Fault Location in High Voltage Transmission Lines Using Resistance, Reactance and Impedance

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Abstract. *This paper presents two methods for on-line computation of dynamic fault location in HV transmission lines using three means; resistance, reactance and impedance. These methods can be used for dynamic distance protection of the transmission line. The Gilchrist method and McInnes method are presented. The proposed methods use digital set of short circuit current and voltage measurements for estimating fault location. A practical case study is presented in this work to evaluate the proposed methods. A study is done to evaluate the best mean to locate the fault. A comparison of these two methods is presented. MATLAB-Simulink software was used to do all the tests. Results are reported and conclusions are drawn.*

Keywords

Transmission line, Fault location, resistance, reactance, impedance.

1. INTRODUCTION

The problem of fault location on transmission lines has been the focus of interest of many researchers in power systems for years. One of the main objective of protective system is to detect faults on transmission lines as fast as possible. The purpose of a protective relays is to clear the fault as quickly as possible, minimize the damage caused due to fault and restore the line quickly. Another important job is to locate this fault point accurately. Therefore, it is very important to have fast reliable methods that can detect and locate faults on transmission lines in order to reduce the time needed to resume the service to consumers. The most common technique used is based on the evaluation of signal amplitudes of currents and voltages at the fundamental frequency [1, 2] This approach is referred to as impedance based measurement technique, and is classified to two methods. The earlier developed one is one-terminal data method, and the other is the currently more prevalent one so-called two-terminal method. These methods use voltage and current phasors to determine the impedance to the fault location, and both suffers from errors mentioned in many papers [3]-[6]. For example, the one-terminal data method needs to make some assumptions for ground condition; the two-terminal impedance based method usually needs accurate and synchronized measurements for extracting the phasors. In this paper, we present two methods for dynamic locating fault in the transmission line using sampling data of current and voltage signals. These methods can be used for dynamic distance transmission line protection.

2. FAULT LOCATION METHODS

There are several techniques for fault locating on transmission line [7]-[11]. Two techniques are proposed in this paper: Gilchrist et al. method and McInnes method. The methods are presented in Appendix. We assume that the current and voltage wave is sinusoidal after the fault. The signals are filtered and sampled. For the two methods, the resistance, inductance and impedance are used to calculate the distance of the fault.

3. SIMULATION AND RESULTS

3.1. Study network

The study network is the west Algerian network as indicated in Fig. 1. The faulty transmission line is of 122.8 km assumed between node S (Saida) and node T (Tiaret) with a voltage of 220 kV (Fig.2).

The transmission line is considered with distributed parameters.

- Resistance: $r_d = 12.73\,\text{m}\Omega/\text{km}$.
- Inductance: $l_d = 0.93$ mH/km.
- Reactance: $x_d = l_d.w_o = 293.33$ mΩ/km.
- Impedance: $z_d = r_d + \ jx_d$

This simulation is carried out by the "Matlab-Simulink" software to regenerate the voltages and currents signals at node S (relay position) for a two-phases fault at a distance of 50 km from S (m= 50 km) in the transmission line S-T (Fig.2). The fault is supposed occurs at time 0.05 sec.

Figure 3 shows the steps performed by the digital relay for fault location. The currents and voltages signals are filtered using the antialiasing filter (Butterworth low-pass) and are sampled at 1 kHz.

The voltage signal is transient. At the beginning of the appearance of the fault at $t = 0.05$ sec., it is oscillatory at a very high frequency which is due to the presence of the capacity and the inductance of the line, then it becomes

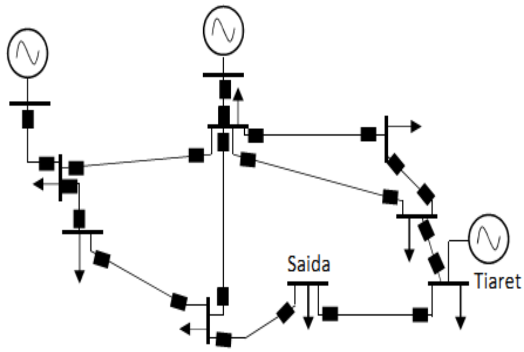

Fig. 1: Study network, the west Algerian network.

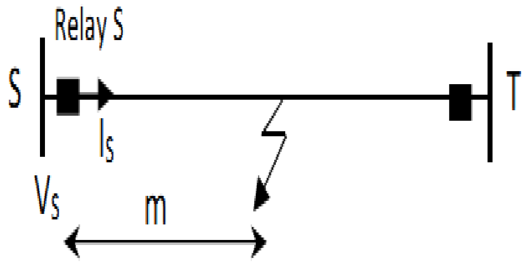

Fig. 2: Fault in transmission line Saida-Tiaret.

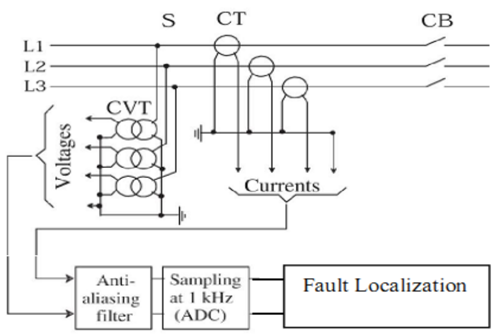

Fig. 3: The steps performed by the digital relay S for fault location.

damped due to the presence of the line resistance.

Figure 4 shows the original and filtered signal of the faulty voltage. The filtered currents and voltages signals are used for fault location. The current and voltage waves are sinusoidal after the fault. The applicate methods can be used for network with complexes loads and unbalanced cases. The fault location m can be calculated at

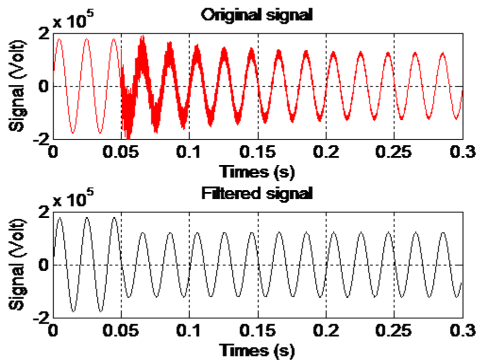

Fig. 4: Signal voltage: original and filtered signals.

sample k by one of the following expression:

$$mR_k = \frac{R_k}{r_d}$$

$$mX_k = \frac{X_k}{x_d}$$

$$mZ_k = \frac{|Z_k|}{|z_d|}$$

$$|z_d| = \sqrt{{r_d}^2 + {x_d}^2}$$

The simulation time for Gilchrist and McInnes methods are 0.010 sec. and 0.013 sec. respectively.

3.2. Using Gilchrist et al. method

Figure 5 shows the fault location as a function of time using the resistance. From Fig. 5 we can see an instability in the response and the distance is not detected rapidly. It can be seen that the value of the fault locator oscillates around the final value 50 km. The Fault localization time is 1.1 sec.

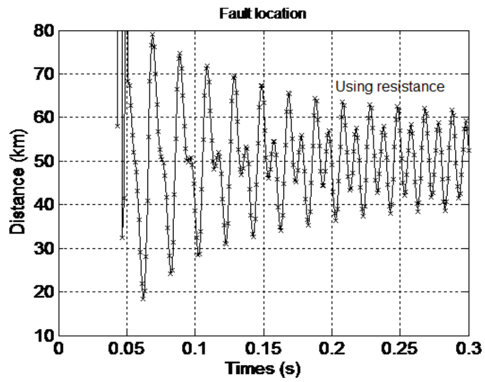

Fig. 5: Fault location as function of time using the resistance.

Figure 6 shows the fault location as a function of time using the reactance. From Fig. 6 we can

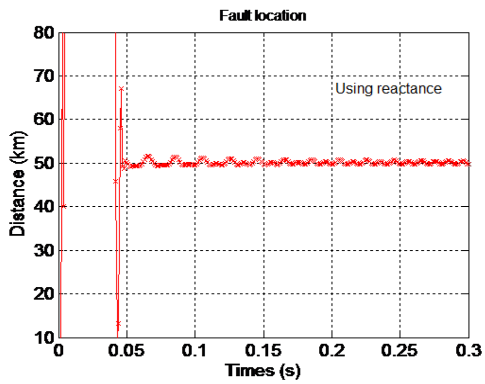

Fig. 6: Fault location as function of time using the reactance.

see a stability in the response and the distance is detected rapidly. It is clear that the final value of the fault locator is 50 km. The fault localization time is 0.25 sec.

Figure 7 shows the fault location as a function of time using the impedance. From Fig. 7 we can see a stability in the response and the distance is detected rapidly. It is clear that the value of the fault locator is 50 km. The Fault localization time is 0.25 sec.

The results obtained show that for the fault location using resistance, reactance and impedance give approximate values at the value of 50 km. It can also be seen that when using reactance and impedance the result gives close value in a short time (fast), however when us-

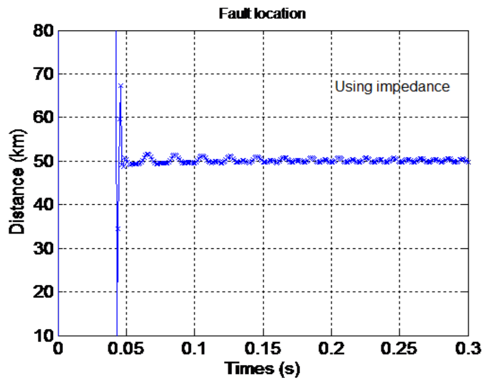

Fig. 7: Fault location as function of time using the impedance.

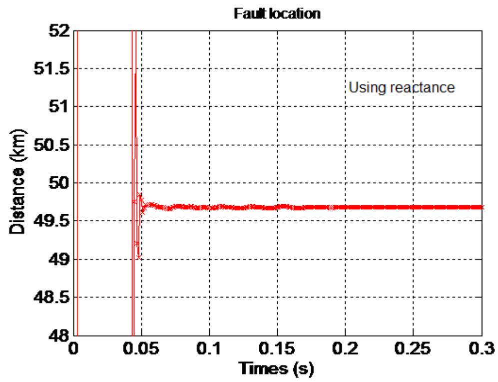

Fig. 9: Fault location as function of time using the reactance.

ing resistance, fault location takes some time to approximate the final value. Therefore, we can say that one must avoid using resistance and use more the reactance or impedance

3.3. Using McInnes et al. method

Figure 8 shows the fault location as a function of time using the resistance. From Fig. 8 we

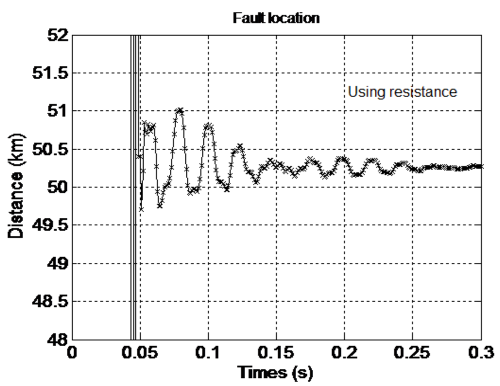

Fig. 8: Fault location as function of time using the resistance.

can see an instability in the response and the distance is not detected rapidly. We can see that the final value oscillates around the final value 50.25 km. The Fault localization time is 0.25 sec. Figure 9 shows the fault location as a function of time using the reactance. From Fig. 9 we can see a stability in the response and the distance is detected rapidly. It is clear that the value of the fault locator is 49.7 km. The Fault localization time is 0.03 sec.

Figure 10 shows the fault location as a function of time using the impedance. From Fig. 10

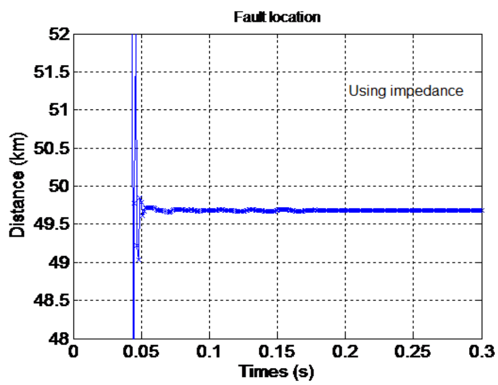

Fig. 10: Fault location as function of time using the impedance.

we can see a stability in the response and the distance is detected rapidly. It is clear that the value of the fault locator is 49.7 km. The Fault localization time is 0.03 sec.

It can be seen that when using reactance and impedance the results give closes values in a short time (fast), however when using resistance the fault location takes some time to approximate the final value. Therefore, we can say that one must avoid using resistance and use more the reactance or impedance.

It is clear that the value of the fault locator is 49.7 km when using reactance and impedance of the line, whoever the value of the fault locator is 50.25 km when using line resistance.

4. COMPARISON OF METHODS

In this part, we use the reactance for the two methods to locating the fault in the transmission line for comparison.

Figure 11 shows the fault location as a function of time using the reactance for the two methods. From Figure 11 we can see that McInnes method gives close value in a short time 0.03 sec. (fast), however Gilchrist method takes some time to approximate the final value at 0.25 sec., the response is unstable and the distance is not detected rapidly.

The comparison of the two methods is shown

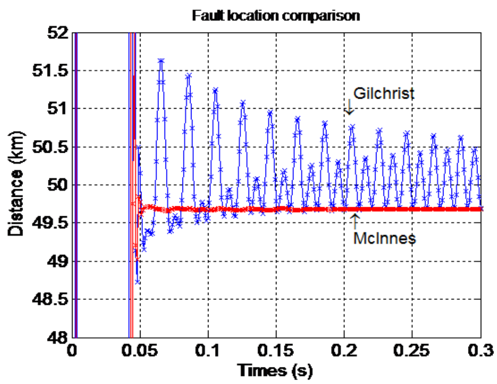

Fig. 11: Fault location as function of time using the reactance.

in Table 1. Table 1 shows the fault is good localized by Gilchrist et al. method when using reactance or impedance of the line.

5. CONCLUSION

The results obtained show that for the fault location using resistance, reactance and impedance give approximate values. When using reactance and impedance the result gives closes values in a short time (fast), there is stability in the response and the distance is detected rapidly. When using resistance, the fault location takes some time to the approximate the final value, the response is unstable and the distance is not detected rapidly. The results obtained show McInnes method gives close value in a short time (fast); however, Gilchrist method takes some time to approximate the final value.

Appendix.

1. Gilchrist et al. method:

This algorithm uses the first and second derivative [12]. This type generally reduce errors arising from subnormal frequencies, as well as those due to slowly decaying DC transients. Essentially, they represent a refinement of the above detailed basic algorithms and aperiodic components are present in the signal waveforms.

Figure 12 shows a fault in a transmission line. The voltage and current waveforms can be denoted:

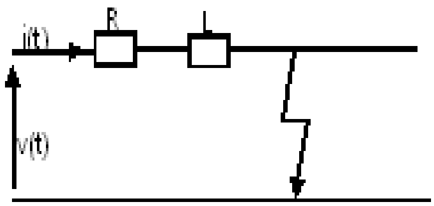

Fig. 12: Fault in transmission line.

$$v\,(t) = \text{Vmax} * \sin(w_0 * t + \theta_v) \quad (1)$$
$$i\,(t) = \text{Imax} * \sin(w_0 * t + \theta_i) \quad (2)$$

Taking the first and second derivative with respect to time, we obtain for the voltage signal:

$$v'\,(t) = w_0 * \text{Vmax} * \cos(w_0 * t + \theta_v) \quad (3)$$
$$\cos(w_0 * t + \theta_v) = \frac{v'(t)}{w_0 * \text{Vmax}} \quad (4)$$

and

$$v''(t) = -{w_0}^2 * \text{Vmax} * \sin(w_0 * t + \theta_v) \quad (5)$$
$$\sin(w_0 * t + \theta_v) = \frac{v''(t)}{-w^2{}_0 * \text{Vmax}} \quad (6)$$

We know that:

$$\sin^2(w_0 * t + \theta_v) + \cos^2(w_0 * t + \theta_v) = 1 \quad (7)$$

Table 1. Comparison of the two methods

Means		Using Z	Using R	Using X
Gilchrist et al. method	Localization time	0.25 sec.	1.1 sec.	0.25 sec.
Gilchrist et al. method	Fault location	50 km	Oscill.	50 km
McInnes method	Localization time	0.03 sec.	0.25 sec.	0.03 sec.
McInnes method	Fault location	49.7 km	50.2 km	49.7 km

So:

$$\frac{v''(t)^2}{\left(-w_0{}^2 * \mathrm{Vmax}\right)^2} + \frac{v'(t)^2}{\left(w_0 * \mathrm{Vmax}\right)^2} = 1 \tag{8}$$

Combining this equation result in an equation for the square of the peak of the assumed sinusoidal voltage:

$$\mathrm{Vmax}_k = \sqrt{\frac{1}{w_0{}^2} * \left[\left(v'_k\right)^2 + \left(v''_k\right)^2\right]} \tag{9}$$

$$\theta_{vk} = \tan^{-1}\left(\left(\frac{-v''_k}{w_0{}^2 * \mathrm{Vmax}_k}\right) / \left(\frac{v'_k}{w_0 * \mathrm{Vmax}_k}\right)\right) \tag{10}$$

The corresponding equation for determining an approximation to the peak of the current is likewise:

$$\mathrm{Imax}_k = \sqrt{\frac{1}{w_0{}^2} * \left[\left(i'_k\right)^2 + \left(i''_k\right)^2\right]}, \tag{11}$$

$$\theta_{ik} = \tan^{-1}\left(\left(\left(\frac{-i''_k}{w_0{}^2 * \mathrm{Imax}_k}\right)\right) / \left(\frac{i'_k}{w_0 * \mathrm{Imax}_k}\right)\right) \tag{12}$$

Thus:

$$Z_k = \frac{\mathrm{Vmax}_k}{\mathrm{Imax}_k} * \left(\cos\theta_{zk} + j * \sin\theta_{zk}\right) \tag{13}$$

Were the impedance angle (θ_{zk}) is given by:

$$\theta_{zk} = \theta_{vk} - \theta_{ik} \tag{14}$$

$$\theta_{zk} = \tan^{-1}\left(\frac{i''_k}{i'_k * w_0}\right) - \tan^{-1}\left(\frac{v''_k}{v'_k * w_0}\right) \tag{15}$$

First and second derivative are commonly determined for use in this algorithm by using divided differences. This is done by substituting the voltage v'_k and v''_k by the following relationships:

$$v'_k = \frac{1}{\Delta \mathrm{t}} * \left(v_k - v_{k-1}\right) \tag{16}$$

$$v''_k = \frac{1}{(\Delta t)^2} * \left(v_{k-1} - 2 * v_k + v_{k-1}\right) \tag{17}$$

Where Δt is the sampling interval, and $k-1$, k and $k+1$ are subscripts referring to a set consecutive samples.

The resistance, reactance and impedance can be determined by:

$$R_k = \frac{\mathrm{Vmax}_k}{\mathrm{Imax}_k} * \left(\cos\theta_{zk}\right) \tag{18}$$

$$X_k = \frac{\mathrm{Vmax}_k}{\mathrm{Imax}_k} * \left(\sin\theta_{zk}\right) \tag{19}$$

$$|Z_k| = \sqrt{R_k{}^2 + X_k{}^2} \tag{20}$$

The fault location can be determined by using resistance R_k, reactance X_k or impedance $|Z_k|$.

2. McInnes method:

This method uses integral electrical equation [12]. Using Figure 1, we can write:

$$v(t) = R * i(t) + L * \frac{di}{dt} \tag{21}$$

Or

$$\int_{t_1}^{t_2} v(t)\,dt = R * \int_{t_1}^{t_2} i(t)\,dt + L * \int_{t_1}^{t_2} \frac{di(t)}{dt} dt \tag{22}$$

Where:

$$\int_{t_1}^{t_2} v(t)\,dt = \frac{v(t_1) + v(t_2)}{2} * \Delta t \tag{23}$$

And:

$$\int_{t_1}^{t_2} i(t)\,dt = \frac{\Delta t}{2} * \left(i(t_1) + i(t_2)\right) \tag{24}$$

And:

$$\int_{t_1}^{t_2} di(t) = i(t_2) - i(t_1) \tag{25}$$

For k :

$$\frac{\Delta t}{2}\left(v_{k+1} + v_k\right) = R\frac{\Delta t}{2}\left(i_{k+1} + i_k\right) + L\left(i_{k+1} - i_k\right)$$

For $k+1$:

$$\frac{\Delta t}{2}\left(v_{k+2}+v_{k-1}\right)=R\frac{\Delta t}{2}\left(i_{k+2}+i_{k+1}\right)$$
$$+L\left(i_{k+2}-i_{k+1}\right)$$

So: $R_k=(E_1-E_2)/(E_3-E_4)$, where

$$E_1=\left(v_{k+1}+v_k\right)*\left(i_{k+2}-i_{k+1}\right),$$
$$E_2=\left(v_{k+2}+v_{k+1}\right)*\left(i_{k+1}-i_k\right),$$
$$E_3=\left(i_{k+1}+i_k\right)*\left(i_{k+2}-i_{k+1}\right),$$
$$E_4=\left(i_{k+2}+i_{k+1}\right)*\left(i_{k+1}-i_k\right),$$

$L_k=\frac{\Delta t}{2}(F_1-F_2)/(F_3-F_4)$, where

$$F_1=\left(i_{k+1}+i_k\right)*\left(v_{k+2}+v_{k+1}\right),$$
$$F_2=\left(i_{k+2}+i_{k+1}\right)*\left(v_{k+1}+v_k\right),$$
$$F_3=\left(i_{k+1}+i_k\right)*\left(i_{k+2}-i_{k+1}\right),$$
$$F_4=\left(i_{k+2}+i_{k+1}\right)*\left(i_{k+1}-i_k\right),$$

$$X_k=L_k*w_0$$
$$|Z_k|=\sqrt{{R_k}^2+{X_k}^2}$$

The fault location can be determined by using resistance R_k, reactance X_k or impedance $|Z_k|$.

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