

# Islanding detection of grid connected distributed generators using TLS-ESPRIT

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## Abstract

A critical protection requirement for grid connected distributed generators (DG) is anti-islanding protection. In this paper, a new islanding detection method is proposed based on monitoring the generator's frequency. Two new features, the frequency of oscillation and the damping factor of the generator's frequency output waveform, are extracted using the total least square-estimation of signal parameters via rotational invariance techniques (TLS-ESPRIT) algorithm. The proposed method has been tested under various scenarios such as load change, short circuit, and capacitor switching.

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## 1. Introduction

Despite the favorable aspects grid-connected DGs can provide to the distribution system, a critical demanding concern is islanding detection and prevention. Islanding is a condition where the DG supplies power and is not under the direct control of the utility. According to the IEEE Std. 929-2000, such situation should be prevented due to several reasons concerning personnel safety, power quality and safe operation of the DG and distribution system. In general, islanding detection methods are classified into two main groups: active and passive methods [1].

Active islanding detection methods interact with the system operation. This could be done by injecting a distorted current waveform, using a frequency pattern, or by varying the output power of the DG continuously. Island loading for which the

islanding detection method fails to detect islanding is known as the nondetection zone (NDZ). Despite that active methods are characterized by small NDZ, active methods affect the power quality of the distribution system. They are most commonly applied to inverter based DGs. Active methods include active frequency drift (AFD), output power variation, slip mode frequency shift (SMFS), and etc. [2–4].

Passive islanding detection techniques depend on measuring system parameters and setting thresholds for the measurable parameters. Passive islanding detection methods can be applied to any type of dispersed generation whether the DG is of the synchronous type or the inverter based type. The main challenge when designing a passive islanding detection method is to choose the most significant parameter and its threshold value to detect islanding for almost all loadings while avoiding nuisance tripping. Thresholds are chosen such that the islanding detection algorithm will not operate for other disturbances on the system. As a result, passive methods suffer from large NDZ.

Regarding the passive islanding detection methods, over/under voltage and frequency (OVP/UVP and OFP/UFP) is the simplest method used for islanding detection. The IEEE Std. 1547 identifies the thresholds for both the voltage and frequency and the time delay required [5]. Unfortunately, if the load and generation on the island are closely matched, the change in voltage and frequency might be very small

*Abbreviations:* DG, distributed generation; TLS-ESPRIT, total least square-estimation of signal parameters via rotational invariance techniques; NDZ, non-detective zone; AFD, active frequency drift; SMFS, slip mode frequency shift; THD, total harmonic distortion; FFT, fast Fourier transform; OVP/UVP, over/under voltage; OFP/UFP, over/under frequency

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and within the IEEE standard specified thresholds, thus leading to an undetected islanding situation. In the phase jump detection method, the voltage waveform is compared with a reference waveform to determine the phase angle. If the phase angle exceeds the threshold value, an islanding condition is declared.

Total harmonic distortion (THD) of the DG voltage has been used as a means of islanding detection. If the system has non-linear loads, the choice of a threshold for the THD becomes a tedious task [6,7]. The rate of change of frequency method overcomes some of the drawbacks of the previous methods but still fails when the load and DG capacity are closely matched. In [8,9], the rate of change of active power was proposed as a measure to detect islanding. The method is capable of differentiating between islanding and load switching conditions but unfortunately, it could fail under other disturbances such as voltage sag due to a short circuit or for a load to generation ratio on the island almost equal to unity. In [10,11], the ratio of frequency variation to load variation was used as a measure of islanding. Similarly, the method suffers from a NDZ.

To enhance the performance of islanding detection methods and decrease the NDZ, several methods have been proposed which use more than one parameter to detect islanding. In [12], both the rate of change of voltage and change in power factor were used to detect islanding. In [13], islanding was detected using the voltage unbalance and the THD of the DG current. In [14], both reactive and active power variation are used as means for islanding detection.

Two types of DG technology are commonly used for DG applications: inverter based and rotating machine technology. This paper proposes a new passive islanding detection method for DG of the synchronous type. Two new parameters, the frequency of oscillation and the damping factor of the generator's output frequency, are extracted using the TLS-ESPRIT algorithm. By analyzing the characteristics of the dominant modes in the DG output frequency signal, an islanding condition could be distinguished from a non-islanding one.

The paper is organized as follows: Section 2 provides the theory of the TLS-ESPRIT algorithm. Section 3 presents the proposed islanding detection method. The system model and data generation are presented in Section 4. Section 5 provides the simulation results. The last section draws the conclusions.

## 2. TLS-ESPRIT

The estimation of signal parameters via rotational invariance techniques (ESPRIT) has proven to be a powerful tool for extracting unknown parameters [15]. ESPRIT belongs to the class of signal subspace methods, which rely on eigendecomposition of the sample covariance matrix. This method yields high accuracy and can be applied to wide variety of problems including accurate detection and estimation of cisoids (damped sinusoids). In this paper the TLS-ESPRIT algorithm, which is a modified version of the ESPRIT algorithm is used to extract signal parameters from the frequency waveform. The TLS-ESPRIT algorithm was introduced and analyzed in [15,16]. TLS-ESPRIT combines a reasonable computational complexity with a good

modeling accuracy. Theory and application of the TLS-ESPRIT algorithm are presented in the next subsections.

### 2.1. Theory

The TLS-ESPRIT algorithm decomposes the signal into a group of damped sinusoids of different frequencies. The algorithm estimates the frequency, damping coefficient, amplitude and initial phase of each component of the signal. The model for the signal to be resolved by the TLS-ESPRIT is given by

$$x(n) = \sum_{i=1}^M h_i S_i[n] + \eta[n] \quad (1)$$

where

$$S_i[n] = e^{c_i n} \quad (2)$$

$c_i = -\sigma_i + j\omega_i$  is the damping coefficient and frequency of oscillation of the  $i$ th signal component,  $M$  the modal order which represents the number of sinusoids representing a signal,  $\eta$  the noise signal and  $h_i$  is the complex amplitude of the  $i$ th signal component:

$$h_i = |h_i| e^{j\vartheta} \quad (3)$$

Given  $N$  snapshots of the transient signal,  $x(n), \dots, x(n-N)$ , then

$$\begin{pmatrix} x(n) \\ x(n-1) \\ \vdots \\ x(n-N) \end{pmatrix} = \begin{pmatrix} 1 & \dots & 1 \\ e^{-c_1} & \dots & e^{-c_M} \\ e^{-Nc_1} & \dots & e^{-Nc_M} \end{pmatrix} \begin{pmatrix} h_1 e^{c_1 n} \\ h_2 e^{c_2 n} \\ \vdots \\ h_M e^{c_M n} \end{pmatrix} + \begin{pmatrix} \eta(n) \\ \eta(n-1) \\ \vdots \\ \eta(n-N) \end{pmatrix} \quad (4)$$

The signal to be analyzed is modeled by a complex  $k$ -dimensional vector  $a(c_i)$ , which is called the steering vector:

$$a(c_i) = [1, e^{-c_i}, \dots, e^{-Nc_i}]^T \quad (5)$$

The  $k$  complex amplitudes are collected in a complex vector  $s(n)$ :

$$s_i = h_i e^{c_i n} \quad (6)$$

From (4)–(6)

$$y = [a(c_1), a(c_2), \dots, a(c_M)]S + \eta = AS + \eta \quad (7)$$

where  $y = [x(n)x(n-1), \dots, x(n-N)]^T$ , and  $S = [s_1, s_2, \dots, s_m]$ .

Let  $y_1$  and  $y_2$  be two subarrays of  $y$

$$y_1 = [a(c_1), a(c_2), \dots, a(c_M)]S + \eta_1 = AS + \eta_1 \quad (8)$$

$$\begin{aligned} y_2 &= [a(c_1)e^{-c_1}, a(c_2)e^{-c_2}, \dots, a(c_M)e^{-c_m}]S + \eta_2 \\ &= A\phi S + \eta_2 \end{aligned} \quad (9)$$

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