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Sliding Mode Control for Power Output maximization in a Wave Energy Systems

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Abstract

Modern wave power generation plants are capable to work in variable speed operations. These wave power generation plants are provided with adjustable speed generators, like the double feed induction generator. One of the main advantages of adjustable speed generators is that they improve the system efficiency compared to fixed speed generators, because turbine speed can be adjusted as a function of the flow coefficient to maximize the output power. However these systems require a suitable speed controller in order to track the optimal turbine reference speed. In this work, a sliding mode control for variable speed wave power generation plants is proposed.
The stability analysis of the proposed controller is provided under disturbances and parameter uncertainties by using the Lyapunov stability theory. Finally simulated results show, on the one hand that the proposed controller provides high-performance dynamic characteristics, and on the other hand that this scheme is robust with respect to the uncertainties that usually appear in the real systems.

Keywords: *Robust control; Doubly Fed Induction Generator; Sliding mode control; Wave energy; Wells Turbine ;*

1. Introduction

Wave power is an abundant renewable source of electricity by converting the kinetic energy of the waves into electricity. Many renewable power-generation plants, like wind turbine systems and wave energy plants, incorporate a doubly fed induction generator (DFIG) to allow variable rotor speed operation [1], [2].
Traditionally the control of a DFIG are simplified by means of the vector or field control schemes and then using a cascaded PI current and power loops. However, as it is well known, the real system parameters always differ from those obtained from the data sheet used for PI tuning, so a fine tuning over the real system is always required to achieve an adequate performance, and the PI controllers may present a considerable lack of robustness depending on the tuning method employed [3].

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Taking into account the previous considerations some kind of robust control scheme should be considered for this kind of systems in order to improve the controller performance under system uncertainties. In this sense, the sliding-mode control (SMC) initially developed by Utkin and successfully applied to diverse types of induction machine drives [4] can be a suitable choice. The SMC, allows to avoid the need of an exact knowledge of the system parameters and offers many desirable properties, such as good performance against unmodeled dynamics, insensitivity to parameter variations, and an excellent external disturbance rejection. Recently some SMC schemes has been proposed in order to extract the maximum power from the wind turbine system equipped with a DFIG [5].
This paper presents a SMC scheme in order to improve the power extraction in OWC wave energy generation plants equipped with a DFIG. The objective is to attain that the turbine speed tracks the optimum speed, that maximizes the power extraction from the Wells turbine, in spite of system uncertainties.

2. OWC Plant modeling

In this work the NEREIDA MOWC project is considered as a system that can be controlled using the proposed robust control design. NEREIDA MOWC is a project involving the integration of an OWC system with Wells turbines in the new rockfill breakwater at the harbor in Mutriku in the north coast of Spain.
In this system, the turbogenerator module is composed by two five-blade Wells turbines that turn together, connected to an air cooled DFIG. In this kind of induction machines, widely employed in diverse generation applications, the stator circuit is directly connected to the grid while the rotor winding is connected via slip rings to a variable frequency converter (VFC). In order to produce electrical active power at constant voltage and frequency to the utility grid, over a wide operation range (from subsynchronous to supersynchronous speed), the active power flow between the rotor circuit and the grid must be controlled both in magnitude and in direction. Therefore, the VFC consists of two four-quadrant IGBT PWM converters (rotor-side converter and grid-side converter) connected back-to-back by a dc-link capacitor [6].
The main advantage of this design is that the power electronic converters only need to handle a fraction about (25%-30%) of the nominal power so that the losses in the power converter are small compared to other kinds of designs, with the consequent cost reduction in the necessary electronics.

For this OWC wave power system, the Wells fixed-pitch turbines are considered. This kind of turbine has a robust and simple symmetrical blade design, which means that it always rotates in the same direction, regardless of the direction of the airflow through the turbine, so that no device is needed to rectify the airflow. The equations used for the modeling of the turbine are given by [8]:

$$dP = C_a\, k\, \frac{1}{a}[v_x^2 + (r\, w)^2] \tag{1}$$

$$T_t = C_t\, k\, r\, [v_x^2 + (r\, w)^2] \tag{2}$$

$$T_t = \frac{C_t\, r\, a}{C_a} dP \tag{3}$$

$$\phi = \frac{v_x}{rw} \tag{4}$$

where $dP(Pa)$ is the pressure drop across the turbine, C_a is the power coefficient, a is the area of turbine duct, $v_x(m/s)$ is the airflow speed, $r(m)$ is the turbine radius, $w(rad/s)$ is the turbine angular velocity, $T_t(Nm)$ is the torque generated by the Wells turbine, C_t is the torque coefficient, k(Kg m) is a turbine constant and ϕ is the flow coefficient.
The performance of the Wells turbine is limited by the onset of the stalling phenomenon on the turbine blades, because when the airflow velocity exceeds a critical value (that depends on the turbine rotational