

A reliable low cost power electronics interface for photovoltaic energy systems

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Abstract

Performance, efficiency, cost of the power converters and their associated control, are important considerations for the commercialization of renewable power sources. In view of this, this paper proposes a reliable and low cost power electronics interface for photovoltaic energy systems, using a single DSP controller. The proposed approach will achieve the following: (a) integrate the DC–DC converter control and inverter control by utilizing a single, low cost, fixed point Digital Signal Processor (DSP controller), (b) implement a fast converging MPP tracking method in the DC–DC converter stage and (c) reduce the size of the DC-link capacitor by using a modified pulse width modulation (PWM) technique for single phase inverter control.

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1. Introduction

The threatened limitations on conventional sources of electric energy, has focused attention on unconventional sources or alternate sources of electric power. Renewable energy sources such as photovoltaic (PV) arrays and fuel cells generate direct current (DC) whereas the electric power system and thus existing end-use equipment have been designed for alternating current (AC). Also DC voltage produced by these renewable sources may vary considerably and are also known to have a slow response time. Hence there is a need for power conversion and possibly energy storage in any system that opts to use renewable

sources of energy. In most cases, the associated power electronics interface includes two converter stages: a DC to DC converter (DC–DC) and a DC to AC converter (inverter). Hence, performance, efficiency and cost of the power converters and their associated control, are important considerations for the commercialization of renewable power sources.

In a photovoltaic (PV) system, the front end DC–DC converter is controlled to achieve maximum power point tracking (MPPT) under all operating conditions. An inverter stage is connected through a DC-link after the DC–DC converter, in order to supply AC loads or for integrating with the utility grid. The single-phase inverter due to its ability to operate at a relatively low capacity with high efficiency, flexibility for future expansion, and ability to be connected to both single and three phase connections, has become very attractive for PV applications (Anwari et al., 2009). The output power of a single phase inverter includes an average portion and a double frequency

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portion. This double frequency power causes a 120 Hz voltage ripple to appear on the DC-link voltage. In order to prevent the low frequency voltage ripple from propagating through the inverter and distorting the inverter output, the common practice is to use a large DC bus capacitor. The large DC bus capacitors provide energy storage to support the double frequency ripple current and filter the DC bus voltage ripple (Gao et al., 2009; Chen et al., 2010). The DC bus capacitors are bulky and are well known to be the least reliable component in an inverter system with limited operational lifetime.

In view of this, this paper proposes a reliable and low cost power electronics interface for renewable energy systems using a single DSP controller. The proposed approach will achieve the following: (a) integrate the DC–DC converter control and inverter control by utilizing a single, low cost, fixed point Digital Signal Processor (DSP controller), (b) implement a fast converging MPP tracking method in the DC–DC converter stage and (c) reduce the size of the DC-link capacitor by using a modified pulse width modulation (PWM) technique for single phase inverter control. A laboratory prototype of the two power converter stages was implemented to validate the proposed control method. TMS320F28035 Piccolo Card by Texas Instruments (TI) was used as the single chip DSP controller. Separate software modules for the DC–DC converter control and inverter control were developed and their integrated operation was tested. Experimental results from the hardware setup validate the proposed concept.

2. Photovoltaic energy systems

Photovoltaic (PV) technology being a promising candidate to be adopted as the future renewable energy source, different topologies and control methods for the associated power conditioning system, has been investigated and proposed in literature. The design and control of the power conditioning depends on the type of load that is supplied by the PV system and whether it is a stand-alone system or grid-tied system. Also, in order to obtain the maximum efficiency the power conditioning system must keep the power extracted from the PV panels close to the maximum power point (MPP). In some topologies the power conditioning is done in a single converter stage (inverter) and in some cases a two converter stage (DC–DC converter and inverter) is utilized. In the single stage PV systems, MPPT embedded algorithms are used for inverter control (Casadei et al., 2006; Kjaer and Blaabjerg, 2003). Two stage topologies utilize a DC–DC converter for MPP tracking and the inverter stage is used to generate sinusoidal voltage and currents that match the load requirements (Anwari et al., 2009; Gao et al., 2009; Chen et al., 2010; Meza et al., 2006; Bae et al., 2009). While the most commonly used topology is a single phase voltage source inverter (VSI), the control mechanisms differ widely. Voltage controlled VSIs provide voltage support to the load (the VSI operating as a voltage source), while current controlled

VSIs provide current support (the VSI operating as a current source). There are advantages and limitations associated with each control mechanism (Ko et al., 2006). The design considerations presented in reference (Ko et al., 2006) for distributed generation systems, confirm that neither the current controlled VSIs nor the voltage controlled VSIs alone can offer all the functions required in distributed generation systems. Hence the most appropriate VSI should be chosen based on its application and priority.

All the methods presented in literature (Anwari et al., 2009; Bae et al., 2009; Nishida et al., 2004; Luo et al., 2004; Nikraz et al., 2004) use current control strategies for the inverter stage in the PV system. References (Sidrach-de-Cardona and Carretero, 2005; Lee et al., 2008; Beser et al., 2010) present grid-connected PV systems using current source inverters. The inverter control presented in this paper uses a voltage controlled VSI which will provide the designers of PV systems the flexibility to chose the control mechanism based on the priority defined by the specific application. Moreover, since the power conditioning unit is placed in the main power flow path between the PV source and the load, reliability is an important design criterion, along with the high efficiency and low cost requirements. In view of this, the proposed inverter control, helps in reducing the size of the DC-link capacitor and hence increase the system reliability.

There is a wide variety of known maximum power point tracking (MPPT) methods for PV power generation (Sokolov and Shmilovitz, 2008a,b; Scarpa et al., 2009; Liu and Huang, 2011). This paper presents a fast converging digital maximum power point tracking (MPPT) method for the DC–DC converter stage. The proposed method allows convergence to the MPP in a single step allowing simple and low cost digital implementation. Moreover, using one controller to implement all functions and by reducing the size of the DC-link capacitor using control means, will result in the following advantages: (1) Single chip solution, (2) Cost savings, (3) Reduced system complexity and (4) Flexibility.

3. Proposed power electronics interface

Fig. 1 shows the block diagram of the proposed power electronics interface which consists of a PV array, a

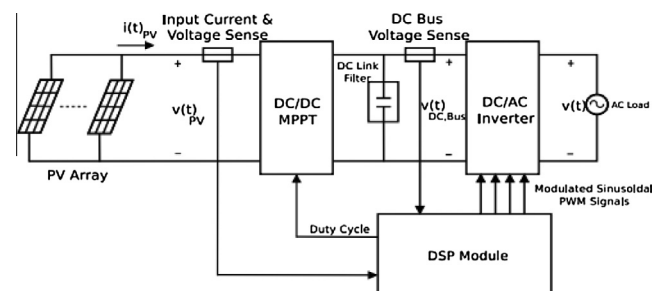


Fig. 1. Block diagram of the proposed power electronics interface.

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