Electrical Power and Energy Systems 30 (2008) 575–580

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Enhancement of islanding-detection of distributed generation systems via wavelet transform-based approaches

Cheng-Tao Hsieh [a], Jeu-Min Lin [b], Shyh-Jier Huang [c,*]

[a] Department of Electrical Engineering, Kun Shan University, Tainan 70101, Taiwan
[b] Department of Electrical Engineering, Far Eat University, Tainan 70101, Taiwan
[c] Department of Electrical Engineering, National Cheng Kung University, Tainan 70101, Taiwan

ARTICLE INFO

Article history:
Received 27 April 2007
Received in revised form 16 July 2008
Accepted 15 August 2008

Keywords:
Distributed generation systems
Islanding
Wavelet transform

ABSTRACT

In this paper, a wavelet transform-based approach is proposed to detect the occurrence of islanding events in distributed generation systems. Thanks to time–frequency localization capabilities exhibited by wavelet transform, the approach embedded with this transform technique has grasped the appearance of the islanding event in a highly effective manner. Moreover, for those regions which are in need of a better visualization, the proposed approach would serve as an efficient aid such that the mains power disconnection can be better distinguished. To validate the feasibility of this approach, the method has been validated through several scenarios. Test results supported the effectiveness of the method for the application considered.

1. Introduction

With the rising consciousness of environmental protection as well as the availability of fossil fuels, the installation of distributed generation systems has shed new light as alternative resources in energy supply. In Taiwan, distributed generators are being promoted and installed in parallel with the utility network. It was reported that with the support of such distributed generations, the efficiency and stability of supplying power would be significantly enhanced. Yet, in order to achieve a more secure and economic operation, several technical obstacles are critically required to overcome. This concern arises because the power output of distributed generation systems may not be directly under the control of utility engineers, where the occurrence of islanding is particularly deemed an urgent issue [1–3]. Fig. 1 depicts a scenario of islanding, where the load-of-interest is severed off from the grid but the system continues to operate because of connected distributed generators. Under this situation, a so-called island is formed, resulting in unexpected consequences that may includes an increased complexity of orderly restoration, a degraded stability of system voltage, and worst of all, a raised risk to related maintenance personnel. In other words, under the scenario of islanding, line-crew members may misjudge the load-side of the line as inactive, where distributed generations are indeed feeding power to loads; hence jeopardizing the life of operators and meanwhile illuminating the importance of a reliable forewarning mechanism to such events.

Recently, in order to signal the islanding events, several methods have been suggested [1,4–13]. Among these published techniques, the supervision of auxiliary contacts of circuit breakers between utility networks and distributed generations was first considered, where a transfer trip scheme was utilized in order to disconnect distributed generators from the mains supply [7]. Then, once the utility supply is restored, the distributed generators would be resynchronized to the grid. This method was conceptually feasible, yet because its effectiveness is highly dependent on the monitoring performance, it is often hard to implement in real-world applications. Subsequently, several anti-islanding solution approaches were also proposed; which can be largely categorized into two groups: active methods and passive methods [1,8–13]. While active methods examine the operation of a power system in a direct manner, passive methods justify the event based on the system parameters.

In active methods, the main theme exists in the design of control circuits such that the required variations can be produced at the outputs of distributed generators. Then, once the loss of grid takes place, this designated bias will accordingly enlarge sufficiently to trip the connected relays, notifying the occurrence of the event. On the contrary, when the utility supply is normally operated, the amount of variations will be insufficient to trip the relays, ensuring that there is no event misidentified. Under several circumstances, this active method has won the confirmation; however, the complicated control circuit for the generation of

* Corresponding author. Tel.: +886 6 2757575 32506; fax: +886 6 234 5482.
E-mail address: clhuang@mail.ncku.edu.tw (S.-J. Huang).

0142-0615/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijepes.2008.08.006

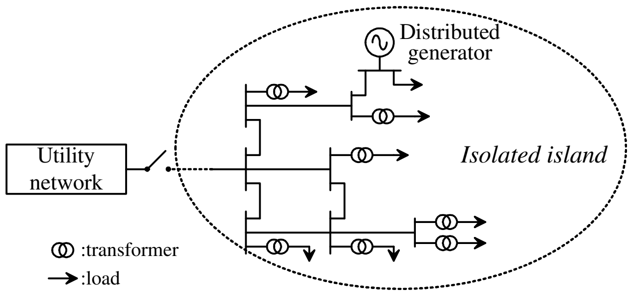

Fig. 1. Scenario of islanding operation.

designated bias may offset its merits [4–6]. As for the passive techniques, they were suggested based on the measurements of system parameters, which may include phase displacement, system impedance, and the change rate of output power. Based on the deviated voltage, current, or frequency following the loss of utility supply, passive methods would justify the islanding through the monitoring of these parameters [12,13]. Yet, without an accurate understanding of parameter variations in the passive method, the possibility of false alarm may largely increase.

In the last decades, with the emergence of wavelet transforms, it has been employed in numerous applications with great appreciation [14–17]. Based on a family of basis functions, wavelets can be formulated to describe signals in a localized time and frequency format [18,19]. By employing the long windows at low frequencies and short windows at high frequencies, the wavelet transform is capable of comprehending the time and frequency information simultaneously. Hence, the discontinuities and transients in the time-varying signals would be better supervised, thereby motivating the application to enhance the islanding-detection in this study.

In this paper, a wavelet transform-based approach is proposed to monitor the parameter variations of interests, where Daubechies wavelet serves as basis. Enhanced by such an approach, it is anticipated that any abrupt change occurred in the acquired signal would be effectively caught, hence increasing the reliability of islanding-detection. Some useful features of this new method are listed below:

(1) It helps improve the islanding-detection capability of protective relays. The safety of utility engineers is, meanwhile, better ensured.
(2) Because the time and frequency information can be simultaneously observed, the robustness of the method can be better realized for the application considered.
(3) With the increased number of installed distributed generators, the proposed method would serve as a potential alternative in addition to existent approaches.
(4) The method is easy to program, facilitating the firmware realization of integrated circuit design for the portable detector applications.

This paper is organized as follows. Paradigms of the approach are introduced in Section 2. Computation procedures are delineated in Section 3. Numerical tests under different scenarios are simulated and discussed in Section 4. Conclusions are drawn in Section 5.

2. Wavelet formulation

Following the emergence of wavelet transform, it has won a high acclaim from several industry applications. The wavelet transform of a signal $f(t)$ can be expressed as:

$$(W_\psi f)(b,a) = |a|^{-1/2} \int_{-\infty}^{\infty} f(t)\overline{\psi\left(\frac{t-b}{a}\right)}dt \tag{1}$$

where $\psi(\cdot)$ is the wavelet basis function, a is the scaling factor, and b is the time shifting factor. When the center and radius of $\psi(t)$ are individually represented by t^* and Δ_ψ, the function of $\overline{\psi((t-b)/a)}$ has the center of $b + at^*$ and the radius of $a\Delta_\psi$. These parameters can be calculated as follows:

$$t^* = \frac{1}{||\psi||_2^2} \int_{-\infty}^{\infty} t|\psi(t)|^2 \mathrm{d}t \tag{2}$$

$$\Delta_\psi = \frac{1}{||\psi||_2} \left[\int_{-\infty}^{\infty} (t-t^*)^2 |\psi(t)|^2 \mathrm{d}t\right]^{\frac{1}{2}} \tag{3}$$

where $||\psi||_2$ is the norm of $\psi(\cdot)$ and the time window becomes $t_w = [b + at^* - a\Delta_\psi, b + at^* + a\Delta_\psi]$. Note that due to the rapid diminishing feature of wavelet basis function, for those regions outside the time window, they can be neglected. Then, by use of Parseval's identity, the wavelet equation can be represented in the frequency domain

$$(W_\psi f)(b,a) = \frac{a|a|^{-1/2}}{2\pi} \int_{-\infty}^{\infty} \hat{f}(\omega)e^{ib\omega}\overline{\hat{\psi}(a\omega)}d\omega \tag{4}$$

where $\hat{\psi}(\omega)$ is a window function and $\hat{f}(\omega)$ is the function of $f(t)$ expressed in frequency domain. Now, as for the selection of wavelet basis function, the Daubechies wavelet was adopted. We favored this wavelet basis because its formulation was effectively realized as a FPGA chip in our laboratory [20]. Fig. 2 describes a three-band decomposition of wavelet transform process. In the figure, the process starts with a low-pass filter $h[n]$ and a high-pass filter $g[n]$ that decompose the original signal $S_0[n]$ into $L_1[n]$ and $H_1[n]$. Then, the post-filtered signal $L_1[n]$ can be further decomposed into $L_2[n]$ and $H_2[n]$ through the digital filter $h[n]$ and $g[n]$, respectively. Meanwhile, the signal $L_1[n]$ can be also computed from the convolution of $S_0[n]$ with $h[n]$ plus a down-sampling with a factor of two, while the signal $H_1[n]$ is obtained from the convolution of $S_0[n]$ with $g[n]$ plus a down-sampling with a factor of two. By performing this operation, the signal of $L_1[n]$ and $H_1[n]$ will individually contains lower frequency components and higher frequency ones. It is worth

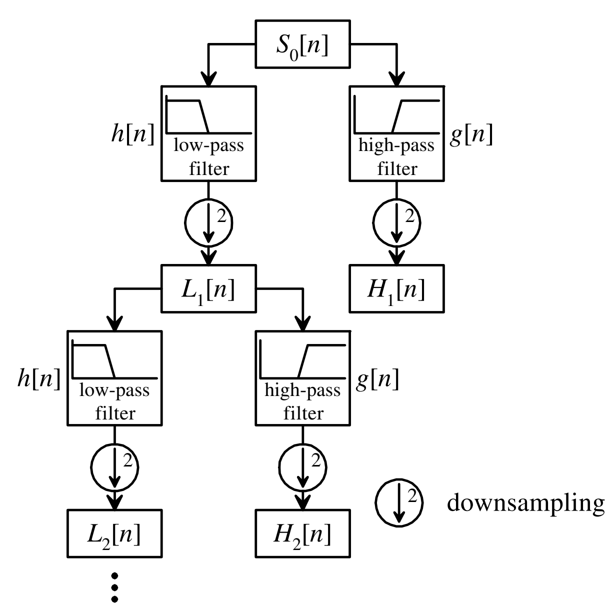

Fig. 2. Wavelet decomposition.