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Wind turbine angular frequency analysis by means of computer vision techniques

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ABSTRACT

The turbine synchronization phenomenon is of great interest in order to estimate the flicker produced by a wind farm. This paper proposes an initial approach to analyze the appearance of this phenomenon by the use of various image processing techniques: a method to automatically calculate the angular frequency of an unknown number of wind turbines from a video. The recorded video images were obtained at the Manzanal wind farm, province of León (Spain).

1. Introduction

1.1. The flicker phenomenon

Flicker is an effect of subjective nature associated to the perception of the variation of lamps brightness caused by voltage fluctuations in the power network. Above a certain threshold, flicker becomes annoying. This discomfort increases rapidly with the magnitude of the fluctuation and depends heavily on the frequency. Flicker is considered by international standards [1] as one of the parameters affecting the voltage wave quality which value must be supervised.

The method to measure the flicker is relatively complex because it is an effect that does not depend on a single electric parameter but on a combination of them (frequency and amplitude of the voltage fluctuations) within certain margins of operation. In addition, the feeling of discomfort depends on the relative variation compared to the brightness of the ambient light. The mechanism of adaptation of the eye is also taken into account.

1.2. Flicker produced by a single wind turbine

Loads with a variable power demand cause variable voltage dips in the network. If these loads are connected to the MV network this problem exacerbates. This is the matter of the great arc furnaces since the disturbances affect a greater number of users. It can also occur that a power source itself is the origin of these disturbances. This can be the case of the wind turbines [2] as outlined below.

In general, a wind turbine produces a variable mechanical power, which involves a variable delivered electrical power. It is unanimously accepted that the causes of the periodic fluctuations of the power are the stratification of the wind speed and, to a greater extent, the *tower shadow* effect [3] illustrated in Fig. 1. Often, the first of these phenomena is due to the fact that the speed of the incident wind on the turbine increases with the height [4]. The growth law depends on factors such as the roughness of the terrain, the type of atmosphere, etc. This means that, even assuming a constant wind speed, the torque transmitted by each blade on different parts of its pathway is not constant. Instead, it has a periodic component of frequency $3p$, being p the frequency of the rotor rotation.

The *tower shadow* effect is caused by the local wind speed decrease in the vicinity of the tower, which causes the decline of the instantaneous torque each time one of the blades passes through its lowest position. The torque oscillations induced by this effect are, again, $3p$.

Each time one of the blades is faced with the tower (minimum torque), none of them is at the highest position (maximum torque), resulting in an addition of both effects.

The wind turbines equipped with variable speed generators can mitigate, at least in part, the variations in the mechanical power by increasing or decreasing its stored kinetic energy.

On the other side, turbines equipped with fixed speed generators must deliver the fluctuations of the mechanical power to the power system, instantly and barely mitigated. Therefore, this type of turbine, equipped with an asynchronous generator and usually known as the "Danish concept", is the potential source of voltage

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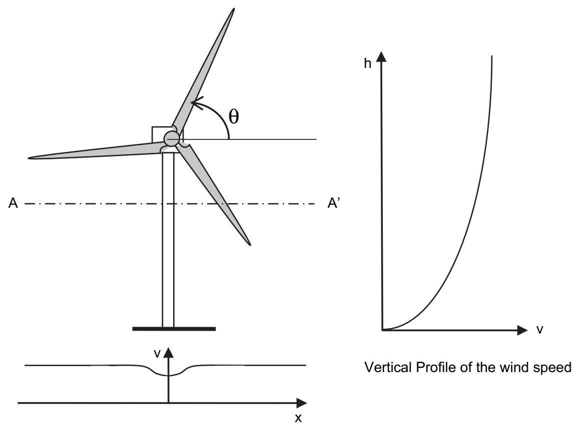

Fig. 1. Effect *shadow of tower* and stratification of the wind speed with the height.

fluctuations causing flicker [5]. In the course of this paper we refer to this type of wind turbine.

In [3,6], as in virtually all the studies published in this field, the maximum amplitude of the periodic power fluctuations produced by the asynchronous, fixed speed is often quantified as 20 percent of the average power, and takes place when the turbine operates with a high wind speed. When this speed is low, the oscillations are lower in relative value. The frequency of the oscillations of the three blade fixed-speed commercial turbines varies between 0.7 and 2.2 Hz [7]. In the case of the turbine NM 52/900 considered in this work, which is used in the Manzanal, wind farm, the turbine speed is 22.4 r.p.m., so that the 3*p* frequency corresponds to 1.12 Hz.

1.3. Combined effect of several generators

To estimate the total voltage distortion of a wind farm due to slow voltage variations, the effects of all generators may be taken into account on the basis of their active and reactive rated power. In other words, the farm could be considered as a single generator which power is equal to the sum of the powers of the single units.

Concerning the fast voltage variations, the question is not as simple because it is not realistic to assume that the power fluctuations are coincident in time (even assuming that they have the same magnitude in all the generators), neither that they may cancel each other.

The practice is to follow the recommendation of the IEC1000-3-7 standard [8] considering that each turbine is responsible of a certain value of flicker, P_{sti} and, the combined effect of all the turbines can be taken into account by:

$$P_{st} = \sqrt[m]{\sum P_{sti}^{m}} \tag{1}$$

the value of m depends on the characteristics of the main sources of the fluctuations and can take values from 1 to 4. Value 4 is set for the cases in which the fluctuations should not be coincident and 1 for those other cases in which the probability of occurrence is very high. Value 2 is used in cases in which the coincidence is just as likely as that of random noise. That means that the fluctuations are not correlated. This is the most appropriate value to our case since, in principle, the disturbance of each turbine is independent of the others. This means that, in the usual case all the turbines are equal and all cause an individual disturbance P_{sti} which is equal for all of them; the global disturbance for N turbines will be:

$$P_{stN} = \sqrt{N \cdot P_{sti}^{2}} = \sqrt{N} \cdot P_{sti} \tag{2}$$

by the above expression, if the disturbance caused by a generator is proportional to its power, a single generator which power is equal to the sum of the powers of N generators will produce in the network a disturbance $N \cdot P_{sti}$, clearly higher than the disturbance produced by N generators.

Subsequently, another IEC standard specifically dedicated to the quality of the energy supplied by the wind turbines [9], described an exhaustive procedure for determining the individual disturbance of each turbine through field tests and by the implementation of a network model. This disturbance was characterized by a coefficient $c(\Psi_k, \nu_k)$ which is a function of the wind speed (ν_k) and the angle of the impedance of the Thevenin network equivalent (Ψ_k) in an specific site. To obtain an estimation of the flicker produced by the farm, it proposes an expression equivalent to (2).

As just seen, the calculation of the overall disturbance caused by a farm is carried out from the individual contribution of each wind turbine, assuming that they are not cross-correlated.

In our case, this is equivalent to assume that the angular position of the rotor regarding each wind turbine tower is a random variable not correlated with the rest of the wind turbines belonging to the same farm.

Nevertheless, some authors [10,11] have analyzed, theoretically, the possibility that the turbines of the same farm, after a few hours working in ideal conditions (constant wind), will reach a synchronized operation. If this is true, the estimation of flicker would no longer be realistic due to the actual correlation between the disturbances produced by the individual wind turbines in the farm.

The SCADA systems in this type of farms do not handle information of the angular position of the rotors. In the best case, the

Fig. 2. For a given frame (left) the histogram is adjusted by increasing the contrast (right).