CROSS DIFFERENTIAL PROTECTION OF DOUBLE LINES BASED ON SUPPER-IMPOSED CURRENT

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INTRODUCTION

The double circuit or parallel transmission lines are more and more widely used in modern power system to improve transmission capability and reliability. Many types of relaying protection techniques can be used to protect parallel double transmission lines, such as over-current relay, distance relay and pilot relay[1]. Current and distance relays do not need communication channel but can not operate at all points on the line without time-delay. Pilot relay is able to offer fast operation without time-delay but need communication channel[2]. The cross differential protection has been more and more widely used to protect parallel double transmission lines in power systems since it can operate without time-delay and does not need communication link.

The conventional cross differential relay is based on the comparison between the current amplitudes of the double lines[3]. Its performance is not only influenced by load currents but also can not operate at weak source end. To solve the problems, the Super-imposed currents are used in this study to improve the characteristic of cross differential protection. Cross differential protection based on super-imposed currents is more sensitive and can operate correctly at both strong source and weak source ends. To demonstrate the performance of the new cross differential protection based on super-imposed current algorithm, a series of tests to a 400km 500kVtransmission system have been conducted using EMTP. Simulation results have proved that the operation of the presented cross differential relay is fast and reliable.

BASIC PRINCIPLE OF CONVENTIONAL CROSS DIFFERENTIAL RELAY

A typical double circuit or parallel (parallel double) transmission line is shown in Fig.1. The terminals of both lines are connected to the same bus and they have the same parameters, therefore the currents and voltages of the double lines are related[4].

The basic principle of the cross differential protection is based on comparing the amplitudes of the currents of the double lines. If no fault or external fault occurs, electric quantities of double lines are similar. When internal faults occur, the balance will be destroyed, from which an internal or an external fault can be distinguished.

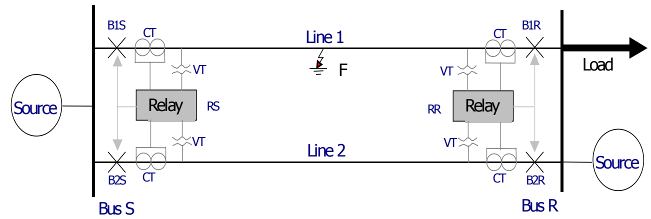


Fig.1 Parallel double lines system

The criterions of conventional cross differential relay are

$$|I_1| - |I_2| > I_{op} \text{ and } |I_2| - |I_1| > I_{op} \quad (1)$$

Where $|I_1|$ and $|I_2|$ are current amplitudes of double lines; I_{op} is operating value.

In order to improve the sensitivity of cross differential relay, a percentage cross differential element can be used[5][6]. The summary current of double lines is used as the bias current. The criteria of percentage cross differential relay is

$$|I_1| - |I_2| > k \cdot (|I_1| + |I_2|)$$
$$|I_2| - |I_1| > k \cdot (|I_1| + |I_2|) \quad (2)$$

Where I_1 and I_2 are currents of double lines; k is bias coefficient. Bias current should be set above the unbalance current of a particular system.

By using percentage cross differential elements, the sensitivity of cross differential relay can be improved, however it is still influenced by load current. Furthermore, when the difference between the source capacities at the two ends of the lines is very large, the current amplitudes of double lines on the weak source end are similar, and cross differential relay can not operate to remove fault.

As shown in Fig.2, 'Bus S' is strong source end and 'Bus R' is weak source end. Amplitudes of current I_{1R} and I_{2R} are similar, $I_{1R} = I_{2R}$. Based on equation (1), the level of the differential current will be low for an internal fault, as a result the cross differential relay may not be able to operate.

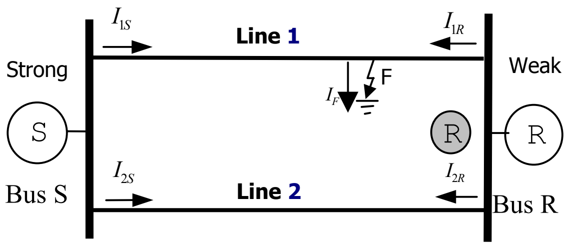


Fig.2 Character of cross differential relay at weak source end

Therefore, it is necessary to develop new criterion improve sensitivity and character of cross differential relay, especially at weak source end.

CROSS DIFFERENTIAL RELAY BASED ON SUPER-IMPOSED CURRENT

To solve the above-mentioned problem, the super-imposed currents are used in this study to improve the performance of the cross differential protection.

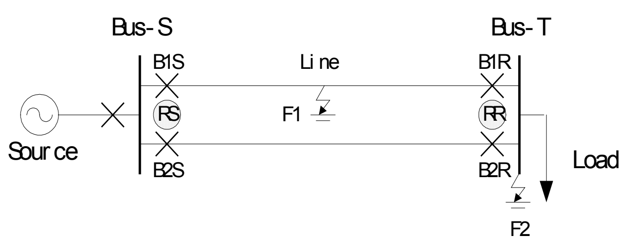
When a fault occurs, super-imposed current will be produced, which can be defined as the differential current between the short circuit current and the load current.

The equivalent circuit for the super-imposed current is shown in Fig.3.

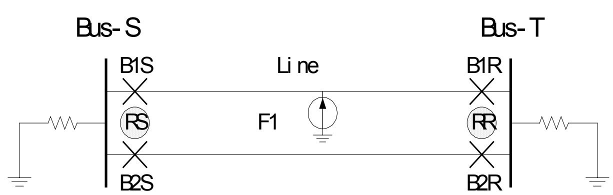
Fig.3 (a) is the source-load system model;

Fig.3 (b) is the equivalent circuit of super-imposed current in case of internal fault;

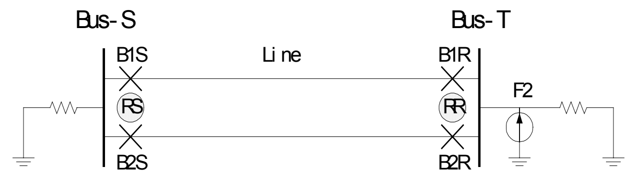
Fig.3 (c) is the equivalent circuit of super-imposed currents in case of external fault.



(a) The source-load system model



(b) The equivalent circuit of super-imposed currents in case of internal fault



(c) The equivalent circuit of super-imposed currents in case of external fault

Fig.3 The equivalent circuit of super-imposed current

If an internal fault occurs on one of the double lines, the short circuit current is fed from the strong source end. When fault point is near to Bus-T, the current amplitudes of double lines at weak source end are similar, consequently the conventional cross differential relay can not operate.

However the source of super-imposed current is at the fault point as shown in Fig.3(b), and the magnitude of the super-imposed current of the faulty line is higher than that of the healthy line. Therefore cross differential protection based on super-imposed currents is able to operate correctly at weak source end.

If an external fault occurs on double lines as shown in Fig.3(c). The magnitudes of the super-imposed currents of the doubles lines are similar and the cross differential relay will not operate.

The criteria of cross differential relay based on super-imposed current are

$$|\Delta I_1| - |\Delta I_2| > k \cdot (|\Delta I_1| + |\Delta I_2|)$$
$$|\Delta I_2| - |\Delta I_1| > k \cdot (|\Delta I_1| + |\Delta I_2|) \qquad (2)$$

Where ΔI_1 and ΔI_2 are super-imposed currents of double lines,

$$\Delta I_1 = I_{1,f} - I_{1,L} \text{ and } \Delta I_2 = I_{2,f} - I_{2,L} .$$

Where I_f is fault current, I_L is load current.

SIMULATION RESULTS

To demonstrate the performance of the new cross differential protection based on super-imposed current algorithm, a series of simulation tests with respect to a 400km 500kV transmission system have been conducted using EMTP.

The configuration of the simulated system is shown in Fig.4. The short circuit capacities of system at ends S and R are varied between 1000 to 8000MVA. Simulation tests with respect to various faults and source conditions are conducted at a number of fault locations as shown in the figure.

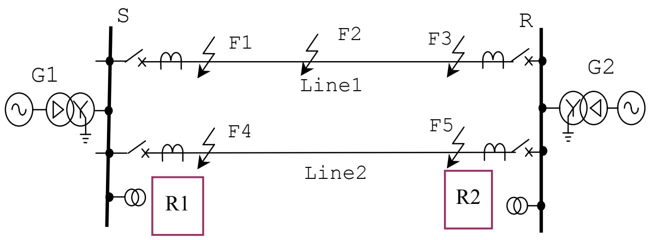


Fig.4 Test system configuration

It can be seen from the figure that the relays under test are installed at each end of the protected line at location R1 and R2. There are two operating modes of the cross differential relay depending on fault locations. Taken relay at location R1 as an example:

- Instant operation ('F1' and 'F2' as shown in Fig.4):

The relay R1 will instantly trip for close-in end and middle line faults.

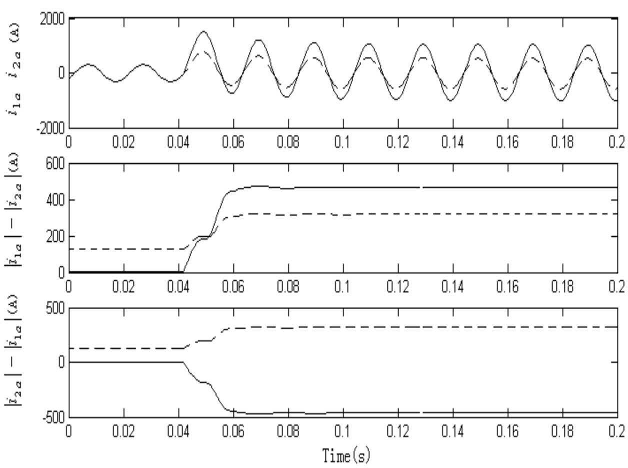
- Successive operation ('F3' as shown in Fig.4):

The relay R1 will trip successively for remote end fault. That is to trip after remote end relay trips.

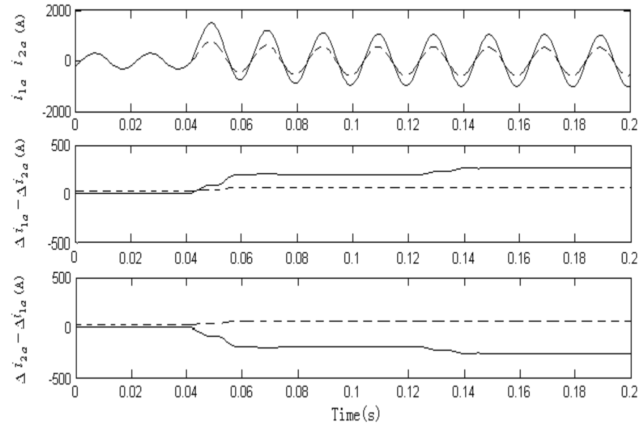
Some typical simulation results of the performance of the conventional and the new relays are given below:

(I) Case 1: phase 'A' fault at point 'F2' with relay in strong source end

Simulation results for relay at strong source end are shown in Fig.5. Fig.5(a) shows the performance of the conventional cross differential relay and Fig.5(b) shows the performance of the new cross differential relay based on super-imposed current.



5(a) Response of conventional cross differential relay



5(b) Response of cross differential relay based on super-imposed current

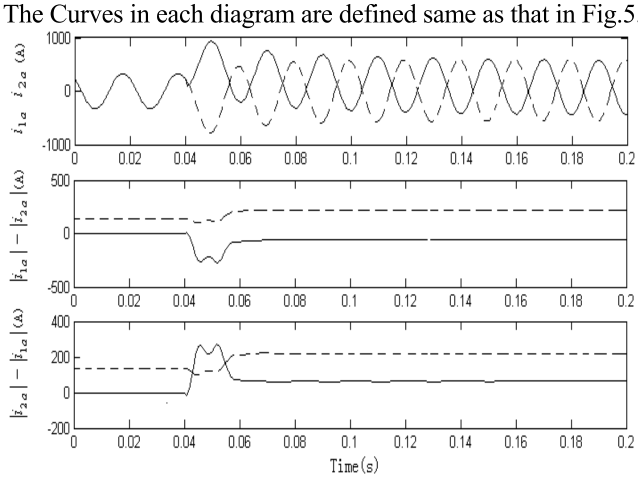
Fig.5 Simulation results at strong source end

The top diagram in the Fig.5 shows currents of the double lines. Solid curve is the phase current of the faulted line and the dash curve is the phase current of the healthy line. The middle and bottom diagrams in Fig.5(a) show the differential currents of the double lines. The middle and bottom diagrams in Fig.5(b) show the superimposed differential currents of the double lines. The solid curve is differential current and the dash curve is the bias current. The relay will operate when the amplitude of differential current is higher then that of the bias current.

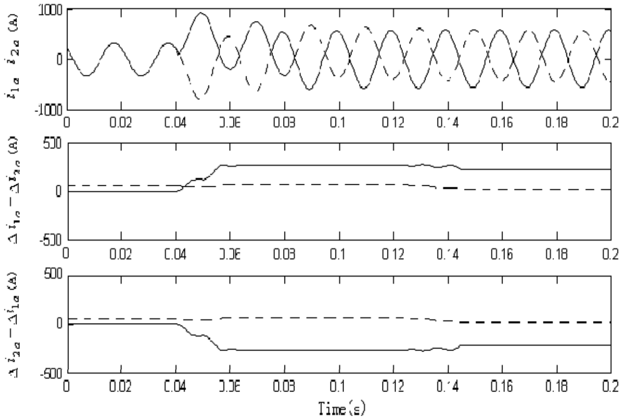
Simulation results show that both the conventional cross differential relay and the new cross differential relay based on super-imposed current are able to operate instantly at strong source end.

(II) Case 2: phase 'A' fault at point 'F2' with relay in weak source end

Simulation results at the weak source end are shown in Fig.6. The Curves in each diagram are defined same as that in Fig.5.



6(a) Response of conventional cross differential relay



6(b) Response of cross differential relay based on super-imposed current

Fig.6 Simulation results at weak source end

Simulation results show that the conventional cross differential relay can not operate at weak source end, however the cross differential relay based on super-imposed current can operate correctly.

(III) Case 3: phase ‘A’ fault at point ‘F3’ for relay at location R1

Simulation results for a phase ‘A’ to earth fault at point ‘F3’ are shown in Fig.7. The top diagram of the figure is the current of double lines. Solid curve is the phase ‘A’ current of the faulted line and dash curve is that of the healthy line. The middle and bottom diagrams show the superimposed differential currents of the double lines. The solid curve is the differential current and the dash curve is the bias current.

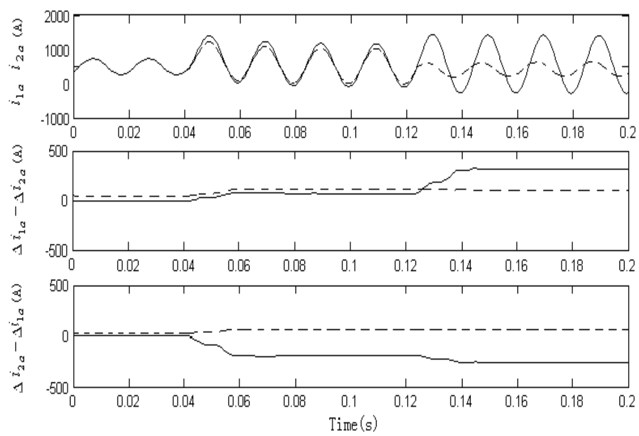


Fig.7 Simulation results of relay R1

Because fault point ‘F3’ is near to Bus R, the super-imposed currents of double lines are similar at relay location R1. Cross differential relay at end S can not operate. For this fault location, the relay at end R operates first and opens its associated circuit breaker. After breaker at end R opens, short current only exists in line 1, as a result, the relay at end S is able to successively operate as shown in the figure.

Various tests have been performed for different types of fault at various locations. The results prove that the cross differential protection based on super-imposed currents is able to remove faults on the double lines by instant or successive operation. Results also show that the relay is also able to operate correctly at both strong source and weak source ends.

CONCLUSIONS

A new cross differential relay based on super-imposed current is presented for double circuit or parallel transmission line protection. The relay is able to remove faults by instant operating and successful operation without the need for communication channel. Comparing to the conventional cross differential protection, the new protection based on super-imposed currents is not only more sensitive but also able to operate correctly at both strong and weak source ends. Results from extensive EMTP simulations have proved that the relay is able to provide fast and reliable operation for various system and fault conditions.

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Acknowledgements

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