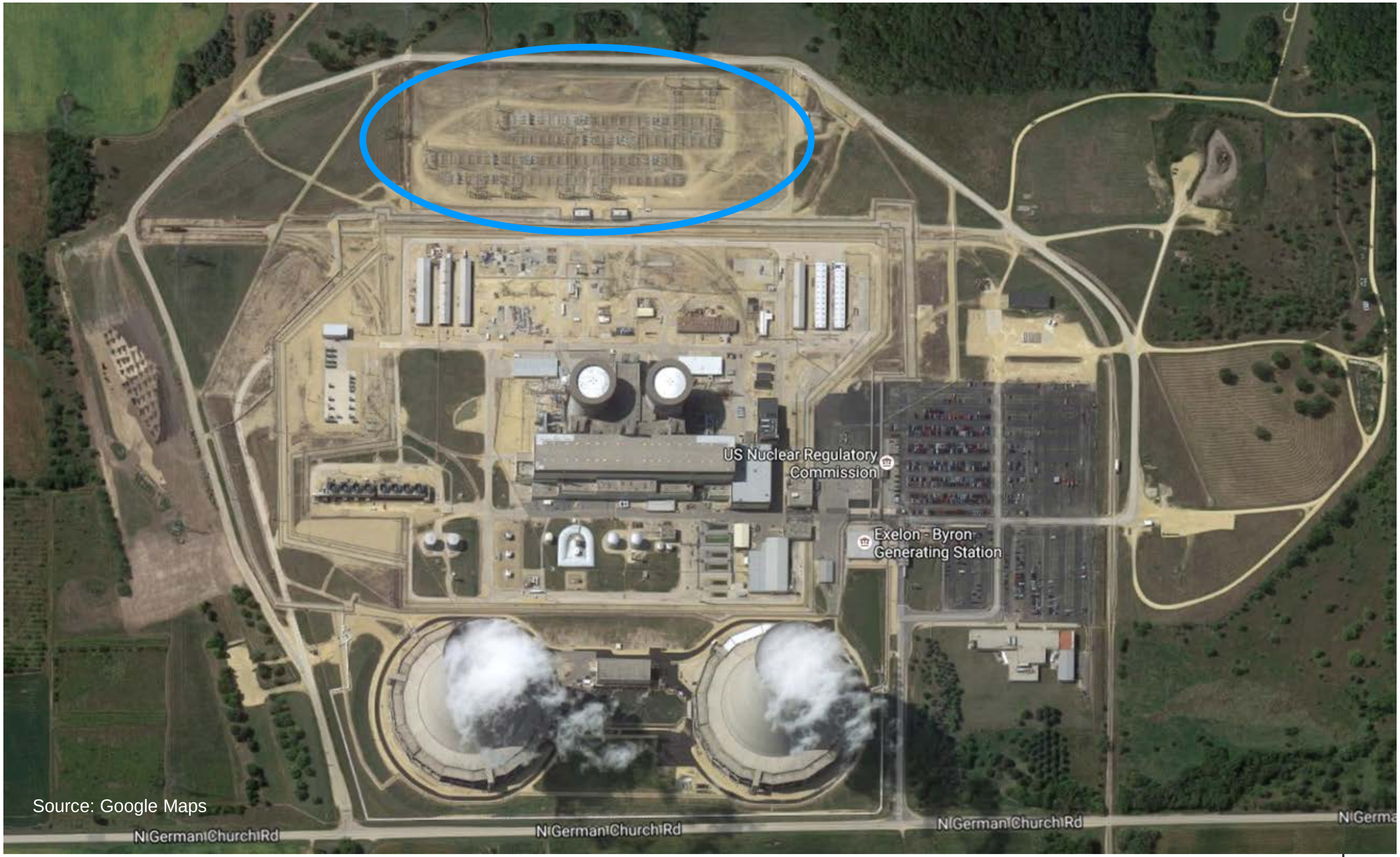
Benjamin Brück; Robert Arians; Claudia Quester

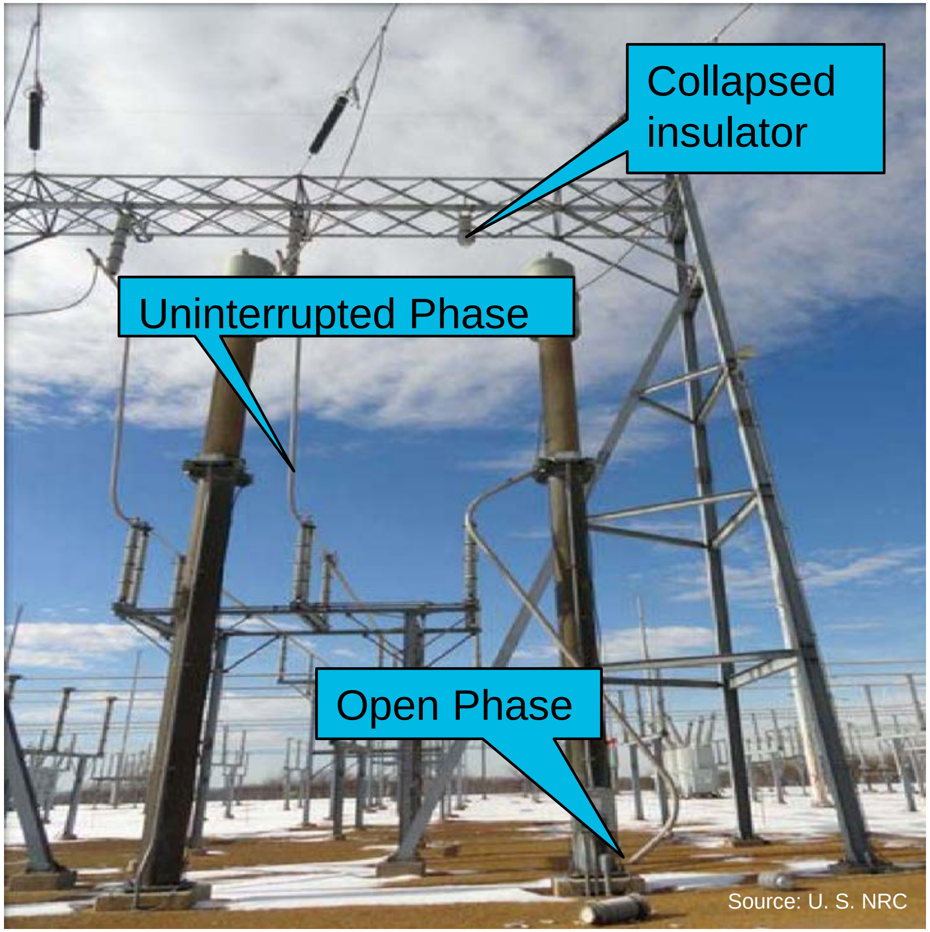
Implications of Open Phase Conditions in the Electrical Grid Connections for the Safety System of NPPs

NPP Byron, Overview with Switchyard



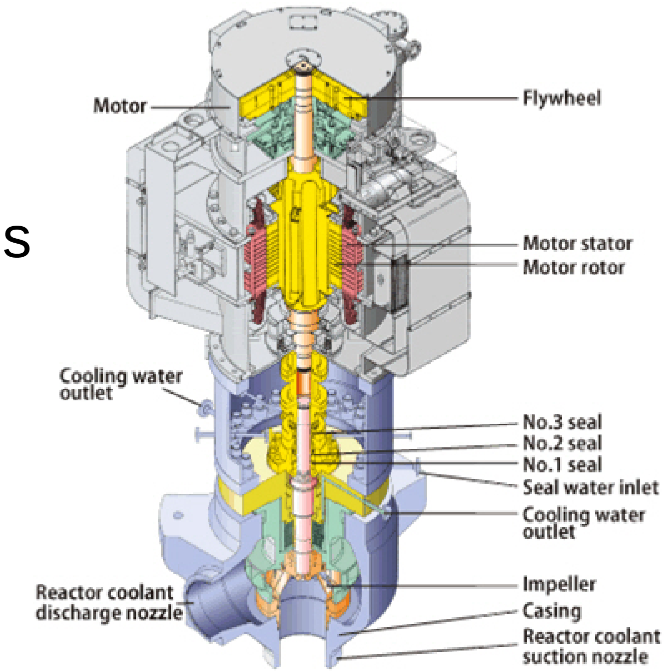
NPP Byron, January 30th, 2012 (1)

- Collapse of a porcelain insulator on the high-voltage side of the auxiliary transformer in the switchyard of the plant
- Interruption of one phase
  - No ground fault
  - Open phase condition
- Automatic reactor trip is initiated



NPP Byron, January 30th, 2012 (2)

- Within the next seconds, multiple pumps failed due to overcurrent protection
  - Essential Service Water
  - Auxiliary Feedwater (motor driven)
  - All Reactor Coolant Pumps
  - …

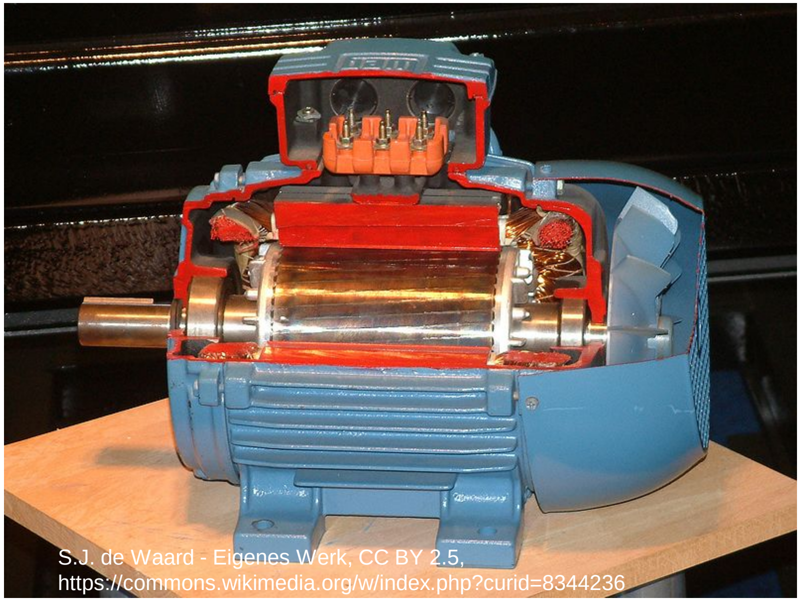


Source: MHI

- The monitoring of the onsite power system is not able to detect and handle the fault
  - No automatic actions of the RPS/ESFAS
  - 8 minutes after the collapse of the insulator the fault is isolated by manual action

Background – Three-phase Alternating Current in NPP

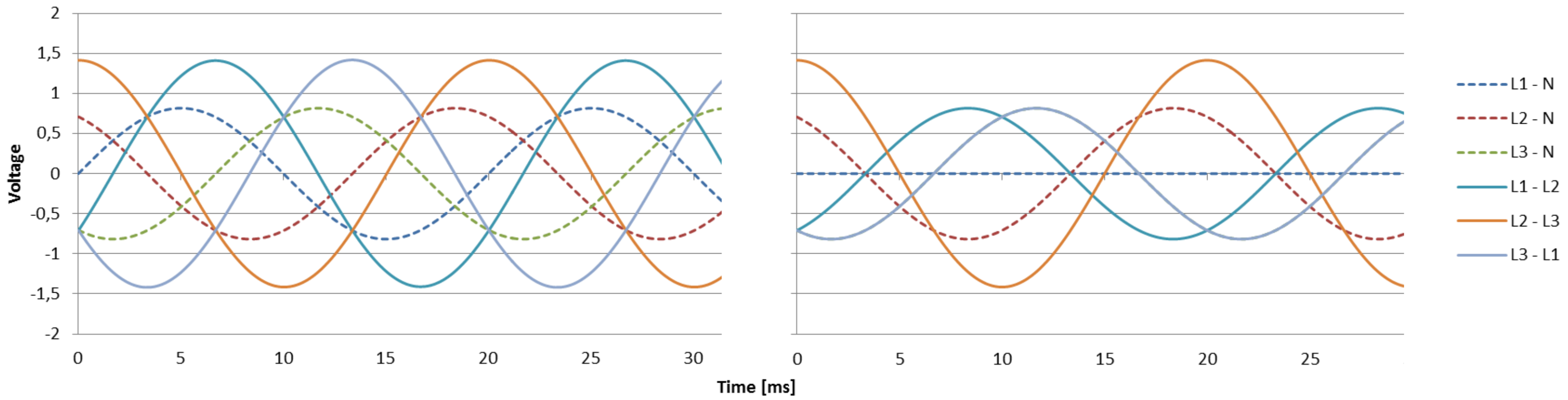
- Operational and safety relevant pumps, fans and valves in NPP are usually driven by asynchronous (induction) motors
- These motors rely on three-phase alternating current which is defined by
  - Voltage amplitude
  - Frequency
  - Symmetry
  - (Wave shape)



- Voltage amplitude and frequency of the onsite power system are monitored by RPS-graded surveillance devices

Background – Symmetry and Asymmetry

- A three phase system is defined as symmetric, if
  - all three line-to-line voltages are equal
  - the distance between the three phases is 120°
- Example of an three-phase system before and after the complete loss of one phase

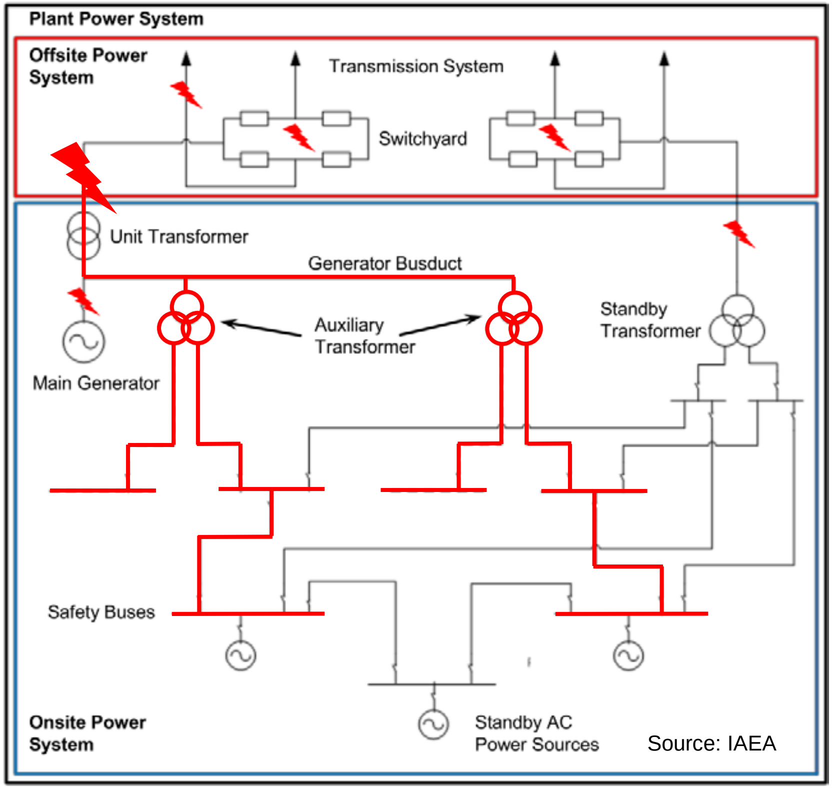


Background – Effects on Induction Motors

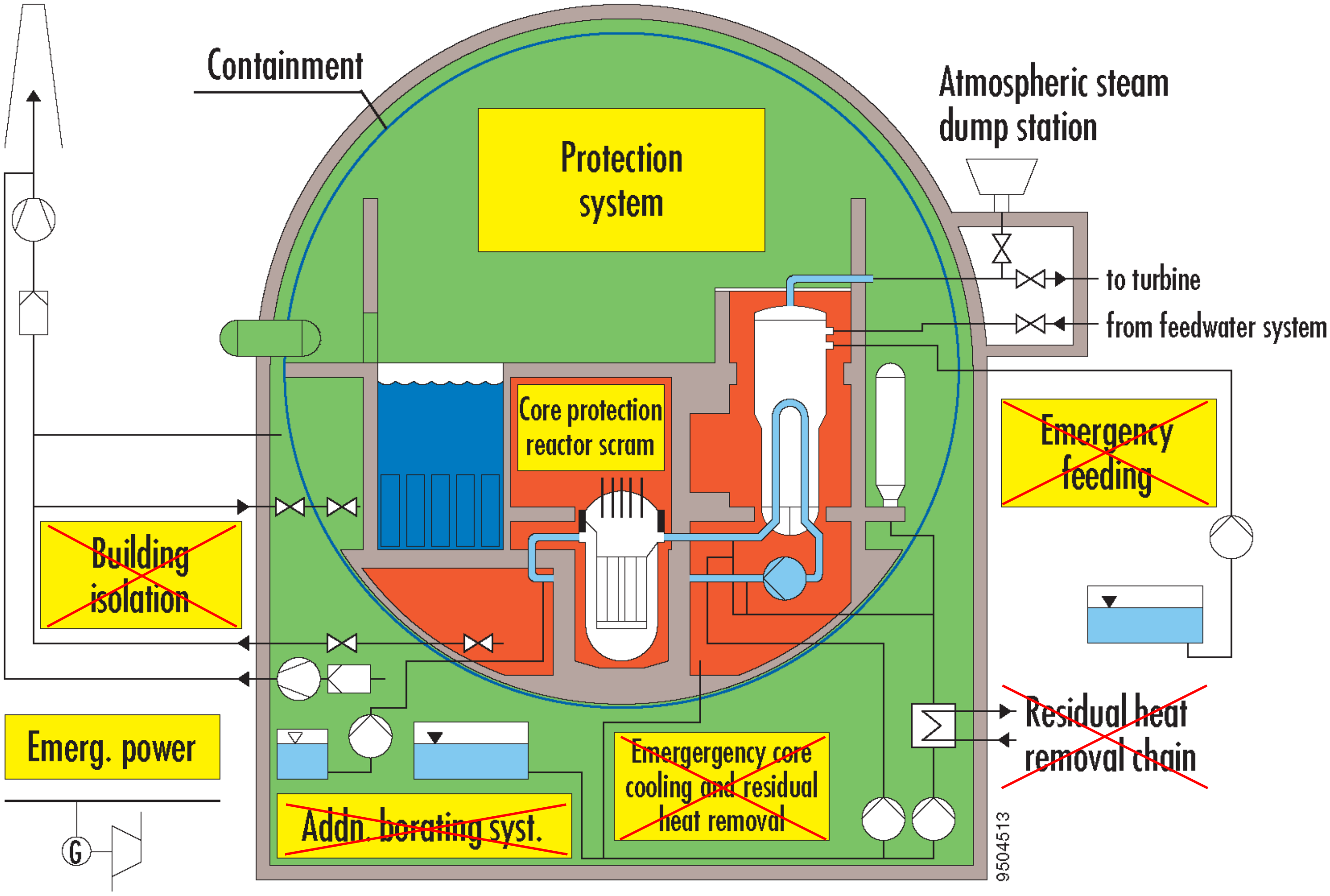
- Reduced torque of the motors
  - Operation or startup of the motors may get impossible
- Increased current intake induced by the asymmetry
  - Increased current intake may trigger overcurrent protection devices of the motors
  - Resetting of the devices requires manual action
- Thermal destruction of the motors if the overcurrent protection does not work appropriately

Redundancy and Open Phase Conditions

- NPPs have several redundant electrical busbars (trains)
- No separation between the redundant electrical busbars during normal power operation
  - All trains connected via the generator bus duct or the HV-side of the Standby Transformer
- Any open phase condition “above” the connections will affect all redundant trains simultaneously



Effects of OPCs on the Safety System



Operating Experience with OPC (1)

- Several electrical asymmetries due to OPC are recorded in NPP operating experience worldwide
  - At least 10 events since 1994 with actual component failures inside the NPP
- Since the event in the NPP Byron, at least one event per year is reported
- Most common direct cause for OPC is the failure of individual breaker poles
- Many events outside the direct responsibility of the NPP utility (e.g., HV switchyard)


Source: IAEA

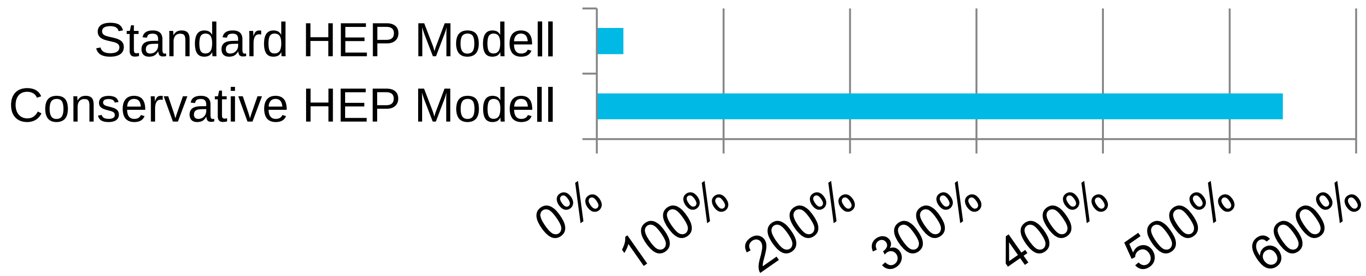
Operating Experience with OPC (2)

Date	Plant	Failure Cause
13.05.1994	Kalinin	Collapse of a transformer duct, OPC in one phase
25.02.1997	Balakovo	Unintended closure of a single breaker pole
31.03.2001	South Texas	One breaker pole in the switchyard failed to close
11.11.2005	Koeberg	One breaker pole in the switchyard failed to close
31.07.2006	Vandellos	Mechanical failure of a disconnector
14.05.2007	Dungeness-B	One pole of a HV-transformer breaker failed to close
30.01.2012	Byron	Collapsed Insulator caused a line interruption
01.12.2012	Bruce	Mechanical line failure during severe weather (storm)
30.05.2013	Forsmark	Failure to open on command of a single breaker pole
27.04.2014	Dungeness-B	Open breaker pole in the switchyard

Quantitative Risk Assessment

- Occurrence frequency: > $1 \cdot 10^{-3}$ / year
  - Comparable with the frequency of a small LOCA event
- Without automatic detection devices, the chance to handle OPC depends on the reliability of the manual actions
  - In case of the Byron event, the U. S. NRC calculates probabilities from $1 \cdot 10^{-4}$ to $3 \cdot 10^{-3}$ for $CCDP$ (depending on the HEP model)

Increase of CDF due to OPC **(for a German plant)**



Mitigating the Risk due to OPCs

- OPCs are easy to cope with once they are detected:
  - The onside power system has to be switched to an alternative power source (stand-by grid connection, diesel generators…)
- OPCs are difficult to detect:
  - Fast detection of the OPC necessary
  - Manual detection not sufficient
  - Monitoring of voltage amplitude and frequency not sufficient
  - A certain degree of asymmetry always exists and must not lead to a false positive detection

Conclusions

- Several events with OPC are recorded in the recent international NPP operating experience
- OPC may compromise essential safety functions of NPP
  - "Undetected Station Blackout"
- Reliable measures to detect OPC have to be implemented
- Multifunctional digital relays will be (or are already) used
  - Reliability assessment of these complex relays difficult
  - Multiple diverse relays should be used

Source: Siemens