
Reliability of offsite power of nuclear power plants in evolving power systems

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Offsite power & Nuclear safety

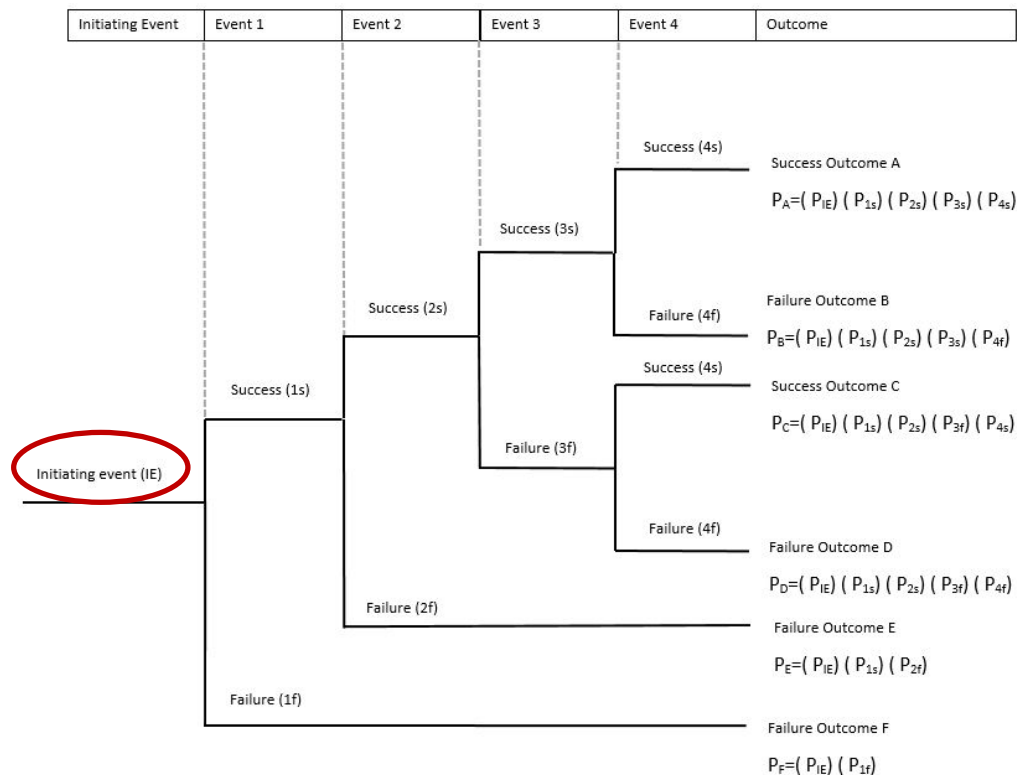
- Permanent cooling of a nuclear reactor, including during the shut-down phase!
 - Risk of core damage
- Primary pumps necessary to cool down the nuclear reactor
 - Power supply of primary pumps: external grid (+ internal grid supplied by diesel generators in case of problem)

Reliability of offsite power crucial to cool down and so for the nuclear safety

- Loss Of Offsite Power = LOOP
- LOOP event: initiating event contributing significantly to the core damage frequency in probabilistic safety assessments (several tens of percent)

Consideration in Probabilistic Safety Assessment (PSA) studies

- Classical PSA: combination of failure trees and event trees
- Significant impact of the initiating event frequency
- How to evaluate that frequency for a rare LOOP event?

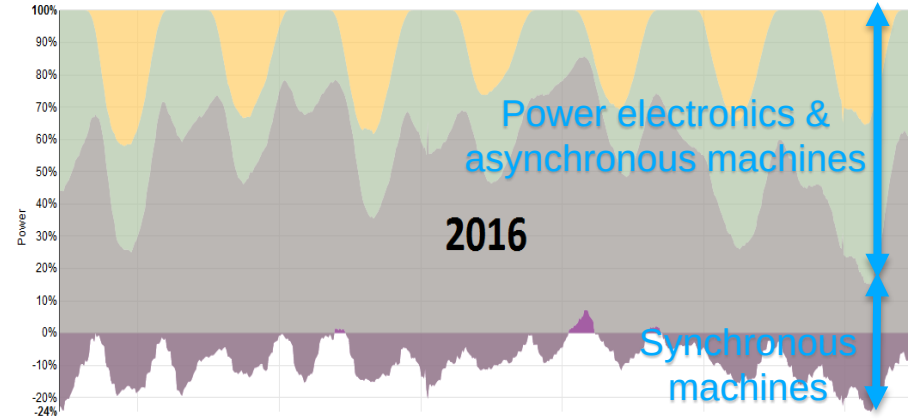
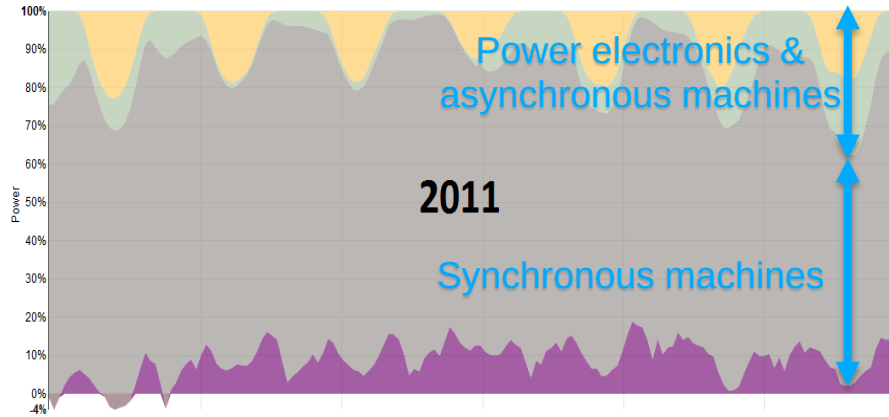


Possible origins of the loss of offsite power

- Three main categories of LOOP events
 - Plant-centered LOOP events
 - Switchyard-centered LOOP events
 - **Grid-related LOOP events**
 - 36% in the United States
 - Electrical grids are strongly evolving (Energy Transition)

Impact of the Energy Transition

Germany case



Conventional > 100 MW Wind Solar
Export Import

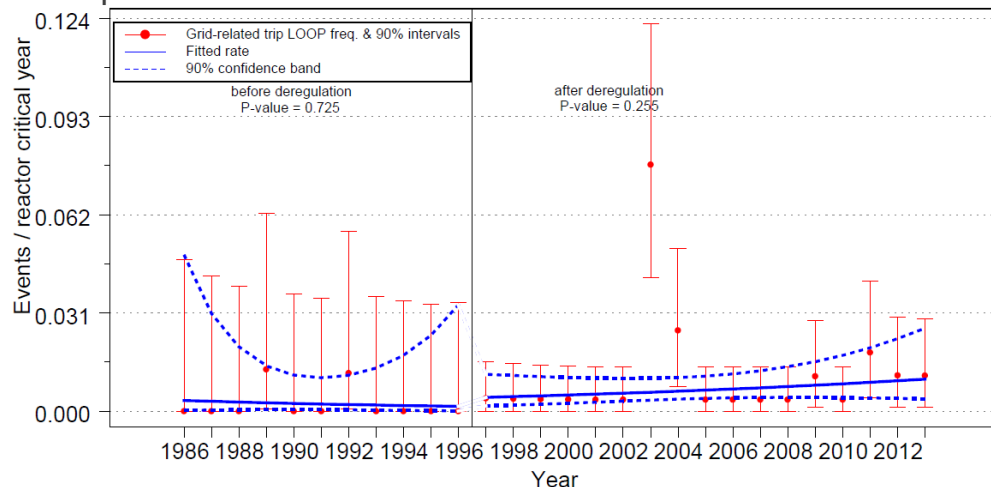
Estimation of the grid-related LOOP frequency

- Classical way to estimate the grid-related LOOP frequency
 - Operational feedback: aggregation of statistics on a large number of reactors and a large number of years (~15 years)...
 - Rare event (with potentially important consequences)!
- Relevance of such an operational feedback, given the evolution of power systems?
 - Energy systems much more complex
 - Energy mix with a large share of Renewable Energy Sources

Evolving power systems and link with the LOOP frequency

- Major changes in the grid → impact on the LOOP frequency

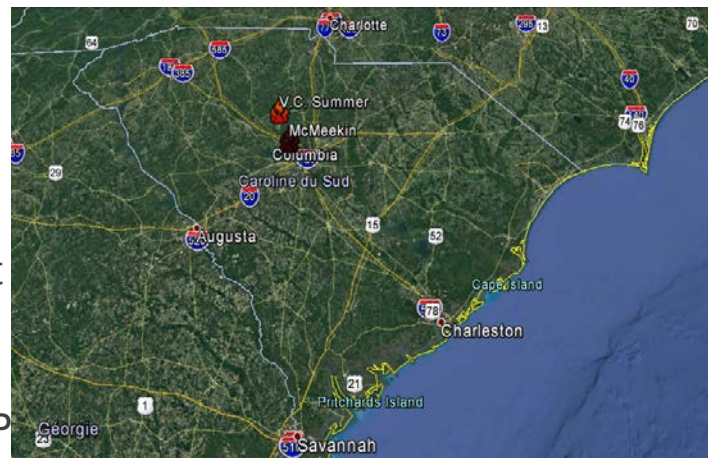
Example of the liberalization in the United States



- Operational feedback approach valid if no major change in the power system
- Need of an simulation-based approach to consider grid evolutions**

Example of a LOOP event: Virgil C. Summer NPP, 1989

- Initiating event: spurious turbine (& reactor) trip
- Important loss of active power (860 MW) + loss of reactive power (440 MVAR)
 - Electrical transient → voltage drop in the area
- Increase of the reactive power generation of McMeekin coal power plant
 - Erroneous disconnection of that unit by a protection system
 - Worsened the voltage drop
- Similar phenomena at Saluda hydro power plant
- Voltage then too low to keep in service a pumped-storage plant
 - Additional disconnection
- Minimum acceptable value for the voltage at the NPP → LOOP



Requirements on the proposed approach

- Need to consider the impact of the initiating event and of next events on the electrical transient
- Need to consider the impact of the electrical transient on the disconnection of elements by associated protection systems
- Need to consider the unreliability of protection systems (configuration errors, measurement errors, spurious trip, failure to trip)

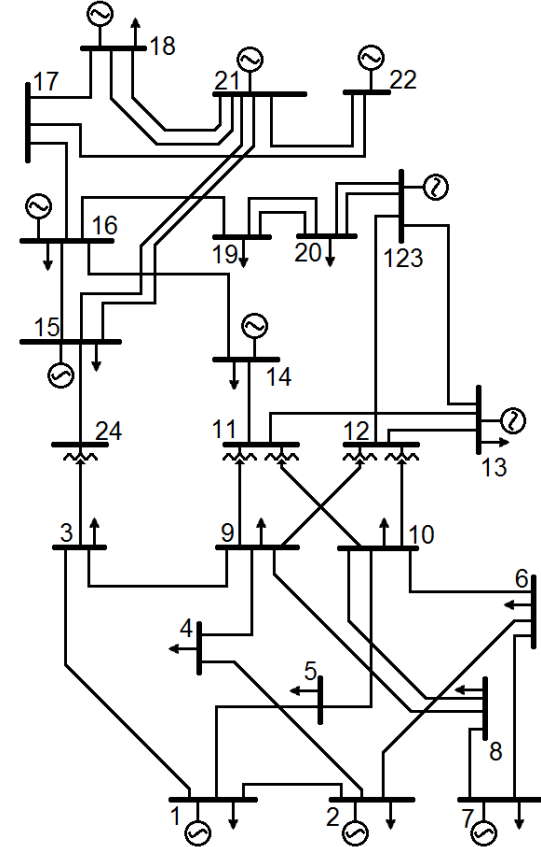
Need of dynamic reliability methods

Proposed approach

- Use of a Monte Carlo method, coupled to a deterministic dynamic power system simulator (Eurostag)
 1. Sampling of the load level in the grid, and of available energy from RES
 2. Economic dispatch of generating units
 3. Sampling of the stochastic behaviour of protection systems
 4. Sampling of the initiating event
 5. Dynamic simulation until electrical steady state reached
 6. LOOP event if NPP voltage lower than a threshold

Example

- Test system with 24 buses
 - 2 nuclear units (bus 18 & bus 21)
 - Thermal and hydro generating units
 - 2 levels of wind penetration (% of the annual load supplied by wind energy)
 - 0%: no wind generation
 - 10%: 7 wind farms of 100 MW



Example

- Results of the probabilistic dynamic simulation

Wind penetration (%)	LOOP frequency (/rcyr)
0	0.145
10	0.192

- Significant change of the LOOP frequency in function of the wind penetration → change of the nuclear risk
- Wind generation does not have the same dynamic properties than classical thermal generation

Conclusions

- The electrical world is changing (Energy Transition)
- The usual computation of the LOOP frequency based on operational feedback is not any more relevant
- New approaches based on dynamic reliability must be developed and used
- The massive penetration of RES can have an significant impact on the nuclear safety