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Nonlinear integral sliding mode control design of photovoltaic pumping system: Real time implementation

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ABSTRACT

The aim of this paper is to provide high performance control of pumping system. The proposed method is designed by an indirect field oriented control based on Sliding Mode (SM) technique. The first contribution of this work is to design modified switching surfaces which presented by adding an integral action to the considered controlled variables. Then, in order to prevent the chattering phenomenon, modified nonlinear component is developed. The SM concept and a Lyapunov function are combined to compute the Sliding Mode Control (SMC) gains. Besides, the motor performance is validated by numeric simulations and real time implementation using a dSpace system with DS1104 controller board. Also, to show the effectiveness of the proposed approach, the obtained results are compared with other techniques such as conventional PI, Proportional Sliding Mode (PSM) and backstepping controls.

1. Introduction

Photovoltaic systems are considered a practical solution to produce electricity without harming the environment. These types of systems depend on natural parameters like solar irradiance and random temperature variation. The recourse of renewable energy is attractive for water pumping applications in rural areas where connecting to the electricity grid is difficult task. The principal element that constitutes the pumping systems is the Induction Motor (IM). The latter is characterized by a robust model, a simple mechanical construction and low costs [1]. Moreover, the IM control is complex due to its nonlinear model. Therefore, the Indirect Field Oriented Control (IFOC) is the most used technique to drive the IM, because this type of control ensures the steady state decoupling between the flux and the torque, in order that the induction motor can be controlled in a similar way to a separately excited DC motor. However, the desired system performances are influenced by uncertainties, parameter variations and external load disturbances, [2,3,17].

To overcome these problems, active research areas include novel controls such as adaptive control [4–6], fuzzy logic control [7,8] and sliding mode control [9–14]. Therefore, the Sliding Mode Control (SMC) presents a good performance, it is characterized by a simpler design and implementation. Thus, the SMC is an effective control approach due to its excellent advantage of strong robustness against model uncertainties, parameter variations, and external disturbances.

Note that, the major drawback of the SMC is the appearance of an undesired effect called "chattering". This phenomenon consists in high frequency oscillations which lead to unstable system dynamics.

Relatively, several SMC works are designed around chattering reduction. In this context, in [15], a low-pass filter is used. But, it may be hard to define a cutoff frequency which lead to poor system performances. Also, higher-order sliding mode algorithm is deployed in order to reduce chattering phenomena. However, this method requires higher order real time derivatives of the outputs [16]. Another approach used the switching function as saturation [17]. In the latter, the switching surface is given by difference between the selected variable and the reference defining the control objectives. However, steady-state error will always exists.

Thus, with respect to the aforementioned papers, the aim of this study is to overcome the problems caused by the chattering phenomena and the steady state error for a photovoltaic pumping system, and this motivates our work.

In this paper, a nonlinear continuous-time SMC of photovoltaic pumping system is proposed. The controller design is based on a modified switching surface which consists of adding an integral term, leading to a high accuracy control against both parametric variations and chattering reduction.

Indeed, a new method is proposed which consists to modify the classical sliding nonlinear component by another expression. Thus, through this modification, the chattering is prevented.

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Consequently, the way to combine the sliding mode control with Lyapunov function is not new, but the contribution is to use these techniques to obtain a new SMC design different to other works in investigated induction motor control method. Also, the proposed control is able to prevent the chattering. Besides, the developed SMC is implemented in dSpace system with DS1104 control board on the Digital Signal Processor TMS320F240, wherein, the majority of the practical implementation methods used the classical non-linear control component method.

Also, to improve the efficiency of the proposed control, a comparative study with recent result [6] is given using the same machine parameters and the same test bench system with an important reference load torque equal to 10 N m. So, in [6], the presented results were shown good tracking errors. However, the chattering phenomenon will always exists.

In the similar way, this work is easily extended for other applications such as control without sensor wherein we can introduce a state estimator [18,19], also for the diagnostic based on control [20] which will be study in future works.

The paper is organized as follows: Section 2 gives the problem statement. In Section 3, the overview of pumping system is detailed. Section 4 presents the SMC design. A simulation and experiment results are developed in Section 5 to demonstrate the effectiveness of the proposed control. Finally, Section 6 consolidates the ideas and presents concluding remarks.

2. Problem statement

In real time control pumping system, the complexity of the state space model presents an undesired effect caused by switching controller in high frequency oscillations. This study contributes to improving both reducing chattering phenomenon with high degree of robustness and good tracking errors. To ameliorate the system performance, comparative study with other techniques was done.

Using the same test bench system with a reference load torque 5 N m, Abderrahmen proposed in [6] an adaptive backstepping induction motor control whose the results are presented by the following figures:

From these results, the electromagnetic torque simulation profile presents a peak start up equal to 40 N m, Fig. 1. In the real time case the peak startup is about 12.5 N m, Fig. 2. The chattering torque band is 2.5 N m and the settling time 2 s.

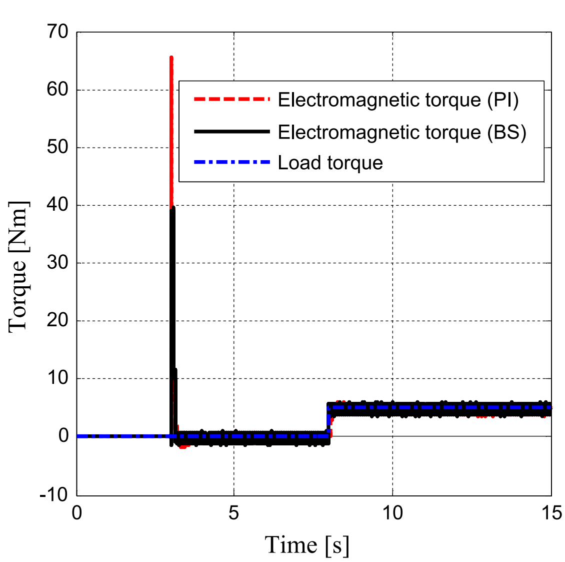

Fig. 1. Torque simulation profile [6].

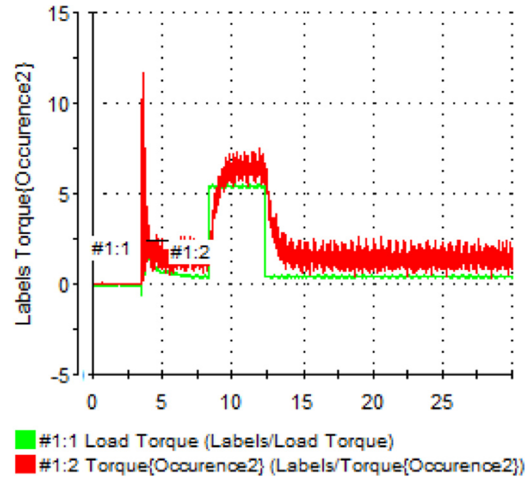

Fig. 2. Experimental torque speed profile [6].

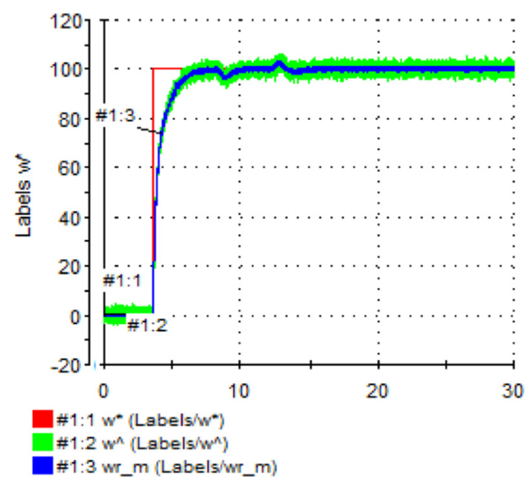

Fig. 3. Experimental rotor speed profile [6].

Fig. 3 follows the real time rotor speed, it presents a good tracking errors. In this case, the reference speed is 100rad/s. The settling time is 2.5s. The integral speed error is given in Fig. 4 with a peak start up 30rad/s and with an important band oscillation.

We remark from above that the adaptive backstepping with integral action presents good tracking errors but the chattering phenomenon will always exists.

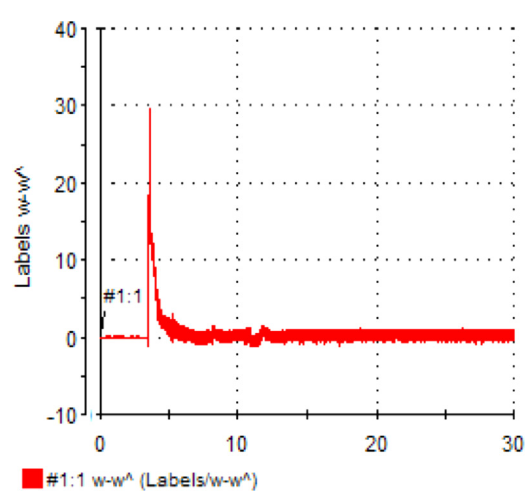

Fig. 4. Experimental integral speed error profile [6].