Available online at www.sciencedirect.com
ScienceDirect
Solar Energy 81 (2007) 1333–1339
SOLAR ENERGY
www.elsevier.com/locate/solener

Modeling and design of phase shift anti-islanding method using non-detection zone

Byunggyu Yu [a,*], Mikihiko Matsui [b], Youngseok Jung [a], Gwonjong Yu [a]

[a] *Photovoltaic Research Group, Korea Institute of Energy Research, 71-2 Jang-Dong, Yuseong-Gu, Daejeon 305-343, South Korea*
[b] *Department of System Electronics and Information Technology, Tokyo Polytechnic University, 1583 Iiyama Atsugi-shi Kanagawa 243-0297, Japan*

Received 7 November 2005; received in revised form 13 April 2007; accepted 14 June 2007
Available online 23 July 2007

Communicated by Associate Editor Aaron Sanchez-Juarez

Abstract

Islanding phenomenon of a grid-connected independent generator like a photovoltaic (PV) system occurs when a section of a utility system is disconnected from the main utility voltage source, but the independent generator continues to energize the utility lines in the isolated section. Since islanding causes a safety hazard to utility service personnel and damage to power supply facilities as a result of unsynchronized reclosure, PV inverter is required to have anti-islanding function. In order to prevent this phenomenon, various anti-islanding methods have been studied. Even though phase shift anti-islanding method including slip mode frequency shift (SMS) method and reactive power variation (RPV) method has been regarded as a highly effective anti-islanding method, the analytical design method of that has not been cleared. This paper proposes a design guideline of the phase shift anti-islanding method based on non-detection zone (NDZ). As leading phase shift anti-islanding methods, both SMS and RPV methods are discussed to verify the validity of the proposed method. Both methods are derived analytically through the modeling and verified visually by simulation and experiment under IEEE Std. 929-2000 test condition. It is shown that both methods designed by the proposed method have effectiveness to detect islanding within 2 s and good power quality above 0.99 power factor. The presented methodology in this paper can be extended to design other active anti-islanding methods.

Keywords: Grid-connected PV inverter; Anti-islanding; Slip mode frequency shift method; Reactive power variation method

1. Introduction

In modern power system, distributed generation (DG) including photovoltaic (PV), fuel cell, wind turbine is growing larger and more complicated. However, the advent of DG makes some problems to the stability and the power quality in the adjacent utility. Especially, the most issued problem is islanding phenomenon which DG has an independent powering to a portion of the utility system even though the portion has been disconnected from the remainder of the utility source. This is because islanding can cause safety problems to utility service personnel or related equipments. Consequently, utility companies and PV system owners require that the grid-connected PV system include the non-islanding inverter (IEEE Std. 929-2000, 2000; Ropp, 1998).

Islanding detection methods, which have been proposed, are generally classified into passive anti-islanding method and active anti-islanding method. It is considered that an inverter equipped with an over voltage relay (OVR), an under voltage relay (UVR), an over frequency relay (OVR), and an under frequency relay (UFR) has the basic passive anti-islanding methods. The inverter equipped with these relays is shut down when the inverter output voltage/frequency deviates from set values. While these methods

* Corresponding author. Tel.: +82 42 860 3411; fax: +82 42 860 3692.
E-mail addresses: bgyuyu@kier.re.kr (B. Yu), matsui@seit.t-kougei.ac.jp (M. Matsui), jung96@kier.re.kr (Y. Jung), y-gj@kier.re.kr (G. Yu).

0038-092X/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.solener.2007.06.009

Nomenclature

Q_f	quality factor	L	local load inductance (H)
Q_L	local inductive load (var)	C	local load capacitance (F)
Q_C	local capacitive load (var)	F	frequency (Hz)
P_R	local resistive load (W)	V	voltage (V)
P	PV inverter effective output power (W)	I	current (A)
Q	PV inverter reactive output power (var)	θ_Z	load line with respect to frequency
ΔP	grid effective power flow (W)	θ_F	SMS line which is the input filter of phase locked loop with respect to frequency
ΔQ	grid reactive power flow (var)		
R	local load resistance (Ω)	θ_I	start phase of inverter output current

are quite simple to use by monitoring only the voltage of the point of common coupling (PCC) at the PV inverter output, these fail to detect islanding when the PV generated power closely matches with the connected local loads. In other words, these passive schemes have relatively large non-detection zone (NDZ) (Ropp et al., 1999).

Unlike these passive anti-islanding methods, active anti-islanding methods make a perturbation into the PV inverter output current by injecting an active signal. Since this perturbation let the power balance between PV generated power and local load power be broken, the active anti-islanding methods are generally considered more effective than the passive ones (Yin et al., 2004). The perturbation parameter can usually be classified into two parts in an inverter output current command in Eq. (1): frequency (f_I), and the start phase (θ_I).

$$I_{inv} = I_m \sin(2\pi f_I t + \theta_I) \tag{1}$$

Between these perturbation parameters, phase shift (θ_I) anti-islanding method has received recent attention on its good islanding detection performance (Yin et al., 2004). Even though phase shift anti-islanding method including slip mode frequency shift (SMS) method and reactive power variation (RPV) method has been regarded as a highly effective anti-islanding method, the analytical design method of that has not been cleared. This paper proposes a design guideline of the phase shift anti-islanding method based on non-detection zone (NDZ). As leading phase shift anti-islanding methods, both SMS and RPV methods are discussed to verify the validity of the proposed method.

In this paper, the concept of the both SMS method and RPV method is introduced first. A parallel RLC circuit is used as a simplified AC load model for 3 kW PV system and the implementation of both methods is derived under the IEEE Std. 929-2000 islanding test condition. Then, the following experimental results are provided for verification.

2. Concept of phase shift anti-islanding method

Phase shift anti-islanding method is implemented by the design of phase locked loop (PLL) input filter as shown in Fig. 1. When PV inverter is controlled to have unity power

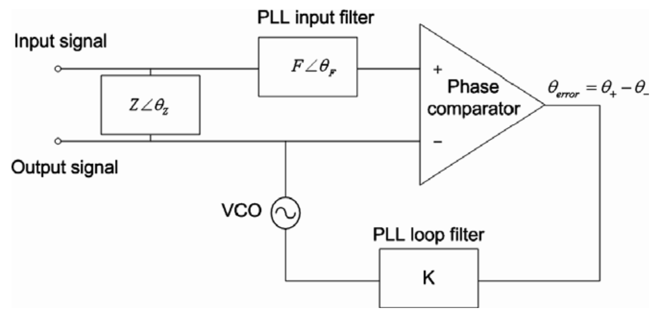

Fig. 1. PLL structure of the SMS method.

factor, the input filter of PLL is removed. In the phase shift anti-islanding method, the current–voltage phase angle of the inverter output is not controlled to be zero for unity power factor.

For SMS method, the current–voltage phase angle of the inverter is determined by a function of frequency of PCC voltage (Ropp, 1998). As shown in Fig. 2, the typical SMS line of PLL input filter is a sinusoidal wave and the load line represented as a paralleled-RLC load is negative first derivative. When the grid is connected, the start phase of inverter current command is determined by the grid voltage frequency regardless of the load line. When the islanding occurs, the operating frequency moves up or down

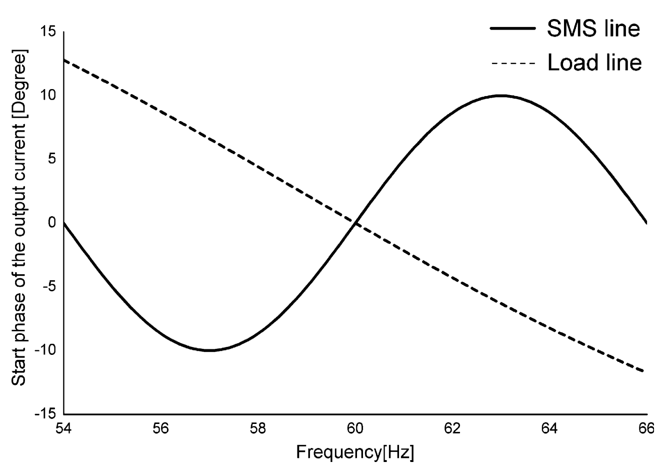

Fig. 2. Phase response of PV inverter and local load.