Sustainable Energy Technologies and Assessments 9 (2015) 55–62

Contents lists available at ScienceDirect

Sustainable Energy Technologies and Assessments

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

Original Research Article

PV interface system with LVRT capability based on a current controlled HFAC link converter

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ARTICLE INFO

Article history:
Received 15 August 2014
Revised 30 November 2014
Accepted 8 December 2014

Keywords:
Estimation
High frequency AC link
Low voltage ride-through (LVRT)
PV
Voltage fluctuations

ABSTRACT

The paper presents a current controlled High Frequency AC (HFAC) link based on Matrix Converter (MC) to interface a photovoltaic (PV) system with the grid. The proposed switching scheme for the MC is based on the hysteresis current control and the sign of the input voltage waveform. A strategy for controlling the HFAC link converter to extract the maximum power by regulating the terminal voltage of the PV array is presented. In addition, the proposed strategy mitigates the voltage fluctuations at the Point of Common Coupling (PCC), resulted from the variation in the harvested active power from the PV. Moreover, the proposed interface system supports the grid with the necessary reactive power needed for the Low Voltage Ride-Through (LVRT) to meet the grid code requirements. The proposed control system is based on a signal processing unit to estimate the PCC voltage magnitude and phase angle, simultaneously, which supersedes the rms calculator and Phase Locked Loop (PLL) circuits. Furthermore, the estimated PCC voltage is utilized for instant sag detection to enable the LVRT controller. Simulation results based on MATLAB/SIMULINK software are provided to verify the effectiveness and to evaluate the dynamic behavior of the proposed PV interface system.

Introduction

Photovoltaic (PV) systems are receiving a wide acceptance in recent years as they are renewable energy resource, pollution free, and incorporate modularity feature. The power electronics interface plays an important role in delivering the adequate voltage, frequency, and power to the loads and enhancing the grid stability. The PV interfacing systems have incorporated great development in the last decades [1].

Traditionally, the PV-grid interface comprises three main stages: a boost dc/dc converter, dc/ac converter, and transformer [2,3]. The boost dc/dc converter is mainly used to manipulate the operating point over the V–I characteristic curve of the PV array. Hence tracking the operating point at which the maximum power can be harnessed from the PV. The inverter is acting as a dc/ac converter to deliver an alternative current with the grid frequency from the dc input. Finally, a power transformer is employed to step up the output voltage to the grid voltage level. Such power transformer operating at a low frequency (50/60 Hz) is bulky and has a relatively low efficiency. Fig. 1(a) shows the layout of the traditional PV-grid interface. In some literatures [4,5], the dc/dc converter is eliminated and the Maximum Power Point Tracking (MPPT) is embedded within the inverter control algorithm. The High Frequency (HF) link has many advantages compared to the traditional interface system in terms of power density, transformer size, and cost. HF link converters are mainly classified into two categories [6]. One is a High Frequency DC (HFDC) link converter, illustrated in Fig. 1(b), and the other is a High Frequency AC (HFAC) link converter, presented in Fig. 1(c). The HFDC link converter suffers from low reliability due to its bulky dc-link electrolytic capacitors. One advantage of the HFAC link converter is the elimination of the bulky electrolytic capacitors needed for the dc-link which results in improved conversion efficiency and reliability [7,8].

The most commonly adopted control strategies for the ac/ac converters are the carrier based Pulse-Width Modulation (PWM) [9] and the Space Vector Modulation (SVM) [10]. However, these voltage modulation techniques lack the direct control of the current fed to the grid which is a necessity for grid interface application. Hysteresis Current Control (HCC) is widely used for conventional dc/ac inverters as it exhibits many advantages such as low harmonics and high quality current waveform. Moreover,

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http://dx.doi.org/10.1016/j.seta.2014.12.006
2213-1388/

Nomenclature

ADALINE	ADAptive LINEar neuron	I_{rated}	Rated current of the MC
DFT	Discrete Fourier Transform	$I_{reactive}$	Injected reactive current component
HF	High Frequency	k	Discrete time step order
HFAC	High Frequency AC link converter	P_{PCC}, Q_{PCC}	Active and reactive power fed to grid at the PCC
HFDC	High Frequency DC link converter	P_{PV}	Extracted power from the PV array
HCC	Hysteresis Current Control	Q1, Q2, Q3, Q4	Switching signals of the high frequency inverter
LPF	Low Pass Filter	t	Time
LVRT	Low Voltage Ride-Through	v_{abc}	Three-phase voltages at the PCC
P&O	Perturb and Observe	v_{PV}	PV array voltage
PLL	Phase Locked Loop	v_a^+	Instantaneous positive sequence component of the fundamental PCC voltage
PV	Photovoltaic	$\hat{v}(k)$	Predicted signal at time k
PCC	Point of Common Coupling	V_G	Thevenin equivalent voltage of the grid
PI	Proportional Integral controller	V_{PCC}	rms voltage at the PCC
PWM	Pulse-Width Modulation	V_{PCC}^+	Magnitude of the positive sequence component of the PCC voltage
MC	Matrix Converter	$W(t)$	Weight vector
MPPT	Maximum Power Point Tracking	X_G, R_G	Thevenin equivalent impedance and resistance of the grid
RLS	Recursive Least Square	X_S	Impedance of the smoothing current reactor
RMS	Root Mean Square	2B	Hysteresis Band
THD	Total Harmonic Distortion	α	Learning parameter
SVM	Space Vector Modulation	θ	Instantaneous angle of the PCC voltage
e	Current error	ϕ	Phase angle of the positive sequence component of the PCC voltage
f	Grid frequency	ω	Angular frequency of the grid ($2\pi f$)
i_{abc}	Three-phase currents of the MC	*	Reference value
i_d^*, i_q^*	d–q reference currents of the MC under normal operation	T	Transpose operator
i_{dlv}^*, i_{qlv}^*	d–q reference currents of the MC for LVRT		
i_{PV}	PV array current		
I	Phasor value of the MC current		

the simple math computations of the HCC render it easy to implement using low cost microcontrollers [11].

Grid codes require renewable energy sources to remain connected during grid disturbances to ride-through the faults. Moreover, this Low Voltage Ride-Through (LVRT) capability obliges the renewable energy sources to supply reactive power to assist the voltage recovery and system stability [12–14]. As a result, an adequate LVRT control must be integrated into the PV interface system. Different control approaches have been presented that complies with grid codes of the PV interfacing systems. The LVRT capability of single-phase PV inverters is explored in Refs. [15,16]. A single-phase two-stage PV interface system incorporating a LVRT controller is presented in Ref. [17]. A sufficiently detailed model for a three-phase two-stage PV system with grid code compatibility is presented in Ref. [18]. One of the objectives of this paper is to integrate the LVRT capability with the proposed control of the HFAC link converter for grid-connected PV system.

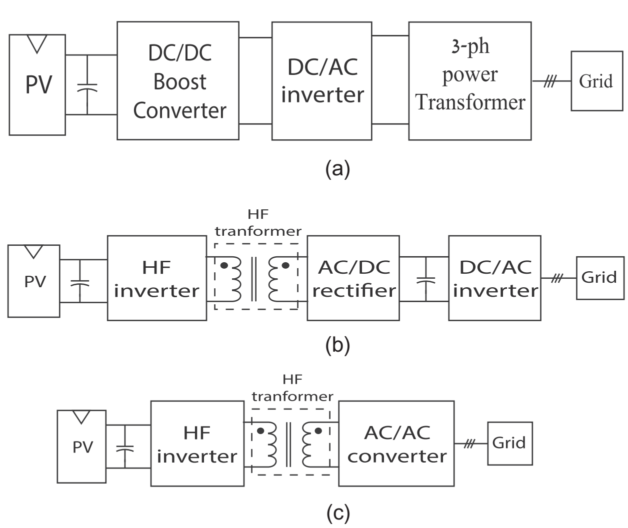

Fig. 1. PV-grid interface systems: (a) traditional, (b) HFDC link, (c) HFAC link.

Several methods have been proposed to estimate the phase angle of the voltage. The Phase Locked Loop (PLL) is normally used for phase angle tracking; however, the reliance of PLL on PI controllers introduces instability problem [19]. The Discrete Fourier Transform (DFT) is employed to measure the phase angle [20]. The main disadvantage of this technique is its sensitivity to the computation accuracy and sampling number. The Hilbert filtering is proposed to overcome the previous problems [21]. In spite of its simplicity, the Hilbert filter is susceptible to phase shift error due to the presence of the high frequency components in the measured voltage. In an effort to overcome such drawbacks, the H_∞ filtering algorithm is introduced for the estimation of the phase angle in Ref. [22]. Despite its accuracy, this algorithm demands bulk calculations which complicate its on-line implementation. In an effort to overcome such difficulties, the Recursive Least Square (RLS) technique is presented in Ref. [23] not only to estimate the phase angle but also to estimate the voltage magnitude. This action eliminates the need for Root Mean Square (RMS) method. To reduce further the computational demand, this paper presents a signal processing unit based on the Widro-Hoff delta rule to estimate the phase angle and magnitude of the voltage at the Point of Common Coupling (PCC). The simplicity of the proposed unit with the fast convergence renders its application for instant sag detection to yield effective LVRT capability.

This paper presents a current controlled HFAC link converter based on Matrix Converter (MC) to interface the PV system with the power grid. The proposed control strategy is not only to harvest the maximum power from the PV, but also to mitigate the voltage fluctuations at the PCC result from the variation of the extracted active power from the PV due to changes in weather conditions.