ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 1, July 2013

Iterative and Non-Iterative Methods for Transmission Line Fault-Location Without using Line Parameters

Sumit, Shelly vadhera

Abstract*—This paper explores iterative and non-iterative methods in order to locate the transmission line fault without the use of line parameters. Firstly, the simulation is carried out in Matlab to obtain the fault voltages and currents at both ends of a transmission line. Then, with the help of enhanced Newton-Raphson based iterative method simulated data is used for estimating the location of unbalanced and balanced faults on line. This method reduces the number of unknown variables in the Newton-Raphson solution process and thus is more computationally efficient. Also, a non-iterative method is applied for locating all types of faults in a line. A comparison is done between iterative and non-iterative methods for medium and long transmission line.

Index Terms— **Enhanced Newton-Raphson method, Matlab, Non-Iterative method, Transmission line fault.**

I. INTRODUCTION

Basic goal of power systems is to continuously provide electrical energy to the users. Like in any other system, failures in power systems can also occur. In that situation it is critical to adopt correct remedial actions as soon as possible. For correct remedial actions it is important to detect accurate fault condition and location. Fault location is a process aimed to locate the fault with the highest accuracy possible. Earlier enormous efforts have been undertaken for determining fault-location based on recorded data. In the past, on the basis of available data, one-terminal, two-terminal, or multi-terminal algorithms have been proposed. In one terminal algorithm fault-location is estimated by using local data which obviates the need of transferring data from the remote end. However, this type of algorithm is adversely affected by the fault resistance, although certain compensation techniques were adopted to remove this effect [1]. To improve the accuracy of evaluation, in [2] remote source impedance has been considered. A new method has been presented for the computation of fault location in two and three-terminal high voltage line in [3] which is based on digital computation of the three-phase current and voltage 60/50 Hz phasors.

Fault detection and classification based on a traveling wave including an implementation of an enthusiastic data sampling synchronization system have been described in [4,5] whereas in [6], a new approach of fault analysis using synchronized measurement was introduced which uses a digital fault recorder with global positioning system(GPS) satellite receiver.

The method proposed in [7] utilized measurement at both the ends of line by using two terminal transmission line model. Reference [8] used a lumped line model and an iterative way to compensate the shunt capacitance for long lines. A method based on synchronized voltage measurement at multi-ends of lines is utilized to locate the fault by assuming source impedances without considering shunt capacitance in [9]. Although these algorithms give accurate fault location but all of them consider that the line parameters are already known. So for obtaining the line parameters, an adaptive line parameter estimation algorithm was proposed in [10] for both transposed and untransposed parallel lines. The drawback in [10] is that for synchronized data phasor measurements at both ends of lines phasor measurement unit (PMU) is used and continuous monitoring of the line under normal condition is required. So to locate the fault without considering line parameters a Newton-Raphson based two terminal iterative algorithm was introduced in [11]. Unsynchronized voltage and currents at both the ends of line is required. Therefore neither data synchronization nor prefault data is required. However, this algorithm is applied to solve three complex equations to calculate six unknowns. In order to decrease the number of unknown variables [12] puts forward an enhanced algorithm which uses EMTP software for carrying out the simulation and evaluating the results. In this paper for the enhancement of the computational efficiency, instead of EMTP software [12] Matlab software is used. In this paper, voltages and currents at both ends of a transmission line during the fault are obtained from Matlab/Simulink. Further, by using these voltages and currents phasor values for both cases iterative and non-iterative methods are used for calculating an accurate fault location. However, it is observed that enhanced Newton-Raphson based iterative method gives better results than non-iterative method for both cases.

II. ENHANCED NEWTON-RAPHSON BASED ITERAT- IVE METHOD

The two-terminal transmission line under consideration is as shown in Fig.1. and represents the equivalent voltage sources at buses P and Q. The fault point is indicated by R.

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 1, July 2013

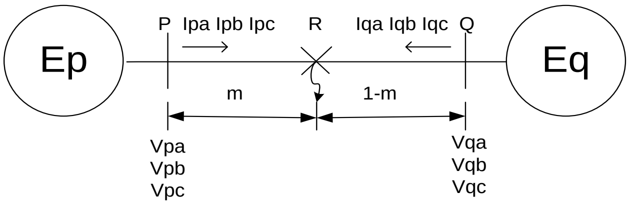


Fig.1 Schematic diagram used for evaluation of enhanced Newton-Raphson based iterative method

The notations used are as follows:

- V_{pa}, V_{pb}, V_{pc} represents phase a, b, c voltages during the fault at terminal P respectively;
- I_{pa}, I_{pb}, I_{pc} represents phase a, b, c currents during the fault at terminal P respectively;
- V_{qa}, V_{qb}, V_{qc} represents phase a, b, c voltages during the fault at terminal Q respectively;
- I_{qa}, I_{qb}, I_{qc} represents phase a, b, c currents during the fault at terminal Q respectively;
- m: per-unit fault distance from terminal P.

The fundamental frequency phasor values of voltages and currents are used for this method. It is assumed that the line is a transposed one and three phase voltages and currents at terminals P and Q are available. Synchronization of the data at terminal P and Q is not required. Eqns. (1) and (2) are obtained by using symmetrical component theory.

$$V_{p1} - mZ_1 I_{p1} = [V_{q1} - (1-m)Z_1 I_{q1}]e^{j\delta} \quad (1)$$

$$V_{p2} - mZ_1 I_{p2} = [V_{q2} - (1-m)Z_1 I_{q2}]e^{j\delta} \quad (2)$$

Where

- V_{p1} and V_{p2} are the positive and negative-sequence fault voltages at terminal P respectively;
- I_{p1} and I_{p2} are the positive and negative-sequence fault currents at terminal P respectively;
- V_{q1} and V_{q2} are the positive and negative-sequence fault voltages at terminal Q respectively
- I_{q1} and I_{q2} are the positive and negative-sequence fault currents at terminal Q respectively;
- Z_1 is the total positive sequence impedance of the line; and
- δ is the synchronization angle between measurements at terminal P and Q.

Eliminate from Eqn. (1) and then obtain Eqn. (3) from Eqn. (2).

$$m(V_{p1}I_{p2} - V_{p2}I_{p1}) + [(V_{p2}I_{q1} - V_{p1}I_{q2}) + m(V_{p1}I_{q2} + V_{q2}I_{p1} - V_{q1}I_{p2} - V_{p2}I_{q1})]e^{j\delta} + [(V_{q1}I_{q2} - V_{q2}I_{q1}) + m(V_{q2}I_{q1} - V_{q1}I_{q2})]e^{j2\delta} = 0 \quad (3)$$

Eqn. (3) results in Eqn. (4).

$$m = \frac{A_2 e^{j\delta} + A_4 e^{j2\delta}}{A_4 e^{j2\delta} - A_1 - A_3 e^{j\delta}} \quad (4)$$

The constants in Eqn. (4) are obtained from Eqns. (A1), (A2), (A3) and (A4).

$$A_1 = V_{p1}I_{p2} - V_{p2}I_{p1} \quad (A1)$$

$$A_2 = V_{p2}I_{q1} - V_{p1}I_{q2} \quad (A2)$$

$$A_3 = V_{p1}I_{q2} + V_{q2}I_{p1} - V_{q1}I_{p2} - V_{p2}I_{q1} \quad (A3)$$

$$A_4 = V_{q1}I_{q2} - V_{q2}I_{q1} \quad (A4)$$

Since m is a real number, the imaginary part of Eqn. (4) is made 0 as shown in Eqn. (5).

$$\frac{A_2 e^{j\delta} + A_4 e^{j2\delta}}{A_4 e^{j2\delta} - A_1 - A_3 e^{j\delta}} - \frac{\bar{A}_2 e^{-j\delta} + \bar{A}_4 e^{-j2\delta}}{\bar{A}_4 e^{-j2\delta} - \bar{A}_1 - \bar{A}_3 e^{-j\delta}} = 0 \quad (5)$$

Where the bar indicates the complex conjugate.

Eqn. (6) and Eqn. (7) are obtained by simplifying Eqn. (5).

$$f(\delta) = b_1 \cos\delta - a_1 \sin\delta - b_2 + b_3 \cos 2\delta - a_3 \sin 2\delta \quad (6)$$

$$f(\delta) = 0 \quad (7)$$

Where a_1, b_1, a_2, b_2, a_3 and b_3 are obtained from real and imaginary parts of Eqns. (A5), (A6) and (A7).

$$a_1 + jb_1 = A_1\bar{A}_2 + A_2\bar{A}_4 + A_3\bar{A}_4, \quad (A5)$$

$$a_2 + jb_2 = A_2\bar{A}_3, \quad (A6)$$

$$a_3 + jb_3 = A_1\bar{A}_4, \quad (A7)$$

The Newton-Raphson method is applied to determine δ. In the k^{th} iteration, δ is obtained as shown in Eqn. (9).

$$\Delta\delta = \frac{-f(\delta_k)}{\left[\frac{df}{d\delta}(\delta_k)\right]} \quad (8)$$

$$\delta_{k+1} = \delta_k + \Delta\delta \quad (9)$$

Where

δ_k and δ_{k+1} are the values of δ at the k^{th} and $(k+1)^{th}$ iteration, respectively. $\Delta\delta$ is the updated value for δ at the k^{th} iteration and k is the iteration number starting from 1.

Eqn. (10) shows the expression of the derivative.

$$\frac{df(\delta)}{d\delta} = -b_1 \sin\delta - a_1 \cos\delta - 2b_3 \sin 2\delta \quad (10)$$

The iteration can be ended when the updated $\Delta\delta$ is smaller than the specified tolerance which is 0.0001. A starting value of 0 is used for δ. After obtaining the synchronization angle, the fault location m is calculated from Eqn. (4).

III. NON-ITERATIVE METHOD

This section describes the method for line-to-ground faults (L-G), line-to-line faults (L-L), double line-to-ground faults (L-L-G), and three phase symmetrical faults (L-L-L).

A. *METHOD FOR LINE-TO-GROUND FAULTS*

A line-to-ground fault at phase *a* and zero value of fault resistance is considered here. The fault location obtained from terminal P is shown in Eqn. (11).

$$m = \frac{V_{pa}}{(I_{pa} + I_{p0}k)Z_1} \quad (11)$$

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 1, July 2013

$$k = \frac{Z_0 - Z_1}{Z_1} \quad (12)$$

Also the fault location is obtained by utilizing measurement from terminal Q as shown in Eqn. (13).

$$1 - m = \frac{V_{qa}}{(I_{qa} + I_{q0}k)Z_1} \quad (13)$$

where I_{p0} and I_{q0} are zero-sequence currents during fault at terminal P and Q, respectively.

Eqns. (11) and (14) does not include the synchronization angle because only local data is utilized in each equation. Eliminating Z_1 from Eqns. (11) and (13) and solving for k reaches

$$k = \frac{A_5 + A_6 m}{A_7 + A_8 m} \quad (14)$$

Where

$A_5 = V_{pa} I_{qa},$

$A_6 = -(V_{pa} I_{qa} + V_{qa} I_{pa}),$

$A_7 = -V_{pa} I_{q0},$

$A_8 = V_{pa} I_{q0} + V_{qa} I_{p0}.$

Since Z_0 and Z_1 of the transmission line normally have similar angles, the imaginary part of k is relatively small. Therefore, Eqn. (15) can be deduced by approximating the imaginary part of Eqn. (14) as zero.

$$c_2 m^2 + c_1 m + c_0 = 0 \quad (15)$$

Where c_0, c_1 and c_2 are defined as

$c_0 = A_5 \bar{A}_7 - \bar{A}_5 A_7$

$c_1 = A_5 \bar{A}_8 + A_6 \bar{A}_7 - \bar{A}_5 A_8 - \bar{A}_6 A_7$

$c_2 = A_6 \bar{A}_8 - \bar{A}_6 A_8$

Two values of m are obtained by solving Eqn. (15), and the value falling between 0 and 1 will be regarded as the *a-g* fault location. Similarly the fault location for L-G fault at phases *b* and *c* are obtained by modifying Eqn. (11) to (15) accordingly.

B. METHOD FOR FAULTS INVOLVING MULTI-PHASES

A fault involving phases *a*, *b* and ground for L-L-G fault and phases *a* and *b* for L-L fault are considered here. Again, assume zero value for fault resistance. The fault location calculated based on the data from terminal P is shown in Eqn. (16).

$$m = \frac{V_{pa} - V_{pb}}{(I_{pa} - I_{pb})Z_1} \quad (16)$$

From terminal Q, we acquire

$$1 - m = \frac{V_{qa} - V_{qb}}{(I_{qa} - I_{qb})Z_1} \quad (17)$$

Eliminating Z_1 from Eqns. (16) and (17) leads to the fault location shown in Eqn. (18).

$$m = \frac{1}{1 + \left\{\left[\left((V_{qa} - V_{qb})\right)(I_{pa} - I_{pb})\right] / \left[(V_{pa} - V_{pb})(I_{qa} - I_{qb})\right]\right\}} \quad (18)$$

Similarly the fault location for L-L-G fault at other phases is obtained by modifying Eqns. (16) to (18). For a three-phase fault, this approach can be applied by utilizing phase *b* and *c* quantities, or phase *c* and *a* quantities, or phase *a* and *b* quantities, resulting in three fault location estimates. These estimates may not be the same for not ideally balanced three-phase faults, and the average value of the three estimates can be regarded as the final estimate.

IV. SIMULATION STUDY

Simulation using the MATLAB/Simulink has been carried out to evaluate the voltage and current measurements at both ends of a transmission line during the fault. A 500KV transmission-line system is used for the simulation, with detailed parameters referred to Appendix. Here two cases are taken:

- A 500KV, 150km transmission-line system is used for the simulation. The fault distance is assumed to be at a distance 70km from terminal P.
- A 500KV, 320km transmission-line system is used for the simulation. The fault distance is assumed to be at a distance 180km from terminal P.

The per-unit system is utilized with a voltage base of 500kV and an apparent power base of 100 MVA. The voltage and current phasor values obtained for line-to-ground fault for both cases are shown in Table 1 and Table 2 respectively. Similarly, voltage and current phasor values are obtained for all type of faults for both the cases.

Table 1: Voltage and current phasor values during L-G fault for case 1.

Quantities	Values (p.u.)
V_{pa}	0.6449 + 0.1966i
V_{pb}	-0.3249 - 0.9827i
V_{pc}	-0.7920 + 0.6740i
I_{pa}	19.9300 -27.1620i
I_{pb}	-1.7997 - 9.7106i
I_{pc}	-7.2788 + 6.0860i
V_{qa}	0.7118 + 0.0042i
V_{qb}	-0.5064 - 0.9174i
V_{qc}	-0.6309 + 0.8104i
I_{qa}	0.5106 -29.2550i
I_{qb}	3.4785 + 8.8853i
I_{qc}	5.9003 - 7.4417i

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 1, July 2013

Table 2: Voltage and current phasor values during L-G fault for case 2.

Quantities	Values (p.u.)
V_{pa}	0.8022 + 0.2653i
V_{pb}	-0.2616 - 0.9900i
V_{pc}	-0.7797 + 0.6730i
I_{pa}	10.4374 -12.1004i
I_{pb}	0.1691 - 8.2887i
I_{pc}	-5.4230 + 2.7513i
V_{qa}	0.8174 + 0.0012i
V_{qb}	-0.5193 - 0.9088i
V_{qc}	-0.5937 + 0.8417i
I_{qa}	0.4824 -17.9435i
I_{qb}	3.4796 + 4.4234i
I_{qc}	2.4126 - 5.7395i

This simulated data of voltage and current phasors is fed to a Matlab based programming in order to locate the transmission line fault location. The voltage and current waveforms at terminal P obtained from Simulink model during L-G fault are shown in Fig. 2. Similarly, the voltage and current waveforms at terminal Q are shown in Fig. 3.

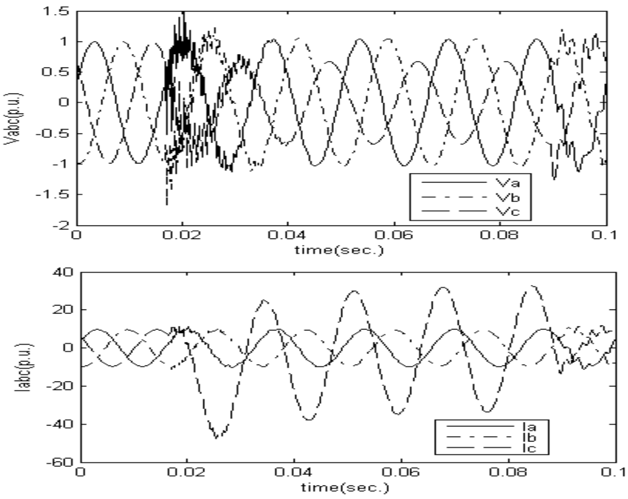
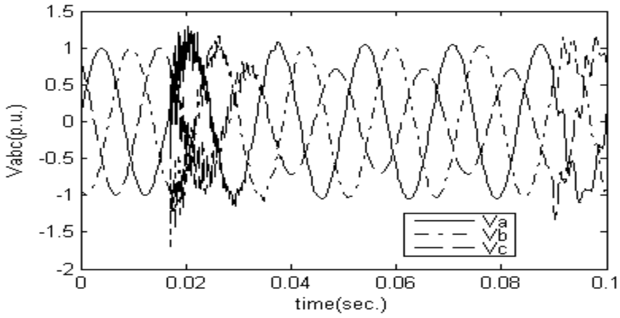


Fig.2 Voltage and current waveforms at P terminal for the L-G fault



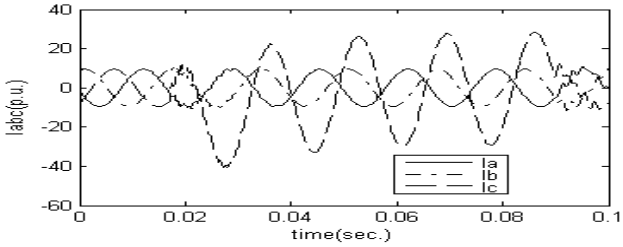


Fig.3 Voltage and current waveforms at Q terminal for the L-G fault

V. RESULTS

For the Enhanced Newton-Raphson based iterative method, starting value of 0 for δ is chosen in all the cases. The iteration process is terminated when the successive update of δ becomes less than 0.0001. The algorithms are applied without any knowledge of the line parameters. The non-iterative methods assume a zero value for the fault resistance and do not model the shunt capacitance of the line. Therefore, the estimate may contain certain errors. However, in absence of line parameters, the algorithms are capable of producing very reliable results. Table 3 and Table 4 show the estimated fault location for case1 and case 2 respectively.

Table 3: Estimated fault location using both the methods for case 1

			Enhanced iterative method	Non-iterative method
Fault type		Actual fault location (p.u.)	Estimated fault location (p.u.)	Estimated fault location (p.u.)
	a-g	0.4666	0.4688	0.4560
L-G	b-g	0.4666	0.4664	0.4558
	c-g	0.4666	0.4712	0.4550
	a-b-g	0.4666	0.4677	0.4675
L-L-G	b-c-g	0.4666	0.4671	0.4654
	c-a-g	0.4666	0.4109	0.4406
	a-b	0.4666	0.4678	0.4677
L-L	b-c	0.4666	0.4663	0.4648
	c-a	0.4666	0.4669	0.4647
L-L-L	a-b-c	0.4666	0.4785	0.4659

Table 4: Estimated fault location using both the methods for case 2

			Enhanced iterative method	Non-iterative method
Fault type		Actual fault location (p.u.)	Estimated fault location (p.u.)	Estimated fault location (p.u.)
L-G	a-g	0.5625	0.5826	0.5480

	b-g	0.5625	0.5608	0.5521
	c-g	0.5625	0.5612	0.5507
	a-b-g	0.5625	0.5560	0.5648
L-L-G	*b-c-g*	0.5625	0.5596	0.5626
	c-a-g	0.5625	0.5606	0.5626
	a-b	0.5625	0.5597	0.5650
L-L	*b-c*	0.5625	0.5543	0.5626
	c-a	0.5625	0.5614	0.5644
L-L-L	*a-b-c*	0.5625	0.5610	0.5641

VI. CONCLUSION

The iterative and non-iterative methods for transmission line fault location using unsynchronized voltages and currents during the fault without requiring line parameters are presented in this paper. The enhanced Newton-Raphson based iterative method is much simple and even imposes less computational burden. It is applicable to both balanced and unbalanced faults. The other approach used in this paper is based on non-iterative method which is also applicable to all types of faults. Evaluation studies based on Matlab simulation have produced quite reliable results. For iterative method, the convergence behavior shows that the average of the estimated fault location including all the faults is 0.4631 for case 1 and 0.5617 for case 2. Similarly, for non-iterative method the convergence behavior shows that the average of the estimated fault location including all the faults is 0.4603 for case 1 and 0.5596 for case 2. Although it may be noted that in case of non-iterative method especially for three-phase faults the percentage error is less.

APPENDIX

The parameters of the lines used for Simulation are:

=0.01273 Ω/km

=0.9337 mH/km

=12.74 nF/km

=0.3864 Ω/km

=4.1264 mH/km

=7.751 nF/km

The source impedances are as follows:

Sending end

=2+18.8495i Ω

=4+0.37699i Ω

Receiving end

=2+18.8495i Ω

=4+0.37699i Ω

REFERENCES

[1] L. Eriksson, M. M. Saha and G. D. Rockefeller, "An accurate fault locator with compensation for apparent reactance in the fault resistance resulting from remote-end in feed", IEEE Trans. Power Appar. Syst., Vol. 104, No. 2, pp. 424–436, 1985.

[2] A. T. Johns, P. J. Moore, and B. Whittard, "New technique for the accurate location of earth faults on transmission systems", IEE Proc. Gener. Transm. Distrib., Vol. 142, No. 2, pp. 119–127, March 1995.

[3] A. A. Girgis, D. G. Hart, and W. L. Peterson, "A new fault location technique for two-and three-terminal lines", IEEE Trans. Power Deliv., Vol. 7, No. 1, pp. 98–107, 1992.

[4] T. Takagi, J.4. Baba, K. Uemura, T. Sakaguchi, "Fault protection based on traveling wave theory: Part I - Theory", IEEE PES Summer Power Meeting, Paper No. A77 750-3, 1977.

[5] F. Aoki, Y. Akimoto, K. Uemura, T. Sakaguchi, 'Totally digitalized control system with simultaneous data sampling and fault protection principle applied to the system", 6th PSCC, Darmstadt, 1979.

[6] M. Kezunovic and B. Perunicic, "Automated transmission line fault analysis using synchronized sampling at two ends", IEEE Trans. Power Syst., Vol. 11, No. 1, pp. 441–447, 1996.

[7] Y. Liao, and M. Kezunovic, "Optimal estimate of transmission line fault location considering measurement errors", IEEE Trans. Power Deliv., Vol. 22, No. 3, pp. 1335–1341, July 2007.

[8] Novosel, D. G. Hart, E. Udren, and J. Garitty, "Unsynchronized two terminal fault location estimation", IEEE Trans. Power Del., Vol. 11, No. 1, pp. 130–138, Jan. 1996.

[9] S. M. Brahma, "Fault location on a transmission line using synchronized voltage measurements," IEEE Trans. Power Del., Vol. 19, No. 4,pp. 1619–1622, Oct. 2004.

[10] C. S. Chen, C. W. Liu and J. A. Jiang, "A new adaptive PMU based protection scheme for transposed/ untransposed parallel transmission lines", IEEE Trans. Power Deliv., Vol. 17, No. 2, pp. 395–404, 2002.

[11] Y. Liao and S. Elangovan, "Unsynchronized two-terminal transmission line fault location without using line parameters", IEE Proc. Gener. Transm. Distrib. Vol. 153, No. 6, pp. 639–643, Nov. 2006.

[12] Y. Liao, "Transmission line fault location algorithms without requiring line parameters", Elect. Power Compon. Syst., Vol. 36, pp. 1218–1225, Oct. 2008.