Masts for wind measurements

Experience feedback from failures and collapses

Elforsk report 11:57

Claes Fahleson

January 2012

Vindforsk Energimyndigheten ELFORSK

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Preface

The design of wind turbines requires detailed information on wind characteristics of the proposed wind turbine site to verify the suitability of the location. For this purpose wind measurements are made in high masts with height comparable of the planned wind turbines.

During the past years some collapses of mast has occurred.

In order to investigate how frequent failures are and to find out causes for failures the project "Masts for wind measurements, Experience feedback from failures and collapses" has been carried out.

The work was carried out by Claes Fahleson at Prodevelopment AB as a project within the Swedish wind energy research programme "Vindforsk – III". The report is the final report for project V-349.

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Sammanfattning

För att klarlägga de eventuella bakomliggande orsakerna till att mätmaster tycks ha större brottrisk än andra byggnadsverk har två typer av enkätundersökningar distribuerats till ett stort antal aktörer på den svenska vindkraftsmarknaden. Tyvärr var svarsfrekvensen ganska låg varför man får tolka svaren med en viss försiktighet. Några intressanta resultat kan dock uttolkas av svaren.

Undersökningen ger att det finns ungefär 400 till 500 stagade fackverksmaster som används för vindmätning i Sverige.

Observera att undersökningen endast behandlar stagade fackverksmaster i stål. För vindmätningar upp till cirka 60 meters höjd används ofta så kallade rörmaster. Denna typ av mast inkluderas inte i undersökningen.

Idag är standardmasten för vindmätning 100 m hög. Då vindkraftstornens storlek tenderar att öka blir det allt vanligare med master som är 120 till 150 meter höga.

Av enkäterna framkom att två mätmaster har kollapsat under de senaste åren. Den direkta orsaken till kollapserna är i dagsläget inte helt klarlagd trots att ordentliga utredningar gjorts. Det har dock konstaterats att haverierna har inträffat då masterna har varit kraftigt nedisade. Brotten har förmodligen initierats i någon staglinas förankring eller infästning. Däremot kan man inte med säkerhet säga om islasten var större än den islast som masten dimensionerats för eller om bärförmågan hos en av mastens komponenter var lägre än vad som förutsatts i dimensioneringen.

Eftersom endast en liten del av marknadsaktörerna har svarat på enkäterna och bara angett egna erfarenheter av haverier så är det sannolikt så att andra eventuella masthaverier har missats. En uppskattning är att det i snitt inträffar ett masthaveri vart annat år. Baserat på antagandet om 450 mätmaster i drift så blir den årliga brottrisken i storleksordningen 10^{-3}. Brottrisken är således minst tio gånger högre än vad den teoretiskt borde vara.

Enkäterna visade att det tycks råda en viss osäkerhet bland vindkraftsföretagen som upphandlar master för vindmätning om vilka nationella krav som gäller beträffande dimensionering och uppförande av mastkonstruktioner. Från och med den 2 maj 2011 gäller ett nytt regelverk för dimensionering, tillverkning och montering av byggnadsverk i Sverige. I denna rapport görs en detaljerad genomgång av vilka standarder som ska tillämpas för dimensionering, tillverkning och montering. De nya standarderna ställer tydliga krav på kvalitetssäkring i alla skeden av byggprocessen vilket i förlängningen kan ge säkrare master.

Vidare anges tydligt av alla aktörer att det råder en stor osäkerhet i att uppskatta de islaster som kan uppkomma på master. I dagsläget saknas det nationella anvisningar för att uppskatta nedisning på master. Ett önskemål från branschen är att det tas fram en genomarbetad nationell bilaga till den eurokodstandard som gäller för dimensionering av master och torn i stål, SS-EN 1993-3-1, så att dimensionerande islast kan bestämmas på ett realistiskt sätt.

Summary

In order to clarify any underlying causes why wind measurement masts seem to have larger failure risk than other structures, two types of surveys have been distributed to a large number of operators in the Swedish wind energy market. Unfortunately, the response rate was quite low and results therefore, have to be handed with some caution. However, some interesting results can be seen in the responses.

The surveys give that there are approximately 400 to 500 guyed steel lattice masts for wind measuring in operation in Sweden today.

Note that this study only covers guyed steel lattice masts. Tubular masts are often used for wind measurements up to 60 meters height. This type of mast is not included in the study.

Today, the "standard measurement mast" is 100 meters high. As the wind power towers size tends to increase it becomes more common with masts that are 120 to 150 meters high.

During the last years two measurement masts were reported collapsed. The immediate causes to the collapses presently are not fully established, although proper investigations have been made. It has been observed that the collapses have occurred when the masts were heavily iced. The collapses have probably been initiated by failure in a guy anchorage or cable termination. However, one can not say with certainty whether the ice load was greater than design ice load or, if the resistance of one of the mast components was lower than assumed in the design.

Since only a small part answered the surveys and only stated personal experience of collapses, it is likely that other mast collapses that may have occurred in Sweden in recent years have been missed. An estimate is that in average one measurement mast collapses every second year. Based on the assumption that 450 masts are operational, the annual failure probability is in the order of 10^{-3}. This estimated probability of failure is at least ten times higher than it theoretically should be.

Among the wind power companies that procure masts for wind measurements, the surveys indicate some uncertainty about which national requirements regarding mast design that applies. From 2nd May 2011 new regulations for design, manufacturing and assembly of structures in Sweden applies. This report provides a detailed review of the standards to be applied for the design, manufacturing and installation of measurement masts. These new standards give clear requirements for quality assurance in all stages of the construction process, which subsequently may increase the safety of masts.

Furthermore, actors interviewed in the study pointed out large uncertainties in determining design values for ice load on masts, Today, national guidelines for estimating icing on masts in Sweden are lacking. A national annex on how to determine realistic design values for ice loads appended to the Eurocode standard used for design of towers and masts in steel, SS-EN 1993-3-1 3, would be highly useful.

Content

1 Introduction

1.1 Background and scope of project

The design of wind turbines requires detailed information on wind characteristics of the proposed wind turbine site to verify the suitability of the location. The primary objectives are to determine whether the wind speed is sufficient to produce expected effect and to get necessary information needed for the design of the turbine.

In order to obtain detailed information on wind data, measurements masts for wind measurement have to be erected on the site of the wind power turbine. In general turbine manufacturers require data from at least one year with continuous measurements. If the site area consists of several wind power towers more than one measurement mast may be needed to cover the variation in wind, which may depend on site topography or obstacles on the ground.

The information required may vary depending on preferences from the turbine manufacturer. It is generally recommended that wind measurements are made up to a level equal to the level of the hub for the planned turbine. A consequence of this recommendation is that masts for wind measurement today more and more often reach heights above 100 meters.

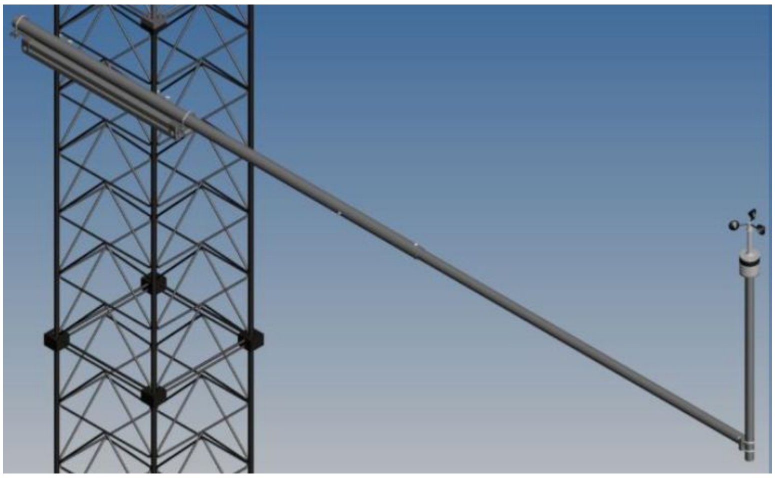

Figure 1: Anemometer mounted at the tip of a cantilever beam. From www.cuedee.se.

A wind measuring mast is intended only to carry measurement device as anemometers, and in contrast to telecommunications masts there are generally no requirements on allowable deflection or curvature for the mast. It is of importance that the measured wind velocity is undisturbed. The anemometers are therefore mounted at the tip of cantilever beams, see figure 1.

The necessary length of the cantilever beam can be determined according to the standard IEC 61400-12-1 [8] and is highly dependent on the width of the mast shaft. Normally a free distance of 5 to 7 times the shaft width (= leg distance) is needed.

Therefore, wind measurement masts normally are much more slender than for example telecommunication masts. A typical measurement mast may have a shaft width of 0,6 meter, a total height of 100 meters and guyed by strands at 6 levels.

Although the number mast for wind measurements in Sweden is considered as relatively low, some serious collapses and incidents has been registered during recent years.

A collapse of a measurement mast may, in addition to the cost of the mast, cause other economic losses due to delay in construction and startup of the turbines as a result of incomplete wind data. This secondary economical effect of a mast collapse is difficult to estimate but can probably be quite substantial. A guess is that the cost of the mast structure itself may be negligible compared with the secondary economical effect if, for example, a large power plant project is delayed one year.

There is always one cause or several interacting factors that result in a collapse or a serious accident, e.g. tension failure in a guy anchor due to unforeseen high loads. The process from design to manufacturing, erection and operation of a wind measuring mast contains several steps where errors or miscalculations may occur.

The main objective of this project is to illuminate the whole process, try to clarify the causes to any failures of masts used for wind measurements and give recommendations that can contribute to increase the quality and safety of measurement masts.

The work within this project consists of three steps.

1. *Collection of information:* The first step is to collect available data on collapses or serious incidents. Other information relevant for any shortcomings that may contribute to the increased risk will be collected, i.e. questions about procurement, design and installation. In order to reach out to a wide group of involved actors the interviews where conducted as a survey. Actually, two types of surveys where made, one for companies or organisations using wind measurement masts and, another one for structural designers, manufacturers and companies erecting the structures.
2. *Compilation and analysis:* The information received about collapses or failures, routines for procurement, design and installation are evaluated and it is determined where in the process shortcomings most likely have arisen.
3. *Conclusions and recommendations:* In order to contribute to increase the quality and safety of measurement masts, some concrete recommendations are presented.

1.2 Masts for wind measurements

In order to reduce the uncertainty in the predicted energy production of a proposed wind power farm project good quality site wind data is of crucial importance. The main purpose for a wind measurement campaign is to provide information to allow the best possible estimate of the energy on the site to be provided. If the site consists of several wind turbines or, if the site terrain or topography is complex more than one mast may be needed.

The wind velocity generally increases with altitude. This characteristic is called "shear" and the shape of the wind velocity curves is known as wind shear profile, or just wind profile. The gradient of the wind velocity and also the air turbulence are dependent on the terrain roughness. Wind velocities near ground in forest terrain are generally lower and more turbulent compared with flat areas in open terrain. If the terrain contains isolated hills, ridges or other escarpments different wind velocities will occur in the lower air layer, see illustration in figure 2, from [16].

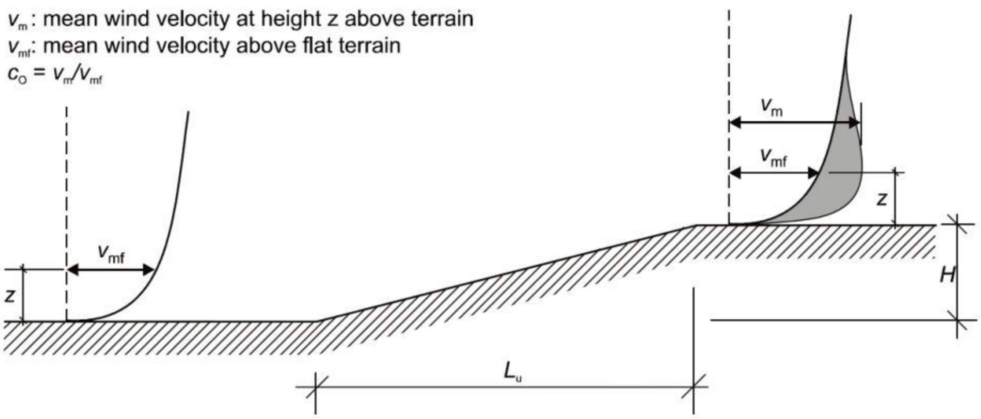

Figure 2: Illustration of increase of wind velocities over orography, from [16]

Given the discussion above about the variation in wind the importance of having accurate wind data is clear. Manufacturers of turbines usually recommend that the wind is measured up to a height equal to the hub height of the proposed turbine. If there is a lack of measurement at higher levels then the wind shear profile must be estimated. This can be done, but it creates uncertainties.

Today commercial wind turbines typically have hub heights in the 60 to 120 meters range. For mast heights of 60 to 80 meters somewhat less expensive so-called tilt-up guyed masts may be used. Beyond such heights cranes are required to install masts, and the costs increase. If 'best practice' of a hub height mast is not followed, then a reasonable compromise is to ensure that masts are no less than 75 percent of the hub height of the turbines.

A typical wind measurement mast will have a number of anemometers installed at different heights along two sides of the mast, and one or two wind vanes to measure wind direction. The measurement device is connected via screened cables to a data logger, normally placed at the base of the mast. At the early stage of wind power projects there are generally no external power supply on the sites. Anemometry systems are therefore usually battery operated. Some systems have battery charging via a solar panel or small wind turbine. For some systems, particularly in cold climates, the measurement of the temperature is important to assist with the detection of icing of the anemometers. In such circumstances, the use of heated or "ice free" anemometers is beneficial; however, their use without an external power source is usually impractical. The market offers some types of sensors that can be used to detect ice accretion. These sensors are in general rather unreliable, at least if they are used to estimate the amount of ice growth.

1.3 Atmospheric icing of structures

Ice loads that arise from atmospheric ice accretion can become quite heavy in some parts of Sweden. In some extreme cases, significant ice loads may be built up in just one or a few days, [5].

The most common type of atmospheric icing that occurs in Sweden is known as soft rime ice. This type of ice is white or opaque with a loosely bonded structure, similar to snow crust. Another common type of atmospheric icing is called glaze ice and is similar to homogeneous clear ice. This type of ice is normally formed by freezing rain. However, in our part of the world this type of weather in generally has a very short duration and does seldom cause ice layers thicker than a few millimetres.

The ice accretion is strongly dependent on several parameters including diameter or width of element being iced, temperature, wind velocity, amount of super cooled droplets hitting the element. For example, an element of 20 mm diameter does in general become much more relatively iced than an element of 200 mm. The air temperature during a icing event is normally between -10 to 0 °C, if it is colder the droplets are frozen. Super cooled droplets are found in clouds when the temperature is some degrees below zero.

Therefore, ice loads formed by rime ice most likely occur on structures located on mountains or ridges in the inland of Sweden. Experiences of icing on a high TV-mast located on the summit of a mountain in Lapland shows that rate of ice accretion is highest when the temperature is some degrees below zero and when wind come with moist air from south or west, see [5]. Since the mountain where the mast is located is surrounded by lakes and low land it often become completely embedded in clouds, this type of icing is referred to as in-cloud icing.

So far, there are no national guidelines that could be used to determine ice loads on masts in Sweden. In a preliminary unpublished national annex to SS-EN 1993-3-1 "Towers and masts" it is referred to that Annex C in SS-EN 1993-3-1, [28], may be applied. Annex C briefly describes the effect of ice loading and recommend the use of experts in atmospheric icing in order to estimate the ice load. Annex C also refers to the standard SS-ISO 12494 [29] "Atmospheric icing of structures" which presents the fundamentals of atmospheric icing. In SS-ISO 12494 the ice loads are classified in ice classes dependent on type of icing (glaze or rime) and load intensity.

There are some basic outlines for Europe concerning number of icing days (in-cloud icing), see figure 3, from [6].

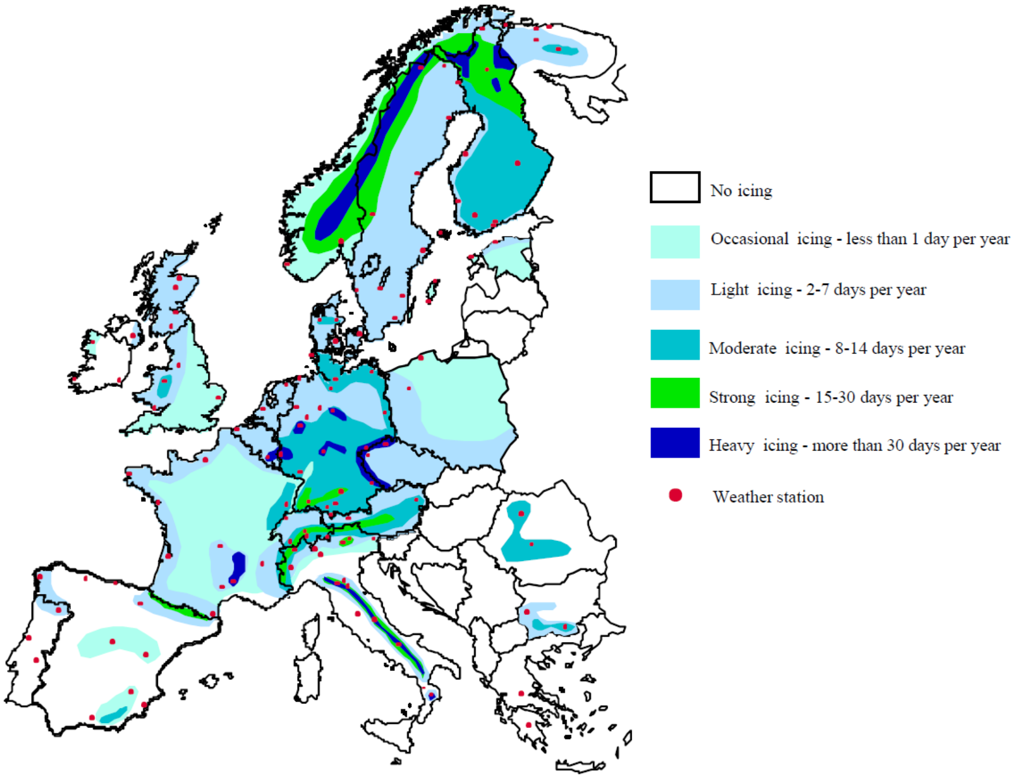

Figure 3: Distribution of the number of icing days in Europe, when the average annual number of icing days is calculated for in-cloud icing for the meteorological observation stations marked with red dot. Data 1991-1996 From [6]

The Finnish National Annex to the standard EN 1993-3-1, [10], presents some rational instructions for determining ice loading on masts and towers. It is primarily recommended that the ice load should be based on statistical data for the specific location and determined in co-operation with a meteorologist familiar with icing. If such information is not available the Finnish National Annex allows the ice load to be indirect determined by prescribing the mast to belong to an *Ice Class* according to the table presented in figure 4. The ice classes are denoted from R1 to R9 and correspond to the classes for rime ice presented in SS-ISO 12494, [29]. The ice class is determined by the altitude for the location of the mast. A measure called relative height and denoted *H* is calculated as the distance from the average level of surrounding terrain within a distance of 10 km from the site up to 2/3 of the mast height. The table in figure 4 also presents characteristic ice loads and combination factors for the different ice classes.

A consequence of the nature of atmospheric icing is that significant ice loads don’t normally arise on structures located in costal areas since the cloud height often is higher than the structure. However, the upper parts of very high masts may be exposed to in-cloud icing.

Ice class	H (m)	G_i (kg/m)	k
R1	0 - 50	0,5	0,40
R2	50 - 100	0,9	0,45
R3	100 - 150	1,6	0,50
R4	150 - 200	2,8	0,55
R5	200 - 250	5,0	0,60
R6	250 - 300	8,9	0,70
R7	300 - 350	16,0	0,80
R8	350 - 400	28,0	0,90
R9	400 - 450	50,0	1,00

H is the relative height from the average level of the surrounding terrain within a distance of 10 km from the site.

G_i is the characteristic unit weight of the ice on the element

k is the reduction factor in load combinations for wind and ice.

Figure 4: Ice loads and k factors for different ice classes. From the Finnish National Annex for EN 1993-3-1, reference [10].

1.4 The process - structural design, manufacturing and erection

Before a final decision is made concerning construction of new wind power plants, the suitability of the location for the wind power plants must be investigated. The investigation will give statistical information on wind characteristics in terms of wind velocity, wind direction and the vertical profile of the wind.

Normally the power company buys one or more measurement masts from a vendor or manufacturer of masts. If the company has several wind power projects they may use masts that already have served their purpose on other sites. When the measurement mast is installed on site it is equipped with various types of measurement instruments. Anemometers are installed at regular intervals from the point corresponding to the lower position of the rotor blade up to a height at least equal to the hub height of the generator. In addition to anemometers and wind direction gages measurement masts are often instrumented with other meteorological instruments as ice detection gages, thermometers and hygrometers.

There are also some specialized actors on the Swedish market that can provide the power company with all necessary wind data by rental of measurement masts. In addition to providing necessary wind data, these companies often contribute in other parts of the process, such as support for application of necessary permits, planning and staff training.

Whether the wind power company owns the measurement mast itself, or if they buy the service from some specialized actor the measurement mast has to be designed to resist loads from wind, equipment and any loads arising from atmospheric icing.

In Sweden a measurement mast is regarded as a building structure and shall be designed according to the newly introduced European structural standard, Eurocode. This European standard is intended to be used with a National Annex giving any complementary regulations or recommendations, for Sweden EKS 8 [7][1] shall be used together with Eurocode.

Eurocode is actually a collection of several individual standards. When designing a traditionally guyed steel truss mast that includes a foundation in concrete different parts of Eurocode are needed. The general rules for design is given in SS-EN 1990, [14], loads except ice loads are found in SS-EN 1991-1-1, [15], SS-EN 1991-1-4, [16], SS-EN 1991-1-5, [17], SS-EN 1991-1-6, [18], and SS-EN 1991-1-7, [19], concrete design in SS-EN 1992-1-1, [20], and steel design in 1993-1-1, [21], 1993-1-2, [22], 1993-1-3, [23], 1993-1-8, [24], 1993-1-9, [25], 1993-1-10, [26], 1993-1-11, [27],and 1993-3-1, [28]. For execution of steel and concrete structures the standards SS-EN 1090-1, [11], SS-EN 1090-2, [12], and SS-EN 13670, [13], shall be applied.

However, in principle all existing measurement masts in Sweden are built or manufactured before May 2011 and therefore designed according to older national standard[2]. These masts are in most cases designed according to the standard BKR [2] together with the handbook’s BBK [1], BSK [3] and BSV [4].

The design verification methods, the level of loads, structural strength and reliability are in much the same whether the design is in accordance with the old or the new standards.

[1] Boverket’s statues EKS is continuously updated. The present edition, no.8, is valid from May 2, 2011.

[2] The older national standards may be applied if construction starts before May 2, 2011.

2 Survey on wind measurement masts

2.1 Target group for the survey

The main objective of the survey is to provide a representative view of the Swedish market for wind measuring masts including the process for procurement, fabrication and assembly of wind measurement mast.

Any possible shortcomings in the process should be revealed by the survey. That is, what conditions can influence the process so that the mast does not receive the expected quality or the required safety against collapse?

Two types of surveys were developed, one for companies and organizations that use wind measurement for wind power development, and another for companies that design, manufacture and install measurement masts. The two surveys are similar and are presented in appendix A.

In order to obtain a high response rate, the surveys were kept brief, with a limited number of questions that could be answered in ten to fifteen minutes. The survey for users of measurement masts was web-based while the other survey was sent as a paper document to the concerned companies.

The web-based survey was distributed to some 150 members of the trade association *Swedish Wind Energy*[3]. It is estimated that approximately half of the total membership are companies that own or operate wind turbines. Unfortunately the response rate was rather low, only a total of nine companies answered the web-based survey. Furthermore, two of the companies did not answer on all questions.

The other survey that concerned designers, manufacturers and installers was sent to three Swedish companies. All three companies responded and the answers in the survey were followed up by personal interviews.

2.2 Results of the surveys

The results from both surveys are merged and in the following presented under three subject areas,

- general questions about the company's, or the organization's, own experience with measurement masts,
- questions about experiences of collapses or other serious incidents, and
- questions about the procurement.

[3] See www.vindkraftsbranchen.se

In the following sections questions, outcome of the answers and comments to the answers are presented.

Note that the outcome includes the response from both surveys. Any differences in responses depending on whether the answer is from the wind power company or the manufacturers of measurement masts are given in the associated comments.

General Questions all

How many masts for wind measurement do you estimate are in operation in Sweden today?

- The responses ranging from 120 to 1000 masts. The average estimate is 450 masts. However, this figure seems to be slightly overestimated if it is compared with wind power plants that are operational or planned for the next years. Statistical information from September 2011 from the trade association *Swedish Wind Energy*[4] shows that there were totally 1723 wind power plants in operation in Sweden at the end of 2010. For year 2011 and 2012 it is estimated that further 350 plants per year will become operational.

  Measurement masts seem to have lower reliability or, are more likely to collapse than other building structures. It is therefore of interest to compare the total number of masts in operation against the number of observed collapses.

Do your masts have other equipment than anemometers and wind vanes?

- The responses shows that measurement masts almost always have other type of equipment attached to the mast, such as, sun panels or small wind turbines generating the electricity needed to operate the measurement device, and other meteorological instruments or cameras.

  Wind measurement masts have no telecom equipment, except any small radio transmitter for sending measurement data.

  The size and weight of this other equipment is relatively small and it is expected that the equipment normally doesn't cause any significant additional loads on the mast.

[4] *Svensk Vindenergi. Vindkraftstatistik 2011-09-14*

General Questions for wind power companies or organisations

How many wind measurement masts does your company or organization have in operation today?

- The response varies between 1 to 15 masts. Assuming that there are approximately seventy market operators and each of them have a average of seven measurement masts, it corresponds well to the estimate of totally 450 masts.

Who is the owner of the measurement masts?

- Only seven companies have answered this question. These companies have totally 54 measurement masts in operation and the response shows that 44 masts are owned by the wind power company while 10 masts are rented. According to one larger actor for rental masts in Sweden this figure is little misleading and should be more like fifty-fifty.

How long are the wind measuring normally carried out?

- Half of the companies surveyed responded that they measure between one and two years while the other half responded that they measure more than two years.

  In order to evaluate the suitability of the site with respect to energy supply and for optimal design of the wind turbine one year of data is normally sufficient. In many cases the measurement continues some time after the wind power turbine has been taken in operation. The purpose is to verify the effect of the turbine against specified effect.

What type of design is the most common for masts used by your company or organisation?

- All companies answered that the average mast today is a 4-sided lattice mast with a height of 100 meters. The number of guy levels varies from 3 to 6.

  The height of the mast is normally dependent on the height of the planned wind power towers. Manufacturers of wind turbines normally require that the wind speed and wind direction is measured up to a height at least equal the hub height.

What type of design does your second most common mast have?

- A majority of the companies answered that the second most common mast was is about 100 meters high or lower while some companies answered that the second most common mast is higher, up to 130-140 meters. All types are guyed 3- or 4-sided lattice masts.

  Modern turbines require higher towers, which in turn require higher measurement masts. It is therefore expected that the standard wind measurement mast in a few years probably will have a height of 120 meters or more.

What type of anchorage is normally used for guy anchors?

- All types of anchorage are used. Rock bolt anchorage seem to be the first choice where possible (when exposed rock), however soil anchor is probably the most common type of anchorage. Gravity foundation works well but is a little more expensive and therefore final choice.

How large proportion of the masts has previously been mounted on other sites?

- Today, a majority of the measurement masts in operation seam to be new masts. However, the number of dismantled and reused masts will probably increase in future since there are quite many high masts in operation today. One company answered that they often install measurement masts that has been in operation on other sites. It is noted that they also reuse the guy cables by mounting them one level lower than on the previous site. Only the cables from the top level are new.

Questions about experiences of collapses or other serious incidents

Have any of the measurement masts in your organisation been involved in a serious incident without the incident causing a total collapse?

- Some of the responding companies have experiences of one or more incidents that didn't cause a total collapse. The total number of incidents, however, are not specified. The comments given by the companies that have answered yes on this question shows if the incident was serious or less severe. Two of the answers can be considered as serious incidents with respect to safety against collapse, that is…
    - displacement of a guy anchor due to high guy forces, and
    - incorrect guy forces due to shortcomings in the installation.

  while two other answers are deemed as less serious,

    - sabotage of climbing protection, and
    - theft of various items of equipment as measurement device, batteries, electric generator, etc.

Have any of the measurement masts in your organisation been involved in a serious incident resulting in a collapse?

- Only one company answered yes on this question. They have experienced two collapses, both during the winter 2009-2010. The collapses occurred when the masts were exposed for heavy in cloud icing. Despite thorough investigations, it has not been possible to clarify the exact cause to the collapses. Either the load was higher than the presumed design load, or the resistance of one component in the mast was lower than its design resistance. Nor is it possible to determine whether the failure was due to poor quality in the production process or poorly executed installation.

  During interviews with some of the actors second hand information of collapses of measurement masts was obtained. The information is however imprecise and no confirmatory facts have been able to find. An estimate is that at least two other collapses have occurred over a period of the last 5 to 10 years.

Note that tubular masts are not included in this survey. None of the companies or organisations that answered this survey has mentioned experiences in using tubular masts.

Questions about procurement

Which of the following conditions are specified by the purchaser and the vendor (manufacturer) respectively?

a) *Wind load? Can be given directly as a value in m/s or indirect as a reference to the mast's location and standard for determining wind load.*

b) *Ice load? Can be given directly as a value, for example ice thickness, or indirect as a reference to an ice class and standard for determining the ice load.*

c) *Codes and standards to be applied in the design?*

d) *Requirements for the function? For example allowable deflection or inclination during service condition?*

e) *Requirements on specified erection method?*

f) *Requirements on execution and inspection? For example by reference to code or standard*.

- The general responses are that codes are not normally specified at the procurement. Since a mast is considered to be a building structure national Swedish regulations for building structures shall be applied.

  In most cases design values for ice and wind load are determined by the vendor.

  If the purchaser specifies the exact location of the mast he indirectly determines the design wind speed since there are detailed wind maps presented for Sweden, see for example BSV[5].

  If the mast is located in areas where icing may occur, some judgement concerning ice loading must be made. It is most common that the manufacturers do a more or less rough assumption about ice load conditions and inform the customer about which design ice load that they have assumed. The ice loading may be determined with reference to the standard ISO 12494, [29].

  A general opinion among the structural designers (manufacturers) is that there are needs for national guidelines for assessing the risk of icing and if it occurs, the size of the ice loads.

[5] Boverket's (The Swedish National Board of Housing, Building and Planning) handbook for Snow- and wind load, BSV 97, edition 2. Not in force, replaced by the Eurocodes May 2, 2011.

Normally the purchaser does not specify any particularly requirements for function. However, it is at the procurement understood that mast shall have a geometry that is suitable for wind measurements, i.e. the geometry will be such that it does not interference the wind measurements. In IEC 61400-12-1 [8] conditions for the data needed to determine the performance for wind generators is specified.

The purchaser usually specifies the conditions that apply on the site, which in turn affect the installation method. There are different methods used for installation, for example high masts are often erected by use of helicopter or crane. Shorter mast up to approximately 80 meter may be so called tilt-up masts. The installation is, regardless of method, a hazardous operation and should therefore be in accordance with an established erection plan.

A majority of the purchasers indicated that they usually specify requirements on execution and inspection while the vendor answereds that it is not so common that the purchaser specify requirements on execution and inspection. The requirement from the purchaser is normally more general, such as by reference to requirements in standards, for example to IEC 61400-12-1, [8].

Three of the purchasers say that they let the vendor/manufacturer decide all conditions specified by points a) to f) above.

2.3 Summary of the surveys

The results from the surveys can be summarized in following points…

- The total number of masts in Sweden used for wind measurements in wind power projects is estimated to approximately 400 to 500 masts.
- The height of standard mast is expected to increase from 100 meters to 120 meters or higher in next few years.
- Masts designed to support equipment for telecom is not used for wind measurement
- Two serious incidents (not collapse) have been reported in this survey. One incident was caused by incorrect forces in the guy cables due to shortcomings in the installation. The other incident was caused by inadequate anchorage when a foundation displaced due to large guy forces.
- Two collapses have been reported in this survey. Both collapses had occurred when the masts were exposed for heavy in cloud icing. Despite thorough investigations, it has not been possible to clarify the exact cause to the collapses. Either the load was higher than the presumed design load, or the resistance of one component in the mast was lower than its design resistance. Nor is it possible to determine whether the failure was due to poor quality in the production process or poorly executed installation.
- Second hand information of collapses of measurement masts indicates that other collapses which are not reported within this survey have occurred. The information however is imprecise and no confirmatory facts have been able to find. An estimate is that at least two other collapses have occurred over a period of the last 5 to 10 years.
- The main cause for a typical collapse is the high loads that arise from the combination of wind and icing. The collapse is initiated by failure in the weakest link of the structure, which probably is the attachment of one guy, i.e. the cable termination or the guy anchorage.
- The purchaser (wind power company) of measurement masts normally give the vendor (manufacturer or contractor) free hands to specify most of the condition that shall apply for the design, manufacture and installation.
- There is a large uncertainty when it comes to evaluation risk of icing and estimate the weight of ice on a mast and its components. This is an important issue for purchasers and vendors and there is a large need for national information.

3 Discussion

3.1 General

Only a small part of all surveys sent out to companies and organizations working with wind power were answered and returned. Roughly only some 10 % of all surveys distributed by the industry organization *Swedish Wind Energy* (Svensk Vindenergi) were answered.

The low response rate makes it difficult to draw firm conclusions from the survey. Any conclusions presented in this report should therefore be interpreted with some caution. It should also be pointed out that the measurement mast industry in Sweden is relatively small, at least if it is compared with masts used for telecom. Today there are approximately 400 to 500 wind measuring masts in operation in Sweden compared with roughly 10.000 telecom masts.

It is estimated that at least 4 guyed masts used for wind measurements has collapsed in Sweden during the last 5 to 10 years. Assuming on average that one mast collapses every second year the annual risk for failure can be estimated to roughly one in thousand. Compared with the risk of failure for building structures in general, this figure is unacceptably high. In most cases a measurement mast can be classified as a structure belonging to safety class 1[6] which corresponds to a nominal annual failure probability of $1 \cdot 10^{-4}$, i.e. one in ten thousand. This comparison gives that masts used for wind measurement roughly has a probability to collapse that is 10 times higher than building structures in general. However, the consequences of the occurred collapses fortunately have so far only been economical.

The data obtained on the wind by measuring is of great importance for the design of the turbines and for decision whether the location for the wind power turbines are appropriate. Whether the estimated failure probability reflects an optimal risk valued with respect to the project economy is difficult to say.

It is likely that buyer do not consider that measurement masts seem to have a lower safety than other structures. He uses the same procedure for the procurement as when for example a structure as an industrial building is ordered. The size and function are specified by the buyer while the structural designer and the contractor design and construct the works so as to meet the demands of society, including requirement for safety against collapse.

However, a high slender guyed measurement mast is a type of structure that differs significant from other types of building structures. Its inherent resistance characteristics make it much more sensitive for variations in external loads and also for unintended defects in the structure.

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[6] For definition and classification of structures in to safety classes, se BFS 2011:10, EKS8 [7].

First, combined loads as wind load and ice load may have a considerable nonlinear behaviour when the loads are transferred to load effect on the mast. The atmospheric ice that is formed on a mast and all of its components may increase the total wind drag (i.e. drag coefficient times the exposed wind area) with a factor that is several times higher than for a non-iced mast. A heavily iced mast may for moderate wind speeds, say 15 to 20 m/s experience the same load effect by wind as if the mast were non-iced and exposed for hurricane winds. In addition to the wind load on the iced mast, the effect of the ice weight shall be added, which may be considerable.

Second, a guyed mast is a structure where all components interact in a way that in general differs from other structures. If one of the structural components in a mast fails or braeks there is a significant risk for progressive failure and thus total collapse, that is the capacity of a mast is in general equal the capacity of its weakest link. A traditional building structure normally has a redundancy that allows one or more components to fail without causing any serious consequence. Masts do not have this redundancy, for example, the ability to form plastic hinges.

In view of the fact that a mast is composed of a very large number of parts it is realized that it is of importance that all parts are installed in a correct way and working as intended.

In some sense it is understood that the safety of the measurement masts is deemed to be of less importance. The cost of a measurement mast compared with the cost of a wind power plant including infrastructure and grid connection is almost negligible. Further, measurement masts are almost always located in areas where people normally not are present, and a collapse normally does not cause damages on other structures or risk for humans. Nevertheless, the collapse of a measurement mast may cause indirect economical losses. Since there is a lack in wind data the installation of the turbines and the start up may be delayed and also the future earnings.

As mentioned in the background to the project, the relative number of collapses or failures of measurement mast seem to be significant higher than for other type of building structures, roughly 10 times higher. This estimate includes all types of measurement masts in Sweden and at all locations. If this estimate would be broken down into smaller subparameters, for example with the mast height as one parameter and the location as an other parameter, the result would probably show us that high masts located on the upland terrain in Sweden's inland has a even greater risk of failure than estimated. On the other hand, shorter masts located in lowland with low intensity of icing would probably have a much lower failure risk.

It is important that the purchaser and the seller agree in a specification that includes accurate conditions used for design, manufacture and installation. A clear specification with well defined requirements makes it easier for sellers to deliver a better structure and contribute to an increased quality. For measurement masts planned to be located at sites where icing is known to occur, a clear specification will most likely give a stronger mast than if it is procured on a general specification that do not specify the site for the mast. In the context of a site with several wind power turbines the extra cost for a stronger mast is probably negligible.

It is worth noting that the Swedish regulation for building structures also applies for measurement masts: The regulation covers as well permanent as temporary structures intended to be used only for a period of time. In relevant standards load levels and values for partial coefficients (≈ safety factors) are set so they meet the society's demands for safety. The requirement level is adopted so that it minimizes the risks of personal injury or, economic, public or environmental impacts.

3.2 Procurement process

An analysis of the surveys and discussion with the experienced participants in the reference group for this project indicates that the purchasers of measurement masts, i.e. wind power companies, might need some practical advice and deeper knowledge in some specific areas in order to establish accurate specification used in the procurement process.

The specification presented by the purchaser can vary somewhat depending on how specific one wants to be. However, in order to achieve sufficient quality some important structural requirements, besides height and measurement equipment, should be specified, that is

- safety class of structural components,
- the conditions required to determine the climatic loads, and
- any other requirements necessary for structural design, manufacturing or installation.

The safety class is a measure of how "important" the structure is deemed to be. If an element of a structure is of such nature that collapse involves high risk of injury to persons the element of that structure shall be assigned to safety class 3. If the risk of injury in case of collapse is small, safety class 1 may be prescribed. Safety class 2 may be used if the risk is deemed to be between class 1 and 3.

Normally measurement masts are located in areas where people seldom are present and the mast may therefore be assigned safety class 1. Note that a structure that is designed according to this safety class still is a very reliable structure. Theoretically the annual probability for failure for a structural component designed according to safety class 1 is one in ten thousand (=1/10.000). For building structures studies has indicated that the reliability is even higher than that figure.

As discussed in previous section, it is of importance to use accurate load conditions in the design. This is especially important for masts located at sites where significant ice loads may appear.

The instructions for determining wind load on structures given in old or new standards or codes are generally very detailed and comprehensive. National standards for wind load specify the design wind loads for all geographical location. For Sweden the design wind load is based on a reference wind velocity, v_b, that is equal the average wind velocity during 10 minutes at a height of 10 meters above the surface in a terrain with a roughness factor of z_0 = 0.05 and with a return time of 50 years. Figure 5 shows a map of

Sweden with isolines drawn for different reference wind velocities. The highest wind velocities, and thus wind loads, are found in the mountains towards Norway and at the southern cost of the country.

It is not unusual to locate wind power plants on ridges or high plateaus in the landscape in order to optimize the distribution of the wind. Such locations can lead to considerably higher wind loads than for locations in flat terrain, see the illustrated wind profile in Figure 2. It may therefore be important, in addition to the location (which indirectly give the reference wind velocity), to specify where in the terrain the measurement mast is planned to be placed.

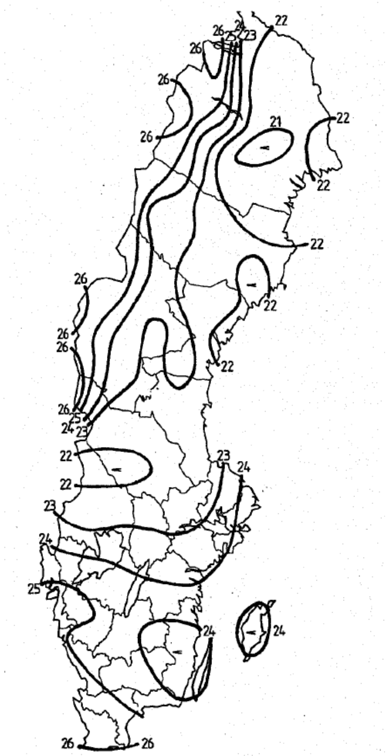

Figure 5: Reference wind velocity v_b in m/s for Sweden, from [7].

If the mast is placed on a ridge or a high plateau it also increases the risk to have large loads caused by atmospheric icing. As discussed in previous sections, the type of icing that cause the most severe ice loads in Sweden is soft rime ice which is formed by so called in-cloud icing. Two important parameters to determine the occurrence and intensity of icing are: the temperature and the topography of the area around the site. It is therefore important not only to specify the location of the intended site but also the topography of the sites surroundings.

Unfortunately, there is so far no national instruction for determining or estimating the ice loads that may arise. In the Finnish National Annex to SS-EN 1993-3-1, [10], it is recommended that the risk of icing and its magnitude should primarily be based on statistical data for the current site obtained in cooperation with a meteorologist familiar with icing. It is a very good intention but statistical data on ice loads for different locations in Sweden is extremely difficult to find.

It is therefore a large need in national guidance concerning the determination of ice loads. Some of the principles adopted by the Finnish National Annex could probably be applied in a corresponding Swedish National Annex. For example, if icing data is not available the Finnish National Annex allows the ice load to be indirectly determined by prescribing the mast to belong to an Ice Class, covering classes from R1 to R9, see table in Figure 4. The loads for selected Ice Class are then determined according to the standard SS-ISO 12494 *Atmospheric icing of structures*, [29]. This ISO-standard also gives values for drag coefficient on iced objects. If same principles are adopted in a Swedish National Annex some corrections for the choice of ice class may be needed since it is expected that the Finnish approach overestimate the ice load to be ascribed to the mast.

For the southernmost part of Sweden the ice loads determined according this method may be overestimated since the number of days with temperature below the freezing point is much smaller compared with the northern parts of the country.

In summary, if national guidance for determining climate-related loads from icing is developed, only following information is needed to determine the load values: location of the site and, topography for the site and the surroundings of the site.

Any other requirements to be specified may for example be specific requirements on corrosion protection, or limitations in deflection during service.

3.3 Design and manufacturing

The design phase can be subdivided in to:

- specification of conditions that should apply to the design,
- determination of design loads,
- verification of resistance for the components in the mast with design calculations, and
- preparation of documentation necessary for manufacturing, assembly and inspection.

First, it is important to clarify that the design, manufacture and assembly shall be in accordance to the European standards, Eurocodes, together with National Annexes for Sweden. To the Eurocodes a large number of other European standards are relating, including product standards for materials, technical specifications and standards for execution.

In addition to the requirements given by the purchaser in the procurement process there are some other requirements concerning the execution that have to be specified. In the execution standard for steel structures SS-EN 1090-2, [12], it is said that necessary information and technical requirements for execution shall be agreed and completed before the beginning of works execution. The information referred to is execution class, tolerance class, technical requirements regarding the safety of the works, etc. Preferably, these requirements are established by mutual agreement between purchaser and designer. A similar execution standard is also available for concrete structures, [13].

In order to determine the loads on the mast several Eurocodes and other standards are needed. In SS-EN 1991-1-4, [16], and appendix B in SS-EN 1993-3-1, [28], it is dealt with wind loads. The Ice Class may be estimated by a person (meteorologist) expert in icing. Desirable would be to have a national guidance, for example similar to table of Figure 4[7] in this report, in order to selected Ice Class. When the mast is prescribed to a ice load class the loads can be determined according to SS-ISO 12494, [29]. Effects of temperature variations may be determined according to SS-EN 1991-1-5, [17]. Further, accidental loads are dealt with in SS-EN 1991-1-7, [19], and actions during execution in SS-EN 1991-1-6, [18].

When all requirements and loads are given the resistance of the mast structure and its foundation must be verified using several other Eurocodes. In SS-EN 1990, [14], together with EKS 8, [7], general methods for verification in ultimate and serviceability limit states are given. In SS-EN 1992-1-1, [20], and SS-EN 1993-1-1, [21], general rules for concrete respectively steel structures are presented. Tower and mast structures are treated in a specific Eurocode, SS-EN 1993-3-1, [28]. Guidelines and design regulations for guys and guy connections are found in SS-EN 1993-1-11, [27]. Other Eurocodes that may be needed for the design are SS-EN 1993-1-2 (fire design), [22], SS-EN 1993-1-3 (cold formed members), [23], SS-EN 1993-1-8 (bolted and welded connections), [24], SS-EN 1993-1-9 (fatigue), [25], and SS-EN 1993-1-10 (material toughness and through-thickness properties), [26].

The execution standard for steel structures, SS-EN 1090-2, [12], also specifies the quality documentation that is necessary for the constructor to prepare. For structures in execution class[8] EXC2 to EXC4 following points shall be documented:

- the allocation of tasks and authority during the various phases of the project;
- the procedures, methods and work instructions to be applied;
- an inspection plan specific to the works;
- a procedure for handling changes and modifications;
- a procedure for handling of non conformities, requests for concessions and quality disputes;
- any hold points or requirement to witness inspections or tests, and any consequent access requirements.

In April 2011 new harmonised conditions for the marketing of construction products was approved by the member states in the European Union. The new conditions Construction Product Regulation, CPR, will step by step replace the existing Construction Product Directive, CPD. The new regulations come fully

[7] From the Finnish National Annex, [10].
[8] For selection of execution class, see Annex X in SS-EN 1993-1-1. Note, Annex X is under preparation in October 2011.

into force from July 1, 2013 and from that date it is required that all construction products sold in the EU must be CE marked. This requirement applies to both individual construction products and structural kits.

The consequence of mandatory CE marking is that workshops and contractors who manufacture and supply structural components and kits in steel for a construction site in Sweden must be certified according to the harmonized standard SS-EN 1090-1, [11].

In summary, it is a massive amount of new European standards that has become effective this year. In addition to the Eurocodes that cover design, unambiguous requirements for manufacturing, assembly and inspection are given in the execution standards for steel, SS-EN 1090-1, [11] and SS-EN 1090-2, [12]. This general sharpening by clarification of requirement for the process at all stages should help to minimize the deficiencies that may arise during design, manufacturing and installation.

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[12] SS-EN 1090-2 Execution of steel structures and aluminium structures - Part 2: Technical requirements for steel structures. In Swedish

[13] SS-EN 13670 Execution of concrete structures

[14] SS-EN 1990 Eurocode - Basis of structural design. In Swedish

[15] SS-EN 1991-1-1 Eurocode 1: Actions on structures - Part 1-1: General actions - Densities, self-weight, imposed loads for buildings. In Swedish

[16] SS-EN 1991-1-4 Eurocode 1: Actions on structures – Part 1-4: General actions – Wind action. In Swedish

[17] SS-EN 1991-1-5 Eurocode 1: Actions on structures - Part 1-5: General actions - Thermal actions. In Swedish

[18] SS-EN 1991-1-6 Eurocode 1 - Actions on structures - Part 1-6: General actions - Actions during execution. In Swedish

[19] SS-EN 1991-1-7 Eurocode 1 - Actions on structures - Part 1-7: General actions - Accidental actions. In Swedish

[20] SS-EN 1992-1-1 Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings. In Swedish

[21] SS-EN 1993-1-1 Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings. In Swedish

[22] SS-EN 1993-1-2 Eurocode 3: Design of steel structures - Part 1-2: General rules - Structural fire design. In Swedish

[23] SS-EN 1993-1-3 Eurocode 3: Design of steel structures - Part 1-3: General rules - Supplementary rules for cold-formed members and sheeting. In Swedish

[24] SS-EN 1993-1-8 Eurocode 3: Design of steel structures - Part 1-8: Design of joints. In Swedish

[25] SS-EN 1993-1-9 Eurocode 3: Design of steel structures - Part 1-9: Fatigue. In Swedish

[26] SS-EN 1993-1-10 Eurocode 3: Design of steel structures - Part 1-10: Material toughness and through-thickness properties. In Swedish

[27] SS-EN 1993-1-11 Eurocode 3: Design of steel structures - Part 1-11: Design of structures with tension components. In Swedish

[28] SS-EN 1993-3-1 Eurocode 3 - Design of steel structures - Part 3-1: Towers, masts and chimneys - Towers and masts

[29] SS-ISO 12494 Atmospheric icing of structures

Appendix A: Surveys sent to operators on the Swedish wind energy market

ELFORSK - VINDFORSK III: Erfarenhetsåterföring från skador och haverier på mätmaster.

Denna enkät riktar sig till företag och organisationer som på ett eller flera sätt deltar i projektering, tillverkning och montering av mätmaster som används vid vindkraftsprojektering.

Frågorna är inledningsvis av allmän karaktär med syfte att ge en uppfattning om vilka masttyper som är vanligast och hur många mätmaster som är i drift i Sverige idag.

Därefter kommer några frågor om era erfarenheter från incidenter och haverier av mätmaster.

Enkäten avslutas med några frågor om upphandling av mätmaster.

Svaren från enkäten kommer att sammanställas och behandlas så att de inte kan kopplas till något företag eller organisation. Förhoppningen är att den information som erhålls kan bidra till handfasta råd och rekommendationer vid uppförande av mätmaster.

Med vänlig hälsning,

Claes Fahleson

ProDevelopment i Sverige AB

Tel. 0920-103 69

Inledande frågor om ert företag

1. **I vilket eller vilka skeden av processen från projektering till montering deltar ert företag?**
   - □ Konstruktionsberäkningar för mast
   - □ Konstruktionsberäkningar för fundament och grundläggning
   - □ Tillverkning av mast
   - □ Tillverkning av fundament
   - □ Montering

Allmänna frågor

Dessa frågor syftar till att ge en uppskattning av hur många mätmaster för vindmätning (för vindkraftsetablering) som finns i Sverige idag och samtidigt ge en uppfattning av vilka typer och storlekar som är vanligast.

2. **Ungefär hur många mätmaster är ni med och projekterar, tillverkar eller monterar per år?____________**

3. **Totalt hur många mätmaster uppskattar du att det finns monterade i Sverige idag?_____________**

   Fråga 3 fråga syftar på alla master som idag finns för vindmätning i samband med de olika vindkraftsetableringaroch vindkraftsundersökningar som pågår i Sverige

4. **Hur ser den ”<u>vanligaste</u> standardmasten” för vindmätning ut? Ange de alternativ som ni tycker stämmer bäst stämmer bäst.**

   Masthöjd i meter__________

   Antal stagnivåer___________

   Typ av masttvärsnitt (3-, 4-sidigt, runt, annat?) ___________

   Masttvärsnittets bredd/diameter i marknivån___________

   Eventuell kompletterande information___________

5. **Hur ser den ”<u>näst vanligaste</u> standardmasten” för vindmätning ut? Ange de alternativ som ni tycker stämmer bäst stämmer bäst.**

   Masthöjd i meter__________

   Antal stagnivåer___________

   Typ av masttvärsnitt (3-, 4-sidigt, runt, annat?) ___________

   Masttvärsnittets bredd/diameter i marknivån___________

   Eventuell kompletterande information___________

6. Har de master ni projekterar, tillverkar eller monterar annan utrustning än vindmätare i era master?

____

Denna fråga ställs eftersom master med t.ex. telekomunikationsutrustning normalt är kraftigare byggda än rena vindmätningsmaster på grund av striktare deformationskrav vid belastning.

7. För stagade master. Vilka typer av grundläggning används för förankring av staglinor?

	Aldrig	Ibland	Ofta	Alltid	Vet ej
Gravitationsfundament	☐	☐	☐	☐	☐
Bergförankring	☐	☐	☐	☐	☐
Jordankare	☐	☐	☐	☐	☐

Annat _________________

8. Hur länge brukar de master ni projekterar, tillverkar eller monterar stå innan de demonteras?_________

9. Fråga för montörer: Hur stor del av de master som ni monterar är ”begagnade master”?_________

Frågor om incidenter och haverier

Master är en typ av byggnadsverk som tenderar att ha en något lägre tillförlitlighet än andra byggnadsverk. Följande frågor syftar till att ge ett underlag för att bedöma vad detta kan bero på.

10. Har någon av de master ni projekterat, tillverkat eller monterat varit utsatt för en allvarlig incident <u>utan</u> att masten har havererat?

____

Om ni svarat ja på föregående fråga var vänlig beskriv incidenten eller incidenterna?

____

____

____

Ange antalet incidenter om de har varit flera, bedömd orsak till incidenten, typ av mast, höjd, antal stagnivåer, vidtagna åtgärder samt om möjligt vilken mast det handlade om.

11. Har någon av de master ni projekterat, tillverkat eller monterat kollapsat?

____

Om ni svarat ja på föregående fråga var vänlig beskriv incidenten eller incidenterna?

____

____

____

Ange antalet incidenter om de har varit flera, bedömd orsak till incidenten, typ av mast, höjd, antal stagnivåer, vidtagna åtgärder samt om möjligt vilken mast det handlade om.

Frågor om upphandling

Följande frågor syftar till att klarlägga eventuella brister i upphandlingsprocessen

Fråga 12 och 13 gäller för konstruktörer/projektörer:

12. Vilka av följande förutsättningar tillhandahåller normalt köparen/beställaren av mätmasten?

Vindlast (t.ex. referensvindhastighet eller indirekt genom hänvisning till mastens läge, topografi och altitud)_____________

Islast (t.ex. tjocklek på is och densitet)___________

Normer eller standarder för dimensionering____________

Krav på funktion (t.ex. tillåten vinkeländring i masten)____________

Krav på monteringsplan___________

Krav på utförande och kontroll (t.ex. genom hänvisning till standard eller norm)______________

Om köparen/beställaren brukar ange krav på funktion eller hänvisa till normer eller standarder ange hur typiska funktionskrav ser ut eller vilka standarder som hänvisas till:

____

____

13. Vilka av följande uppgifter specificerar och upprättar ni normalt i er roll som konstruktör/projektör?

Dimensionerande värde på vindlasten____________

Dimensionerande värde på islasten __________

Vilka normer eller standarder som används vid dimensionering__________

Begränsningar i mastens funktion (t.ex. maximal vinkeländring i masten)_________

Specifika krav på utförande vid tillverkning___________

Kontrollplan för tilläggskontroll vid tillverkning_________

Monteringsplan inkl. kontrollplan för montering__________

Om ni själva bestämmer vilka standarder som används, ange dessa.

____

____

<u>Fråga 14 och 15 gäller för montörer:</u>

14. **Följer monteringen normalt en upprättad monteringsplan?________**
Om JA, vem har normalt upprättat monteringsplanen________________

15. **Följer monteringen normalt en upprättad kontrollplan som t.ex. anger tillåtna lutningar, stagförspänningar, kontroll av skruvförband_________**
Om JA, vem har normalt upprättat kontrollplanen______________

Eventuella kommentarer till fråga 14 och 15:
____
____

Enkät mätmaster

ELFORSK - VINDFORSK III: Erfarenhetsåterföring från skador och haverier på mätmaster.

Denna enkät riktar sig till företag och organisationer som använder mätmaster för vindmätning kopplad till vindkraftsutbyggnad.
Frågorna är inledningsvis av allmän karaktär med syfte att ge en uppfattning om vilka masttyper som är vanligast och hur många mätmaster som är i drift i Sverige idag.
Därefter kommer några frågor om era erfarenheter från incidenter och haverier av mätmaster.
Enkäten avslutas med några frågor om upphandling av mätmaster.

Svaren från enkäten kommer att sammanställas och behandlas så att de inte kan kopplas till något företag eller organisation. Förhoppningen är att den information som erhålls kan bidra till handfasta råd och rekommendationer vid uppförande av mätmaster.

Det tar uppskattningsvis 15-30 minuter att basvara enkäten.

Med vänlig hälsning,

Claes Fahleson
ProDevelopment AB

Enkät mätmaster

Allmänna frågor

De allmänna frågorna syftar till att ge en uppskattning av hur många mätmaster för vindmätning (för vindkraftsetablering) som finns i Sverige idag och samtidigt ge en uppfattning av vilka typer och storlekar som är vanligast.

Hur många mätmaster för vindmätning har er organisation i drift?

Hur många av dessa mätmaster äger ni (räkna ej med hyrda master)?

Totalt hur många mätmaster uppskattar du att det finns monterade i Sverige idag?

Denna fråga syftar på alla master som idag finns för vindmätning i samband med de olika vindkraftsetableringar och vindkraftsundersökningar som pågår i Sverige.

Enkät mätmaster

Allmänna frågor

Vilken är er standardmast för vindmätning? Ange de alternativ som stämmer bäst.

Masthöjd i meter

Antal stagnivåer (om torn ange 0)

Typ av masttvärsnitt (3-, 4-sidigt, runt, annat?)

Masttvärsnittets bredd/diameter i marknivån

Eventuell kompletterande information

Enkät mätmaster

Allmänna frågor

Vilken är er näst vanligaste mast för vindmätning? Ange de alternativ som stämmer bäst.

Masthöjd i meter	
Antal stagnivåer (om torn ange 0)	
Typ av masttvärsnitt (3-, 4-sidigt, runt, annat?)	
Masttvärsnittets bredd/diameter i marknivån	
Eventuell kompletterande information	

Enkät mätmaster

Frågor om era mätmaster

Hur länge låter ni mätmasterna vara i drift innan mätningarna avslutas och masten demonteras? Dvs hur länge varar en mätserie?

- < 1 år
- 1-2 år
- 2-4 år
- > 4 år
- Vet ej

Enkät mätmaster

Frågor om era mätmaster

Har ni annan utrustning än vindmätare i era master?

- ◯ Ja
- ◯ Nej
- ◯ Vet ej

Om ni svarat Ja, ange vilken typ av utrustning

Denna fråga ställs eftersom master med t.ex. telekomunikationsutrustning normalt är kraftigare byggda än rena vindmätningsmaster på grund av striktare deformationskrav vid belastning.

Enkät mätmaster

Frågor om era mätmaster

Om ni använder stagade master -Vilka typer av grundläggning används för förankring av staglinor?

	Aldrig	Ibland	Ofta	Alltid	Vet ej
Gravitationsfundament	◯	◯	◯	◯	◯
Bergförankring	◯	◯	◯	◯	◯
Jordankare	◯	◯	◯	◯	◯
Annat	◯	◯	◯	◯	◯

Ge eventuell kommentarer

Enkät mätmaster

Frågor om era mätmaster

Ungefär hur stor andel av era master är master som tidigare har använts för mätning på annan plats?

- ◯ < 10%
- ◯ 11-30%
- ◯ 31-70%
- ◯ 71-90%
- ◯ >90%
- ◯ Vet ej

Enkät mätmaster

Frågor om incidenter och haverier

Master är en typ av byggnadsverk som tenderar att ha en något lägre tillförlitlighet än andra byggnadsverk. Följande frågor syftar till att ge ett underlag för att bedöma vad detta kan bero på.

Har någon av era mätmaster varit utsatt för en allvarlig incident utan att masten har havererat?

- ◯ Ja
- ◯ Nej
- ◯ Vet ej

Om ni svarat ja på föregående fråga var vänlig beskriv incidenten eller incidenterna?

Ange antalet incidenter om de har varit flera, bedömd orsak till incidenten, typ av mast, höjd, antal stagnivåer, vidtagna åtgärder samt om möjligt vilken mast det handlade om.

Enkät mätmaster

Frågor om icidenter och haverier

Har någon av era mätmaster kollapsat eller havererat?

- Ja
- Nej
- Vet ej

Om ni svarat ja på föregående fråga var vänlig beskriv händelsen och bedömd orsak?

Ange antalet händelser om de har varit flera, trolig orsak till kollapsen, typ av mast, höjd, antal stagnivåer, vidtagna åtgärder samt om möjligt vilken mast det handlade om.

Enkät mätmaster

Frågor om upphandling

Vilka av följande förutsättningar specificerar NI vid inköp/inhyrning av mätmaster?

	Ja	Nej	Vet ej
Vindlast (t.ex. referensvindhastighet eller indirekt genom hänvisning till mastens läge, topografi och altitud)	☐	☐	☐
Islast (t.ex. tjocklek på is och densitet)	☐	☐	☐
Normer eller standarder för dimensionering	☐	☐	☐
Krav på funktion (t.ex. tillåten vinkeländring i masten)	☐	☐	☐
Krav på monteringsplan	☐	☐	☐
Krav på utförande och kontroll (t.ex. genom hänvisning till standard eller norm)	☐	☐	☐
Inget av ovanstående, vi låter säljaren/uthyraren ombesörja dimensionering och montering	☐	☐	☐

Om ni brukar ange krav på funktion eller hänvisa till normer eller standarder ange funktionskraven eller berörda standarder

Enkät mätmaster

Frågor om upphandling

Vilka av följande uppgifter tillhandahåller den ni köper/hyr mätmaster av?

	Ja	Nej	Vet ej
Dimensionerande värde på vindlasten	☐	☐	☐
Dimensionerande värde på islasten	☐	☐	☐
Vilka normer eller standarder som används vid dimensionering	☐	☐	☐
Begränsningar i mastens funktion (t.ex. maximal vinkeländring i masten)	☐	☐	☐
Specifikation på utförande	☐	☐	☐
Intyg på kontroll/inmätning vid tillverkning och montering	☐	☐	☐
Inget av ovanstående, vi förutsätter att säljaren/uthyraren levererar en tillräckligt bra och säker mast	☐	☐	☐

Kommentarer

Enkät mätmaster

Frågor om upphandling

Vem ansvarar normalt för monteringen av era mätmaster?

☐ Egna organisationen ☐ Säljaren/uthyraren ☐ Företaget som monterar ☐ Vet ej

Enkät mätmaster

Kontaktinformation

Om vi skulle behöva ställa kompletterande frågor till er vill vi gärna att ni fyller i nedanstående kontaktinformation. Informationen är frivilligt, men vi ser gärna att ni anger ert företags/organisations namn så att vi inte får flera svar från samma företag/organisation.

Era kontaktuppgifter

Namn:

Företag:

E-postadress:

Telefonnummer:

Eventuella övriga kommentarer kan ges nedan

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Tack för er medverkan,

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ELFORSK

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