

# Transmission Line Fault Detection using Prony Method: A Case Study of Nigerian 330kV Network

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## ABSTRACT

The power systems of many developing countries like Nigeria are always characterized by poor generation, overloading, and less smart controls. Consequently, many fault occurrences lead to a total shut-down of the system. Accurate detection of faults, which improves the relay's decision making, increases the system reliability. This paper presents an accurate fault detection technique based on Prony method.

The Prony method is used to decompose fault signals into damped sinusoids; and based on the frequency and the amplitude of the resulting sinusoids; a fault occurrence decision is made. The proposed method is applied to a section of Nigerian 330kV, network modeled in Simulink/MATLAB software and all types of line faults were accurately detected. The results show that the proposed method accurately differentiates faults from load switching transients.

(Keywords: distance relay, fault detection, power systems, Prony method, transmission line)

## INTRODUCTION

The Nigeria power system like that of other developing countries is characterized by inadequate generation, overloading and less smart controls. The availability of power at the load center depends on both available generation and the security of the transmission system. Generally, transmission lines are susceptible to faults, especially when they are overhead. Specifically, in a developing country like Nigeria, fault occurrence is heightened, due to overloading and less smart technologies to detect them. Since

transmission line faults are inevitable, methods for detecting them and isolating the faulted lines are crucial.

Many intelligent techniques have been proposed in literature for fault detections. Artificial Neural Network (ANN) has been proposed by several researchers for protection, through the detection, classification and location of faults along a power transmission line [1-3]. ANN is composed of number of inter-connected units (artificial neurons) inspired by the learning process that takes place in biological systems. The strength of ANN is the ability to learn by training, but its effectiveness depends on the level of training. ANN trained with fewer data sets with respect to fault will not be as effective as one trained with a good number of fault scenarios. Fuzzy logic fault detection [4-6] uses linguistic variables instead of numerical variables and so is much simpler than the neural network-based techniques. However, accuracy is not certain in fuzzy logic-based systems for wide variations in system conditions. Wavelet transform is also a powerful tool for fault detection and has been used by [7, 8]. It is similar to Fourier transform but unlike Fourier transform, it uses variable window in its analysis.

Prony method is another tool that decomposes and fits a signal with a sum of damped complex exponentials (damped sinusoids). It also estimates amplitude, phase, frequency and damping of these sinusoids. Prony method has been used extensively in power system for characterization of oscillation modes in signals [9-18] and specifically for fault detections [10,11,14,15,16]. Khan, et al. [10] proposed an algorithm for detecting and locating single-line-to-ground fault based on Prony estimation. By this algorithm, fault is detected when frequency is

outside the tolerance of  $\pm 5 \text{ Hz}$ . However, not only fault conditions can exceed the frequency tolerance. Elraefiaie [11] used a combination of Wavelet transform and Prony method to detect high impedance fault and differentiate them from switching transients. In this work, the wavelet transform is used to extract the fault signal. Then the Prony method is used to check the amplitude of the third harmonic believed to contain the high impedance fault. Based on the amplitude of this third harmonic component and its damping, fault is detected. A combination of Prony and ANN was proposed by Tawfik, et al. [14] for fault location in a loop system. In this work, Prony method was first used to identify the frequency components of the supposed sinusoids that make up the fault signal.

These frequencies were then used to train the ANN. The above two works focus on the harmonic frequencies containing the faults. Lotfifard, et al. [15] proposed an algorithm for symmetrical fault detection by distance relay during power swing. In this work, fault was detected by checking for the presence of decaying DC current signal in the resulting signals after Prony application. The criterion is very efficient since there is an inherent decaying DC current whenever fault occurs, a phenomenon not observed under normal operation of the system. However, the ability of Prony to identify other types of faults was not explored. Recently, the applicability of Prony method to the analysis of the fault characteristics in low voltage DC distribution system has been reported [16].

Although some fault detection literatures exist based on Prony method, more research is still needed to fully explore its potentials. In this paper Prony method is used to detect fault in Nigerian 330 kV transmission network based on decaying DC current inherent in fault signals. This work is similar to [15] except that all types of transmission line faults are rigorously investigated, unlike [15] which is based on symmetrical faults. Such extended investigation is deemed necessary because even though symmetrical faults are most severe, they are less common. This work then tries to elaborate on Prony capabilities for fault detection. To the authors' knowledge Prony technique has not been used to study Nigerian power system before now. Therefore, this work introduces a new tool for fault detection in Nigeria power system.

## THEORITICAL BACKGROUND

Let a linear time invariant system be represented in state-space as:

$$\begin{aligned} \frac{dx(t)}{dt} &= Ax(t) + Bu(t) \\ y(t) &= Cx(t) + Du(t), \end{aligned} \quad (1)$$

where  $y(t)$  is the system output response,  $x(t)$  is the system state,  $u(t)$  is the input to the system.  $A$  is the state matrix,  $B$  and  $D$  are constant matrices that weigh the input  $u$  and  $C$  is a matrix that weighs the states  $x$  while  $y$  is the output matrix.

The matrix  $A$  is of size  $n \times n$  and has eigenvalues  $\lambda_i$  which implies that the system is of order  $n$ . Let the right and left eigenvectors of  $A$  be denoted respectively as  $V_i$  and  $W_i$ . If the input is zero, it can be shown that the solution of Equation (1) is expressed as:

$$x(t) = \sum_{i=1}^n (V_i^T x_0) W_i e^{(\lambda_i t)} \quad (2)$$

The Prony analysis directly estimates the parameters of the eigen structure described in equation (2) by fitting a sum of complex damped sinusoids to evenly spaced sample values of the output as:

$$\bar{y}(t) = \sum_{i=1}^J \beta_i e^{(\sigma_i t)} \cos(2\pi f_i t + \phi_i). \quad (3)$$

Where:

$\beta_i$  = Amplitude of component  $i$ ,

$\sigma_i$  = Damping coefficient of component  $i$ ,

$\phi_i$  = Phase of component  $i$ , (rad)

$f_i$  = Frequency of component  $i$ , (Hz)

$J$  = Total number of damped exponential components,

$\bar{y}(t)$  = Estimate of observed data for  $y(t)$  consisting of  $N$  samples  $y(t_k) = y[k]$ ,  $k=0,1,2,\dots,N-1$  that are evenly spaced.

After some trigonometric manipulations, Equation (3) reduces to:

$$\bar{y}(t) = \sum_{i=1}^J \frac{\beta_i}{2} e^{j\phi_i} \left( e^{(\sigma_i + j2\pi f_i)kT} \right) \quad (4)$$

$$y[k] = \sum_{i=1}^J C_i \mu_i^k \quad (5)$$

Where

$$C_i = \frac{\beta_i}{2} e^{j\phi_i} \quad (6)$$

$$\mu_i = e^{(\sigma_i + j2\pi f_i)T} \quad (7)$$

$\mu_i$  are referred to as the poles of the estimated response and T is the sampling period. Prony obtains the amplitude  $\beta_i$ , damping  $\sigma_i$ , initial phase  $\phi_i$ , and the frequency  $f_i$  of the sinusoids using three steps below.

### Estimation of the Characteristic Polynomial Coefficients

Consider the linear prediction model:

$$\begin{bmatrix} y[J] \\ y[J+1] \\ \dots \\ \vdots \\ y[N-1] \end{bmatrix} = \begin{bmatrix} y[J-1] & y[J-2] & \dots & \dots & y[0] \\ y[J] & y[J-1] & \dots & \dots & y[1] \\ y[J+1] & y[J] & \dots & \dots & y[2] \\ \dots & \dots & \dots & \dots & \dots \\ y[N-2] & y[N-3] & \dots & \dots & y[N-J-1] \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ \dots \\ a_J \end{bmatrix} \quad (8)$$

Where  $\mathbf{a}$  is a linear predictor parameter determined by solving (8) in a least square (LS) sense.

### Computation of the Modes Frequency and Damping Factor Roots of Characteristic Polynomial

Using the  $a^J$  coefficient previously estimated, the roots of the characteristic polynomial expressed as

$$\mu^J - [a_1 \mu^{J-1} + a_2 \mu^{J-2} + \dots + a_J \mu^0] = 0 \quad (9)$$

Since the vector  $\mathbf{a}$  is known, the roots of (9) can be computed. The roots are the discrete time approximation of the continuous time eigenvalue in the Z-domain. Thus, the damping ratio and frequency are respectively calculated as:

$$\sigma_i = (\ln |\mu_i|) / T$$

and

$$f_i = \tan^{-1} \left( \frac{\text{Im}\{\mu_i\}}{\text{Re}\{\mu_i\}} \right) * \frac{1}{2\pi T}, i = \{1, \dots, J\}.$$

### Computation of the Modes Amplitude and Initial Phase

With the roots  $\{\mu_1, \mu_2, \mu_3, \dots, \mu_J\}$  and using (5), the linear regression model is given by:

$$\begin{bmatrix} y[0] \\ y[1] \\ \dots \\ \vdots \\ y[N-1] \end{bmatrix} = \begin{bmatrix} 1 & 1 & \dots & \dots & 1 \\ \mu_1^1 & \mu_2^1 & \dots & \dots & \mu_J^1 \\ \mu_1^2 & \mu_2^2 & \dots & \dots & \mu_J^2 \\ \dots & \dots & \dots & \dots & \dots \\ \mu_1^{N-1} & \mu_2^{N-1} & \dots & \dots & \mu_J^{N-1} \end{bmatrix} \begin{bmatrix} C_1 \\ C_2 \\ C_3 \\ \dots \\ C_J \end{bmatrix} \quad (10)$$

C is obtained by solving (10) in similar way as (8). Then the amplitude and initial phase are respectively calculated as:

$$\beta_i = |C_i|$$

and

$$\phi_i = \tan^{-1} \left( \frac{\text{Im}\{C_i\}}{\text{Re}\{C_i\}} \right), i = \{1, \dots, J\}.$$

### Fault Detection Criterion

The Thevenin equivalent of a power system under fault can be represented by Figure 2.

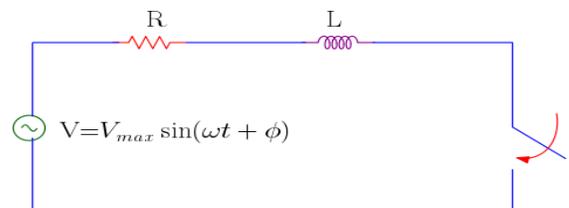


Figure 2: Thevenin Equivalent of a Faulted System.

The system can be analyzed by applying the well-known Kirchhoff's voltage law (KVL) which leads to a first order differential equation:

$$V_{\max} \sin(\omega t + \phi) = Ri + L \frac{di}{dt} \quad (11)$$

where  $R$  is the system resistance,  $L$  the system inductance,  $\phi$  the phase angle  $V_{\max}$  is the maximum value of the voltage,  $\omega$  the angular frequency and  $i$  the current flowing in the circuit. Integrating both sides of equation (11) and solving for the current leads to:

$$i(t) = e^{-\left(\frac{R}{L}\right)t} \left( \frac{-V_{\max}}{\sqrt{R^2 + \omega^2 L^2}} \sin \left[ \phi - \tan^{-1} \left( \frac{\omega L}{R} \right) \right] \right) + \frac{-V_{\max}}{\sqrt{R^2 + \omega^2 L^2}} \sin \left[ \omega t + \phi - \tan^{-1} \left( \frac{\omega L}{R} \right) \right] \quad (12)$$

Inspection of Equation (12) reveals two different kinds of signals: the first member on the right is a decaying DC part while the second member is a sinusoidal signal. Therefore, fault current can be said to comprise a decaying DC part and a sinusoidal part. This is very crucial in this work because there is no such part in a current waveform during normal operation. Notice that if

$\phi = \tan^{-1} \left( \frac{\omega L}{R} \right)$  in Equation (12), then the

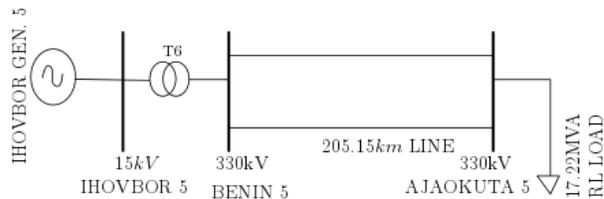
decaying DC part disappears from the studied phase.

Although the above Thevenin equivalent is based on balanced three phase fault, the appearance of decaying DC current is also apparent in at least a phase for every type of fault. Decaying DC current criterion has been used by [15] to detect symmetrical fault. The extension of this criterion to other types of fault is the contribution of this paper in addition to the different power system being considered. Moreover, the effectiveness of this criterion for fault distance variations was not considered in [15] which is now being considered in the present work.

## MATERIALS AND METHODS

### Materials

The studied system is Benin-Ajaokuta transmission line section of Nigeria's Transmission Network shown in Figure 3. It is a 330kV double circuit transmission line of length 205.5km. A total load of 17.22 MVA is connected to the receiving end of the line, precisely at Ajaokuta 5 bus. The line is fed by a 240 MVA transformer (T6) which steps up the 15 kV generated at Ihovbor by generator named Ihovbor gen. 5. Ihovbor gen. 5 plant is made up of four generators each of 141.25MVA.



**Figure 3:** One Line Diagram of Benin-Ajaokuta 330kV Transmission Line.

The system data were obtained from the National Control Centre (NCC) Annual Technical Report except 30 MVAR capacitor bank that was introduced to investigate capacitor switching. The data for the study is presented in Table 1.

### Methods

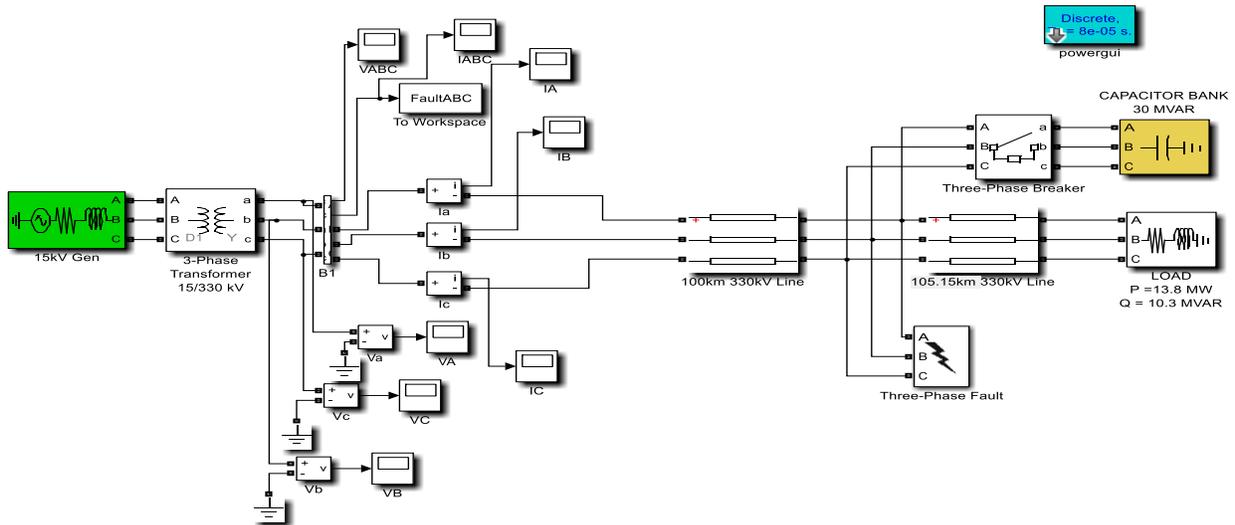
Firstly, the transmission line model described in Figure 3 is implemented with the help of Simulink, embedded in MATLAB software. Secondly, the simulation is run for fault scenarios and the signal generated is used as input to Prony program code written in MATLAB. Based on the Prony computations, fault occurrence is detected. It is recommended to pass the current signal through an anti-aliasing filter to frequencies higher than one-half of the sampling frequency before passing it to Prony toolbox. A common anti-aliasing filter used for protective relays is Butterworth low pass filter [19].

**Table 1:** System Data [18].

Benin-Ajaokuta Line Data	
Components	Parameters
Frequency	50Hz
Source voltage	330kV
Transmission line impedance	$R_1 = 0.0394$ $R_0 = 0.02614$ $X_1 = 0.3310$ $X_0 = 1.0019$
Capacitance	$C_1 = 0.011167 \mu\text{F/km}$
Line Length	205.15km
Load Data	
RL Load	17.22MVA
Ihovbor Generator Data	
Components	Parameters
Rating (MVA)	141.25MVA
Voltage	15kV
Power Factor (Cos $\phi$ ) (PU)	0.8
Resistance (PU)	$R_1 = 0.0027$ at 75°C $R_0 = 0.0041$ at 75°C
Ihovbor Transformer Data	
Components	Parameters
Rating (MVA)	90/143 MVA
Rated Voltage (kV)	343/15 kV
Impedance (%)	$Z_1 = 13, Z_0 = 13$

The model, as created with Simulink is shown in Figure 4. Different types of faults are created by just toggling the needed phases with the help of the three-phase fault breaker. The 205.15 km Benin-Ajaokuta transmission line is divided into two sections connected in series, with each modelled as distributed parameter line.

The splitting of the line is is to make possible fault inceptions at different lengths of the line. The three-phase breaker is used to switch the 30 MVAR capacitor bank connected to the line. This breaker is normally open during simulations except for the time it is needed to switch on the capacitor bank. The "To Workspace" block automatically routes the fault signals to the MATLAB workspace where the Prony tool box can access them to determine the parameters of the fitted sinusoids. The six multi-meters measure the per phase current and voltages while the scopes allow visualization of the output signals.



**Figure 4:** Benin-Ajaokuta 330 kV Transmission Line Model.

**Table 2:** Prony Results for the Three Phases under No-Fault Condition.

IA			IB			IC		
Amplitude	Freq.(Hz)	Damp.	Amplitude	Freq.(Hz)	Damp	Amplitude	Freq.(Hz)	Damp
200.78	49.99	$1.3e^{-5}$	200.71	49.99	$6.6e^{-7}$	200.69	-49.99	$-1.2e^{-6}$
200.78	-49.99	$1.3e^{-5}$	200.71	-49.99	$6.6e^{-7}$	200.69	49.99	$-1.2e^{-6}$
0.1548	0	1	0.0248	$1e^4$	0.012	0.1728	0	1
0.0682	$1e^4$	0.012	0.0106	0	1	0.0434	$1e^4$	0.012

**Table 3: Prony Results for the Three Phases under L-G Fault Condition.**

IA			IB			IC		
Amplitude	Freq.(Hz)	Damp.	Amplitude	Freq.(Hz)	Damp	Amplitude	Freq.(Hz)	Damp
1.5e <sup>4</sup>	0	1	1.1e <sup>3</sup>	-825.04	0.862	1.5e <sup>3</sup>	0	1
1.4e <sup>4</sup>	0	1	1.1e <sup>3</sup>	825.04	0.862	1.2e <sup>3</sup>	0	1
621.17	4.4e <sup>3</sup>	0.31	199.12	-55.64	0.05	410.54	4e <sup>3</sup>	0.37
621.17	-4.4e <sup>3</sup>	0.31	199.12	55.64	0.05	410.54	-4e <sup>3</sup>	0.37
445.98	-59.09	0.07	198.79	-4.5e <sup>3</sup>	0.25	357.46	54.51	0.047
445.98	59.09	0.07	198.79	4.5e <sup>3</sup>	0.25	357.46	-54.51	0.047

## RESULTS AND DISCUSSION

In this section, the results of the simulations are presented. The results are first presented for the no-fault condition which serves as a reference, and then followed by the fault conditions. The fault type is created and simulated with the help of the fault breaker and then corresponding results are used to check if Prony analysis recognized the fault occurrence. In what follows, the results are systematically presented along with relevant discussions.

### Reference Condition (No Fault)

The Prony solution for the healthy condition is shown in Table 2. This table is interpreted, say for phase-A as: a sinusoidal current with an amplitude of 200.78, frequency of 49.99Hz and damping of 1.3e-5; another sinusoidal current with amplitude 0.0682, frequency of 1e4 Hz and damping of 0.0120; a decaying DC current with amplitude of 0.1548, frequency of 0Hz and damping of 1. Note that decaying DC signal has zero frequency and positive damping. This interpretation is similar for other phases and is implied throughout the work. Observe that the amplitudes of the decaying DC currents are very infinitesimal compared to the dominant signal. This will be compared with fault condition. The results will show that when fault occurs, the decaying DC current rises very high and is a member of the first 2 to 4 amplitudes.

### Single Line to Ground Faults (L-G)

The results from Prony computations are shown in Table 3. It can be observed clearly from phase-A and phase-C that the DC currents in these phases have the highest amplitudes in the observed signals. This shows that fault has

occurred. As stated earlier, the DC current must not necessarily be in the affected phase.

### Double Line to Ground Faults (2L-G)

Table 4 presents the Prony analysis for the 2L-G fault. There are decaying DC currents of very high magnitude in phase-A and phase-B which confirms fault has occurred. It is interesting to remark that the actual measurement of this decaying DC current is not required before the relay takes decision. The algorithm is based on the presence of this current.

### Line to Line Faults (L-L)

As in the previous cases, Prony computations are done and decaying DC current observed as presented for L-L in Table 5. It can be seen that the high amplitude decaying DC currents are present in all phases confirming the occurrence of fault.

### Line-to-Line-to-Line Faults (L-L-L)

The last type of fault is the three-phase fault. Its Prony analysis is presented in Table 6, which is very consistent with the previous ones. The decaying DC current is observed in all the phases.

### Differentiating Faults from Load Switching

For the Prony algorithm to be effective, it has to be able to differentiate faults from load switching since there are other sources of decaying DC current. We reiterate here that, when there is no fault, there is no significant decaying DC current.

**Table 4:** Prony Results for the Three Phases under 2L-G Fault Condition.

IA			IB			IC		
Amplitude	Freq.(Hz)	Damp	Amplitude	Freq.(Hz)	Damp	Amplitude	Freq.(Hz)	Damp
4.1e <sup>3</sup>	1e <sup>4</sup>	0.76	1.1e <sup>3</sup>	0	1	3.6e <sup>3</sup>	519.21	0.959
3.4e <sup>3</sup>	0	1	788.32	0	1	3.6e3	-519.21	0.959
1.4e <sup>3</sup>	-4.8e <sup>3</sup>	0.32	338.62	-61.17	0.096	445.74	5e <sup>3</sup>	0.351
1.4e <sup>3</sup>	4.8e <sup>3</sup>	0.32	338.62	61.17	0.096	445.74	-5e <sup>3</sup>	0.351
404.84	-58.24	0.079	267.24	-5.1e <sup>3</sup>	0.349	336.70	-52.50	0.036
404.84	58.24	0.079	267.24	5.1e <sup>3</sup>	0.349	336.70	52.50	0.036

**Table 5:** Prony Results for the Three Phases under L-L Fault Condition.

IA			IB			IC		
Amplitude	Freq.(Hz)	Damp	Amplitude	Freq.(Hz)	Damp	Amplitude	Freq.(Hz)	Damp
5e <sup>3</sup>	0	1	4.9e <sup>3</sup>	0	1	200.71	-49.99	-7e <sup>-7</sup>
4.6e <sup>3</sup>	0	1	4.7e <sup>3</sup>	0	1	200.71	49.99	-7e <sup>-7</sup>
845.39	4.6e <sup>3</sup>	0.242	375.09	-60.86	0.08	0.41	0	1
845.39	-4.6e <sup>3</sup>	0.242	375.09	60.86	0.08	0.07	-2.6e <sup>3</sup>	0.24
417.47	-57.95	0.078	174.85	4.7e <sup>3</sup>	0.20	0.07	2.6e <sup>3</sup>	0.24
417.47	57.95	0.078	174.85	-4.7e <sup>3</sup>	0.20	0.03	1e <sup>4</sup>	0.012

**Table 6:** Prony Results for the Three Phases under L-L-L Fault Condition.

IA			IB			IC		
Amplitude	Freq.(Hz)	Damp	Amplitude	Freq.(Hz)	Damp	Amplitude	Freq.(Hz)	Damp
1e <sup>3</sup>	0	1	1e <sup>4</sup>	0	1	5.6e <sup>3</sup>	0	1
1e <sup>3</sup>	1e <sup>4</sup>	0.77	1e <sup>4</sup>	0	1	5e <sup>3</sup>	0	1
362.96	4.2e <sup>3</sup>	0.27	341.42	67.44	0.081	902.02	4.6e <sup>3</sup>	0.232
362.96	-4.2e <sup>3</sup>	0.27	341.42	-67.44	0.081	902.02	-4.6e <sup>3</sup>	0.232
98.29	-60.25	0.169	108.81	4.7e <sup>3</sup>	0.197	575.25	51.63	0.073
98.29	60.25	0.169	108.81	-4.7e <sup>3</sup>	0.197	575.25	-51.63	0.073

So switching a load say capacitor bank should not be detected as fault causing the relays to operate at undesired time.

To investigate the capability of the proposed scheme to differentiate faults from load switching, a 3-phase 30 MVar capacitor bank was switched on during simulation at 0.08 seconds. This event produces some remarkable fault-like transients.

The fault-like signals were passed to Prony toolbox for analysis. The Prony results are listed in Table 7. Examination of Table 7 shows clearly that there is no fault since there is no high amplitude decaying DC current in any of the phases. There are only the sinusoidal signals with frequencies very near to the fundamental frequency (approx. 50Hz).

### **Robustness to Fault Distance Variations**

Since distance relay works by measuring the distance of the fault occurrence using measured fault impedance, it is necessary to show that Prony can operate effectively no matter the fault distance. To this, faults were created at three points: 10%, 50% and 75% of the line lengths with reference to the sending end.

The Prony results to 3-phase fault at these fault distances are shown respectively in Table 8, Table 9, and Table 10. It is clearly seen that the faults were accurately detected in each case since the decaying DC current could be seen significantly in each case.

**Table 7:** Prony Results for the Three Phases under Capacitor Switching Condition.

IA			IB			IC		
Amplitude	Freq.(Hz)	Damp	Amplitude	Freq.(Hz)	Damp	Amplitude	Freq.(Hz)	Damp
415.72	-51.43	0.294	559.41	51.96	0.431	370.42	-50.76	0.366
415.72	51.43	0.2940	559.41	-51.96	0.431	370.42	50.76	0.366
233.34	2.2e <sup>3</sup>	0.302	145.66	-1.3e <sup>3</sup>	0.203	78.65	-2.2e <sup>3</sup>	0.299
415.72	-51.43	0.294	559.41	51.96	0.431	370.42	-50.76	0.366

**Table 8:** Prony Results for 3-Phase Fault at 10% of the Line Length.

IA			IB			IC		
Amplitude	Freq.(Hz)	Damp	Amplitude	Freq.(Hz)	Damp	Amplitude	Freq.(Hz)	Damp
1.3e <sup>3</sup>	0	1	436.27	0	1	3.4e <sup>3</sup>	0	1
440.45	1e <sup>4</sup>	0.236	381.08	0	1	1.8e <sup>3</sup>	1e <sup>4</sup>	0.394
287.76	-3.8e <sup>3</sup>	0.201	376.49	66.11	0.068	877.94	3.9e <sup>3</sup>	0.238
287.76	3.8e <sup>3</sup>	0.201	376.49	-66.11	0.068	877.94	-3.9e <sup>3</sup>	0.238

**Table 9:** Prony Results for 3-phase Fault at 50% of the Line Length.

IA			IB			IC		
Amplitude	Freq.(Hz)	Damp	Amplitude	Freq.(Hz)	Damp	Amplitude	Freq.(Hz)	Damp
830.81	0	1	885.19	0	1	4.8e <sup>3</sup>	0	1
735.54	1e <sup>4</sup>	0.588	861.53	0	1	4e <sup>3</sup>	0	1
304.19	4.2e <sup>3</sup>	0.280	342.74	67.53	0.086	1e <sup>3</sup>	4.6e <sup>3</sup>	0.262
304.19	-4.2e <sup>3</sup>	0.280	342.74	-67.53	0.086	1e <sup>3</sup>	-4.6e <sup>3</sup>	0.262

**Table 10:** Prony Results for 3-Phase Fault at 75% of the Line Length.

IA			IB			IC		
Amplitude	Freq.(Hz)	Damp	Amplitude	Freq.(Hz)	Damp	Amplitude	Freq.(Hz)	Damp
1.3e <sup>3</sup>	1e <sup>4</sup>	0.555	1.1e <sup>3</sup>	0	1	5.4e <sup>3</sup>	0	1
1.2e <sup>3</sup>	0	1	908.40	0	1	4e <sup>3</sup>	0	1
575.52	4.7e <sup>3</sup>	0.307	346.02	4.9e <sup>3</sup>	0.340	1.7e <sup>3</sup>	4.9e <sup>3</sup>	0.336
575.52	-4.7e <sup>3</sup>	0.307	346.02	-4.9e <sup>3</sup>	0.340	1.7e <sup>3</sup>	-4.9e <sup>3</sup>	0.336

## CONCLUSION

In this work, accurate fault detection using Prony method has been presented. We have exploited the ability of Prony method to extract damped sinusoids in a signal. This method has been demonstrated on a 330kV, 205.15km transmission line and all the types of transmission line faults were accurately identified. From the results obtained, it was observed that whenever fault occurs in at least one phase, there is a high amplitude decaying DC current while such phenomenon is absent under other system transients like capacitor switching. This conclusion is an extension of the previous researches where

decaying DC current criterion was limited to symmetrical faults.

For the studied system, the results showed that the algorithm presented in this work can differentiate fault transients from switching transients accurately. This is a huge success because faults must be distinguished from switching to avoid irrational operation of distance relays. In general, the presented method gives good results and can be added as alternative fault detection tool used by power system operators.

Although the presented method identifies fault occurrences, it is not able to precisely classify them since decaying DC current can be observed in the phase not involved in fault. To classify the faults, further analysis is needed.

As with any fitting method, more data samples give better result but computation increases. This is not desirable since fast detection of fault is needed. There are several research works aimed at reducing Prony computations. In future work, time economics of this technique will be considered.

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