During normal operation, K_1 is normally closed, K_2 is open, and shunt resistance R is not in use.

2) After the fault occurs, K_1 may be opened due to the protection action or the delay time cause the pressure loss. When the subsequent reclosing operation is required, K_2 is first closed to make the shunt resistance R input, then detected the current characteristic flowing through the shunt resistance R to judge whether the fault exists. If it is judged as "no fault", that is, a transient fault occurs, K_1 is closed, and K_2 is opened after the switch is stabilized, and the shunt resistance R is exited; if it is judged as "faulty", a permanent fault occurs, then control K_2 is directly opened, the shunt resistance R is taken out of operation, and K_1 is no longer controlled to be closed.

![Figure 1. The structure of shunt resistance type of adaptive reclosing switch.](image)

Due to the input of the shunt resistance R, the first step is to reclose the switch K_2, even if it is superposed to a permanent fault, it will not cause a large short-circuit shock to the system. At the same time, by using the current characteristics flowing through the parallel auxiliary closing circuit during the reclosing process, the fault property can be discriminated and the adaptive reclosing can be realized. Compared with the original automatic reclosing mode of the direct drive main circuit breaker K_1 closing, this method can avoid the large short circuit impact caused by the permanent failure to the system and improve the power supply safety of the system.

3. Key technical principles

3.1. The Setting of Permanent Fault Criteria

The core content of the adaptive reclosing technology is the discrimination of permanent faults. The shunt resistance R should limit the short-circuit current of the feeder to 1.5~5 times the rated current capacity. If the limit is too deep, the impact on the system is small, but the load current is difficult to distinguish; if the limit is too high, it is conducive to the determination of permanent faults, but the system is greatly damaged. At the same time, it should be ensured that after the shunt resistance R is input, the bus voltage drops not less than 0.7p.u.. Therefore, the following formula is proposed to identify permanent faults:

\[
I_{act.1} = K_k \times \beta \times I_{L,max}
\]  

Among them, \(I_{act.1}\) is the setting current of switch k_2, \(I_{L,max}\) is the maximum load current, \(\beta\) is the reliability coefficient, generally 1.5, \(K_k\) is the sensitivity coefficient, generally 1.2~1.3; that is, the action current should meet 1.5 times of the load current, and meet a certain margin.

3.2. Suppression of Magnetizing Inrush Current
There are a large number of distribution transformers in the distribution network. When the transformer is closed at no load, or the voltage is restored after the external fault is removed, a large magnetizing inrush current will occur, which is easy to be misjudged with the short-circuit current. In order to study the suppression of the magnetizing current form the shunt resistance R, This paper establishes the 10kV power distribution network as shown in Figure 2 in the PSCAD simulation software.

![Figure 2. The simulation model of inrush current of a feeder](image)

By changing the shunt resistance value of the shunt resistance type adaptive recloser switch, the different closing resistance (1~10Ω), different load rates (no load, 5%, 10%, 15%, 20%, 25%) impact on the magnetizing current was studied when it on different numbers of transformers (10, 30, 50). The transformer capacity is 315KVA, the specific simulation is as follows.

Figure 3 shows the suppression of the inrush current by the shunt resistance, where is the ratio of the shunt resistance R to the magnetizing inrush current:

\[ \Delta I = \frac{I_0 - I_{RM}}{I_0} \]

Among them, \( I_0 \) is the peak value of the magnetizing inrush current when there is no shunt resistance, and \( I_{RM} \) is the peak value of the magnetizing inrush current under different closing resistance values. Z is the load rate.

Figure 4 shows the transformer magnetizing inrush current exceeding the steady-state current under different shunt resistances, where K is the percentage of the transformer magnetizing inrush current exceeding the steady-state current peak:

\[ K = \frac{I_{RM} - I_M}{I_M} \]

Where \( I_M \) is the peak at which the magnetizing inrush current decays to steady state.

Figure 5 shows the transformer magnetizing inrush current decay time T after the transformer has no load and the different shunt resistance R are input.
Figure 4. The percentage of magnetizing inrush current exceeding the steady-state current peak

Figure 5. Magnetizing inrush current decay time

From the above simulation, the following conclusions can be drawn:

1) As the number of transformers and the load increase, the suppression effect of the shunt resistance R on the magnetizing inrush current gradually increases, and the highest time is more than 90%.

2) As the shunt resistance and the load increase, the percentage of the peak value of the magnetizing inrush current exceeding the steady-state current peak gradually decreases, and the lowest is about 4%.

3) As the shunt resistance increases, the excitation inrush current decays faster. And the decay time is less affected by the load change. When the shunt resistance R is greater than 2Ω, the magnetizing inrush current is attenuated to the load current about 10ms.

In summary, the input of the shunt resistance R can better suppress the magnetizing inrush current. When the reclosing is required after the fault occurs, the switch K2 is closed and R is put into the line, and a delay of 0.1s is added to discriminate the permanent fault (At this time, the inrush current has been attenuated within 1.5 times the maximum load current), and the discriminant (1) can be used to effectively identify the permanent fault and improve the success rate of the reclosing.

4. Case Analysis
Taking the 10kV distribution line with lengths of 3, 5,10km as an example, the permanent fault criterion (1) proposed in Section 2.1 is verified by pscad simulation. The rated current of the line is 300A, and the load is constant power load. At this time, the voltage drop is the most serious.
In Tables 1~3, R is the shunt resistance; $I_1$ is the current flowing through the parallel auxiliary closing circuit when the line has a transient fault; $I_2$ is the minimum short-circuit current of the parallel auxiliary closing circuit when the permanent fault (two-phase short-circuit fault) occurs at the end of the line. $U'$ is the per unit of the bus voltage drop after the R is input. According to the permanent fault criterion (1), the sensitivity $K_k$ is 1.3, and the line current setting value $I_{act}$ is 585A.

| Table 1. Influence of shunt Resistance on 3km Line |
|--------------------------------------------------|
| R (Ω) | $I_1$ (kA) | $I_2$ (kA) | $U'$ (p.u.) |
|-------|------------|------------|-------------|
| 1     | 0.32       | 2.34       | 0.94        |
| 2     | 0.35       | 1.68       | 0.88        |
| 3     | 0.41       | 1.28       | 0.80        |
| 4     | 0.40       | 1.02       | 0.77        |
| 5     | 0.37       | 0.85       | 0.70        |

| Table 2. Influence of shunt Resistance on 5km Line |
|--------------------------------------------------|
| R (Ω) | $I_1$ (kA) | $I_2$ (kA) | $U'$ (p.u.) |
|-------|------------|------------|-------------|
| 1     | 0.30       | 1.73       | 0.95        |
| 2     | 0.33       | 1.36       | 0.89        |
| 3     | 0.38       | 1.10       | 0.81        |
| 4     | 0.36       | 0.92       | 0.77        |
| 5     | 0.34       | 0.78       | 0.73        |

| Table 3. Influence of shunt Resistance on 10km Line |
|---------------------------------------------------|
| R (Ω) | $I_1$ (kA) | $I_2$ (kA) | $U'$ (p.u.) |
|-------|------------|------------|-------------|
| 1     | 0.30       | 1.04       | 0.95        |
| 2     | 0.31       | 0.91       | 0.90        |
| 3     | 0.32       | 0.80       | 0.85        |
| 4     | 0.32       | 0.70       | 0.80        |
| 5     | 0.31       | 0.63       | 0.76        |

The example analysis proves that after the permanent fault occurs, the minimum short-circuit current $I_2$ is greater than the setting current $I_{act}$, that is, the criterion (1) proposed in Section 2.2 can effectively identify the permanent fault. Based on the above analysis, a shunt resistance with a size of 4~5Ω can be selected. This resistance can not only limit the short-circuit current, reduce the system impact, but also effectively suppress the magnetizing inrush current (less than 1.5 times the rated current) and ensure the bus voltage is greater than 0.7p.u. Realize the reciprocal adaptation.

5. In Conclusion

1) When the transmission line fails and needs to be reclosed, the first step is to close the parallel auxiliary closing circuit switch $K_2$ (this operation is a type of resistance overlap), by selecting the appropriate resistance value, even if it overlaps to a permanent fault, it will not cause a short circuit impact on the system. At the same time, the shunt resistance can also effectively suppress the magnetizing inrush current, and provide a powerful condition for the discrimination of the fault property.
2) By setting a reasonable current setting value, using the current value flowing through the parallel auxiliary closing circuit during the coincidence process can be used to determine whether there is a permanent fault in the downstream, and the reclosing is adaptive.

3) The shunt resistance type of adaptive reclosing switch can be separately applied to the power distribution switch to replace the original reclosing mode, and is used as a switch with protection function to effectively improve the safety of the fault handling process.

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