

Obstacle Markings on Wind Turbines for Safe Aviation and Marine Navigation

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August 2004, meb@foi.se

1. Introduction

Wind turbines need obstacle warning aids to help the crew of airplanes, helicopters and ships to avoid collisions with the turbines. So far, the organizations performing the logistics of applying for building permits, site preparation and erection of wind turbines have generally handled each such activity as an isolated event. Thus, obstacle warning lights or markings have been applied as seen fit for the particular wind turbine or group of turbines. Although similar principles have emerged, there exists a recognition of a need for a general set of rules in this respect. The rules should preferably be international – at least valid within the European Union.

Accidents of airplanes colliding with wind turbines have not happened at all as far as this author is informed. It must be assumed that the natural visual signature and today's markings are adequate, although not uniform across the globe. Thus no response to any accident record forms part of the background for this document. The need for the present investigation rather emanates from a concern in the industry that investments made in obstacle marking may have to be protected. The number of wind turbines in the world, estimated to be of the order of magnitude 25 000, is increasing exponentially, with an annual growth of about 30% in terms of installed megawatts (MW), approaching 50 000 MW presently. This is power delivery equivalent to about 17 modern nuclear power blocks with 75% availability. Despite this fact there is still a lack of firm rules for the design and application of obstacle lights. The costs for lighting are thus becoming an issue of increasing importance. If new regulation will enforce a comprehensive and therefore expensive retrofit program, that regulation better be known as soon as possible. It seems strategically advantageous for the industry to pave the ground proactively for such regulation.

A Swedish trade organization recently took the initiative to organize the present thinking into a coherent text. The result is the present document, which is produced within a small project in an organization whose expressed work approach is to be free from business oriented influence from industry and other organizations. An existing Swedish reference group consists, however, of representatives from wind turbine manufacturers, representatives from trade and the Swedish government agencies for energy, civil aviation and marine administration. The viewpoints from the participants of the group have been merged by this author. Two meetings with the reference group have been held. This has caused two rewritings of the present text.

Thoughts and viewpoints presented in this text are to be thought of as an input to discussions about rules and regulation in Sweden as well as in an international context. The contents can be thought of as consisting of two groups of messages, i.e. partly possibilities and partly recommendations.

2.The Basic Need

Over land the reason for markings is to guide only aviators to avoid collisions with the turbine. The visual information from any high object should be as clear and unambiguous as possible. It must be possible to interpret the lighting information as “wind turbine” as opposed to all other static high objects.

At sea the visual markings must serve the need of both mariners and aviators. From the discussion in the reference group it was concluded that there seems to be no particular reason why any new markings on wind turbines should be devised for marine traffic. Thus, the present warning system in the form of lighting for marine traffic should be retained or possibly modified in accordance with the IALA text, see Ref. 1. The aviation markings at sea should be identical to those on land

It is emphasized that ambiguous information from lights for aviation and those for ships must be avoided. Thus a marine light signal code must not mean a different thing to an aviator. It may be helpful to screen off regions to limit the lobes inside of which the lights will be visible. At a reasonably close range such screening would result in the aviation marking being seen by aviators only and the marine markings will be seen by mariners only. At a large distance both marking systems may be seen by both categories.

Although a proposed separation of light information, as proposed, is recommended the consequence for low flying operation is that the pilot must be able also to correctly interpret the sea marking. This has relevance for several civil flight services, including the need to fly at low heights, as well as for some military air operations. It is, however, strictly not necessary that the mariner is able to interpret the aviation signals for obvious reasons – airplanes may fly at low altitude but ships never fly at high altitude.

3. Present Application of Safety Markings

Sweden

Swedish marking of the wind turbines consists of lights on top of the nacelle. This light is generally red and steady. The two early large machines at Maglarp (3MW) and still at Näsudden (2MW) had/has yellow light, which today can be seen as historical exceptions. Obstacles of 150m of height and higher have a certain status as far as marking requirements go. But, no distinction between turbines under 150m of total height and those over has been an issue yet since all operating turbines so far are below 150m. No particular paint scheme, for daytime attention elevation is required. It has been considered satisfactory without them. This is based on the tacit assumption that what is visible at night is certainly visible during the day, provided the lights are turned on around the clock.

Germany

In Germany a distinction between day and night is made. At daytime the markings of warning are painted patterns. Basically two orange stripes on white bottom is required at the blade tips. If, however, the turbine is located more than 5km away from an airport (size of airport is not specified) it may be provided by one orange stripe at the tip only, see Fig. 1. What happens when a new airport is to be built is not mentioned. It would logically mean that all wind turbines within 5km, having one stripe only, must have their blades repainted. The text seems to invite unnecessary complication to be avoided in future texts.

For nighttime warning purposes a steady red light on a turbine may be placed on the nacelle roof if *basically* the additional blade tip maximum height does not exceed 50m. The light may be turned on also during daylight. It is noteworthy that the German text has inserted the word basically (grundsätzlich) in the text, which will allow excesses of 50m perhaps with a special permit when required.

The exact design of these markings is defined in Ref 2.

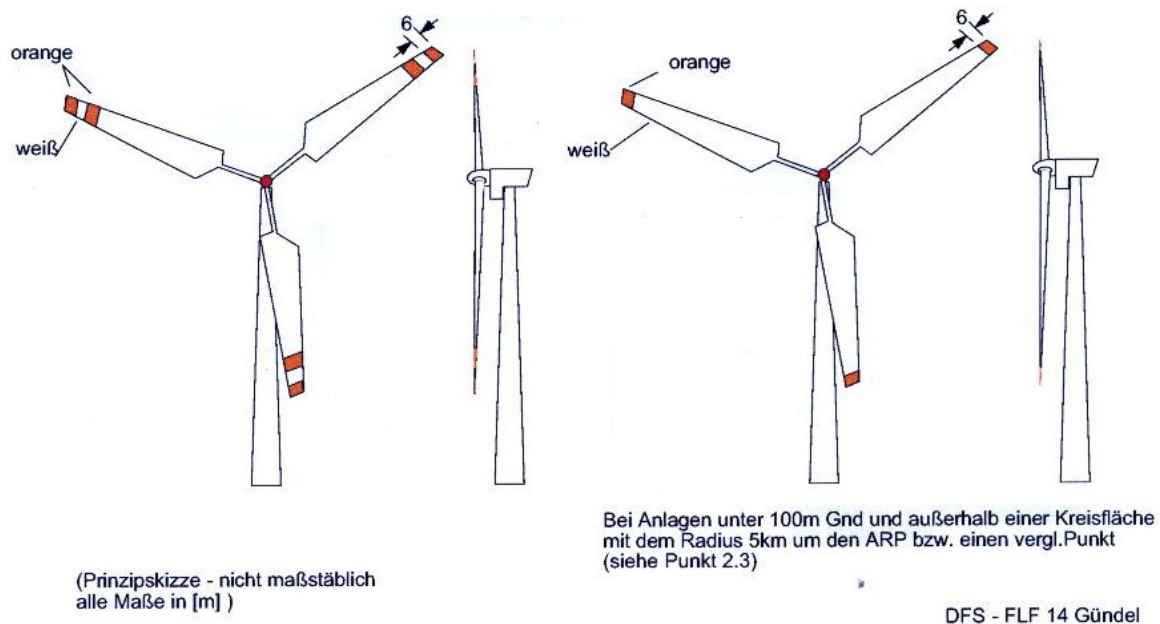


Figure 1 – Copy from Ref. 2

Denmark

In Denmark the present marking consists of two red and flashing lights on top of the nacelle. This is accepted for obstacles of heights up to 150m. If the blade tip in top position is lower than 100m no particular markings are required. The blades so far have not been required to be marked at all. But, in ongoing discussions requests have been voiced in favor of a paint scheme similar or equal to that of the German pattern. The Danish rules for markings on wind turbines are still a bit fluid (as in Sweden). Active discussions on the topic are presently taking place in Denmark as well.

4. Implementation of Future Wind-Turbine/Obstacle Warning Lighting

Several possibilities for markings exist. Some of these are discussed below. The basic view must include the fact that the highest point on a horizontal axis wind turbine is a mobile blade tip. For some, very unusual, vertical axis machines there may or may not be a highest point on the structure, which is not mobile. In the case of a fixed highest point it is simply proposed that the turbine be marked as a fixed tower, see b in the figure below. All arguments discussed below should therefore apply equally to turbines of horizontal axis and vertical axis with mobile highest points on the structure (a and c, see figure 2).

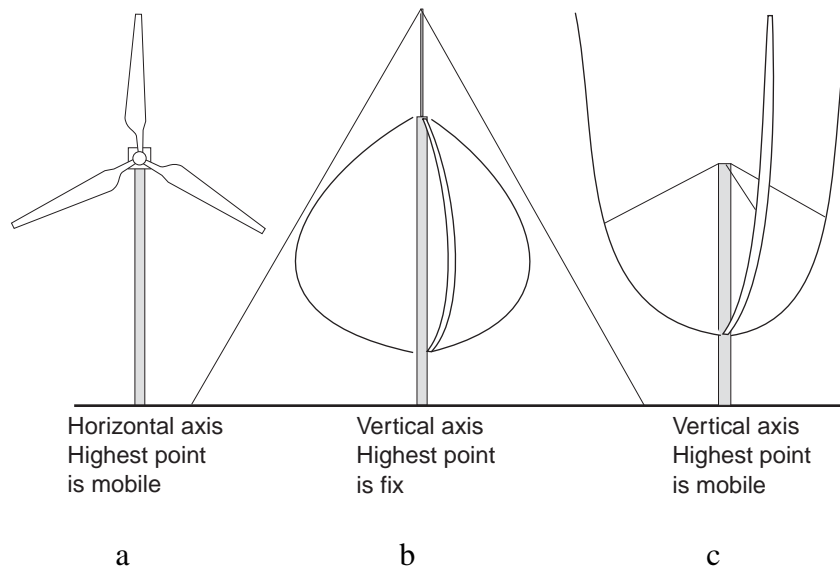


Figure 2 – Different types of wind turbines

4.1 Illumination at the Highest Point

It is possible to provide the blade tips with lights. One example of available lights comes from ENERTRAG, see Ref 3. The function for a three-bladed rotor, as proposed by the Enertrag company, is to turn on the horizontal axis light 60° before zenith and turn it off 120° later, while the lower blades are unlit. As soon as the upper blade has reached its 60° past zenith the light of the next blade repeats the on/off cycle etc. For a two-bladed rotor a similar on/off schedule can easily be imagined. How this scheme would apply to the type c vertical axis machine is not equally obvious.

Enertrag also provides variable light intensity depending on the intensity of the natural light. Typically the light intensity at night is one tenth of that of daylight.

The system would provide the aviator with maximum perception awareness while people on the ground, especially those unrelated to the turbine operation, would experience the mobile light as that coming from an amusement park with solid complaints as a consequence. Shielding this type of light from view is not possible.

It can be reasoned that turbines already in operation would be free from the obligation to carry blade tip lights, while new blades would be stipulated to have them. But, the weakness in such a proposal lies in the dual behavior of turbines, because, old blades may live for a number of decades. As a consequence the dualism in the light signals would linger on for quite some time. Moreover, the installation of tip lights require a relatively costly extra activity for inserting electrical wiring in the blade material during manufacturing and furthermore to shield these lines from lightning. When a failure occurs, perhaps because of a strike of lightning, the rotor would not rotate after the emergency stop procedure is finished. Thus, the blade that happens to be near vertical and up would probably be the one carrying the faulty light (Murphy's law) such that the turbine would produce no light at all for the long time it takes to replace/mend the faulty blade. This must be compared with a light on top of the nacelle where repair can mostly be carried out promptly. The equipment has not been widely tested, which in itself would contribute to a certain reluctance to apply the technique.

It seems that tip lighting has many features detrimental to regular safe and inexpensive operation of wind turbines but it has only one advantage, although a strong one.

This discussion does not rule out the Enertrag system. It may find its place in certain specialized locations where its light signals certainly would be well understood by any aviator. Such locations could be in the proximity of airfields.

4.2 Lighting at the Nacelle Top

a. Specifying the Need

Placing the warning light on the roof of the nacelle raises the question about sufficient pilot awareness. Since, during the dark hours, the pilot will not see the highest point on the turbine he must be able to ascertain that what he sees are the markings of a *wind turbine*. This information should be enough to estimate a safe flying height above the topmost blade position. Thus, it is critical that the pilot understands that the obstacle is truly a wind turbine. This insight can only be had if the light on the top of the nacelle signals this fact with distinction in relation to other ambient lights.

b. Lights must be visible from all directions of the compass

A fixed light at the top of the nacelle is easy to operate and repair. When a problem is identified with such a light an additional advantage might be that it probably has a “twin light” which still works. This gives continuous lighting while one is faulty. The reason for the possible need of two (almost) identical lights is that when there is no rotation, for whatever reason, the vertical up blade may obscure a singular light. The cure might be an adjacent “twin light”. At least one of the two will then be visible from all directions of the compass (provided both are active).

Other schemes may be devised such as one light behind the nacelle and another at the hub (spinning with the rotor), although shielding downward will be practically impossible at the rotating light. But, any design that permits the light to be visible from all directions at all times should in principle be permissible.

c. Steady or Blinking Light

In order to be able to discriminate a wind turbine light from a fixed object light, two classes of lights can be discussed. Either a special blinking pattern or a steady light could be used. As indicated previously, blinking lights should be avoided for reasons of public tranquility, although they are superior for attracting the aviator’s attention.

A steady light, which allows the knowledgeable observer to discriminate the turbine from any fixed obstacle, will also serve the need for safety. Blinking will, however, occur under all circumstances at every blade passage if the rotor is between the light and the observer. This is unavoidable. A few more aspects on blinking light, in relation to public annoyance, are presented under subsection *g* below.

d. Distinguishing Turbine Light from Other Lights

In order not to confuse the turbine light with all other visible light sources a two-color light seems to be an answer to this need. The following idea is offered.

The combination of red and yellow, both steady, should not have been reserved for any other purpose. Advantages are that yellow allows maximum penetration during hazy conditions and red provides maximum reception by the human eye during dusk and darkness.

Should dual and steady lighting be considered unacceptable for reasons of not attracting attention and/or technical complexity of four lights, only one yellow light could be used. If, after discussions, the light is required to flash, the IALA rules, for marine navigation, could be copied. IALA proposes that yellow flashing lights could be used for groups of sea based wind turbines. The flashing is furthermore suggested to signal a special “IALA mark”, Morse code fashion. A question of the IALA implementation of the yellow light presents itself because that text proposes white light flashing the Morse code for “U” for singular turbines at sea while, for groups of turbines the yellow flashing light is to be used. It is not immediately clear to the novice reader why a distinction of light signals would be necessary, since one turbine would have one light and a group of turbines would have several. It should be easy to distinguish one from several, thus clarifying to the observer if he is approaching a single turbine or a group of turbines.

To have identically equal signal systems for sea and air would promote safety. But, the air safety signals would have to be equal on land and at sea which brings up the question of public acceptance again (flashing light). Speaking in favor of one flashing light is the fact that this light signal is universally understood to mean “danger – watch out”. Another example is road construction block light, which is flashing yellow. The flashing light would not, however, distinguish the turbine from other objects.

People in the wind turbine industry tend to shy away from flashing light because of the stigma from the experience of civil court action caused by individuals who oppose what they perceive as visual pollution, which is largely generated by the flashing light. From discussions with the reference group application of two yellow and steady lights would be a probable industry stance in a negotiating role on this matter.

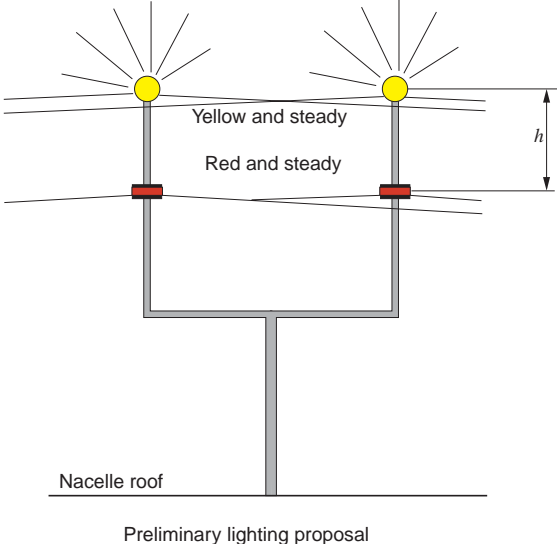


Figure 3 – Proposed lighting where the red lights may or may not be removed

e. Judging the Distance to a Turbine

If the two-light arrangement is applied it is important that the distance, indicated by the letter *h* in the sketch of Fig. 3, be specified to be equal at all installations in order for the interpreter to be able to judge the distance to the turbine. For a recommendation of the value of *h* the physics of light mixing with increasing distance will have to be penetrated first. Then also the maximum distance at which the red and the yellow will be perceived as two lights, rather than a mixed orange shade, must be specified.

f. Possibilities to Judge the Radius of the Rotor

At night the proposed lighting according to Fig. 3 will not convey any information of the added height above the light caused by the rotor blades. It is possible to use different flashing frequencies for different sizes of the rotor or alternatively more lights. Such arrangements are, however, more complicated. They might even invite misinterpretation in addition to the extra unavoidable unwanted visual pollution.

The Y arrangement of the poles holding the lights, in Fig. 3, is not meant to be an indication how to build the structure for the lights. The lights may be extended from the nacelle with individual arms or in any other way compliant with the basic requirement that the light must be visible from all directions.

g. Light Lobe Limitations

The light is proposed to be shielded from view at the ground. However, because of the need for wide visibility to aviators it is to be made visible on flat ground at a radial distance from the turbine of 5 km. This defines the limiting cone angle downward. Considering the remote possibility of a helicopter pilot descending from above a turbine, without having observed the turbine prior to the manoeuvre, the limiting upward cone angle should be considerably higher than that defining the lower limit, preferably 90° but acceptably much lower. Helicopter flying procedures explicitly warns against such flying patterns, which is information to be analyzed carefully before an upward cone angle is to be defined. Therefore no such corresponding angle appears in the sketch above. During the discussions in the reference group 10° was mentioned as a very high angle. The number was compared with airplane landing procedures where the descent angle is typically 3° only.

The lower cone angle limit proposal is, however, directly taken from existing regulations valid for towers with heights in excess of 150m where a white blinking light is required. The proposed steady light is in itself non-obtrusive. Furthermore, if the light is hidden from view, within a radius of 5km from the turbine, the public complaint activity will be minimized. The remaining annoyance, because of lighting, consists of blinking because of blade passage, especially in hazy conditions where the flashing will be observable at much closer range.

h. Remote Monitoring

To make prompt repair possible, when a light ceases to function, positive remote light status signaling must probably be a requirement in the regulatory text on the matter. This can be used to alert the repair team to the need for action. This is a standard feature already today and it should meet with no objections in future discussions.

i. Intensity of Light

In daylight conditions the turbine should be visible even without lights. But, because of very variable daylight conditions, it will be desirable to keep the lights operational 24 hours per diurnal. Presently the lights on top of fixed towers are adapted to the ambient light by variation of the intensity of the light emission such that the highest intensity occurs at daytime and the lowest at night. This practice should probably be retained in a proposed future lighting system as well. But argumentation has been put forth in favor of having the same intensity based on the thought that what can be seen at night certainly can be seen in daylight. If such an argument is accepted a low constant intensity light would be chosen. But, the existence of mist degrades this argument.

The light intensity arises, as the compound physical effect, from the light source power and the size of the stereometric angle defining the lobe within which the light is visible. It is therefore important to investigate the human perception characteristics connected with reception intensity and level of haziness in the atmosphere together with a specified distance required for first perception. These parametrical relationships should be readily available from the literature, in support of such an effort.

4.3 Clusters

Each turbine in a cluster may carry its own lighting as any isolated wind turbine. But, a group of wind turbines should not need individual lights. If the applicant company so wishes an investigation to reduce the number of lights may be conducted. As a guide for such an investigation only the turbines that constitute the corners of the group need be provided with lighting. If the highest turbines, or any other highest object, happen to be located inside the perimeter, defined by the corner turbines, they may need their own lighting if their height exceeds that of the corner machines by a certain differential height, say 40m.

The logics of reduction of the number of lights hinges upon the important definition of which turbines that belong to the “group”. If e.g. five wind turbines are configured with two of the turbines located ten rotor diameters away from the three and the three are five diameters away from each other, it can hardly be said that the outlying two are part of the cluster of five. In brevity, the internal distance between turbines determines what should be considered a group.

5. Alternate Obstacle Warnings

5.1 Paint Schemes

In order to attract attention German rules stipulate that the blade tips be marked orange and white in tangential stripes.

From observation of several wind turbines over the years mostly it appears as an unnecessary measure to provide the blades with the German paint scheme. This statement holds for times of the year when there is no snow on the ground. For a pilot with a view of the turbine from the air the contrast between the white blades and tower against the darker ground is clear enough for identification of the turbine. Orange markings, at the tips only, adds only marginally to the pilot’s attention. When the ground is covered with snow the paint markings will possibly have a place. But, if warning lights are turned on also during the day they will have the effect of attracting attention. This should eliminate the need for paint marks. Thus, it is recommended that no particular paint schemes be required in a future regulatory text on this matter.

5.2 Transponder

One possibility that has been mentioned is to exploit the transponder technique. In aviation this is standard even for small airplanes. The area control sends out a radar pulse/message in a narrow lobe, which rotates covering the 360 degrees in a certain amount of time. Any airplane within this lobe, with a transponder active, will respond to the control radar pulse. The receiving electronics at the control station will then interpret the response and present the distance and also mostly the altitude of the airplane to the air traffic control personnel. The very same technique could be utilized to alert a pilot to the proximity of a wind turbine. If so, the airplane would have to carry the radar equipment while the wind turbine would contain a transponder. By means of adjustment the airplane receiving electronics could filter out any responses from wind turbines being too far away to merit attention, thus providing warning

only for those that are of interest. The exclusive application of the transponder technique for this purpose has not seriously been proposed. Not even one experiment known to the author has been carried out.

5.3 GPS

It would be possible to set up and maintain a database of high obstacles. Each obstacle could be characterized by at least geographical position coordinates and the height above ground. On board the air plane the computer would contain this database and logics to utilize it. Two difficulties emerge when this idea is pondered. The coordinates will be erroneously given for some high objects and there is a known difficulty in updating such a database. Recently FOI, Aeronautics Div., FFA has been looking into the status of the Swedish database of wind turbines locations thereby gaining insight into the shortcomings of system and procedures. A rigorous and well functioning system for this purpose would be costly, and yet, probably not completely dependable anyway.

For the future, however, it is highly desirable to develop legislation such that channels for information flow, of coordinates and other elements of relevant information, to a continuously updated database can be a reality. It would most likely be a simple matter to first organize a database for wind farms at sea. But, it is clearly desirable to also include the land based turbines in this database. Then the step toward a complete database for all high obstacles, of any kind, is not a remote thought. Once the dependable database is set up there is no clash of interest between lighting and GPS coordinate information utilization by the low flying aviators. A reporting system for identified errors in the database must also be part of the overall database system.

5.4 Night Vision Goggles

For specially trained rescue teams, performing flights at low altitude, infrared radiation from the ground and the turbines usually provide adequate contrast to be utilized by the infrared technique. Thus, night vision goggles could be used alone or in combination with lighting on wind turbines.

5.5 Radar Reflectors.

Radar 90 degree corner reflectors will increase the radar reflection intensity. However, wind turbine tower and rotor combinations are already powerful reflectors. Radar reflectors are therefore presently not seen as necessary.

6. Balancing Safety against Aesthetics

The German warning paint scheme on the blades is considered an eye sore to many people. In a discussion of these matters the value of the paint will have to be pitched against the freedom from visual pollution. No paint scheme is presently used in Sweden or Denmark.

Since it is considered by some that light markings are unaesthetic and therefore disturbing, how ever discrete, there is a technique available to keep the lights off most of the time. This is accomplished by radio communication from the particular airplane that is being used for low level flight. The wind turbine is equipped with a radio receiver, which identifies this message from the airplane and switches on the warning lights. The very same technique is being used in aviation at unattended airports where the radio is set at the particular airport frequency. By holding the sender button for typically 10 seconds the runway lights are turned on. Although this is a well proven technique it inevitably invites problems with reliability, which in the balance makes the value of the application of radio/light control doubtful.

The conflicting requirements from safety and visual aesthetics may be described with the aid of a simple intuitive diagram. Light intensity on the x axis signifies intensity of light as perceived by the public. Increasing intensity is caused by more powerful light emission and/or intensity of flashing, which is equivalent with increasing obtrusiveness. The public acceptance curve for this intensity is seen to drop relatively gently. The aviation safety curve rises rapidly and reaches the “knee” of diminishing return. Thus even modest lighting reaches a high level of safety while public acceptance is still at a high level. The guidance from this exercise in overview is teaching us that low level lights are probably good enough. As pointed out previously no accidents involving the combination of wind turbines and airplanes have occurred so far. Since there should be a certain coupling between “light intensity” and investment in lighting, the lower intensity on the x scale will, furthermore, promote a modest beneficial lower cost of energy production.

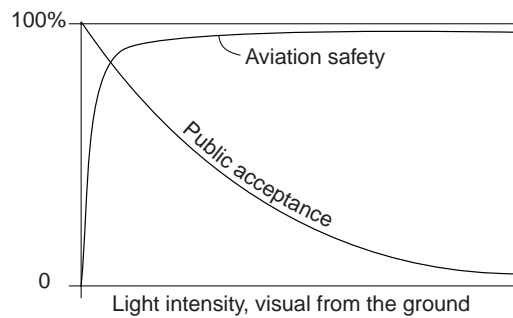


Figure 4

This way of reasoning does not give any exact numbers. But, this conclusion merely reflects the “softness” of this issue. There are certainly complicating factors attached to this issue, such as e.g. light lobe control. Despite the need to weigh many small issues the writers of recommendations, and later rules, should not lose sight of a few important points. They are:

- a) The light must be interpretable as *beware of wind turbine*
- b) Modest lighting can be made to promote aviation safety
- c) Equality of signaling across national borders promotes safety

7. Some Manufacturers of Lighting Equipment and their Products

ENERTRAG, See Ref. 3. - Products include LED lights for wind turbines. Light control boxes with different logics for switching with time or ambient light are part of the assortment. Some inventive features are presented in their prospectus available from the web.

HONEYWELL, with various addresses in different countries, has a variety of lights including those for wind turbines.

Brøndberg & Tandrup International A/S (BTI) of Copenhagen, Denmark has an assortment of lights some of which are suited for wind turbines.

8. References

1. The International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA), Recommendation AISM O-117, first issued in May 2000. A revised issue is planned to appear during 2004.
2. Nachrichten für Luftfahrer, Teil 1, 48. Jahrgang – Richtlinien für die kennzeichnung von Luftfahrthindernissen des Bundesministeriums für Verkehr, Bau- und Wohnungswesen, 22 Dezember 1999
3. ENERTRAG, Windfeld Systemtechnik GmbH, Nechlin 7, 17337 Nechlin (Uckerland) in Germany - An information package can be found on the web (www.enertrag.de).