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A high-performance control scheme for photovoltaic pumping system under sudden irradiance and load changes

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ABSTRACT

A low-cost photovoltaic (PV) pumping system based on three phase induction motor (IM) without the use of chemical energy storage elements is presented in this paper. The PV generator-side boost converter performs the maximum power point tracking (MPPT), while the IM – side two-level inverter regulates the net DC-link voltage and the developed electromagnetic torque by IM, which is coupled with a centrifugal pump. An improved variable step size perturb and observe (P&O) algorithm is proposed to reduce the steady-state PV power fluctuation, to accelerate the tracking operation under sudden irradiance changes, and to protect IM under load drops. The proposed algorithm is based on a current control approach of the boost converter with a model predictive current controller to select the optimal control action. Moreover, predictive torque and flux control (PTC) is used to control IM drive, due to its advantages such as faster torque response, lower torque ripple, and simplicity of implementation. Furthermore, a Takagi-Sugeno (T-S) type fuzzy logic controller (FLC) is developed in order to regulate the DC-link voltage, by producing the torque reference for PTC algorithm. In order to examine and assess the performance of the proposed control scheme for PV pumping system, a complete simulation model is developed using MATLAB/Simulink™ environment and confirmed through real-time hardware in the loop (HIL) system. The obtained results indicate the excellent performance of the proposed control scheme, which is much better than the conventional scheme based on conventional techniques (P&O algorithm and direct torque control (DTC)).

1. Introduction

In recent years, the photovoltaic (PV) power application in off-the-grid is becoming more widespread, particularly in water pumping system. These PV systems are employed widely in the fractional power range. In a continued effort to increase the efficiency, to decrease the cost and to improve the reliability performance of the PV pumping system, different configurations have been proposed in the literature (Achour et al., 2016; Antonello et al., 2017; Betka and Attali, 2010; Chergui and Bourahla, 2013; Elgendy et al., 2010; Elkholy and Fathy, 2016; Jain et al., 2015; Kumar and Bhim, 2016; Mohamed et al., 2017; Mohammedi et al., 2014; Niapour et al., 2011; Periasamy et al., 2015; Rahrah et al., 2015; Singh et al., 2016; Vitorino et al., 2011). The PV pumping systems based on AC motors, particularly induction motors (IM) are often preferred because it makes them more reliable, economical, and no need to the permanent maintenance (Periasamy et al., 2015). The two typical configurations of a PV pumping systems using IM are single or dual stages (Periasamy et al., 2015). In dual stages, the first stage is a DC-DC boost converter, in general from the PV module to a DC link (usually as a capacitor). This converter is used for boosting the PV voltage array and maximizing the power; the second one is for conversion of the PV power into variable frequency power source. While, in the single stage, the DC-DC converter is not required, and a number of PV panels must be connected in a series arrangement. This method is impractical for fractional kilowatt rating (< 1 kW) PV system.

However, in such systems the generated PV energy must be properly regulated and maximized. Various control strategies have been suggested in the literature for tracking the maximum power point (MPPT) of PV array. Although these control strategies can achieve the same goals, such as high efficiency and fast speed under varying atmospheric (irradiance and temperature) conditions, their principles differ. The

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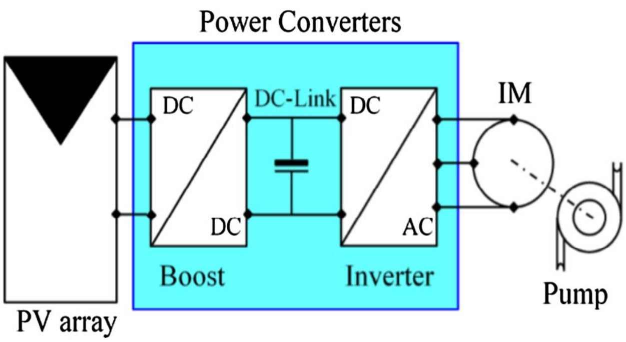

Fig. 1. Schematic diagram of the PV pumping system.

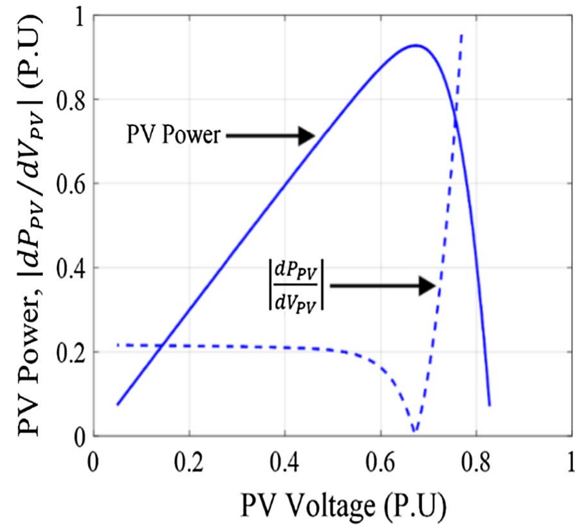

Fig. 3. The normalized PV power and its derivative variation.

most conventional MPPT techniques are known as Perturb and Observe (P&O) (Ahmed and Salam, 2015; de Brito et al., 2013; Femia et al., 2005; Femia et al., 2012) and incremental conductance (INC) (de Brito et al., 2013; Safari and Mekhilef, 2011; Tey and Mekhilef, 2014). Non-conventional MPPT techniques based on intelligent controller have been developed recently, such as fuzzy logic (Alajmi et al., 2011; Al Nabulsi and Dhaouadi, 2012; Bendib et al., 2015; Radjai et al., 2014; Salam et al., 2013), artificial neural network (Rizzo and Scelba, 2013; Salam et al., 2013), neuro-fuzzy (Syafaruddin et al., 2009), genetic algorithm (Shaiek et al., 2013) and particle swarm optimization (Ishaque et al., 2012). Nevertheless, the flexibility and simplicity of the P&O, make it the most used in the commercial product (Femia et al., 2012). However, this control technique suffers from high frequency oscillations, large steady-state errors and poorer tracking of the MPP for sudden irradiance changes. In order to overcome these drawbacks, a closed loop performing the P&O is used to regulate the PV voltage in the case of the P&O voltage-based (VMPPT) (Elgendy et al., 2012; Harrag and Messalti, 2015; Piegari and Rizzo, 2010), or the PV current in the case of the P&O current-based (CMPPT) (Bianconi et al., 2013a, 2013b; Kollimalla and Mishra, 2014; Shadmand et al., 2014). According to the linear relationship between the PV current and irradiance, the CMPPT

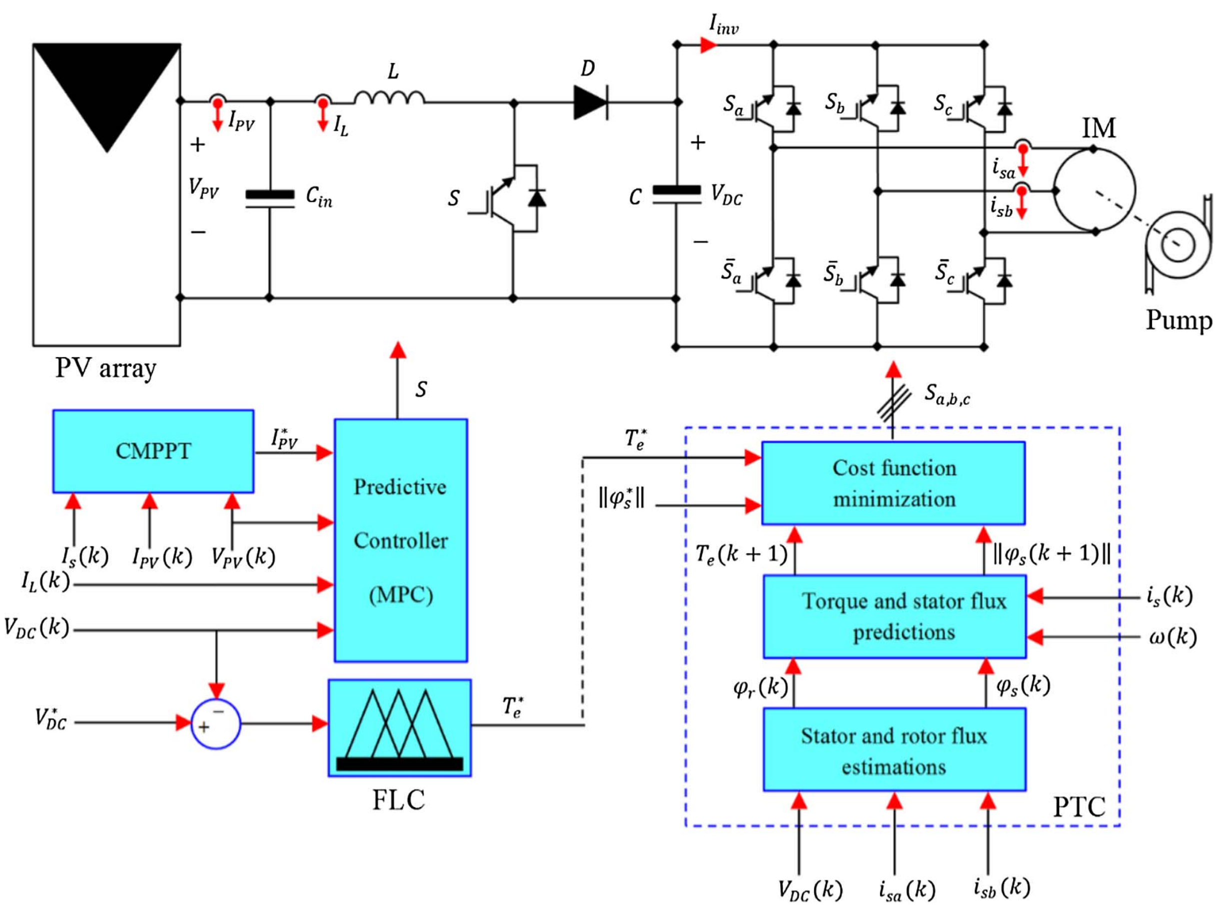

Fig. 2. Proposed control scheme for PV pumping system.