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Lessons learned from the Forsmark 1 event related to the safety-related electrical systems in the Belgian NPPs

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Formark 1 event (25/07/2006) – Summary (1/2)

- At full power, a short circuit occurred on the 400 kV bus bar during maintenance activities in the offsite 400 kV switchyard. The default was not immediately eliminated by the protections due to improper connections.
- The voltage decreased very quickly. The unit breakers opened on undervoltage protections.
- This opening caused a loss of load on both turbine generator units and an **overvoltage transient up to 120 % Un occurred during 1 s.**

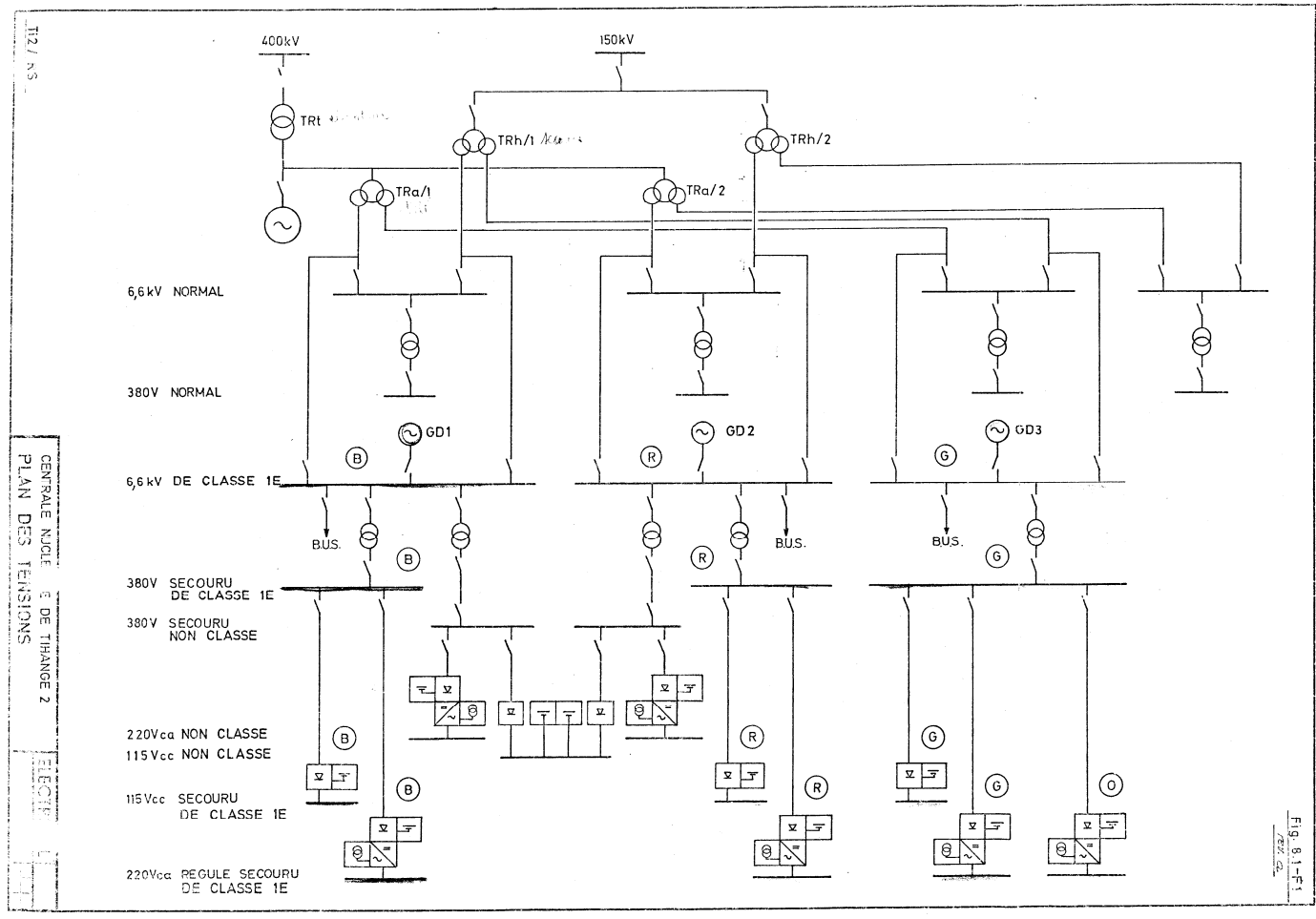
Formark 1 event (25/07/2006) – Summary (2/2)

- 2 s later the rectifiers and inverters of two (out of four) 220 Vac UPS tripped on overvoltage. The two failed inverters were automatically by-passed.
- Short house load operation and loss of back-up offsite grid due to malfunction of the underfrequency protections of the turbine generators breakers (\Rightarrow total loss of offsite power)
- Starting of four EDGs on undervoltage but only two were connected to their bus bar \Rightarrow **2/4 safety trains were lost !**
- 22 min later the operators reconnected the offsite power to the lost safety trains.

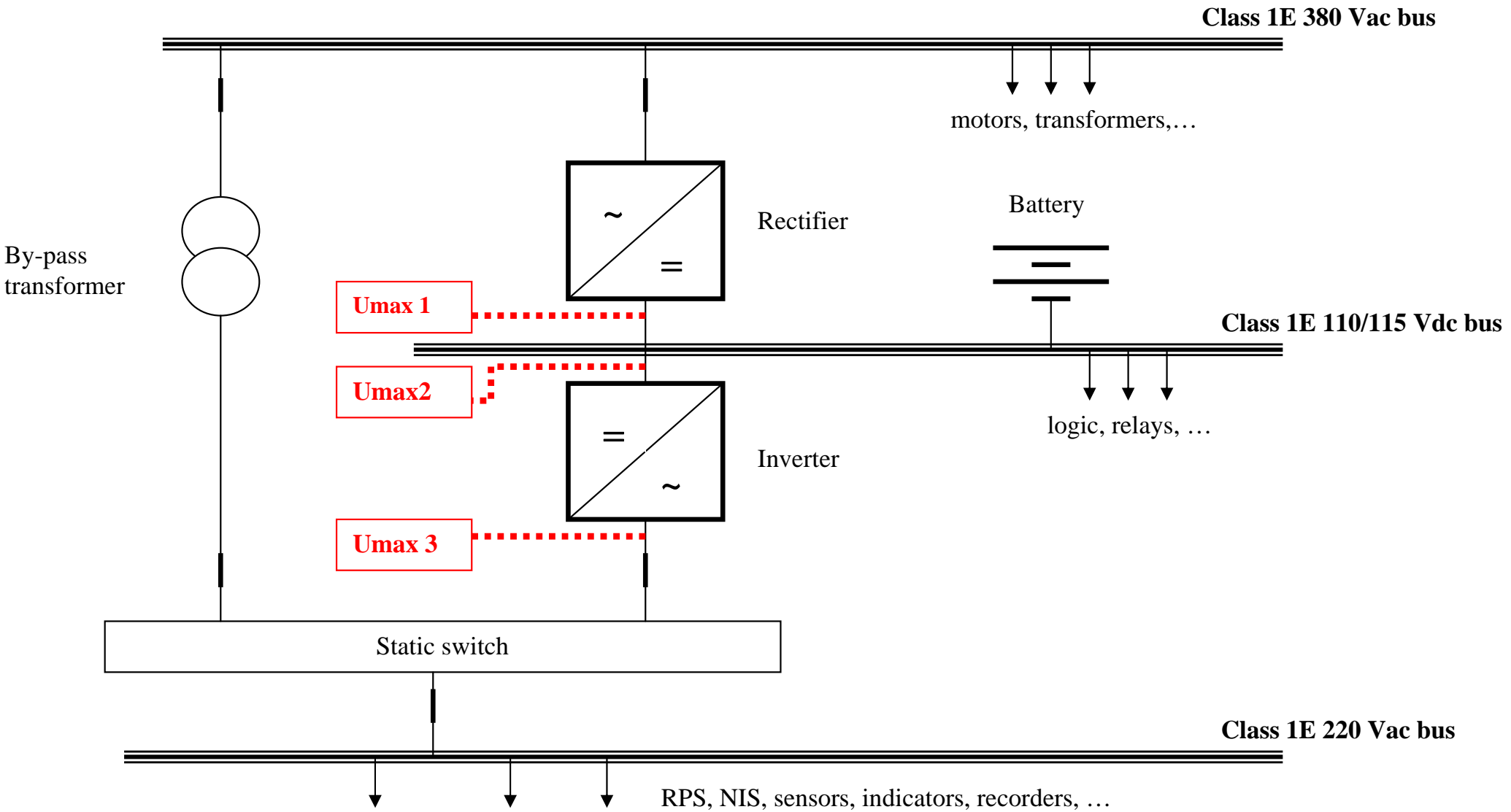
Forsmark 1 event - Lessons learned

- Important lessons learned related to the safety electrical power systems :
 1. The set points of the overvoltage protections of the rectifier and the inverter must be adequately coordinated (selectivity of the protections). (design failure)
 2. The EDGs must be independent from the safety-related 220 Vac bus bars. (design failure)
 3. The malfunction of the under frequency protections was due to a faulty wiring of the phases in these protections. This was identified as a weakness in the unit's modification management process. (management failure)

Single line diagram of Belgian NPPs



Typical UPS diagram in Belgian NPPs



Bel V requests to the licensee

- Verification of the selectivity of the UPS overvoltage protections (between rectifier and inverter):
 1. During an overvoltage transient the rectifier (and not the inverter) should trip so that the Class 1E 220 Vac bus bar is still supplied by the battery via the inverter.
 2. The required selectivity should be demonstrated on the basis of the overvoltage protection values set up in the rectifier and the inverter.
 3. Testing should be carried out with a representative equipment to validate the demonstration.
 4. Periodic testing of the rectifier/inverter protections should be planned and implemented.
 5. The SAR must be supplemented to describe correctly the design principles related to the protections of such an equipment.
- Verification of the independence of the EDGs from the Class 1E 220 Vac bus bars

Licensee action plan

- Study of the behaviour of the UPS equipment during an overvoltage transient
 - Analysis of documentation (manufacturer, type of equipment, protections (threshold, delay))
 - Definition and justification of the most conservative overvoltage transient for the Belgian NPPs
 - Fast rise of voltage (during $40 \text{ ms} \leq T \leq 50 \text{ ms}$) from 80% to 130% U_n (maintained during 3 s)
 - Testing of representative equipment with the most conservative overvoltage transient
 - Conclusion : No modification of the design needed to face an overvoltage transient like a “Forsmark” transient (CCF) but some proposals to improve the UPS in case of single failure

Licensee action plan

- Verification of the independence of the EDGs from the Class 1E 220 Vac bus bars
 - All the 1E classified control functions (such as the sequences of starting, coupling, load shedding, stop) and the protection functions of the 1st and 2nd level EDGs are independent from the Class 1E 220 Vac bus bars.
 - The EDG automatic load sequence is independent from the Class 1E 220 Vac in all Doel NPPs and Tihange 1 NPP but not in Tihange 2 and 3 NPPs.
 - Tihange 2 and 3 NPPs:
 - 1st level : when the EDG is connected to its 6 kV bus, the sequence would proceed normally, except for the auxiliary feedwater pump. This pump will be started by the operator from the MCR (via 115 Vdc).
 - 2nd level : the load sequence is not initiated as long as the 2nd level RPS is not reset. The safety equipment can be started by the operator from the 2nd level MCR (via 115 Vdc).

Bel V assessment

- Identification of cases with potential risk of CCF (possible trip of inverters in more than one safety train during an overvoltage transient)
 - Doel 3 and 4 NPPs (2/3 trains)
 - Tihange 2 and 3 NPPs (3/3 trains)
- Improvement of the selectivity in case of a single failure
 - Tihange 1 NPP
- Request of a more detailed assessment on the non activation of the inverter output AC overvoltage protection

Licensee short term corrective actions

- Doel 3 and 4 NPPs :
 - Simulations of the inverter (by manufacturer)
 - The risk of trip of the inverter cannot be ruled out in 2/3 trains (1st & 2nd levels of protection) during a “Forsmark” transient.
 - Justification of Continuous Operation
 - Drawing up of a specific accident procedure in case of loss of 2/3 safety-related 220 Vac trains
 - Adjustment of inverter input protection delays (2008-2009)
- Tihange 2 and 3 NPPs :
 - Further verification and justification of inverter output protection delay (2008)
- Tihange 1 NPP:
 - Adjustment of rectifier output protection delay (2008)

Licensee long term actions (1/2)

- Replacement of the Class 1E UPS (2008-2011)
 - The new equipment takes into account the experience feedback from the Forsmark 1 event. The selectivity of the protections between the rectifier and the inverter has been adapted (no inverter input overvoltage protection) and a voltage limiter has been added at the rectifier output.
 - The new UPS has been tested into factory with the most conservative overvoltage transient defined in the study. No trip or anomaly of the equipment (rectifier and inverter) has been observed during testing.

Licensee long term actions (2/2)

- Participation to the CSNI Task Group (Sw, Be, Fr, Fi, Ge, Ja, US) related to “*Defence in Depth of Electrical Systems and Grid Interaction*” (started in April 2008)
- The final recommendations of the CSNI Task Group will be used as a reference for a future reassessment of the design of the safety electrical systems.
- For instance, various themes should be examined/reviewed:
 - Relationships between the nuclear licensee and the grid owner;
 - Review of the electrical transients to be taken into account in the design of the safety electrical systems
 - Defense in depth of the safety electrical systems

Conclusions

- Bel V requests were focusing on the important lessons learned of the Forsmark 1 event related specifically to the design of the EPS system.
 - Adequate selectivity of the UPS protections between the rectifier and the inverter, following the most conservative overvoltage transient.
 - Independence of the EDGs from the Class 1E 220 Vac bus bars.
- The licensee has studied these two safety concerns, justified and carried out short term corrective actions that meet Bel V requests.
- As long term actions, the licensee will replace the current UPS by new ones taking into account the lessons learned from the Forsmark 1 event.

Further developments

- The design of the safety electrical systems will be further evaluated by the licensee, taking into consideration the final recommendations of the CSNI Task Group related to « *Defence in Depth of Electrical Systems and Grid Interaction* ».