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On-line fault detection algorithm of a photovoltaic system using wavelet transform

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Abstract

The fault detection algorithm of a grid-connected photovoltaic system using wavelet transform is suggested in this paper. When the faults occur in the power conditioning system, the impact on the grid system is very risky. Therefore, it is necessary to detect faults in a short time period. When using the conventional detection method, extra hardware and sensors are required to detect the inverter failure; moreover, the disadvantage of the conventional method are its high cost and re-design problem if the inverter specification needs to be changed. Multi-level decomposition wavelet transformation is an efficient method to detect the fault location and components of the inverter. Prompt and accurate diagnostic function is possible using the normalized standard deviation of the wavelet coefficients. The proposed algorithm has simple calculation and precise diagnostic capabilities of the fault detection. A computer simulation is performed and the experimental result verifies the validity of the proposed method.

Keywords: Wavelet transform; Fault detection; Photovoltaic system; Islanding detection

1. Introduction

A typical grid-connected photovoltaic system consists of solar array, power conditioning system (PCS), local loads and a grid system with magnetic contactor and the configuration is shown in Fig. 1. The connection point between PCS and grid system is defined as Point of Common Coupling (PCC).

The major function of the PCS is to transfer solar energy (dc) into a grid system (ac) with the unity power factor using power electronics technologies. Since the dynamic and steady-state characteristics of the PV system affect their connection to the grid system, grid protection and power quality have become the major issues in the grid-connected PV system.

Islanding detection is very important issue for grid protection. It occurs when the system containing both the load and PCS remains energized by the PV system when it is isolated from the grid system, while the voltage and frequency are maintained around their nominal values. The IEEE Std. 1547-2003, specifies that the anti-islanding system must instantly disconnect the PV system within 2 s of the islanding.

In terms of the power quality issues, IEEE Std. 929-2000 specifies the recommended standards for interfacing PV systems to the grid system. The PCS output should have low current-distortion levels to ensure that no adverse effects on other equipment connected to the grid system. The PCS output at the Point of Common Coupling (PCC) should comply with Clause 10 of IEEE Std

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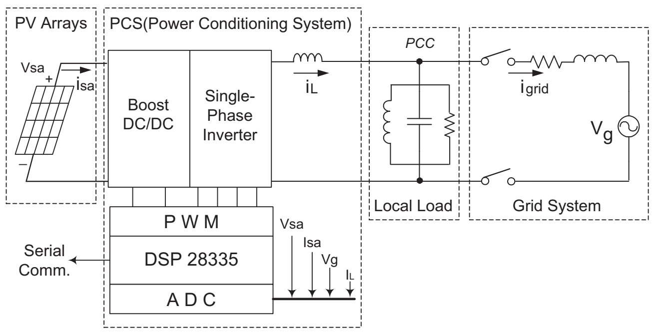

Fig. 1. Photovoltaic system configuration.

519-1992 and should be used to define the acceptable distortion levels for PV systems connected to a grid. The key requirements of this clause are summarized as follows (IEEE, 2003, 1992):

– The total harmonic current distortion shall be less than 5% of the fundamental frequency current at the rated inverter output.
– Each individual harmonic shall be limited to the percentages listed in Table 1. The limits in Table 1 are a percentage of the fundamental frequency current at full system output. Even harmonics in these ranges shall be <25% of the odd harmonic limits listed.

The PCS should be manufactured to comply with the requirements of the Std. 519-1992. If the PCS generates more harmonics than the regulation, it should be detected and the operation of the PCS should be stopped immediately to protect the grid system. Unwanted harmonics can be generated by the failures of PCS such as IGBT (Insulated Gate Bipolar Transistor) fault or a sensor or controller fault. Therefore, PCS needs to have harmonic detection capability for interfacing with the grid. Also, other kinds of faults such as islanding operation should be rapidly detected and the PCS should be disconnected from the grid network to guarantee safe operation.

Many researches have been performed on PCS fault detection. Inverter open fault detection methods have been widely researched over the past few years (Kim et al., 2009; Zidani et al., 2008; Khomfoi and Tolbert, 2007; Druant et al., 2013; Jung et al., 2013; Najafabadi et al., 2011; Akin et al., 2009; Karimi et al., 2009; Diallo et al., 2005; Silvestre et al., August 2013; Hu et al., October 2013; Peuget et al., 1998; Riberio et al., 2003; Trejo et al., 2013; Gokmen et al., 2012; Kalogirou et al., 2008). The method based on measured voltage is commonly used. However, these methods require additional voltage sensors. Kim et al. presented a method to detect open-circuit faults in a single switching device for a three-phase NPC inverter. This was achieved by measuring the pole voltage and its time period. However, this method necessitates additional circuits. Further, the location of the faulty switch could not be identified (Kim et al., 2009). Zidani et al. suggested a fuzzy-logic-based technique that detects and identifies the faulty switches in a voltage-fed PWM inverter for an induction motor drive by using Concordia current patterns. However, this method requires a relatively long diagnosis time because the dimension of the current patterns is used when the fault occurrence is determined (Zidani et al., 2008). Khomfoi and Tolbert proposed a fault diagnosis scheme to detect and identify the location of a fault in a multilevel inverter by using a neural network algorithm. However, this technique requires high computational effort (Khomfoi and Tolbert, 2007).

Table 1
Distortion limits as recommended in IEEE Std 519-1992 for six-pulse converters.

Odd harmonics	Distortion limit
3rd – 9th	<4.0%
11th – 15th	<2.0%
17th – 21st	<1.5%
23rd – 33rd	<0.6%
Above the 33rd	<0.3%

Fourier transform is the conventional method used to detect harmonics from the PCS current or voltage. It can decompose signals into frequency components with magnitude and phase. It is implemented with Discrete Fourier Transform (DFT) to convert an analog signal into digital harmonic components. The harmonic components up to the *n-th* switching frequency can be obtained. The disadvantage of the Fourier transform is that its calculation is too complex to implement into a real-time on-line application. When implemented, additional high speed signal-conditioning boards are required for the controller, which incurs a high manufacturing cost.

The wavelet transform (WT) is another way of obtaining harmonic components (Aktas and Turkmenoglu, 2010; Kim and Aggarwal, 2000; Gaouda et al., 1999; Zheng et al., 1999; Wilkinson and Cox, 1996). It employs a mother wavelet instead of orthogonal sine and cosine functions to extract frequency components. The high and low frequency components are obtained using a dyadic frequency filter. The low frequency components are decomposed into higher frequency components. It is possible to obtain signal levels at frequency bands instead of exact components. The advantage of WT is the simple calculation and it can be completed in less time than DFT.

Some applications of WT based islanding detection in grid-connected systems have been presented (Hanif et al., 2012; Pigazo et al., 2009; Wilkinson and Cox, 1996; Samui and Samantaray, Jan. 2013; Datta et al., December 2014; Perpinan and Lorenzo, 2011). The wavelet energies and their standard deviations are used to determine the islanding condition (Wilkinson and Cox, 1996).

A new fault detection algorithm of the PCS using wavelet transform is proposed in this paper. It can detect a switch open fault and any over harmonics using the Multi Level Decomposition (MLD) algorithm of the wavelet transform. The proposed algorithm can also detect an islanding condition using wavelet coefficients energies.