Sliding mode control, implementation and performance analysis of standalone PV fed dual inverter

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A B S T R A C T

This paper presents the development and implementation of an enhanced forced switching sliding mode control (FSSMC), for dual inverter-based single stage solar photovoltaic (PV) system a stand-alone. A dual inverter fed open winding three-phase transformer is used to supply a stand-alone load in the considered topology. The FSSMC is developed for the current control of the dual inverter, while the dc-link voltage control loop is developed through indirect vector control. The solar irradiance and load impedance variations are successfully handled by the developed control scheme. The stability and disturbance rejection analyses are conducted on a linear model of the system to characterize the dynamic properties of the system and to evaluate the robustness of the controllers. The controller is implemented in simulation and experimental environments at different operating conditions. Experimental tests have been conducted on a laboratory scaled prototype using the digital controller. The performance is found to be satisfactory and have been successfully verified with the real time results.

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1. Introduction

The focus on access of electricity from the stand-alone photovoltaic (PV) system is increasing and receiving considerable attention. The availability of power electronics inverters in stand-alone solar PV system applications is the most important aspect. The said availability depends on the robustness, efficiency, safety, and its maintenance (Debnath and Chatterjee, 2015). Cascaded multilevel inverter (CMLI), topology has evolved as a promising solution to the issue of next-generation PV power inverter (Gupta et al., 2016; Kouro et al., 2010). The topology is gaining attention along with other commercial and well-established multilevel inverter (MLI) topologies, such as the neutral point clamped (NPC), flying capacitor (FC), and cascaded H-bridge (CHB) (Kouro et al., 2010; Prabaharan and Palanisamy, September 2017). The salient features of the CMLI include: (i) its modular circuit layout, (ii) distributed maximum power point tracking (MPPT) capacity, (iii) reduced current and voltage harmonics on the ac side, and (iv) lower dc voltage requirement with the increased number of levels in the output voltage (Gupta et al., 2016). One of the interesting CMLI topologies is the dual inverter topology, which is a suitable choice for PV-based stand-alone system applications.

In Babu and Fernandes (2014) and Pires et al. (2012), the proposed cascaded two-level inverter (CTLI) output is found to be associated to open winding three-phase transformer and low switching frequency is adopted. However stand-alone PV based power supply has not been developed with this topology. In this paper also the transformer is connected at the output of the PV supplied dual inverter.

There are many control strategies available in research papers on the subject, and a good overview of control of the converter topologies (Prabaharan and Palanisamy, 2017; Babu and Fernandes, June 2014; Pires et al., 2012; de Almeida Carlos et al., Jan. 2016; Edpuganti and Rathore, Aug. 2015) are studied, incorporating the space vector pulse width modulation (SVPWM) (Pires et al., 2012) and sinusoidal PWM (Edpuganti and Rathore, 2015) switching schemes. The focus of this work is to design and implement a novel sliding mode control (SMC). The SMC is a special class of the variable-structure systems (VSSs), and considered to be fast and robust nonlinear control technique. Many authors have reported favorable disturbance rejection capability and good tracking of current reference, low total harmonic distortion (THD) in current and voltage waveform, and allow a constant switching frequency for low switching losses by the SMC (Guzman et al., 2016; Tan et al., 2008; Utkin et al., 2009). Such properties promote the usage of SMC in commercial and industrial utilities, viz. grid-connected converter (Pires et al., 2012; Hassine et al., 2017), electrical drives (Lascu et al., 2004), wind energy system (Mozayan...
et al., 2016), fuel cell (Park and Gajic, 2014), multilevel inverter (Pires et al., 2012), dc–dc converters (Tan et al., 2008) and Uninterruptible power supply (UPS) (Pichan and Rastegar, 2017).

The switching frequency plays a vital role in implementation of SMC. The controller suffers from chattering phenomenon with high switching frequency, because of discontinuous function in SMC.

Many literatures addressed to eliminate or attenuate chattering phenomenon, which is undesirable in some applications (Rigatos et al., 2014; Fallaha et al., 2011). An interesting method to reduce chattering phenomenon is to use hysteresis band in the forced switching pulse width modulator (fixed switching frequency operation) based SMC (Tan et al., 2008; Utkin et al., 2009).

In the literature, the stand-alone PV system is found more popular for rural electrification, because it provides a more affordable and reliable source of electricity (Debnath and Chatterjee, 2015). These systems are developed using battery (Das and Agarwal, 2015) and without battery (Kumar et al., 2011). Many stand-alone PV systems are using three-phase inverter connected load (Sanchis et al., 2005). Daher et al. (2008) has proposed a stand-alone PV system with a battery backup. However, this system uses multilevel inverter with transformer. A scheme employs an additional dedicated conventional full-bridge inverter to realize MPPT operation (Debnath and Chatterjee, 2015). In (Wu et al., 2015), a new family of high-efficiency dc–ac grid-connected inverter, with a wide variation of input dc voltage, is proposed. A novel design method for distributed maximum power point tracking (DMPPPT) synchronous boost converter (Adinolfi et al., 2015) is proposed. The grid-connected Power Conditioning Units (PCUs) with different sizes, technologies and PV system architectures are developed in Spertino and Graditi (2014).

The dual-inverter topology has been utilized as static reactive power compensation (STATCOM) (Prabaharan and Palanisamy, 2017; Babu and Fernandes, 2014), to drive induction motor (Mohapatra et al., 2003) and for grid-connected PV systems (Pires et al., 2012). The idea of this paper is to develop and implement an efficient and reliable dual-inverter interface for a PV-based stand-alone system. The topology, used in this work, is shown in Fig. 1.

The circuit-based model of a PV array, which can be implemented in any simulation environment, is proposed in Villalva et al. (2009) and Gow and Manning (1999). In the present study, single diode model of the solar cell is used, following the mathematical model developed in Villalva et al. (2009).

This paper focuses on modeling, control, and real-time implementation of a dual inverter–based PV system. In this paper, the PV modules are designed to supply rated power at 48 V, with normal Indian solar irradiance. The normal Indian solar irradiance is considered as 1000 W/m² (Dash et al., 2017). The irradiance level of 1000 W/m² is the conventional STC value in India like in all the countries of the world. The PV modules are connected at the dc–links of the dual inverter. A control strategy is developed to control the real power of two inverters. The control of the dc-link capacitor voltage is using an outer dc-link voltage regulator (PI-based vector control) and inner current controller (forced switching topology based sliding mode control). The solar irradiance level is varied by ±20% in simulation and perturbation in load impedance is made to be ±50% to check the efficacy of the controller.

The implemented scheme can effectively be utilized for solar heaters, water pumps, battery chargers, electric vehicles, home, agricultural irrigations etc.

The work presented in this study is capable of operating in grid-connected and stand-alone modes, with the following contributions.

(i) The FSSMC based current control is developed for the considered system and implemented for the first time in available literature.

(ii) Advanced hysteresis band calculation for the FSSMC is developed and implemented in real-time with limited switching frequency.

(iii) The efficiency and THD of the system are improved considerably.

(iv) The transfer function of the dual inverter is developed to analyze the system performance with the designed controllers.

Fig. 1. Block diagram of the power circuit for dual inverter–based stand-alone PV system.
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