Risks and challenges – results from study

Seppo Hänninen VTT Ltd

Flexible nuclear power and ancillary services - Conference

23 - 24 Jan 2018, Stockholm, Sweden

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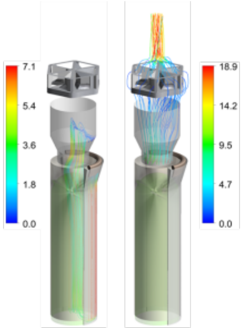
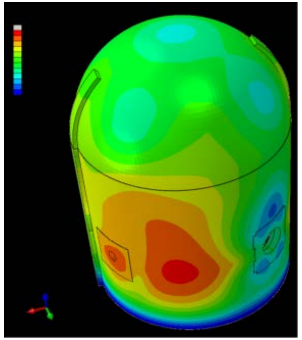
SAFIR2018

The Finnish Nuclear Power Plant Safety Research Programme 2015-2018

Plant safety and systems engineering



Reactor safety



Structural safety and materials

Jari Hämäläinen, Programme director, VTT Ltd

Vesa Suolanen, Project coordinator, VTT Ltd

SAFIR2018 Projects in 2015-2017 and 2018

28-29 projects annually in 2015-2017:

- SG1 Plant safety and systems engineering
- SG2 Reactor safety
- SG3 Structural safety and materials.
- RG6 Research infrastructure

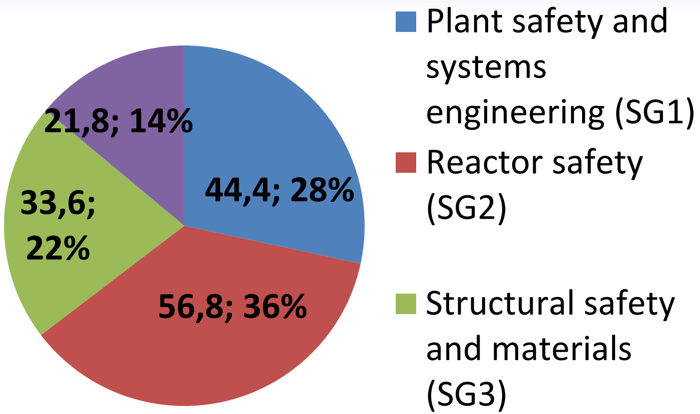
Project year 2018

Planned total funding is 7,1 M€ and volume 45 person years.

Research in 32 projects is guided by six reference groups:

- RG1 Automation, organisation and human factors (SG1; 5 projects)
- RG2 Severe accidents and risk analysis (SG1, SG2, SG3; 7 projects)
- RG3 Reactor and fuel (SG2; 5 projects)
- RG4 Thermal hydraulics (SG2; 4 projects)
- RG5 Structural integrity (SG3; 7 projects)
- RG6 Research infrastructure (4 projects)

160 person years in 2015-2017



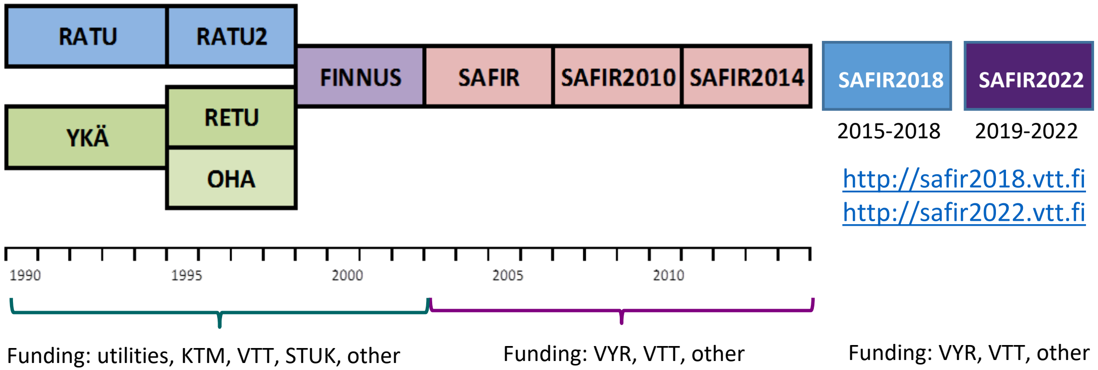
SAFIR2022
The Finnish Research Programme on Nuclear Power Plant Safety 2019-2022

Jari Hämäläinen, Programme director

Vesa Suolanen, Project coordinator

http://safir2022.vtt.fi/

Finnish Nuclear Power Plant Safety Research



Finnish Nuclear Energy Act:
should new matters related to the safe use of nuclear power plants arise, the authorities possess sufficient technical expertise and other competence required for rapidly determining the significance of the matters.

SAFIR2022 is continuation to a series of earlier national nuclear power plant safety research programmes that have proven their value in maintaining and developing expertise.

The nuclear facility operators pay an annual fee for the Finnish State Nuclear Waste Management Fund (VYR) that finances research projects in SAFIR2022. The volume of SAFIR2018 has been approximately 11 M€ annually (research projects 7 M€ and the rest allocated for infrastructure investments).

The research projects shall be of a high scientific standard and their results shall be published.

SAFIR2022 Research Areas

Overall safety and systemic approach to safety (8 projects)
Overall safety and systemic approach to safety includes a wide range of overarching nuclear safety research topics, as well as topics affecting the nuclear power plant as a whole.

Reactor safety (11 projects)
Reactor safety research focuses on the development of experimental and computational analysis methods aimed to ensure that a nuclear facility and its systems are able to implement the safety requirements set for them.

Structural safety and materials (9 projects)
The aim of the research on structural safety and materials is to increase knowledge that supports long-term and reliable use of the nuclear power plants, particularly with respect to matters involving the integrity of barriers and material issues that affect the reliability of the safety functions.

Research infrastructure development (4 projects)
Domestic infrastructure and experimental research are vital for the maintenance and enhancement of national competences, as well as for leveraging international experimental capabilities for national needs.

For details, see SAFIR2022 Framework Plan available on the website http://safir2022.vtt.fi

Nuclear Power Plants in Finland

Operating nuclear power plants

- Loviisa (2 x 500 MW PWR)
- Olkiluoto (2 x 880 MW BWR)

Under construction

- Olkiluoto (1600 MW EPR) - *operating license phase, start of operation in Autumn 2019.*

Decision-in-principle

- Hanhikivi (1200 MW PWR) - *construction license phase*

Proportion of nuclear power of the electricity production in Finland is ca 27%.

Nuclear waste management

- Operating waste storages and final repositories at Olkiluoto and Loviisa
- Spent fuel interim storages at Olkiluoto and Loviisa
- Spent fuel repository by Posiva in Olkiluoto - *under construction since 2016.*

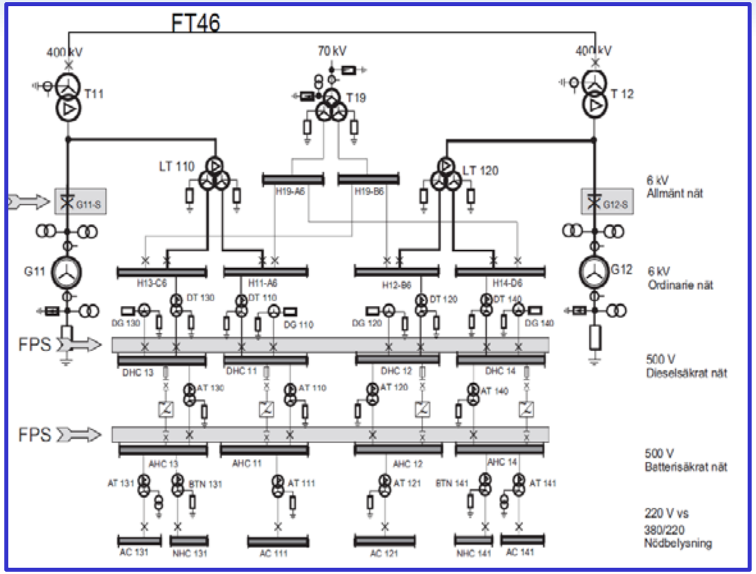
ESSI – Electric Systems and Safety in Finnish NPP

Background and objective

ESSI project examines disturbances and common cause faults which can cause the loss of in-site electrical system in NPP. The objectives of research are to examine the possible common cause fault impacts of open phase condition (OPC) and large lightning strikes in Finnish NPP electrical systems. Also the risks of adaptive operation of NPP in load following mode will be examined.

Results exploitation and effect on safety

1. **OPC related research** will be exploited by developing early detection solutions for unbalance condition in the NPP electric systems. Another important issue is to provide NPP operation personnel understanding about the time criticality of the OPC situation and possible means of mitigating the situation by operation decisions.
2. **The lightning research** will be utilized in improving the lightning overvoltage protection and grounding arrangements of the NPP electric, automation and control systems.
3. **The research regarding flexible operation** of nuclear power plant can be exploited to setting the technological limits of adaptive control in today's nuclear power plants with regard to electrical systems in order to avoid the increase of disturbances in power plant.



A general schematic electrical diagram of a nuclear power plant

Resources

- Project manager: Seppo Hänninen, VTT
- VTT, Aalto University, Risk Pilot
- 2017: 13 pm
- 2018: 11 pm

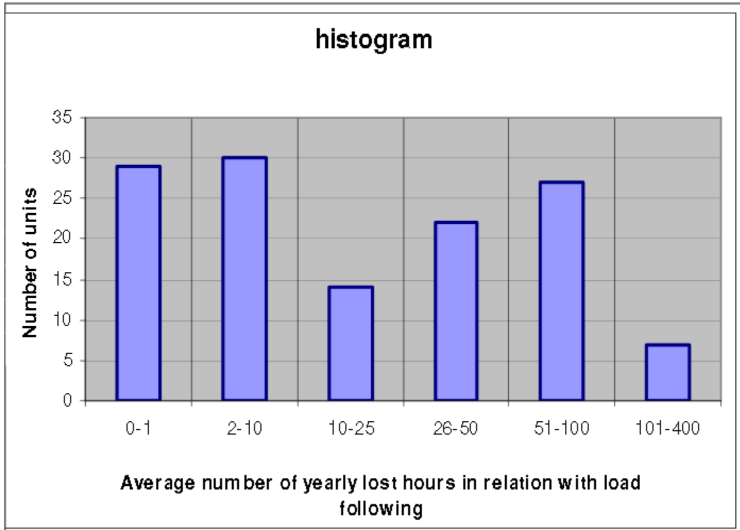
Research method

- Literature review on flexible operation of nuclear power plants
- Contacts and interviews of:
  - Plant operators Fennovoima, Fortum and TVO
  - Radiation and Nuclear Safety Authority in Finland (STUK)
  - Swedish Centre Authority for Nuclear Technology
  - Finnish Transmission System Operator Fingrid
- Simulation based studies

Flexible operation of NPP

- The objective was to estimate the technological limits and risks of flexible control in today’s nuclear power plants with regard to electrical systems in order to avoid the increase of disturbances in power plant.

- Many countries use or have done experiments in non base load operation of NPP in Europe

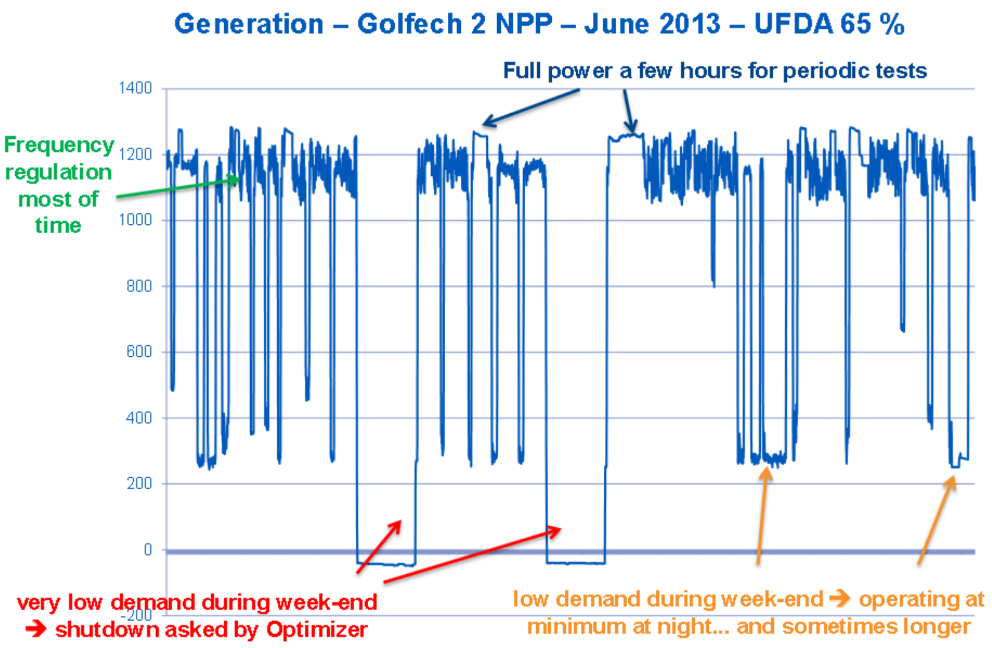


bins of yearly average hours lost for LF	number of units
0-1	29
2-10	30
10-25	14
26-50	22
51-100	27
101-400	7

Average number of lost production due to load following of nuclear power plants in Europe.

*Bruynooghe, C., Eriksson, A., Fulli, G., 2010. Load-following operating mode at Nuclear Power Plants (NPPs) and incidence on Operation and Maintenance (O&M) costs. Compatibility with wind power variability, JRC report series.

Some plants in France are used very actively in flexible operation



*Power output curve of Golfech 2 power plant in June 2013**

*Souque, D., 2013. Frequency control experience in French NPPs IAEA Technical Meeting.

Results of the literacy review

- Flexible operation is actively use in some countries, mainly in Germany and France.
- France uses flexible operation because plants have to be designed for that to have 70% penetration of nuclear power in the national power system.
- Germany has invested 200 billions to wind and solar power and nuclear power is operated in load-following mode due to high percentage of renewables.
- In this regard, Finnish power system is very different and balanced compared with Germany or France.
- Future grid codes require more flexibility from power plants (no special exceptions for new NPPs)
- Nuclear power plants are slower to respond to control commands than coal or gas plants
- Optimal control range of NPPs is around 60 – 100%
- Negative market prices and compensation on lost production are typical income models.
- No major wear to components in E.ON’s experience but components are monitored in shorter intervals

Results of the interviews

- No plans to implement load-following in any of the plants in Finland (old or new)
- New plants will be technically capable of load-following
- If implemented, seasonal control would suit better to old plants using manual controls
- Some operators have persons with expertise with load-following but large investments in knowledge and personnel would be needed for actual operation
- Concerns pointed out in the interviews were:
  - Thermal system & turbine stress
  - Control room modifications
  - Personnel training
  - Financial profitability
  - Disturbance sensitivity of the electrical components and ICT systems can increase
  - Ageing of certain operational components and an increase in the maintenance work and cost
- The Finnish authority STUK sees flexible operation as technical and design issue and not something that is not allowed by the law.

Risk and challenges to electric systems

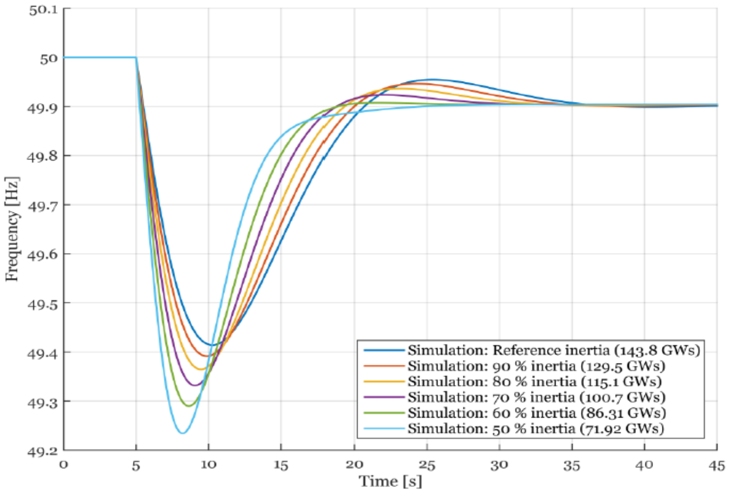
- No bigger risks for electric system regarding flexible operation were found.
- Basic problem with this is that NPPs are high capital and low running costs type of units. For this reason and reactor physics, savings in fuel costs of load-following are smaller with nuclear power plants when compared with traditional power plants.
- If more flexibility in Finnish power system are needed, also bio based units will be competing from their share of flexibility providing service if it pays well.
- If flexible operation is wanted to be researched more in electric system perspective, power plant models including automation system for simulation are needed.

Risks and challenges to transmission grid

The study covered;

- Risks of adaptive control to NPP electrical systems and stability of the grid
- An interview to national transmission system operator Fingrid.
- Possible market segments for NPPs cover issues of power system stability. Analysis will be done on what kind of participation NPP could have to stability of Nordic power system.
- The work uses the performance values found in first phase of study (2017).

Low ineartia effect on power grid stability



Frequency sag in simulation of 1170 MW production disconnecting with different inertia amounts. (Ørum;Kuivaniemi;& Laaksonen, 2013)

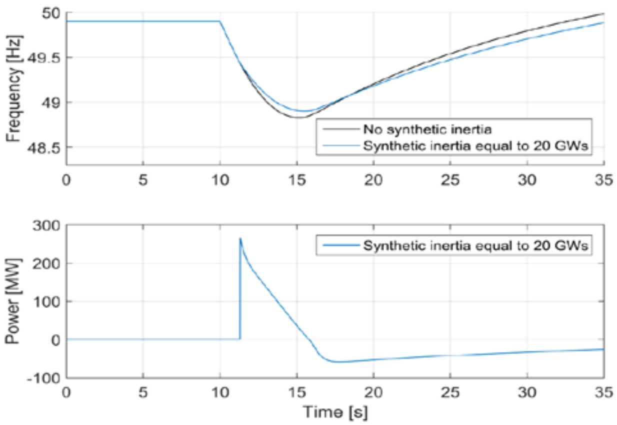
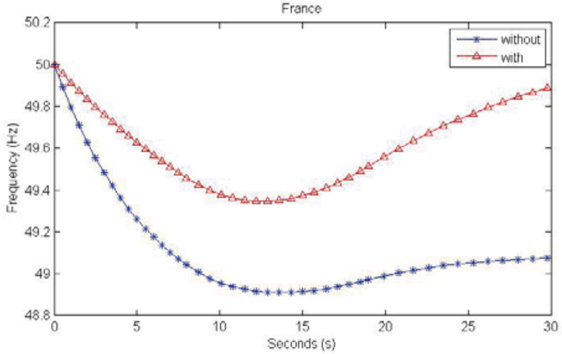


Figure 5. Synthetic inertia of 20 GWs (Ørum;Haarla;Kuivaniemi;& Laaksonen, 2015)

NPP Frequency control has different effect on different power systems

Table 1. Primary frequency response in France (Wyman-Pain;Yuankai;& Li, 2016)

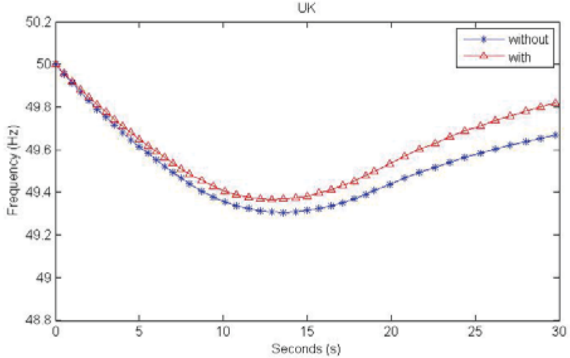
	Initial Rate of Change of Frequency	Generation Inertia	Minimum Frequency
With Nuclear Response	0.238 Hz/second	5.51 pu	49.35 Hz
Without Nuclear Response	0.099 Hz/second	1.13 pu	48.91 Hz



As comparison some system are the opposite. Not needing to rely on NPP primary frequency control. Following table presents UK primary frequency response as comparison.

Table 2. Primary frequency response in UK (Wyman-Pain;Yuankai;& Li, 2016)

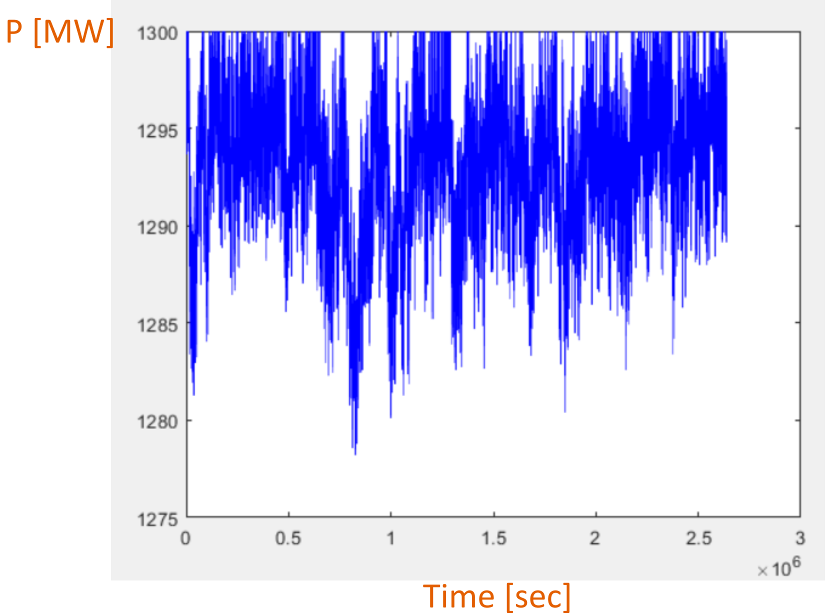
	Initial Rate of Change of Frequency	Generation Inertia	Minimum Frequency
With Nuclear Response	0.092 Hz/second	6.02 pu	49.37Hz
Without Nuclear Response	0.101 Hz/second	5.30 pu	49.31 Hz



Simulation results of NPP unit participation in the primary frequency market [FCR-N]

Assumptions:

- Frequency data is from year 2016, 2 months period.
- The change of output power 3%/minute
- Simulated NPP unit: 1300 MW
- Minimum production capacity 10 GW
- $\text{Frequency droop} = \dfrac{\frac{\Delta f}{50\ Hz}}{\frac{\Delta P}{P_{nom}}}$
- Simulation with droop value of 0.5



NPP unit (1300 MW) participation in load following

Finnish Transmission System Operator, FINGRID views

- Fingrid sees that 2020 onwards rotating generation will be less in the power system, and there also will be less controllable power plants. This means that price variations might be large.
- There has been some discussions about the use of flexible nuclear power to balance network, but energy producers have better resources than NPP’s to this purpose for the present
- There has been no instances that Fingrid would have demanded nuclear power plant to reduce power or disconnection. Market based solutions have been enough for now. For voltage control, however, there has been more requests to change voltage setpoint.
- If Fingrid would require a power change, the communication and command would be sent directly from Fingrid’s control center to NPP control center.

Conclusions

- Market participation possibilities to FCR-N was estimated with assumption of 4.6% additional cost of flexible operations. Using market data from 2016, there were 1144 hours when flexible operation could have been profitable. In this case 4.6% increase was calculated respect to Nordpool SPOT price but in reality there is plant specific operation cost.

- Also a rough estimation of system where all power plants would take part in automatic frequency regulation was done. Capacity factor decrease in estimation per plant was estimated to be 0.5% with two months of measured frequency data with 1 s interval.

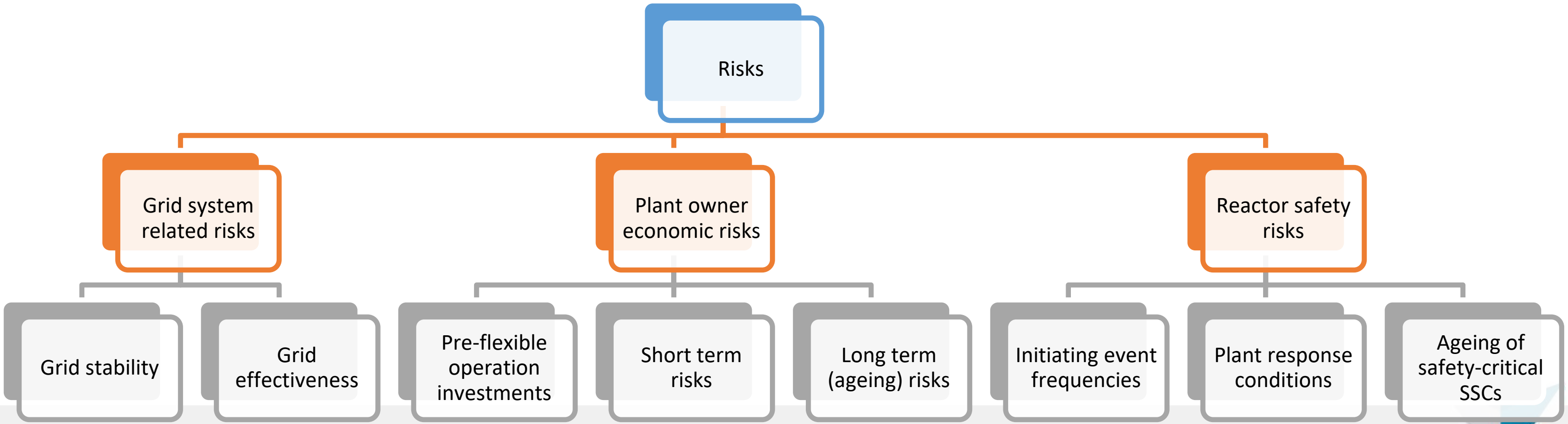
- Instead of bidirectional balancing, nuclear power plants could serve better in down regulation reserve in cases for system over-frequency and normally leave bids to down-regulation balancing market. This practice would guarantee down-regulation capacity even if NPPs would never win the bids to actually activate. It should be noted that FCR-D for disaster situations is only defined for situations when there is lack of power in the system(and not for over-frequency).

- The most obvious risk to system stability is that if large nuclear plant is taking major role in system balancing and plant disconnects from grid when there is low inertia in the grid (summer time). For risk analysis perspective, role of a single plant in balancing should be limited.

- It is likely that pressures on all generation to participate more actively on system balancing will increase and it is very likely that new NPPs will be required to take part at some point of their long operation life cycle.

Preliminary risk analysis approach for flexible operation of nuclear power plants

- Risk analysis to support decision making to compare options for flexible operation
- Decision maker is the operator of a NPP fleet
  - Other relevant stakeholders include the grid operator, other producers, consumers and stakeholders of the connected grids (neighbouring countries)



Next steps

VTT

SAFIR2022 management board has accepted funding for year 2019 in order to start a new project:
"CO-simulation model of plat internal electrical network interfacing thermal hydraulic, automation and external power grid"

Task	2019	2020	2021	2022
WP1: CO-simulation model of NPP	Architecture for COSI platform	COSI platform first version	CO-Simulation platform	Support work for WP2
WP2: Simulation studies	Simulation case definitions ready	Baseline simulations and verification	Operation mode based electric risk events identified	Fault simulation results
WP3: Safety assessment of electric systems for new operational modes	Overall safety case for electric systems defined	Design principles of systems for SMR	Role and scenarios for flexible nuclear power	Evaluation of current safety requirements Evaluation principles for design of flexible NPP