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ORIGINAL ARTICLE

# Proposed Sandia frequency shift for anti-islanding detection method based on artificial immune system

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Non-detection zone (NDZ);
Total harmonic distortion (THD);
Artificial immune system (AIS);
Clonal selection algorithm

**Abstract** Sandia frequency shift (SFS) is one of the active anti-islanding detection methods that depend on frequency drift to detect an islanding condition for inverter-based distributed generation. The non-detection zone (NDZ) of the SFS method depends to a great extent on its parameters. Improper adjusting of these parameters may result in failure of the method. This paper presents a proposed artificial immune system (AIS)-based technique to obtain optimal parameters of SFS anti-islanding detection method. The immune system is highly distributed, highly adaptive, and self-organizing in nature, maintains a memory of past encounters, and has the ability to continually learn about new encounters. The proposed method generates less total harmonic distortion (THD) than the conventional SFS, which results in faster island detection and better non-detection zone. The performance of the proposed method is derived analytically and simulated using Matlab/Simulink. Two case studies are used to verify the proposed method. The first case includes a photovoltaic (PV) connected to grid and the second includes a wind turbine connected to grid. The deduced optimized parameter setting helps to achieve the "non-islanding inverter" as well as least potential adverse impact on power quality.


## 1. Introduction

Distributed generations (DG) are small-scale generation units that can be installed near to consumers with the ability of interacting with the grid importing or exporting energy. One of the major problems associated with such generators is the unwanted islanding phenomenon. Islanding occurs when a portion of the distribution system becomes electrically isolated from the remainder of the power system yet continues to be energized by one or more DGs. An important requirement to interconnect a DG to a power distributed system is the capability of the DG unit to detect islanding with the minimum time possible. The continued energizing of the load can lead to damage of equipment or injury to maintenance personnel working within the islanded section without knowing the system is still alive. Most DG units are designed in such a way that they are disconnecting from the grid when over/under voltage or frequency occurs on the network. In the case that the grid is disconnected while the load and the source are matched, the DG units will thus continue to power the line, thereby leading to the formation of an island.

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DGs must detect islanding and immediately stop feeding the utility lines with power. This is known as anti-islanding. Anti-islanding methods assist the DG units to detect islanding or force the islanded section out of the normal operational specifications of the grid. This is achieved by attempting to perturb either the voltage or the frequency of the network. In the presence of the grid, these perturbations will have no effect on the voltage or frequency. If the grid is disconnected, variations in voltage or frequency can occur. These variations can be detected by the over/under voltage or frequency protection system, and the DG is disconnected or shutdown.

Anti-islanding methods generally can be classified into four major groups, which include passive methods, active methods, hybrid methods and communication base methods [1]. Passive methods monitor selected parameters, such as voltage, frequency or their characteristics, and they switch off the inverter if one of these parameters deviates outside specified boundaries or conditions [2]. The boundary limits of these parameters define the non-detection zone (NDZ). The passive methods include Over/Under Voltage Protection (OVP/UVP), Over/Under Frequency Protection (OFP/UFP), voltage phase jump detection, and detection of voltage and current harmonics methods [2–4]. These methods are conceptually simple and easy to implement and do not introduce any change to the power quality of the system. However, they have a number of weaknesses including the inability to detect islanding because they have a large NDZ. They tend to false trip due to disturbances on the grid which may weaken grid stability and security.

In order to reduce the NDZ, particularly in cases where the local loads are close in capacity to the DG systems, active detection methods have been proposed. Active methods perturb the connected circuit and then monitor the response to determine whether islanding has occurred [2,5–8]. Active methods include Impedance measurement method [9–11], Slip Mode Frequency Shift (SMS) [12], Active Frequency Drift (AFD) [13–19], Sandia Frequency Shift (SFS) [13,20–22], Sandia Voltage Shift (SVS) [5,8], Reactive Power Variation (RPV) method [23], and Mains monitoring units with allocated all-pole switching devices connected in series (MSD) [24]. Active methods attempt to create a power mismatch between the load and the DG when they are closely matched. It is possible that some of the active methods can cancel out the mismatch in an attempt to create one. It should also be noted that the positive feedback in some active methods could lead to power-quality degradation [25]. The injection signals can also induce some voltage waveform distortion.

Among frequency drift islanding detection methods, SFS is considered as one of the most effective methods in detecting islanding conditions. The method can be used to improve the NDZ and THD by using a positive feedback gain, but still affect the power quality of the system. This paper presents a proposed technique to modify SFS anti-islanding method using Artificial Immune Systems (AIS). The method optimizes the parameters of the SFS method to reduce both the NDZ and the THD of the current waveforms.

AIS are computational paradigms that belong to the computational intelligence family and are inspired by the biological immune system. During the past decade, they have attracted a lot of interest from researchers aiming to develop immune-based models and techniques to solve complex computational or engineering problems. Authors in [26,27] propose a technique that is based on AIS for fault detection. Ref. [28] applies AIS for disturbance detection. On the other hand, AIS was used for fault detection in the stator and rotor circuits of induction machines in [29].

The impacts of the load parameters on the performance of the SFS method have been discussed in many papers. However these papers are concerned with reducing NDZ only and ignore the impact on power quality deterioration. In [19] the performances of SFS method and its major factors affecting the phase-frequency characteristic of the islanding system were analyzed. Ref. [20] proposed a technique to estimate the parameter of SFS using fuzzy logic. Ref. [21] proposed SFS methods that prevent islanding without any deregulation in power quality. Authors in [22] presented a method to improve the dynamic NDZ in load parameter space. In [30] a SFS based PLL algorithm was proposed for islanding detection. Authors in [31,32] discussed the impact of load frequency and DG on the parameters of SFS method.

There are many artificial intelligence techniques used for islanding detection [33–36]. Ref. [33] presented a passive method for detecting islanding of DG inspired by the information processing properties of natural immune system. Ref. [34] proposed an islanding detection algorithm using combination of an optimal Artificial Neural Network (ANN) based on Particle Swarm Optimization (PSO) with a simple active method. Two-dimensional particle swarm optimization (2D-PSO) method for optimizing the weighting in extension theory to detect the islanding in the presence of photovoltaic (PV) power generation systems was presented in Ref. [35]. Authors in [36] presented an islanding detection method that is based on neuro-fuzzy system which is trained by using four different heuristic algorithms and finally among all of them, PSO with the best results is elected.

This paper presents a proposed AIS-based technique to obtain optimal parameters of SFS anti-islanding detection method. This method improves the performance of the conventional SFS method by reducing THD, NDZ, and results in faster island detection. The proposed method is derived analytically and simulated using Matlab/Simulink. The verification of this method can be achieved by a two case studies; the first case includes a photovoltaic (PV) connected to grid and the second includes a wind turbine connected to grid.

The remainder of this paper is organized as follows: Section 2 describes the SFS anti-islanding method, Section 3 describes the system modeling and simulation, Section 4 introduces the AIS method and the clonal selection algorithm, Section 5 presents the modified SFS based AIS method and the AIS algorithm for solving this problem, and Section 6 presents the results and discussion. Finally, Section 7 concludes the paper.

## 2. Sandia frequency shift anti-islanding method

Sandia Frequency Shift (SFS) is one of the active islanding detection methods that rely on frequency drift to detect an islanding condition. These methods depend on injecting a distorted current waveform into the original reference current of the inverter; therefore, in the case of islanding operation the frequency drift up or down depending on the sign of the so called chopping factor "$C_f$". A positive feedback is utilized

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