J Electr Eng Technol Vol. 8, No. 1: 64-69, 2013
http://dx.doi.org/10.5370/JEET.2013.8.1.064

ISSN(Print) 1975-0102
ISSN(Online) 2093-7423

A Fast Algorithm of the Apparent Factor Calculation for Distance Relay Setting without Fault Analysis

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Abstract – For power system protection, the distance relay settings are important. Apparent factor is a necessary parameter in distance relay settings. Apparent factors have to be calculated when setting the distance relays and doing the resetting in case of configuration change in power system. The problem is that the current method to calculate apparent factor requires tools and plenty of time to do fault analysis and this method is complex especially in case of configuration change. Therefore this paper proposes a fast algorithm to calculate apparent factor without the fault analysis. Test results prove that this algorithm is simple and accurate by simulation.

Keywords: Distance relay, Apparent factor, Relay setting, Fault calculation, System change

1. Introduction

In the modern society, power system is omnipresent in all aspects of human life. For protecting power system, protective relays are used to detect overload, short-circuits, and other faults. Distance protection is widely used in power systems due to its numerous characteristics and merits. When fault occurs in power system, distance relays protect system devices, prevent expansion of fault section and sustain power system reliable and stable by separating the section quickly. Thus, distance relays are very important for the reliable and stable operation of power system [1].

According to the setting rules of distance relay, apparent factor is a necessary parameter for the zone-2 and zone-3 settings. In case of configuration change in power system, apparent factor calculation is necessary to reset the distance relays. Therefore apparent factor calculation is important for distance relay settings in power system [2].

Up to now, the common method to calculate apparent factor requires to do fault calculations with calculation tools to get protective and protected branch currents at first, which is complex and time-consuming. When it is applied to a complicated system or in case of configuration change, problems become even more serious. Because the time-consuming fault calculation processing needs to be repeated from the very start again. Thus an algorithm which can deal with these problems is appealing.

In this paper, a fast algorithm of the apparent factor calculation for distance relay settings without fault analysis is proposed to solve the problems mentioned above. This method only needs network impedance matrix and certain line impedance to do the calculations. By using the proposed algorithm, apparent factor can be obtained quickly. In case of configuration change, this algorithm provides the short approach to the new apparent factor, based on which people can locate the target resetting relays. This is convenient and time-saving especially when it is applied to a large power system.

The next section introduces the concept of apparent factor and common calculation method based on fault calculation. Then the proposed fast algorithm is expounded. After that the simulative cases are tested to verify the algorithm.

2. Apparent Factor Calculation in Distance Relay Setting

2.1 Apparent factor in distance relay setting

Distance relay used for power system protection monitors the impedance between the relay location and the fault. If the impedance falls within the relay setting, the relay will operate [3].

There are almost always feed lines in power systems. As

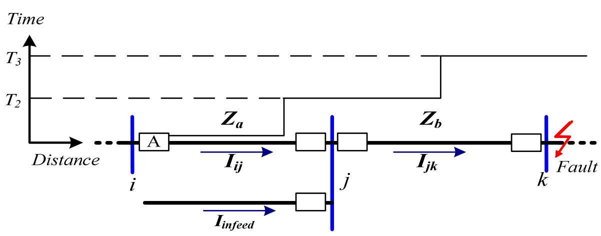

Fig. 1. Part of a transmission system protected by distance relays

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Received: December 5, 2011; Accepted: August 11, 2012

a result of feed effects brought by the feed lines, the distance relay measures the apparent impedance. Fig. 1 shows a part of power system network with feed lines. I_{ij}, I_{jk} represent the current flowing through the protected branch and the protective branch, respectively. Because of the feed line connected to bus *j*, relay *A* will "see" the apparent impedance [4, 5].

$$Z_{apparent} = \frac{Z_a \times I_{ij} + Z_b \times I_{jk}}{I_{ij}} = Z_a + \frac{I_{jk}}{I_{ij}} \times Z_b = Z_a + K \times Z_b \quad (1)$$

Depending on the type of the feed lines, *K* can be either bigger or smaller than 1.The feed lines might bring the dangers of under reaching or over reaching to the settings of the relays, which are so-called feed effects. To set distance relay considering these feed effects, it is necessary to determine which is the shortest adjacent line for zone-2 setting and the longest for zone-3 setting. The apparent impedance for each adjacent line is needed for comparison, i.e., the apparent factor for each adjacent line is needed [6].

2.2 Classical method for apparent factor calculation

Based on the current method, people have to do the time-consuming fault calculation for each adjacent line to get corresponding apparent factor. As shown in Fig.1 the apparent factor for relay *A* with a fault located at bus *k* is

$$K_{ijk} = \frac{I_{jk}}{I_{ij}} \quad (2)$$

Since the reduplicated fault calculation is needed for every line, the time will increase incredibly many fold with regard to a complex power system with intricacy feed lines.

When the system configuration changes because of tripping, inspection, etc., miscoordination brought by feed lines being removed or changed might appear. For power system security, the relays should be reset in the meantime. Following the current method, there is no choice but to do all the fault analysis again for every adjacent line to modify the part associated with apparent factor in the distance relay settings. Every time the system has any change, all the fault current calculations need to be repeated again. The consumed time and efforts are really huge.

3. The Fast Algorithm of the Apparent Factor Calculation

3.1 Derivation of the branch current without fault analysis

Assume that when the fault occurs, the current injected from fault node *F* into the network is I_F. This injected fault current I_F will produce voltage at every node. The voltage produced by the injected I_F^r at node *i* can be derived following the equation

$$V_{iF}^r = z_{iF}^r I_F^r \quad (3)$$

Where, z_{iF}^r = trans- impedance between nodes *i* and *F*

Suppose the node voltage at normal state is V_{i0}^r, then the *i*th voltage at fault state is $V_i^r = V_{i0}^r + V_{iF}^r$. In a simplification calculation the paper assumes that in a normal state node voltage in per unit is unified, which means $V_{i0}^r = V_{j0}^r$, thus the branch current can be calculated as in (4), and similarly in (5):

$$I_{ij}^r = \frac{V_i^r - V_j^r}{Z_a^r} = \frac{(V_{i0}^r + V_{iF}^r) - (V_{j0}^r + V_{jF}^r)}{Z_a^r}$$
$$= \frac{V_{iF}^r - V_{jF}^r}{Z_a^r} = \frac{z_{iF}^r I_F^r - z_{jF}^r I_F^r}{Z_a^r} = \frac{(z_{iF}^r - z_{jF}^r) I_F^r}{Z_a^r} \quad (4)$$

$$I_{jk}^r = \frac{(z_{jF}^r - z_{kF}^r) I_F^r}{Z_b^r} \quad (5)$$

3.2 Simplified equation of apparent factor in case of 3-phase fault

Combining (4) with (5), the apparent factor of the present system with 3-phase fault can be calculated using the following equation:

$$K_{ijk} = \frac{I_{jk}^1}{I_{ij}^1} = \frac{\dfrac{(z_{iF}^1 - z_{jF}^1) I_F^1}{Z_b^1}}{\dfrac{(z_{jF}^1 - z_{kF}^1) I_F^1}{Z_a^1}} = \frac{Z_a^1}{Z_b^1} \frac{(z_{jF}^1 - z_{kF}^1)}{(z_{iF}^1 - z_{jF}^1)} \quad (6)$$

In case of configuration change in power system, the apparent factor can be calculated similarly:

$$K_{ijkNew} = \frac{Z_a^1}{Z_b^1} \frac{(z_{kFNew}^1 - z_{jFNew}^1)}{(z_{jFNew}^1 - z_{iFNew}^1)} \quad (7)$$

3.3 Simplified equation of apparent factor in case of 1-phase-ground fault

Because under 1-phase-ground fault, there is relationship:

$$I_F^1 = I_F^2 = I_F^0 \quad (8)$$

Therefore the apparent factor of the present system with 1-phase-ground fault can be calculated using the following equation:

$$K_{ijk}=\frac{I_{jk}^{1}+I_{jk}^{2}+I_{jk}^{0}}{I_{ij}^{1}+I_{ij}^{2}+I_{ij}^{0}} =\frac{\dfrac{I_F^1(z_{kF}^1-z_{jF}^1)}{Z^1{}_b}+\dfrac{I_F^2(z_{kF}^2-z_{jF}^2)}{Z^2{}_b}+\dfrac{I_F^0(z_{kF}^0-z_{jF}^0)}{Z^0{}_b}}{\dfrac{I_F^1(z_{jF}^1-z_{iF}^1)}{Z^1{}_a}+\dfrac{I_F^2(z_{jF}^2-z_{iF}^2)}{Z^2{}_a}+\dfrac{I_F^0(z_{jF}^0-z_{iF}^0)}{Z^0{}_a}} \tag{9}$$

In case of configuration change in power system, the apparent factor can be calculated similarly:

$$K_{ijkNew}=\frac{\dfrac{z_{kFNew}^1-z_{jFNew}^1}{Z^1{}_b}+\dfrac{z_{kFNew}^2-z_{jFNew}^2}{Z^2{}_b}+\dfrac{z_{kFNew}^0-z_{jFNew}^0}{Z^0{}_b}}{\dfrac{z_{jFNew}^1-z_{iFNew}^1}{Z^1{}_a}+\dfrac{z_{jFNew}^2-z_{iFNew}^2}{Z^2{}_a}+\dfrac{z_{jFNew}^0-z_{iFNew}^0}{Z^0{}_a}} \tag{10}$$

3.4 Matrix modification in case of configuration change in power system

In case of configuration change in power system, we calculate the new apparent factor using Eqs. (7) or (10) according to the fault type. In Eqs. (7) and (10), the admittance is from the admittance matrix of the new network. The modification of the admittance matrix is vital to get the new transfer impedance in order to calculate the new apparent factor. Fig. 2 shows the network deleting a branch with impedance *Zc* between nodes *p* and *q* as an example.

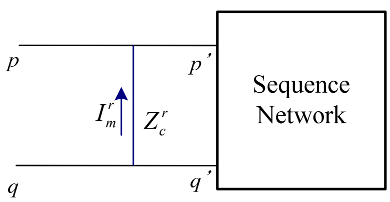

Fig. 2. Deleting a Z_c branch between nodes *p* and *q*

For any node *i* in the network, the new voltage can be given:

$$\begin{aligned}V_i^r&=z_{i1}^rI_i^r+\ldots+z_{ip}^r(I_p^r+I_m^r)+z_{iq}^r(I_p^r-I_m^r)+\ldots\\&=z_{i1}^rI_1^r+\ldots+z_{ip}^rI_p^r+z_{iq}^rI_p^r+\ldots+(z_{ip}^r-z_{iq}^r)I_m^r\end{aligned} \tag{11}$$

Integrate polynomials after substituting the new voltage at nodes *p* and *q*, V_p^r, V_q^r, into $V_p^r=V_q^r-(-Z_c^r)I_m^r$, we get:

$$I_m^r=\frac{(z_{q1}^r-z_{p1}^r)I_1^r+(z_{q2}^r-z_{p2}^r)I_2^r+\ldots}{z_{pp}^r-z_{pq}^r-z_{qp}^r+z_{qq}^r-Z_c^r} \tag{12}$$

Substituting (12) into (11), the new impedance matrix element can be derived: [7]

$$z_{nmNew}^r=z_{nm}^r-\frac{(z_{np}^r-z_{nq}^r)(z_{pm}^r-z_{qm}^r)}{(z_{pp}^r-z_{pq}^r-z_{qp}^r+z_{qq}^r-Z_c^r)} \tag{13}$$

$$(m,\ n=1,2,3,\ldots,N)$$

3.5 The advantages of the proposed algorithm

In this section, a fast algorithm of the apparent factor calculation for distance relay settings without fault current analysis is proposed.

This method only needs network impedance matrix and certain line impedance to do the calculations. The fault current calculation tools and processing are needless. It is convenient and time-saving without fault current analysis especially when it is applied on a large power system.

In case of configuration change in power system, all we need to do is to modify the impedance matrix and substitute it in the one-step equation. Having the values of apparent factor before and after system configuration changes, the variation of setting values can be calculated via equation shown below. Analyzing the variation of setting values, which relays need resetting can be known. The workers only need to reset the target relays.

This algorithm is simple, effective, time-saving, accurate and easy-to-apply with one-step equations to do the calculation without fault analysis. If the algorithm is applied to real system, setting values of distance relays can be calculated quickly and accurately because only impedance matrix is needed. In case of configuration change in power system, this algorithm can be used for determination of setting region of distance relays influenced by system configuration change quickly. The resetting can be easily and quickly done.

4. Case Study

4.1 Apparent factor calculation in case of 3-phase fault

There is a simple example system to estimate accuracy of the proposed algorithm shown in Fig. 3.

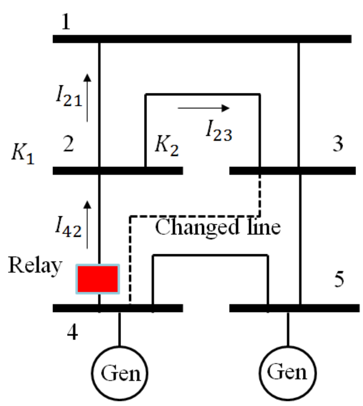

Fig. 3. The example system under accuracy estimation

The example system has 5 buses, 7 lines and 2 generators which are connected directly to each bus. Each of the lines has different impedance, and there are not transformers in it.

If the system is changed, two apparent factors which are K_1 and K_2 have to be calculated to set the Relay.

Suppose there is 3-phase fault appearing at the bus 1 and 3 to calculate apparent factors for the Relay resetting, the system configuration change is cutting off the line between bus 3 and 4 in Fig. 3.

Define the estimation error of the algorithm as the following equation:

$$\%\text{Error} = \left| \frac{K_{\text{alg}} - K_{\text{mea}}}{K_{\text{mea}}} \right| \times 100 \tag{14}$$

K_{alg} : Apparent factor calculated from the proposed algorithm

K_{mea} : Apparent factor measured from Matlab Simulink

The bus admittance matrix Y can be easily obtained by inspection, while the bus impedance matrix cannot be written by inspection like Y. but it can be obtained by inverting Y because of their mutually inverse relationship. Using the impedance matrix, the K, K_{New}, can be calculated easily following the Eqs. (6, 7, 9, 10) from the proposed algorithm just as expected.

The estimation errors between the values calculated from Matlab m-file by the proposed algorithm and the values measured from the Matlab Simulink are displayed in Table 1. At this point, K_1 and K_2 are as in Eq. (15, 16).

$$K_1 = \frac{I_{21}}{I_{42}} \tag{15}$$

$$K_2 = \frac{I_{23}}{I_{42}} \tag{16}$$

Table 1. Calculated values, measured values and estimation errors by Matlab in case of 3-phase fault

	Calculated value	Measured value	%Error
K_1	1.266746	1.266393	0.0279[%]
K_{1New}	1.059524	1.059322	0.0191[%]
K_2	0.5	0.5	0.0[%]
K_{2New}	0.5	0.5	0.0[%]

4.2 Apparent factor calculation in case of 1-phase-ground fault

Suppose there is 1-phase-ground fault appearing at the bus 1 and 3 to calculate apparent factors for the Relay resetting, the system configuration change is cutting off the line between bus 3 and 4 in Fig. 3.

The values obtained from two methods are also displayed in Table 2.

Table 2. Calculated values, measured values and estimation errors by Matlab in case of 1 line-ground fault

	Calculated value	Measured value	%Error
K_1	1.287597	1.286	0.1242[%]
K_{1New}	1.068247	1.067	0.1169[%]
K_2	0.5	0.5	0.0[%]
K_{2New}	0.5	0.5	0.0[%]

4.3 Summary

From the estimation errors shown in Table 1 and 2, it can be preliminary estimated that the proposed algorithm is accuracy enough to calculate the apparent factor because apparently the %Error is so small. Errors might come from the disposition of accuracy during the different calculation processing. The algorithm can be made use of in application to solve the problems presented.

5. Conclusion

Apparent factor is an important parameter for distance relay setting and coordination in power system. At present, common method to calculate apparent factor is complex and needs a lot of information because it requires calculation tools to do reduplicative fault calculation.

When a transmission line is changed, all distance relays in system have to be reset because it's impossible to foresee exactly how the change will affect the system in the future. That brings some problems such as system instability due to the long-time calculation.

This paper proposed a fast calculation algorithm of the apparent factor in power system protection. Through the case study, it is proved that the proposed algorithm is accurate and robust enough in theory.

Overall, the proposed algorithm simplifies the problem to a great extent without fault current calculation tools and processing. In this way, settings can be done quickly and accurately. In case of configuration change in power system, resetting target relays being found quickly, the settings can be done quickly and accurately. Much time can be saved when the proposed algorithm is employed, especially when a complicated system is at hand. It is easy to be applied and can achieve the goals very well.

6. Future work

The fast algorithm is proved by simple system in case study. If the algorithm is applied to real system, setting values of distance relays can be calculated quickly. When system configuration changes, this algorithm can determine of setting region of distance relays and resetting can be done quickly.

At present, this algorithm has been applied on the real system in Korea. The setting and resetting for zone-2 protection under 3-phase fault are finished. So far, it is working very well.

In the future the setting and resetting of the whole 3-zone protection under both of 3-phase and 1-phase-ground can be developed [8].

Acknowledgements

This work supported by the Power Generation & Electricity Delivery of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government Ministry of Knowledge Economy (No.2010T100200301)

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