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Disturbance detection in grid-connected distributed generation system using wavelet and S-transform

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ABSTRACT

In this paper, wavelet transform and S-transform based approach is proposed for islanding detection and disturbance due to load rejection in distributed generation (DG) based hybrid system. The two types of distributed generation technology: inverter based and rotating machine based, that consists of photo-voltaic, fuel cell and wind systems are considered in hybrid system configuration. The negative sequence voltage signal is analyzed through wavelet transform and S-transform for islanding detection of these resources from the grid. The above two approaches are also used in study of voltage profile at point of common coupling (PCC) with a non-linear load connected. The study for different scenarios in operation of DG system is presented in the form of time–frequency analysis. The energy content and standard deviation (STD) of S-transform contour and wavelet transform signal is also reported for both islanding detection and disturbance due to load rejection.

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1. Introduction

Distributed generation (DG) is one of the most promising alternatives for generation of electric power in today's time. The need for DG is enhanced world-wide due to the restructuring of the electric power industry and the increase of electric power demand. In addition, the need of DG becomes more important because of the present-day energy shortage and requirements of both power quality and system reliability. Generally, a DG system consists of small-scale power generation resources like wind, photovoltaic, fuel cell, etc., that are located close to loads. The primary advantages of DG systems are that consumers can generate electric power with or without grid backup and the surplus power generation (PG) can be sold back to the grid under low load-demand conditions. But the unpredictable variations in wind speed and solar radiations make wind and photo-voltaic power generation unreliable for uninterruptible power supply to the loads specially when used for stand-alone mode of operation. As a matter of fact, these energy sources need to be interconnected among themselves or to the conventional power generating sources to form hybrid system (HS) for a better power quality and reliable supply with appropriate controls and effective coordination among various subsystems [1,2]. In fact, many utilities around the world already have a significant penetration of DG in their power system. But there are many issues that need to be seriously considered with the DG connected to utility grid and one of the main issues is islanding detection. If DG feeds power to the local loads and utility grid supply gets isolated due to some emergency conditions, then it is called islanded operation which leads to several negative impacts on utility power system and the DG itself, such as the safety hazards to utility personnel and the public, the quality problems of electric service to the utility customers, and serious damages to the DG if utility power is wrongly restored [3,4]. Therefore, during the interruptions of utility power, the connected DG must detect the loss of utility power and disconnect itself from the power grid as soon as possible. It is desired to know the sources of power system disturbances and find remedies to mitigate them.

Recently several methods have been suggested in the study of islanding detection [4–8]. In some literatures, trip scheme was discussed in order to disconnect distributed generators from the mains supply [3]. 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 approaches were also proposed; which can be largely categorized into three groups: active methods, passive methods and communication-based methods [4–10]. While active methods examine the operation of a power system in a direct manner, passive methods justify the event based on the system parameters with threshold set for the measurable parameters. In fact, passive islanding detection techniques can be applied to both types of DG systems. However, the challenge exists in selection of most

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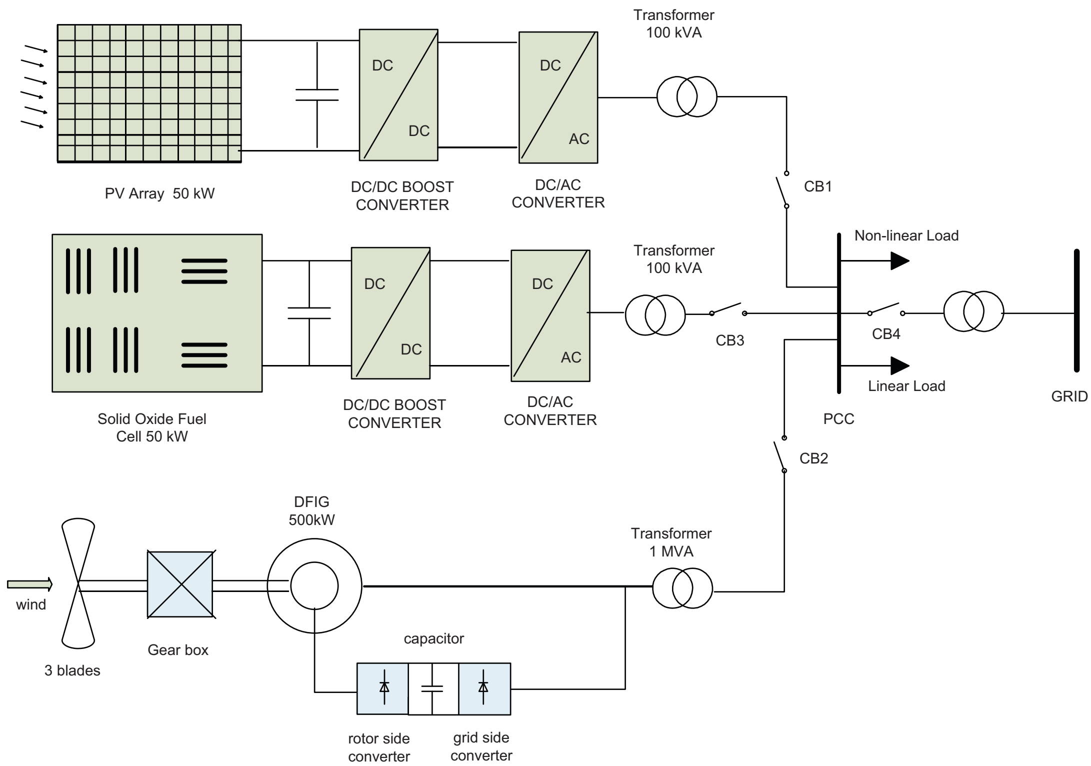

Fig. 1. Configuration of hybrid distributed generation resources.

significant parameter. Now with the emergence of wavelet transforms, it has been employed in numerous applications with great appreciation. Based on a family of basis functions, wavelets can be formulated to describe signals in a localized time and frequency format [9,10]. 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. Wavelet transform is useful in detecting and extracting disturbance features of islanding condition disturbances because it is sensitive to signal irregularities but insensitive to the regular signal behaviour.

The major drawback of wavelet transform is its batch processing step, which results to introduction of delay. An extension to wavelet transform is the S-transform [11,12], which is based on moving a varying and scalable localizing Gaussian window. The S-transform has an advantage of providing multi-resolution while retaining the absolute phase of each frequency component. The S-transform is fully convertible from the time domain to two-dimensional (2D) frequency translation domain and to then familiar Fourier frequency domain. The amplitude frequency–time spectrum and the phase–frequency–time spectrum are both useful in defining local spectral characteristics. The superior properties of the S-transform are due to the fact that the modulating sinusoids are fixed with respect to the time axis while the localizing scalable Gaussian window dilates and translates [13,14]. As a result, the phase spectrum is absolute in the sense that it is always referred to the origin of the time axis, the fixed reference point. The real and imaginary spectrum can be localized independently with a resolution in time, corresponding to the basis function and the changes in the absolute phase of a constituent frequency can be followed along the time axis. The phase correction of the wavelet transform in the form of S-transform can provide significant improvement in the detection and localization of disturbances due to islanding and load rejection events even under noisy conditions. 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 disturbance detection.

This paper is organized as follows; synchronous and inverter based DG system is introduced in Section 2, paradigms of the approach for islanding detection is given in Section 3, followed by results and discussion in Section 4. Lastly conclusions drawn from the study is given in Section 5.

2. DG based hybrid system

In the past years, with the rise in consciousness of environmental impact due to utilization of fossil based power plants, the installation of distributed generation systems has been given priority in energy supply. However, to obtain secure and economic operation, several technical limitations are required to be critically studied. Such distributed generation systems have interconnections of synchronous based like wind, inverter based like photovoltaic and fuel cell for power generations. These interconnected resources may be considered feeding power to the grid, apart from having a local load. An islanding event refers to the situation of their independent operation without the control of utility engineers. If loss of grid remains undetected, the distributed generator may quickly loose synchronism with the utility grid supply. This introduces the possibility of reconnection of the two systems while their generators are out of phase. The consequences of out-of-phase re-closing cause severe stresses on the distributed generation power and disruption of the utility supply. There are also safety and protection risk to related maintenance personnel. It is possible that the remaining load from the utility system in the islanding event would be greater than the capacity of the distributed generation. This would cause the distributed generator to be dragged down, along with the industrial process, leading to a

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