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Neural control for voltage dips ride-through of oscillating water column-based wave energy converter equipped with doubly-fed induction generator

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ABSTRACT

The increasing penetration of renewable distributed power generation systems within electricity markets has given rise to new technical requirements. One of the most demanded skills is a fault-ride-through capability during voltage drops in the transmission system. This paper investigated the application of a neural control scheme to achieve the uninterrupted operation of oscillating water column-based wave energy converter equipped with doubly-fed induction generator during balanced grid faults. It is proposed an innovative solution consisting of a control scheme that suitably coordinates the air flow control, the active crowbar and the variable frequency converter, fulfilling the Spanish Grid Code. Besides, the variety of cases presented due to different sea states (amplitude and frequency) and characteristics of the grid fault (voltage drop and fault period), makes it necessary to adequately modify the references used by the controllers in order to achieve the desired fault-ride-through capability. In this sense, it has been implemented a neural control that adapts the controller references according to the pressure drop and voltage reduction, improving the controllability of the active and reactive power and the fault-ride-through capability during voltage drops.

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1. Introduction

In the last years, there has been a worldwide resurgent interest for wave energy amid increasing concerns about global warming and reliability of oil and gas supplies. Harnessing the immense wave power in the oceans can be part of the solution to our present energy problems. Worldwide, the energy production potential for ocean wave energy has been estimated about 8000–80,000 TW h/year [1], and the actual development in this sector is comparable to that of wind energy a few decades ago, with similar economic potentials.

In this sense, many governments are adopting new energy generation and renewable energy guidelines towards an ecologically sustainable society. As an example, the UK Government has risen the environmental challenge with an agreement on goals to generate 15% of UK electricity demand from renewable sources by 2015 with the aim of reaching 20% by 2020 [2]. The penetration of medium and high capacity power production plants, like wind farms and similar facilities, has reached such a level in diverse countries as Denmark, Germany or Spain that represent a major impact on the characteristics of the power network [3].

Many of these renewable power generation plants incorporate doubly-fed induction generators (DFIG) to allow variable rotor speed operation. Nevertheless, the DFIG is very sensitive to voltage dips. Grid faults are short term voltage drops in one or more phases of the grid system, often caused by the transient earthing of one or more phases on the transmission lines. The fault period is the duration of the voltage dip and the fault recovery time is the period starting at the clearance of the fault and ending when the voltages return to balanced steady-state values. In particular, balanced faults are those causing an equal dip in voltage on all three phases [4].

When a grid fault occurs on the transmission system, the speed of the turbo-generator group increases due to the imbalance between the mechanical torque imposed by the turbine and the electromagnetic torque of the induction generator. Also, during the fault period and the fault recovery the induction generator injects large peak currents, with the risk of damaging the rotor converter and increasing the consumption of reactive power, so that if the plant would not be tripped from the grid, it would contribute to the voltage dip. However, the politics of disconnecting the system from the grid may propitiate the collapse of the power network, so new Grid Codes oblige the distributed power generation systems to remain connected to the Point of Common Coupling (PCC) during the fault to avoid massive chain disconnections so that

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the implementation of an adequate Fault-Ride-Through (FRT) capability is indispensable [5].

In this sense, although at present day it does not exist a specific normative on wave energy, the arising issues regarding power grid faults are similar to those of more extended renewable energies as it is the case of wind energy, and must also be solved by means of adequate fault tolerant control schemes. A solution employed is the use of a control scheme that suitably coordinates the air flow control, the crowbar and the Variable Frequency Converter (VFC) so as to allow the plant to remain in service during the grid fault, and to contribute to its attenuation [6]. But the different cases presented due to different sea states (amplitude and frequency) and characteristics of the grid fault (voltage drop and fault period), make it also necessary to modify the references used by the control to overcome the voltage sag.

The innovative aspect exploited in this paper is the application of a neural control to change the reference values of the air flow control, the crowbar and the VFC according to the pressure drop and voltage dip, improving the controllability of the active and reactive power and the FRT capability during voltage drops.

The rest of the paper is organized as follows: Section 2 provides the necessary background. In Section 3, the uninterrupted operation feature during grid faults is explained. In Section 4 the behavior of the wave power generation plant under different sea scenarios and different voltage drop grid faults is studied. In Section 5 the proposed neural control is presented. In Section 6 some demonstrative simulation examples are given in order to test the performance of the controller, and finally concluding remarks end the paper in Section 7.

2. Theoretical analysis and modelling

In this section we will present the necessary theoretical analysis to model the different components of the systems, i.e.: Artificial Neural networks (ANN), wave model, oscillating water column and Wells turbine.

2.1. Artificial neural network design

ANNs have been used to perform complex tasks in various fields of application including pattern recognition, identification, classification, speech, vision and control systems [7]. The most widely used neural network algorithm is back-propagation. This algorithm attempts to minimize the error by adjusting the weights of the neurons using a gradient descent optimization algorithm. In the back-propagation learning, the actual outputs are compared with the target values to derive the error signals, which are propagated backward layer by layer for the updating of the synaptic weights in all the lower layers [8].

The general formula for the activation of each unit in the network (except for the inputs units whose activation is clamped by the input vector) is given by:

$$A_j(w,h,y) = \frac{1}{1+e^{-\left(\sum_{i=1}^{N}(w_{j,i}y_i)+h_j\right)}} \tag{1}$$

where: $w_{j,i}$ strength of the coupling between unit j and i N total numbers of units in the layer y_i activation of unit i h_j threshold or bias for unit j.

The most used ANN design consist of a layer of input units (x), one or more layers of hidden units (y), depending of the chosen network design and a layer of output units (z) as may be seen on Fig. 1. The activation of a hidden unit, output unit and the total error measuring the performance of the network E are defined as:

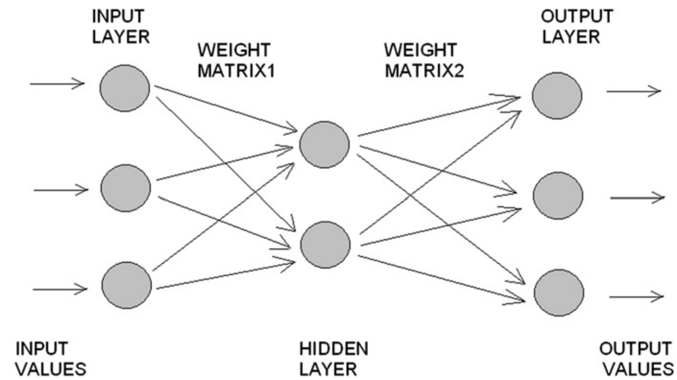

Fig. 1. Feed-forward neural network.

$$y_i = A_j(v,h_j,x) \tag{2}$$

$$z_i = A_j(w,o_j,y) \tag{3}$$

$$E = \frac{1}{2}\sum_{c=1}^{N_c}\sum_{j=1}^{N_z}(z_{j,c}-t_{j,c})^2 \tag{4}$$

where: v strength of the couplings between layer x and y h_j bias of hidden unit j w strength of the couplings between layer y and z o_j bias of output unit j c input vectors with their corresponding target vectors N_c total number of cases z_j actual value (activation) of output unit j N_z total numbers of output units t_j target value of unit j.

2.2. Waves model

The first objective of our analysis is to model the input to the system. The Linear or Airy Wave Theory is generally accurate enough for many engineering purposes and specifically for control design purposes [9]. Linear Wave Theory describes ocean waves as simple sinusoidal waves as shown in Fig. 2.

The waves model considered has been particularized for the case of the NEREIDA MOWC, a project involving the integration of an OWC system with Wells turbines in the new rockfill breakwater at the harbour in Mutriku, located in the Basque coast of Spain. The breakwater is located at 7 m (h) of the still water level (SWL) [10]. The average height of waves in the Cantabrian coast is less than two meters with a period (T) between 8 and 12 s [11]. According to these data, the most suitable approach in our case is to use the linear

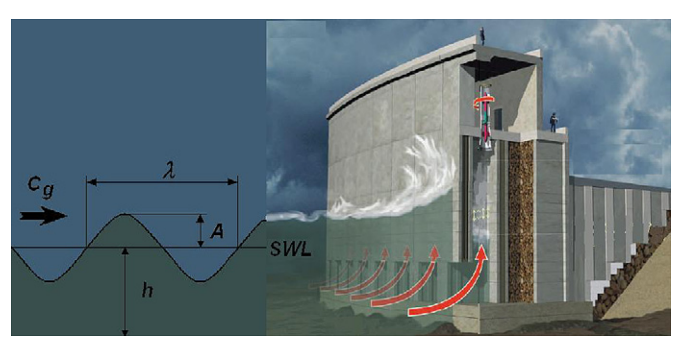

Fig. 2. Scheme of OWC and ocean wave.

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