평형 2회선 송전 계통의 1선지락시 고장점 표정 알고리즘

양하, 최면송, 이승재
명지대학교 차세대전력기술연구센터

Parallel Transmission Lines Fault location Algorithm for single line-to-ground fault

Xia Yang, Myeon-Song Choi, Seung-Jae Lee
Next-generation Power Technology Center, Myongji-university

Abstract - This paper proposes a fault location algorithm for two-parallel transmission line in the case of single line-to-ground fault. Proposed algorithm is using voltage and current measured in the sending-end. The fault distance is simply determined by solving a second order polynomial equation due to the direct circuit analysis. The simulations by PSCAD/EMTDC have demonstrated the accuracy and effectiveness of the proposed algorithm.

1. Introduction

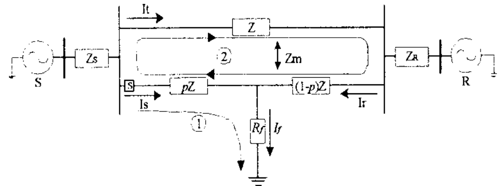
Fault location technique for double-circuit transmission line are more difficult and complex than single lines since double-circuit lines are characterized by a significant increase in the mutual coupling effects. When the fault location algorithm applicable to single lines is directly used for double-circuit lines, the location accuracy can not be ensured because of the mutual coupling between parallel lines.

Various fault location algorithms on parallel transmission lines have been put forward. The most popular method is recording the voltage and/or current signals are at the ends of the line. It can be classified into two categories: double-ends method [1]-[2] and single-terminal fault location method [3]-[8]. Although two ends algorithms may present a better performance, single end algorithms have advantages from the commercial viewpoint. This is mainly due to the extra-complexity associated with two ends algorithms including communication and synchronization between both ends as well as the cost increasing. Thus, the importance of improving the performance of single end algorithms significantly increases. Therefore, there are more researches focused on the application of the single end method so far.

This paper proposes a much simpler approach for fault location on two-parallel transmission line in the case of single line-to-ground fault. The proposed algorithm requires voltage and current in the sending-end. The effectiveness of the proposed algorithm has been testified on a simple double-circuit transmission line through simulations by EMTDC. The results show a very high degree of accuracy with variation of fault resistance.

2. Proposed Algorithm

The proposed algorithm requires the three-phase voltage and current at the relaying point of the sending-end and the zero sequence current of the adjacent parallel line. An assumption is that the mutual impedance between two circuits is the same as that between phases in a single circuit, which is equalized to distribute in line. In addition, the shunt capacitance of the system is not taken into account. Fig. 1 shows the one line system diagram of a simple double-circuit transmission line in the case of a single line-to-ground fault.



<Fig.1> A simple distribution system

where,

Zs: impedance for source S;
ZR: impedance for source R;
Z: line impedance;
Zm: mutual impedance between circuits;
Is: current at the local end of faulted circuit;
Ir: current at the remote end of faulted circuit;
It: current at the healthy circuit;
Rf: fault impedance;
If: fault current;
p: fractional fault distance from the local end.

In terms of the superposition principle in linear networks, the faulted network is decomposed into three sequence networks - positive, negative and zero-sequence networks. Thus, the relationship between the a-phase voltage Vsa and its sequence components Vs0, Vs1, Vs2 is

$$V_{sa} = V_{s0} + V_{s1} + V_{s2} \quad (1)$$

In the faulted circuit, assuming that phase a is to ground, the voltage at the relaying point is achieved through the analysis of the loop 1 based on KVL.

$$V_{sa} = p(I_{s0}Z_0 + I_{s1}Z_1 + I_{s2}Z_2) + I_f R_f + pI_{t0}Z_{m0} \quad (2)$$

where,

Is012: sequence current at the local end of faulted circuit;
Zm0: zero-sequence mutual impedance between circuits
It0: zero-sequence current at the healthy circuit.

For a transmission line in a three-phase power system, the positive and negative sequence impedances Z1 and Z2 are always equal.

$$Z_1 = Z_2 \quad (3)$$

Substituting (3) into (2), (4) can be obtained below.

$$V_{sa} = pZ_1(I_{s0}(\frac{Z_0}{Z_1} - 1) + I_{sa}) + I_f R_f + pI_{t0}Z_{m0} \quad (4)$$

where, Isa is a-phase current at the local end of faulted circuit. Define,

$$I_A \equiv I_{s0}(\frac{Z_0}{Z_1}-1)+I_{sa} \quad (5)$$

Thus, $$V_{sa} = pZ_1 I_A + I_f R_f + pI_{t0}Z_{m0} \quad (6)$$

In (6), all impedances except for fault resistance Rf are known constants; Vsa, Isa, Is0, and It0 can be obtained at the measuring point. On the other hand, fault current If can not be calculated with only the local end relaying signals of the faulted circuit. Hence, KVL based loop 2 is taken into account in zero-sequence circuit.

$$-pZ_0 I_{s0} - pZ_m I_{t0} + (1-p)Z_0 I_{r0} - (1-p)Z_m I_{t0} + Z_0 I_{t0} + pZ_m I_{s0} - (1-p)Z_m I_{r0} = 0 \quad (7)$$

where,

Ir0: zero-sequence current at remote end of faulted circuit.

Thus, $$I_{r0} = \frac{pI_{s0} - I_{t0}}{(1-p)} \quad (8)$$

In the case of a single line-to-ground fault, the relationship between zero-sequence If0 and the currents Ifa, Ifb, Ifc is considered,

$$3I_{f0} = I_{fa} + I_{fb} + I_{fc} = I_f \quad (9)$$

where, $I_{fb} = I_{fc} = 0$

To eliminate the unknown *If*, substituting (9) into (6),

$$V_{sa} = pZ_1 I_A + 3I_{f0}R_f + pI_{t0}Z_{m0} \quad (11)$$

Furthermore, $$I_{f0} = I_{s0} + I_{r0} \quad (10)$$

Substituting (10) into (11),

$$V_{sa} = pZ_1 I_A + 3(I_{s0} + I_{r0})R_f + pI_{t0}Z_{m0} \quad (12)$$

Then substituting (8) into (12) to eliminate Ir0,

$$V_{sa} = pZ_1 I_A + 3(\frac{I_{s0} - I_{t0}}{1-p})R_f + pI_{t0}Z_{m0} \quad (13)$$

Define, $$I_B \equiv I_{s0} - I_{t0} \quad (14)$$

Thus, $$V_{sa} = pZ_1 I_A + \frac{3I_B R_f}{1-p} + pI_{t0}Z_{m0} \quad (15)$$

According to (15), the second order polynomial equation of fractional fault distance variable can be achieved below.

$$p^2(Z_1 I_A + I_{t0}Z_{m0}) - p(V_{sa} + Z_1 I_A + I_{t0}Z_{m0}) + V_{sa} - 3I_B R_f = 0 \quad (16)$$

Since the mutual impedance between two circuits is the same as that between phases in a single circuit, thus,

$$Z_{m0} = 3Z_m \quad (17)$$

Substituting (17) into (16),

$$p^2(Z_1 I_A + 3I_{t0}Z_m) - p(V_{sa} + Z_1 I_A + 3I_{t0}Z_m) + V_{sa} - 3I_B R_f = 0 \quad (18)$$

Define,

$$a \equiv (Z_1 I_A + 3I_{t0}Z_m)\ b \equiv -(V_{sa} + Z_1 I_A + 3I_{t0}Z_m),\ c \equiv V_{sa},\ d = -3I_B \quad (19)$$

Thus, $$ap^2 + bp + c + dR_f = 0 \quad (20)$$

In order to eliminate Rf, (20) would be separated into the real and imaginary parts shown below.

$$(a_r + ja_i)p^2 + (b_r + jb_i)p + (c_r + jc_i) + (d_r + jd_r)R_f = 0 \quad (21)$$

Thus,

$$a_r p^2 + b_r p + c_r + d_r R_f = 0 \quad (22)$$

$$a_i p^2 + b_i p + c_i + d_i R_f = 0 \quad (23)$$

So, fault resistance can be obtained according to (23).

$$R_f = -\frac{a_i}{d_i}p^2 - \frac{b_i}{d_i}p - \frac{c_i}{d_i} \quad (24)$$

Substituting (24) into (23),

$$(a_r - \frac{a_i}{d_i}d_r)p^2 + (b_r - \frac{b_i}{d_i}d_r)p + (c_r - \frac{c_i}{d_i}d_r) = 0 \quad (25)$$

Define,

$$A = (a_r - \frac{a_i}{d_i}d_r),\quad B = (b_r - \frac{b_i}{d_i}d_r),\quad C = (c_r - \frac{c_i}{d_i}d_r) \quad (26)$$

Thus, the final second order polynomial equation is reached below.

$$Ap^2 + Bp + C = 0 \quad (27)$$

The roots of (27) is

$$p = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A} \quad (28)$$

The fractional fault distance p is between 0 and 1.

3. A Conventional Algorithm

A conventional algorithm is as similar as the proposed algorithm. The only difference is the conventional algorithm with an assumption.

As in (6) above, it is transformed into (29) below.

$$V_{sa} = pZ_1(I_{s0}(\frac{Z_0}{Z_1}-1) + I_{sa} + I_{t0}\frac{Z_{m0}}{Z_1}) + I_f R_f \quad (29)$$

Define,

$$I_{fA} = I_{s0}(\frac{Z_0}{Z_1}-1) + I_{sa} + I_{t0}\frac{Z_{m0}}{Z_1} \quad (30)$$

Thus, $$V_{sa} = pZ_1 I_{fA} - I_f R_f \quad (31)$$

Further transformation,

$$\frac{V_{sa}}{I_{fA}} - pZ_1 - \frac{I_f}{I_{fA}}R_f = 0 \quad (32)$$

On the assumption that the angle of If and that of IfA are same, then it would achieve,

$$imag(\frac{V_{sa}}{I_{fA}} - pZ_1) = 0 \quad (33)$$

The solution is, $$p = imag(\frac{V_{sa}}{I_{fA}}) / imag(Z_1) \quad (34)$$

4. Case Study

4.1 Accuracy

Simulations by PSCAD/EMTDC have been performed in a simple double-circuit transmission system on a 154 [kV], 100 [km] as same in Fig. 1. The data for the system are given in Table 1.

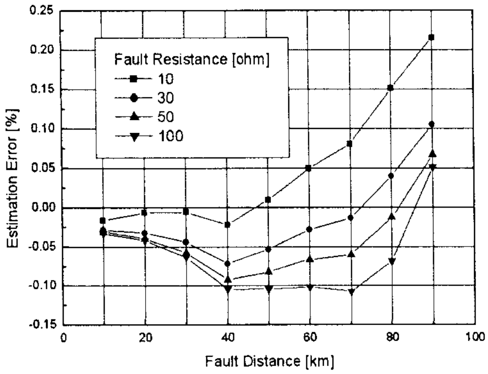
<Table 1> System Data

		positive-sequence impedance	zero-sequence impedance	
			Self	Mutual
Line [Ω/km]		0.0357 +j0.4828	0.3610 +j1.3790	0.3252 +j0.8963
Source [Ω]	S	4.145∠82.6106°	10.261∠79.5°	
	R	13.4187∠80.2905°	49.0618∠68.9051°	

Phase-a to ground fault is considered. The fault distance is varying from 10 [km] to 90 [km]with variation of fault resistance from 10 [ohm] to 100 [ohm]. And the estimated fault distance is shown in Table 2. Fig. 2 shows the estimation error of fault distance.

<Table 2> Estimated fault distance

Rf[ ] / d[km]	10	30	50	100
10	9.9838	9.9713	9.9686	9.9668
20	19.9936	19.9673	19.9603	19.9580
30	29.9944	29.9559	29.9426	29.9367
40	39.9779	39.9279	39.9075	39.8957
50	50.0093	49.9465	49.9177	49.8959
60	60.0492	59.9716	59.9334	59.8985
70	70.0805	69.9865	69.9398	69.8926
80	80.1511	80.0399	79.9871	79.9314
90	90.2156	90.1050	90.0672	90.0513



<Fig. 2> Estimation error

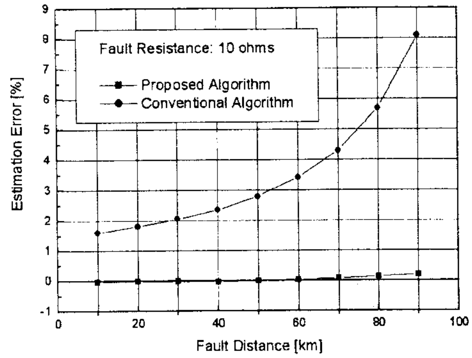
4.2 Comparison

The comparison between the proposed algorithm and the conventional algorithm has been carried out in the same simulation model system shown in Fig. 1.

<Table 3> Comparison

Rf / d[km]	10 [ohm]		30 [ohm]	
	Proposed	Conventional	Proposed	Conventional
10	9.9838	11.5968	9.9713	14.6776
20	19.9936	21.8019	19.9673	25.2348
30	29.9944	32.0480	29.9559	35.9248
40	39.9779	42.3446	39.9279	46.7887
50	50.0093	52.7944	49.9465	57.9991
60	60.0492	63.4147	59.9716	69.6707
70	70.0805	74.2891	69.9865	82.0615
80	80.1511	85.6940	80.0399	95.8735
90	90.2156	98.1058	90.1050	112.5061

The results are listed in Table 3. When fault is 10 [ohm], the conventional algorithm could not achieve an accurate estimation; when fault is 30 [ohm], it comes out with a large error. But on both cases, the proposed algorithm can achieve a high degree of accuracy. Fig. 3 gives the comparison curve between both algorithms when fault resistance is 10 [ohm].



<Fig. 3> Comparison

5. Conclusion

The proposed algorithm includes two steps. Firstly, establishing two KVL equations around the parallel line loops; secondly, applying these to the voltage equation at the measuring point and separating the real and imaginary parts, the fault resistance can be eliminated and the final second order polynomial equation can be obtained. With taking voltage and current at the sending-end, the proposed algorithm achieves a high accuracy almost not influenced by the variations of the fault resistance.

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