TV Interference from Wind Turbines

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Abstract— **Wind turbines may be a source of disturbance in the radiation fields of TV broadcast transmitters. The situation is particularly serious when the direct path from the transmitter to the receiver antenna is obstructed while both transmitter and receiver antennas have a unblocked path to the wind turbine. Starting from an analysis of the diffracted field by the pylon we proceed to implement a simple rule derived from ITU Recommendation 805 to define a minimum clearance distance from an isolated wind turbine and a TV transmitter antenna. Measurements using a scaled model confirm the existence of the floor level in the scatter model used in ITU Recommendation BT.805.**

I. Introduction

WInd turbines are becoming increasingly popular as non polluting sources for electric power. In many cases the best locations for wind farms happen to coincide or be close to existing transmitter antennas, for broadcast (radio and TV), fixed service and mobile cellular.

To the surprise of some, experience has shown that wind turbines may present a potential interference problem, which is particularly serious with (analogue) TV broadcast.

Given current pressure to use the (few) favorable locations there is considerable interest in defining simple, but safe, clearance rules to enable co-siting of wind turbines and transmitter antennas.

In a previous paper [1] we considered this problem, in the VHF and UHF frequency bands, concentrating in the diffraction of radio waves by the pylon. In this paper we include the potentially more hazardous and serious effect of blades which, especially when moving, can cause significant impairments in (analogue) TV reception.

The presence of wind turbines near transmitter antennas has two effects. One, is diffraction mainly by the pylon, and the other is the reflection, mainly by the blades, both producing amplitude oscillations in the radiation fields.

Another way to look into the problem is to consider that the received signal, which in the absence of the wind turbine may be considered as deriving from a single (direct) ray between the transmitter and the receiver, is now the sum of a direct ray plus a reflected/diffracted ray with a potentially significant time lag. For analogue TV, time lags of the order of microseconds give rise to visible ghosts and, in extreme cases, may lead to loss of synchronism. When blades rotate, the situation worsens because the amplitude of the reflected ray is modulated by the movement causing increased image scintillation, which translates into a significant subjective image quality degradation.

This situation is TV specific because, in practice, the likely delays are too short to be perceived in analogue sound broadcast or in low speed digital signals (GSM cellular radio). In the latter cases only amplitude oscillations matter.

ITU-R Recommendation BT.654 [2] establishes criteria for subjective assessment of analogue TV image quality in presence of echo signals. A bound for the amplitude of the interfering signal can be defined according to this recommendation to ensure a pre-defined subjective quality. Thus, once a reliable method is found to calculate the reflected ray amplitude and delay relative to the direct ray, co-siting criteria and clearance rules may be defined.

ITU-R Recommendation BT.805 [2] presents a simple method to assess the impairment caused to (analogue) color TV reception by the blades of a wind turbine where the reflected ray amplitude is calculated as the larger of the following two values: the amplitude of the forward lobe, taking the blades as perfect flat reflectors, and -10 dB below the maximum value of the forward lobe. Modelling a typical wind turbine and measuring the reflected ray in an anechoic chamber (at 60 GHz) enabled us to validate this assumption.

Although the previously referred recommendation does not mention the effect of the pylon, our results suggest the possibility that, in some cases, pylon backward diffraction may have a non negligible influence in subjective image impairment, even if its non moving character reduces its importance. In addition the simple ITU-R method assumes that both the transmitter antenna, the wind turbine and the receiver antenna are in free space, which may not be the case in practice.

This model, besides providing insight into the physical basis of the simple ITU-R method, further enables to extending it to situations closer to real life.

Extension of this model to wind farms may be achieved using an empirical procedure [3].

Given the complexity of the problem, we approached it using different techniques. Thus we considered separately the diffraction around the pylon, assumed to be an infinite cylinder, and the scattering by the rotor blades, modelled as metallic sheets of rectangular shape. These results were compared to those ITU-R Recommendation BT.805 [2] and to experimental values obtained from a scaled model at 60 GHz.

II. Diffraction by the pylon

The pylon diffraction is treated as the canonical problem of a plane wave diffraction by an infinite cylinder.

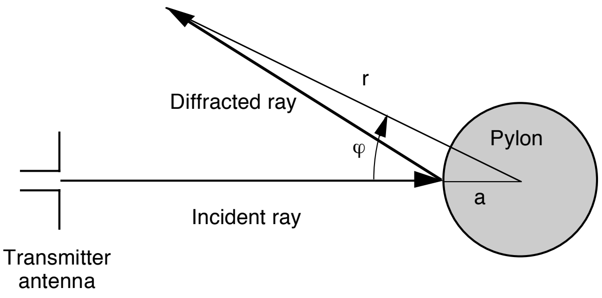

Fig. 1. Geometry for the diffraction of a plane by an infinite cylinder.

The pylon is a metallic cylinder about 30-40 meters high and 3 meters wide. Usually its cross section decreases from the base to the top but it is possible to neglect this variation in the calculation of the diffracted power, without significantly affecting the results. Therefore, in the theoretical analysis a metallic cylinder with constant section and infinite length can replace the pylon. Its infinite length allows to calculate exactly the scattered electric field although the diffraction on the top is completely neglected.

Assuming that we have a vertically polarized plane wave incident on the pylon as shown in Figure 1, the electric field scattered by the pylon, at a distance of r from the cylinder axis, along the direction φ, is given by [4]:

$$\begin{aligned} E_s &= E_0\left[\frac{J_0(ka)}{H_0^{(2)}(ka)}H_0^{(2)}(kr)+\right. \\ &\left. 2\sum_{n=1}^{n=\infty}(-j)^n\frac{J_n(ka)}{H_n^{(2)}(ka)}H_n^{(2)}(kr)\cos(n\varphi)\right] \qquad (1) \end{aligned}$$

where a is the cylinder radius, $k = 2\pi/\lambda$ is the free space wave number, $J_n(x)$ the first kind Bessel function of order n and argument x and $H_n^2(x)$ is a Hankel function, of order n and argument x.

Total field E is obtained by adding the incident field $E_0 \exp(-jkr\cos\varphi)$ and the scattered field.

Figures 2 shows a density plot of the total field E around a vertical cylinder with $r = 1.5$ m at 1 GHz. Total dynamic range is this figure is from $+1.5$ to -3 dB.

Similar results (see Figure 3 were previously reported by some of us [1], where the pylon was modelled by a semi-infinite plane metallic strip equal to the semi-infinite cylinder cross-section. Results compare quite well for a receiver antenna at 38.5 m below the tip of the metallic strip.

III. Scattering by the rotor blades

Rotor blades are taken as perfect flat reflectors with rectangular shape. Direct and reflected ray amplitudes at the receiver are computed using existing propagation conditions (that is free space plus obstacle attenuation). The

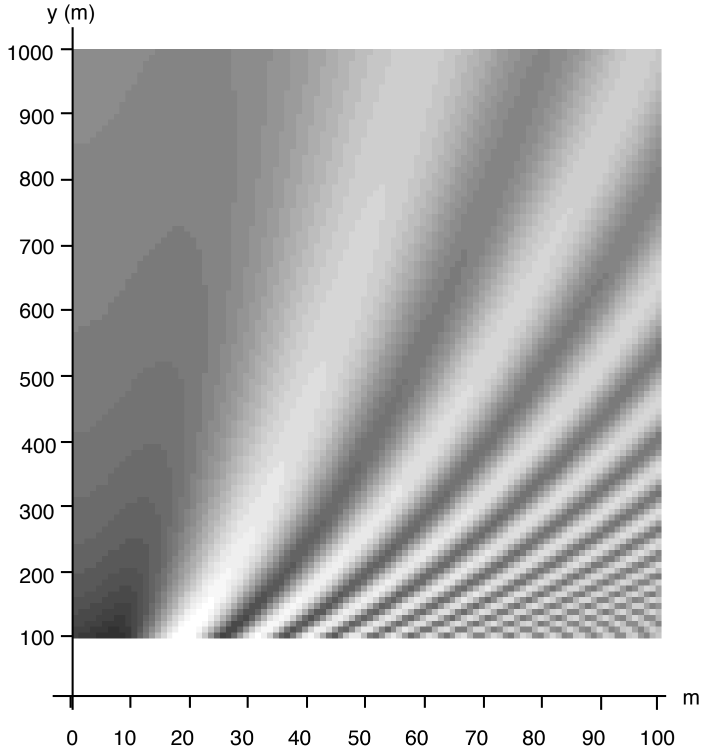

Fig. 2. Density plot of the total field E around a vertical infinite cylinder with $r = 1.5$ m at 100 MHz.

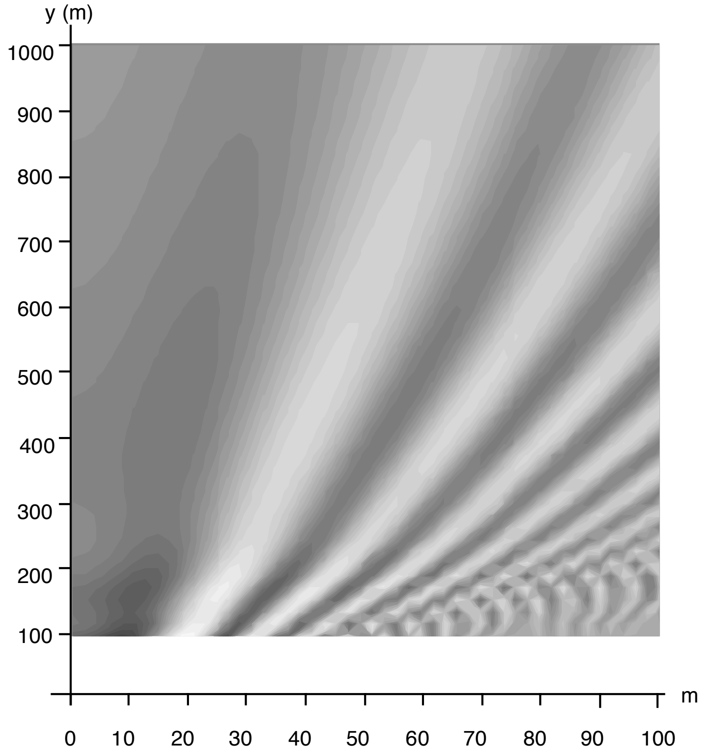

Fig. 3. Density plot of the total field E around a semi-infinite plane metallic strip equal to the semi-infinite cylinder cross-section, with $r = 1.5$ m, at 100 MHz.

delay is computed assuming free space propagation conditions.

We start by considering a single rotor blade, a transmitter and a receiver, both using isotropic antennas, all in line (Figure 4). The ground effect is neglected.

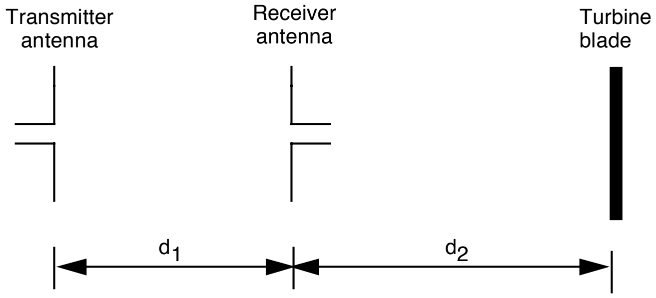

Fig. 4. Geometry for the scattered field by a rotor blade.

Under free-space propagation conditions, the ratio between direct and scattered powers at the receiver antenna is given by:

$$\frac{p_s}{p_d} = \frac{A^2}{\lambda^2}\frac{d_1^2}{d_2^2(d_1+d_2)^2}\frac{\sin(v\sin\alpha)}{v\sin\alpha} \tag{2}$$

where p_s is the power scattered by the blades in the direction of the receiver antenna, p_d is the direct path power at the receiver antenna, d_1 is the distance from the transmitter to the receiver, d_2 the distance from the transmitter to the turbine blade, A is the blade area, α is the angle between the wind turbine and the receiver antenna, $v = kw/2$ and w is the blade width. For wind turbines with more than one blade, the total blade area should be used.

A. A simple rule to compute a clearance distance

The ratio p_s/p_d, in dB, together with the time delay from the main criteria to define the disturbance caused by wind turbine in TV reception according to ITU-R Recommendation BT.805 [2]. The latter places a lower limit of -10 dB on the value of $\sin(x)/x$ function in equation (2).

For a subjective quality of TV reception rated as *good* (disturbances perceptible but not annoying) ITU-R Recommendation BT.805 [2] defines a maximum value of the ratio $\frac{p_s}{p_d}$ as a function of the delay which may be approximated as:

$$\frac{P_s}{P_d} = -28 - 6\left[1 - e^{-1.5(\frac{2d_2}{c}-1)}\right] \tag{3}$$

where $\frac{P_s}{P_d} = 10\log_{10}(\frac{p_s}{p_d})$ and c is the free space velocity of light expressed in m/μs when d_2, the distance between the transmitter and the wind turbine, is expressed in meters.

Combining equations (2) and (3) and solving the implicit resulting equation in relation to d_2 we can easily define a clearance distance $d_{2_{min}}$ between transmitter antenna and rotor blades as a function of angle α.

So far we have assumed free space propagation conditions between the transmitter and receiver antennas and the wind turbine. In practice however potentially worse conditions may exist, particularly when only the path between transmitter and receiver antennas is obstructed by an obstacle. This fact can be accounted for by increasing the required value of $\frac{P_s}{P_d}$ by the excess attenuation due to this obstacle A_{obs}. Figure 5 shows the clearance distance $d_{2_{min}}$, for a total blade area equal to 60 m^2 at 500 MHz, with excess obstacle attenuation values of 0, 10, 20 and 30 dB.

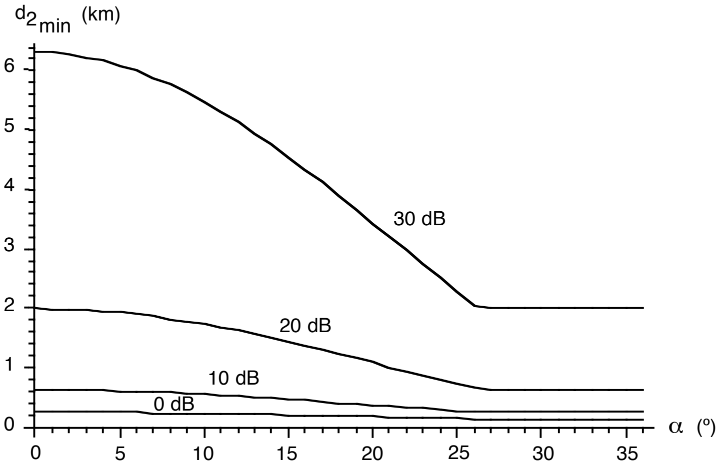

Fig. 5. Clearance distance for a wind turbine with a total blade area of 60 m^2 at 500 MHz, and excess obstacle attenuation A_{obs} values of 0, 10, 20 and 30 dB

In the case of a wind farm an empirical rule in [3] states that for a small number of turbines operating with their blades in parallel, the scattered fields add voltage wise while for larger wind farms a power addition is more appropriate. Under free space propagation conditions, in the worst case, a 10 wind turbine farm increases the value of $\frac{P_s}{P_d}$ by 20 dB just as an obstacle with the same attenuation

IV. Experimental results using a scaled model

An 1:250 scaled down model of a Enercom NTK 500/37 500 kW wind turbine was built in order to obtain experimental data on the scattering of an incident electromagnetic wave. The pylon was made of aluminium and two sets of blades were used: one in aluminium and another in acrylic glass. The measuring frequency was 62.5 GHz, which corresponds approximately to 250 MHz for the real turbine.

The choice of measuring frequency and model size was dictated by the available anechoic chamber and measurement equipment, mainly transmitter power and receiver sensitivity.

Figures 6 and 7 shows the wind turbine scale model placed on the chamber azimuth positioner and the measurement set-up, respectively.

The incident wave was produced by a 25 dBi shielded solid dielectric pyramidal horn placed at 1.615 m from the pylon axis. The scattered signal was picked up by a 25 dBi pyramidal metallic horn, placed side-by-side with the

Fig. 6. Wind turbine scaled model placed on the chamber azimuth positioner.

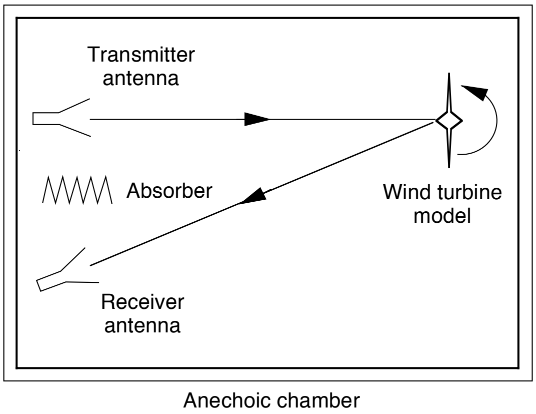

Fig. 7. Measurement set-up.

transmitter horn, at 1.622 m from the pylon axis. The 0.5 m direct path between the two horns was blocked by a microwave absorber panel.

The horns produce a reasonably uniform illumination of the scattering aperture, but the phase front is not quite planar (phase error < 2 radians) which, for a plane scatterer entails a reduction of up to 3 dB in the scattered signal level and broadens (about 19 %) the main lobe of its scattering diagram.

The transmitter power is rather low (17 dBm) and the chamber noise floor level was measured and found to be about -70 dBm. The measured peak scattered level was -45 dBm.

The turbine model was placed on the chamber azimuthal positioner and rotated while logging the received power. The scattered signal plotted as a function of the azimuthal angle of the model is shown in Figure 8.

The scatter diagram clearly shows a main lobe over an irregular floor. The level of the floor changes with the angular position of the blades while the peak scatter level remains constant. In the worst case the floor level is about 10 dB below the peak scatter level, the same value that is referred to in the ITU-R Recommendation BT.805 [2].

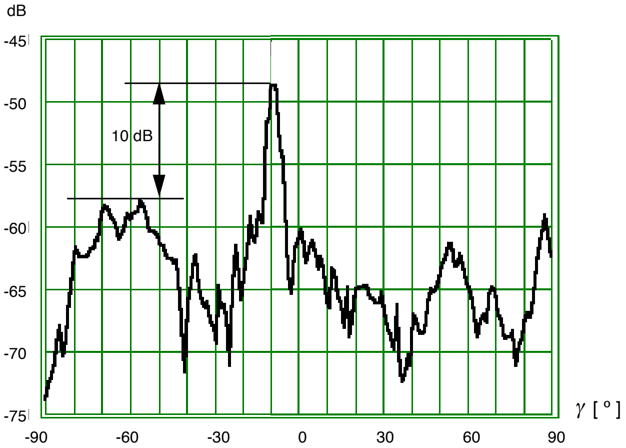

Fig. 8. Measured power scattered by the wind turbine model as a function of the azimuthal angle.

V. Conclusions

Wind turbine interfere with radio wave propagation in two ways. The pylon acts an obstacle, introducing an attenuation, that does not exceed 3 dB at 100 MHz, 100 m beyond the pylon. This attenuation increases with frequency and reaches 8.5 dB at 1 GHz, at the same distance. In turn, the blades act as a rather effective scatterer given their almost plane surface.

Among broadcast services, television is the most affected by wind turbines because the scattered field may arrive at the receiver with a time delay such that it causes an annoying disturbance. ITU-R Recommendation BT.805 [2] suggests a threshold for the scatter-to-direct field intensity as a function of the scatter delay to achieve a good subjective quality television reception. It also defines a simple model of the wind turbine as a scatterer. Scatter measurements with a scaled model of a wind turbine in an anechoic chamber are in good agreement with the recommendation.

Following the ITU-R Recommendation 805 [2] and assuming free space propagation it was possible to derive a clearance distance for an isolated wind turbine at 500 MHz. When the path between the transmitter and receiver antennas is obstructed the clearance distance increases significantly (from 0.25 km to 2 km for an obstacle attenuation of 20 dB). Interestingly the ITU Recommendation states that under free space propagation a single wind turbine is unlikely to impair reception at more than 0.5 km.

Greater clearance distances refer to combinations of obstacle attenuation and wind farms, particularly large ones. In any case we believe that clearances in excess of 5 to 6 km are not required at 500 MHz. This compares well with the statement in the ITU-R Recommendation where a 5 km clearance is suggested unless the path between the transmitter and receiver antennas is obstructed and the path between the wind turbines and the receiver antenna is not.

Finally we should note that an omnidirectional receiver antenna was assumed in all cases and that the clearance may be reduced when the receiver antenna provides discrimination between the direct ray (from the transmitter) and the reflected ray (from the wind turbine blades).

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