Measurement 44 (2011) 1136–1142

Contents lists available at ScienceDirect

Measurement

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

Real-time measurement method of dc injection for transformerless PV systems

Xiao-Qiang Guo

Key Lab of Power Electronics for Energy Conservation and Motor Drive of Hebei Province, Department of Electrical Engineering, Yanshan University, Qinhuangdao 066004, China

ARTICLE INFO

Article history:
Received 6 June 2010
Received in revised form 28 February 2011
Accepted 8 March 2011
Available online 12 March 2011

Keywords:
Transformerless PV systems
Dc injection
Real-time measurement

ABSTRACT

Measurement of dc injection is crucial for the transformerless PV systems. IEEE Std.929-2000 specifies that the PV systems shall not inject the dc current greater than 0.5% of the full rated output current. Dc injection measurement is not only useful for evaluating whether a transformerless PV system meets IEEE standards, but also for the effective dc suppression with injecting an equal but opposite dc component via a proper control scheme. In practice, however, it is difficult to extract the very low-level (0.5% I_{rated}) dc currents in the presence of high levels of ac currents in transformerless PV systems. In order to overcome the limitation, this paper presents a real-time dc injection measurement technique. Some major issues such as the basic operating principle, frequency excursion effect mitigation and discrete-domain implementation of the proposed method are discussed. Theoretical analysis and performance evaluation results verify the effectiveness of the proposed dc injection measurement technique.

1. Introduction

The environmental concerns and electric utility deregulation promote the development of distributed generation (DG) in a rapid pace. DG systems using renewable energy sources like solar have advantages due to the on-site power production for the local loads, and the losses due to transmission lines can be significantly reduced. According to the latest report of IEA-PVPS on installed PV power [1], by the end of 2009, there has been a total of 20.4 GW of installed PV systems, of which the majorities (74%) are installed in Germany and Italy. Fig. 1 illustrates the cumulative growth in PV capacity since 1992.

From Fig. 1, it is clear that most of installed PV systems are grid connected. In general, PV systems connect to the grid via a line frequency isolation transformer, which enables the galvanic isolation, leakage current and dc injection suppression, voltage level adjustment, and so on. However, the line frequency transformer is bulky, heavy and costly component, which typically increases about 25% material costs [2], and reduces 2% system efficiency [3,4]. Therefore, the transformerless PV systems have been increasing in recent years [5–11].

Indeed, removal of the line frequency transformer leads to the cost and size reduction and system efficiency improvement. However, some major issues of the transformerless PV systems should be settled such as the leakage current and dc injection suppression. In general, the leakage current (ground current) can be significantly mitigated from the viewpoint of topology or modulation [12,13], and a practical example is the single-phase H-bridge topology with bipolar modulation [14]. On the other hand, dc injection is also a major problem for the transformerless PV systems [15]. Dc injection into the grid may lead to the substation transformer saturation, corrosion of underground equipments and malfunction of protective equipments [10]. Therefore, IEEE Std.929-2000 specifies that the PV systems shall not inject the dc current greater than 0.5% of the full rated output current.

E-mail address: yeduming@163.com

0263-2241/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.measurement.2011.03.009

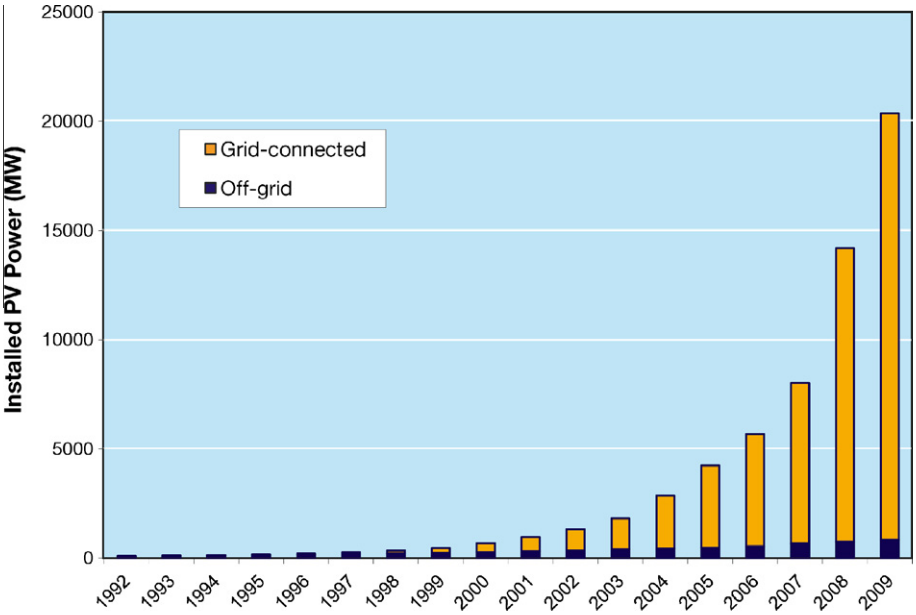

Fig. 1. Cumulative installed capacity between 1992 and 2009 in the IEA-PVPS reporting countries.

Dc injection measurement is not only useful for evaluating whether a transformerless PV system meets IEEE standards, but also for the effective dc suppression with injecting an equal but opposite dc component via a proper control method. Generally speaking, the current measurement can be readily achieved in isolation using Hall Effect sensors or other devices. In practice, however, it is difficult to extract the low-level (0.5% I_{rated}) dc currents in presence of high levels of ac currents in transformerless PV systems.

The aim of this paper is to provide a real-time low-level dc injection measurement technique despite the presence of large ac currents for the transformerless PV systems.

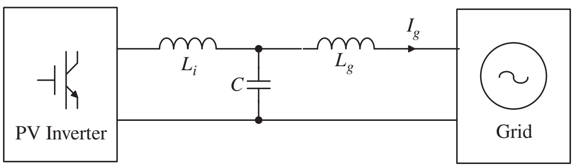

Fig. 2. Schematic diagram of the transformerless PV inverter.

2. Proposed method

This section will present the basic principle and discrete-domain implementation of the proposed dc injection estimation method. A typical schematic diagram of the transformerless PV inverter is shown in Fig. 2, where L_i, L_g are the inverter-side and grid-side inductors, C is the filter capacitor, and I_g is the grid current.

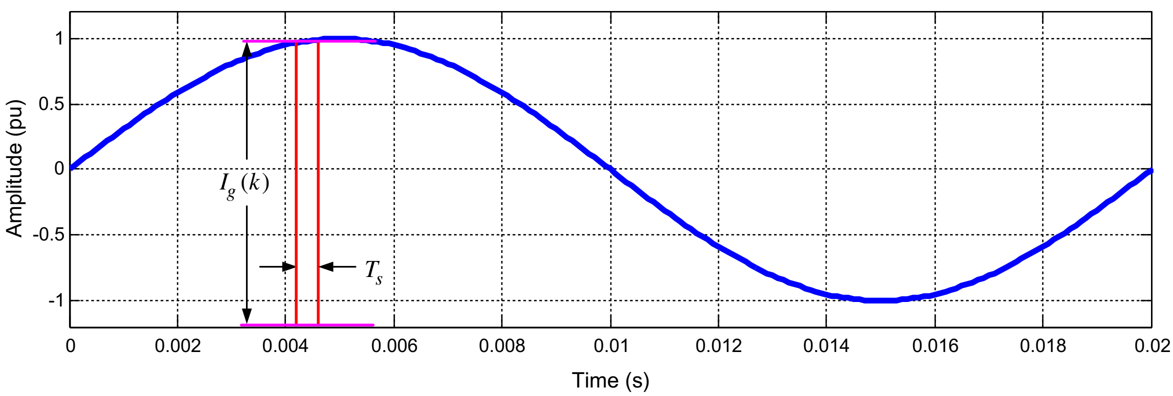

Fig. 3. Principle of discrete implementation of integration manipulation.