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# Survey of Operational Events …

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# Content

- **Background to the study**
- **Conclusions from literature survey**
- **Notable events at Nordic NPPs**
- **Mitigating actions taken at the Nordic NPPs**
- **Toolbox for future mitigating actions**
  - Detection of loss-of-phase
  - Double circuit-breakers in series
  - Duplicated analyses
  - Implementing “withstand or isolate” concept
- **Conclusions**



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# Background to the Study

In the Energiforsk report *Grid interference on operations, Mapping of R&D needs* a number of topics for future work were identified

- Survey of operational events from the offsite power system with focus on retrofit of mitigating actions
- Sub-synchronous resonance phenomenon and modelling combined with hybrid simulations
- Survey on new electrical devices with different technology compared to existing electrical devices
- Survey of methodologies to verify that the outer grounding line network in the nuclear power plants is intact
- Generic lightning model of the Nordic nuclear power plants to study lightning incidents due to conducting



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# Conclusions from Literature Survey

- The reliability of critical on-site equipment must be ensured
- Training of personnel to handle situations of loss of off-site power is important
- Perform testing to ensure proper function of equipment and procedures
- Assess (by simulations and experienced events) the immunity of the plant towards events in the off-site power system



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# Conclusions from Literature Survey

- **Susceptibility of Nuclear Stations to External Faults, NUREG-7175**
  - "Many of the LOOPs and plant trips [… ] would otherwise have been avoided if the existing properly-designed protection systems had operated as originally intended."
  - "In some cases it may be possible to reduce the time delays for backup protection or breaker failure schemes to reduce or mitigate the effects of electrical transient events."
  - Increasing the reliability in critical parts of the system
  - Increasing the redundancy in the protection system
  - Identify crucial and significant components
  - Inspection, testing and maintenance of protection system and equipment

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# Notable Events at Nordic NPPs

- **Forsmark**
  - On June 25, 2006, June 13, 2008 and July 13, 2012 events occurred that stressed the power electronics (rectifiers and inverters) due to fast voltage transients and jeopardized the battery-secured system
  - On May 30, 2013 at least one non-functioning circuit-breaker pole in the unit circuit-breaker caused an unbalanced supply voltage for the on-site power system. This could have led to severe damage to asynchronous motors
- **Oskarshamn**
  - A number of events in the off-site power system close to Oskarshamn, due to the protection system, have led to disconnection of the units from the grid – inadvertent operations



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KD3

# Notable Events at Nordic NPPs

- **Olkiluoto**
  - On May 30, 2008 the generator excitation system of OL1 caused high excitation current, and the generator output voltage rose to 125%. The unit circuit-breaker disconnected the unit leading to a further increase of the generator voltage. Differential protection tripped the generator and turbine and led to a reactor trip



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**Bild 9**

**KD3** - Känns ju lite knepigt att genertor-diffskyddet löste….. det antyder shuntfel snarare än överspänning……

- Men jag gör ingen stor affär av det …….

Karlsson, Daniel; 2016-06-12

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# Mitigating Actions Taken

- Improvement of the fault-clearing system in the off-site power system to minimize fault-clearing times and improve reliability
- Improvement of the relay protection system for main generators, transformers, etc.
- Extensive studies of the units' ability to withstand disturbances in the off-site power system
- Improved communication between the NPP and the network operator to ensure a reliable supply during revisions and maintenance work in the power system
- Verification, by test, of transfer to house-load operation
- Special attention given to selectivity of protection for rectifiers/inverters for battery-secured systems



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# Toolbox of Mitigating Actions

The outcome of the survey of events and experiences and the actions taken at the NPPs has led us to four "tools" that could be further investigated and applied to minimize the impact of future incidents and events related to loss of off-site power

- Detection of loss-of-phase
- Double circuit-breakers in series
- Duplicated analyses
- Implementing "withstand or isolate" concept



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# Detection of Loss-of-Phase

## *(Patent Pending, SE 1400207-5)*

- Current-based calculation
- To be implemented on the infeed to the step-up transformer and start-up transformer, in existing IEDs.
- Not to function for three-phase interruption. A threshold value in at least one phase must be exceeded. This is a start criterion *S* for function.
- Six test values, based on the value of the phase currents, are defined, $D_a$, …, $D_{ab}$, … Small values implicate function, large values does not.

$$D_{\mathrm{a}} = \frac{2|i_{\mathrm{a}}| + \varepsilon}{|i_{\mathrm{b}}| + |i_{\mathrm{c}}| + \varepsilon} \qquad D_{\mathrm{ab}} = \frac{|i_{\mathrm{a}}| + |i_{\mathrm{b}}| + \varepsilon}{2|i_{\mathrm{c}}| + \varepsilon}$$

$\varepsilon$ is a small value to prevent division by zero



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# Detection of Loss-of-Phase

## *(Patent Pending, SE 1400207-5)*

- The test values are compared to threshold values ($T_0$ and $T_1$) to detect loss-of-phase.
- The threshold values shall fulfill the conditions, $0 < T_0 < 1$ and $1 < T_1 < M$, where $M$ is a large number.
- For function it is required that S, $C_1$, $C_2$ and $C_3$ are all fulfilled.

| State | Criteria | | |
|---|---|---|---|
| | $C_1$ | $C_2$ | $C_3$ |
| Loss of phase a | $D_a < T_0$ | $D_b > T_1$ | $D_c > T_1$ |
| … | … | … | … |
| Loss of phase a and b | $D_{ab} < T_0$ | $D_{bc} > T_1$ | $D_{ca} > T_1$ |
| … | … | … | … |



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# Double Circuit-breakers in Series

- "In some cases it may be possible to *reduce the time delays* for backup protection or breaker failure schemes *to reduce or mitigate the effects of electrical transient events*." – Susceptibility of Nuclear Stations to External Faults, NUREG-7175
- The only relevant reason for long fault-clearing times, in a protection system with duplicated protections, is a *non-functioning circuit-breaker*
- Reliability is ensured by duplicating the components of the fault-clearing system, i.e. protection functions, relay protection, current-transformer cores, trip coils, etc. However, it has not been practice by many network owners to *duplicate the circuit-breakers*



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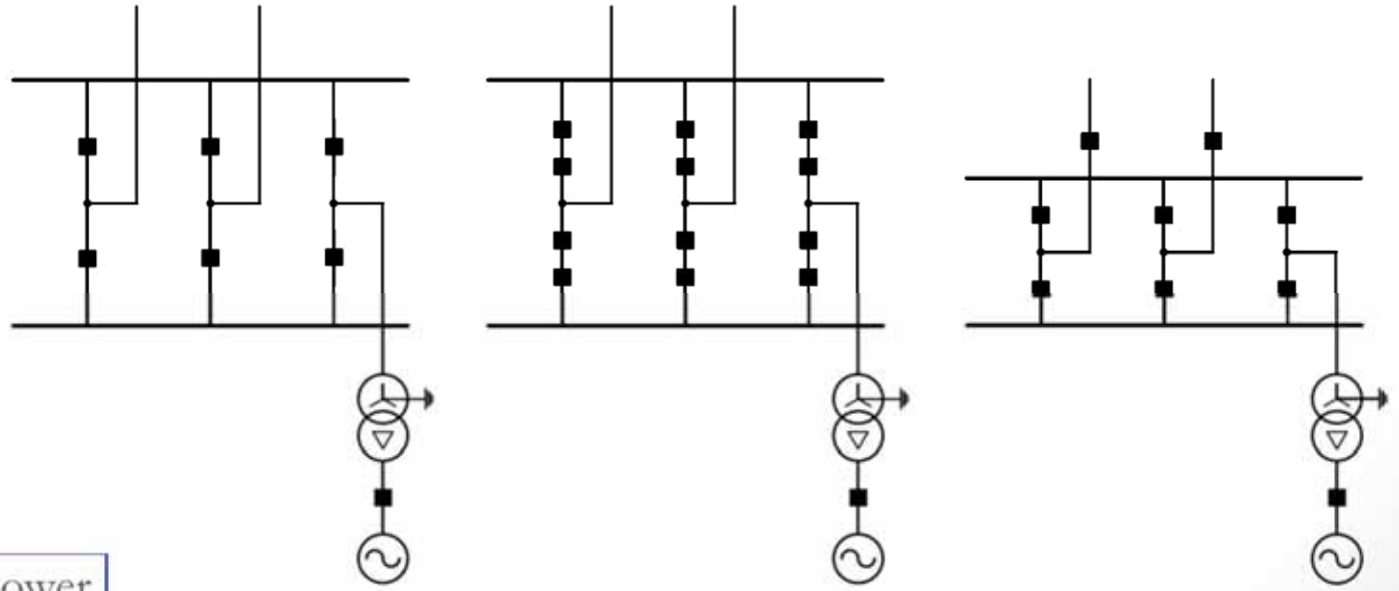
# Double Circuit-breakers in Series

- A non-operating circuit-breaker (or one or more of the poles) in a series arrangement will not lead to a prolonged fault-clearing time since the adjacent circuit-breaker will operate
- There might be a possibility to retrofit existing double-breaker substations with a third line circuit-breaker, according to the arrangement to the right





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# Duplicated Analyses

- **Reliability is ensured by duplicating the components of the fault-clearing system, i.e. protection functions, relay protection, current-transformer cores, trip coils, etc.**
- **From practical and economic reasons technical analyses of protection relay settings etc. are often performed**
  - By the same person that has performed previous analyses
  - By different person, but using data from previously performed analyses
  - By only one person (even if several persons review the work)
  - Results/settings from analyses are often "inherited" by other units in the same station or even by other nuclear power stations



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# Duplicated Analyses

**A possible way to improve the reliability of analyses, relay protection schemes and settings could be**

- ***Let two engineers perform the same analysis independently***
  It could be that technical analyses (e.g. calculation of physical or electrical properties or relay protection settings) are performed by the contractor as part of a purchase agreement. This could open for the possibility of the NPP's engineers to independently perform the same analyses.
- ***Do not use existing reports or analysis as basis for the renewed analysis***
  By reading a previous analysis report the engineer most certainly will be biased.



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# Duplicated Analyses

- ***Diversify by using different entrepreneurs***
  When purchasing and installing apparatuses and systems a way to avoid common-cause errors is to use different brands, manufacturers and/or models of the equipment, e.g. for SUB1 and SUB2 relay protection. The idea is that a latent fault in one model does most probably not exist in a model of another brand or manufacturer. The same thinking can be used in the analysis phase.

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# “Withstand or Isolate” Concept

- This concept is formed around the idea of what the critical equipment can endure or withstand – its immunity towards disturbances in the electrical environment
- This is in contrast to the method were a limited number of external events or scenarios are postulated and the response from the equipment is evaluated
- Experienced disturbances reveal the difficulty to predict what could happen and this holds also for the future …



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# “Withstand or Isolate” Concept

- **Withstand …**

  **The method of obtaining the immunity levels may include**

  - *Relying on manufacturer data*
    For less critical equipment this may be sufficient. The equipment can be manufactured according to specific standards on EMC.
  - *Performing theoretical analyses or simulations*
    As a complement to available manufacture data it may be necessary to perform analyses of how the equipment will behave under certain conditions. To obtain information of how different components behave together this may also be necessary.



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# “Withstand or Isolate” Concept

- **Withstand …**
  - *Estimating the immunity from registrations of earlier events*
    Information of the immunity can be concluded from registered events where the equipment both have succeeded and failed to operate as intended. Having a sufficient amount of such registrations can serve as a basis for such estimation.
  - *Performing tests on equipment*
    Sometimes the only (but always the best!) way to get information on the immunity of a component or equipment is to perform testing to see under what conditions it will operate as intended.

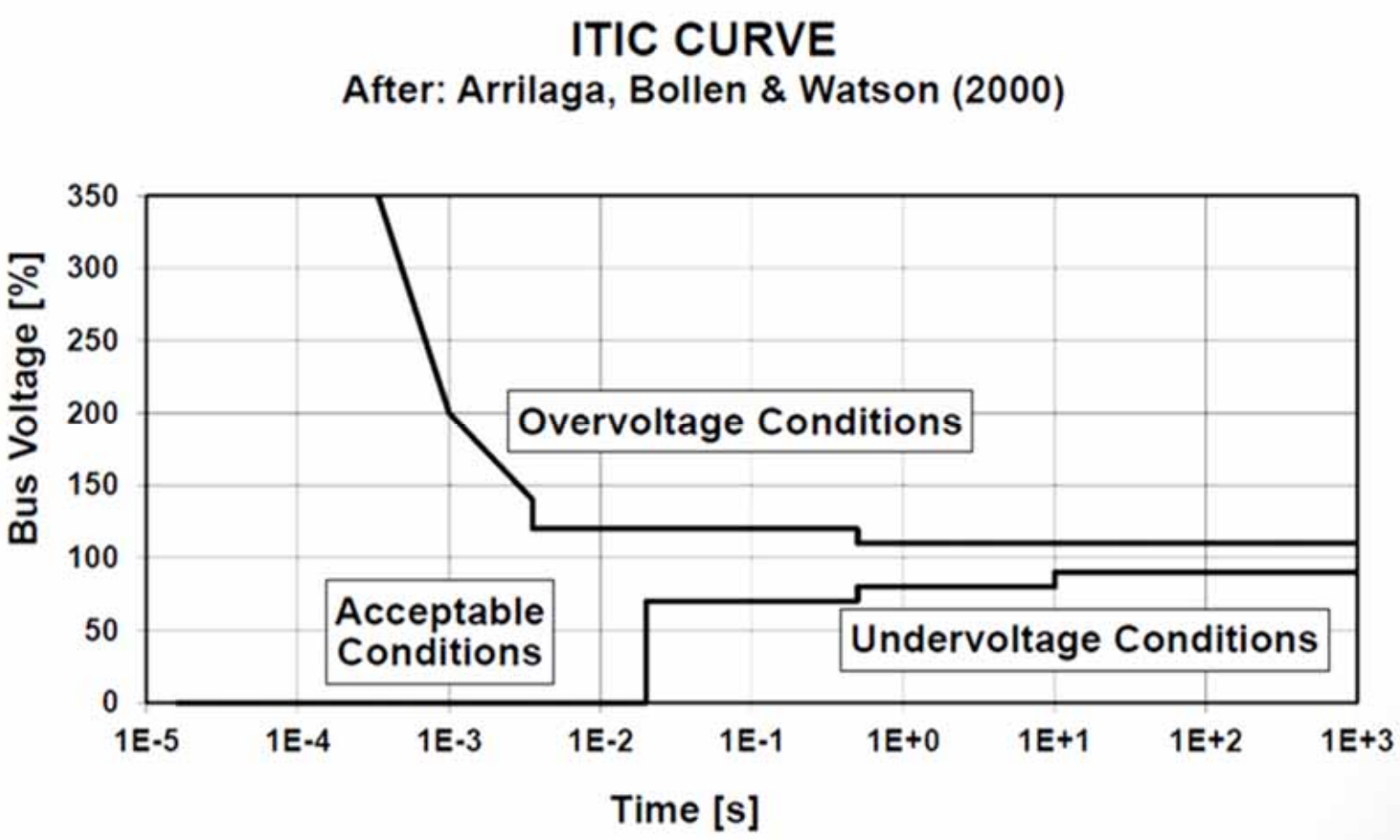
# “Withstand or Isolate” Concept

- **… or …**
  - The decision between “withstand” and “isolate” is performed by protective relaying and automatic sequences
  - The protective system must be set to function when the equipment cannot withstand
  - The protective system must be reliable (redundance)
  - The protective system must be fast enough not to jeopardize the function of the equipment

# “Withstand or Isolate” Concept

- **… Isolate**
  - Given that the on-site power system is isolated from the off-site power system it is important that the level of isolation is sufficient
  - Circuit-breakers that have tripped form a galvanic barrier between the two systems
  - Keep the system isolated also with respect to inductive and capacitive phenomena
  - Should the critical equipment form several sub-systems, isolated from each other? What about disturbances from within the on-site power system?

# “Withstand or Isolate” Concept



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# Conclusions

- **A survey has been performed in available literature on events at NPPs around the world that has been triggered from the off-site power system**
- **Events related to loss of off-site power have led to mitigating actions at the Nordic NPPs**
- **Four possible "tools" are presented that could be further investigated and applied to minimize future incidents and events related to loss of off-site power**
  - Detection of loss-of-phase
  - Double circuit-breakers in series
  - Implementing "withstand or isolate" concept
  - Duplicated analyses



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# Thank You for Your Attention!