AN ENVIRONMENTAL EFFECT OF LARGE WIND TURBINES

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Anybody who watches television has observed instances when the picture flickers, followed (perhaps) by a picture 'flip' as vertical hold is lost. One cause of this is a reflection of the TV signal off the wings of an aircraft somewhere overhead in the region between the TV transmitter and receiver, creating for a moment a secondary transmission path. When the installation of large wind turbines (WTs) was proposed in the 1970s, it seemed possible that the blades could produce the same type of interference, with the added disadvantage that because a turbine is fixed in location, the phenomenon would no longer be transitory.

Studies carried out in 1976 and subsequently confirmed the fact that interference does occur. To some extent all electromagnetic systems are affected, and by analysis, simulation and, where practicable, experiments, the effects on a variety of systems have been quantified. Such work has made it possible to assess the impact of a proposed WT site on the electromagnetic environment. Of all systems, however, TV is of most concern, and we shall discuss this in some detail.

Figure 1 illustrates the situation. The signal from a distant TV transmitter reaches the receiver R directly but also impinges on a blade B of the WT. The blade is typically metallic and reflects the signal in an almost mirror-like fashion so that with the blade positioned as shown, the reflected signal will also reach the receiver to produce a secondary received signal. If the blade were stationary, the result would be a 'ghost' picture whose constant physical separation from the picture provided by the direct signal is determined by the difference in path lengths of the two signals. The strength of the ghost is proportional to (i) the strength of the signal that impinges on the blade, (ii) the equivalent scattering (or 'mirror') area A of the blade (this is typically about 65 percent of the physical area projected on a plane), and (iii) the frequency of the transmission; and decreases with increasing distance r of the receiver from the WT. If the blade is now allowed to rotate, the received secondary signal and, hence, the ghost, turns on and off in synchronism with the blade rotation, to produce a horizontal jitter or pulsation of the video reproduction. With a machine having coned blades, each blade contributes separately, and the interference occurs at twice the blade rotation frequency.

This type of flickering can be quite objectionable. It is obviously worse the stronger the ghost is relative to the undistorted picture, and the greater the physical separation of the two. In this connection we observe (Fig. 1) that for a given value of r, the separation is largest when the receiver is in line and between the transmitter and WT, and zero when it is in line and beyond the WT.

From simulation experiments using different strengths and time delays of the secondary (scattered) signal E^S relative to the primary (direct) signal E at the receiver, a criterion has been established for interference which is so severe as to be unacceptable for extended periods of viewing. Although obviously subjective, the criterion has been found adequate for practical purposes, and has been set at m_c = 15 percent for $\phi = 0$ (see Fig. 1), increasing to 45 percent for ϕ = 180 degrees. In other words, if $m = E^S/E > m_c$ the interference is too strong to be acceptable, and this defines a region of possibly unacceptable interference about the WT.

For a given TV transmission and given WT, the interference zone can be computed by taking into account the propagation conditions. If local terrain effects are ignored, the zone is typically a cardioid with a forward 'spike' directed away from the transmitter. The spike often represents the largest distance out from the WT where the interference can remain objectionable, and in the case of the MOD-1 WT at Boone, NC, such interference has been measured out to 5 km from the WT.

The larger the WT, the larger the blade size (and, hence, A), and the larger the interference zone. For the 200 kW MOD-OA machines with blades 38 m tip-to-tip installed at Clayton (NM), Culebra (PR), Block Island (RI) and, most recently, Oahu (HI), A = 12 m^2, whereas for the 2 MW MOD-1 machine (blades 61 m tip-to-tip) at Boone (NC), A = 40 m^2. For the newest 2.5 MW MOD-2 machine having a single tip-controlled blade 91 m in length, A = 140 m^2. If the blades are made of composite material or wood, the effective A required for the calculations can be as much as a factor 2.5 smaller depending on the amount of metal remaining. An increase in size of a machine also increases its height above the ground, and this will in general expose the blade to a stronger ambient field. In practice, the height differential between the blade and the receiving antenna has a major effect on the size of the interference zone. In addition, the zone increases with frequency (or TV Channel number), and all other things being equal, the interference is worst on the upper UHF Channels.

An interference zone is merely a region where unacceptable interference could occur with a poor quality (omnidirectional) receiving antenna, and there are many factors that affect the actual interference observed. In the first place, the maximum scattered signal is received only when the blade is so positioned to direct this signal to the receiver. As the wind veers and the machine rotates in azimuth, the interfering signal will shift to a different sector of the zone. Thus, at any given instant, only a small portion of the zone will suffer interference, and the probability of interference at any particular location in the zone depends on the prevailing wind direction. Moreover, since the zones differ from one TV Channel to another, it is unlikely that any one location will simultaneously experience interference on two different Channels. The antenna used can also be important. In the cardioid (but not the forward scattering) portion of the interference zone, a high performance directional antenna can be deployed to discriminate against a secondary signal from the WT. Lastly, there are the local site and terrain effects. A hill, building, or even trees that shield the antenna from the WT can markedly reduce the interference, but if these attenuate the primary signal instead, the interference will be increased.

The reason why the video but not the audio part of a TV reproduction is affected by this type of interference can be seen by considering the nature of a TV signal. The video information is transmitted by an amplitude modulated signal, whereas the audio portion is frequency modulated. Because of the blade rotation, the WT introduces extraneous time-varying amplitude modulation to the signal which enters the TV receiver, and the spectrum of this modulation function extends out to 100 Hz or more. The majority of this is passed by the detection and filtering stages of a TV receiver (indeed, the line hold is a 30 Hz signal and must be passed), and can then perturb the video reproduction. The effects do not appear to depend on the particular receiver used, and in no instance have we found any significant interference to the audio portion of TV, or to an FM broadcast transmission. With AM radio, any interference is swamped by the other noise that is almost always present.

A small WT of a few kW capacity such as an individual homeowner might have produces the same type of interference, with the zones extending out at most a few tens of feet. We have also observed interference from large vertical axis machines such as the Darrieus and Gyromill, but present indications are that the interference is less than from a horizontal axis machine of the same power rating.

The effect of a large WT on other electromagnetic systems has been investigated. The VOR (Very high frequency Omni Range) and DVOR (Doppler VOR) aircraft navigational radars are relatively insensitive to the interference, and the blade rotation actually reduces the effect of the scattering below that of a comparable stationary structure. For this reason, the criterion which the Federal Aviation Administration has established for the siting of a stationary structure in the vicinity of an antenna is adequate for a WT. Loran-C (Long Range Navigation-C) is also immune, the wavelength being large compared with the dimensions of even thelargest WT, but a point-to-point microwave link could be affected by the presence of a WT close to the transmission path or to one of the terminal antennas. By an analysis similar to that used for TV interference, a zone can be defined enclosing the antennas and the line-of-sight path where the placement of a WT would be unacceptable. The precise shape depends on the frequency, modulation and antennas used for the link, and the dimensions of the zone are determined by the smallest signal-to-noise ratio, e.g., 60 or 40 dB, that can be tolerated by the system.

Although more work remains to be done with these (and other) systems, and is being carried on with support from the Department of Energy and the Solar Energy Research Institute, our knowledge of the interference that a WT produces is now sufficient to provide guidance in the siting of a machine to minimize its impact on the electromagnetic environment.

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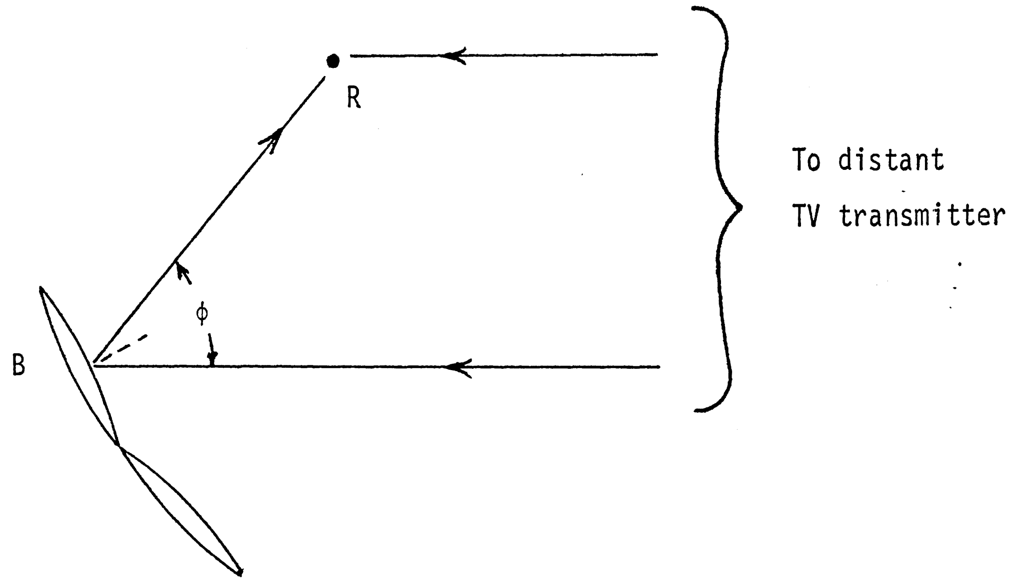
R
B
ϕ
To distant
TV transmitter

Legend for Figure

Figure 1: A TV signal reaches a receiver directly and by reflection off a WT blade, suitably oriented.