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A Robust Fault Location Algorithm for Single Line-to-ground Fault in Double-circuit Transmission Systems

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Abstract - This paper proposes an enhanced noise robust algorithm for fault location on double-circuit transmission line for the case of single line-to-ground (SLG) fault, which uses distributed parameter line model that also considers the mutual coupling effect. The proposed algorithm requires the voltages and currents from single-terminal data only and does not require adjacent circuit current data. The fault distance can be simply determined by solving a second-order polynomial equation, which is achieved directly through the analysis of the circuit. The algorithm, which employs the faulted phase network and zero-sequence network with source impedance involved, effectively eliminates the effect of load flow and fault resistance on the accuracy of fault location. The proposed algorithm is tested using MATLAB/Simulink under different fault locations and shows high accuracy. The uncertainty of source impedance and the measurement errors are also included in the simulation and shows that the algorithm has high robustness.

Keywords: Distribution factor, Fault location, Double circuit transmission line, Robustness

1. Introduction

An electric power system comprises generation, transmission and distribution of electric energy. Transmission lines are used to transmit electric power to distant large load centers. The rapid growth of electric power systems over the past few decades has resulted in a large increase in the number of lines in operation and their total length. In modern power systems, double-circuit transmission lines have been widely used to increase transmission capacity and enhance dependability and security. These lines are exposed to faults as a result of lightning, short circuits, equipment faults, mis-operation, human errors, overload, and aging. Many electrical faults manifest in mechanical damages, which must be repaired before returning the line to service. The restoration can be expedited if the fault location is either known or estimated with a reasonable accuracy.

The subject of fault location has been of considerable interest to electric power utility engineers for a long time. Various effective fault location algorithms for fault in single-line transmission system have been developed, which can be broadly classified as using power frequency phasors in the post-fault duration 0-0, using the differential equation of the line and estimating the line parameters 0-0, and using traveling waves including traveling wave protection systems 0-0.

However, when these fault location algorithms designed for single lines is directly used for double-circuit lines, which is often the practice, the location accuracy cannot be guaranteed because of the mutual coupling effect. Thus, a dedicated fault location algorithm for double-circuit transmission lines must be used.

Many studies on fault location on double-circuit transmission lines have been developed 0-0. They can be classified into two types: algorithms using two-terminal voltages and currents and those using single-terminal voltages and currents. In 0, a distributed parameter model-based fault location algorithm using two-terminal data, which does not require source impedance and fault resistance, was proposed. Meanwhile, 0 used two-terminal data and presented a novel time-domain fault location algorithm that uses a differential component net. Algorithms using two-terminal information can provide better performance.

However, these algorithms are not acceptable from a commercial point of view due to the extra complexity associated with communication and synchronization between both ends as well as the high cost. Therefore, more and more researchers are focusing on the application of the single-terminal method. A practical fault location approach using single-terminal data of the double-circuit transmission lines is presented in 0 depending on modal transformation. A least error squares method for locating fault on coupled double-circuit transmission line presented in 0 also uses single-terminal data. A more accurate fault location algorithm for double-circuit transmission systems that uses a current distribution factor in order to estimate the fault

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current using the voltage and current collected only at the local end of a single circuit is proposed 0. However, it has to solve the fourth-order polynomial equation, which is difficult and time consuming to solve. In 0, a simpler fault location algorithm for double-circuit transmission lines is proposed by solving second-order polynomial equation. It uses only single-terminal data, but also needs to use the data of other healthy lines.

This study proposes an enhanced algorithm for fault location on double-circuit transmission line for the case of single line-to-ground (SLG) fault. The proposed algorithm uses single-terminal data and does not require adjacent circuit current data, although it considers the mutual coupling effect. The final fault location equation is given as a simple second-order polynomial equation. Its effectiveness is testified on a simple double-circuit transmission system through various simulations using MATLAB. Tests results of the proposed algorithm show the accuracy of the fault location.

2. Proposed Algorithm

2.1 Fault Circuit Model

A single line diagram of double-circuit transmission systems with an SLG fault on one circuit is shown in Fig. 1.

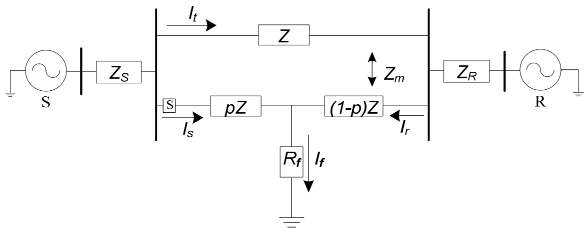

Fig. 1. Double-circuit transmission systems with SLG.

Z: Line impedance
Z_{012}: Sequence impedance of lines
Z_m: Mutual impedance between circuits/lines
Z_{ss}: Self-impedance for faulted phase
Z_{sm}: Mutual impedance between phases
I_s: Current at the local end of the faulted circuit
I_t: Current at the remote end of the faulted circuit
I_r: Current at the healthy circuit
I_f : Fault current R_f: fault impedance
p: Fractional fault distance from the local end

2.2 Fault Circuit Analysis

The voltage at the measuring point of the faulted phase A is givens as follows:

$$V_{sa} = p\left(Z_{ss}I_{sa} + Z_{sm}I_{sb} + Z_{sm}I_{sc}\right) + p\left(Z_m I_{ta} + Z_m I_{tb} + Z_m I_{tc}\right) + I_f R_f \quad (1)$$

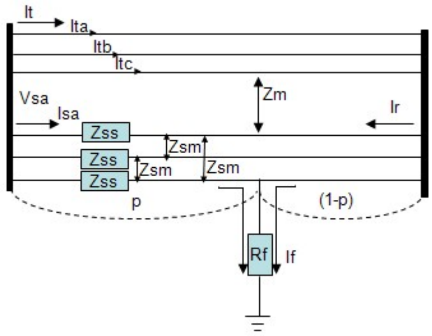

Fig. 2. Fault circuit analysis for a double-circuit system.

$$V_{sa} = p\left(Z_{ss}I_{sa} + Z_{sm}\left(I_{sb} + I_{sc}\right)\right) + pZ_m\left(I_{ta} + I_{tb} + I_{tc}\right) + I_f R_f \quad (2)$$

Since $I_{s0} = \left(I_{sa} + I_{sb} + I_{sc}\right)/3$ and $I_{ta} + I_{tb} + I_{tc} = 3I_{t0}$, (2) can be rewritten as the below equation:

$$V_{sa} = p\left(Z_{ss}I_{sa} + Z_{sm}\left(3I_{s0} - I_{sa}\right)\right) + 3pZ_m I_{t0} + I_f R_f \quad (3)$$

Rearranging the equation, (3) is obtained.

$$V_{sa} = p\left(\left(Z_{ss} - Z_{sm}\right)I_{sa} + Z_{sm}\left(3I_{s0}\right)\right) + 3pZ_m I_{t0} + I_f R_f \quad (4)$$

Sequence impedances, self-impedances, and mutual impedances have the following relationships:

$$\begin{cases} Z_1 = Z_{ss} - Z_{sm} \\ Z_0 = Z_{ss} + 2Z_{sm} \\ Z_{sm} = \left(Z_0 - Z_1\right)/3 \end{cases} \quad (5)$$

Substituting (5) into (4), (6) can be derived.

$$V_{sa} = p\left(Z_1 I_{sa} + \left(Z_0 - Z_1\right)I_{s0}\right) + 3pZ_m I_{t0} + I_f R_f \quad (6)$$

Defining $I_A = I_{s0}\left(Z_0/Z_1 - 1\right) + I_{sa}$,
thus,

$$V_{sa} = pZ_1 I_A + 3pZ_m I_{t0} + I_f R_f \, . \quad (7)$$

Note that in (7), there are four unknown variables - I_{t0}, I_f, R_f, and p - but only two equations are available, which are obtained from real and imaginary parts. Hence, in order to solve the equation, two unknown variables have to be eliminated or two more equations are needed. In this study, current distribution factors are utilized to estimate I_{t0} and I_f.

2.3 Current Distribution Factors

Fig. 3 shows a zero-sequence network of the faulted network in Fig. 1. Applying Kirchhoff's voltage law to the loop A, the following equation is obtained:

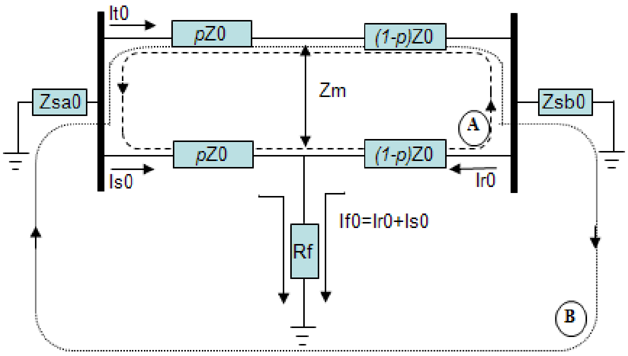

Fig. 3. Zero-sequence network analysis.

$$pZ_0 I_{s0} + pZ_m I_{t0} + (1-p) Z_m I_{t0} - (1-p) Z_0 I_{r0} + (1-p) Z_m I_{r0} - Z_0 I_{t0} - pZ_m I_{s0} = 0 \quad (8)$$

Rearranging equation (8) by changing the order of variables yields the following:

$$(1-p)(Z_0 - Z_m) I_{r0} = p(Z_0 - Z_m) I_{s0} - (Z_0 - Z_m) I_{t0} \quad (9)$$

Equation (8) can be further reduced to the below equation:

$$I_{t0} = pI_{s0} - (1-p) I_{r0} \quad (10)$$

Considering another loop, B, in Fig. 3, another KVL equation can be set up, as follows;

$$Z_{sa0}(I_{s0} + I_{t0}) + Z_0 I_{t0} + pZ_m I_{s0} - (1-p) Z_m I_{r0} - Z_{sb0}(I_{r0} - I_{t0}) = 0 \quad (11)$$

Simplifying the equation by rearranging the variables will yield the following:

$$I_{s0}(Z_{sa0} + pZ_m) + I_{r0}(pZ_m - Z_m - Z_{sb0}) + I_{t0}(Z_{sa0} + Z_{sb0} + Z_0) = 0 \quad (12)$$

Substituting (10) into (12), the following equation can be obtained:

$$I_{s0}(Z_{sa0} + pZ_m) + I_{r0}(pZ_m - Z_m - Z_{sb0}) + (pI_{s0} - (1-p) I_{r0})(Z_{sa0} + Z_{sb0} + Z_0) = 0 \quad (13)$$

The ratio of I_{t0}/I_{s0} can then be given as follows:

$$\frac{I_{r0}}{I_{s0}} = \frac{Z_{sa0} + pZ_m + pZ_{sa0} + pZ_{sb0} + pZ_0}{(Z_m + Z_{sb0} + (Z_{sa0} + Z_{sb0} + Z_0)(1-p) - pZ_m)} \quad (14)$$

We then define

$$A = Z_m + Z_{sa0} + Z_{sb0} + Z_0,\ B = Z_{sa0},\ C = A + Z_{sb0};$$

equation (14) can be expressed as follows:

$$\frac{I_{r0}}{I_{s0}} = \frac{Ap + B}{-Ap + C} \quad (15)$$

Using equations (10) and (15), the ratio of I_{r0}/I_{s0} can be derived.

$$\frac{I_{t0}}{I_{s0}} = \frac{p(A + B - C) + B}{Ap - C} \quad (16)$$

These two ratios, which are called current distribution factors, are used to estimate two unknown values - I_{t0} and I_{r0} - from the known I_{s0}.

2.4 Fault Location Algorithm

In case of a single line-to-fault case, the fault current is three times the zero-sequence current, i.e., $I_f = 3I_{f0}$. Using $I_{f0} = I_{r0} + I_{s0}$, (7) can be expressed as follows:

$$V_{sa} = pZ_1 I_A + 3pZ_m I_{t0} + 3(I_{s0} + I_{r0}) R_f \quad (17)$$

Eliminating I_{t0} and I_{r0} from (17) by using the distribution factors in (15) and (16), V_{sa} is given as follows:

$$V_{sa} = pZ_1 I_A + 3I_{s0}\left(1 - \frac{Ap + B}{Ap - C}\right) R_f + 3pI_{so} \frac{p(A + B - C) + B}{Ap - C} Z_m \quad (18)$$

Rearranging the variables of (18) in such a way that the equation is expressed as second-order polynomial equation of p, we can obtain the following:

$$p^2 (Z_1 I_A A + 3I_{so} Z_m (A + B - C)) + p(-Z_1 I_A C + 3I_{so} B Z_m - V_{sa} A) + V_{sa} C - 3I_{s0}(B + C) R_f = 0 \quad (19)$$

Equation (19) can be expressed as

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

where

$$a = Z_1 I_A A + 3I_{so} Z_m (A + B - C)$$
$$b = -Z_1 I_A C + 3I_{so} B Z_m - V_{sa} A$$
$$c = V_{sa} C$$
$$d = -3I_{s0}(B + C).$$

Note that these variables are complex values. Equation (20) can be written with real and imaginary parts as follows:

$$\left(a_r + ja_i\right)p^2 + \left(b_r + jb_i\right)p + \left(c_r + jc_i\right) + \left(d_r + jd_i\right)R_f = 0 \tag{21}$$

This means that

$$a_r p^2 + b_r p + c_r + d_r R_f = 0 \quad \text{and} \tag{22}$$

$$a_i p^2 + b_i p + c_i + d_i R_f = 0\,. \tag{23}$$

Fault resistance R_f can be achieved from (23), as follows:

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

Substituting (24) into (22), the final fault location equation is obtained.

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

The following can be defined:

$$m_1 = a_r - \frac{a_i}{d_i}d_r\,,\; m_2 = b_r - \frac{b_i}{d_i}d_r\,,\; m_3 = c_r - \frac{c_i}{d_i}d_r$$

Then, (25) can be simplified as

$$m_1 p^2 + m_2 p + m_3 = 0\,. \tag{26}$$

The roots of (26) are as follows:

$$p = \frac{-m_2 \pm \sqrt{m_2^{\,2} - 4m_1 m_3}}{2m_1} \tag{27}$$

There are two roots for equation (26). Note that the fractional fault location p is between 0 and 1.

3. Case Study

3.1 Test Model

Accuracy evaluation of the proposed algorithm has been carried out using MATLAB/Simulink. The system model is shown in Fig. 4, with system voltage of 154 kV and double circuit lines that are 100 km long. System parameters are shown in Table 1. Various fault cases with different fault locations and fault resistances have been tested.

The fault distance variation is specified every 10 km between 10 and 90 km. Different fault resistances are also considered, namely 10, 25, 50, 75, and 100 ohm. A fault location error is defined as in (32).

Table 1. System parameters

Parameters		Positive sequence impedance	Zero sequence impedance	
Line (Ω/km)		0.0184 + j0.3505	Self	0.2649 + j1.0271
			Mutual	0.2462 + j0.7540
Source	S	0.5331 + j4.1092	1.8699 + j10.1034	
	R	2.2631 + j13.2324	17.6580 + j45.7667	

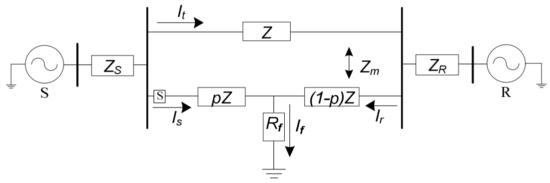

Fig. 4. Simulation system

$$Error(\%) = Abs\left(\frac{Estimated - Actual}{TotalLineLength}\right)x100 \tag{28}$$

3.2 Simulation Test

Various fault cases with different fault locations and fault impedances are tested. Simulation results are shown in Table 2, and errors are shown in Fig. 5. Most errors are

Table 2. Estimated fault distance

d [km]	Estimated fault distance [km]					
	Rf = 0 [Ω]	Rf = 10 [Ω]	Rf = 25 [Ω]	Rf = 50 [Ω]	Rf = 75 [Ω]	Rf = 100 [Ω]
10	10.030	10.093	10.144	10.428	10.019	10.312
20	20.030	20.015	20.255	20.475	20.548	20.893
30	30.062	30.134	30.420	30.476	30.742	31.080
40	40.193	40.148	40.518	40.592	40.912	41.323
50	50.171	50.074	50.395	50.844	50.962	51.199
60	60.146	59.984	60.236	60.622	60.548	60.194
70	70.174	69.940	70.131	70.180	70.327	70.464
80	80.391	80.018	80.269	80.660	81.006	81.476
90	90.076	90.087	90.701	89.877	90.983	91.501

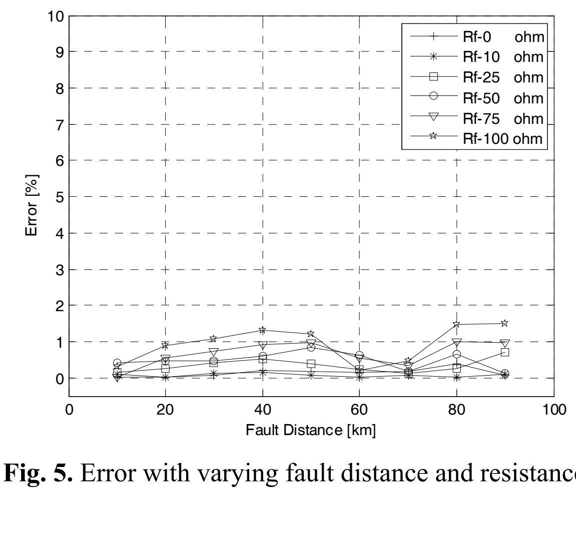

Fig. 5. Error with varying fault distance and resistance.

below 1%; the biggest error of the estimated fault distance occurring when a fault is near the remote end with high fault resistance, albeit it is still less than 2%.

3.3 Robustness to Uncertainty

3.3.1 Robustness to Source Impedance Uncertainty

Although the impedances of a system are assumed to be available for the fault location, they can hardly represent exact values since there is a certain degree of uncertainty that cannot be ignored, especially in the source impedance.

For the system shown in Fig. 4, the average of ±30% variations is added to the zero sequence source impedance in the fault location algorithm and the following four cases are investigated:

Case 1: $Z'_{sa0} = 1.3Z_{sa0}$, $Z'_{sb0} = 1.3Z_{sb0}$
Case 2: $Z'_{sa0} = 0.7Z_{sa0}$, $Z'_{sb0} = 0.7Z_{sb0}$
Case 3: $Z'_{sa0} = 1.3Z_{sa0}$, $Z'_{sb0} = 0.7Z_{sb0}$
Case 4: $Z'_{sa0} = 0.7Z_{sa0}$, $Z'_{sb0} = 1.3Z_{sb0}$

The fault location results with fault resistance of 10[Ω] and 50[Ω] are shown in Figs. 6-9, wherein the biggest error

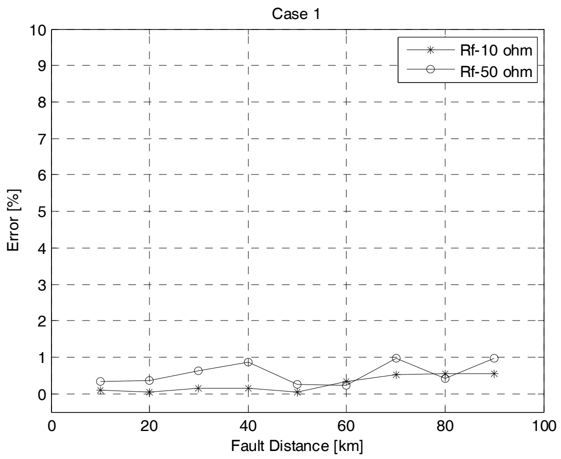

Fig. 6. Fault location error for case 1.

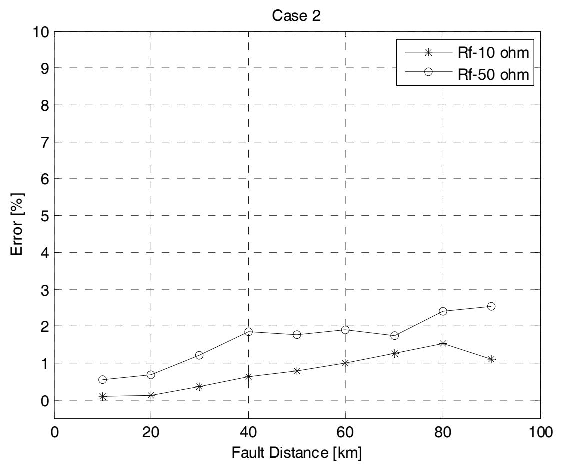

Fig. 7. Fault location error for case 2.

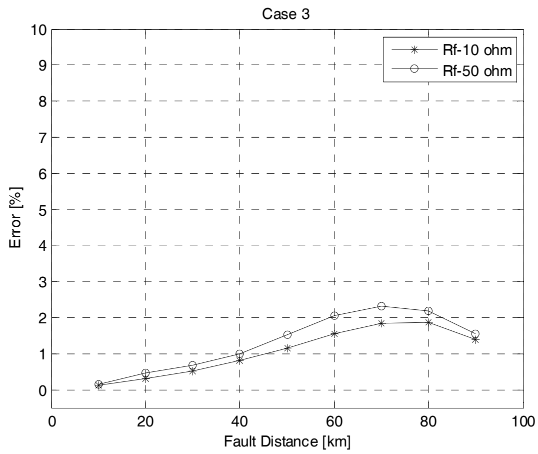

Fig. 8. Fault location error for case 3.

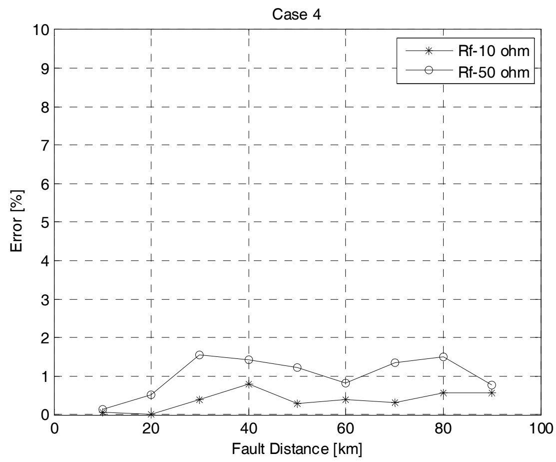

Fig. 9. Fault location error for case 4.

is not more than 3%, which is a fairly good enough accuracy for practical use. The presented algorithm shows high effectiveness not only in terms of accuracy but also in robustness to impedance uncertainty.

A. Robustness to Measurement Errors

Because of CT and VT errors, inaccuracy of line impedances, and A/D conversion error, among others, the performance of the fault location algorithm must be studied.

In this simulation, we assigned the noise in voltage ($\Delta\alpha$), in current ($\Delta\beta$), and in impedance ($\Delta\gamma$) by random value of between -5% and 5%. The coefficient of voltage, current, and impedance can be defined as $\alpha = \Delta\alpha + 1$, $\beta = \Delta\beta + 1$, and $\gamma = \Delta\gamma + 1$.

The simulation results for the fault at 30, 60, and 80 km with fault resistance of R_f= 10[Ω] are shown in Tables 3, 4, and 5, respectively.

As can be seen from the tables, the highest noise input among $\Delta\alpha$, $\Delta\beta$, and $\Delta\gamma$ is 5%, and the error of the estimated fault distance caused by the measurement errors is no more than 3%. Compared to the measurement errors input, the proposed fault location algorithm shows high performance on noise robustness. Other cases with different fault resistance R_f have been simulated with similar results.

Table 3. Estimated errors for fault at 30 km

No.	Max input (Among $\Delta\alpha/\Delta\beta/\Delta\gamma$)	d-estimated (km)	d-estimated error
1	-2.46%	29.98	0.02%
2	3.22%	29.27	0.73%
3	-3.87%	30.76	0.76%
4	-2.75%	30.40	0.40%
5	-3.78%	30.71	0.71%
6	-1.93%	30.36	0.36%
7	-2.86%	30.04	0.04%
8	-3.1%	30.45	0.45%
9	3.55%	31.22	1.22%
10	2.74%	31.02	1.02%
11	3.67%	28.75	1.25%
12	3.49%	29.81	0.19%
13	-3.55%	30.29	0.29%
14	3.17%	30.23	0.23%
15	4.69%	29.58	0.42%

Table 4. Estimated errors for fault at 60 km

No.	Max input (Among $\Delta\alpha/\Delta\beta/\Delta\gamma$)	d-estimated (km)	d-estimated error
1	-2.25%	60.08	0.08%
2	3.00%	60.58	0.58%
3	3.55%	59.82	0.18%
4	2.90%	59.38	0.62%
5	3.56%	60.03	0.03%
6	-2.91%	59.85	0.15%
7	-2.44%	60.36	0.36%
8	2.18%	59.76	0.24%
9	-3.11%	60.65	0.65%
10	3.55%	59.50	0.50%
11	-4.37%	58.15	1.85%
12	2.94%	60.66	0.66%
13	-3.68%	60.51	0.51%
14	-4.38%	61.46	1.54%
15	3.00%	60.77	0.77%

Table 5. Estimated errors for fault at 80 km

No.	Max input (Among$\Delta\alpha/\Delta\beta/\Delta\gamma$)	d-estimated (km)	d-estimated error
1	-4.34%	79.98	0.02%
2	2.82%	79.74	0.26%
3	-3.21%	79.98	0.02%
4	3.41%	79.94	0.06%
5	-2.56%	81.14	1.14%
6	2.62%	79.03	0.97%
7	2.63%	79.81	0.19%
8	3.51%	79.63	0.37%
9	3.06%	79.65	0.35%
10	2.35%	78.89	1.11%
11	4.51%	81.81	1.81%
12	-3.18%	78.70	1.30%
13	-4.48%	81.98	1.98%
14	-4.46%	77.36	2.64%
15	2.79%	80.03	0.03%

4. Conclusion

This study proposed a fault location algorithm for a SLG fault in double-circuit transmission systems using only single-terminal measurements of voltage and current. The proposed algorithm utilizes current distribution factors to estimate the unknown currents from the measured currents derived from a circuit analysis of phase-circuit and zero sequence networks. The fault location could be achieved by solving a simple second-order polynomial equation.

Simulation tests using MATLAB/Simulink for faults at different locations with various fault resistance demonstrate high accuracy. Considering the source impedance uncertainty and the measurement errors, the simulations also show that the proposed algorithm has high robustness.

Acknowledgments

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References

[1] T. Takagi, Y. Yamakoshi, J. Baba, K. Uemura and T. Sakaguchi, “A new algorithm of an accurate fault location for EHV/UHV transmission lines. Part I: Fourier transform method”, IEEE Trans. Power Appar. Syst. PAS-100, 3, (1981), pp. 1316-1322.

[2] T. Takagi, Y. Yamakoshi, J. Baba, K. Uemura and T. Sakaguchi, “A new algorithm of an accurate fault location for EHV/UHV transmission lines. Part II: Laplace transform method”, IEEE Trans. Power Appar. Syst. 101, 3, (1982), pp. 564-573.

[3] S. A. Soliman, M. H. Abdel-Rahman, E. Al-Attar and M. E. El-Hawary, “An algorithm for estimating fault location in an unbalanced three-phase power system”, International Journal of Electrical Power and Energy Systems, Vol. 24, 7, Oct. 2002, pp 515-520.

[4] B. Liana, M. M. A. Salamaa and A. Y. Chikhanib, “A time domain differential equation approach using distributed parameter line model for transmission line fault location algorithm”, Electric Power Systems Research, Vol. 46, Issue 1, July 1998, pp 1-10.

[5] A. Gopalakrishnan, M. Kezunovic, S.M.McKenna, D.M. Hamai, “Fault location using the distributed parameter transmission line model”, IEEE Transactions on Power Delivery, Vol. 15, Issue 4, Oct. 2000 pp - 1169-1174.

[6] M. Kizilcay, P. La Seta, D. Menniti, M. Igel, “A new fault location approach for overhead HV lines with line equations”, IEEE Power Tech Conference Proceedings 2003, Bologna, 23-26 June 2003, Vol. 3, pages: 7.

[7] G. B. Ancell, N. C. Pahalawaththa, "Maximum likelihood estimation of fault location on transmission lines using traveling waves," IEEE Trans. Power Delivery, Vol.9, pp.680-689, Apr. 1994.
[8] M.M. Tawfik, M.M. Morcos, "A novel approach for fault location on transmission lines", IEEE Power Eng. Rev. 18, Nov. 1998, pp. 58U″ 60.
[9] H. Heng-xu, Z. Bao-hui, L. Zhi-lai, "A novel principle of single-ended fault location technique for EHV transmission lines", IEEE Transactions on Power Delivery, Vol. 18, 4, Oct. 2003, pp. 1147-1151.
[10] Liqun Shang, Wei Shi, "Fault Location Algorithm for Double-Circuit Transmission Lines Based on Distributed Parameter Model", Journal of Xi'An Jiaotong University, Vol. 39, No. 12, Dec. 2005
[11] Guobing Song, Suonan Jiale, Qingqiang Xu, Ping Chen; Yaozhong Ge, "Parallel transmission lines fault location algorithm based on differential component net", IEEE Transactions on Power Delivery, Vol. 20, Issue 4, pp.2396-2406, Oct. 2005.
[12] Kawady T., Stenzel J., "A practical fault location approach for double circuit transmission lines using single end data", IEEE Transactions on Power Delivery, Vol.18, Issue 4, pp.1166-1173, Oct. 2003
[13] Hongchun Shu, Dajun Si, Yaozhong Ge, Xunyun Chen, "A least error squares method for locating fault on coupled double-circuit HV transmission line using one terminal data", Proceedings on PowerCon 2002, Vol.4, pp.2101-2105, Oct. 2002
[14] Yong-Jin Ahn, Myeon-Song Choi, Sang-Hee Kang, Seung-Jae Lee, "An accurate fault location algorithm for double-circuit transmission systems", IEEE Power Engineering Society Summer Meeting, Vol.3, pp.1344-1349, July 2000.
[15] Xia Yang, Myeon-Song Choi, and Seung-Jae Lee, "Double-Circuit Transmission Lines Fault location Algorithm for Single Line-to-Ground Fault". Journal of Electrical Engineering & Technology, Vol.2, No.4, pp.434-440, Dec. 2007.

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