IMPLEMENTACIÓN DEL ALGORITMO Z-DOMAIN METHOD PARA LA PROTECCIÓN DIRECCIONAL EN SISTEMAS DE POTENCIA

IMPLEMENTATION OF THE Z-DOMAIN METHOD ALGORITHM FOR THE DIRECTIONAL PROTECTION IN POWER SYSTEMS

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Resumen. En este artículo se propone un algoritmo para la detección de oscilaciones electromecánicas como una alternativa para la protección direccional en los Sistemas Eléctricos de Potencia. La protección direccional ayuda en la protección de sistemas radiales como mallados. A través de la medición de voltaje, corriente y potencia se puede determinar la dirección de los flujos y realizar la activación de los interruptores. El algoritmo Z-Domain Method (ZDM) puede obtener los parámetros como: amplitud, frecuencia y fase de señales oscilantes como; voltaje y la corriente, con lo que se puede determinar la dirección del flujo de potencia. Una de las características del ZDM es la rapidez con la que obtiene resultados, pues utiliza una ventana de 6 muestras para una señal mono-componente.

Palabras clave: Protección direccional, ZDM.

Abstract. This article proposes an algorithm for detecting electromechanical oscillations as an alternative [for] directional protection in Electrical Power Systems. Directional protection helps protect meshed/radial systems. By measuring voltage, current, and power, it is possible to determine flow direction and activate the switches. The Z-Domain Method (ZDM) algorithm can obtain parameters such as the amplitude, frequency, and phase of oscillating signals such as voltage and current; with this, it is possible to determine the direction of the power flow. One feature of ZDM is the speed with which it obtains results, as it uses a sampling of 6 windows for a mono-component signal.

Key Words: Directional protection, ZDM.

1. Introduction

The protection system in Electric Power Systems (EPS) is fundamental for good network operation and performance. In a radial section of a network, transmission lines can be protected using overcurrent protection (ANSI N. 51), which is only sensitive to the magnitude of the current and its activation could be instantaneous or inverse time [1]. This protection can be used in radial feeders with a load along the line by applying protection coordination to trigger the circuit breaker closest to the fault, thus avoiding disconnection of the entire load.

Equipment redundancy is common in EPS; one piece of equipment can fail without interrupting the power supply. Using multiple pieces of equipment such as generators, lines, and/or transformers make it possible to reduce service interruption and facilitate maintenance. Also, the use of multiple lines in parallel is common, since it allows transporting more power to a given location [2]. In cases of multiple radial lines, overcurrent protection works, but is not discriminative and can open even healthy lines, resulting in interruption of the power supply. Directional protection can discriminate the direction of the current/power

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and determine if the fault is in the protection zone. A mix of directional overcurrent and overcurrent protection is commonly used in multiple parallel lines, since they offer more precise protection [2].

This article proposes the ZDM method for determining the parameters of a signal, which are the amplitude, frequency, and phase. As these are the parameters used by the differential protection, ZDM is a possible alternative for this kind of protection.

One of the main features of this method is its response time, as it has a 2 + 4C sample window, where C is the number of signal components. Once the window has the necessary samples, there is output data for all input data.

This work is divided as follows: The proposed methodology is introduced in Section 2, while tests and a simulation performed using synthetic signals are described in Section 3. Conclusions are presented in Section 4.

2. Proposed Method

The proposed method, here denominated the Z-Domain Method (ZDM), characterizes the functions that compose a single or multi-component signal, determining amplitudes, frequencies, phase angles, damping constants, and the direct current component. Frequency and damping can be determined by knowing the poles of a signal; thus, this method is based on transforming an oscillatory signal that may or may not possess damping from the discrete time domain to the Z-domain. This signal can be written as follows [3]:

$$x(n) = Ae^{-\sigma n\Delta t}\cos\left(2\pi fn\Delta t + \phi\right) + \zeta^{n\Delta t} \tag{1}$$

where A is the amplitude, σ is the damping constant, *f* is the frequency, ϕ is the phase angle, and ζ is the DC component, Δt is the time step and n = 0, 1,…N.

Using the sampling frequency, fs = 1/Δt , (1) can be written as

$$x(n) = Ak^{n}\cos\left(\omega n + \phi\right) + \zeta^{n/f_s} \tag{2}$$

where $k = e^{-\frac{\sigma}{f_s}}$ $\omega = 2\pi f / f_s$

Determination of Frequency and Damping

Transforming $x(n)$ to the Z-domain

$$X(z) = X_{ac}(\mathrm{z}) + X_{dc}(\mathrm{z}) = \frac{A(\cos\phi - k\cos(\omega-\phi)z^{-1})}{1-2k\cos(\omega)\,\mathrm{z}^{-1} + k^{2}z^{-2}} + \frac{1}{1-\zeta z^{-1}} = \frac{B(z)}{E(z)} \tag{3}$$

From (3), the poles of the mono-component signal $X(z)$ are defined by the zeros of

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$$E(z) = z^{0} - (kc + \zeta) z^{-1} + (k^{2} + \zeta c) z^{-2} - (\zeta k^{2}) z^{-3} \tag{4}$$

where $c = 2\cos(\omega)$

$$f = f_S \cos^{-1}(c/2)/2\pi \tag{5}$$

$$\sigma = -f_S \ln(k) \tag{6}$$

Determination of Amplitude and Phase

The following equation can be obtained from (2)

$$\acute{x}_1(n) = \frac{A}{2} e^{j\phi} k^{n} e^{jwn} \tag{7}$$

Now, defining $\alpha = -\sigma / fs$, $\beta = 2\pi f / fs$, and

$$\Gamma = \frac{A}{2} e^{j\phi} \tag{8}$$

which can be written as

$$\acute{x}(n) = \Gamma e^{\lambda n} \tag{9}$$

where $\lambda = \alpha \pm j\beta$

3. Test Case and Results

According to the operational logic of directional protection, the direction of the current or the power is determined based on the phase between the voltage and the current. Two cases are presented in this section; the first is two synthetic signals which emulate the voltage and current in a 60-Hz system, while the second is a simulation of a radial system with two lines in parallel which feed a load.

A Synthetic Signals

In this case, two signals are used to test the performance of the proposed method. These signals have a phase between them, which presents a change at a given time during the simulation.

The following table shows the parameters of the two test signals; signal S1 is constant, while the phase of S2 changes from -31.78° to 31.78 (180°).

Table I Synthetic test signals

Signal	*Frequency (Hz)*	*Amplitude (RMS)*	*Phase (degree)*	*Fs (samples/sec)*
S1	60	1.5	0.0 °	2000
S2	60	1.0	t < = 0.25s -31.78° t > 0.25s 31.78°	2000

Figure 1 depicts the test signals. S1 shows no change to its parameters and is taken as a reference and S2 lags until 0.25s, where a phase shift is carried out and S2 is leading.

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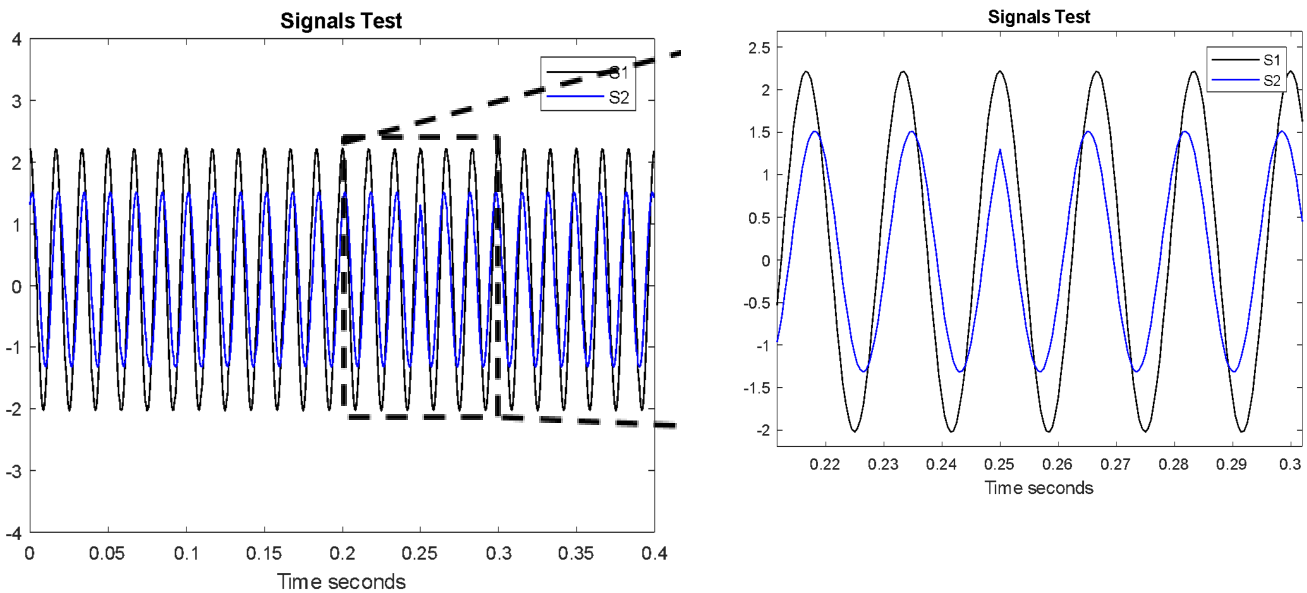

Figure 1 Synthetic signals

Signals S1 and S2 are processed using the proposed method, obtaining the phases and phase differences. These results are shown in Figure 2.

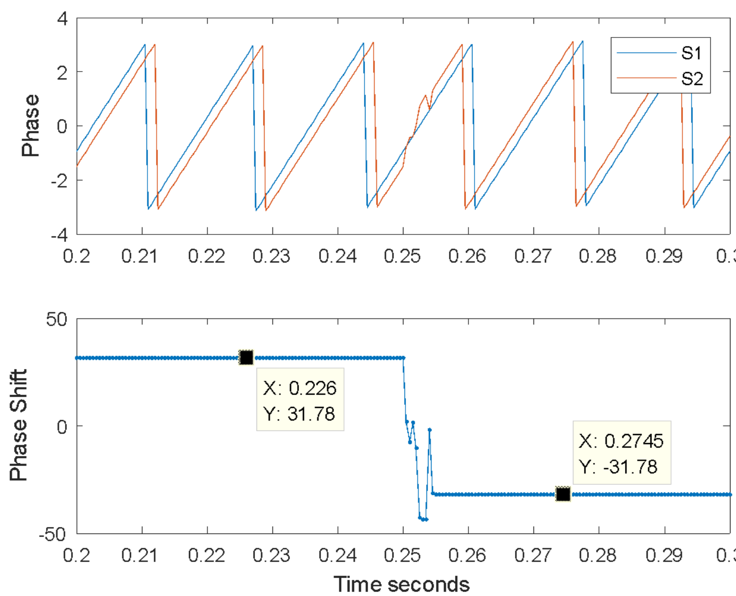

Figure 2 Phase Signals and Shift Phase of Case 1

The phase shift is correctly detected by the ZDM, as can be observed in Figure 2.

B Two Parallel lines

A radial network with a parallel feeder is simulated using a professional Matlab/Simulink program. For this kind of feeder, the protection system normally uses a combination of overcurrent and directional overcurrent relays to discriminate the fault location and avoid the disconnection of both lines when only one contains the fault. In this case, the 1600 Mw and 400 Mvar load is fed by the two parallel lines. The power factor (PF) of the load is 0.97, indicating that the current lags the voltage by 14.02°.

Normal condition

Figure 3 shows normal operation without faults. The currents through lines 1 and 2 are equal; this redundancy offers more reliability should a fault occur in one of the lines.

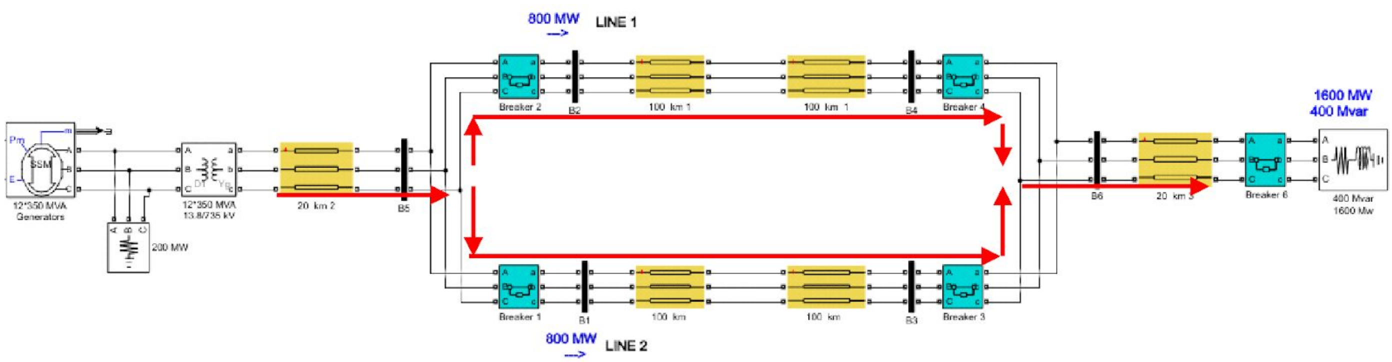

Figure 3 Case B - Two Parallel Lines

Current measurements from phase A are taken from buses 1, 2 ,3, and 4, as shown in Figure 4.

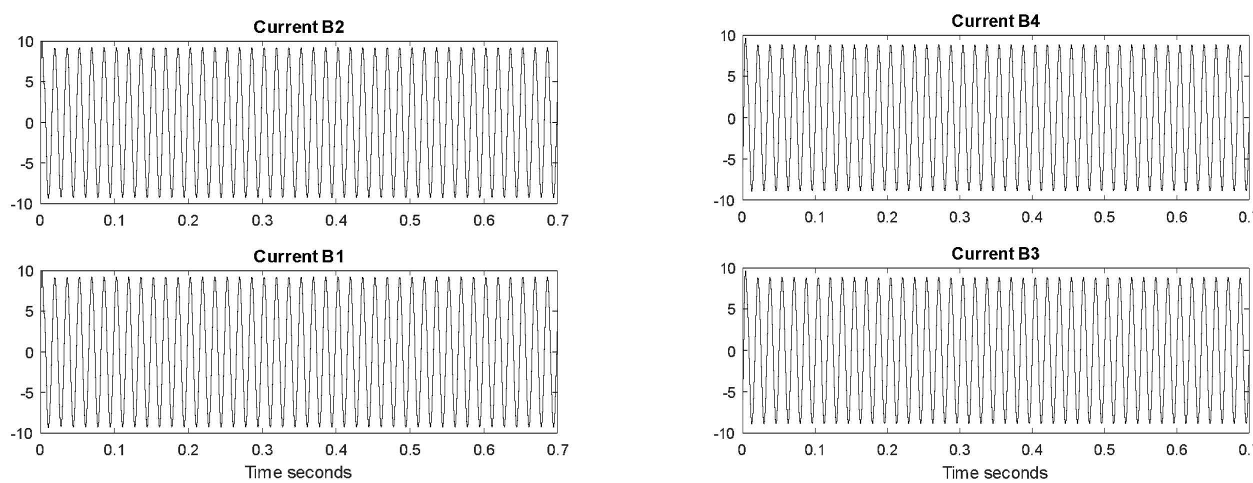

Figure 4 Phase A - Current

Phase A from bus 3 is chosen to test the proposed method; these measurements can be observed in Figure 5

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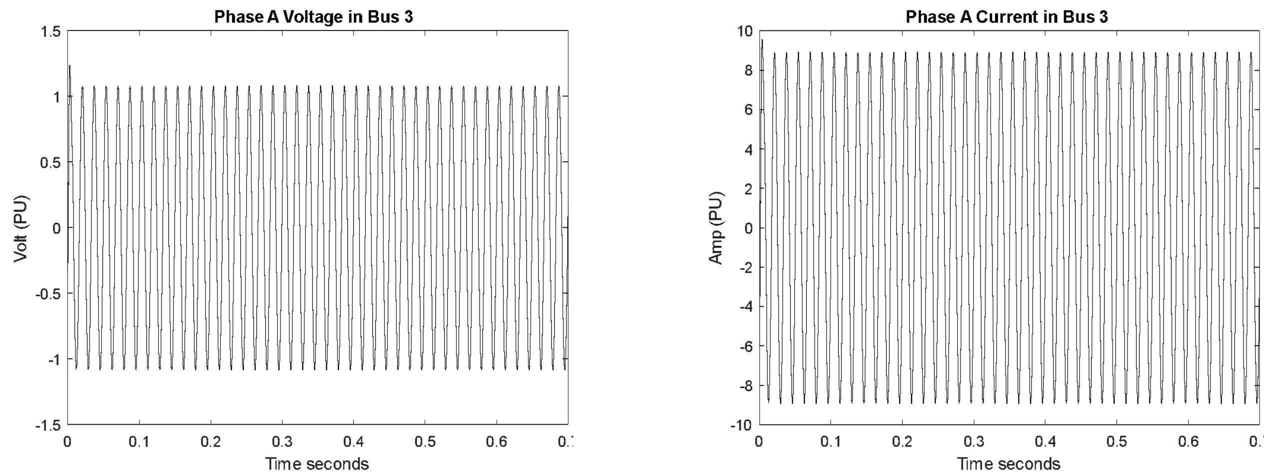

Figure 5 Current and Voltage Phase A in Bus 3

The results from the proposed method are depicted in Figure 6. The phase shift matches the load connected to the test network.

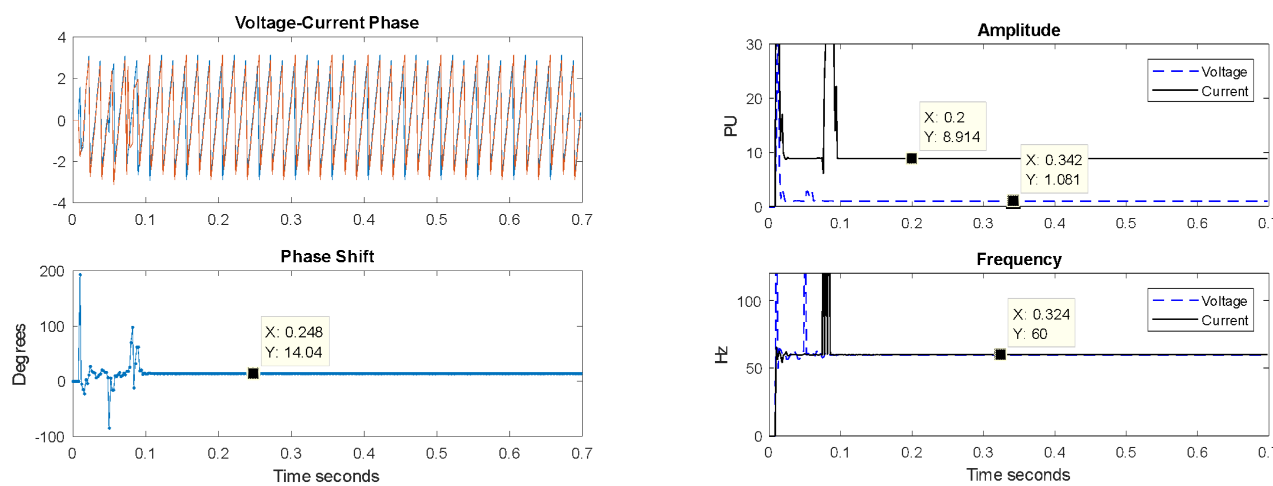

Figure 6 ZDM Results from the Phase A Current in bus 3

The phase shift shown in Figure 6 corresponds to the load in the network case (PF=0.97); the magnitude and frequency of both signals are correctly determined by the ZDM.

Fault condition

A three-phase fault with 10 ohms and 10 cycles in the middle of line 2 is simulated in the test network (Figure 7), and the current direction in line 2 on bus 3 is reversed to normal conditions. This change in the current's direction and amplitude should be detected by the ZDM.

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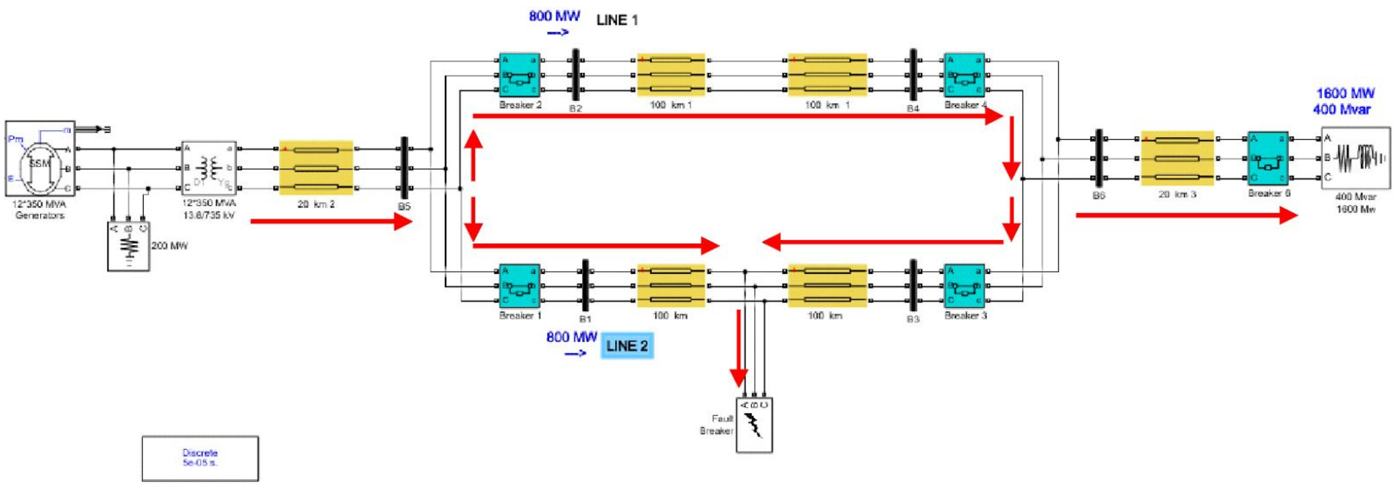

Figure 7 Case B - Two Parallel Lines (During the Fault)

Once again, the measurements in the four buses are recorder and the fault can be observed in all of these.

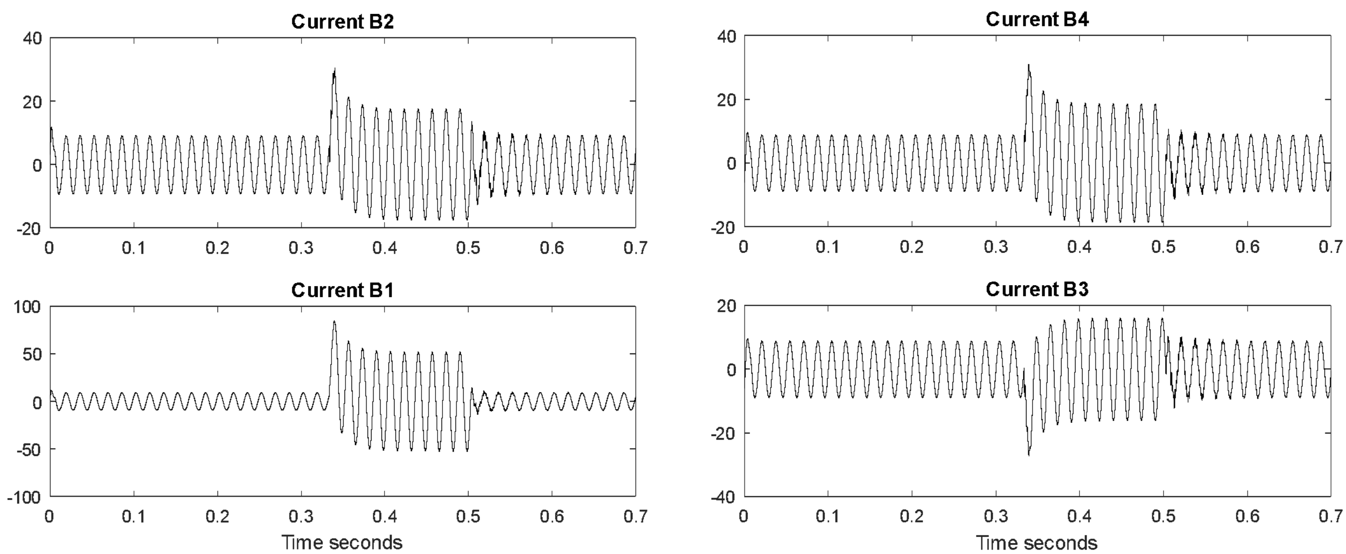

Figure 8 Phase A - Current (During the fault)

While the currents that feed the fault come from both lines, the current through bus 1 is bigger, as it is closer to the source and to the fault location. Phase A’s voltage and current on bus 3 were selected to test the proposed method. Figure 9 shows these signals.

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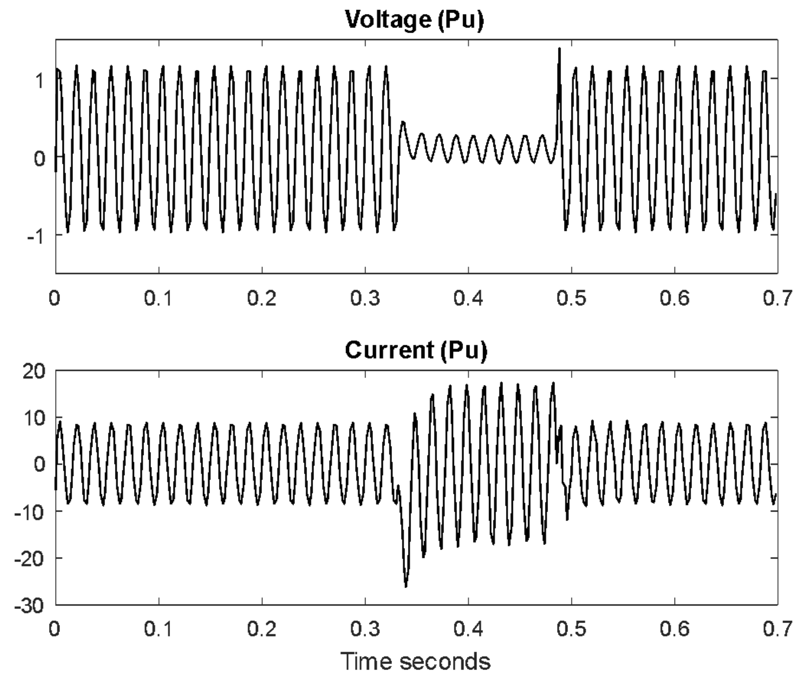

Figure 9 Voltage and Current in Line 2

The fault occurs at 0.25s and lasts for 10 cycles; after that, it is cleared. This temporary fault is used to determine if the proposed method is capable of detecting the change in the current, which could be applied as a signal to activate the protection.

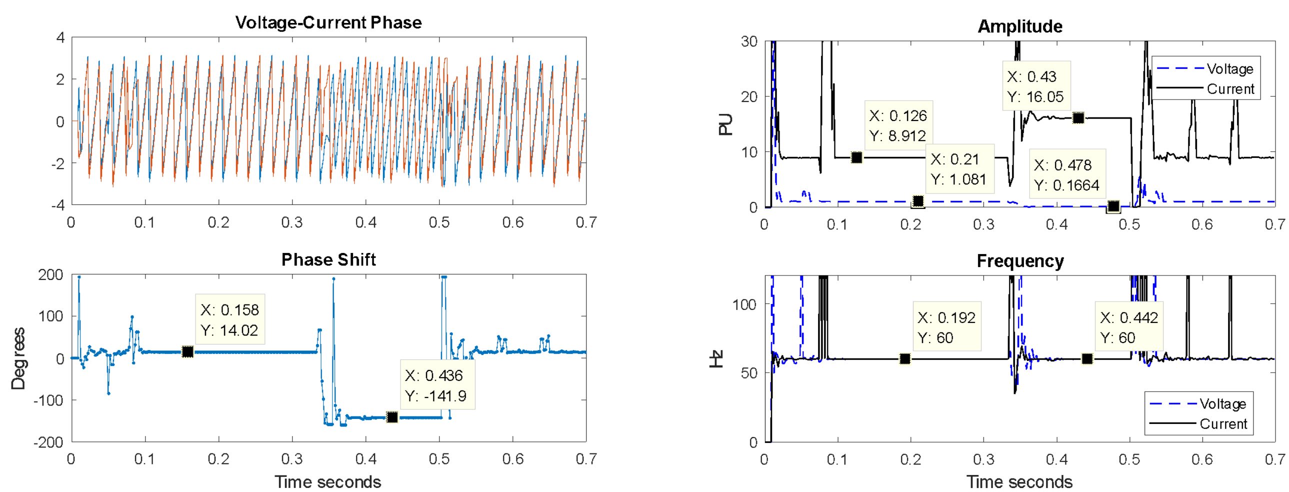

Figure 10 Results of the ZDM

The results depicted in Figure 10 match the fault condition. Before and after the fault, the phase shift is positive (14.02°), whereas during the fault, the current flows in the opposite direction and, consequently, the phase shift is negative. The results from the proposed method also show that the current amplitude increases and the voltage amplitude decreases, which agrees with the fault time and signals in Figure 9. Overcurrent and phase shift are used in the directional protection relay. A brief definition of directional overcurrent protection is presented below.

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The directional overcurrent (67 as per ANSI standard C37.2) [2] is defined as “a relay that functions on a desired value of AC overcurrent flowing in a predetermined direction. In other words, it is an overcurrent relay that trips only when the fault current flows in a given direction.” (© Festo Didactic Ltée/Ltd, Quebec, Canada 2016, p.4).

4. Conclusions

According to the results in this document, the ZDM could be an alternative for application in a directional protection scheme. The different methodologies — ZDM and traditional directional relays — will contribute to redundancy and improve EPS protection systems.

5. Acknowledgements

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