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# An impulsive noise filter applied in wireless control of wind turbines

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ABSTRACT

This paper proposes a novel non-linear filter applied to wireless-transmitted reference signals in a deadbeat control strategy of a doubly-fed induction wind turbines. These signals are likely to be corrupted by spikes intrinsically imposed by the wireless channel. This impulsive noise is traditionally mitigated using classical error-correction schemes, and the proposed filter is an alternative that is simpler and has lower computational cost. The proposed technique, hereby designated as Functionally-Weighted Moving Average (FWMA) filter, is based on a non-conventional weighting of the signal samples, which is carried out by a rectangular function. The filter realization is as straight as any linear technique. The generator control scheme, which includes the filter, is embedded in a microprocessor locally placed at the generator site, where it acts on the reference signals at the receiving end of the channel. The performance of both the filter and the control system are verified by simulations that include the wind turbine dynamics and the communication channel. The proposed technique is compared with a morphological filter, previously suggested for the same purpose. The results endorse the FWMA filter efficacy to clean out impulsive interferences with minor delays.



## 1. Introduction

In recent times, the power grid has been experiencing significant changes in both its structure and operation. Additionally, there has been an increasing penetration of alternative sources, mainly in the grid distribution level. On the other hand, monitoring and control of these new sources are demanding advanced solutions from the utilities. Most of the alternative sources connected to the mains are from renewable nature, as photovoltaic and wind systems that may be widely spread along the grid. This raises obstacles in coordinating and integrating the different sources, primarily regarding communication procedures [1].

Wireless communication techniques are becoming quite popular in power systems applications in the last decade [2–4]. This trend is explained due to the increasing reliability and reduced costs, high speed links, and easy setup of connections among different devices/appliances [5–8]. In literature, it is possible to find an extensive use of wireless technology for generation control of renewable energy systems [9–13].

However, signals transmitted through wireless channels are prone to distortions and errors that can cause problems in the monitoring and control processes that are essentials for a proper power grid operation. When employing low-complexity error-correction coding under a highly degraded transmission conditions, some samples are corrupted at the receiver. In this way, the resulting received signal is polluted with impulsive noise, in which is not so simple to be mitigated.

Despite the aforementioned difficulties, the usage of renewable sources controlled by wireless data transmission is growing attractive. The emergence of smart grid technologies are enabling techniques for optimal management of these sources [14]. Among them one can highlight, the arisen of wind turbines connected to the distribution power grid [15]. One method for generating power from the wind is using Switched Reluctance Machine (SRM) [16].

Another usual approach is the application of Doubly-Fed Induction Generators (DFIG). These generators can be controlled by a deadbeat technique, such as presented in Ref. [17]. In the present work, this method is implemented aided by a wireless system, in which, the reference control signals of active and reactive power are transmitted from the utility operation center to the generator site, as shown in Fig. 1. The destructive effects of the wireless multipath fading channel contaminate the reference signals with

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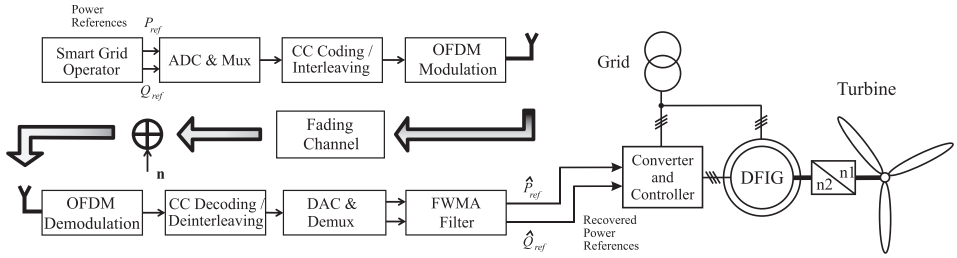


**Fig. 1.** Wireless system control schematic for a DFIG wind turbine.

spikes. In a previous work, the authors proposed a morphological technique to filter out these distortions [17].

From the signal processing perspective, most commonly, noise are clean out by the use of linear filters, specially low-pass filters [18–22]. Unfortunately, this approach is not suitable for impulsive noise, since it imposes great response delays. To overcome such drawback, one may apply multi-rate digital processing strategies, for which the wavelet transform is the most prominent [23–25]. This technique is likely to work out properly since it separates the signal from noise, whose components are in scales of higher resolution. Another usual strategy to filter out impulsive interference is the adoption of non-linear techniques, such as median filtering [26,27], stack filtering [28] or morphological filtering [17,29]. These approaches are effective and are also applied for purposes other than noise suppression, such as phasor estimation [30], or image processing [31].

Among these ones, the standard median filter is the most popular [32]. This filter operates a non-linear ordered statistics, sampling in a sliding window and making the filter insensitive to the presence of an outlier. Basically, the idea is to operate a sliding window through the signal samples, so that, the filter outcome is the median of the samples contained in the window which are sorted in numerical order. Due to the sorting, the computational effort may be considerable for large windows and the filter may distort edges and not sufficiently attenuate nonimpulsive noise [33–36].

In this context, this paper proposes a filtering approach particularly suitable for wiping off impulsive noise from constant references. Essentially, the filter works cutting abrupt changes in the filtering signal. Its structure, presented in detail in Section 4, resembles a weighted moving average filter. However, unlike a linear filter, the weights are not constant values, but a discrete-time function $w[n]$, which constrain the rate of changing for subsequent samples. Also, the weighting moving average filters previously proposed are more effective to clean Gaussian and colored noise rather than impulsive interferences [37,38]. The results obtained here enhance the effectiveness of the ones reported in Ref. [17] for the same purpose.

In addition, it is worth highlighting that the filter acts on signals transmitted from remote points to the locals, where the wind turbines are deployed. Here, it is not being considered any wireless communication system internally to the wind turbine. This paper suggests that, at smart grid applications, real-time communication between generation and demand sides is a trend and, in some cases, wireless communication is a viable alternative. Some schemes have already been proposed in the literature employing this technology for monitoring purposes [39,40].

This work is organized as follows. The second section briefly describes the fundamental equations for the DFIG and its control strategy. The third section presents the proposed wireless coded system and the wireless fading channel. The fourth section outlines the proposed filtering algorithm. The results and discussions are presented in the fifth section and the conclusion are drawn in the sixth section.

## 2. The machine model and deadbeat power control

### 2.1. Machine model

The independent stator active $P$ and reactive $Q$ power control for a DFIG can be made by regulating its rotor current. Thus, $P$ and $Q$ have to be represented by each rotor current component by using stator-flux-oriented approach, which allows to decouple the direct and quadrature $(dq)$ axis [41]. Initially, the relationship between stator and rotor current is presented by Refs. [42,43]:

$$i_{1d} = \frac{\lambda_1}{L_1} - \frac{L_M}{L_1} i_{2d}, \tag{1}$$

$$i_{1q} = -\frac{L_M}{L_1} i_{2q}, \tag{2}$$

where: $\lambda_1 = \lambda_{1d} = \left|\overrightarrow{\lambda}_{1dq}\right|$ is the magnitude of the stator flux. Hence, the stator active and reactive power may be represented as:

$$P = \frac{3}{2}\left(v_{1d} i_{1d} + v_{1q} i_{1q}\right), \tag{3}$$

$$Q = \frac{3}{2}\left(v_{1q} i_{1d} - v_{1d} i_{1q}\right). \tag{4}$$

The stator power presented in equations (3) and (4) can be calculated from equations (1) and (2), by using stator-flux-oriented, as:

$$P = -\frac{3}{2} v_1 \frac{L_M}{L_1} i_{2q}, \tag{5}$$

$$Q = \frac{3}{2} v_1 \left(\frac{\lambda_1}{L_1} - \frac{L_M}{L_1} i_{2d}\right), \tag{6}$$

where: the subscripts 1 and 2 refer to the physical values of the stator and rotor, respectively. The subscript $d$ and $q$ apply to the synchronous axes in which the currents $i$ and voltages $v$ vectors are in the decomposed form. $L_1$ and $L_2$ are the proper inductances of the stator and rotor windings, respectively, while $L_m$ is the mutual inductance. The variable $\overrightarrow{v}_{dq}$ is the voltage synchronous vector and $v_1 = v_{1q} = \left|\overrightarrow{v}_{1dq}\right|$ are the stator voltage vector magnitude.

Thus, by using the stator-flux-oriented control, the rotor current will reflect on the stator current and also on each component of stator power. Hence, the stator active and reactive power control can be made by controlling each rotor current component for a DFIG in which its stator is directly connected to the grid supply.