# Robust Control of Oscillating Water Column (OWC) Devices: Power Generation Improvement

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***Abstract*— Wave energy composes a direct and easy way of harnessing power from the Ocean. Among the different techniques used, OWC devices stand as one of the most promising ones.** NEREIDA MOWC demonstration project is a breakwater wave plant located in the Basque location of Mutriku, using Wells turbines and **Doubly Fed Induction (DFI) generators. Since one of the main objectives when dealing with renewable energies is to make them economically viable to compete with fossil fuels and nuclear fission, all technological improvements are particularly welcome. In this context, this paper presents a new Variable Structure (VC) controller for OWC wave power generation plants.** Due to the nature of the control law, it allows overcoming uncertainties caused by parametrical errors or system disturbances. The proposed design has been successfully validated and compared with the traditionally used PI-based vector control, improving the power extraction when applied for maximum power generation purposes.

***Keywords*— Wave Energy, OWC, Power system control, Robust control, Variable structure systems.**

## I. Introduction: OWC Plant Description

The aim of the NEREIDA MOWC project, promoted by the Basque Energy Board (EVE), is to demonstrate the feasibility of the OWC technology with Wells turbine power take-off into a newly constructed breakwater in Mutriku, in the north coast of Spain. It consist of of 16 18.5kW turbines that provide a total power of 296kW [1,2]. See Fig 1. It was inaugurated in July 2011 and produced 200.000kWh during the first year while it was estimated a 600.000kWh production per year. Although the difference if mainly due to a storm that damaged the control room and kept the facility closed during the best wave months, an improvement in the power generation could highly benefit the system.

Fig. 1. Turbines in Mutriku MOWC breakwater

## II. VS Controller

As it has been indicated, the turbo-generator modules use Wells turbines, which provides unidirectional rotation despite of the air flow direction [3], combined with DFIGs. This kind of AC drives is usually controlled using a vector control scheme and cascaded PI-current and power loops [4]. Nevertheless, since the actual system parameters always differ from those from the data sheet used for PI tuning, a fine tuning over the real equipment is generally required to achieve an adequate performance [5]. Besides, some tuning methods require a detailed modelling of the system, and it is well known that, depending on the tuning method

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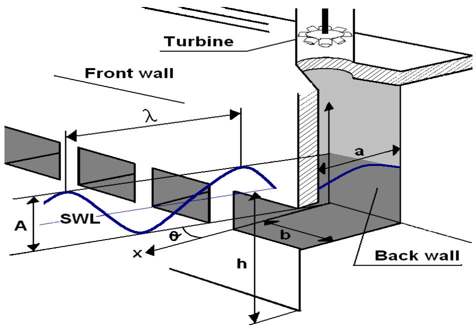


Fig. 2. Wave and OWC capture chamber parameters

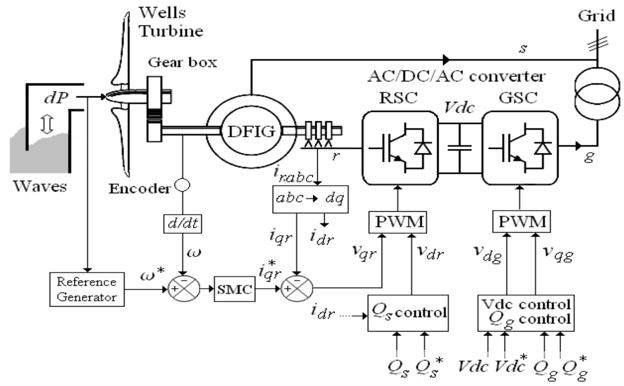


Fig. 3. Control design

used, PI controllers may present a considerable lack of robustness [6]. To avoid these drawbacks, a suitable option is to consider some kind of robust control scheme as it is the case of the Sliding Mode Control (SMC) initially developed by Utkin [7] and successfully applied to diverse types of induction machine drives [8].

Taking into account the wave and the OWC chamber parameters, it is possible to obtain the power available from the airflow in the OWC chamber as (see [9] and Fig. 2):

$$P_{in} = \left(dp + \rho v_x^{\,2}/2\right) v_x \; a \tag{1}$$

On the other hand the equations used for the modelling of the turbine are given by (see [10]):

$$\begin{aligned} & dp = C_a K(1/a)[v_x^{\,2} + (r\omega_r)^2]\,;\; T_t = C_t K r [v_x^{\,2} + (r\omega_r)^2] \\ & T_t = dp\; C_t\, ra / C_a \;\;;\;\; \phi = v_x / r\omega_r \;;\; K = \rho\, b\, n\, l/2 \\ & q = v_x\, a\,;\; \eta_t = T_t \omega_r / dp\, q\,. \end{aligned} \tag{2}$$

The proposed SMC scheme is used within the rotational speed controller to regulate the slip of the generator, while maintaining the traditional air valve controller, as it is shown in Fig. 3 (see [4]).

It is known that the, the dynamic equation of the IM drive system may be expressed as:

$$\dot{\omega}_r = 1/H\left(T_t - K_T i_{qr} - F\omega_r\right), \tag{3}$$

where $K_T$ is the torque factor and $H$ and $F$ the inertia and the friction factor the system respectively, so that the generator slip can be controlled by regulating the q-axis rotor current components $i_{qr}$.

Now, adequately managing this expression, it is possible to obtain the speed tracking error *e(t)*, that in turn allows to define a sliding variable:

$$S(t) = e(t) + \int_0^t (k + a)\, e(\tau)\, d\tau \tag{4}$$

and the SMC law as:

$$u(t) = -k\, e(t) - \beta\, \mathrm{sgn}(S) \tag{5}$$

Where, $a = F / H$ , $k$ is a constant gain, $\beta$ represents the switching variable and sgn(•) is the signum function (see [10]).

Then, it is *demonstrated using the* Lyapunov stability theory that tracking error converges to zero exponentially as time tends to infinite, so that the desired current command $i^*_{qr}$ can be expressed as (see [11]):

$$i^*_{qr} = \tfrac{1}{b}\left(k\, e + \beta\, \mathrm{sgn}(S) + f - a\,\omega^* - \dot{\omega}^*\right). \tag{6}$$

Therefore, the VS controller designed solves the power tracking problem for DFIG-based OWC power plants in the presence of uncertainties.

## III. Design Validation

In order to prove the proposed control scheme, it has been firstly tested for maximum power extraction and then compared with the traditionally employed PI-based vector control for the same purpose in presence of uncertainties.

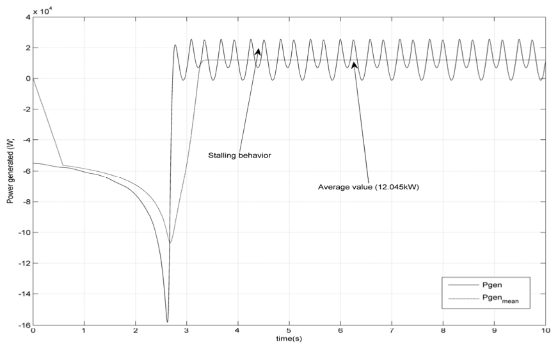


Fig. 4. Limiting stalling behaviour ((|7000|Pa dP input, uncontrolled case)

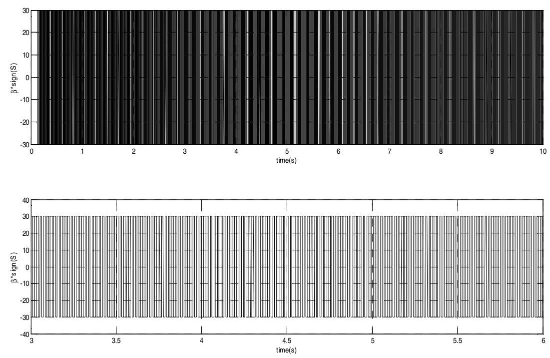


Fig. 6. Chattering phenomenom

### *A. Power Extraction*

A comparative study for both uncontrolled and controlled cases has been performed with the aim of demonstrating the maximum power extraction capability of the proposed SMC approach. It has been considered a scenario where waves produce a typical variation in the pressure drop of $|7000|$ Pa. This pressure drop generates an undesired stalling behaviour as it may be observed for the uncontrolled case in Fig. 4, where the power generated is limited to 12045 W. In contrast, the proposed SMC scheme avoids this stalling behaviour as shown in Fig. 5 for the controlled case, increasing the generated power up to a maximum of 15025 W. As it can be seen in the detail of Fig. 6, the output presents the chattering inherent to this kind of controllers due to the switching nature of the control law. This high frequency dynamics of the controller is usually filtered by the mechanical inertia of the system.

### *B. Uncertainties and Disturbances*

In this case the proposed SMC controller has been compared with a PI-based vector control for the same pressure drop input, including a 30% of uncertainties.
As it may be observed in Fig. 7, the result of the PI-based control presents a considerable steady state error due to the deviation of the actual machine parameters. As it is well known, one of the f the main drawbacks for PI-based controller is that the performance highly relies on its tuning, and therefore on the accurate knowledge of the machine parameters that are sometimes difficult to obtain.

In contrast, the SMC is able to assume these uncertainties providing a higher power generation, as it may be seen in Fig. 8. Indeed, it may be observed that there are hardly any differences with the case of Fig. 5 even with such large deviation in the system parameters. The generation system presents pretty good performance and the uncertainties are overcome by the controller.

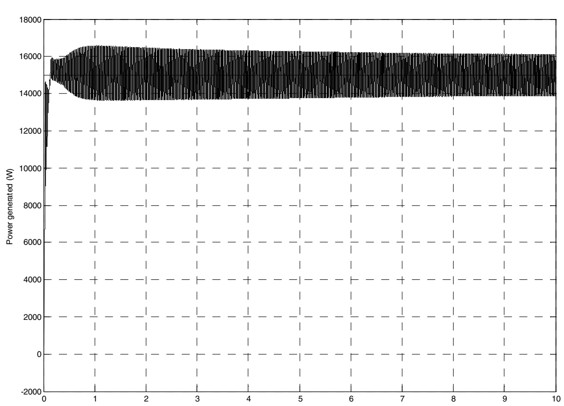


Fig. 5. Stalling-free bahaviour ((|7000|Pa dP input, SMC case)

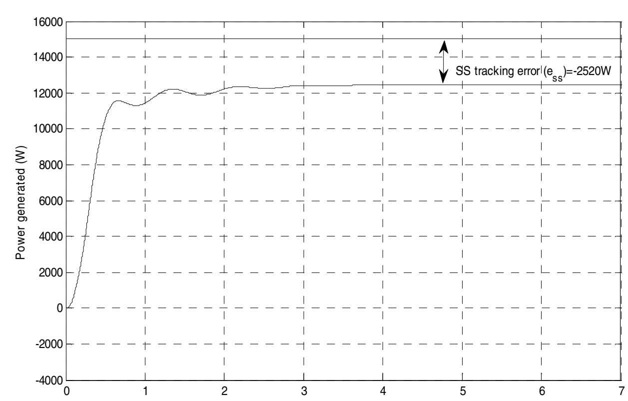


Fig. 7. Power generated (|7000|Pa dP input, 30% uncertainties, PI)

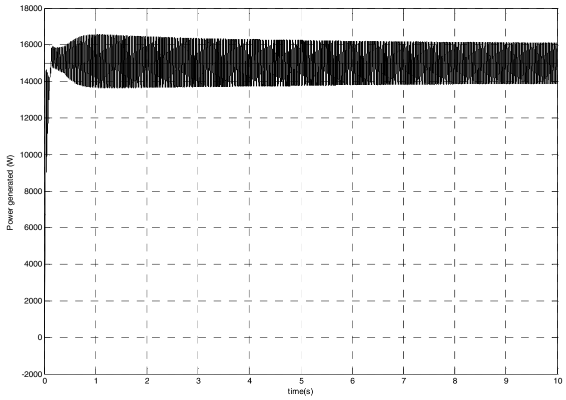

Fig. 8. Power generated (|7000|Pa dP input, 30% uncertainties, SMC)

## IV. CONCLUSION

A robust SM control for OWC devices has been presented. The stability of the proposed controller has been is proven using the Lyapunov theory. It may be demonstrated that the control scheme allows overcoming parameter uncertainties and system disturbances, providing a higher power production that the traditional PI-based vector control.

## ACKNOWLEDGMENT

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