Significant Loss of Safety-Related Electrical Power at Forsmark Unit 1

Briefing For Nuclear Power Engineering Committee

Institute of Electrical & Electronics Engineers

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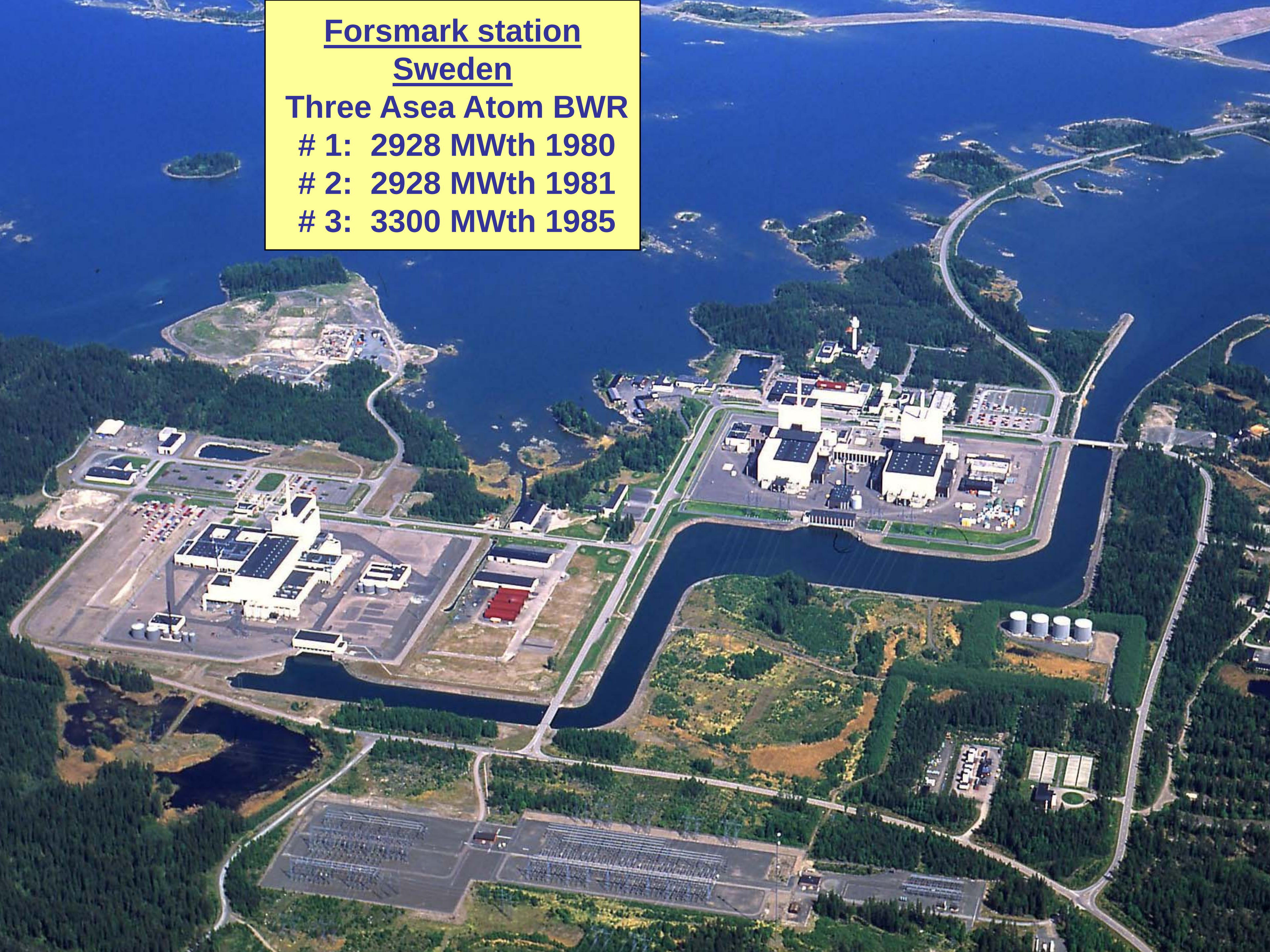

Forsmark station
Sweden
Three Asea Atom BWR
1: 2928 MWth 1980
2: 2928 MWth 1981
3: 3300 MWth 1985

Presentation Outline

- Forsmark Safety Systems Overview
- Overview of Event
- Event Details
- Risk Insights
- Impact on US Plants
- Millstone-2 Electrical Event
- Action for IEEE

Forsmark Safety Systems Overview

- Safety systems are divided into four trains, each with its own emergency diesel generator and capacity to manage 50% of the ECCS loads
- Two diesel generators started automatically and worked during the event

Overview of Event

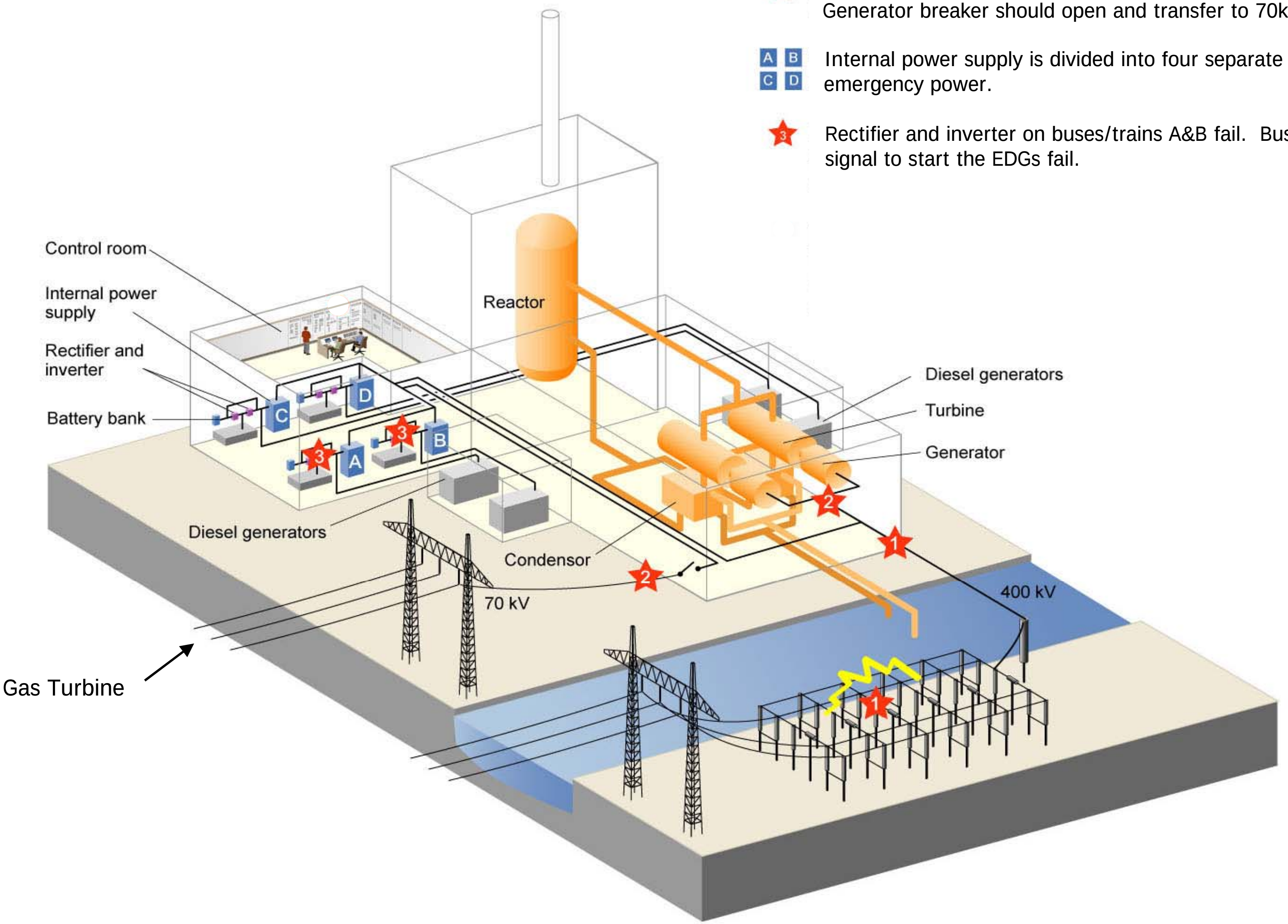
- July 25, 2006; Plant at 100%
- Opened 400 kV disconnect and caused an Electrical Fault
- Generator voltage dropped to 30%
- Unit disconnected from the grid
- Generator over-voltage (OV) 120%
- OV caused 2 of 4 UPSs to fail
- 2 of 4 Emergency Diesel Generators (EDG) failed to connect to the safety buses

1 Maintenance work in the switchyard causes an arc and a short circuit. Unit 1 is disconnected from the grid and reactor scrams.

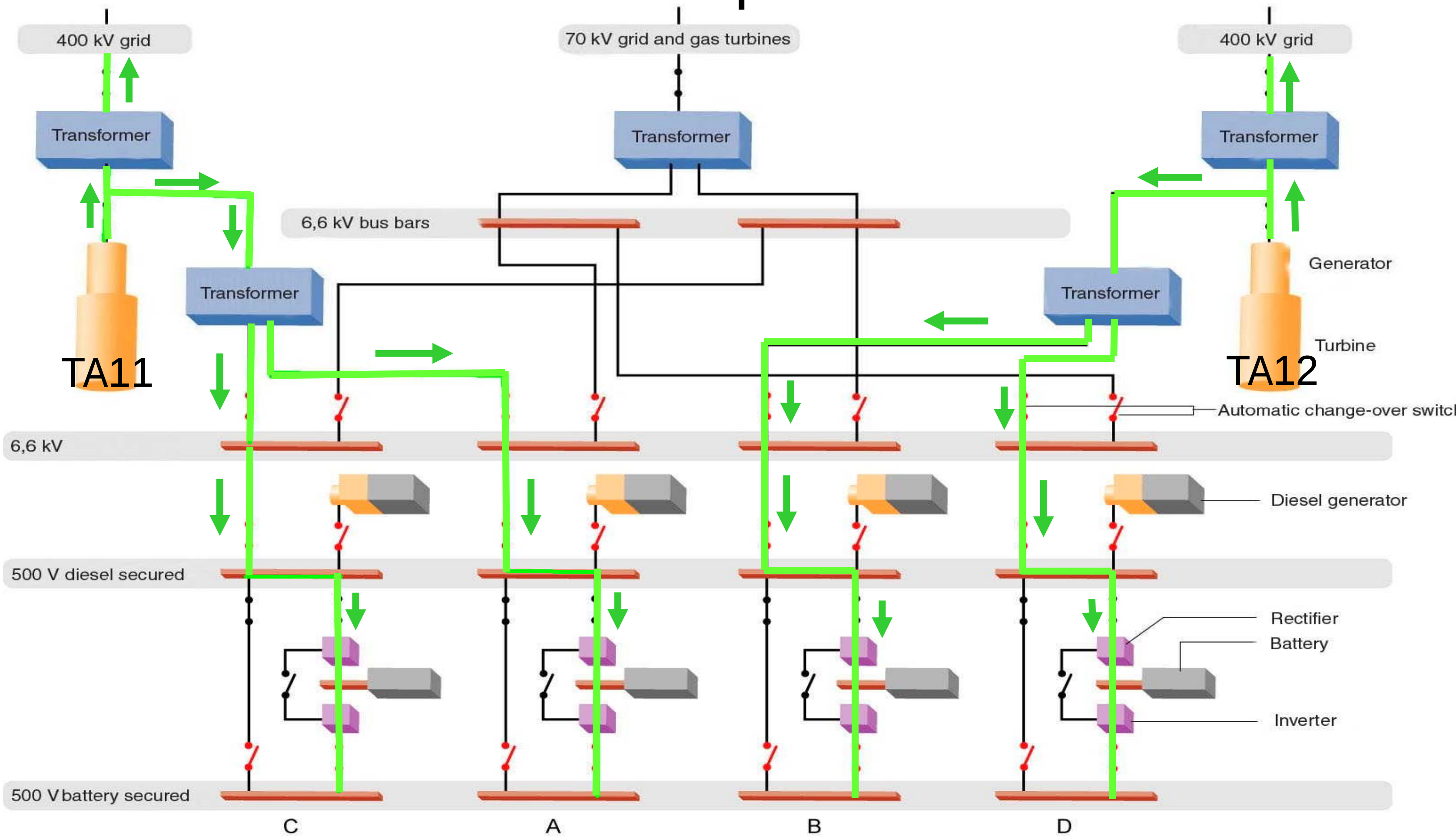
2 Failure in the generator protection results in generator breaker not opening. Generator breaker should open and transfer to 70kV offsite power.

A B C D Internal power supply is divided into four separate buses/trains (A,B,C,D) for emergency power.

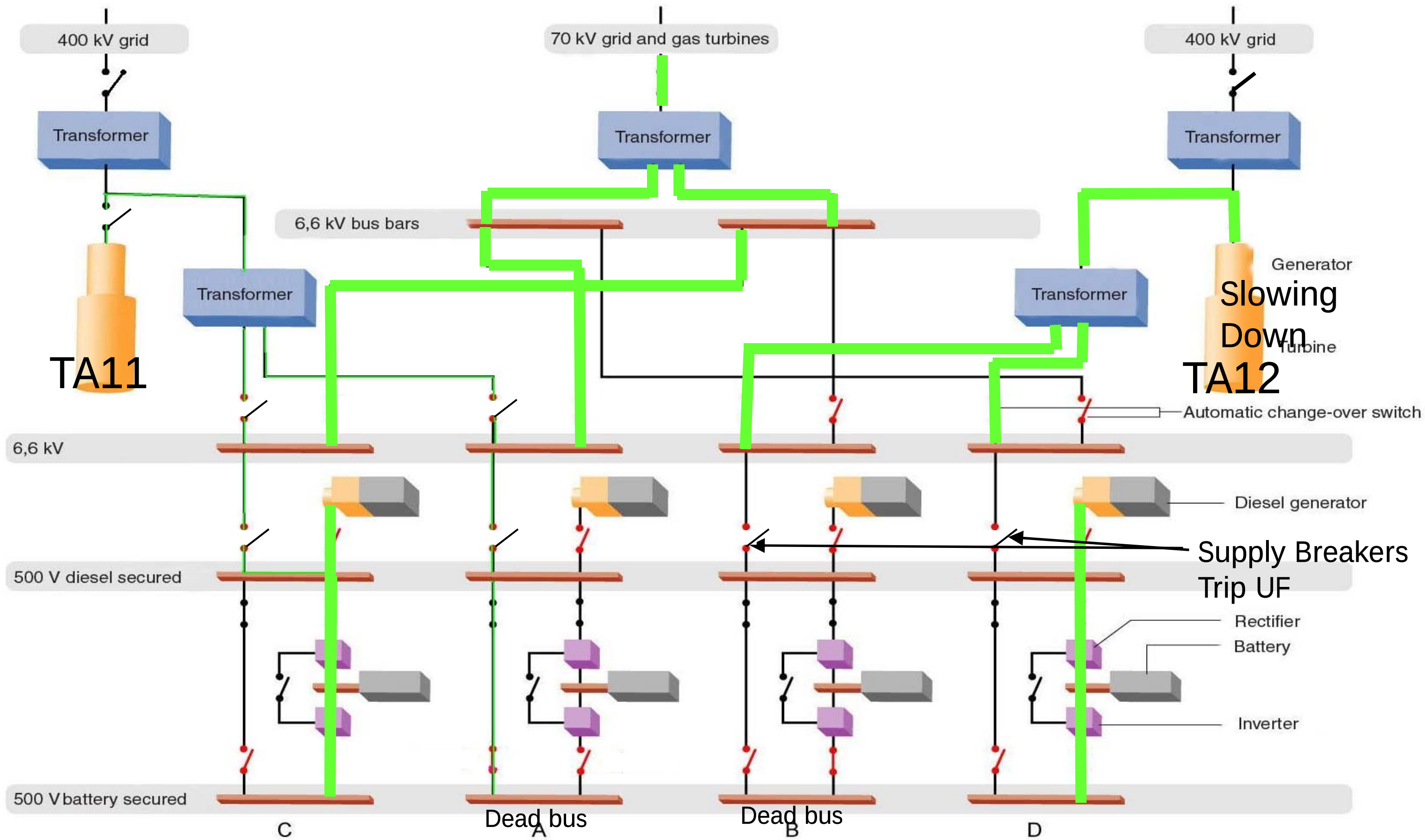
3 Rectifier and inverter on buses/trains A&B fail. Buses A&B loss power and the signal to start the EDGs fail.



Normal Operation



Supply Breakers Trip, EDG D Connects, EDG B Fails



Event Details

- Both generator breakers should have tripped immediately
  - Common Cause Failure
- Over voltage tripped two battery charges & two inverters (2/4 UPS shutdown)
  - Common Cause Failure
- 2/4 EDGs failed to energize the safety bus
  - Common design flaw
- Gas turbine failed to start
  - 70kV grid was available
- Loss of control room information
  - Loss of network power A&B

Risk Insights

- Plant Uniqueness that influence risk :
  - No steam/diesel-driven pumps (diversity w/defense in depth)
  - 2 Common Cause Failures (UPS, Generator Relay Protection)
  - EDG controls relied on AC power from UPS
  - Failure of power supplies to control room indications
  - Gas Turbine didn’t start

Risk Insights

- Inverter failures resulted in instrumentation without power on buses A&B
  - Control rod indication (buses A&B)
  - Neutron monitoring system (channels A&B)
  - Reactor level & pressure indications (channels A&B)
  - Faulty indication on electrical system mimic panels
- EDGs A&B failed to connect
  - Speed sensor was powered from inverter
- Plant could have lost all four inverters, battery chargers and EDGs along with loss of offsite power

Impact on US Plants

- Most EDG control and starting logic circuits for US nuclear power plants (NPP) are powered from the DC system instead of inverters as is the case in Forsmark
- Control and starting circuits for US NPP are supplied either from dedicated Class-1E diesel generator batteries or from Class-1E station batteries

Simplified Class 1E DC Power System

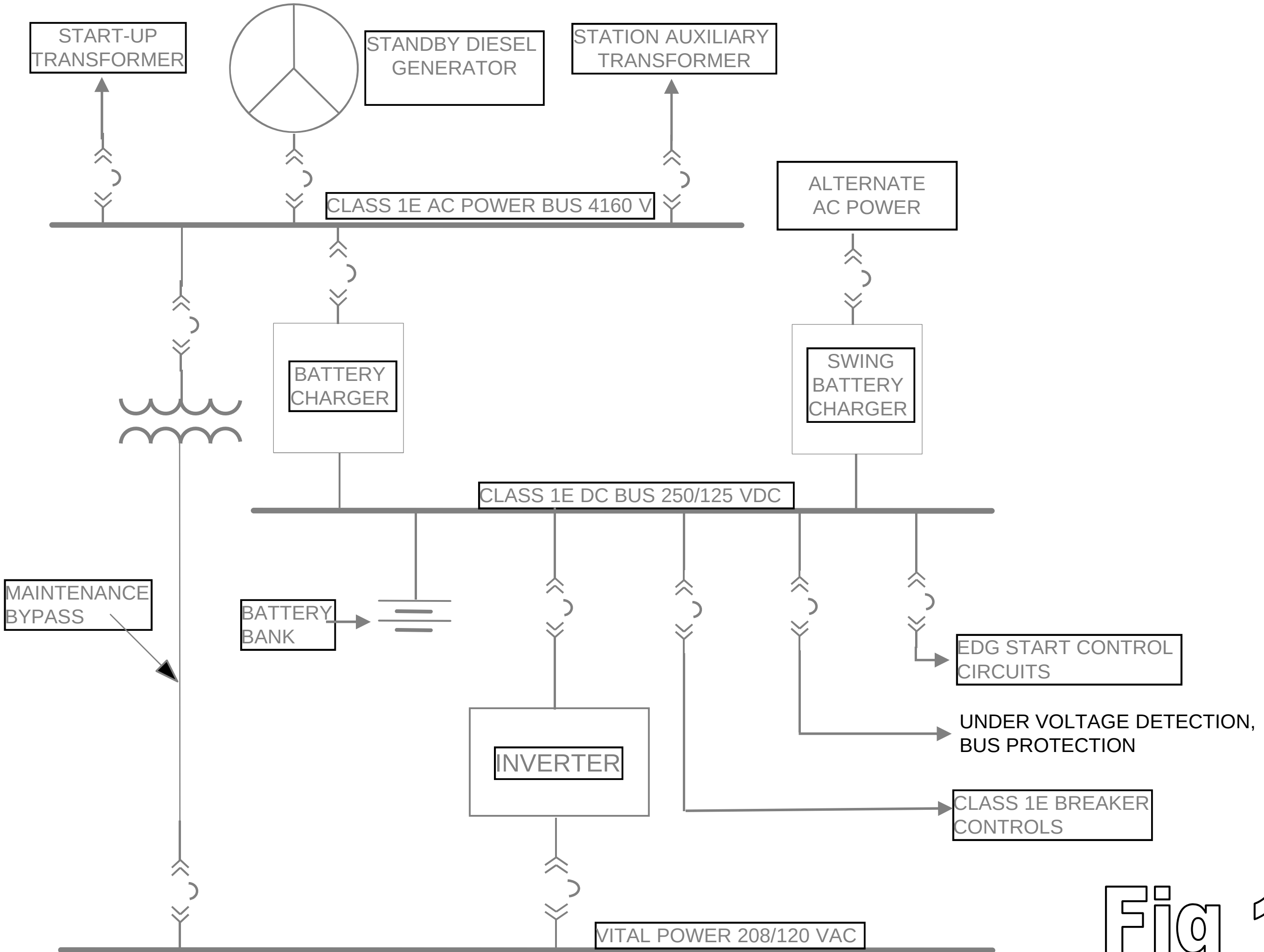


Fig 1

Event Unlikely for US Reactors

- DC systems for US NPPs are normally supplied by the battery chargers/rectifiers which are in turn powered from the AC distribution system
- EDG battery could still supply the required DC power to start and control the emergency diesel generators loads for about 2 hours

Event Unlikely for US Reactors

- U.S. plants are required per the 10 CFR 50.63 to be able to keep the core cooled and maintain containment integrity with a loss of offsite power & unavailability of onsite EDGs

Operating Experience

- Event Notification (EN) 25162, LER 93-001-00, Sequoyah Unit 2 “Large Steam Leak in MFW Heater Extraction Header”
  - IN 94-77 - Main Generator OV @ 119% for 3 minutes
- EN 21602, LER 91-017-01, Nine Mile Point 2 “Loss of Non-Class 1E UPS” (1991)
  - IN 91-64, Supplement 1 - Five UPS units shutdown as a result of a logic initiated trip

Millstone-2 Electrical Event

- On July 6, 1992 , during a refueling outage, the licensee identified several undesirable failure modes of a two-out-of-four logic following an event. The plant was designed with two sensor cabinets and one actuation cabinet for each of the two trains. ***(Information Notice 93-11)***
  - When power is lost to either one of the vital buses it caused safety injection and sump recirculation actuation.
  - When two of the sensor cabinets in a train lost power it caused the containment sump outlet valves to open
  - Loss of DC power to one actuation train caused power operated relief valve in the other train to open
- The logic was modified to limit certain combinations of two-out-of-four logic to prevent this problem.

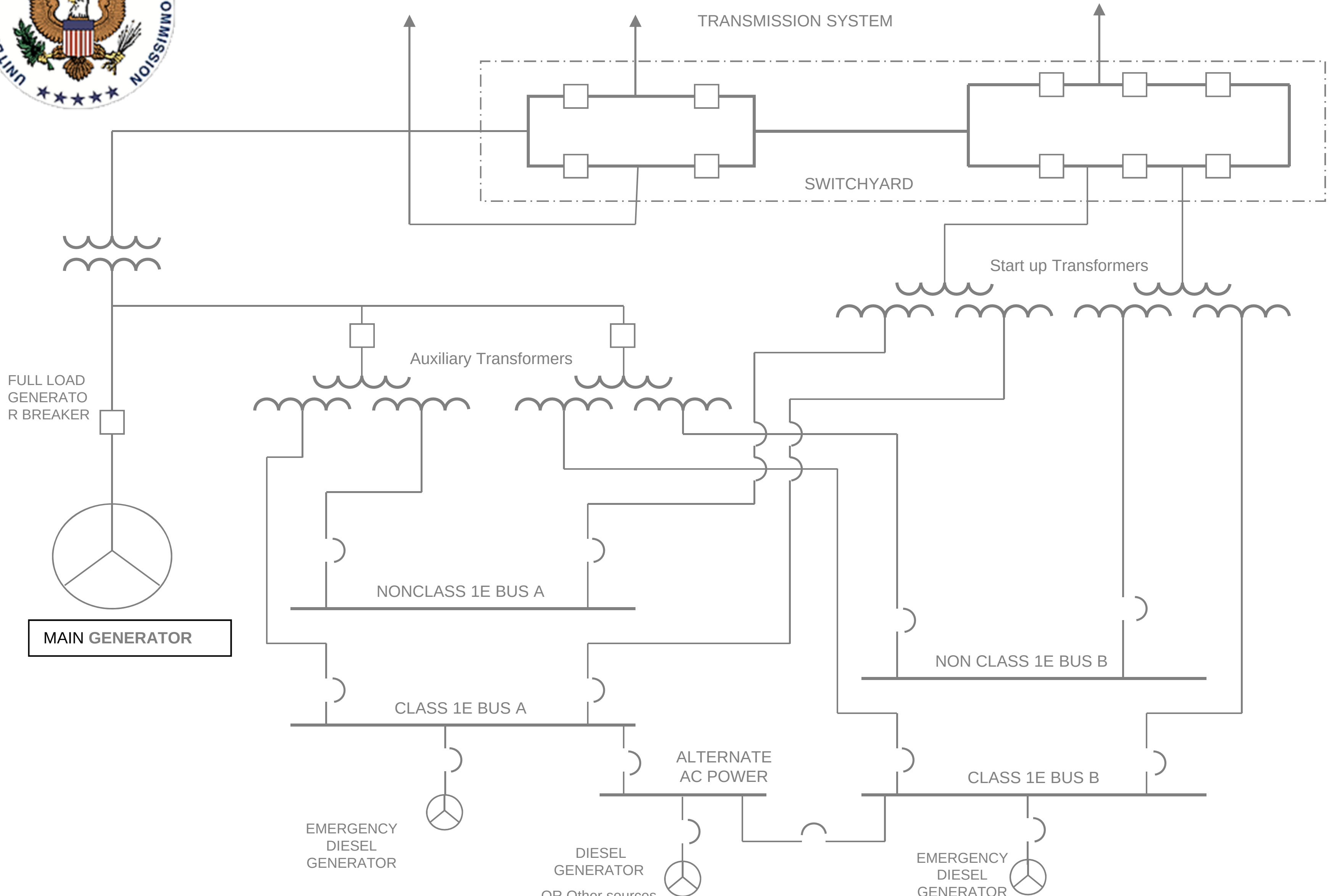
NRC Guidance on Control Systems

- Bulletin 79-27 “Loss of Non-Class 1E Instrumentation and control Power System Bus During Operation” – Evaluate the effects of loss of power to control systems
- Generic Letter 89-18 “Systems Interactions in Nuclear Power Plants” – concerns regarding automated safety related actions with no preferred failure modes

Action for IEEE

- Consider revising IEEE 352-1987 to include the following:
  - Provide design guidance to address failure modes for reactor trip systems and core cooling systems
  - Provide design guidance for addressing known failure modes in software driven systems and the supporting hardware
  - Provide guidance on the defense-in-depth requirements for power supplies in the protection and information systems for reactor safety

ONE LINE DIAGRAM FOR SINGLE UNIT NUCLEAR STATION



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