ON-SITE COLD CLIMATE PROBLEMS

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ABSTRACT: Many operators of wind turbines have to face problems of frequent or occasional functional impairment of turbine operation due to icing. This paper presents hands-on experience from operators as well as research results. It gives insight on the amount of time which might affect turbine operation for central Europe. Examples of the variety of on-site problems which operators and equipment have to live with are presented as well.

1. INTRODUCTION

The work presented here is being done as a part of the project "Wind Turbines in icing environment: improvement of tools for siting, certification and operation (New Icetools)" funded under FP5 contract NNE5/2001/00259 which runs from 2002-2004. This project is being co-ordinated by the Finnish Meteorological Institute. Contractors are VTT (FI), FOI (SE), Enairgy (AT), IMG (AT) and ISET (DE).

The overall objective of the project is the development and improvement of tools suitable for manufacturers, operators, developers and consultants to exploit wind energy utilisation in hostile terrain and ice-endangered sites. Areas of interest are especially mountainous regions in southern and Central Europe, arctic hills and valleys, the Alps, the coast of northern Europe and sites suitable for off-shore wind energy applications.

The paper gives figures on the probability of icing for German sites. Furthermore views and experiences of icing related problems from projects in Germany are discussed as well.

2. ON-SITE COLD CLIMATE PROBLEMS

2.1. Icing conditions

The major part of today's wind energy projects are being operated rather in landscapes with moderate climate conditions than in areas considered to be cold climate regions. However, wind turbines in operation under moderate climate can of course be struck by occasional extreme weather situations as well. According to evaluations from the "250 MW Wind"-programme around 50 reports per year on average are sent to ISET, giving details of circumstances and malfunction of operation disruption due to icing. Constraints of turbine operations due to icing in these climatic areas are usually not taken into consideration in wind farm planning[1].

The winter climate conditions in Germany and its neighbouring countries are generally spoken dominated by two major weather systems. On the one hand a continental high pressure system brings cold and dry weather conditions connected with chilly eastern winds. The other predominant system bringing maritime climate is related to low pressure systems drifting from west to east over the Atlantic ocean and transporting relatively warm temperatures even in winter. Depending on the balance of these two major systems the weather situation can change quite dynamically. With regard to wind turbine icing this means that conditions for icing, de-icing and ice free periods are subject to rapid fluctuations as well.

There are two major circumstances when icing of objects happens in nature. Depending on the conditions of the lower atmosphere either rime or glace ice will form on objects in the environment. Rime ice will occur when objects e.g. trees or wind turbines are exposed to low temperatures in combination with fog or clouds of super cooled water droplets. This kind of icing – in-cloud icing – is mostly found on hilltops or mountains. Depending on the duration of the ice conditions significant amounts of rime ice can get collected by the turbines and increase static and dynamic loads. Glace ice can occur when a warm front drifts above cold air. The falling rain can get cooled down to temperatures below the freezing point without actually freezing into solid ice. If the "super cooled" rain hits the surface or objects with temperatures below 0° Celsius it will instantly turn to a layer of solid ice. This weather phenomenon is commonly known as "ice rain". [2], [3].

2.2. Estimation of icing days for onshore projects

According to own evaluations of data from the German Meteorological Service (DWD) the average number of days with maximum temperatures below 0°C is about 20 days. Depending on the location of the met-station and the evaluated year this data may vary significantly. So the minimum number of registered days with maximum temperatures below 0°C equals 1 (!), while the maximum value is 77 days. If the relative humidity of the air is additionally taken into consideration in the evaluation this number changes significantly, e.g. to an average of 11 days for relative humidity above 85%. This value complies very well with observation from turbine operators in Germany, who have reported of disturbance due to icing in the range from a few days up to two weeks. The complete result list is compiled in Table 1. The evaluated data refer to more than 110,000 records of daily met-data from 28 stations in the time period from 1991 to 2002. At different locations, e.g. in mountainous regions or in arctic areas the overall duration of icing conditions can be significantly higher.

Table 1: *Number of days with icing conditions in Germany*

Number of days	Weather conditions			
	max. temperature = 0° C	max. temperature = 0° C and rel. humidity > 85%	min. temperature = 0° C and rel. humidity > 90%	min. temperature = 0° C and rel. humidity > 95%
Minimum	1	1	1	1
Maximum	77	54	41	26
Average	**19**	**11**	**7**	**4**

2.3. Estimation of icing days for offshore projects

The analysed data includes three met-stations which can be used as a first exposure to estimate icing conditions to be expected for offshore wind energy projects in the German waters of the North and Baltic Sea. The meteorological stations are located on the islands of Helgoland and Sylt (North Sea) and Fehmarn (Baltic Sea). The best compatibility to offshore weather conditions are to be expected from the island Helgoland. This tiny island is located in a distance of about 70 km to the coast. It's area of approximately 1,0 square kilometre is rather small. The two other mentioned islands Sylt and Fehmarn are much bigger in size and closer to the mainland (Sylt: area ~100 km², distance to mainland~10 km; Fehmarn: area ~185 km², min. distance to mainland ~1 km). The query results for these selected weather stations show that the icing "footprint" has been measured less frequent for data of the three analysed islands. The data results are compiled in Table 2.

Table 2: *Estimation of days with icing conditions for offshore applications*

Number of days	Weather conditions			
	max. temperature = 0° C	max. temperature = 0° C and rel. humidity > 85%	min. temperature = 0° C and rel. humidity > 90%	min. temperature = 0° C and rel. humidity > 95%
Helgoland (1991 – 2002)				
Minimum	0	0	0	0
Maximum	33	10	5	1
Average	**6**	**2**	**1**	**0**
Sylt (1991 – 2002)				
Minimum	2	1	0	0
Maximum	46	20	11	6
Average	**11**	**7**	**4**	**1**
Fehmarn (1996 – 2002)				
Minimum	1	1	0	0
Maximum	19	12	6	3
Average	**7**	**5**	**3**	**1**

2.4. Ice accretion on wind turbines

According to operator reports [1] and own observations turbines affected by ice accretion react in different ways according to the relevant ambient and initial turbine conditions. The initial conditions of the wind turbine (WT) can be divided into operating, idling or paused/stopped turbine. The ambient conditions can be classified into various kinds of icing conditions in combination with sufficient wind for turbine operation or calm air.

Ice accretion can be collected by all parts of the turbine structure. The normal turbine operation is mostly influenced by firmly bonded deposit of ice on the rotor blades and on sensors for wind speed and wind direction. The reactions of WT to ice accumulated e.g. on the blades are multiple. Ice accretion on rotor blades changes the surface and geometric dimensions of the rotor blades and thus affects their aerodynamic design properties (Fig.2). According to calculations from the WECO-project [4, 5] the power output of a pitch regulated turbine will be reduced already for only little amounts of ice adhered to the leading edge. With increasing amounts of ice the original power curve will be changed into a power curve showing the aerodynamic characteristics of rotor blades designed for stall operation (Fig 3). A reduction in power output means less electricity production and thus reduced financial efficiency. If the icing conditions last for a longer period of time the economic viability of the project may not be secured. Moreover static and dynamic loads can increase significantly and may cause emergency shutdowns due to severe vibrations of the whole structure. A compilation of possible effects due to icing to a turbine is shown in Table 3.

Fig.2: Modification of aerodynamic design of a iced rotor blade [4]

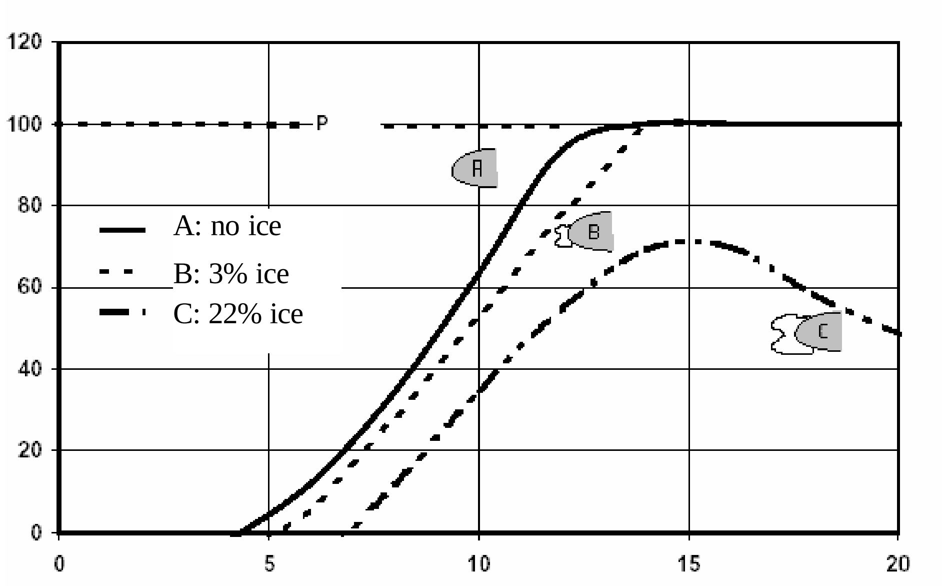

Fig. 3: Calculated power curves of a pitch turbine with different amounts of ice accretion [4]

2.5. Other issues

Besides the direct effects of icing to the wind turbines itself there are a few other issues to be considered as site specific cold climate problems. These problems concern for instance site accessibility, noise, safety regulations, production losses, and financial losses.

- **site accessibility**: The access to WT site by the operator or service personnel may be restricted or completely impossible during winter seasons for many locations, especially in mountainous regions. This may affect the duration of downtime significantly even for standstills caused by minor failures. Reasons for reduced accessibility can be snow or ice covered access roads, roads blocked by broken trees, etc.

- **noise**: wind turbines increase their emissions of aerodynamic noise significantly if the rotor blade is partially covered with ice fragments due to an increase of turbulence of the airflow around the rotor blade. This might lead to complaints of residents if the turbines are operated in the vicinity of villages or other accommodation facilities.
- **safety regulations**: debris of ice from wind turbines can be dangerous if persons, animals or other objects get hit by ice fragments. According to reliable calculations there is no significant risk ($< 10^{-7}$) from ice fragments in a distance from about 250 m from any turbine [6]. It has been reported that in a few cases authorities in Germany have obliged operators to shut down turbines for safety reasons, whenever air temperature is below 0° C.
- **production losses**: this is one of the main issues as already shown above, Production losses occur due to reduced power output caused by decreased aerodynamic efficiency of iced rotor blades. Furthermore downtimes can be prolonged significantly if the turbines are not accessible for service and operators due to closed roads. Disruption of aerial lines by broken trees have also been reported as a reason for significantly long turbine downtimes.
- **financial losses**: these are connected directly to production losses. Longer downtime periods can lead to a decrease in liquidity up to bankruptcy of projects.

Table 3: *Overview of possible effects to wind turbine (WT) under icing conditions*

Effects	WT Operating	WT Idling	WT Stopped
Reduced aerodynamic efficiency	✓	✓	
Untrue sensor signals	✓	✓	✓
yaw angle declination	✓	✓	✓
Reduced power output	✓		
Noise increasement	✓	✓	
Vibrations	✓	✓	
Increased loads (static / dynamic)	✓ / ✓	✓ / ✓	✓ / -
Ice throw / drop	✓ / ✓	✓ / ✓	- / ✓
Plant stoppage	✓	✓	
Restart problematic		✓	✓
Financial difficulties	✓	✓	✓

3. CONCLUSIONS

Wind turbine operation under icing conditions can lead to variety of problems on-site. These problems might affect – directly or indirectly – the economic viability of wind power projects due to reduced energy production or significant downtimes. Statistical evaluations of meteorological data from Germany show that icing conditions are to be expected for about 10 to 15 days per year on average. According to a first evaluation icing does not seem to be a serious problem for offshore projects in German waters of the North and Baltic Sea. However, significantly longer periods have to be expected in mountainous or arctic regions. One big public concern of iced turbines is safety. However, the ice throw or drop from wind turbines has to follow physical laws. According to a risk assessment the danger to get hit by a piece of ice from a wind turbine can be quantified as considerably low to individuals and objects beyond distances of 200 – 300m.

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REFERENCES

[1] Durstewitz, M.; A statistical evaluation of icing failures in Germanys "250 MW Wind"-Programme – Update 2003 –; BOREAS VI; April 9-11, 2003, Pyhä; Finland

[2] Lacroix, A., Manwell, J.F.; Wind Energy: Cold Weather Issues; University of Massachusetts at Amherst; Renewable Energy Research Laboratory; June 2000, http://www.ecs.umass.edu/mie/labs/rerl/research/Cold_Weather_White_Paper.pdf visited March 2003

[3] Durstewitz, M.; Frozen wind turbines; DEWI-Magazin. Windenergie – Wind Energy – Energia Eólica, No. 22; Feb. 2003.

[4] Seifert, H.; Betrieb von Windenergieanlagen unter Vereisungsbedingungen – Ergebnisse und Empfehlungen aus einem EU – Forschungsprojekt; AUF·WIND 99 St. Pölten, October, 21- 22, 1999, Austria

[5] Seifert, H., Richert, F.; A recipe to estimate aerodynamics and loads on iced rotor blades; Proceedings Wind Energy Production in Cold Climates, BOREAS IV, 31 March – 2 April 1998; Hetta, Finland

[6] Morgan, C., Bossanyi, E.: Wind turbine icing and public safty – A quantifiable risk? Proceedings Wind Energy Production in Cold Climates, BOREAS III, 19–21 March 1996; Saariselkä, Finland