Fault Location System for Transmission Lines in One-terminal By using Impedance-Traveling Wave Assembled Algorithm

Sachin R. Yerekar
Department of Electrical Engineering
Veermata Jijabai Technogical Institute,
Matunga, Mumbai-400019
sachin_yerekar@yahoo.co.in

***Abstract:* - Considering roundly reliability and accuracy of one terminal fault location system for transmission lines, an impedance-traveling wave assembled algorithm, which combines measurement impedance method with traveling wave method, is presented. At first, it uses measurement impedance method to calculate roughly fault distance. Then regions of reflected waves from fault point and opposite bus to detective bus are confirmed respectively through the distance. At last, exact time of reflected wave from fault point to detective bus and that of reflected wave from opposite bus to detective bus are identified respectively in corresponding regions, and fault location is implemented according to the result detected. It has complementarities of both methods, because measurement impedance method guarantees reliability and traveling wave method improves accuracy. Results of simulation are that located errors are within 100m if fault location based on traveling wave algorithm is available. It is improved that assembled algorithm proposed is correct.**

***Keywords:-* Accuracy; Assembled algorithm; Fault currents; Fault location; Fault resistance; Measurement impedance; One-terminal; Reliability; Transmission lines; Traveling wave.**

I. INTRODUCTION:

Transmission lines are vital in electric power systems, because they shoulder missions of transmitting power energy. However, they are also the parts which are bounded to have faults, and it is very difficult to find the faults. Thus, fast and accurate fault location for transmission lines, which is an imperative problem to be solved, plays an increasingly important role in electric power systems. It not only saves a large amount of manpower and material resource, but also makes it easy to find some covert faults, such as the insulator puncture. Various fault location methods have been developed and fault location techniques have been a subject for many researchers [1].

One-terminal fault location system just installs fault location device on one terminal of transmission lines, and doesn't have to use communication device, so it is more economical than two-terminal fault location system [2], [3]. In one-terminal fault location system, there are two categories, one is based on power frequency quantities, and the other is based on traveling wave. The former is economical and easy to implement, especially, measurement impedance algorithm is the most robust algorithm of one-terminal fault location based on power frequency quantities [4], [5], but has no high accuracy. The latter has high accuracy except of reliability [6]. However, both reliability and accuracy are vital in fault location technology. Thus, considering roundly reliability and accuracy of one-terminal fault location system, an impedance-traveling wave assembled algorithm, which combines measurement impedance method with traveling wave method, is presented. The assemble algorithm have complementarities, because measurement impedance method guarantees reliability and traveling wave method improves accuracy [7], [8].

II.IMPEDANCE - TRAVELING WAVE ASSEMBLED ALGORITHM:

The algorithm proposed includes two parts, one is measurement impedance method, and the other is traveling wave method.

A. Measurement impedance method:

An algorithm named measurement impedance method is proposed in document [9]. It eliminates fault resistance for calculating fault distance according to measurement impedance, transmission line positive-sequence impedance angle and detective currents.

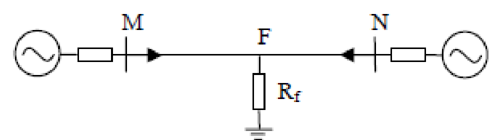

Fig.1 Fault diagram of three-phase power system

According to fault location algorithm based on measurement impedance method, fault distance can be calculated by Equation (1).

$$xx_1 = X_M - \frac{R_M tg\varphi_L - X_M}{a\, tg\varphi_L - b} b \quad (1)$$

Where $a = \mathrm{Re}[I_{Mf} / I_M]$, $b = \mathrm{I_m}[I_{Mf} / I_M]$, x is fault distance from bus M to fault point F, x_1 is positive-sequence reactance per kilometer of transmission lines, φ_L is transmissions' line positive-sequence impedance angle, I_{Mf} is fault component current, U_M and I_M are respectively detective voltage and current with the definition of distance protective measurement impedance, that's $R_M + jX_M = U_M / I_M$.

In the algorithm named measurement impedance method, it's assumed that the phase angle between fault current I_f and fault component current I_{Mf} is zero, so the fault error will be inevitably led.

Simplicity and reliability are the main characteristic of algorithm based on measurement impedance. It's basic principle is the same as the one of distance protection. With measurement impedance, distance relay determines the fault section and trip fault line selectively. So the algorithm based on measurement impedance can be taken to boundary the fault section of transmission lines [8].

B. Traveling wave method:

When a fault occurs in transmission lines, fault traveling wave will transmit from fault point to detective bus and opposite bus along the transmission lines. Because of discontinuous impedance, fault traveling wave to detective bus will be reflected at detective bus and transmit to fault point, then will be reflected at fault point and transmit to detective bus for the second time. For the same reason, fault traveling wave to opposite bus will be reflected at opposite bus and transmit to fault point, and may be refracted at fault point and transmit to detective bus.

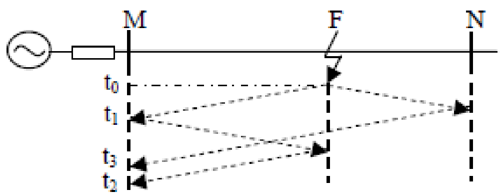

Fig.2 Diagram of fault traveling wave propagation

As shown in Fig.2, L is the length of the fault lines, x is the fault distance from detective bus M, t_0 is the time when fault occurs, t_1 is the time when initial traveling wave arrives at detective bus, t_2 is the time when traveling wave reflected at fault point arrives at detective bus, t_3 is the time when traveling wave reflected at opposite bus and refracted at fault point arrives at detective bus.

A great deal of computer simulation showed that the largest error of algorithm based on measurement impedance is within the limit of 10% under different fault case [8]. So the actual distance to fault point is sure in the region of (x-10%L, x +10%L). t_M , t_N and δ_t are defined as the needed time that fault traveling wave transmits from fault point to detective bus M, the needed time that fault traveling wave transmits from fault point to opposite bus N, and the corresponding time error of the distance error of 10%L .
They are expressed as in (2).

$$\begin{cases} t_M = \dfrac{x}{v} \\ t_N = \dfrac{L-x}{v} \\ \delta_t = \dfrac{10\%}{v} L \end{cases} \qquad (2)$$

Where v is defined as velocity of traveling wave which can be calculated according to lines' parameters or be obtained from former velocity of traveling wave modified by (4).

Using $t1$ as time reference, $t2$ is in the region of $(t_1+2t_M -2\delta_t , t_1+2t_M+2\delta_t)$ and t_3 is in the region of $(t_1+2t_N-2\delta_t , t_1+2t_N+2\delta_t)$.

In case of that both 2 t and 3 t can be detected, simultaneous
equation will be expressed as in (3).

$$\begin{cases} v'(t_1 - t_0) = x' \\ v'(t_2 - t_0) = 3x' \\ v'(t_3 - t_0) = 2L - x' \end{cases} \qquad (3)$$

Where v' , t_0 and x' are unknown, denoting respectively as the true velocity of traveling wave, the time when fault occurs and fault distance.

The equation as in (4) can be obtained from equation as in (3).

$$\begin{cases} t_0 = \dfrac{3t_1 - t_2}{2} \\ x' = \dfrac{t_2 - t_1}{t_2 + t_3 - 2t_1} L \\ v' = \dfrac{2L}{t_2 + t_3 - 2t_1} \end{cases} \qquad (4)$$

In case of that t_2 can be detected, but t_3 cannot be, simultaneous equation will be expressed as in (5).

$$\begin{cases} v(t_1 - t_0) = x' \\ v(t_2 - t_0) = 3x' \end{cases} \qquad (5)$$

The equation as in (6) can be obtained from equation as in (5).

$$\begin{cases} t_0 = \dfrac{3t_1 - t_2}{2} \\ x' = \dfrac{1}{2}(t_2 - t_1)v \end{cases} \qquad (6)$$

In case of that t_3 can be detected, but t_2 cannot be, simultaneous equation will be expressed as in (7).

$$\begin{cases} v(t_1 - t_0) = x' \\ v(t_3 - t_1) = 2(L - x') \end{cases} \qquad (7)$$

The equation as in (8) can be obtained from equation as in (7).

$$\begin{cases} t_0 = \dfrac{t_1 + t_3}{2} - \dfrac{L}{v} \\ x' = L - \dfrac{1}{2}(t_3 - t_1)v \end{cases} \qquad (8)$$

In worst case of that both t_2 and t_3 cannot be detected, t_0 and x' will be expressed as in (9).

$$\begin{cases} t_0 = t_1 - \dfrac{x}{v} \\ x' = x \end{cases} \qquad (9)$$

C. Analysis in theory:

Simplicity and reliability are the main characteristic of algorithm based on measurement impedance. Its basic principle is the same as the one of distance protection. With measurement impedance, distance relay determines the fault section and trip fault line selectively. So algorithm based on measurement impedance can be taken to boundary the fault section of transmission lines.

In the algorithm, exact time of reflected wave from fault point to detective bus and that of reflected wave from opposite bus to detective bus are identified respectively in the regions of $(t_1+2t_M -2\delta_t , t_1+2t_M+2\delta_t)$ and $(t_1+2t_N -2\delta_t , t_1+2t_N+2\delta_t)$. So it's unnecessary to detect t_2 and t_3 in full region of $[t_1,t_1+2L/v]$, but in its sub-regions of $(t_1+2t_M -2\delta_t$,

$t_1+2t_M+2\delta_t$) and ($t_1+2t_N-2\delta_t$, $t_1+2t_N+2\delta_t$). As a result, total length of its sub-regions is $v\ L\ t$ 8™ = 0.8 , only 40% of the length of full region. Moreover, the algorithm can also decrease the disturbance of traveling wave reflected from neighbor buses.

In case of that both t_2 and t_3 can be detected, the precision of fault location can avoid the effect of traveling wave velocity, what's more, the velocity of traveling wave can be modified online [11]. Because of the velocity of traveling wave modified endlessly, it will approach the true velocity. In case of that just t_2 or t_3 can be detected, the precision of fault location calculated by Equation (6) or (8) is hardly affected by the effect of traveling wave velocity. In worst case of that both t_2 and t_3 cannot be detected, fault location based on traveling wave algorithm isn't available, but fault location algorithm based on measurement impedance method can guarantees reliability.

III. SIMULATION TEST:

In order to demonstrate the correctness of the assembled algorithm proposed, a model with length of 300km, voltage grade of 500kV and frequency of 50Hz is built for simulation. As shown in Fig.3, single transmission lines between bus M and bus N connect Equivalent system M and Equivalent system N. Fault distance can be set by the means of changing the lengths of line part1 and line part2. Fault type and fault resistance can be set through the module of Fault Setting. Ports for measurement are set at bus M. Waveforms of currents and voltages at bus M can be detected by the way of oscillograph module, and data of voltages and currents will be put out through the outputs of Out1 and Out2.

Transmission lines' distributed parameters are given as following:

r_1 =0.0270 Ω/km , x_1 =0.2783 Ω/km ,

c_1 =0.0127 $\mu F/km$, r_0 =0.1948 Ω/km ,

x_0 =0.6494 Ω/km, c_0 =0.0090 $\mu F/km$.

Parameters Equivalent system M and Equivalent system N are given as following:

$Z_{M1}=Z_{N1}$ =2.534 $+j$ 120.46 (Ω) ,

$Z_{M0}=Z_{N0}$ =1.121+j 40.23 (Ω).

The velocity of traveling wave can be obtained from the transmission lines' distributed parameters [11]:

$v=\sqrt{(1/l_1c_1)}= 2.98137\times 10^5\ km/s$ ·

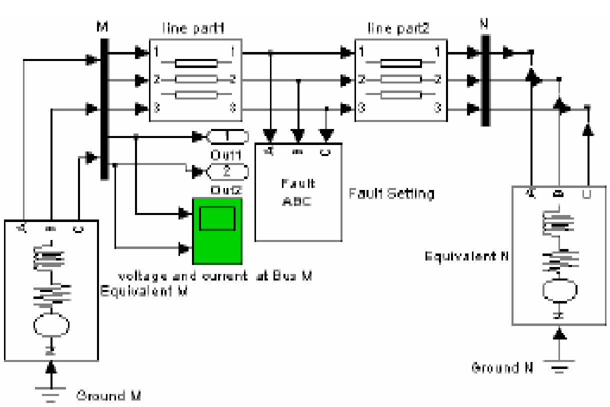

Fig.3 Model for simulation

Single phase-to-grounded fault with distance of 100km from bus M is taken as an example. Setting sample frequency at 2 kHz and sampling ten power frequency cycles, fault distance of x=102.4km is calculated via Equation (1) with Fourier transform, and results of t_M=343.5μs, t_N=662.8 μs and δ_t =100.6 μs are also calculated. Then just keeping the current output of Out1 and setting sample frequency at 2MHz and sampling half power frequency cycles, data are treated with using digital filter, modal transform and wavelet analysis [12],[13]. According to maximum likelihood estimation, time reference of t_1=2817 μs is obtained, and times of t_2=3488 μs and t_3= 4158 μs are identified respectively in corresponding regions of (3302.8,3705.2) and (3941.4, 4343.8) as shown in Fig.4. The results of t_0 = 2481.5 μs, v'= 2.98211·10^5 km/s and x'=100.05 km are calculated finally.

Changing respectively fault resistance, fault distance, fault type and so on, a number of results of fault location are gained using assembled algorithm proposed. Results of simulation are that located errors are within 100m if fault location based on traveling wave algorithm is available. So it is improved that assembled algorithm proposed is correct.

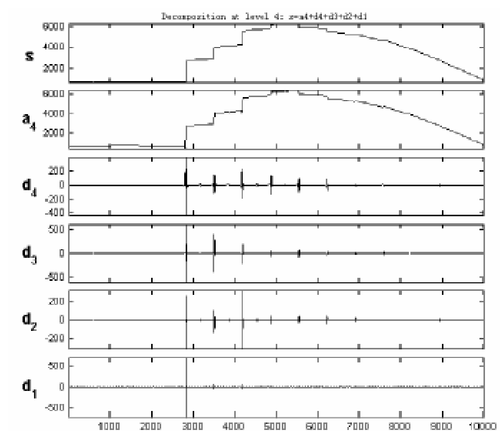

Fig.4 Wavelet analysis

IV. CONCLUSION:

Considering roundly reliability and accuracy of oneterminal fault location system for transmission lines, an impedance-traveling wave assembled algorithm, which combines measurement impedance method with traveling wave method, is presented. The assemble algorithm have complementarities, because measurement impedance method guarantees reliability, especially when fault point is very near to the detective bus, and traveling wave method improves accuracy, especially when fault point is far from the detective bus. Results of simulation test have improved that assembled algorithm proposed is correct. In the case of that exact time of reflected wave from fault point to detective bus and that of reflected wave from opposite bus to detective bus can both be detected, traveling wave velocity has no relation with fault accuracy, and can be corrected to its actual velocity online. In the worst situation, measurement impedance method can still guarantees reliability in despite of that traveling wave method is no available. So it is prospected that the assemble algorithm will have a positive effect on fault location technology for transmission lines of electric power systems and be applied practically.

V. REFERENCES:

[1] A. Elhaffar and M. Lehtonen: An improved GPS current traveling-wave fault locator in EHV transmission networks using few recordings. Presented at Future Power Systems, 2005 International Conference

[2] M. Aurangzeb, P.A. Crossley, P. Gale, "Fault location using the high frequency traveling waves measured at a single location on a transmission line," in *Proc. 2001 IEE* Developments in Power System Protection, Seventh International Conf., pp: 403-406.

[3] Darren Spoor and J. G. Zhu, "Improved Single-Ended Traveling-Wave Fault Location Algorithm Based on Experience with Conventional Substation Transducers," *IEEE Trans. Power Delivery*, vol. 21, pp. 1714-1720, Jul. 2006,

[4] Z. Chen, X. Z. Dong and C. M. Lou, "Robustness of one-terminal fault location algorithm based on power frequency quantities," in *Proc. 2002IEEE, Power Engineering Society Summer Meeting,* vol.3 pp. 1118-1122.

[5] K. Zimmerman, D. Costello, "Impedance-based fault location experience," in *Proc. 2006 IEEE, Rural Electric Power Conf.,* pp.1-16

[6] D.W.P. Thomas, C. Christopoulos, Y. Tang, P. Gale and J. Stokoe, "Single ended travelling wave fault location scheme based on wavelet analysis," in *Proc. 2004 IEE, Developments in Power System Protection, Eighth IEE International Conf.,* pp. 196 –199.

[7] X. Z. Dong, Z. Chen, X. He, K. Wang, and C. Luo, "Optimizing solution of fault location," in *Proc.2002 IEEE Power Eng. Soc. Summer Meeting*, pp. 1113–1117.

[8] V. Pathirana, P. McLaren, and E. Dirks, "Investigation of a hybrid travelling wave/impedance relay principle," in *Proc. IEEE Power Eng. Society Transmission and Distribution Conf.*, pp. 48-53.

[9] Sant and Y. Paithankar, "Online digital fault locator for overhead transmission line," in *Proc. 1979 IEE*, vol. 126, pp.1181-1185, Nov. 1979.

[10] T. Jiang, Y. P. Lu. "Study of fault locating based on single traveling waves avoiding wave speed influence," *Electric Power Automation Equipment,* vol. 24, pp. 29-32, Dec. 2004.

[11] A. Gopalakrishnan, M. Kezunovic, S.M. McKenna and D.M. Hamai, "Fault location using the distributed parameter transmission line model," *IEEE Trans. Power Del.*, vol. 15, pp. 1169-1174, Oct. 2000.

[12] A. Abur and F. Magnago, "Fault location using wavelets," *IEEE Trans. Power Del.*, vol. 13, pp. 1475--1480, Oct. 1988.

[13] G. Kim, H. Kim, and J. Choi, “Wavelet transform based power transmission line fault location using GPS for accurate time synchronization,” in *Proc. IEEE Power Eng. Soc. Transm. And Distribution Conf.*, vol. 1, 2001, pp. 495-499.