ESSI: Electric systems and safety in Finnish NPP

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Content

ESSI project 2017-2018

- Ø WP1: Open Phase Conditions (OPC)
- Ø WP2: Lightning overvoltages
- Ø WP3: Flexible operation of NPP

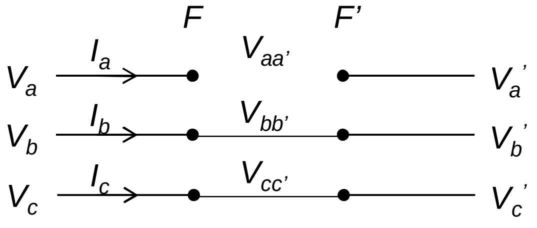
Research method

- Literature review
- 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

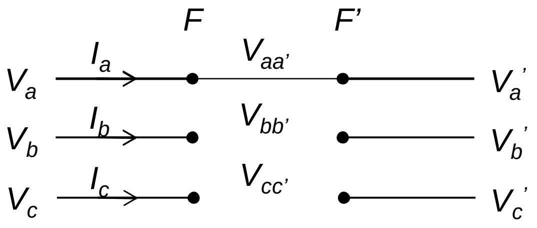
Open Phase Conditions (OPCs) in NPPs

The project investigated:

- How different OPCs influence NPPs
- Preparedness of Finnish NPPs against OPC
- Protection methods against OPC
- Detailed studies on the effect of OPC on induction motors (analytical calculations, simulations and laboratory measurements)



Single OPC



Double OPC

Why OPC studies are important?

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- OPC can be a cause of common cause failure in a NPP if not properly detected by protection
- Safety issues related to OPC events have been detected in literature review
  - Voltage unbalance caused by an OPC has resulted in disconnection of safety critical loads
  - NPP backup connection has had an undetected OPC for a long time
- Some non-safety electrical equipment has been damaged due to OPC

Conclusions of the OPC work

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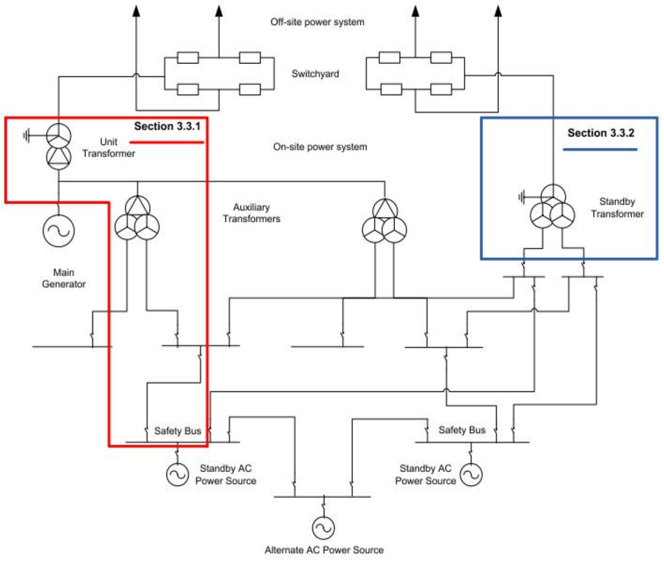
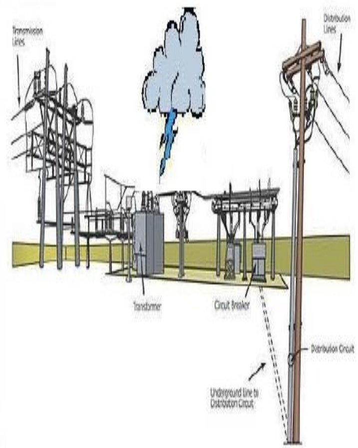
- Voltage and current unbalances due to OPC depend on the type and location of the OPC, transformers between the faulted and observed point and loading condition
- OPC is most difficult to detect in lightly loaded conditions
- Rotating machines (main generator, induction motors) and power electronics are sensitive to voltage unbalance



- Protection against OPC is implemented using undervoltage protection at different NPP buses, main generator negative sequence current protection and voltage unbalance protection
- No safety risks regarding OPCs have been identified in Finnish NPPs

Lightning induced overvoltages



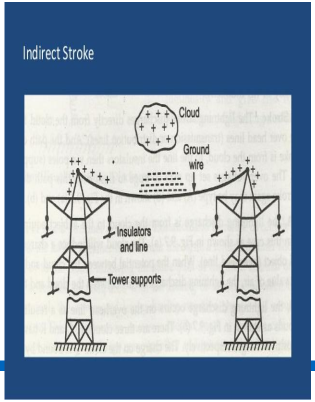
Ø 2 types of lightning stroke

a) Direct stroke

- Lightning stroke strikes the phase conductor of the line resulting in generation of a travelling voltage wave.
- Presence of the shield wire decreases the probability of phase conductor being hit by a direct stroke.

b) Indirect stroke (Back flashover)

- Lightning stroke strikes the transmission tower or the shield wire resulting in voltage wave which travels back and forth.
- Back flashover occurs when the insulator voltage exceeds the basic insulation level of the insulator.



Conclusions

- Presence of 400 kV surge arrestor has significantly reduced the transient over-voltage for both cases of direct stroke and back flashover.
- 15.75 kV surge arrestor & over voltage capacitor is required for the protection of generator having BIL of 68 kV at the 15.75 kV side.
- These surge arrestors & capacitors are enough to protect the generator against 20 kA and 26.6 kA lightning.
- If substantially larger surges are to be expected (> 50 kA), surge arrestor rating might be required higher ó statistical analysis needed for the probability of these entering the transformer 400 kV winding
- Motors in 6 kV are well protected by surge arresters in 15.75 kV and 6 kV levels

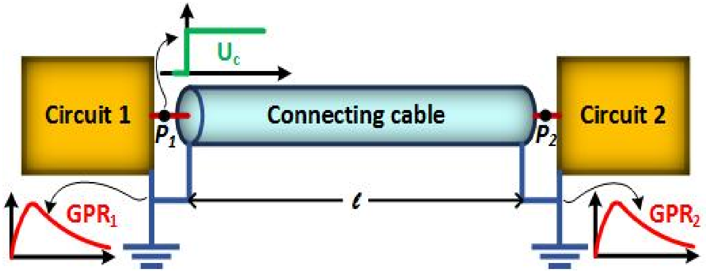
Lightning overvoltages due to the GPR

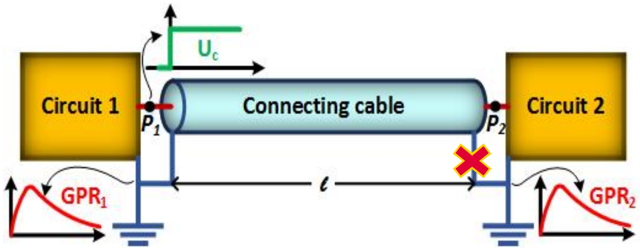
- Large-scale grounding systems in nuclear power plants are designed to ground the various electric apparatus and circuits inside the plant.
- For lightning surges, such large-scale grounding system may cause electrical stresses on the relatively long circuits that are grounded at different points of the grounding system
- Consequently, it is needed to investigate the ground potential rise due to lightning strokes at different points of such-large scale grounding system.

Electrical stresses in long signal cables due to GPR

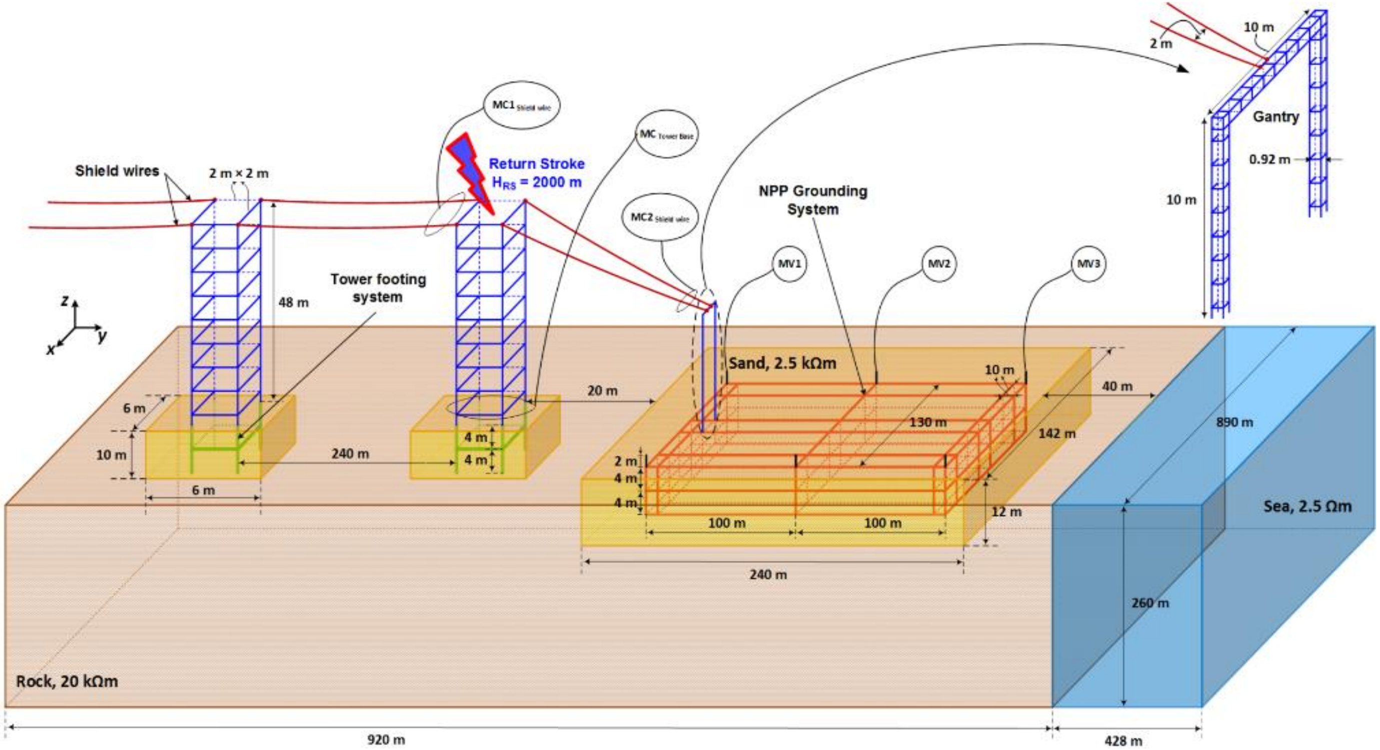
With lightning surge and GPR

- $U_{P1} = (U_c + GPR_1) - GPR_1 = U_c$ (OK), $U_{P2} = (U_c + GPR_1) - GPR_2 = U_c + (GPR_1 - GPR_2)$ (Hazard)
- Ground potential difference between two grounded points stresses the signal cable insulation
- According to initial simulations this potential difference can be several kV per meter
- In control circuits the sheath is sometimes grounded only in one end

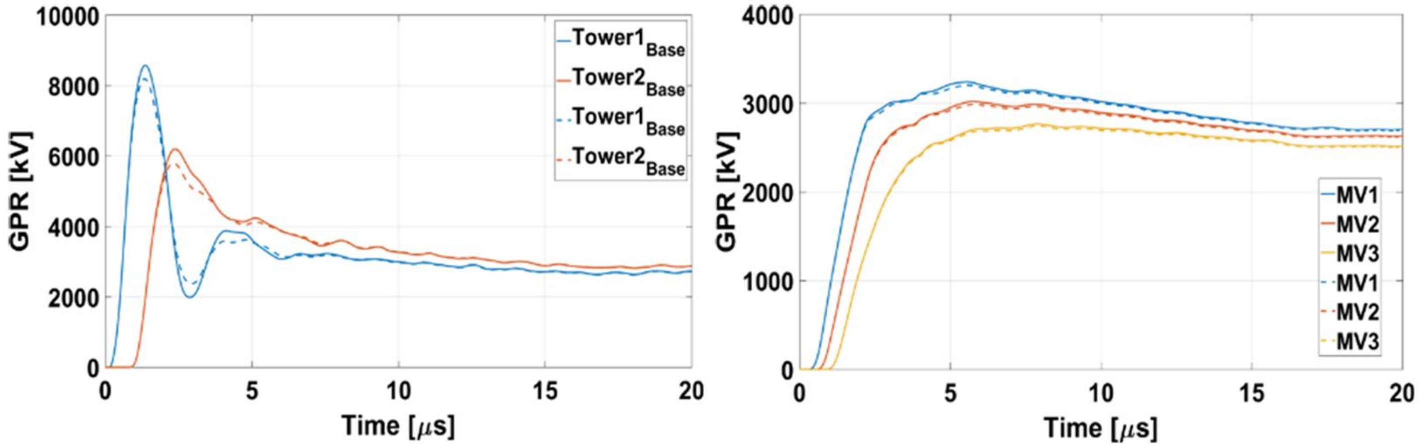




Grounding system model in simulations



Example of simulation results



a b

Figure: Ground potential rise: a) in tower bases and b) in three different points of grounding system, solid line without ionization and dash line with ionization. The lightning current has a peak value of 100 kA, the rise time of strike is 4 µs and the resistivity is 20/2.5 kΩm for rock/sand.

Conclusion of GPR

- The lightning strike to the gantry or adjacent transmission tower of a large power generating station is critical
- Magnitude of ground potential rise (GPR) at different points of large scale grounding system (LSGS) is strongly influenced by sea.
- Soil ionization causes a decrease in the soil resistivity and subsequently, in the computed GPR.
- High soil resistivity, the ground potential rise may cause high voltage stress in the connected equipment.
- A large lightning current may cause huge potential differences between different grounded parts of the electrical systems and excessive stress to the insulation of the signal cables
- Mitigation methods are external conductive cables parallel to the protected signal cables and surge protective devices in most critical locations.

Impacts of lightning strike on low voltage power electronic devices and their protection

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Simulation assumptions

- Voltage profile simulated at LV AC connection point taken from aforementioned overvoltage simulations
- Transient simulation in PSCAD tool using the profile
- Power electronic 3-phase load model

Simulation results

§ Metal oxide protector are effective to limit over voltage, but a rise in DC bus voltage was noticed.

§ The capacitors are very effective at damping fast transient overvoltages

§ Mechanical breakers are effective devices, but they have operational delay for noticing the fault and acting

§ The dampening effects of batteries are also considerable.

Flexible operation of NPP

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- Flexible operation is actively use in some countries, mainly in Germany and France.
- Finnish power system is very different and balanced compared with Germany or France and other type of balancing resources are available.
- Nuclear power plants are slower to respond to control commands than coal or gas plants
- Optimal control range of NPPs is around 60 – 100%
- Plant operators have no plans for the time being to implement load-following in any of the plants in Finland (old or new)
- If implemented, seasonal control would suit better to old plants using manual controls
- Investments in knowledge and personnel would be needed for actual flexible operation
- Main concern is financial profitability, high capital and low running costs.
- Concerns are also thermal system & turbine stress, ageing of components and increased maintenance work
- The Finnish authority STUK sees flexible operation as technical and design issue and not something that is not allowed by safety rules.

Risks and challenges to transmission grid

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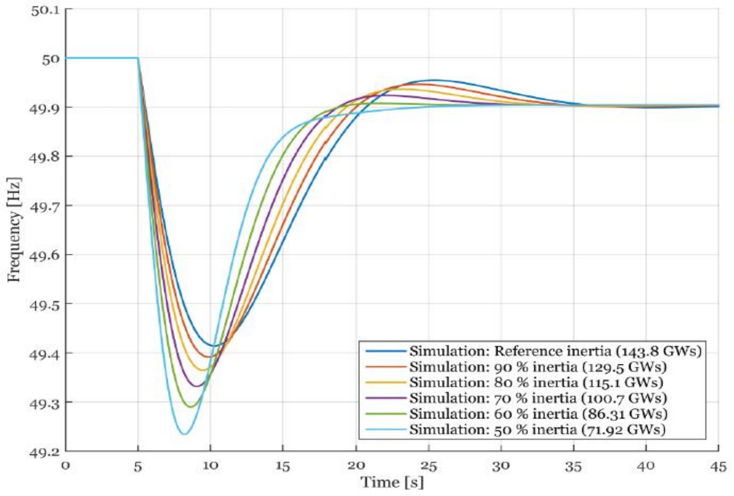
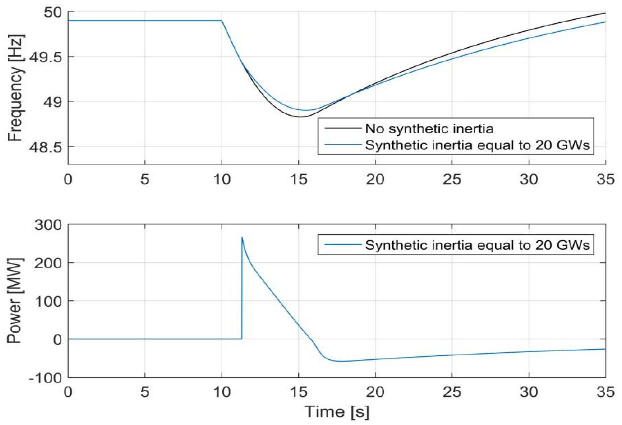
Low ineartia effect on power grid stability



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



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

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

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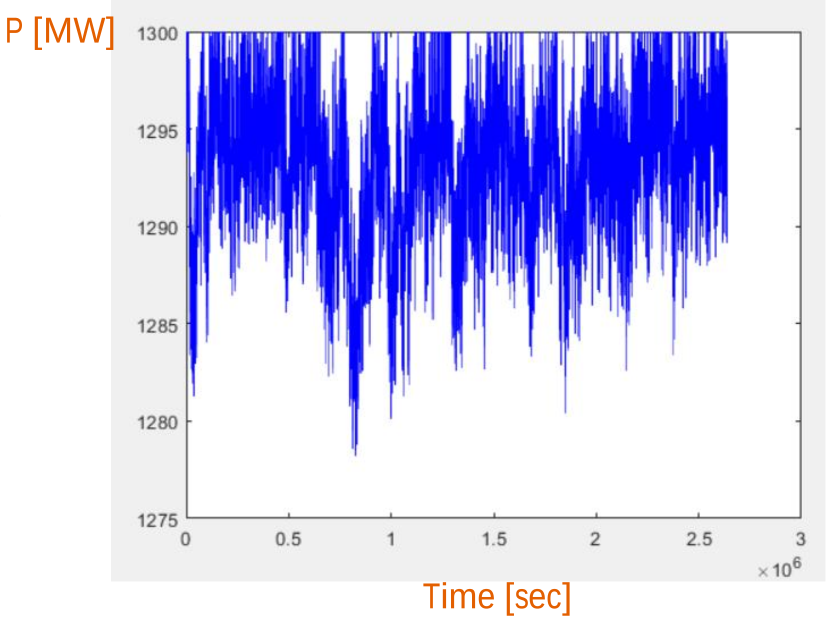
Assumptions:

- Frequency data is from year 2016, 2 months period data with 1 s interval.
- The change of output power 3%/minute
- Simulated NPP unit: 1300 MW
- Minimum production capacity 10 GW
- Frequency droop $= \dfrac{\frac{\Delta f}{50\ Hz}}{\frac{\Delta P}{P_{nom}}}$
- Simulation with droop value of 0.5
- 4.6% additional cost of flexible operations respect to Nordpool SPOT price



NPP unit (1300 MW) participation in the frequency control

Conclusions of flexible operation

- Using market data from 2016, there were 1144 hours when flexible operation could have been profitable.
- Capacity factor decrease per plant was estimated to be 0.5%.
- 2020 onwards rotating generation will be less in the power system leading higher price variations.
- Nuclear power plants could serve better in down regulation reserve
- 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.
- Future grid codes require more flexibility from power plants and it is very likely that new NPPs will be required to take part in flexible operation 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)