Improved Modelling of External Hazards at Forsmark NPP

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Abstract: Forsmark Nuclear Power Plant is located at the eastern coast of Sweden and consists of three boiling water reactors. Ever since external hazards were implemented in the PSA it has been a large contributor to the total core damage frequency and because of this a benchmark was initiated with Ringhals NPP, located on Sweden's west coast. During this benchmark major differences were found in the modelling of some weather related events. In particular, it was found that extreme winds, causing loss offsite power, had a significantly larger influence on the core damage frequency in the Forsmark PSA than in the Ringhals PSA. An effort was made to improve both the data and the modelling in the Forsmark PSA. The data collection was increased and adjusted to the different heights of the wind measuring stations. The formula converting wind gusts to average wind speeds was also replaced while the method for calculating the initiating frequency for wind remained the same. The result of this effort was that the core damage contribution from the initiating event strong wind was significantly decreased. The risk balance between all analyzed external hazards also became much more evenly distributed. Since the effort was relatively small considering the improved risk profile, the project is considered as a successful improvement.

Keywords: PSA, external hazards, wind, wind induced LOOP, frequency estimation, initiating events, uncertainties

1. BACKGROUND

Forsmark Nuclear Power Plant (NPP) consists of three boiling water reactors (BWRs), which commenced commercial operation in 1980, 1981 and 1985. It is situated at the eastern coast of Sweden, approximately 150 kilometers north of Stockholm. Forsmark Nuclear Power Plant (Forsmarks Kraftgrupp AB) is a subsidiary to Vattenfall AB. The vendor for all three units in Forsmark was Asea-Atom AB. Forsmark Nuclear Power Plant units 1 and 2 are of a design called BWR 69, while unit 3 is a BWR 75.

The climate in Sweden and Forsmark is, in general, less extreme compared to many other places although the four seasons are distinct. In the winter the temperature is often below zero and snowfall is common and the summers are usually quite mild or warm. The rainfalls are moderate but fairly strong and consistent winds can be experienced at Forsmarks NPP due to the proximity to the Baltic Sea. However, more extreme winds such as hurricanes and tornados are rare.

Ever since external hazards was implemented in the PSA it has been a large contributor to the total core damage frequency. To learn more about the external hazards a benchmark was initiated with Ringhals NPP (located on the west coast of Sweden). During the benchmark major differences were found in the modelling of some weather related events. In particular, it was found that wind events leading to loss of offsite power (at 43 m/s, the offsite power grid at Forsmark is assumed to become unavailable with no recovery due to prolonged overhead power lines and/or tower damage) had a significantly larger influence on the core damage frequency at Forsmark NPP than at Ringhals NPP. The wind contributed almost 25 % to the core damage frequency at full power operation in the Forsmark PSA which is far more than other external hazards (earthquake not included), see Figure 1. The reason for this could not be fully explained by the difference in location between the plants and there was a concern that the modelling in the Forsmark PSA was too conservative. Hence, a project was initiated to examine the modelling of wind related events at Forsmark.

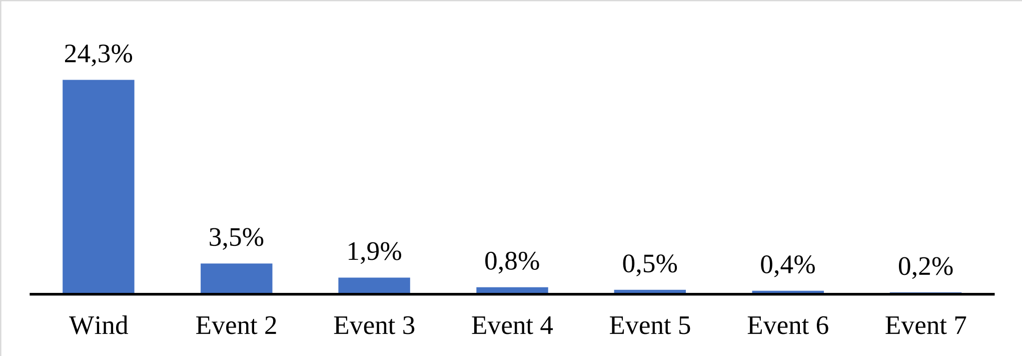

Figure 1. Contribution to the core damage frequency from external hazards at full power operation at Forsmark NPP.

2. IDENTIFIED SIMPLIFICATIONS AND CONSERVATISMS

The external power grid mainly consists of overhead power lines, supported by towers with a height of approximately 25 meters, and is assumed to become unavailable at wind gusts over 43 m/s. This assumption is based on the design criteria for failure of the power lines due to wind gusts. The wind gusts were earlier converted to an average wind speed, 27 m/s, based on a formula from a reference that was no longer available. Compared to the subsequent findings, the formula in question predicted very large differences between average wind speeds and wind gusts, which resulted in a conservative average wind speed being used.

The frequency of the estimated average wind speed, 27 m/s, was calculated in a simplified manner using linear interpolation of table values from the used Gumbel distribution. This simplified calculation led to the initiating frequency of the wind speed being twice as high as the real value when applying the actual distribution to calculate the frequency.

The measurement station from where the wind data was collected began operation in 2003 and the data used in the PSA had only been updated once and therefore did not include any new data after the year 2014. This can arguably be seen as an insufficient amount of data to create a robust extreme value distribution.

3. IMPROVEMENTS

An effort was made to improve both the data and the modelling.

3.1 New Data Collection and Adaption to Height

The old wind data was based on the yearly maximum value collected between the years 2003-2014. Corresponding measurements from 2015-2023 were added.

The measurement station of the old data was at the height of 25 meters which is the same as the overhead power lines. However, in 2015 the old measurement station was retired and a new one was introduced that measures the average wind speed at 10, 50 and 100 meters height. Therefore an adjustment had to be made to calculate the frequency of a wind strong enough to cause failure of the power lines at the height of 25 meters.

All available data points at 10, 50 and 100 meters height were used to create an average wind speed at the specified heights. Measurements with an average wind speed below 10 m/s at 10 meters height were excluded from the data since only high speed winds were of interest. The average wind speed was plotted as a function of height, see Figure 2.

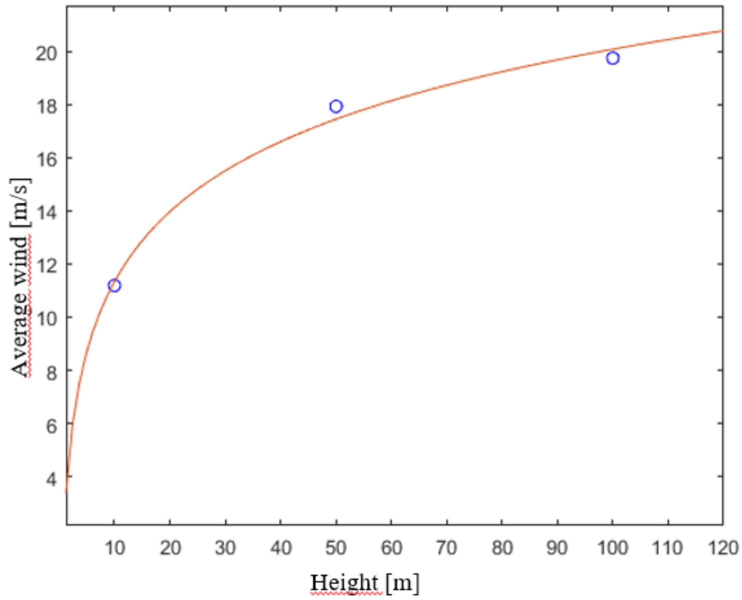

Figure 2. Average wind speed as a function of height (Data from the Forsmark weather station).

When the data points were plotted it was noted that the relationship is logarithmic and the following formula was derived and used:

$$\frac{v_m(H_2)}{v_m(H_1)} = \frac{ln(1.97H_2)}{ln(1.97H_1)} \tag{1}$$

where v_m is the average wind speed, H_1 is the lower altitude and H_2 is the higher altitude. (1) is similar to a formula mentioned by the Swedish institute of standards [1] where different topographies are taken into account when transforming wind speeds at different heights. The reason [1] was not used in Forsmark was that the location of Forsmark did not quite fit any of the given topographies since it is close to the coast but also less exposed to high wind speeds than what was assumed in [1] due to protective vegetation. Therefore a location specific formula is used rather than the one proposed by the Swedish institute of standards.

3.2 Conversion of Wind Gusts to Average Wind Speed

The design criteria for the offsite power grid, but also for buildings, are based on wind gusts since it only takes a short period of time for a high wind speed to be fatal for the power lines or buildings. The data collection consists of measurements of average wind speed and therefore the relation between wind gust and wind speed needs to be determined. The old reference on how to convert wind gusts to average wind speeds could not be found, and therefore it was replaced by a formula from a study from Gothenburg University [2]. The formula used is:

$$v_b = 1.2v_m + 6.0 \tag{2}$$

where v_b is the wind gust and v_m is the 10 minute average wind speed. To further investigate and visualize how (2) fits the local environment at Forsmark, data from the Swedish Meteorological and Hydrological Institute (SMHI) on the Örskär island close to Forsmark NPP was used to create a comparison between (2) and the empirical data. As opposed to the Forsmark data which only contains average wind speeds, the Örskär weather station also records the maximum wind gusts for each 10 minute interval. Even though the Örskär site is somewhat windier than Forsmark, it was still found to be the closest comparable site. Figure 3 shows the plot of data from the year 1995 to 2023 with only wind speeds above 20 m/s taken into consideration. It was noted a linear approximation could be used (red line) and the green line shows (2) based on the same data set and it is confirmed that (2) gives a slightly more conservative result. The conservatism is considered acceptable since the available data for Forsmark contains some uncertainties due to short data series.

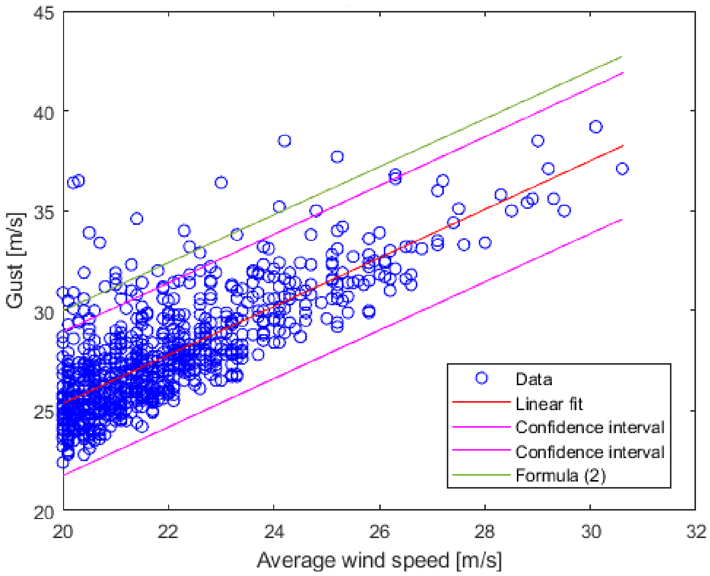

Figure 3. Wind gusts as a function of average wind speeds above 20 m/s (data from the Örskär weather station).

When applying (2) to the Forsmark wind data a wind gust of 43 m/s equals an average wind speed of 30,8 m/s. This is an increased average wind speed compared to the previous used value of 27 m/s.

3.3 Frequency of Wind Speeds Exceeding 30,8 m/s

To calculate a new frequency for wind speed over 30,8 m/s based on maximum values of the collected data, a new Gumbel distribution was fitted in the same manner as before, but with new data. In the new distribution, measurements from 2015-2023 were added, first having been transformed from 50 m to 25 m height using (1). Additionally, the resulting values were outputted with more precise frequency estimation instead of scarce table values. In Figure 4 the maximum wind speed per year is plotted against time to illustrate the return times. The return times were calculated from the estimated yearly frequencies for different wind speeds (in turn found by using the cumulative distribution function of the fitted distribution). It is noted that the return time for a wind speed of 30,8 m/s is almost one time per 300 years.

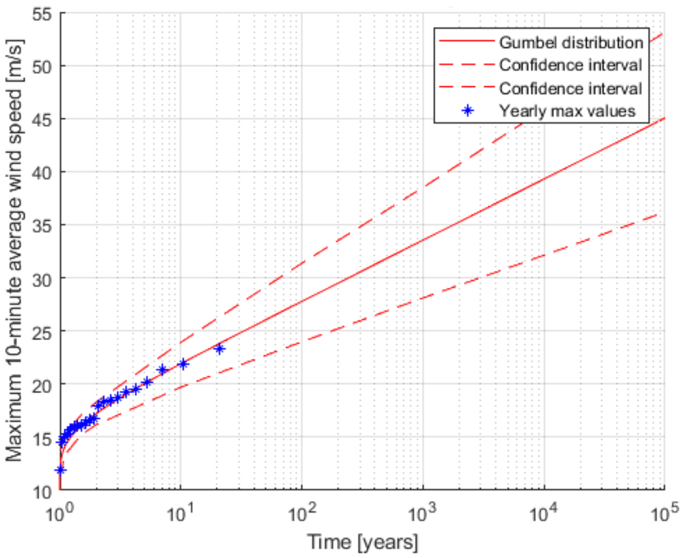

Figure 4. Return time for maximum average wind speed (data from the Forsmark weather station).

4. FINAL RESULTS

The increased data series, the increased value for an average wind speed and a decreased value of the initiating event frequency resulted in a reduced core damage frequency for full power operation. The previous initiating event frequency for an average wind speed above 27 m/s was about 1,65E-2 per year and the new one was reduced to about 3E-3 for an average wind speed above 30,8 m/s, as can be seen in Figure 5.

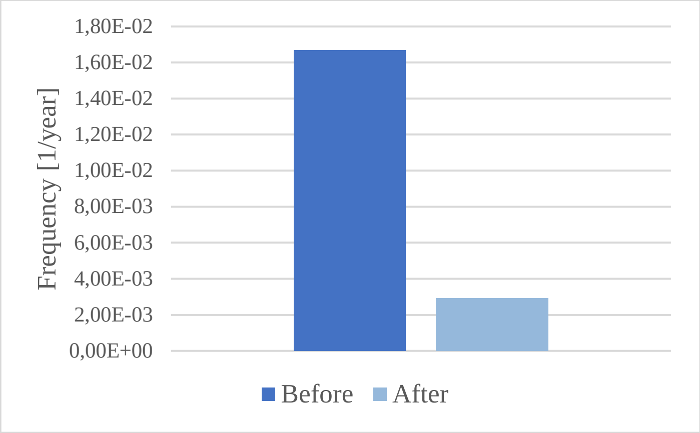

Figure 5. Initiating event frequency of wind gusts over 43 m/s or average wind speed over 27 m/s (before) and 30,8 m/s (after).

The contribution to the core damage frequency from the initiating event wind over 30,8 m/s (previously 27 m/s) was significantly decreased from about 25 % to just above 5 %, as shown in Figure 6. Even though wind is still the initiating event, among the external hazards (earthquake excluded), that contributes the most to the core damage frequency, the risk profile has become much more evenly distributed. The contribution from some of the other external hazards has also slightly changed due to the modifications regarding wind.

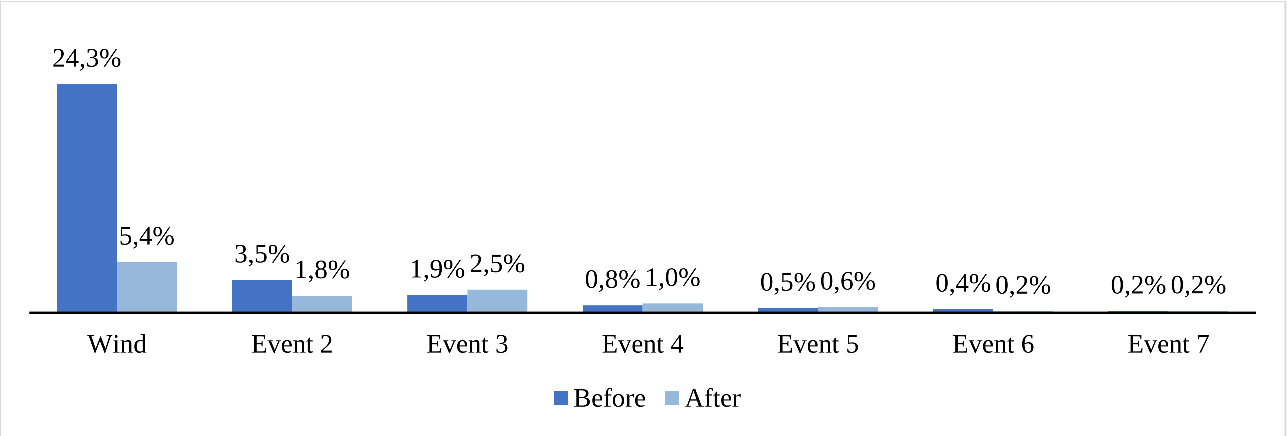

Figure 6. The external hazards that contributes the most to the total core damage frequency at full power operation

5. CONCLUSION

A conclusion of the project is that a minor reduction of conservatism can give a significant impact on the PSA results. One issue with analyzing external hazards is that the data series usually are relatively short and contains uncertainties – which is also reflected in the result. A partial solution for this problem is to regularly update the PSA with new data to reduce uncertainties and thus make both inputs and results as realistic as possible. Uncertainties are to some extent inevitable when transforming data through assumed relations and estimating distributions, but it is still clear that the new wind modelling practice at Forsmark is more robust than the old one. The effort put into this project was relatively small considering the improved risk profile and that is one reason the project is considered to have been a successful improvement of the PSA.

References

[1] Eurokod 1: Laster på bärverk – Del 1-4: Allmänna laster – Vindlast, Svenska institutet för standarder, SS-EN 1991-1-4:2005.

[2] Dahlström B., Extremvind och turbulent variation, Göteborgs Universitet, 1980.