Grid Stability and Safety Issues Associated With Nuclear Power Plants

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Items to Be Discussed:

- What are Nuclear Safety Implications of an "Unreliable" Electric Power Grid?
- What types of Electric Power Grid Scenarios are of concern to NPP Safety?
- How do US and International Nuclear Safety Standards address Electric Power Grid Reliability concerns?

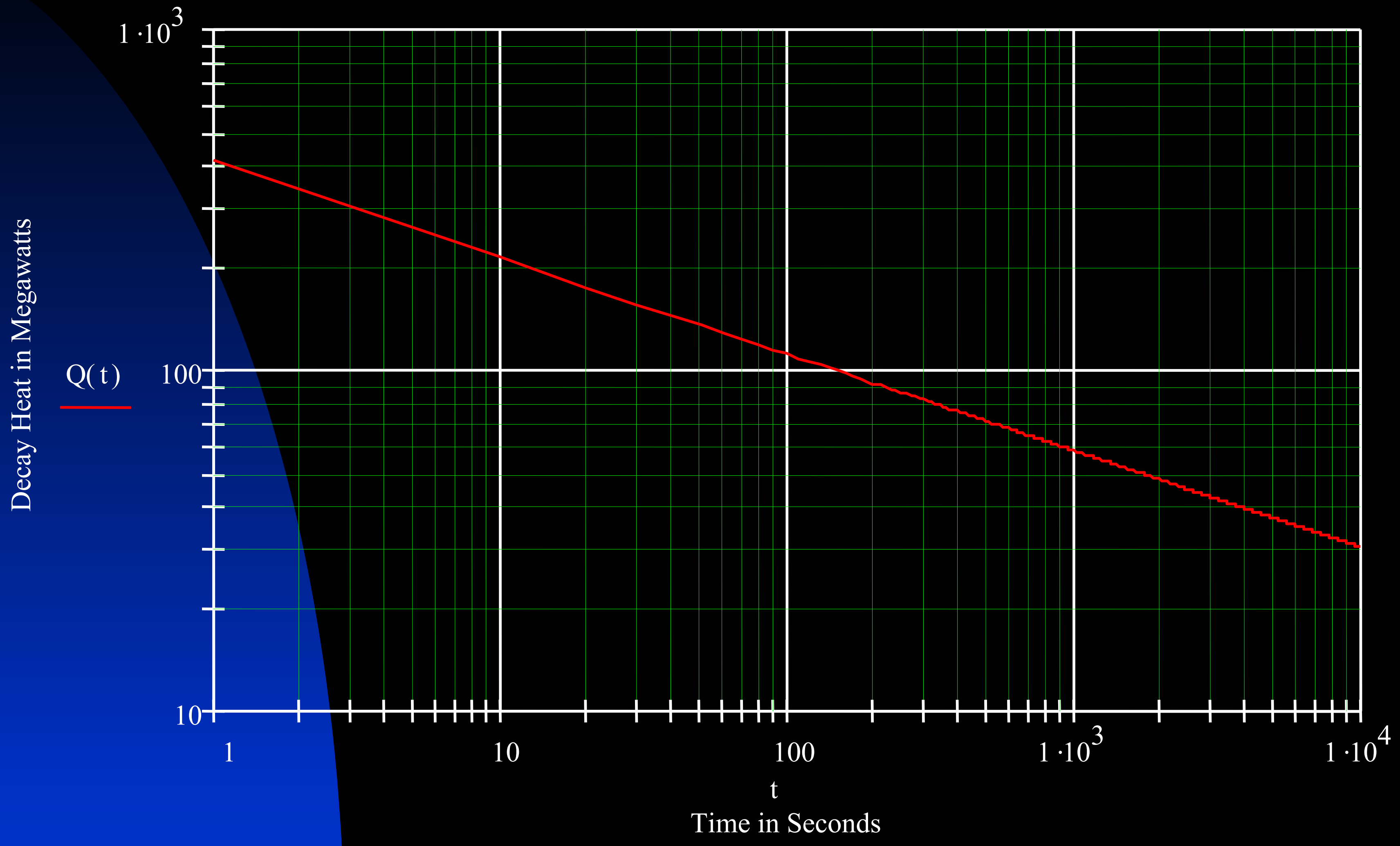
Previous Speakers Have Noted:

- Proper interconnection of regional grids can improve reliability by providing redundancy in generating sources, transmission pathways to major load centers.
- Interconnection allows sharing of generating resources for both economic and environmental benefits.

How Is Safety of NPP Impacted by Electric Power Grid Reliability?

- Load Rejection, Loss of External Load.
- Degraded Voltage / Frequency.
- Loss of Offsite Power due to External Grid Disturbance.
- NPP trip causing cascading grid collapse and Loss of Offsite Power to NPP.

Unlike Other Units Heat From NPP Persists a *Very Long* Time After Shutdown.



Automatic NPP Shutdown Alone Is Insufficient to Assure Safety.

- Electric power needed to remove fission product decay heat… indefinitely.
- Electric power is needed to power instrumentation, control, and monitoring systems in control room.
- Battery power for instruments typically available for ~ 4 hours.
- Electric power needed to power HVAC systems used for assuring operable environments for equipment and personnel.

How US and International Standards Address Grid Reliability:

- US NRC Regulations regarding Electric Power supply requirements are found in Title 10, Code of Federal Regulations, Appendix A, GDC 17.
- Industrial Standards such as: IEEE Std 308-1980, IEEE Std 741-1990… provide clearer guidance.
- Similar requirements found in IAEA Safety Guide No. 50-SG-D7 (Emergency Power Systems at Nuclear Power Plants).

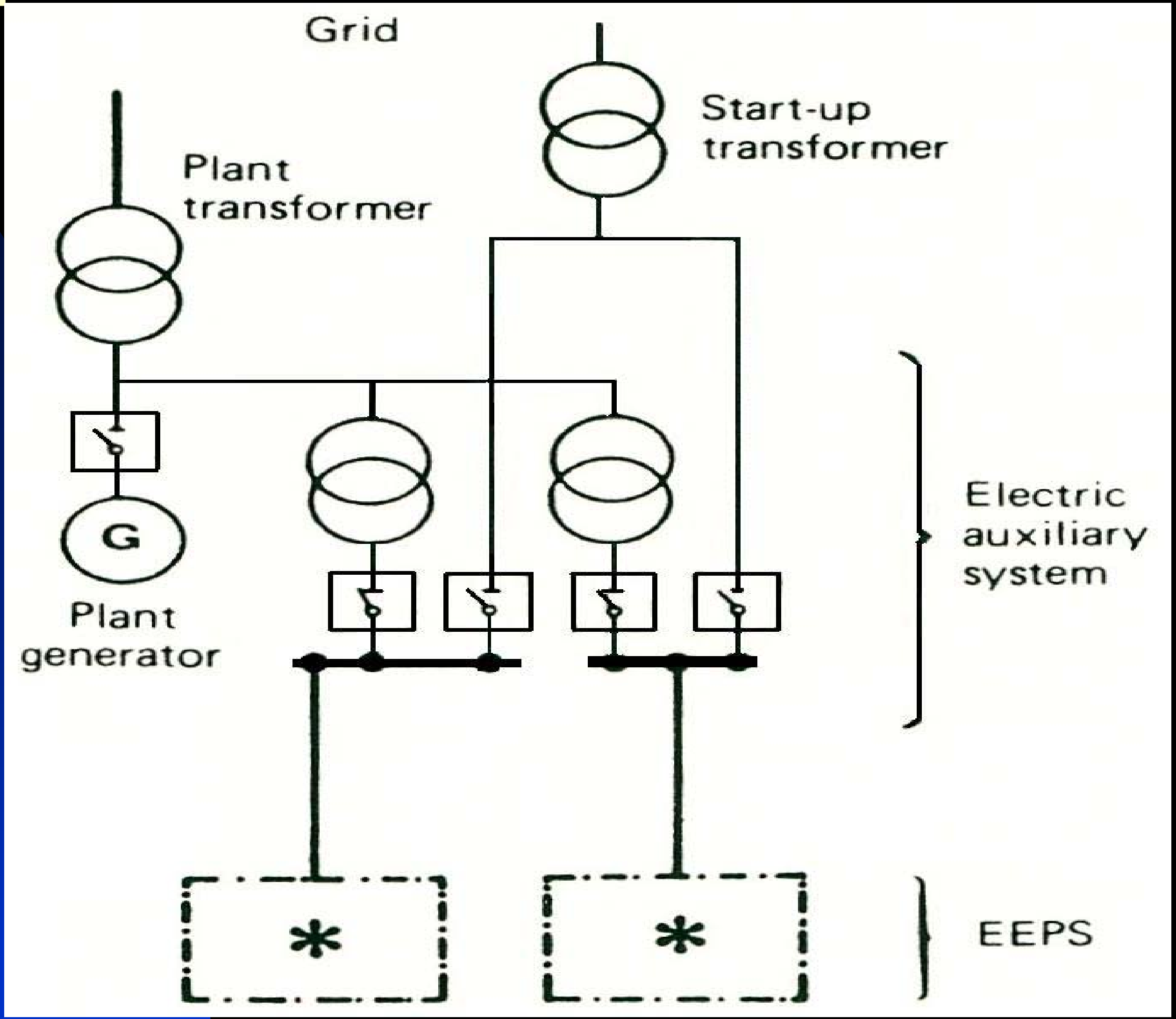
GDC 17 Requires:

- "An onsite and offsite electric power system shall be provided to permit functioning of structures, systems, and components important to safety."
- ".. each system shall provide sufficient capacity and capability to assure:
  - SAFDLs and reactor coolant pressure boundary not exceeded..
  - Core is cooled and containment integrity and other vital functions maintained in event of postulated accidents."

- “onsite electric power supplies, including the batteries, and onsite electric distribution system, shall have sufficient independence, redundancy, and testability to perform their safety functions assuming a single failure.”

- “Electric power from transmission network to onsite electric distribution system shall be supplied by 2 physically independent circuits (not necessarily on separate right-of-ways) designed and located to minimize likelihood of their simultaneous failure..”
- “A switchyard common to both circuits is acceptable.”

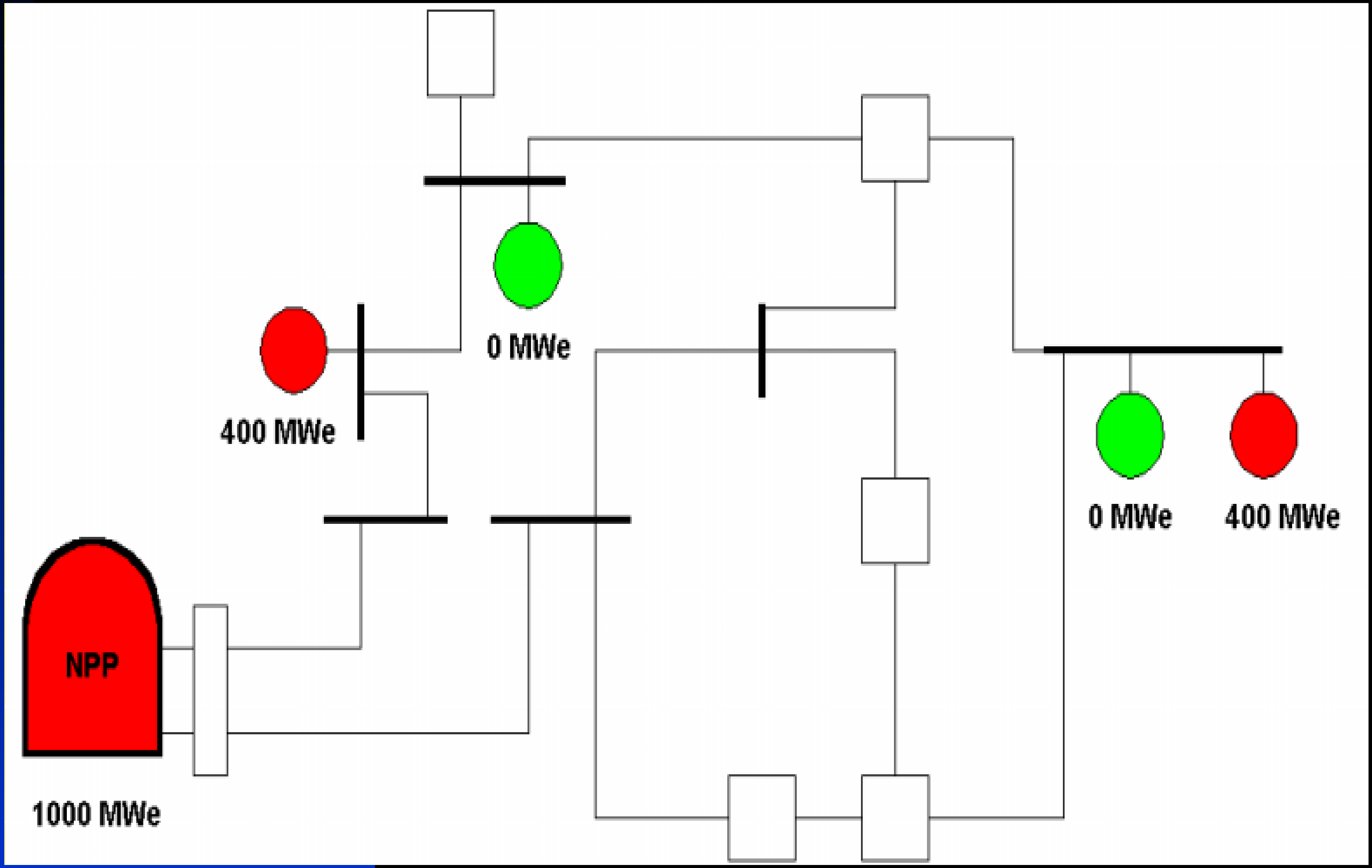
Example NPP Interface With Grid:



- “Each of these circuits shall be designed to be available in sufficient time following a loss of all onsite alternating current power and the other offsite alternating current power circuit…”
- “One of these circuits shall be designed to be available within a few seconds following a LOCA…”

- “Provisions shall be included to minimize probability of loosing electric power from any remaining supplies as a result of, or coincident with loss of power generated by nuclear power unit, loss of power from transmission network, or loss of power from the onsite electric power supplies.

Independent Offsite Circuits?



Grid Assumptions Used in NPP Design:

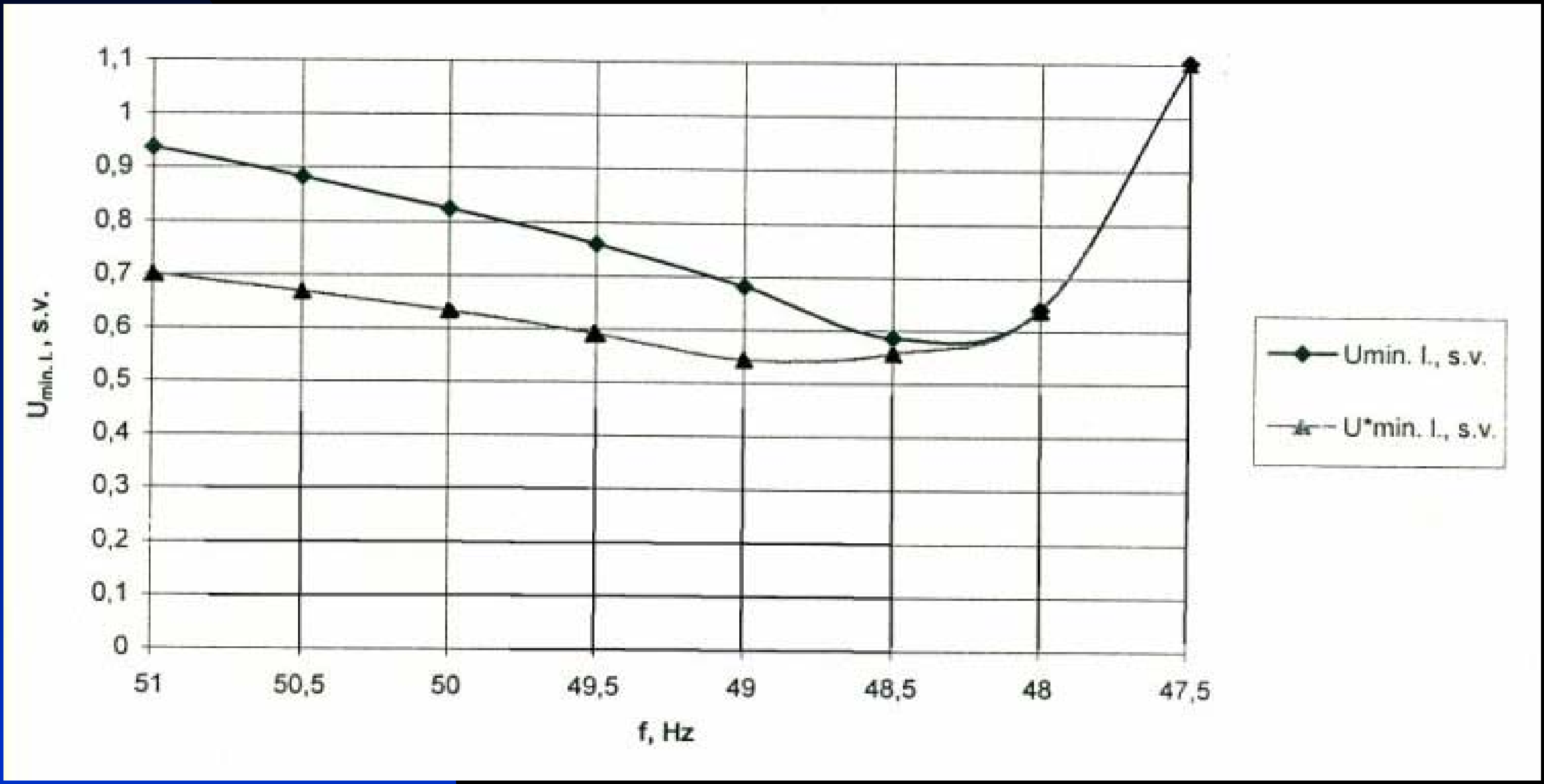
- Demand / Generation mismatch resulting in frequency decay accomodated by.
  - Successive Voltage reductions (~ 5%) coordinated by Regional Dispatch Center.
  - Automatic “Load Shedding” if frequency, voltage decay becomes worse.
- Increased generation during grid emergency supplied by fast responding units (e.g. Hydroelectric Dams, Gas Turbines) - *not NPPs*.
- NPPs assumed to be “Base Load Units.”
- NPPs assumed not to load any faster than 5% /minute within limited range due to nuclear fuel metallurgical limits.
- NPPs assumed to unload at 5-10% /minute.

Load Rejection / Loss of Load:

- NPP designs capable of controlled runback (without trip) following 40% Load Rejection via Fast Turbine Control Valving, Steam Bypass, and Reactor Control Rod Insertion.
- When Load Reject capability is exceeded, NPPs will trip – and will not be able to return to service for many hours.
- Specific NPP designs (CE System 80) capable of fast controlled runback to house load following a Full Load Rejection or temporary Loss of Load.

Degraded Voltage:

Large Pump Motor Minimum Starting Voltage Requirements vs. Frequency



Degraded Voltage:

- Large pump motor starting voltages are typically > 85% Nominal. Lower voltages causes over-current and opens protective fusing or breakers. Thus: stand-by pumps can not be started.
- Degraded voltage to running pump motors will cause over-current and over-heating.
- Nuclear power plants are provided with logic to sense degraded voltage condition and trip reactor. *Safety analyses presume back-up power sources have correct voltage and frequency for long term decay heat removal.*

Degraded Voltage:

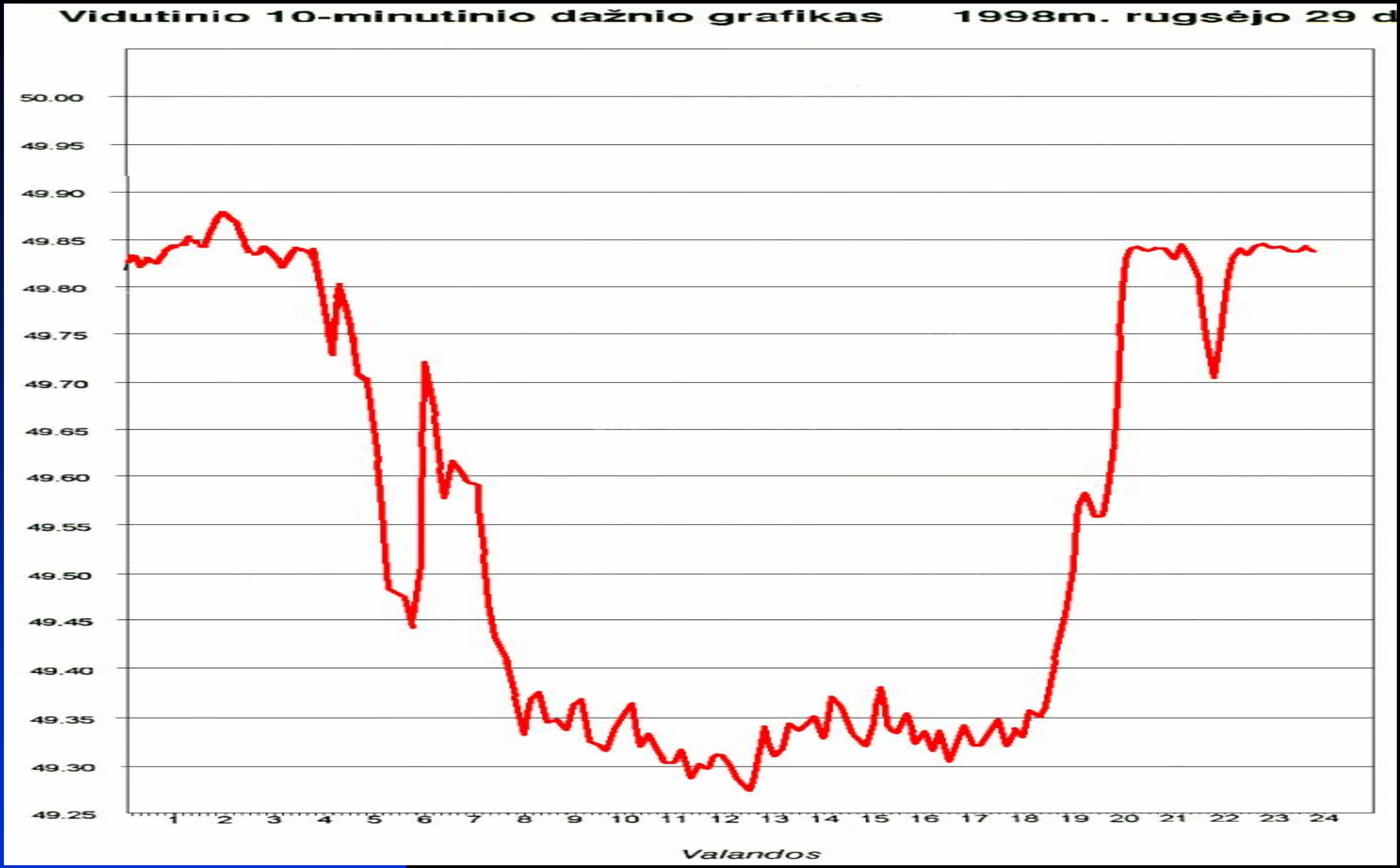
- A window exists for allowable in-plant voltages.

- Protective system voltage setpoints must be:
  - Sufficient to protect safety related cooling pump motors during starting transients.
  - Not too high - so that protection settings do not result in premature unit trip and disconnection from grid.

Degraded Frequency:

- Simplistically: Coolant flow $\propto f$ (grid frequency).
- Drop in grid frequency reduces coolant flow.
- NPPs provided with logic to sense severe degraded frequency and automatically trip reactor. *Safety analyses presume back-up power sources have correct voltage and frequency for long term decay heat removal.*

Long Term Degraded Frequency Event:



Loss of Offsite Power Concern:

- Loss of Offsite Power causes numerous reactor protective trips (turbine/generator trip, low coolant flow, loss of feed water flow, etc.).
- In-plant electrical loads must then be temporarily powered by batteries and stand-by diesels until offsite power restored.
- Diesels typically fail to start or run ~ 1% of time.
- Diesels are not as reliable as offsite grid.

Insights From NPP Probabilistic Risk Assessments:

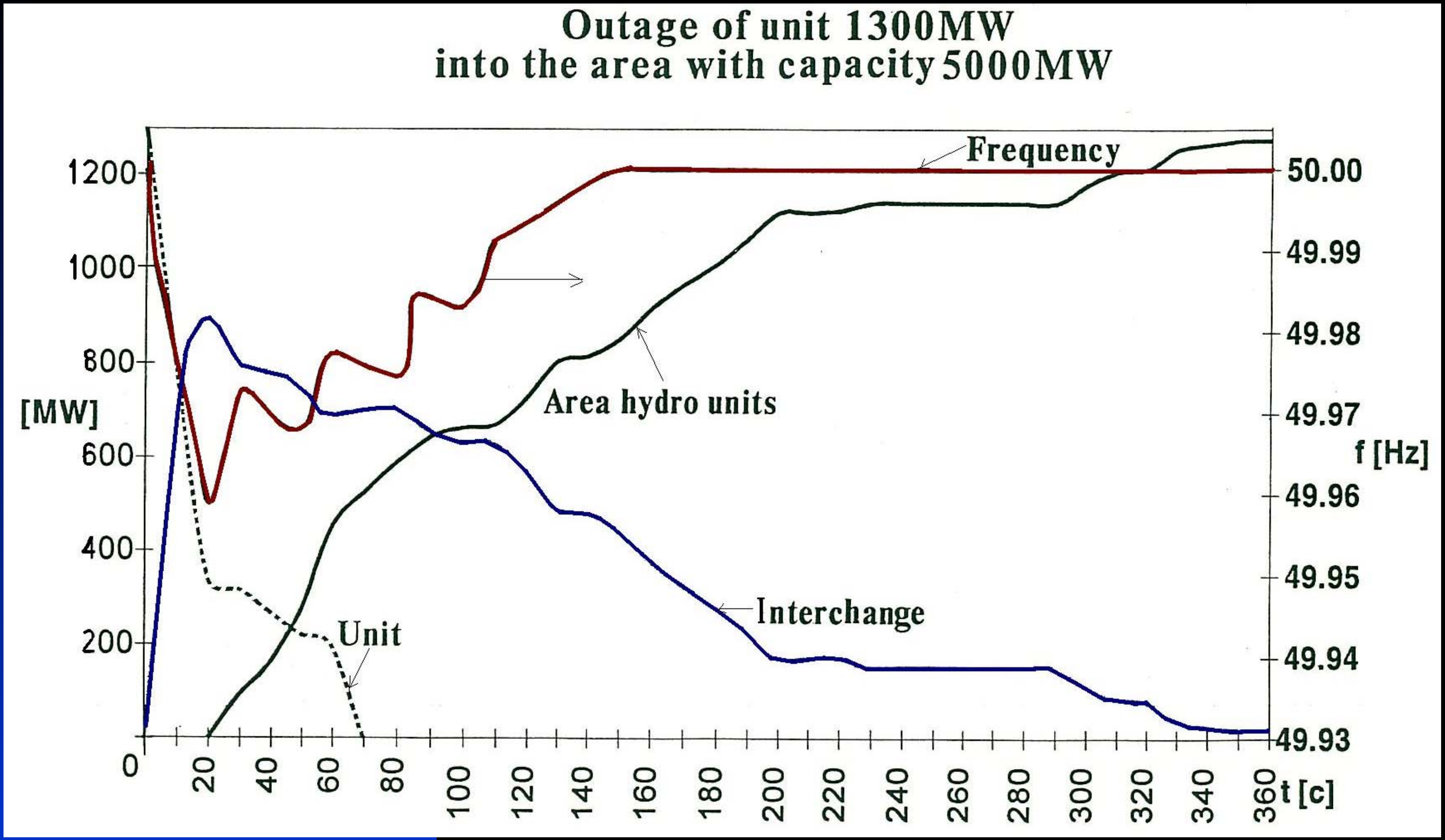
Sequences involving:

- (Loss of Offsite Power) + (stand-by diesels fail) + (slow recovery of grid) are dominant contributors to core damage risk in Probabilistic Risk Assessment Studies for all types of nuclear reactors.

NPP Trip With Cascading Loss of Offsite Power:

- ***Following any plant trip, safety analysis presumes back-up power sources will be available at correct voltage and frequency.***
- If nuclear power plant "carrying" a disproportionate amount of system load suddenly trips… collapse of the grid is likely.
- Two incoming circuits to NPP are not independent in this specific case.
- Outcome similar to Loss of Offsite Power but is caused by NPP itself.

Example Trip of Large NPP:



Interconnected Grid Alone Is Not Sufficient to Assure Grid Stability.

- “Blackouts” occurred in Northeastern USA in 1966, 1977 due to improper switching and protective breaker timing.
- 1977 New York City Blackout involved sequential lightning strikes on two circuits from Indian Point NPP 3 reactor.
- Power system simulations needed to confirm adequacy of protective relaying schemes to avoid grid instability.

Historical Situation (Pre-1980's):

- Voltage and frequency protection in many NPPs (US, European, Soviet) was based on presumed total loss of offsite power.
- Grid transients involving prolonged 50 – 85% Nominal voltage operation – were not considered.
- Long-term scenarios involving attempts to restore degraded grid voltage/frequency are more likely.
- Actual NPP operating events forced need to consider prolonged voltage and frequency levels in 50 – 85% Nominal range.

Today's Situation:

- It is recognized that: NPP voltage / frequency protection requirements must assure equipment availability for emergency purposes.
- NPP may be switched off during an electrical grid voltage / frequency transient in order to protect safety related equipment at NPP.
- Sudden trip of large nuclear unit during grid transients must be considered in NPP siting and in design of connected electrical grid.

Recommendations:

- Grid operators must recognize grid reliability requirements imposed by NPPs on their system – and *design grid accordingly*.
- Grid performance should be simulated to assure reliability and independence of offsite power circuits, and not simply relying on NPP's Diesels for safe shutdown.
- NPPs should confirm consistency of voltage / frequency requirements ….particularly when dealing with *foreign designed nuclear power plants – that are designed presuming GDC 17 (or IAEA 50-SG-D7) compliance*.

Recommended Reading on Power Grids:

- Website devoted to Electric Grid Blackouts, contains links to historical papers on power system planning http://chnm.gmu.edu/blackout/archive/a_power.html
- Website of the Proceedings of the IEEE Special Edition on Power Systems http://www.spectrum.ieee.org/pubs/trans/0200/88proc02-scanning.html