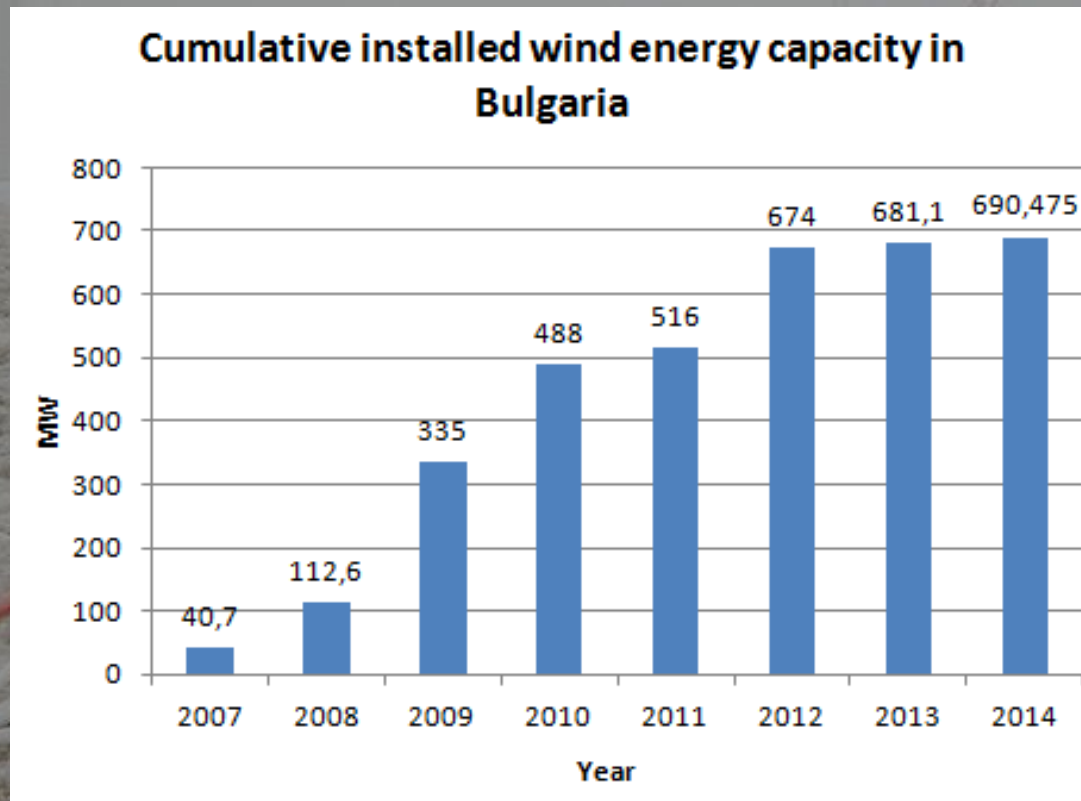


REVIEW OF ICING RELATED FAILURES OF WIND MASTS IN BULGARIA

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- Wind energy in Bulgaria has rapidly developed since 2008 and nowadays the amount of the energy from the installed wind turbines reaches more than 690 MW.



This paper summarizes the registered cases with failures of tall wind masts due to icing in different locations in the country since 2011.

- There have been 10 reported failures for the last 5 winters;
- Reported are only those cases where the equipment is insured – this means that the number of the collapses is higher;
- Three of these 10 cases were in high mountain regions and was caused by rime icing and strong winds;
- The other 7 cases were in plane regions and were caused by wet snow, freezing rains, rime ice as well as by combined processes.

Methods

- Four basic methods for assessment of the deposited ice and snow loads have been used:
 - the model of Makkonen for wet snow accretion (1989) - LM;
 - the model of Kathleen Jones for ice accretion in freezing rain (1996) - KJ;
 - the method of Ahti and Makkonen (1982) for rime icing, which is included in ISO 12494 - AM;
 - the height factor from ISO 12494 for estimation of the ice load at different heights above the terrain.

Comparison of some of the model estimations with the available measurements

- Unfortunately only in two of the cases there are some measurements of the ice depositions.
- The first of these cases is better documented. The case happened on 05-08.02.2012 and was caused by the combined influence of freezing fog and freezing rain.
- For the second case there is only one measurement of the ice thickness available. The process was freezing rain.

Case 1, 05-08.02.2012, NE Bulgaria

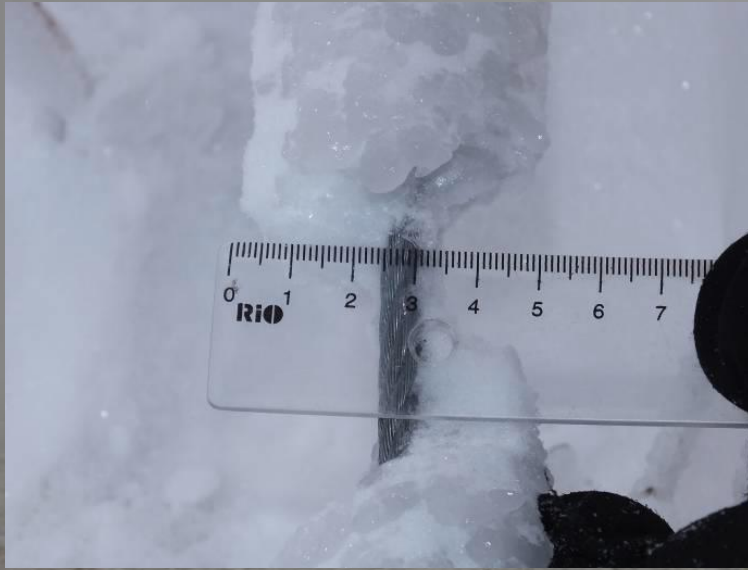


Model results for the radius of the deposition for case 1, assuming equal circular deposition, for different heights for the guy ropes ($D=0.8\text{cm}$) and for the main body of the mast ($D=5\text{cm}$); used models - KJ and AM and the height factor from ISO 12494.

Height, m	Radius, cm ($D_{\text{gays}} = 0.8 \text{ cm}$)	Radius, cm ($D_{\text{mast}} = 5 \text{ cm}$)
10	1.5	2.3
20	1.8	2.7
50	1.9	3.1
<u>80</u>	<u>2.2</u>	<u>3.7</u>
100	2.4	4.2

Good agreement of the estimation for height level 80 m with the measurements – see next slide.

Case 1, 05-08.02.2012, NE Bulgaria



- Measurements of the ice depositions – on the guy ropes (left) and on the main body of the mast (right) at height level of about 80 m.

Case 2, 01-02.12.2014, NW Bulgaria



- Type of the icing – glaze;
- Used model – KJ;
- Measured value – about 1.8 cm thickness but not equal distributed;
- Estimated value – 7.0 mm equivalent radial thickness;
- Model underestimates little the measured value in this case.

Conclusions

- This study is only illustrative with the purpose to demonstrate the possibility to use simple approaches for estimation of the ice loads on tall structures at different height above the terrain.
- The model results for the two cases with available measurements show relatively good results.