LOOP frequency estimates due to external events

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Agenda

Site characteristics

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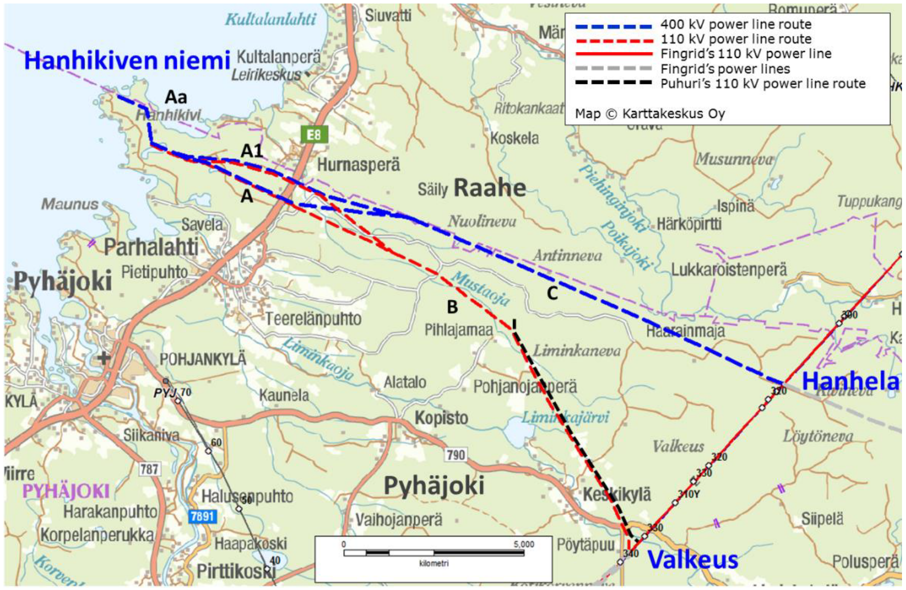
The nuclear reactor project site is situated on the Hanhikivi headland roughly at 64°31'N 24°15'E.



Power line	Route	Length	Width of lane	Surface area
2 x 400 kV	Hanhikivi	1.45 km	76 m	0.11 km²
2 x 400 kV 2 x 110 kV	Hanhikivi – Hurmasperä	4.76 km	115 m	0.55 km²
2 x 400 kV	Hurmasperä – Hanhela	13.89 km	76 m	1.06 km²
2 x 110 kV	Hurmasperä - Pihlajamaa	6.24 km	46 m	0.29 km²
3 x 110 kV[1]	Pihlajamaa – Valkeus	7.28 km	66 m	0.48 km²

[1] only two of these are for the purposes of the Hanhikivi NPP

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Methodology

Following events were considered:

- No electricity in one 100 kV power line
- No electricity in both 110 kV power lines
- No electricity in one 400 kV power line
- No electricity in both 400 kV power lines
- No electricity in both 400 kV and both 110 kV lines

The examination of these events has been chosen as the plant response differs within these events.

Any single power line is alone capable of supplying electricity to the necessary safety systems.

Considered failures:

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Mean times to repair (MTTR)

- 1-phase technical fault
  - Short fault of the system in which the current is returned within 30 seconds
- Permanent failure
  - Estimated repair time 10 hours (by grid operator)
- Major national grid failure
  - Electricity should be restored within 30 minutes to an hour (assessment by the electricity transmission grid operator). Major power plants are preferred. 45 minutes has been applied as a best-estimate assumption.
- Weather events
  - Likely to cause vast damages to the grid. 15 hours is assumed as an engineering judgement relying on information on previous incidents.

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Technical failures

- Relevant failure data of the Fingrid transmission network covers 10 years, 2006-2015.

	Faults per 100 km	Share of faults in different categories (%)							1-phase	Permanent
		Lightning	Other environmental	External influences	Operation and maintenance	Technical equipment	Other	Unknown		
110 kV overhead	2.05	36	18	1	1	0	5	38	78	4
400 kV overhead	0.25	71	10	2	6	2	5	5	64	10

- 1-phase faults 0 - 0.5 % → 0.25 % best-estimate
- Permanent faults
- 5 % of single power line technical failures are assumed to be common cause failures (engineering judgement)
- Results

Cause	Measure	Lines affected	Frequency (1/a)
Technical failure (1-phase)	Single failure	1. 400 kV	6.43E-04
	Single failure	2. 400 kV	6.43E-04
	Single failure	Either 400 kV	1.29E-03
	Common cause	2x 400 kV	3.22E-05
	Single failure	1. 110 kV	7.31E-04
	Single failure	2. 110 kV	7.31E-04
	Single failure	Either 110 kV	1.46E-03
	Common cause	2x 110 kV	3.65E-05
Technical failure (long)	Single failure	1. 400 kV	1.01E-04
	Single failure	2. 400 kV	1.01E-04
	Single failure	Either 400 kV	2.01E-04
	Common cause	2x 400 kV	5.03E-06
	Single failure	1. 110 kV	3.75E-05
	Single failure	2. 110 kV	3.75E-05
	Single failure	Either 110 kV	7.49E-05
	Common cause	2x 110 kV	1.87E-06

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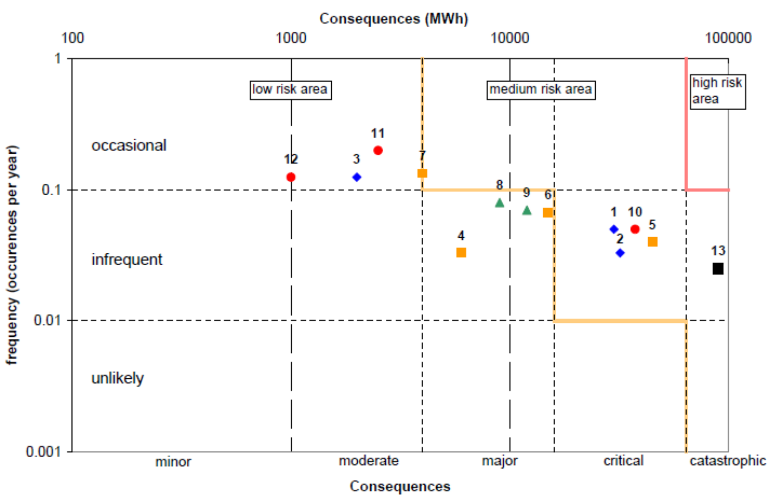
Major national grid disturbance

- Frequency estimate 3.33E-2 /a (once in 30 years) based on an extensive report [1] on the vulnerability of the Nordic power system. The study is the latest extensive research done on the topic in the Nordic countries.



[1] G. Doorman, G. Kjolle, K. Uhlen, E. Ståle Huse and N. Flatabo, *"Vulnerability of the Nordic Power System,"* SINTEF Energy Research, May 2004.

- Especially scenario 2 can be considered representative for Hanhikivi

"This scenario assumes light load in Finland and high generation in the southern parts of Finland. In this situation there can be maximum power export to Sweden through AC connection in the north (1100 MW) and on the FennoSkan HVDC link in the South (550 MW). In this operating condition the transfer limits are determined from stability constraints. The critical contingency in this situation is outage of the FennoSkan link, which will increase power transfer on the interface P1 (three 400 kV lines from north to south in Finland) and on the Sweden-Finland interface. If a second line outage occurs, e.g. P1, this may cause undamped power oscillations that in the worst case could result in an almost total collapse of the Finnish power grid. "

- During the study window (1983-2003), two critical national grid failures in the Nordic countries (Sweden 1983 and Southern Sweden/Eastern Denmark 2003)

  → Frequency of 1/30 years in the right range for a single country

- New connections most likely have an effect and the study should be updated

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Lightning

- Same method as for technical failures

		Share of faults in different categories (%)								
	Faults per 100 km	Lightning	Other environmental	External influences	Operation and maintenance	Technical equipment	Other	Unknown	1-phase	Permanent
110 kV overhead	2.05	36	18	1	1	0	5	38	78	4
400 kV overhead	0.25	71	10	2	6	2	5	5	64	10

- Half of the share of faults in the category ”Unknown” allocated to lightning as the reference raport assesses

“A large number of disturbances with unknown cause probably have their real cause in the categories other environmental cause and lightning.”

$$f_{1-phase} = L * N_{100km} * p_{lightning} * p_{1-phase},$$

$$f_{permanent} = L * N_{100km} * p_{lightning} * p_{permanent}$$

- It is conservatively assumed that a lightning caused fault would affect both power lines in the same lane
- Permanent common cause failure assumed with a 5 % probability from the 400 kV power line permanent failure frequency on the route where all four lines go side by side.
- Results

Cause	Lines affected	Frequency (1/a)
Lightning failure (1-phase)	2 x 400 kV	2.36E-02
	2 x 110 kV	1.61E-01
Lightning failure (long)	2 x 400 kV	3.69E-03
	2 x 110 kV	8.24E-03
	2 x 400 kV, 2 x 110 kV	4.37E-05

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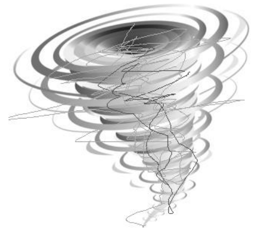
Strong wind

- Large effect area, and the design basis exceeding wind speeds are thus likely to damage all of the 400 kV and 110 kV power lines
- Limit for a structural failure has been assessed as 39 m/s at the height of 30 meters
- Return periods assessed for 3 second gust wind speeds by the Finnish Meteorological Institute (FMI)

→ Frequency $2 \cdot 10^{-4}$ /a

Tornados and downbursts



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- Return periods and destruction path lengths for tornados and downbursts assessed by FMI
- Fujita class F1 sufficient to damage power lines

	Fujita scale	Probability (1/(km² a)	Destruction path length (km)
Tromb			
	F5	2.61E-08	54.6
	F4	1.26E-07	43.6
	F3	6.08E-07	22.5
	F2	2.94E-06	10.7
	F1	1.42E-05	4.7
Downburst			
	F3	9.02E-06	27.4
	F2	4.35E-05	21.9
	F1	2.10E-04	11.3

- Three parts examined:
  - Hanhikivi, length 1.45 km (2 x 400 kV power lines on plant site)
  - Hanhikivi – Hurmasperä, length 4.76 km (all power lines on the same route)
  - Hurmasperä – Hanhela/Valkeus, length 13.89 km (according to the longer of the two alternative routes), average distance of power lines routes 2.5 km

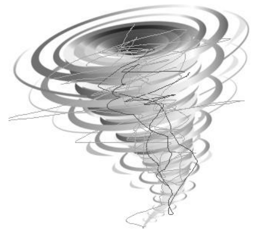
- For each tornado and downburst it is conservatively assumed that the target area is defined by ”destruction path length” multiplied by the ”power line section length”.
- Factor 0.5 applied to account that movement has to be towards the power lines.
- Distance between power line routes accounted with factors based on the destruction path length of the tornado/ downburst examined

$$f_{tromb\_x} = p_{tromb\_x} * L_{dl} * W_{pl} * p_w,$$

$$f_{downburst\_x} = 0.1 * p_{downburst\_x} * L_{dl} * W_{pl} * p_w$$

- 0.1 used as an expert coefficient for downbursts as the results were unrealistically high (mainly because downburst probabilities have been derived from tornado probabilities by FMI)

Tornados and downbursts



	Fujita scale	400 kV and 110 kV power lines damaged (1/a)	110 kV power lines are damaged (1/a)	400 kV power lines are damaged (1/a)
Tromb				
	F5	1.33E-05		1.03E-06
	F4	4.93E-05	9.54E-07	4.94E-06
	F3	1.18E-04	4.75E-06	1.47E-05
	F2	2.39E-04	2.73E-05	5.01E-05
	F1	3.91E-04	1.16E-04	1.64E-04
	SUM	**8.10E-04**	**1.49E-04**	**2.35E-04**
Downburst				
	F3	2.22E-04	4.29E-06	2.22E-05
	F2	8.22E-04	3.31E-05	1.02E-04
	F1	1.88E-03	1.65E-04	3.37E-04
	SUM	**2.93E-03**	**2.02E-04**	**4.61E-04**

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Wildfires

- Based on forest fire data gathered by the Finnish Forest Research Institute (covers years 1980-2013).
- Annual average of 1004 forest fires per year with an average burnt area of 0.50 hectares
- 12 % of forests located in Northern Osthrobotnia -> average 120 fires/year
- For simplicity a burnt area has been assumed to have a round shape, 0.5 hectares has a diameter of 80.1 m

Power line	Route	Length	Width of lane	Surface area
2 x 400 kV 2 x 110 kV	Hanhikivi – Hurmasperä	4.76 km	80.1 m	0.38 km²
2 x 400 kV	Hurmasperä – Hanhela	13.89 km	80.1 m	1.11 km²
2 x 110 kV	Hurmasperä - Pihlajamaa	6.24 km	80.1 m	0.50 km²
3 x 110 kV	Pihlajamaa – Valkeus	7.28 km	80.1 m	0.58 km²

- Factor 0.5 for wind blowing towards the power lines
- Factor 0.1 to account for the small size of the fires (unlikely to generate enough heat to damage grid components). Tall trees also cleared from a minimum 10 m distance from the power lines.
- Proportion of the considered surface areas and the whole forest surface area in Northern Osthrobotnia
- Results

Power lines lost	Frequency (1/a)
2 x 400 kV, 2 x 110 kV	1.67E-04
2 x 400 kV	4.88E-04
2 x 110 kV	4.76E-04

Freezing rain, heavy rainfall, extreme temperature

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- Freezing rain
  - 40 mm of freezing rain has been reported to cause long lasting and wider spread outages in Canada.
  - Frequency for the event assessed by FMI $2.15 \cdot 10^{-7}$ /a
  - Snow load (hard rime) estimated to be close to the freezing rain LOOP frequency
  - Freezing rain or snow $4.31 \cdot 10^{-7}$ /a
- Extreme temperature
  - Design value of grid from +40 °C to -50 °C
  - Neglible probability to be exceeded ($\ll 10^{-8}$ /a)
- Heavy rainfall
  - Considering the makeup and geographical nature of the area, heavy rainfall is extremely unlikely to cause LOOP events

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Summary

- Assessed LOOP values (loss of both 110 kV and both 400 kV power lines) with regards to different mean times to repair
  - MTTR 45 minutes: 3.33E-02 /a
  - MTTR 15 hours: 4.15 E-03 /a

- The study can be further improved at later stages by removing excess conservatism, when new data or improved assessment methods are available.
  - Especially:
    - Downburst return periods rather scarce and based on simple assumptions derived by FMI
    - Update of major national grid disturbance frequency to include all lately built connections


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