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Journal of Electrical Systems and Information Technology 2 (2015) 314–327

www.elsevier.com/locate/jesit

Control scheme towards enhancing power quality and operational efficiency of single-phase two-stage grid-connected photovoltaic systems

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Received 29 March 2015; received in revised form 12 May 2015; accepted 27 May 2015
Available online 8 December 2015

Abstract

Achieving high reliable grid-connected photovoltaic (PV) systems with high power quality and high operation efficiency is highly required for distributed generation units. A double grid-frequency voltage ripple is found on the dc-link voltage in single-phase photovoltaic grid-connected systems due to the unbalance of the instantaneous dc input and ac output powers. This voltage ripple has undesirable effects on the power quality and operational efficiency of the whole system. Harmonic distortion in the injected current to the grid is one of the problems caused by this double grid-frequency voltage ripple. The double grid frequency ripple propagates to the PV voltage and current which disturb the extracted maximum power from the PV array. This paper introduces intelligent solutions towards mitigate the side effects of the double grid-frequency voltage ripple on the transferred power quality and the operational efficiency of single-phase two-stage grid-connected PV system. The proposed system has three control loops: MPPT control loop, dc-link voltage control loop and inverter current control loop. Solutions are introduced for all the three control loops in the system. The current controller cancels the dc-link voltage effect on the total harmonic distortion of the output current. The dc-link voltage controller is designed to generate a ripple free reference current signal that leads to enhance the quality of the output power. Also a modified MPPT controller is proposed to optimize the extracted power from the PV array. Simulation results show that higher injected power quality is achieved and higher efficiency of the overall system is realized.

Keywords: Single-phase; Grid-connected; Total harmonic distortion (THD); Photovoltaic; DC-bus control; Maximum power point tracking

1. Introduction

In past few years, penetration of photovoltaic energy resources into the medium and low voltage electricity distribution grid has increased and expected to increase in future due to its economical, technical and environmental benefit

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Peer review under responsibility of Electronics Research Institute (ERI).

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.jesit.2015.05.002

[Lal et al., 2013]. Single-stage and two-stage grid-connected systems are commonly used topologies in single- and three-phase PV grid connected systems [Du et al., 2014; Yang et al., 2013; Yang and Smedley, 2008]. Two-stage configuration is mainly used because of its advantages of decoupled control since maximum power point tracking (MPPT) control and current injection control are decoupled at different stages. In addition, this gives the freedom to push the switching frequency of the DC–DC converter to an order higher than the inverter stage. As a result, the size and the cost of the converter are decreased [Ahmed et al., 2013]. The photovoltaic supply has the feature that the output voltage is widely varying either in DC or AC forms. So a regulated converter is needed to provide stable DC or AC energy [Wang et al., 2007]. In two-stage grid connected PV systems, a dc-link capacitor is used to link the two stages. The designer has the flexibility to choose the dc-link voltage and the capacitor size. In single-phase two-stage grid-connected PV system, double grid-frequency voltage ripple can be found on the dc-link voltage because of the unbalance of the instantaneous dc input and ac output powers [Yang et al., 2013; Du et al., 2015]. The amplitude of the dc-link voltage ripple can be determined by the selected dc-link voltage, the dc-link capacitor size, and the transferred power to the grid [Yang et al., 2013]. Increasing the dc-link voltage reduces the voltage ripple but increases the stresses on the power devices, the switching losses, and the higher frequency ripple in the output current. On the other side, reducing the dc-link capacitor size for saving costs increases the dc-link voltage ripple. The double grid-frequency voltage ripple has undesirable effects on the current controller of the inverter, the voltage controller of the dc-link voltage, and the efficiency of the MPPT controller. One issue caused by this double grid-frequency voltage ripple is harmonic distortion in the output current. These harmonics have a large impact on the power quality, operational efficiency, and reliability of the power system, loads, and protective relaying [Jain and Singh, 2011; Larose et al., 2013]. Many standards as IEEE 929 and IEEE 1547 state that total harmonic distortion in the injected current to the grid from distributed generation must be less than 5% [Zhou et al., 2012]. To compensate the dc-link voltage ripple effects a PWM control method is introduced in Enjeti and Shireen (1992). This control method feed forward the dc-link information to compensate the ripple effects. A control technique that allows for 25% ripple voltage without distorting the output current waveform is proposed in Brekken et al. (2002). Where the sampling frequency of the DC voltage controller output is 10 Hz. This technique leads to attenuate the voltage ripple in the control loop, but the system dynamic performance is degraded. Proportional resonant controller with a modified carrier signal is proposed in Darwish et al. (2011) to mitigate the oscillation effect on the dc-link voltage. Double grid-frequency ripple on the dc-link leads to ripple in the PV output voltage in single-phase grid-connected systems. As a result of voltage ripples on the dc-link voltage on the output of the boost converter, the boost converter input voltage may contain ripples too. In this case, the extracted power from the PV will contain ripple which leads to power loss due to inaccurate MPP operation unless the MPPT controller is well designed.

This paper proposes new control scheme for single-phase two-stage photovoltaic grid-connected system. The paper introduces solutions towards mitigate the side effects of the double grid-frequency voltage ripple on the transferred power quality and the operational efficiency of single-phase two-stage grid-connected PV system. The system has three control loops; MPPT control loop, dc-link voltage control loop and inverter current control loop. Solutions are introduced for all the three control loops in the system.

2. System configuration

The single-phase two-sage photovoltaic grid-connected system with its control is shown in Fig. 1. The system contains three controllers. The H-bridge inverter is controlled by a dual-loop controller. The outer loop controls the dc-link voltage to follow the reference value (V_{ref}) and generate the peak value (I_{ref}) of the reference current (i_{ref}) for the inner loop. For unity power factor operation, I_{ref} is multiplied by a unit-amplitude sinusoidal signal which is in phase with the grid voltage. A phase-locked loop (PLL) is used to obtain this signal. The current control loop regulates the inverter current (i) according to the reference current (i_{ref}). A MPPT controller is used to extract the available maximum power from the PV array.

2.1. Source of the double grid-frequency ripple

For unity power factor operation and based on Fig. 1, the inverter output power can be calculated as follows:

$$v_a = V_m \sin \omega t \tag{1}$$