Icing events assessment of a wind park in high wind speed

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Abstract

Cold regions have good wind energy potential due to low temperature and higher air density. Wind resource assessment at cold climate sites is challenging, but important, as wind energy projects development decisions are based on these estimated results. This paper describes a case study of one year (2014) icing event assessment using seasonal SCADA (Supervisory Control and Data Acquisition) data analysis and WRF (Weather Research and Forecasting) simulation of a wind park located in the high north. SCADA data analysis have been carried out with the main focus on seasonal effects on wind power production and icing events assessment and has been sorted in three seasons; winter 1, winter 2 and summer, where results show that seasonal effects are considerable on power production of the wind park. Mesoscale WRF simulations are carried out in addition to microscale Computational Fluid Dynamics (CFD) based simulations for better estimation of wind resources under icing conditions, where a good agreement is found with the wind park field SCADA data. Both SCADA and mesoscale WRF methods used for assessment of icing events in this paper are focused on high wind speed conditions (from 20 to 25 m/s). Icing events assessment under high wind speed analysis shows that icing events depends on the meteorological conditions, wind flow behavior as well as the location of the wind turbine. Even in same wind park, it is not sure that ice will accretes on all the wind turbines as the wind park layout and change in flow behavior due to wind turbine wakes can effects the occurrence of ice accretion despite the favorable conditions for icing events.

Keywords: SCADA, WRF, seasonal effects, wind energy, icing, high wind speed.

1. Introduction

Low temperature and high wind speed in ice prone regions are not the most favorable sites for the wind energy projects despite having good wind resources, mainly due to icing that has been recognized as a hindrance limiting the wind energy production at elevated cold climate sites. Estimated wind energy capacity in cold climate areas is about 60 GW [1]. When developing a wind park in ice prone cold region, it is important to better estimate the impact that icing may have on its installation, operation and maintenance. Icing events are defined as, periods when the atmospheric temperature is below 0 $^{\circ}$ C and the relative humidity is above 95% [2]. Icing conditions affect the underlying wind resources by reducing the available energy yield that the wind turbines are able to capture [3]. To better estimate the Annual Energy Production (AEP) of a wind park in cold region, in addition to standard meteorological parameters such as wind speed, direction and temperature, the information about possible icing events (type, frequency load and duration) is also important to be known. Investment decisions for wind park development in cold regions are based on better assessment of the icing conditions and its resultant effects on wind energy production. The severity of icing varies depending on local weather conditions, and the wind park site altitude compared to the average height of the terrain as the planetary boundary layer (PBL) in High Latitude Cold Climate (HLCC) regions [4] has a significant difference when compared to the lower latitudes, primarily due to reason that in HLCC regions thermal energy is unavailable to drive transport processes for majority of the year, in addition, these transport processes modulate the local atmospheric structure.

Different techniques have been used for wind resource and icing events assessment in cold regions

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involving meteorological field measurements and numerical modelling of weather forecast. A combination of validated meteorological modelling approach and onsite measurements of wind resources are used to evaluate the energy yield potential of wind park site. Numerical modelling approach can also be used to develop the icing map of the region to provide information about icing intensity, duration or impact to the developers in the planning phase of a wind park project in cold region. Mesoscale atmospheric model simulations are used to provide the spatial weather information needed to create the icing map, such as WRF. Meteorological field instruments are used for wind resource assessment to collect and sample the data on regular time intervals, where different techniques are used for sorting, filtering and analysis of this data, such as SCADA, WRF, CFD and so on. For wind turbines, SCADA system is used to collect a database of time series of temperature, wind velocity, power production, etc. Statistical methods like mean, standard deviation, regression, sample size determination, hypothesis testing etc. are used to analyze this database in daily, monthly and annually time intervals. In the cold regions, when performing the SCADA data analysis, it is necessary to consider low-temperatures & icing events. SCADA data from wind turbine can be used as icing event indicator after performing a detailed data filtering and analysis. This paper is focused on using wind turbine SCADA data to identify the icing events and their effects on resultant energy production of a wind park in high north. Moreover, WRF simulations are used to compare with SCADA data and better estimate and forecasting of icing events for the wind park.

2. Wind Park Site Description

The wind park used in this study is located in Arctic region and consists of 14 wind turbines at an average elevation of 400 m.a.s.l. This wind park is situated in High Latitude Cold Climate (HLCC) regions, which makes it suitable for the objective of this study. All 14 turbines' SCADA data collection is used to study resultant icing events for one year (2014). Figure 1 shows the wind park site during summer and winter periods.



Fig. 1. Wind Park during summer (left) and winter (right) periods.

3. Results and Discussion

Based on the Annual Energy Production (AEP) comparison and operational availability from this wind park, both SCADA and WRF simulations have been used for icing events assessment of this wind park. For these wind turbines, cut in wind speed is 3m/s; cut off wind speed is 25m/s and the intersection point between thrust coefficient and power production is 11m/s. Six wind turbines are used for SCADA analysis. In addition, all wind turbine icing events has been studied for high wind conditions (from 20 to 25 m/s). One the other hand, reference turbine (Turbine 01) is selected to do WRF simulations in order to make the better overview and forecasting of the meteorological conditions and resultant icing events.

3.1. SCADA Data & Icing Events Analysis

One year (2014) SCADA data from six wind turbines of the wind park has been used for this study,

which includes meteorological and production data for every 10 minutes. For each year, SCADA data is sorted in three seasonal categories; 1) winter 1 (January to April); 2) winter 2 (October to December); & 3) summer (May to September) to better understand the seasonal effects of icing events on the wind power production. Results of seasonal effects on wind power production for 6 reference turbines are given in Figure 2 by using the average percentage of wind power production comparison. Analysis shows that in some cases, power production is significantly reduced from nominal capacity during wintertime below freezing temperature, which can be indication of possible icing events occurrence and as a result – loss of power production due to degraded performance of iced wind turbine. Ice accretes on leading edge of the wind turbine blades, which significantly changes its aerodynamic performance. Such change in aerodynamic performance effects the torque and overall performance of the wind turbine blade.



Fig. 2. Wind power production comparison.

COST 727 report [2] described that the type of accreted ice on a structure can be a function of wind speed and air temperature. As mentioned in previous section that SCADA data has been sorted in three seasons (*Winter 1, Winter 2 and Summer*) to better understand and analyze the seasonal effects on wind power production. Seasonal effect study shows that during winter 1 and winter 2, each season has possibility of different types of accreted ice. Change in ice type, effects the ice density, which results in different accreted ice loads and a significant change in wind turbine performance and resultant power production. In case of highly dense ice (glaze/mix ice) the ice loads are high and accreted ice shapes are more complex, whereas for the low dense ice (dry ice) the ice loads are not high and ice shapes are streamlined. Fig. 3 shows the example case of Turbine 01, where the relation between average wind speed and temperature shows three different types of ice regimes with change in operating temperature and wind speed as described in COST 727 [2].



Fig. 3. Type of ice classification for Turbine 01.

Analysis shows that the average temperature during winter 1 was less than winter 2. Analysis about icing type shows that most of the time during winter 1, the meteorological conditions were in favour of soft rime ice, whereas during winter 2 was hard rime. For these analysis the icing events occurrence criteria is selected assuming these conditions: temperature below 0 $^{\circ}$ C; wind velocity more than 20m/s, as well as the power production between 600–2200 kW. The occurrence frequency of these conditions selected to be at least 3 times in a row for same day to confirm an icing event. Figure 4 shows the results of SCADA data analysis about occurrence of icing event for each wind turbine. It is interesting to note that duration and timing of icing event is different for different wind turbines, which clearly indicate that an icing event depends upon the local meteorological conditions, wind flow behaviour and location of the wind turbine. Even in same wind park, it is not certain that ice accretes on all wind turbines. The wind park layout and change in flow behaviour effects the occurrence of ice accretion, despite the favourable conditions for icing events. This is clear from results presented in Figure 4, where "1" means icing events occurred, "0" means no icing event.



Fig. 4. Icing events occurrence of 14 turbines in 2014.

Analysis show that icing events occurred 09 days at this wind park site and most icing events occurred from January- April (winter 1). Further analysis show that during most icing events the meteorological conditions fall in hard rime ice category.

3.2. WRF Simulations and Forecasting

WRF simulations focuses on turbine T01 as a reference turbine and the simulation domains are set up as two telescoping nested domains with grid spacing of 15000m×15000m, 5000m×5000m for domain 1 and 2 respectively and the time step is set to 80 seconds. The temporal resolution of WRF is selected to 10 minutes to get one-to-one comparisons to the observational SCADA data.



Fig. 5. Geometric map for WRF simulations.

WRF simulation mainly focus on the specific dates (5 days for Turbine 01). The simulated results wind speeds and temperatures for those icing events are shown in Table 1 and Table 2. In WRF-simulation, ρ denotes the correlation coefficient, and p denotes the p-values. The temperatures are simulated at 2 meters above ground level.

Icing	On-site		WRF-simulations								
events			Domain 1				Domain 2				
Day	Mean	St. dev.	Mean	St. dev.	p(obs,d01)	p(obs, d01)	Mean	St. dev.	p(obs,d02)	p(obs, d02)	
08.03	14.54	7.26	14.93	4.11	0.79	2.79 10-31	15.42	4.71	0.83	3.38 40 ⁻³⁶	
12.03	15.36	6.81	12.76	6.34	0.97	9.81 10-89	13.35	7.14	0.97	7.63 40 ⁻⁸²	
14.03	20.95	2.09	20.83	2.31	0.36	3.16 10 ⁻⁴	21.60	2.84	0.35	5.33 10-4	
20.03	13.46	6.39	14.70	6.03	0.95	$1.80 \cdot 10^{-69}$	9.56	5.50	0.95	1.99 10 ⁻⁷²	
19.04	17.55	2.80	16.23	1.76	-0.23	7.09 10 ⁻³	16.41	1.66	0.24	3.69 10 ⁻³	

Table 1. The simulated wind speeds (m/s) for icing events at Turbine 01.

Table 2. The simulated temperatures (Kelvin) for icing events at Turbine 01.

Icing	On-site		WRF-simulations								
events			Domain 1				Domain 2				
Day	Mean	St. dev.	Mean	St. dev.	ρ(obs,d01)	p(obs, d01)	Mean	St. dev.	p(obs,d02)	p(obs, d02)	
08.03	273.0	1.12	271.79	0.91	0.90	~0	272.35	1.01	0.91	~0	
12.03	273.4	0.62	271.52	1.14	0.48	$2.55 \cdot 10^{-9}$	272.09	0.94	0.59	3.93 10-14	
14.03	271.8	0.44	271.04	0.32	0.03	0.79	271.70	0.33	0.40	$4.49 \cdot 10^{-5}$	
20.03	262.5	0.83	260.86	1.74	-0.11	0.21	261.80	2.31	0.01	0.90	
19.04	274.4	0.92	272.70	0.90	0.77	9.20 10 ⁻²⁹	273.30	0.91	0.75	$2.48 \cdot 10^{-26}$	

From Table 1 and Table 2, results shows on-site and WRF simulation comparison for each icing case of Turbine 01. According to Table 2, on March 14 of 2014, the average wind speed is highest within these icing dates, whereas the average atmospheric temperature is lowest, around -10 $^{\circ}$ C. Taking into account of this paper, highest wind speed and lowest temperature dates can be the sample models for WRF and SCADA comparison. For the highest wind speed event (March 14, 2014) and lowest temperature event (March 20, 2014), the wind speed and temperature comparison of WRF domain 1, WRF domain 2 and SCADA data shows in Figure 6. Compare Table 2 and 3 with Figure 6, same as other icing events, considering the simulation and prediction of the atmosphere with wind park model, the mesoscale from WRF simulation about specific icing events shows a good agreement with SCADA data from this wind park.



Fig. 6. Wind speed and temperature comparison

4. Conclusion

This paper described a case study of icing event assessment and seasonal effects on wind power production using SCADA data analysis and WRF simulation of a wind park in high north region. Analysis show a significant change in power production during summer and winter time periods, which clearly highlights the importance of seasonal meteorological conditions on performance of a wind park in cold region. The results in this paper show that duration and timing of icing event is different for different wind turbines in a wind park, which clearly indicate that icing events depend on the local meteorological conditions, wind flow behaviour and also the location of wind turbine. Even in same wind park, it is not given that ice will accretes on all wind turbines. The wind park layout and change in flow behaviour effects the occurrence of ice accretion, despite the favourable conditions for icing events. In this case study, icing events has been successfully identified using SCADA data. WRF simulation have a good agreement with meteorological field data. Results show that during one year (2014) icing events occurred 9 days at the wind park. Most of icing events occurred from January- April months (Winter 1). Further seasonal analysis of large data set of at least five years are recommended for future studies of icing events assessment.

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References

- Baring-Gould, I., et al., IEA Wind Recommended Practice 13: Wind Energy in Cold Climate. IEA Wind Task XIX, VTT, Finland, 2012.
- [2] Fikke, Svein M., et al. COST 727: atmospheric icing on structures: measurements and data collection on icing: state of the art. Meteo Schweiz, 2006.
- [3] Ville L, IEA Wind task 19- wind energy in cold climates- available technologies report, 2016.
- [4] Xie, SP, Liu WT, and Nonaka M. (2001), Far-reaching effects of the Hawaiian Islands on the Pacific Ocean.