Multi Sensor Atmospheric Icing Station Performance in Cold Climate- A Case Study

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***Abstract*— To amicably acquire the data through sensors is posing a big challenge in harsh cold climatic conditions. In comparison to operation under ambient weather conditions, cold region has more challenges to offer in terms of system performance and consistent reliable measurements. The drastic changes are evident in sensors measurement over a period right from the start of installation and normal routine operations till its degradation. The range of factors influencing the system performance is quite diverse in nature and always not easy to ascertain, but with the introduction of standardized design, installation, integration, and maintenance procedures the mean time between failures can be increased considerably. In the said context, cold and harsh environment plays an important role in provoking the undesirable events. This paper discusses the system performance of a custom based meteorological ice monitoring station installed in Northern Norway. The overall system design in perspective of data acquisition and logging is analyzed along with pinpointing of the degradation of the sensors and associated data validation over a period of time. The impact of the variations in climatic conditions is presented including the probable causes affecting the system performance in brief.**

Keywords-*atmospheric icing; sensors; operation; performance; cold region.*

I. INTRODUCTION

Heavy icing loads and icing events are crucial parameters for structural design in cold climatic regions. The unpredictability elements in such situations could easily cause extensive ice loading on equipment/sensors and structures within no time. Simultaneously, human activities are increasingly extending to the cold climate regions due to the availability of extensive unexplored natural resources, where, atmospheric icing not only creates human inconveniences, but also affects human activities especially in the construction industry (communication towers and ski lifts), energy distribution (power network cables and towers), maritime activities, aviation conditions on the ground, meteorological observations and wind energy power production [1]. Various structures such as, power network cables, telecommunication masts, and others have been damaged or destroyed on numerous occasions due to the added mass of ice or an increase in aerodynamic interaction leading to unacceptable movements [2]. To avoid certain situations and for a better preparedness and more reaction time for preventive measures, it is essential to predict such events involving extensive databases over longer periods of time.

Atmospheric icing on structures occurs in conditions where cooling of an air mass causes super cooling of water droplets resident in the air mass. Water droplets in the earth atmosphere can remain in the liquid state at air temperature as low as -40 ^{o} C, before spontaneous freezing occurs [3],[4]. The rate of atmospheric ice accretion on a structure is governed by two processes; the impingement of super cooled water droplets on the structure surface and surface thermodynamics, which determine what portion of the water droplets, will freeze or, on the other hand, cause melting of previously accreted ice. The systems installed under cold climate conditions to monitor atmospheric icing are subjected, directly or indirectly, to harsh environmental conditions affecting their performance and resulting in intermittent or unreliable behavior. The unpredictable nature of the climatic changes leads to uncertain behavior of the equipment, which can ultimately lead to missing project timelines, loss of significant data and excessive utilization of resources and capital. Therefore, detailed knowledge of frequency and duration of icing events, as well as, maximum ice loads are crucial parameters for the design of structures in cold regions.

To achieve this goal, an atmospheric ice monitoring station based on metrological equipment was designed within the ColdTech-RT3 project at Narvik University College, Norway. The system was installed at the mountain height, ‘Fagernsfjellet (1007 m.a.s.l., 68˚ 25’20’’ N, 17˚ 27’26’’ E) located east from the Ofotfjorden and towards the north east from Beisfjorden on the western coast of Norway, as shown in Fig.1. The region is affected by the Gulf streams flowing across the North Atlantic Ocean, which retains the coastal area at sea level ice free. The mountain faces the open sea from the south across the SW towards the west. Air masses related to these streams are usually humid and have air temperatures favorable for atmospheric icing during the winter season ($-25<T$ ºC <0). The objective of this paper is to analyze the performance of metrological sensors under harsh cold environment; practical issues are highlighted based on their impact on the overall system performance.

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Figure 1. Location of HiN atmospheric icing station, Fagernsfjellet, Narvik, Norway.

This paper is arranged in three main sections. In the section two, the design of a remote icing station is briefly explained. This section is followed by the performance evaluation of this icing station (Section III). In the last section, the reasons for the station failure are evaluated based upon the experience and some technical flaws, which are planned to be avoided in the next installation.

II. DESIGN OF THE ATMOSPHERIC ICING STATION

The multi-sensor ice monitoring station used for this study was comprised of a multifunctional weather sensor (*Lambrecht – ELOS IND)* along with an ice load monitor (*Ice Monitor- Combitech*) and a (*HoloOptics T44*) icing rate monitor. A robust industrial scale data logging system Campbell Scientific (*CR1000*) was used for data-logging over a longer period of time in harsh cold conditions. The multifunctional weather station measures five parameters namely: wind speed and direction, temperature, humidity, atmospheric pressure and dew point. The ice monitor yields the accreted ice mass, whereas the HoloOptics icing rate monitor gives the icing rate. The data acquisition (*DAQ*) system and dc-power distribution/supply units (used for icing station) were housed inside the small winterized cabinet mounted inside the available facility at Fagernsfjellet, utilized for skiing and tourism.

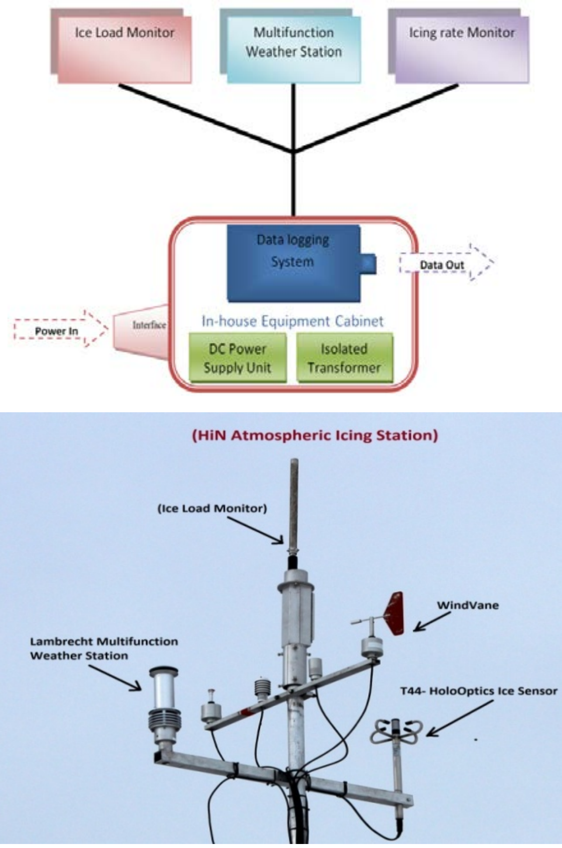

Figure 2. HiN Atmospheric icing station at Fagernsfjellet, Norway

The main power source for this station was acquired from the existing facility at the site. The data retrieval option was exercisable through RS-232 port through which data could be accessed, stored, deleted, overwritten, and appended by the vendor software interface. The overall system breakdown in terms of sensors and major elements is shown in Fig. 2.

III. ATMOSPHERIC ICING STATION PERFORMANCE

The sensors used for HiN atmospheric icing station were designed for cold climate and the performance parameter were expected to satisfy the desired outcome, but still these were affected by the cold environment with the uncertainty element inside and the sensors output was evident after the data-retrieval. Icing station was installed at Fagernesfjellet during the 2nd week of October, 2012. To have a quality check on the icing station data, icing station was planned to

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be inspected periodically after its installation, but this task could not be accomplished several times mainly due to harsh weather conditions and associated facility's maintenance problems and logistics, which were also linked to the alternative mode of transportation to the site (*cable car and snow bikes*). The installed equipment could only be reached and tested first time four months after its installation. Initial analysis of retrieved data from the icing station showed that from the installation date the system component's operations were normal as expected, but within a few days the HoloOptics sensor malfunctioned and started to provide erroneous icing rates. Similarly, after seamless operations of one week the atmospheric temperature and relative humidity parameters from the *Lambrecht – ELOS IND* were defective. The remaining parameters of *Lambrecht – ELOS IND*, such as: wind speed, direction and dew point were satisfactory for the following two months but turned erroneous for the remaining period of operation leaving the ice load monitor as the only valid amongst the data-set recorded in the logger system. Occurrences along with related measured observations to have a vivid understanding of the system's performance in the duration span of approximately six months after installation are shown in Table 1.

TABLE 1
ATMOSPHERIC ICING STATION OPERATING PARAMETERS

S.No.	Parameter Description	Sensor	Correct Funtionality Period	Unserviceability Reported After	Last Valid Recording
1.	Ice rate	Holoptics T44	1 days	04- Months	0 (No Ice)
2.	Humdity	*Lambrecht – ELOS IND*	1-week		93.5%
3.	Atm. Temp (C)				0
4.	Dew Point Temp (C)				0
5.	Wind speed (Avg)	*Lambrecht – ELOS IND*			6 m/sec
6.	Wind direction		2 Months		NE
7.	Avg Pressure		5 Months		930
8.	Ice Load	*Ice Monitor-Combitech*	Complete Period	Nil	N/A

The equipment maintenance checks were performed in more details after data retrieval. Initial investigation at the station site disclosed that degradation of atmospheric icing station component performance was mainly the result of weather changes specifically related to the region where the combination of several climate factors negatively impacted the sensors, both in terms of the mechanical and electrical failures. Heavy ice deposition on the exposed components of sensors, power extension (interface) and frequent power break downs of the associated facility (through which the main power was supplied) caused the malfunctioning of the sensors.

Despite the fact that sensors used in the reported ice monitoring station were designed to withstand harsh cold weather conditions, the weather sensor malfunctioned unexpectedly at cold conditions. The minimum atmospheric temperature reached -25 °C at the installation site and varied considerably; it was observed that the equipment got unserviceable at 0 °C. It is worth mentioning here that the weather sensors were functional at -25 °C during this study, but analysis of atmospheric data for the last 12 hours prior to failure of the weather sensor indicated that the initial crash occurred at 0 °C, average wind speed was 6 m/sec, relative humidity was 93.5%, and most importantly, the average icing loads on ice monitor were quite high. Analysis confirms the combination of extreme weather conditions leading to heavy ice loads at the time of malfunctioning of the weather sensor. Wind direction and wind speed data for the period of 12 hours preceding the crash of the weather sensors are presented in Fig. 3.

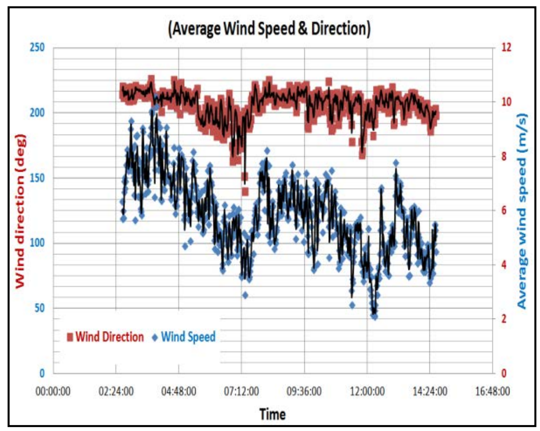

Figure 3. Wind speed and wind direction data for the seamless period of 12 hours prior to malfunctioning of the weather sensor.

It is observed from Fig.3 that wind was southwesterly at an average speed of 4 to 8 m/s. The southwesterly side of mount Fagernesfjellet faces the Beisfjord and the Ofotfjord of the Atlantic, which means that the wind is loaded with water droplets.

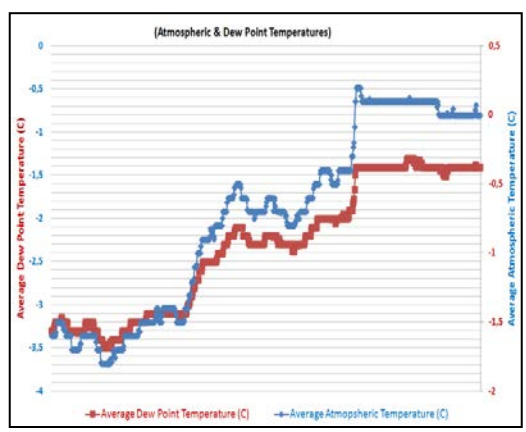

Figure 4. Atmospheric temperature and due point data for the seamless period of 12 hours prior to malfunctioning of the weather sensor.

Atmospheric temperature and due point data for the seamless period of 12 hours prior to malfunctioning of the weather sensor is represented in Fig. 4. It is observed that temperature was generally below freezing. It is also observed that the dew point was less than average temperature for the last few hours, which can be interpreted as a cause of freezing of the water droplets in the air mass blowing across the weather station. Those reasons coupled with the wind data indicating the presence of water vapors in the air blowing from the sea and dropping temperatures and dew point to below freezing will cause ice accretion once the droplets get in contact with freezing particles or surfaces such as the icing station or other objects in the region. Those expectations are confirmed by the available measurements of humidity and ice loads represented in Fig. 5 below.

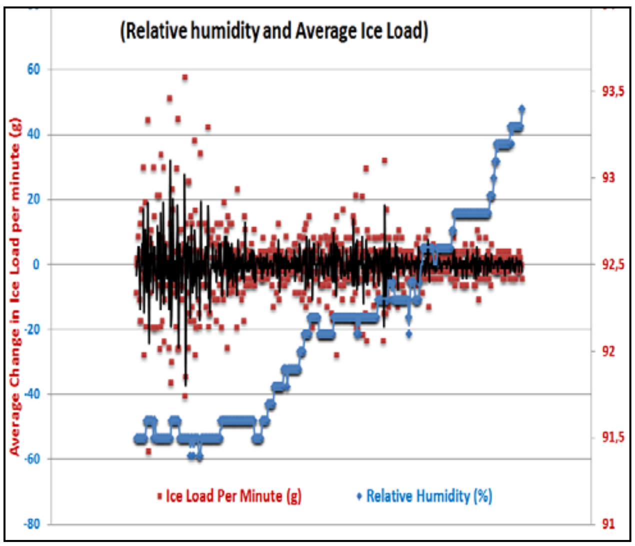

Figure 5. Relative humidity and icing load data for the seamless period of 12 hours prior to malfunctioning of the weather sensor

Fluctuations are observed in ice load measurements, but those fluctuations are in correlation with variations in humidity. The ice load readings are highest at lower humidity due to the fact that some of the humidity in the air is transformed into accreted ice on the system components.

IV. Reasons of System Failure

The dimension of operational problems faced in cold climate is quite different from the operations in normal atmospheric conditions. More often, the factors not significant at all in the normal conditions become extremely critical in cold climate regions. Investigations were carried out to track down possible reasons of the HiN icing station's components failure from operational point of view. Analysis showed that in addition to the harsh weather conditions, a combination of various design and operational aspects could also lead to the system's failure in harsh conditions. In the following, we present some noteworthy causes in this regard.

a) Intermittent Power Source

The system installed at the location takes power from the available commercial facility, where high load machines are being operated. Due to the demographic location of the site in terms of accessibility and complicated power infrastructure available in terms of maintenance, several power breakdowns have been frequently reported. The instantaneous power surge could be one reason that has affected the sensors operations.

b) Electrostatic Discharge

The electrostatic discharge phenomena could not be fully neglected in weather station breakdown. For snowstorms, temperature gradients in the ice particles produce charge separation because the concentration of H+ and OH- ions in ice increases rapidly with increasing temperature. H+ ions are much more mobile within the ice crystal than OH- ions. As a result, the colder part of an ice particle becomes positively charged, leaving the warmer part charged negatively [5]. The resulting electrostatic phenomena due to blizzard can be hazardous for the control circuitry inside the sensor module, provided the said consideration is not catered for in the design. Over and above this fact, the proper maintenance of earthing at the site becomes all the more critical in this perspective.

c) Data Links / Interfaces Winterization

Interface links between the components are data and power based. Data links might include the Ethernet/serial links with supporting routing cables or interface panels, whereas, power links have distribution panels, supplying power requirements to the computing and sensing equipment. Interface links along with power support systems have direct and/or indirect exposure to cold climatic conditions and they are under sudden transitional states, hence are most vulnerable to degradation and failure.

d) Power Cable Insulation

Electrical insulation of external power cables can be another possible cause of system failure. Many of the insulations normally used on electrical wires and cables are not compatible with colder temperatures. Cracking of the insulation exposes the conductor to the environment creating a serious hazard. This is particularly a problem for the extension cords used outdoors. Several polyvinylchloride (PVC) insulations that are commonly used as electrical insulation do not withstand flexing at low temperatures, in the range of or below -30ºC, PVC insulations crack and peel off leaving exposed conductors, which can cause short circuiting or develop grounding problems making data unreliable[6],[7].

e) Material & Winterization

The sensitivity of problems encountered in cold regions is largely a function of materials used in the sensor construction and degree of stress, under which they are operated. Some materials get stronger at cold temperatures while other materials can be altered to become more cold tolerant [6],[8]. Similarly, sensor winterization can be another possible reason for this failure. Sensors must be properly winterized to make them possible to use during winter and reduce cold related wear and breakage [9].

V. CONCLUSION

Based on the experience from the operation of a multi-sensor ice monitoring station, it is evident that factors leading to sensor failure in cold climate regions are generally overlooked. Failure of the sensor components during this expedition has raised questions regarding the standards specified for the design of sensors for cold regions. Anticipated and preventive design, monitoring, and maintenance culture should be invoked as a regular practice, which could encounter the unpredictable impact of cold harsh environment upon sensor operation and performance. The problem areas identified and discussed can be utilized as guidelines for better design, integration, installation, and maintenance of sensors installed in remote cold regions.

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