Wind Farms and Microwave Links

Harvey Lehpamer, Ph.D., P.Eng, POWER Engineers, Inc.

Abstract – *New wind farm deployments in North America and the rest of the world require engineers and project managers to pay close attention to the existing communications systems in the area. This brief paper focuses on one specific type of wireless communications – terrestrial microwave point-to-point systems.*

Index Terms *– Wind Farms, Microwave Links, Fresnel Zone, Interference*

I. Introduction

Wind turbines convert the kinetic energy from wind into mechanical energy, which is then used to generate electricity. Although wind is considered an important potential source of alternative energy, and wind turbines have been erected in many locations around the world, there are a large number of technical considerations in siting wind developments.

Wind turbines in large numbers are called *wind farms* and can potentially impact nearby radio communications systems, including broadcasting stations, weather radars, airport radars, satellite communications, and terrestrial microwave point-to-point systems.

Any time engineers are designing a new wind farm, they should investigate the existence and proximity of microwave links. In this brief paper we will discuss some of the concerns engineers must address during the wind farm planning process to ensure peaceful coexistence of microwave links and wind turbines.

The same conclusions are also applicable to projects that might involve construction of a new microwave link near existing or planned wind farms.

II. Microwave Radio Propagation and the Fresnel Zone

The concept of the Fresnel zone is an important part of any terrestrial microwave point-to-point link design. The most common use of Fresnel zone information on a profile plot is to check for obstructions that penetrate the zone and to calculate possible diffraction.

Engineers perform microwave link engineering, including Fresnel clearances and path profiles, based on the assumption that microwave antennas are in the far-field region—i.e., that the distance between them is sufficiently large.

A. Near and Far Field

The terms far field and near field describe the fields around an antenna, or more generally, around any electromagnetic-radiation source. Any large object (reflective or not), including a wind turbine, in the near field of the antenna may distort the radiation pattern of the antenna and, therefore, should be avoided.

The question is, where is the end of the near field, and where does the far field begin? There is no simple answer to this question, but the following explanation is widely accepted in microwave system design.

The names imply the existence of two regions with a boundary between them. In fact, as many as three regions and two boundaries exist (Figure 1), and it is important to note that these boundaries are slightly overlapping and not fixed in space.

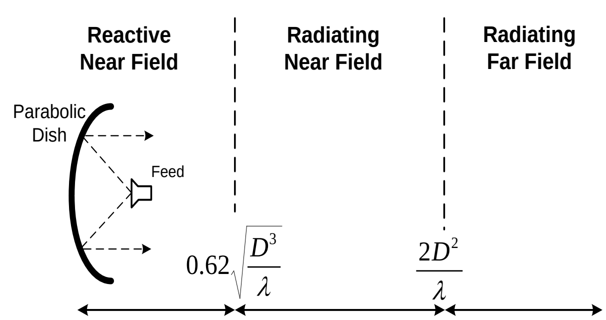

Figure 1 Radiation fields of an antenna

Here, D is the diameter of the parabolic dish antenna and λ is the wavelength of the signal.

Usually, two- and three-region models are used. In the near field, the field strength does not necessarily decrease steadily with distance away from the antenna, but it may exhibit an oscillatory character, and therefore it is difficult to predict the antenna gain and radiation pattern in that region [1].

B. Concept of the Fresnel Zone

Fresnel zones are specified by an ordinal number, n, that corresponds to the number of half-wavelength multiples that represent the difference in the radio wave propagation path from the direct path.

The first Fresnel zone is therefore an ellipsoid (Figure 2) whose surface corresponds to one half-wavelength path difference and represents the smallest volume of all the other Fresnel zones.

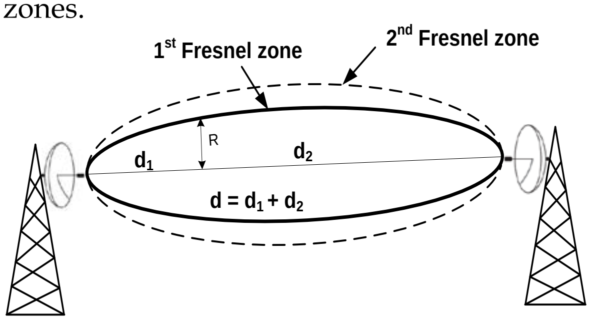

Figure 2 Fresnel zones

In microwave engineering, the radius of the first Fresnel zone is the parameter used to establish appropriate clearance of the link from different types of obstacles. The general formula to calculate the radius of the n^{th} Fresnel zone is approximated by:

$$R_n = \sqrt{n\lambda \frac{d_1 d_2}{d_1 + d_2}} \qquad (1)$$

Here, it is assumed that:

$$R_n << d_1 \text{ and } R_n << d_2$$

In this formula λ is the wavelength, R is the radius of the Fresnel zone, d_1 and d_2 are distances from the antennas to the point of interest, and d is the microwave link length. Diffraction theory indicates that the direct path between the transmitter and the receiver needs a clearance of at least 60 percent of the radius of the first Fresnel zone to achieve free-space propagation conditions.

If the geometry of the path is such that an even-numbered Fresnel zone happens to be tangential to a good reflecting surface (e.g., a lake, highway, or smooth desert area, or wind turbines in this case), signal cancellation will occur as a result of interference between the direct and indirect (reflected) signal paths.

The refractive properties of the atmosphere are not constant and the variations of the index of refraction in the atmosphere (expressed by the Earth-radius factor k) may force terrain irregularities to totally or partially intercept the Fresnel zone.

III. Basics of Wind Turbine Construction

To make wind turbines as efficient as possible, they are typically designed to be very large structures. If the design includes three long blades mounted on top, this is known as a *horizontal axis wind turbine* (HAWT) [2]. Towers and blades having total of 450 feet high are very common these days. Some wind turbines are so large they have built-in elevators used for transportation of people and equipment up and down the tower.

Wind turbines are typically sited on high points in the landscape to take advantage of higher wind speeds and lower turbulence.

Figure 3 depicts a typical wind turbine construction.

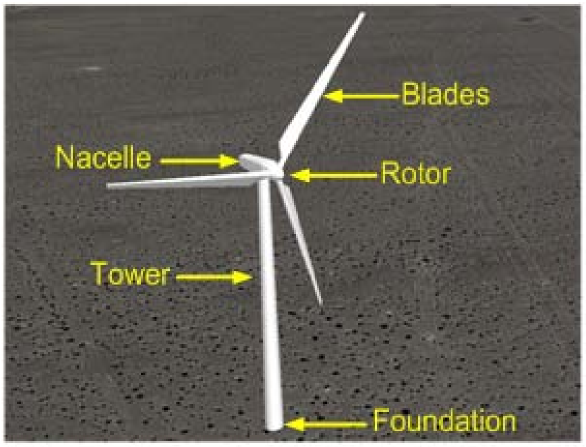

Figure 3 Wind turbine construction

Tower - In most cases, the wind turbine comes with a tubular steel tower. The tower is 200-300 feet tall and 10-15 feet wide at the base. The tower can be climbed from the inside and consists of a several steel tube sections connected with each other by means of bolted flanges. The tower is connected to the foundation by anchor bolts, which are set into concrete at the foundation. The power cables between wind turbine and grid are routed through conduits set into the foundation.

Nacelle - The nacelle is an enclosure that consists of a cast main frame with a bolted-on girder system and a nacelle cover. It contains the equipment that converts the wind power captured by the rotor blades to electric power. The entire nacelle and rotor assembly turns as needed to face the wind. The nacelle cover is made of fiberglass-reinforced plastic and designed in such a way that the internal components are fully protected against various ambient conditions [3].

Rotor - The rotor typically consists of a high strength cast iron hub supporting three rotor blades. These blades are connected to the hub via roller bearings, and they can be turned with the pitch system. The rotor is directly connected to the main shaft and transmits the rotation of the rotor via the drive train to the generator.

Blades - The rotor blades are made of high grade fiberglass-reinforced plastic, making them lightweight but at the same time providing a high degree of stiffness and mechanical strength.

Even so-called non-metallic rotor blades are slightly magnetic; they contain a small amount of copper wires for lighting protection as well as small metallic blocks whose function is to dampen the potential vibrations of the blade. Lightning is guided from the receptors to the hub and thus to the rotor shaft, and from there to the grounded main frame with the help of spark gaps. A small number of metallic strips along the non-metallic blade can cause the blade to behave almost as a completely metallic blade [4].

Foundation - The foundation construction for the tower is site-specific, depending on the ground conditions, load requirements, and the local codes and regulations.

IV. Microwave Links in the Proximity of Wind Turbines

Three different radio propagation mechanisms could potentially cause degradation of an RF communications system, i.e., *near field*, *diffraction*, and *reflection/scattering*. Perhaps the most troublesome situation is if the wind turbine is blocking or impinging the first Fresnel zone. Diffraction (obstruction) or reflection of radio waves by a wind turbine can degrade the performance of a point-to-point microwave link due to the effect of large blades rotating at approximately 32 rpm. Thus, any significant interfering signal, such as a delayed multipath component, will fluctuate in signal level around 1.0 to 1.5 Hz [5].

Based on measurements, a single turbine can cause fades of 2-3 dB on microwave links with frequencies up to 18 GHz. A wind farm with only 17 turbines can produce up to 20 dB of fading if it is inside the Fresnel zone. Considering that the microwave link fade margin is typically 30-35 dB, this could be a very significant loss of signal [6].

Signal reflection from the physical structure of a turbine propagating into the microwave receiver can potentially result in the receiver's threshold degradation, causing a critical increase in the C/I (the carrier-to-interference ratio, usually expressed in decibels, depends on the modulation and coding schemes) requirement for the link.

Care should be taken to prevent multiple reflections from the individual turbines of a wind farm. A long string of wind turbines running in parallel with the microwave link could be especially detrimental.

V. Microwave Link Exclusion Zone

There has been very little research conducted on wind turbine effects on microwave point-to-point systems, even while this topic has become increasingly interesting and important with more and more wind farms being constructed.

For any planned wind farm, a detailed desktop study of licensed microwave links should be performed (Figure 4.) However, even a detailed study may not identify license-exempt microwave links; one must hope that the owners will hear about the project and come forward with their concerns.

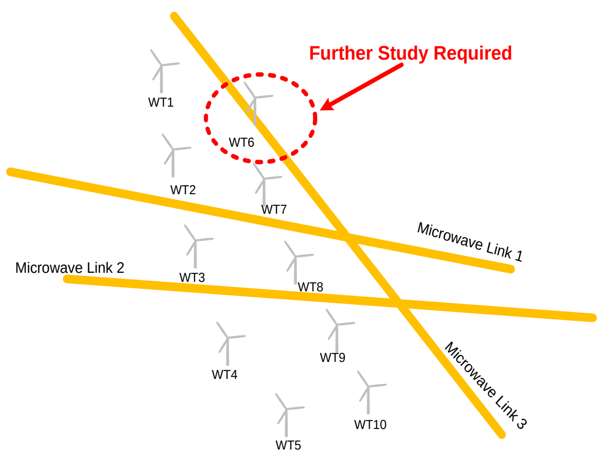

Figure 4 Planned wind farm and existing microwave links

Is it possible to know if there are any microwave links in the vicinity just by looking around? Unfortunately, it is not - many microwave links are 20-60 miles long, so it is unlikely that any towers and antennas would be visible from any planned wind farm site location.

A. How Close is Too Close?

How far from the microwave link must the wind turbine be, and what is the minimal distance for peaceful coexistence of wind turbines and microwave systems?

Local or state regulations establish minimum setbacks of wind turbines from roads, houses and other buildings. The Federal Aviation Administration (FAA) currently treats wind turbines the same as any other physical obstructions. There are currently no official Federal Communications Commission (FCC) standards or even objectives regarding microwave links, and most FAA rules only apply to physical dimensions and lighting.

Exclusion zones shown below (Figure 5) are depicted by dashed lines around the microwave link as well as microwave radio sites. Exclusion zones represent areas that should be free of wind turbines; they are based on semi-empirical recommendations, best practices, and rules of thumb.

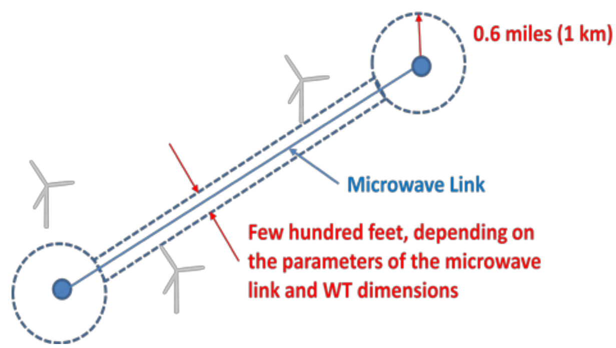

Figure 5 Exclusion zones

It is important to remember that the horizontal axis of blade rotation varies in azimuth according to the wind direction; wind turbines are not static obstacles, like trees or buildings. Although 60 percent clearance of the first Fresnel zone is usually sufficient to guarantee undisturbed performance of a microwave link, in the case of wind turbines, the recommendation is to keep the first Fresnel zone 100 percent clear.

In addition, even a clear first Fresnel zone may not be sufficient; a more stringent requirement of also keeping the second Fresnel zone clear should be implemented.

B. Modeling Impact of Wind Turbines

All the mechanisms for potential dangers to radio communications facilities caused by wind turbines have still not been sufficiently investigated. Wind turbine impact on radio propagation is not easy to understand and not trivial to model and describe mathematically.

Most models are unreliable and out-of-date (developed over 20 years ago for smaller, all-metallic wind turbines). Although this is an interesting and important topic, there is very little ongoing research in U.S. at the present time.

C. Objectives and Recommendations

While wind turbines do not transmit or radiate other than background audio noise, the physical characteristics of wind turbines and their operation are known to have effects on the performance of communication systems.

For microwave links, in most cases it is sufficient to ensure that the blades of the wind turbine are outside of the second Fresnel zone, as shown in Figure 6.

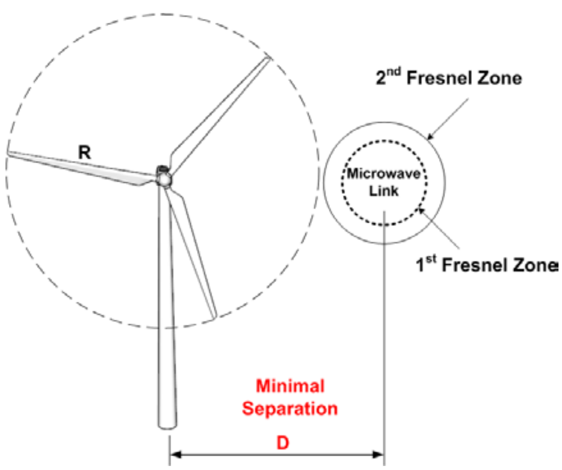

Figure 6 Minimal separation objectives

Since Fresnel zone radius depends on the location along the microwave link length, it is important to calculate the radius of the second Fresnel zone.

In formula (2), d is the microwave link length in kilometers, d_1 is the distance from one end of the microwave link to the wind turbine location (see Figure 1), f is the frequency in gigahertz, R is the length of the blade in meters, and D is the minimal required distance between the wind turbine and the microwave link, based on the second Fresnel zone radius and expressed in meters.

$$D \geq R + 24.4\sqrt{\frac{d_1(d-d_1)}{d \cdot f}} \qquad (2)$$

Another commonly used formula (3) does not utilize the second Fresnel zone; it is based on a width of three times the worst case of the first Fresnel zone radius [7].

$$D \geq R + 26\sqrt{\frac{d}{f}} \qquad (3)$$

Here, d is the microwave link length in kilometers, f is the frequency in gigahertz, R is the length of the blade in meters, and D is the minimal required distance between the wind turbine and the microwave link, expressed in meters.

Formula (3) is the more conservative formula of the two presented here. It will give slightly more conservative results than formula (2) towards the middle of the microwave link, but it will be a lot more conservative when the wind turbine is close to the end of the microwave link. This means that the exclusion zone based on formula (3) will always be wider than the exclusion zone calculated using formula (2).

Table 1 shows an example of calculations for a 50-kilometer link at 6 GHz, and a wind turbine with 50-meter blades. Five cases were analyzed for the microwave link – close to one end, at the middle, and close to the other end. As expected, formula (3) does not depend on the wind turbine location along the microwave link; therefore, it is more conservative, requiring bigger separation between the wind turbine and the microwave link.

Table 1 Formula Comparison

d [km] f [GHz] R [m]	50 6 50	D [m] $D \geq R + 24.4\sqrt{\frac{d_1(d-d_1)}{d \cdot f}}$	D [m] $D \geq R + 26\sqrt{\frac{d}{f}}$
d1 [km]	1	59.9	125.1
d1 [km]	5	71.1	125.1
d1 [km]	25	85.2	125.1
d1 [km]	45	71.1	125.1
d1 [km]	49	59.9	125.1

VI. Conclusions and Future Directions

The process of designing a microwave link in the vicinity of wind turbines follows the usual good practices of microwave engineering – avoid obstacles in the near field of the antennas, keep the first (and second in this case) Fresnel zone clear of obstacles, and pay special attention to reflections when running a microwave link in parallel to a long string of wind turbines.

There are very few documented cases of field-verified wind turbine interference with microwave links. A lot more research is needed but in the meantime, we should try to anticipate and prevent potential problems before they happen.

The cost of a detailed study is much lower than the cost of mitigating a previously undiscovered problem, which can be one, or even two, orders of magnitude more. Careful work during the planning stages of a project may help to identify and address these factors, thus mitigating future radio interference concerns.

Using appropriate software tools, detailed study of proposed wind turbine exclusion zones and potential effects on existing radio communications facilities should be undertaken every time a new wind farm is planned.

VII. About the Author

Harvey Lehpamer, Ph.D., P.Eng, is a licensed Professional Engineer of the Province of Ontario, Canada. He is presently working as a Senior Project Engineer at POWER Engineers, Inc., San Diego, California. He can be reached at Harvey.Lehpamer@powereng.com.

He has published author a number of technical articles and books, including: *"Transmission Systems Design Handbook for Wireless Networks,"* Artech House, 2002; *"Microwave Transmission Networks - Planning, Design and Deployment,"* McGraw-Hill, 2004, and a second edition in 2010; and *"RFID Design Principles"* Artech House, 2008, and a second edition in 2012.

Dr. Lehpamer is also teaching a course, "Microwave Transmission Engineering," at University of California - Extension, in San Diego.

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