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Using gold sequences to improve the performance of correlation based islanding detection

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ABSTRACT

One of the problems encountered when connecting distributed generators to a distribution system is the possibility of islanded operation. Traditionally this has been prevented through the application of passive under/over voltage and frequency relays which are triggered if the island contains mismatched amounts of active and/or reactive power, respectively. Various active techniques which reduce the power mismatch required for operation of the passive relays have been developed. These active techniques may fail to detect islanding in multiple generator islands if all the generators do not have identical active anti-islanding strategies. An islanding detection technique based on the correlation between disturbances in system voltage and a pseudo-random sequence used to perturb the generator's output was developed for use in islands where generators may have different anti-islanding strategies. Previous investigations have always used pseudo-random sequences from the maximal length family of sequences. It is demonstrated in this paper that using either a Gold or Kasami sequence instead of a maximal length sequence can improve the performance of the correlation technique.

1. Introduction

The potential for a number of different problems arises when distributed generators (DGs) are connected to a distribution system. One of these problems is the islanding condition. Islanding is the situation where a part of the system containing equal amounts of generation and load becomes isolated from the rest of the system and the DG(s) in the isolated portion continue to power the loads. This condition is generally undesirable because it risks damage to equipment from out of phase reclose attempts and, more importantly, may create a shock hazard for utility personnel [1]. Thus, it is standard practice to require DGs to detect the formation of an island and disconnect themselves from the system [2].

Often, the islanding condition can be detected passively through the use of over/under voltage (OV/UV) and over/under frequency (OF/UF) relays since a mismatch between the active or reactive power generated and consumed within the island will result in deviations in the island's voltage or frequency, respectively [1]. A number of active islanding detection methods have been developed to deal with the unlikely event of the OV/UV and OF/UF relays' failure to detect islanding. This can occur if the power generated and consumed in the island is matched. Many of the active methods are reviewed in [3]. These methods all rely on introducing some disturbance to the system which is held in check by the relatively strong utility source during normal (grid-connected) operation but triggers some positive feedback mechanism during an islanding event. This positive feedback of the disturbance eventually results in either the voltage or frequency deviating outside of acceptable limits and the islanding is then detected by the passive OV/UV or OF/UF relays. Many of the active methods have been shown to fail when there are multiple DGs connected within an island if they are not all equipped with identical active anti-islanding (AI) protection [4,5].

Some authors have proposed that in the future, islanding be allowed under certain circumstances as a means of increasing the reliability of service provided to customers [6–8]. Active islanding detection techniques are not suitable for use in such systems as they cannot detect islanding without causing the system to violate acceptable voltage or frequency operating limits.

An islanding detection method suitable for inverter interfaced DGs based on the correlation principle was first proposed in [9] and further investigated in [10,11]. This method operates by perturbing the output of a DG according to a predetermined pseudo-random, or pseudo-noise (PN), sequence and observing the correlation between the PN sequence and disturbances in system voltage. The correlation technique was shown by [4,5] to have superior performance to many active methods in multi-DG islands. Furthermore, the correlation AI technique is capable of detecting islanding without forcing the system to violate operating limits.

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Previous investigations into the correlation AI technique have used maximal length sequences (M sequences) as the PN sequence controlling the perturbation of the DG's output. It is demonstrated in this paper that the performance of the correlation technique can be improved through the use of Gold or Kasami PN sequences. This is verified through numerical simulations using the PSCAD/EMTDC power system simulation software. The paper is organized into six sections. Section 2 describes the correlation technique and the PN sequences investigated. Section 3 defines the system model and test cases simulated. Test results are given and then discussed in Sections 4 and 5, respectively. Conclusions are found in Section 6.

2. Correlation anti-islanding

2.1. Correlation technique

Correlation can be thought of as a measure of how much two signals are like one another. The correlation technique works by scaling the output of an inverter interfaced DG up or down according to a predetermined PN sequence and then observing the correlation between the PN sequence and disturbances in the system voltage. The DG's output is increased slightly if the current bit of the PN sequence is high (+1) and down slightly if the current bit of the PN sequence is low (−1). The current bit of the PN sequence is advanced one bit every power system cycle. To prevent a reduction in the power quality of the DG's output, the output of each phase of the DG is only allowed to change at that phase's zero crossing.

If one assumes that during normal (grid connected) operation the system voltage in the potential island is mostly determined by the relatively strong utility source then any disturbances in system voltage should be largely uncorrelated with the PN sequence used to perturb the DG's output. During islanding, which by definition is the loss of the utility, the DG(s) are responsible for the system voltage and so the correlation between the PN sequence and any disturbances in system voltage would be expected to rise. An exaggerated example of what the system voltage might be during islanding where a DG in the island is equipped with correlation AI is shown in Fig. 1.

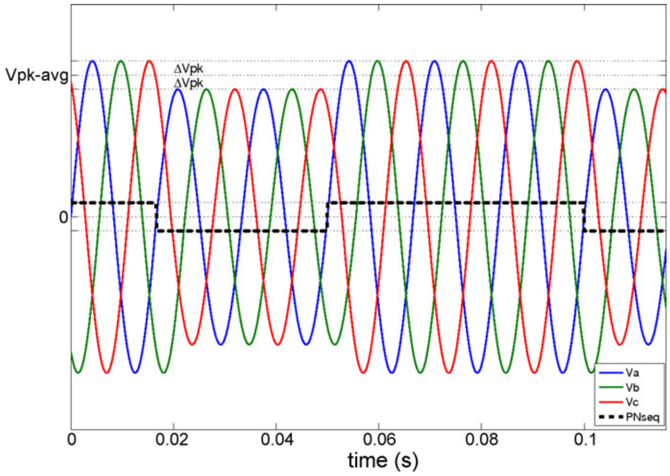

Fig. 1. Exaggerated system voltage during islanding.

The definition of the discrete version of the correlation function used in this work appears in Eq. (1). PN[n] is the value of the PN sequence n power system cycles ago. As seen in Eq. (2), $\Delta V[n]$ is the difference between the average rms system voltage during the last N power system cycles and the rms system voltage n cycles ago. N is the number of bits in the PN sequence. Strictly speaking, Eq. (1) can be used to calculate an infinite number of correlations since $\tau \epsilon [-\infty \cdots \infty]$, but the PN sequence is used repetitively so there is a maximum of N distinct values of $\phi[\tau]$ corresponding to $\tau = 0, 1, 2, \ldots, N-1$.

$$\phi[\tau] = \sum_{n=1}^{N} \mathrm{PN}[n+\tau]\Delta V[n] \tag{1}$$

$$\Delta V[n] = V_{\mathrm{rms}}[n] - V_{\text{rms-avg}} \tag{2}$$

In the case of single DG islands, simply monitoring the peak of $\phi[\tau]$ is sufficient to detect islanding. A spike in the peak value of $\phi[\tau]$ means islanding has occurred. However, if there are multiple DGs in an island and their PN sequences are not synchronized, more positive peaks exist in $\phi[\tau]$ but the magnitude of the highest peak is reduced. It was shown by [9,11] that monitoring the sum of all non-negative coefficients of the correlation function, $\phi[\tau]$, was a solution to this problem. This sum, named S, is defined in Eqs. (3) and (4).

$$\phi_+[\tau] = \begin{cases} 0 & \phi[\tau] < 0 \\ \phi[\tau] & \text{otherwise} \end{cases} \tag{3}$$

$$S = \sum_{\tau=0}^{N-1} \phi_+[\tau] \tag{4}$$

If the following assumptions are made then the correlation function from Eq. (1) becomes Eq. (5) during islanding:

- All the DGs with correlation AI use the same PN sequence;
- Relative phase shifts of the correlation AI equipped DGs are defined as $s_1 = 0, s_2, \ldots, s_{\#core}$;
- All DGs supply an equal fraction of the load power;
- Each DG's output is ideal;
- ΔV is normalized such that if all the DGs in the island had correlation islanding detection and all their PN sequences were +1 then $\Delta V = 1$.

$$\begin{aligned} \phi[\tau] &= \sum_{n=1}^{N} \mathrm{PN}[n+\tau] \frac{\sum_{x=1}^{\#core} \mathrm{PN}[n+s_x]}{\#\mathrm{DGs}} \\ &= \frac{1}{\#\mathrm{DGs}} \sum_{n=1}^{N} \sum_{x=1}^{\#core} \mathrm{PN}[n+\tau]\mathrm{PN}[n+s_x] \\ &= \frac{1}{\#\mathrm{DGs}} \sum_{x=1}^{\#core} \Phi_{\mathrm{PN}}[\tau+s_x] \end{aligned} \tag{5}$$

$$\text{where } \Phi_{\mathrm{PN}}[\tau] = \sum_{n=1}^{N} \mathrm{PN}[n+\tau]\mathrm{PN}[n]$$

Eq. (5) shows that the autocorrelation (correlation of a function with time shifted versions of itself) of the PN sequence selected for a correlation islanding detection system is likely to be very important when determining which PN sequences are most suited for use in a correlation AI scheme. Since the correlation between the PN sequence and ΔV is expected to be very small during normal operation regardless of the PN sequence, maximizing S during islanding is the key to ensuring the best possible performance of a correlation anti-islanding scheme. Since S is the sum of non-negative correlation coefficients then a PN sequence whose autocorrelation function, $\Phi[\tau]$, has a large sum of non-negative coefficients is likely to yield superior performance.

2.2. PN sequences

As was mentioned in the introduction, previous investigations have always implemented correlation islanding detection using M