Settings-Free Traveling Wave Based Earth Fault Location Using Unsynchronized Two-Terminal Data

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***Abstract*—This Letter presents a two-terminal traveling wave (TW) based earth fault location algorithm. It works using unsynchronized data and does not require information about the line parameters. Evaluated signals are decoupled into aerial and ground modes and, then, only the incident TWs of each mode are detected at the line ends. Earth fault case studies are carried out to attest the proposed algorithm feasibility, comparing its performance with those of one- and two-terminal approaches reported in the literature. Obtained results reveal the proposed algorithm is straightforward and quite reliable.**

***Index Terms*—Fault location, power systems, traveling waves.**

I. Introduction

FAULT locators have played a crucial role in modern power networks. By using these devices, the restoration times of lines after faults have been speeded up, improving the quality and reliability of the power supply to the costumers [1].

In the literature, several methods have been reported [1], among which the impedance-based ones are still the most widespread. Nevertheless, TW based functions have been increasingly investigated due to its robustness to typical sources of errors that affect most impedance-based approaches. It is well known that the performance of classical TW based methods depends mainly on the data-acquisition system sampling rates and, in some cases, on the time synchronization and accuracy of the available line length information. Furthermore, uncertainties in line parameters also lead to errors in the computed TW propagation velocities, what, in turn, jeopardizes the performances of both one- and two-terminal fault locators.

Two-terminal classical approaches depend on the data synchronization and knowledge of line parameters (TW propagation velocities and line length), which typically suffer from inaccuracy [1]. In [2], a two-terminal algorithm which does not require the data to be synchronized is presented, but it requires that the fault locator routines are executed in real-time and a communication link is available to exchange data between both line ends. In this context, one-terminal techniques seem to be the best choice to overcome these drawbacks, since their formulations do not require line length information, data synchronization and communication systems [1]. However, these techniques depend on the TW propagation velocities, as well as the detection of waves reflected from the fault point, what has been reported as difficult to deal with [1], [2].

As far as one knows, earth faults are those that most likely take place in electrical power systems [1]. Based on that, one-terminal fault locators based on aerial and ground mode TWs have been reported [3], [4]. The earth fault locator reported in [4] estimates the mode propagation time delays to eliminate the need for detecting reflected TWs. However, it requires information regarding both ground and aerial mode propagation velocities, which depend on the zero and positive sequence line parameters, respectively [1]. To overcome such a drawback, a three-terminal approach which eliminates the wave propagation speed from the fault location formulation is reported in [5]. Although this method is able to provide reliable fault location estimations, it depends on the line length information and on the three-terminal data synchronization.

Aiming to overcome the aforementioned shortfalls of existing fault location approaches, a new settings-free two-terminal TW based earth fault location algorithm is proposed in this Letter. It works using unsynchronized data and does not require information about the line parameters, in such a way that its accuracy depends solely on the data-acquisition system sampling rates and on the accuracy of the TW detectors.

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II. Proposed Earth Fault Location Algorithm

In this letter, only ground and aerial mode of currents are evaluated, since current transformers (CT) have a frequency response with almost equal magnitude in a wider range than capacitive voltage transformers [1]. Ground and aerial mode quantities can be computed through several transforms, such as the Clarke, Karrenbauer and Wedephol ones [1]. In this Letter, the Karrenbauer transform is applied using [1]:

$$\mathbf{i}_{012} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & -1 & 0 \\ 1 & 0 & -1 \end{bmatrix} \cdot \mathbf{i}_{abc} \ , \tag{1}$$

where $\mathbf{i}_{012}$ and $\mathbf{i}_{abc}$ are the modal (subscripts: 0 - ground mode, 1 and 2 - aerial modes) and phase currents, respectively.

Fig. 1 depicts a time-space diagram in a two-terminal line, where t_{L0}, t_{L1}, t_{R0}, t_{R1} are the arrival times of incident ground and aerial mode TWs at buses L and R; v_0 and v_1 are the ground and aerial mode TW propagation velocities, respectively; d is the fault distance and ℓ is the line length.

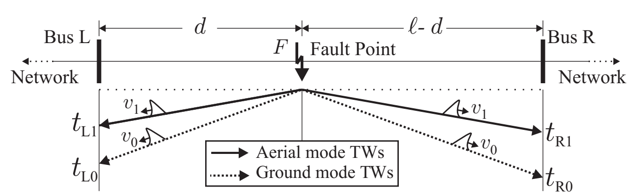

Fig. 1. Time-space diagram for a line monitored at two terminals.

As reported in [4], $v_1 > v_0$, i.e., there is a time delay between the arrival of ground and aerial mode TWs at the line

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ends (Fig. 1). Thus, assuming that v_1 and v_0 do not change along the line, d and $\ell - d$ are estimated for earth faults by:

$$d = \{(t_{L0} - t_{L1})\, v_0 v_1\} / (v_1 - v_0) \ , \quad (2)$$

$$\ell - d = \{(t_{R0} - t_{R1})\, v_0 v_1\} / (v_1 - v_0) \ . \quad (3)$$

The line length ℓ is obtained by adding (2) to (3). Therefore, $d\% = (d/\ell)100$ can be derived as:

$$d\% = \{(t_{L0} - t_{L1}) \,/\, [(t_{L0} - t_{L1}) + (t_{R0} - t_{R1})]\}\, 100 \ . \quad (4)$$

Likewise for other reported TW based methods, close-in faults are challenging for the proposed one, due to the need for very high sampling rates to accurately capture the first ground and aerial TWs at the line ends [1]. However, as (4) requires no propagation velocity information and analyzes the arrival times at the line ends separately, the proposed algorithm has the advantage of being independent of data synchronization and line parameters, thereby it is completely settings-free.

III. Performance Evaluation

The proposed algorithm was evaluated through Alternative Transients Program (ATP) simulations of solid earth faults in the 230 kV power system shown in Fig. 2, whose parameters were taken from an actual Brazilian system.

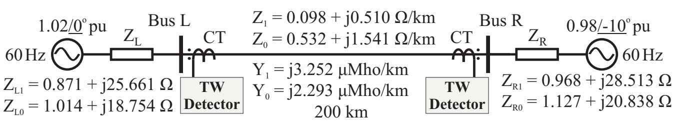

Fig. 2. Test power system.

Currents are taken at both line ends from CTs, whose model is reported in [6]. Since this paper does not aim to analyze the TW detectors itself, but rather, the performance of the proposed settings-free fault locator, the data acquisition system was assumed to be ideal. A time step of 1 μs was used in ATP and a sampling frequency of 100 kHz was simulated. The TW detector reported in [7] was applied, which is based on the Maximal Overlap Discrete Wavelet Transform (MODWT). The Daubechies 4 mother wavelet was used, as suggested in [7]. Fig. 3 shows the proposed algorithm application for an ABG solid fault 40% far from Bus L. In this case, $t_{L0} - t_{L1} = 170\ \mu$s and $t_{R0} - t_{R1} = 260\ \mu$s. Thus, $d\% = \frac{170}{(170+260)} \cdot 100 \approx 40\%$, attesting the proposed algorithm feasibility.

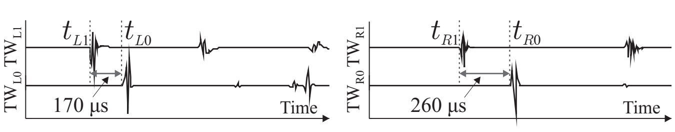

Fig. 3. Wavelet coefficients for ground and aerial mode TWs.

To better evaluate the algorithm, additional AG solid faults are simulated. Firstly, ideal cases are analyzed, by considering exact line parameters and synchronized data. Then, the influence of non-homogeneities (NH) in the grounding resistance along the system is evaluated. In order to do so, positive and zero sequence resistance and inductance in the line section downstream the fault were taken as being 5% greater than those in the opposite line section. Finally, the influence of inaccuracies in line parameters (ϵ_{rlc} = +10% of actual zero and positive sequence parameters), in ℓ (ϵ_ℓ = +10% of ℓ) and in data synchronism (ϵ_{syn} = 0.926 ms ≈ 20°) were taken into account. For each simulation, d was estimated using: the proposed algorithm (estimation d^*_{prop}); the one-terminal technique reported in [4] using (2) (estimation d^*_{1t}); and the classical two-terminal approach using $d = 0.5 \cdot \{\ell - [t_{R1} - t_{L1}]v_1\}$ (estimation d^*_{2t}) [1]. Obtained results are depicted in Table I.

TABLE I
Obtained results.

Distance	Applied errors				Estimated d value (%)		
d (%)	ϵ_{rlc}	ϵ_ℓ	ϵ_{syn}	NH	d^*_{prop}	d^*_{1t}	d^*_{2t}
10	-	-	-	-	9.7	9.6	9.7
50	-	-	-	-	50.0	47.8	50.0
90	-	-	-	-	90.3	89.2	90.3
30	-	-	-	✓	29.0	28.7	28.8
10	✓	-	-	-	9.7	8.7	13.4
	-	✓	-	-	9.7	9.6	14.7
	-	-	✓	-	9.7	9.6	77.5
	✓	✓	✓	-	9.7	8.7	80.0

The results reveal that: 1) For the ideal cases, d^*_{1t} is less accurate than d^*_{prop} and d^*_{2t}, which in turn presented the same performance; 2) All the algorithms are sensitive to the non-homogeneity in line parameters; 3) After adding the errors ϵ_{rlc}, ϵ_ℓ and ϵ_{syn}, the accuracy of d^*_{1t} and d^*_{2t} was jeopardized, whereas d^*_{prop} remained as accurate as in the ideal cases.

IV. Conclusions

A new settings-free two-terminal traveling wave-based earth fault location algorithm was presented. It neither requires synchronized data nor information regarding the line length and traveling wave propagation velocities. The obtained results reveal the proposed algorithm is reliable and quite useful for fault location procedures in transmission systems, since earth faults are those ones that most likely take place in electrical power systems. Indeed, the proposed algorithm has advantages and facilities which have never been reported before, attesting the major contribution of the present Letter.

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