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NUCLEAR ENERGY AGENCY
COMMITTEE ON NUCLEAR REGULATORY ACTIVITIES

NEA/CNRA/R(2011)8
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Status of OECD/NEA Country Regulatory Responses to the Forsmark-1 Event of 25 July 2006 and NEA/CSNI DiDELSYS Task Group Report Recommendations

Working Group on Operating Experience (WGOE)

December 2010

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The mission of the NEA is:

- to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes, as well as
- to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information.

The NEA Data Bank provides nuclear data and computer program services for participating countries. In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

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COMMITTEE ON NUCLEAR REGULATORY ACTIVITIES

The Committee on Nuclear Regulatory Activities (CNRA) shall be responsible for the programme of the Agency concerning the regulation, licensing and inspection of nuclear installations with regard to safety. The Committee shall constitute a forum for the effective exchange of safety-relevant information and experience among regulatory organisations. To the extent appropriate, the Committee shall review developments which could affect regulatory requirements with the objective of providing members with an understanding of the motivation for new regulatory requirements under consideration and an opportunity to offer suggestions that might improve them and assist in the development of a common understanding among member countries. In particular it shall review current management strategies and safety management practices and operating experiences at nuclear facilities with a view to disseminating lessons learnt. In accordance with the NEA Strategic Plan for 2011-2016 and the Joint CSNI/CNRA Strategic Plan and Mandates for 2011-2016, the Committee shall promote co-operation among member countries to use the feedback from experience to develop measures to ensure high standards of safety, to further enhance efficiency and effectiveness in the regulatory process and to maintain adequate infrastructure and competence in the nuclear safety field.

The Committee shall promote transparency of nuclear safety work and open public communication. The Committee shall maintain an oversight of all NEA work that may impinge on the development of effective and efficient regulation.

The Committee shall focus primarily on the regulatory aspects of existing power reactors, other nuclear installations and the construction of new power reactors; it may also consider the regulatory implications of new designs of power reactors and other types of nuclear installations. Furthermore it shall examine any other matters referred to it by the Steering Committee. The Committee shall collaborate with, and assist, as appropriate, other international organisations for co-operation among regulators and consider, upon request, issues raised by these organisations. The Committee shall organise its own activities. It may sponsor specialist meetings and working groups to further its objectives.

In implementing its programme the Committee shall establish co-operative mechanisms with the Committee on the Safety of Nuclear Installations in order to work with that Committee on matters of common interest, avoiding unnecessary duplications. The Committee shall also co-operate with the Committee on Radiation Protection and Public Health and the Radioactive Waste Management Committee on matters of common interest.

TABLE OF CONTENTS

1. INTRODUCTION

On 25 July 2006, Forsmark Unit 1 experienced a short circuit in the offsite 400kV switchyard causing the inoperability of two emergency diesel generators. Following the event, the information about the event was spread through the International Reporting System (IRS) system (IRS report 7788). In October 2006, the event was presented at the IRS National Coordinator's meeting in Vienna, Austria. In 2008, the European Union Clearinghouse on Operational Experience (European Clearinghouse) issued a report on the Forsmark Unit 1 event (Nuclear Power Plant Clearinghouse report 2008/02) and included the actions taken by EU country. Additionally, many countries have also written their own technical reports about the event.

The event identified weaknesses in the electrical system design that could be generic for nuclear power plants. The discussions about the event at Nuclear Energy Agency (NEA) resulted in a workshop in Stockholm, Sweden, in September 2007. The workshop discussed lessons learnt from the Forsmark event as well as others of similar kind and resulted in a recommendation to the NEA from the Swedish regulatory body to establish a task force to thoroughly penetrate these issues. In January 2008, the NEA Committee on the Safety of Nuclear Installations (CSNI) authorised the formation of the Defence in Depth of Electrical Systems (DiDELSYS) task group. In May 2008, the group was established, led by Mr John Bickel on behalf of the Swedish regulatory body. Nine organisations and countries were represented in the group. A draft report was presented to the CSNI and the Committee on Nuclear Regulatory Activities (CNRA) in December 2008. Both CSNI and CNRA wanted the work to be reviewed by more organisations and decided that a workshop would be held in Paris in May 2009. The subsequent report was issued in draft in September 2009 and finalised in November 2009 (NEA/CSNI/R(2009)10). The DiDELSYS work is continuing in a follow-up phase and more knowledge will be acquired, the task group is called DiDELSYS2.

At the 5th Working Group on Operating Experience (WGOE) meeting in spring 2009 at NRC headquarters, the regulatory practices and methodologies applied by member countries in responding to the Forsmark event were discussed in a roundtable exchange. It was agreed to request CNRA approval for the acceptability of writing summaries on the WGOE member country activities. These summaries should then be amended to the EU Clearinghouse report on the Forsmark event and posted as an updated version to the NEA/WGOE site. In June 2009, the CNRA decided that this material should be a standalone NEA report.

At the 6th WGOE meeting in fall 2009, it was decided that Sweden would take the lead to write the WGOE report including updated regulatory responses to the Forsmark event and also include actions taken in response to the outcome from the DiDELSYS task group.

At the 8th WGOE meeting in fall 2010, the member countries discussed the country responses to the DiDELSYS report to-date. Some countries had provided several updates on their country's actions in response to the Forsmark event and subsequent analyses. The WGOE members decided that country actions for DiDELSYS and for Forsmark were interwoven and could not easily be separated at this point. It was decided to stop collecting input at this point and publish a report on the actions and decisions taken to-date.

This report is a status report of the country actions and responses to the event in short term and to the up-to-date responses to the DIDELSYS task group findings in long term.

2. OBJECTIVES AND SCOPE OF THE REPORT

This report aims to provide an update on the activities performed by the WGOE member countries in response to the Forsmark-1 event of 2006 (IRS 7788). This report is also intended to provide an update on actions proposed and taken by participants to address the recommendations of the OECD/NEA CSNI Task Group on Defence in Depth in Electrical Systems and Grid interactions (DiDELSYS).

The aim of this report is not to reproduce the IRS 7788 Forsmark-1 report nor is it to conduct a detailed technical analysis; those tasks have already been performed and reported by authorised institutions, regulatory bodies and their technical support organisations (TSOs).

3. OUTLINE OF THE FORSMARK UNIT 1 EVENT

On 25 July 2006, Forsmark-1 was in full power operation when a disturbance occurred in the offsite 400 kV switchyard that caused the reactor to scram. The event generated a severe disturbance in the power supply of the unit. Initially an over voltage transient caused the failure of two UPS units serving the 220 V AC grid in subdivisions A and B (a CCF but subdivisions C and D were not affected). The 220 V AC is necessary for the operation of the emergency diesel generators (EDG). In addition, a malfunction of a relay protection caused a low frequency on the auxiliary buses. This prevented a connection of the alternative offsite power to the safety related bus bars.

The transient resulted in an automatic reactor power reduction, through a partial reactor scram, and reduction of the speed of the primary circulation pumps. The unit briefly went on in-house load operation before signals were received for reactor scram, isolation of the containment, and start of the reactor safety systems.

All four emergency diesel generators (EDG) started automatically, but EDG A and EDG B did not connect to their respective bus bar due to loss of power in the same divisions of the battery backed-up 220 V AC grids. In this situation, two out of four trains in each safety system were operating (auxiliary feed water system, core spray system and containment spray system). The loss of the two 220 V AC bus bars caused however several isolation signals and loss of information in the control room. After 22 minutes, the operators reconnected offsite power to subdivisions A and B thus all power was available at the unit. After in total 45 minutes, the operators could confirm that the unit was in a safe and stable shutdown mode.

In the unit safety analysis report (SAR), the event "Loss of external power" is analysed, together with a postulated coincident loss of power in one safety system subdivision. The actual event sequence represents a more serious event than the analysed event in SAR. The licensee informed the Swedish Nuclear Power Inspectorate (SKI) rapidly after the reactor scram.

The licensee assessed early that the causes behind some parts in the event chain could be generic, and informed in due time other licensees in Sweden and Finland. SKI asked, in a letter three days after the event, all licensees to provide information as to whether their units could resist to such an event. As a consequence of the request, some units were shut down.

4. DIDELSYS TASK GROUP

Based on the findings of a NEA-sponsored workshop on lessons learnt from the Forsmark Unit 1 event, the NEA CSNI authorised the formation of a task group in January 2008 to examine the defence in depth of electrical systems and grid interactions with nuclear power plants (DiDELSYS) with the following general objectives:

- Evaluate the robustness of existing safety related electrical; systems in nuclear power plants (including: design standards, acceptance criteria, design bases disturbances);
- Evaluate the basic principles used to develop a robust safety related electrical system in terms of critical design features, redundancy, diversity, and use of proven technologies;
- Evaluate methodologies used to demonstrate the robustness of safety related electrical systems, considering: definition of input transients, analytical approaches, defence in depth considerations, simulation techniques and use of computer codes (including the verification and validation of obtained results), definition of safety margins; and
- Evaluate the various modes of interactions between nuclear power plants and the electrical grid and the command and control interface between operators of the electrical grid and nuclear power plants.

From the DiDELSYS task group work, the NEA CSNI requested a summary report that would:

- Provide information on the state-of-the-art regarding the robustness of safety related electrical systems, taking into account their interaction with other electrical equipment, the use of new technologies and the problems encountered when modernisation of existing plants is undertaken; and
- Provide guidelines for improving the communication and co-ordination between the grid (grid operator and regulator), the nuclear safety authorities and the licensees.

The key findings from the DiDELSYS task group work

Current nuclear power plant safety relies on the availability of preferred power sources for operation of emergency core cooling and decay heat removal systems. The defense in depth concept of nuclear power plant electrical systems can be viewed as a combination of the following design and operational practices:

- Preventing electrical grid and plant generated electrical faults which are capable of interrupting the preferred source of power to decay heat removal systems,
- Robustness of nuclear power plant electric power systems to cope with electrical grid and internal plant generated electrical faults without further fault propagation or degradations to safety related equipment,

- Continuously improving nuclear power plant and external transmission system operator training, procedures, and information capabilities to deal with possible degraded electrical systems,

- Coping capability of nuclear power plants to deal with severe electrical grid and internal plant generated electrical faults, and:

- Ability to recover offsite electric power by co-ordinated actions of the nuclear power plant and transmission system operator.

Recent international operating experience has indicated that generally accepted design practices and standards which have been relied upon for decades to assure defense in depth have not kept pace with ongoing changes in technology and in changes in the organisation of electrical suppliers. These ongoing changes, if not commensurately addressed by improved practices and design standards could eventually result in events with serious nuclear safety implications. The sequence of events observed at Forsmark Unit 1 in 2006 and Olkiluoto in 2008 are such accident precursors.

Examples of major technology changes include: replacements of robust, but maintenance intensive, motor-generator sets with less robust solid state uninterrupted power supply (UPS) units for supplying vital control and instrument power, and replacement of older hardwired relay-based control and protection devices with microprocessor-based devices which can be more sensitive to degraded input power supplies.

Examples of changes in the organisation of electrical suppliers include the re-organisation of electrical industries into separate generating companies, transmission system operators, and local electrical distribution companies who may have competing market interests on where power is needed.

The DiDELSYS task group recognised that for nuclear power plants operating throughout the world to maintain their current safety levels while these external changes are going on, efforts must be initiated to commensurately upgrade older design practices and standards.

Recommendations from DiDELSYS task group

The Defence in Depth of Electrical Systems and Grid Interaction Task Group, Final DiDELSYS Task Group Report, was issued on 9 November 2009 (NEA/CSNI/R(2009)10). Refer to Appendix A for a detailed list of recommendations from this report. The recommendations from the DiDELSYS task group work relate to:

- ***preventing electrical grid and plant generated electrical faults***
- ***robustness of nuclear power plant electric power systems***
- ***improving training, procedures, and information capabilities***
- ***coping capability of nuclear power plants***
- ***electrical system recovery***

See Appendix A for a detailed list of recommendations

5. ACTIONS TAKEN BY OECD/NEA MEMBER COUNTRIES

The actions taken by member countries are included as Section 6.

5.1 Country Responses to the Initial Forsmark-1 Event

A review of those country response reports indicate that all countries have taken the event under consideration. The scope of those considerations have varied but all countries seem to have addressed the significant issue of transient overvoltage effects causing anomalous behaviour of safety critical systems. Most countries concluded that the Forsmark-1 event was not directly applicable to their NPPs.

5.2 Country Responses to the DiDELSYS Task Group Report

The DiDELSYS Task Group report was issued in November 2009. In less than one year, some WGOE member countries have responded to the recommendations of the DiDELSYS task group report, while others are still the process of evaluation. This is the status as of October 2010. Although a review of the responses to the initial implications of the Forsmark-1 event indicates that most member countries appear to have considered the wider aspects of grid disturbances and their implications for NPPs, the DiDELSYS work has some recommendations that reach further.

A task for the WGOE member countries could be to confirm that the recommendations from the DiDELSYS task group report have been considered and actions taken to address identified shortfalls.

This report recommends that WGOE member countries follow the ongoing DiDELSYS work and confirm that the recommendations from the DiDELSYS task group report will be adequately addressed.

6. STATUS OF RESPONSES BY OECD/NEA COUNTRIES TO THE FORSMARK-1 EVENT AND DIDELSYS TASK GROUP RECOMMENDATIONS

The following section provides summary response of the OECD-NEA countries to the Forsmark-1 event of July 2006.

6.1 Belgium

Two important lessons learnt are related to the design of the Class 1E electrical power systems: 1) The setpoints of the overvoltage protections of the rectifiers and the inverters of the Class 1E UPS should be adequately adjusted (protection selectivity) and 2) The control systems for starting and coupling of the emergency diesel generators (vital on-site AC-power supply) should be independent of the Class 1E 220 Vac UPS.

As a result Bel V made formal requests to the Belgian licensee: 1. To demonstrate UPS overvoltage protection selectivity (selectivity between rectifier and inverter), perform periodic testing of rectifier & inverter protections and describe design principles related to the protections of this type of equipment in the FSAR; 2. To demonstrate independence of EDG from the class 1E 220 Vac uninterruptable power supply.

An action plan was launched by the utility based on a safety study covering all Belgian NPPs that considered a conservative voltage transient (more severe than the transient in the Forsmark event). This action plan included technical analysis and tests on representative equipment with the purpose to identify needed technical improvements to the UPS equipment as well as verification of the periodical testing of the protections of this equipment. The action plan also includes an update of the FSAR based on the conclusions of the analysis and on modifications implemented.

This action plan is still in progress. Some short term technical improvements have been performed (e.g. adjustment of rectifier output protection delay at Tihange unit 1 and inverter input protection delay at Doel units 3 & 4 in order to improve protection selectivity). Long term actions include replacement of Class 1E UPS equipment at some units in the period 2008 to 2011 (accelerated replacement at the Doel units 1 & 2, principally for reason of obsolescence; replacement at the Doel units 3 & 4 and Tihange units 2 & 3 as a direct consequence of the analysis of the Forsmark event). The design of the replacement equipment will have to take into account the lessons learnt from the Forsmark event (verification of the behaviour during the defined conservative overvoltage transient).

Finally the licensee will analyze the recommendations of the final Didelsys report and propose an action plan to answer to these recommendations.

6.2 Canada

CNSC staff has reviewed the summary description you provided on the Forsmark 1 event which occurred on July 25, 2006.

The design differences between the electrical system configuration at the Forsmark 1 Station and the electrical system configuration of Canadian CANDU stations are such that electrical disturbances/failures similar to the ones described in the Forsmark 1 event would cause different equipment unavailabilities and thus result in a different station response.

Canadian operators have been informed of this event and CNSC staff sees no need for further regulatory actions or changes as a result of the Forsmark 1 event.

6.3 Czech Republic

The following information is from a presentation by the Czech Republic Regulatory Authority, SUJB in the WGOE meeting.

These sources have been used by the Czech Republic Regulatory Authority, SUJB:

- IRS 7788 (preliminary, main)
- Requests for additional information –emails SÚJB –SKI Licensee
- IRS 7788
- WANO SER 2007-01Other Sources
- DiDELSYS workshop (Stockholm IX/2007)
- OECD/NEA WGOE meeting

Safety significance of event was evident:

- Event recorded in external OEF systems of operator and regulator
- Event analysis reviewed on both (regulator, operator) sides
- Available information used
- Aspects relevant for Czech NPPs identified
- Czech specifics taken into account

The results of analyses are the following:

Design aspects

- Similarities
- Principal power supply scheme (accumulators, invertors)
- Type of rectifiers and invertors –ETE (AEG)
- Gas generator -ETE
- Differences
- Power supply scheme in Czech NPPs more robust –110kV backup

- Redundancy 3x100% (ETE, EDU) versus 4x50% (Forsmark)
- Type of rectifiers and invertors –EDU
- Setpoints of rectifiers and invertors protection different (sufficiently selective)
- Voltage peaks in power supply scheme less severe
- Operational modes of power supply
- EDG supporting systems powered from DC sources
- All safety relevant information in MCR 3x100% redundant, all necessary information through safety classified systems powered by safety grade power supply
- Different functions of gas generator (non-safety)
- "Island mode" — operation capability of Czech NPPs

Organisational/technical aspects

- Similarities
- Relation licensee x grid operator
- Relation licensee x maintenance staff (contracted)
- Procedures for modifications management –documents prepared by contractors
- Differences
- Protective functions of grid switchyards regularly tested (licensee –grid operator testing common procedure) –results OK
- Loss of off-site power transient tested during commissioning and after each core reload outage – results OK
- Work orders for maintenance staff sufficiently detailed
- Island mode— operation regularly tested –results OK

The main recommended actions are:

Design modification

- ETE
- selectivity of invertors' protective functions improved -time delay for DC side switch off increased (approval by AEG, information from WANO/EDF used)Organisational aspects -both NPPs
- Review of procedures for modifications preparation
- additional review/hold points
- more detailed information from suppliers required and reviewed
- more comprehensive testing of replacement components required

Wider considerations, trends. One of Root Causes (the most important)

- Some aspects of modification preparation not taken into account
- Generic issue –subsequently similar events (Finland –IRS7932)

- How to ensure excellence in preparation of modifications? What corrective actions are adequate
- Specific x generic
- Technical, organisational
- Difficulties with this issue in Czech Republic
- Continuous discussion licensee x regulator

Exchange of information - Adequate IOEF actions in the Forsmark case. Many similar events are not internationally reported (near misses)

- Insufficient resources for reporting as well as for adequate analyses
- Positive trends -OECD/NEA, JRC, etc.

Monitoring, improvements of (I)OEF systems, storage of information.

Activities ongoing all over the world.

SW support improvements ongoing (WBIRS).

Major (large release) accidents prevented.

Resources questionable.

Human factor analyses sufficiency - ongoing issue – criteria ?

Corrective actions sufficiency – ongoing issue – criteria ?

Conclusions:

- Forsmark lessons learnt used efficiently in Czech NPPs
- Generic issues –topic for continuous discussions
- Resources for (I)OEF
- Human factor analyses
- Modifications management

6.4 Finland

Forsmark-1 event started a series of investigations and modifications. The first reaction was to check, if a similar event could be possible at Finnish nuclear power plants. After the acute phase power companies have made in-depth analyses and performed corrective actions.

Finnish utilities met on August 10 2006 to discuss whether the Forsmark event sequence could occur at Finish nuclear power plants. The meeting concluded that a more detailed study on possible disturbances, robustness of electrical systems, and protection settings may be subject of corrective actions.

Olkiluoto unit 1 and 2 has similar electrical systems design features as Forsmark-1. The first study of the possibility of similar events was completed in August 17 2006. Interesting is the fact that Olkiluoto plant has originally had the similar EDG speed control systems dependency on UPS power as Forsmark-1. The power supply of the EDG speed control system was modified and the dependency on UPS power was removed during outages in 2000-2005. The overvoltage setting for the UPS rectifier was 260 V, and for the inverter 279 V; these settings were revised in forthcoming outages to increase the UPS internal components selectivity.

New fast over voltage protection devices, based on active main thyristor shut down circuit, are also fitted in UPS rectifiers. The protection circuit is now installed in a part of the rectifiers. All the modifications will be completed in 2010 outages.

On May 30 2008 unit 1 main generator excitation system failed and the generator output voltage jumped rapidly over 150 % for duration of 150 ms (IRS-7932). All UPS-systems of the plant operated correctly during the event. Only significant electrical malfunction was the tripping of reactor circulation pump drive system.

The licensee has also performed several other studies at Olkiluoto 1 and 2 units like:

- dynamical studies of possible voltage and frequency transients (all parts are not ready yet)
- selectivity study of electrical protection systems
- functionality study of 400 kV bus bar protection system
- check of operation and emergency instructions
- FSAR update
- negotiations with grid operator
- operation study of the generator breaker during turbine trip
- study how equipments important to safety can tolerate voltage transients
- study of dimensioning principles of important electrical equipments
- new design bases guide for electrical equipments

The Olkiluoto-3 unit (EPR) has originally all battery-backed electricity supply from UPS systems. Although this design has some advantages, AREVA the vendor for Olkiluoto-3 unit, reassessed the design and proposed some modifications. There is now a DC bypass parallel to the UPS (AC) feed of DC consumers (especially I&C). In addition, possible voltage disturbances were assessed, and equipment protection selectivity was re-analyzed.

Loviisa nuclear power plant completed the first study on the possibility of a similar event August 18 2006. This review concluded that the design of Loviisa electrical systems is quite different from those at Forsmark-1. As a result, there was no eminent need for corrective action.

The power company has also made several other studies at Loviisa 1 and 2 units like:

- dynamical studies of possible voltage and frequency transients
- primary tests of rectifiers voltage and frequency transient capacity
- reliability study of 400 kV grid connection
- study of possible voltage transients during the malfunction of main generator excitation system (not totally ready yet)
- check of operation, maintenance and emergency instructions
- estimation of co-operation and communication between power plant and grid operator

- estimation of the maintenance and use of gas turbine plant

Current understanding is that Finnish nuclear power plants can stand possible over voltage transients. The final completed transient analyses may have some influence to components, instructions or operation practices.

STUK organised in autumn 2008 a workshop concerning "Operational experience and learning (from experience)". The meeting focused on safety culture and underlying management issues related to the Forsmark event. The management of both Finnish licensees, specialists from Technical Research Centre of Finland and other specialists working in the nuclear industry as well as the members of the Advisory Committee of STUK participated in the occasion.

An introductory presentation was given by the first CEO of Teollisuuden Voima Oyj (TVO). Since the public interest and concerns of Vattenfall management on how they should have operated on the event an investigation report was ordered from Magnus von Bonsdorff and Lars Larsson. As a conclusion they introduced new findings that could be identified as early warning signals and recommendations. These were discussed in the meeting.

The licensees' representatives presented how the substantial lessons of the event have been used and furthermore the possible risks assessed in their organisations. It was evident that all the participants agreed the managers´ commitment to the principle of "safety first" to be essential. The meeting was considered as an important function for raising awareness and reflecting on organisational issues that have an effect on nuclear safety, the importance of an organisations continued learning perspective and that this inevitably projects to the existent safety culture in every organisation and work community.

Answers to recommendations of DiDELSYS Task Group Report:

4.2.1 Recommendations related to preventing electrical grid and plant generated electrical faults

- **Establishment of Binding Agreements between nuclear power plant operators and transmission system operators for communication and coordination of planned activities such as major upgrades**
  - OL1/OL2: Co-operation agreement exists. This agreement defines responsibilities e.g. for the maintenance works. Olkiluoto Nuclear Plant has established regular meetings between plant operations planning personnel and grid operators to exchange maintenance and testing activity schedules. These meetings are timed at intervals of approximately six months. Additionally, notifications of intent to perform the grid maintenance or testing are sent to Olkiluoto one week prior to the activity, then again three days before the activity. Finally, immediately prior to grid maintenance or testing, the grid crew is required to call the control room and notify the crew that the activity will begin.
  - OL3: See previous item when applicable. OL3 unit is not yet in operation.
  - LO1/LO2: Cooperation contract exists. Sufficient information between contractors will be ensured in meetings.
- **Jointly planning and coordinating electrical circuit test and maintenance activities**
  - See previous recommendation
- **Requiring transmission system operators to provide nuclear power plant operators with early warning of any on-going electrical grid problems that may become more severe.**

- OL1/OL2: Upcoming grid maintenance works nearby NPP are designed/coordinated together with grid operator. As an example, during NPP emergency diesel maintenance, work on the off-side grid are minimised. As an normal daily work, grid operator submits before switching operations to TVO official switching orders.
- OL3: See previous item when applicable. OL3 unit is not yet in operation.
- LO1/LO2: Scandinavian electrical market will prerequisite to inform from possible known production threats or production limits.

- **Requiring nuclear power plant operators to provide transmission system operators with early warning of any operational limitations that might impact nuclear power plant output. Examples would include: technical specification limitations that might require a power reduction or controlled shutdown.**
  - OL1/OL2: Scandinavian electrical market will prerequisite to inform from possible known production threats or production limits.
  - OL3: See previous item when applicable. OL3 unit is not yet in operation.
  - LO1/LO2: Scandinavian electrical market will prerequisite to inform from possible known production threats or production limits.
- **Assuring that transmission system operator procedures recognise that nuclear power plants are priority load centers that must be avoided when load shedding is necessary and which need priority during restoration activities given blackout.**
  - OL1/OL2: TVO has gas turbine plant in Olkiluoto which is owned by TVO and grid operator. Gas turbine plant has two main tasks - fast power reserve for off-side grid and electrical power supply to NPP in case of emergency diesels failure or long time loss of off-side grid. NPP has priority.
  - OL3: See previous item when applicable. OL3 unit is not yet in operation.
  - LO1/LO2: Cooperation contract will exist. Contract will not determine a special position for nuclear power plant units.

4.2.2 Recommendations related to robustness of nuclear power plant electric power systems

- **Hazard Review to determine the plant-specific range of possible voltage surge transients**
  - Analysis of the voltage and frequency transients have been made for all nuclear power plants in Finland. Also main generator voltage regulator failure has been included into the analysis.
  - Already once designed OL3 emergency power supply system was modified after the Forsmark 1 incident.
  - The impact of phase shift (phase unbalance) during near-by grid short-circuit has been analysed in all nuclear power plants in Finland. Results of analysis are under inspection.
- Analysis of peak switch on surge current (asymmetrical) of big motors and transformers during starting and switching on has been made:
  - OL1/OL2: Analysis are under inspection
  - OL3: Will be analysed with selectivity analysis
  - LO1/OL2: Analysis has been inspected.

    - Momentary over current trip settings have been modified upwards of over current relays of Essential Service Water Pump motors.

- **Review of plant safety systems to confirm their capability to withstand the worst case power frequency overvoltage transients**

Over voltage transient analysis have been made for all nuclear power plants in Finland.

- OL1/OL2:
  - UPS rectifiers (excluding 1 pc, which will be modified 2011) have been updated according to the OL3 UPS rectifiers having a voltage limiter.
  - OL1 UPS rectifiers were tripped during the OL1 incident (voltage transient) 30.5.2008, but they were restarted automatically after the voltage recovery. Voltage level max. ca.150% Un.
- OL3:
  - UPS rectifiers have voltage limiters. Limiters have been designed after the Forsmark 1 incident.
  - Over voltage transient test has been made for OL3 UPS rectifier.
- LO1/LO2:
  - rectifiers have been tested at site during outages
  - Momentary over voltage setting has been reduced of all voltage relays of main generators.
- **Review the potential voltage degradations, their rate of change, and duration, and evaluate its impact on voltage sensitive devices such as local power supplies, MOVs, SOVs, contactors, etc.**
  - Analysis have been made for all nuclear power plants in Finland:
    - OL1/OL2: 80% Un 1h, analysis is under the inspection
    - OL3: 80% Un 1h
    - LO1/LO2: 80% Un 1h
- **Review solid state device-based equipment such as: UPS, local power supplies, for their response (e.g. risk of tripping) to design basis voltage transients**
  - **Risks of tripping of solid state device-based equipments have been reviewed.**
  - **Actions for the RCP frequency converters (FC) have been made as following:**
  - **OL1/OL2**:
    - Modifications to the interlockings of the trip signal of the plant circuit breaker.
    - Delay to the trip signal of the plant circuit breaker in case of 400 kV bus-bar fault or circuit breaker fault has been added.
    - Over voltage protection to the house load transformers has been added.
    - Over voltage trip setting adjustment for RCP FC supply circuit breakers.
    - After modifications the transfer to the house load operation in 400 kV bus-bar faults is not any more possible.
  - **OL3: No RCP FC’s**

- **LO1/LO2: No RCP FC's**
- Actions for the UPS-rectifiers have been made as following:
  - OL1/OL2: Over voltage limiters have been installed, voltage limits have been readjusted
  - OL3: Over voltage limiters have been installed
  - LO1/LO2: Rectifiers have been tested during outages.
- Situation of the other rectifiers/converters:
  - OL1/OL2 other rectifiers: test capabilities have been studied
  - OL3: DC/AC- and DC/DC- converters have been tested like a type- test (supplied from batteries).
  - LO1/LO2: Rectifiers have been tested during outages.

- **Review the possible impact of voltage surge transients propagating through UPS, rectifiers, and other power supplies, causing detrimental effects on safety system loads.**
  - OL1/OL2: UPS rectifiers have been modified adding the voltage limiter like OL3 UPS rectifiers. Test capabilities for UPS rectifiers and the other rectifiers have been studied.
  - OL3: UPS rectifier has been tested and output voltage has been measured.
  - LO1/LO2: Rectifiers have been tested during outages and the output voltages have been measured. New rectifiers have been factory tested.
- **Consider the need for additional protection or equipment upgrade if the protective system response is not fast enough.**
  - No need for additional voltage protection at this moment.
- Reducing the risk of grid disturbances caused by Geomagnetic Induced Currents (GIC)
  - OL3 main transformers (3 pcs one-phase transformers) are equipped with geomagnetic induced current (DC-current) blocking device. The purpose of this device is to inhibit the saturation of the main transformers and so reduce the risk of grid disturbances during solar storms. Particles from the sun with magnetic field of the earth can induce DC-current to the transmission lines.

4.2.3 Recommendations related to improving training, procedures, and information capabilities

- **Review the existing reliability and diversity of power supplies needed to support Operator Information Systems important to safety.**
  - OL1/OL2: Power supply reliability for operator information systems has been rewired after the Forsmark 1 incident. Only control rod indications need modifications. Existing power supply from UPS system. After modifications power supply from batteries.
  - OL3: No need for additional diversity of power supplies at this moment.
  - LO1/LO2: Information systems for control room operators (process computer, LOMAX information system, fire alarm system, communication systems) have back up power supply from battery and emergency diesel switchgear.

- **Given that the investigative processes recommended in Section 4.2.2 may require some time to fully implement, consider recovery procedures for events involving more than one safety related electrical supply until any corrective actions are completed.**
  - OL1/OL2: Failure and emergency instructions for different grid faults will exist. Grid faults have been included into the simulator training program.
  - OL3: Failure and emergency instructions will be made.
  - LO1/LO2: Failure and emergency instructions for different grid faults will exist. Power plant operators will have training with simulator every 3 years. Grid faults have been included into the simulator training program.
- **Review and confirm that WANO SOER 99-1 and 2004 Addendum recommendations related to electrical system recovery at the nuclear power plant have been carried out.**
  - OL1/OL2: According to TVO WANO recommendations (items to e) are complied.
  - OL3: See previous item when applicable. OL3 unit is not yet in operation.
  - LO1/LO2: Based on recommendations of WANO SOER-report some correcting actions have been made: portable illuminator clarification, better UPS- back up for LOTI information system.

4.2.4 Recommendations related to coping capability of nuclear power plants

- **Review RPS and ESFAS logic circuits for undesirable failure modes from loss of power, air, hydraulic pressure etc.,**
  - In principle essential auxiliary systems are supplied from the same source than the main system.
- **Develop procedures and/or design modifications to address concerns arising from such undesirable failure modes.**
  - See previous recommendation.

4.2.5 Recommendations related to electrical system recovery

- **For BWRs and PWRs that are designed with only electric power driven decay heat removal systems: evaluate a diverse means for promptly supplying power to core cooling systems**
  - OL1/OL2:
    - Emergency diesel generators
    - Gas turbine power supply
    - Power supply from another unit (OL1 <->OL2) emergency diesel generator to the emergency diesel bus bar
    - Transmission line from hydro power plant available
  - OL3:
    - Emergency diesel generators
    - Gas turbine power supply
    - Station black out diesel (also for severe accident management)

- LO1/LO2
    - Emergency diesel generators
    - Transmission line from hydro power plant
    - Diesel engine driven feed water pump (2 pcs/unit) for heat removal
    - Gas turbine power supply
    - Power supply from another unit (LO1 <-> LO2) via 110 kV switchyard
    - Severe accident management diesel generators

- **Confirm existence of, or immediately develop a protocol for delivering offsite power to the nuclear station as a high priority and that transmission system operator procedures recognise that nuclear power plants are priority load centres which need priority during restoration activities given blackout.**
    - See last recommendation from 4.2.1.
- **Review plans for grid recovery from brown and blackout events to assure adequate priority is given to NPPs and other essential high priority facilities.**
    - See three last recommendations from 4.2.1.

6.5 France

In 2006, EDF (Electricité de France) analysed the consequences of the Forsmark event, including:

- making a comparison between the Swedish and the French reactor design ;
- testing some equipment resulting in some adjustments, for the 1300 MWe reactors; and
- programming an analysis of the sensitivity of the safety systems and materials submitted to offsite disturbances.

EDF conclusions regarding French pressurised water reactors (PWRs) were that:

- there is no possibility of common failure leading to the loss of two emergency diesels generators and their safety related bus bars;
- there are sufficient margins, however for the 1300 MWe reactors, these margins are smaller; and
- an in-depth analysis was needed for the 1300 MWe reactors. It led to adjustments of the some electrical materials of 1300 MWe reactors.

IRSN (L'Institut de Radioprotection et de Sûreté Nucléaire) carried out a safety assessment related to the risk of loss of Uninterruptible Power Supply (UPS) after a voltage transient. The safety review did not reveal design weaknesses in the UPS which could lead to the loss of the emergency diesels generators. However IRSN considered that the analysis carried out by EDF has to be extended notably to identify potential common mode failures on inverters inducing loss of equipment other than diesel generators. In addition, according to IRSN:

- some protection thresholds have to be changed in order to be sure that during extreme voltage transient the trip of the rectifier will take place before the trip of the inverter,
- the consequences of loss of offsite power combined with the loss of UPS have to be studied in order to check that the safe shutdown can be reached using the emergency operating procedures.

In October 2008, ASN received the first results of EDF tests concerning the sensitivity of the safety systems submitted to offsite disturbances. These first results are positive but need to be confirmed by EDF in-depth analysis.
These results are currently analysed by ASN. The investigations might lead to request additional testing, studies and actions from EDF.

6.6 Germany

The German regulatory bodies acted shortly after the Forsmark event by asking three questions to the licensees:

- Can a high voltage transient cause a diesel start failure?
    - Licensees answer: All plants have adequate selectivity in their protection devices so the rectifiers will be switched off before voltage transients reach the inverters
- Is the diesel start dependent on DC or battery backed up AC?
    - Licensees answer: All German plants answered that diesel start depends on DC supply. In one plant the connection of electrical loads to the diesel bus bar needs AC power from the backed up bus bar. (This was be changed a short period later)
- What are the measures to supply the control equipment and instrumentation even in the case of loss of power in two redundancies?
    - Licensees answer: In all plants the instrumentation and control important to safety will work correctly even when two trains in the emergency power system fail.

On behalf of BMU, **German** Ministry for the Environment (BMU), GRS (Gesellschaft für Anlagen- und Reaktorsicherheit) developed a German Information Notice issued in November 2006. The following recommendations should be considered in order to exclude comparable events in German plants:

- It should be ensured that forced external and internal voltage transients (e.g. undervoltage, overvoltage, short-circuit, lightning stroke into the overhead lines and the plant) and the resulting electromagnetic effects will not be followed by any inadmissible impairments of the relevant safety-related equipment.
- For this purpose, in a first step the design basis impacts and the associated operating experience - also from conventional plants - have to be collected, and the resulting scope of electrical transients has to be determined.
- In a second step, the effects on the electrical energy supply thus determined have to be compared with the plant's current protection measures (actual condition), with consideration of recent knowledge and the requirements of the regulations. This applies in particular to an adequate selectivity of the electrical protection installations. Here, operating experience relating to the control of past voltage transients is also to be taken into account. Apart from the emergency power supply system, the second-level emergency power supply system and the grid connections also have to be included in the analyses. The analyses can be carried out using analytical methods and experimental studies. If necessary, simulators can be used to determine possible consequences for process-based systems. Operational and different accident-induced loads on the busbars and adjustment tolerances of the protective installations have to be taken into account. The failure of individual protection installations, e.g. in the area of the generator, the grid connection or the auxiliary power supply has to be considered.
- Any deviations detected in the course of the comparison have to be assessed in a third step. If any relevant safety-related deviations are found – especially those that may lead to redundancy-wide failures – back-fitting measures should be taken.

- Any future changes to the grid connection, the unit protection system, the auxiliary power supply and the emergency power supply systems including the response values of protective systems have to be assessed with regard to their effects on the measures to prevent a loss of preferred power and their effects on the protection and selectivity of systems safeguarding the electrical equipment and the emergency power supply.
- It should be checked whether the values specified for the protective equipment of the electrical installations are documented according to their safety significance and whether the protective equipment is subject to in-service inspection at regular intervals.
- We recommend that to increase reliability, the DC overvoltage control system of the inverters should be rendered ineffective. Should the technical conditions not allow this, the DC switch-off limits for rectifiers and inverters (in the present text, the term "inverter" is always understood as "rotary inverter" or "static inverter") should have a sufficiently long distance. In this case overvoltage control systems are recommendable that will automatically reconnect the inverters.
- Installations that are needed for starting up the emergency diesels and connecting the consumers should be supplied at least by the attributed DC systems to increase reliability (in the case of twin supply systems, a further neighbouring redundancy would have to be added). As to the accident overview and wide-area indication systems according to KTA 3502 it should be analysed whether for reasons of reliability it is advisable to supply these systems completely from the DC system, too.
- It should be verified that the failure of a battery-supplied emergency power busbar can have no inadmissible safety-related (e.g. redundancy-wide) effects, e.g. due to any hidden dependencies. If necessary, the allocation of consumers has to be rectified.
- The nuclear power plant operators should make sure that they are informed in good time about any forthcoming work on the external grid that may have an effect on the plant. The operating personnel should receive training as soon as possible with regard to the effects of such possible failures in the external grid in connection with such work. Existing regulations in this respect should be pointed out or new ones should be prepared.
- As the event at Forsmark has shown, failures in the uninterrupted emergency power supply can lead to considerable difficulties in judging the plant state on levels of defence 1 to 4. We therefore recommend that it should be checked whether existing procedures and training measures consider operating experience in this field adequately. The personnel should in particular be given guidance on the effects of such failures on the indications signalled on control room panels, on how these are to be interpreted by the personnel, and on how to proceed.
- Taking the present event into account, we refer in particular to Information Notices 07/99 and 07A/99 ("Reactor scram following load rejection to auxiliary power supply") and recommend that it should be checked whether plants that so far have only been checked once or not at all for proper functioning of the "Load rejection to auxiliary power supply" function should be scheduled for regular checking of this function, especially in connection with any major past changes to the plant's electrical system. Furthermore, automatic switch-over to the standby grid should be checked regularly.
- Other relevant recommendations resulting from the insights gained from the present event can be found in Information Notices 88/09 ("Switch-off of an inverter due to DC overvoltage“), 16/92 ("Switch-off of a rectifier due to defects in the DC voltage control"), 11/95 ("Failure to connect a rectifier due to defects in the DC voltage control") and 2002/07 ("Inadvertent opening of circuit-breakers in emergency power busbars"). Against the background of the present event it should be checked whether the measures taken at the time are still sufficient.

The analysis of the event by SKI has shown that there have been deficiencies in the safety management system at Forsmark. These concerned in particular the procedure in connection with plant modifications and the maintenance concepts. German operating experience has also revealed events in which latent errors – especially in connection with wiring – could not be avoided by the modification concepts and inspection procedures applied by the individual plants. This is the reason why GRS will deal more closely with this problem on a wider basis in a supplementary Information Notice and give corresponding recommendations.

The licensees have agreed on a common licensee approach to develop their actions on basis of the regulatory bodies' questions (see above) and the recommendations given in the German Information Notice. A generic report has been issued in 2009 that comprises the evaluation of voltage transients and potential subsequent actions. Plant specific actions will be derived on the basis of this generic report.

Additional recommendations following the DiDELSYS Report in Germany:

1. Interface between power plant and grid operator

- The grid operator should be informed about the high significance and the priority of the nuclear power plants (NPP).
- Procedures regarding the electrical supply in emergency situations (loss of grid, return of grid) should respect the priority of NPPs.
- The cooperation between NPP and grid operator should be strengthened (e.g. procedures and communications during disturbances and restrictions)
    - The Power Plant Operator's Organisation (VGB) has recommended further enhancement of the communication more than the usual info on plant outage times etc. (coordination of yearly planning, coordination of unplanned maintenance, establishment of contact points).

2. Further actions are ongoing but these are not in the responsibility of the NPP operators or grid operators only (like further development of the rules and regulations). Other recommendations should be tackled by the designers (robustness of electrical systems against transients, selectivity)

6.7 Hungary

The Hungarian Atomic Energy Authority (HAEA) reviewed the Forsmark-1 event in detail. There was a consultation meeting held with the Paks NPP experts shortly after the event was reported to the international nuclear community. The meeting participants found that the Forsmark-1 event circumstances are not relevant for the Paks NPP, and therefore there is no need for immediate measures. The meeting conclusion was based on the following reasoning:

- The disturbances of the emergency power supply system cannot lead to similar situation in Paks NPP (see the second part of conclusions and lessons learnt below).
- The disturbances of the diesel generators can not lead to similar situation in Paks NPP.
- The control room indication system has three redundant power supplies, therefore similar loss of information to Forsmark-1 cannot occur.
- Associations cannot be established between the Forsmark-1 event and the WANO SOER 99-01 report
- The NPP experts' opinion was that the event analysis would require more detailed information on what happened before and during the event (spurious actuation of systems, common cause failure, etc.).
- Regarding the possible incidents of the 400 kV electrical network the NPP experts proposed to request further details on the event and then the review of the former Paks NPP event reports for potential similarities with Forsmark-1 event. For this reason Paks NPP requested additional information through the WANO to clarify some details, making it possible to further analyze the event.

The most important lesson learnt from Forsmark-1 event is that a common cause failure could cause the failure of two out of four (in principle redundant) subdivisions, and could have caused even the failure of all the four redundant subdivisions too.

Most of the failure occurrences and their causes are not relevant to Paks NPP because of the different design and the modifications made in the past. For example, Paks NPP design of electrical systems uses different methods of UPS protection without actuating the over voltage protection (which gives only a signal), three redundant power supplies of the control room information system, EDG start up logic is independent from the uninterrupted power supply system, and the robust old-fashioned simple rectifier equipment, which provides the DC power for the UPS.

The final conclusion is that there is no need for further measures in Paks NPP. The conclusions and lessons learnt have been included in the plant personnel training programme.

6.8 Japan

1. Response to the Forsmark Event

(1) Discussion within the regulatory side

- JNES has reviewed the Forsmark-1 Event reported in IRS 7788, "Bakgrund" by KSU and other related information.
- Main discussion issues are the followings and compared with the design of the plants in Japan.

(2) Opening of a disconnector

- Maintenance work of the grid had been done by SVK. The disconnector was erroneously opened by the worker of SVK. According to "Bakgrund", it seems that SVK did not provide the interlock not to enable to open the disconnector when the current exist.
- Communication was not sufficient between SVK and FKA (Forsmark Kraftgrupp AB). Forsmark NPS was generating power to the grid.
- Usually a protection interlock is provided in Japanese plants not to open the disconnector when there exist current.
- In addition NPP switchyard bus protection systems are provided with redundancy or breaker failure backup scheme so that the clearing time of the faults current may not exceed specified design times against any fault generated within the protective zone for the switchyard bus system.

(3) Loss of UPS due to the over voltage transient

- There occurred a voltage variation more than 110% of the nominal value. This caused trip of two UPS (Uninterrupted Power Supply System) units serving 500V battery secured AC grid buses, subdivision, A and B. The UPS was expected to function between 85 to 110% of the nominal voltage. This caused the loss of the 220V AC power of the control system such as EDG control and the main control room display systems.
- As explained in the above, the interlock is provided not open the disconnector erroneously, the trip of the UPS is very unlikely. Furthermore, the UPS is designed and function up to around 120% of the nominal at the plants in Japan. The UPS had been improved and more resistant to the momentary high voltage.

(4) Onsite DGs dependent on AC power

- Forsmark onsite EDG had a specific dependence on power from 220V AC battery secured bus bars. Due to the loss of UPS of the subdivision A and B, they lost neither the instrumentation signal of the EDG start nor the record, and could not connect to 500V SFGD bus bars, A and B, even though the EDGs were actually started.
- The control signal to start EDG and to connect to SFGD bus bar of the Japanese plants are powered by only DC power and not dependant on the AC power.

(5) Missing and misleading information in the control room

- Some information was missing and some information was misleading, since they were dependant on the power supply of the battery backed 220V AC power.
- The reactor control signal is powered from the DC backed up AC power supply bus bar. So, the reactor protection system also will not function if they lose UPS power supply.

(6) Discussion at the Safety Information Review Meeting.

- NISA and JNES discussed this issue comparing with the domestic plant design and concluded no regulatory action is to be taken, but both the utilities and the regulators should well understand this issue and share the related information.

(7) Discussion with JANTI

- At the monthly meeting between JNES and JANTI (Japan Nuclear Technology Institute), we have discussed and shared information related Forsmark event. As an industry side Institute, JANTI has disseminated the review results to the utilities.

(8) Regulatory Action taken by Japanese Regulatory Agency (NISA)

- At the periodical top management level meeting between NISA and the Utilities regarding the safe operation of the NPP, this issue was discussed. The utilities had recognised this incident and will be careful with this kind operation and maintenance. The information had been already disseminated to all the NPPs.

2. Current Status to the Recommendations by DiDELSYS Task Group

(1) Recommendations related to preventing electrical grid and plant generated electrical faults

In Japan, both transmission systems and power plants are principally operated by the same entities (electric utility). The organisation of operation management to control the whole electric grid of each electric utility has a hierarchical structure which consists of a central load dispatching station, system load dispatching centers, local load dispatching offices etc. The management areas of the instructions, controls and operations of the electric grid are clearly specified for each voltage class. Accordingly, the clear division of roles for electric supply-demand control, including system operation works and instructions to power stations, is established.
For operation of the electric grid in Japan the Electric Power System Operation Rule to ensure reliability of electricity supply is formulated by ESCJ (Electric Power System Council of Japan) which is the electricity reliability organisation authorised by the government agency, and each electric utility has prepared in reference to the ESCJ rule a set of systematically developed electric grid operation

rules that stipulate detailed procedures, including the notice and communication necessary for system operation during normal and abnormal conditions.

All nuclear power plants (NPPs) in Japan are connected to the trunk power transmission network that plays a critical role to maintain reliability of the electrical grid. The operation of the trunk power system is controlled by the central load dispatching station to assure the electricity availability required during normal and emergency conditions in accordance with systematic procedures consisting of "system operation during normal conditions", "actions for abnormal situations" and "contingency responses". In addition, the maintenance work for equipment and facilities of the electric grid is controlled by the procedure "system operation during normal condition" so that study for maintenance outage scheduling may be carried out in advance of a planned shutdown in order that balance of electric supply-demand and reliability of the electric power supply be maintained and also the shutdown work be performed in an effective manner.

As stated above, the trunk power transmission network to which NPPs are directly connected assumes the most important role in the electric grid to maintain reliability of the electricity supply, appropriate contingency operation principles and measures are taken for the trunk power system according to the reliability standard defined by the ESCJ (e.g. N-2 failure criteria) to minimise interruption of electricity supply. This means that high priority is given to the restoration of the availability of the offsite power grid for the affected NPPs.

The recommendations presented here are related principally to the operational agreement between NPP operators and the Transmission System Operators (TSO). Since, in Japan, both operators belong to the same entity, the interface agreements between the two sectors have already been documented in place and are deemed to function smoothly.

(2) Recommendations related to robustness of nuclear power plant electric power systems

In Japan, the control targets and acceptable variation ranges of voltage and frequency of the electric grid are specified by considering postulated transients (load change, various types of accidents and system instabilities) in the grid. In addition the effects of plant-specific events (load rejection, house load operation, etc.) are taken into account to determine the variation ranges of voltage and frequency to be assumed at each plant. Measures are taken in the plant design to ensure and verify that variation ranges of voltage and frequency fall within allowable ranges specified by the standards for electrical equipment. (typically; ±10% of rated voltage and ±5% of rated frequency for normal steady-state operation)

With regard to over-voltage surges with steep waveform that could be introduced into the plant electrical systems from the transmission system due to lightning strikes or switching of circuit breakers, measures are established commonly in a manner that assures insulation coordination by adequately installing surge arresters.

However, looking at a probability of occurrence of power frequency-based overvoltage transients that exceeds assumed variation ranges and cannot be protected by a surge arrester, the profile of the electrical transients to be assumed for the present plants and their ability of coping with such events are not clearly defined because there is no standard that specifies what type of electrical transients be evaluated for the worst-case condition.

In discussing near future the issues of what type and magnitude of electrical transients or faults should be postulated in Japan as a worst case initiating event caused by grid events that could significantly impact a nuclear power plant, it is considered essential to develop screening on what transients could be likely and unlikely taking into consideration not only operating experiences but in addition characteristics of the current Japanese electric grid and unit generators (reliability standard, protection system performance etc.).

As to the potential sustained voltage degradation arising from partial failures in the grid, it is our current position that the voltage-related transients caused by grid failures should restore in a short time within the normal variation ranges, or the situation would soon develop to a blackout condition which is enveloped within the postulated loss of offsite power (LOOP) event. Such a sustained voltage degradation that will not reach under-voltage protection levels of the onsite power buses is deemed unlikely in Japanese NPPs, since the trunk electric grid is so well configured and operated that it can maintain the capability to adjust required reactive power against postulated disturbances caused by grid faults during the heaviest power flow condition in order for voltage stability to be assured (prevent voltage collapse).

The on-site safety related uninterruptible power supply (UPS) is designed to only generate an alarm without protective trip for overvoltage at the AC power input resulting from the external power transient.

Similarly, the DC-AC inverter of the power supply for instrumentation and control system that uses the semiconductor device, or the rectifier and DC stabilised power supply equipment (specific power supply units), etc. are designed to withstand the assumed voltage transients (load rejection) so that they may not lose safety functions during those transients.

The electric protection system is designed to ensure the elimination of fault circuits and the protection of equipment by providing proper and rapid detection of faults. Therefore if a failure of protective function would lead to significant effects, a measure to provide a redundant protective relaying scheme is applied.

(3) Recommendations related to improving training, procedures, and information capabilities

To provide information to operators, alarms, status lights, indicators, recorders, and computer-aided information systems such as abnormal status notification systems and detailed alarm information systems are installed. In addition, post accident monitoring systems with redundancy and independency are provided to supply safety-related plant parameters.

Since the systems to supply information of non-safety systems and equipment except the post accident monitoring systems, such as alarms and status lights, do not basically have redundancy, some of them would lose the capability to provide information when assuming a single failure.

The recovery procedures for abnormal events which involve multiple failures of the safety-related electrical power systems are described in the technical specifications. (Actions for an abnormal event: e.g., typically in cases where no automatic trip signal is generated although an event requiring an automatic reactor trip is deemed to have occurred, etc.)

However, it is speculated that there is room for examining the scope and degree of the multiple failures of electrical power systems that should be taken into account in light of this recommendation.

(4) Recommendations related to coping capability of nuclear power plants

Since the safety-related electrical system design is based on the “single failure criteria”, no multiple failure modes of redundant train/channel of safety-related electrical equipment or control and protection systems (e.g., failure of more than one train in a 2-train configuration, failure of two or more channels in a 4-channel configuration) are required to be taken into account as the design basis with the exception of consideration for a potential common cause failure for software-based safety system application.

At present, no consideration involving specific countermeasures is given to the failure modes resulting from "loss of power to multiple safety related electrical or control and protection system divisions" except specific events such as station blackout.

(5) Recommendations related to electrical system recovery

Since the decay heat removal systems of the domestic plants are equipped with a turbine-driven pump in addition to electric pumps and safety relief valves, they achieve measures to ensure a decay heat removal function independent of the on-site AC power supply to cope with "station blackout (for 30 minutes)".

See Item #1 with regard to the agreement with electrical grid operators to ensure priority to power supply to nuclear power plants during grid recovery.

6.9 Korea, Republic of

After Forsmark event, the Korean Regulatory Bodies have investigated the recurrence possibility of similar event for all domestic NPPs and concluded that the possibility was extremely low due to design difference in the related electrical and control systems between Korean NPPs and Forsmark NPP. Therefore, no specific regulatory actions were imposed to domestic NPPs.

Corrective Actions

1. Investigated over-voltage protection and its related set-point for the Main Transformer and verified proper protection and control against over-voltage

- Confirmed multiple and redundant protection signals against over-voltage
- Verified an interlock between the Generator Circuit Breaker and the protection relay

2. Investigated over-voltage protection and its related set-point for the Inverter and verified its function

- Confirmed that the UPS still functioned normally under over-voltage condition
- Confirmed automatic power transfer to the Back-up power source (from the
- regulating transformer) within 4.2 msec when the Inverter became unavailable or
- input power to the Inverter being unavailable

3. Investigated the Actuation and Control Circuit for EDG and verified that the EDG Actuation were not interrupted in case of UPS power loss

- Confirmed that the actuation and logic circuit were powered from an independent
- DC power for seven domestic NPPs
- Confirmed that the logic circuit were powered from the UPS power, however,
- manual startup for EDG and ESF components were available under UPS power
- loss for the other domestic NPPs

4. Investigate the Operating Experiences with the EDG and Inverter failure for domestic NPPs

5. Investigate the adequacy of Collection and Dissemination of the Forsmark event and/or other similar events

6.10 Netherlands

Several parts of the conclusions and recommendations from the DiDELSYS task group report had already been addressed in a former study by NPP Borssele on the causes and effects of the Forsmark incident 2006. However, the presentation of an overall list of topics as mentioned under section 4.2 of the report led to an additional regulatory request for evaluation by NPP Borssele. These recommendations will be part of the reference documents package for a third periodic safety review of the plant. The scope of this review is being established these days.

The investigation of Borssele induced by the Forsmark experience up till now brought the conclusion that the Forsmark's specific failures are not found. Systems are not directly sensitive to the specific incident course. NPP Borssele accomplishes this by the following features.

- Start-up of Borssele's emergency generators and connecting to emergency buses do not depend on alternating current. Power supply of its control is guaranteed by VDC batteries during normal as well as emergency circumstances. So a black period in the diesel power control is excluded.
- Low voltage on the line to the external grid leads to turbine trip and disconnecting of house load transformer followed by switch over to start transformers. Last ones are normally fed by a second redundancy of the external grid. Fast switch over is applicable above 70% voltage. If fast switch over may fail, a "Langzeit" (delayed) switch over will follow, which tends to go together with activation of emergency power.
- In case of unavailability of normal and emergency power, the steam generators' inventory assures 45 minutes heat sink after reactor trip without any operator action. Longer period is achievable by human F&B emergency operations.
- Control room instrumentation is powered by battery backed-up DC current and so not sensitive to black emergency buses. (no rpm problem)
- A voltage spike in alternating current does not lead to bypass either unavailability of inverters or batteries.
- Inverter and battery safeguards provide only blocking during thresholds being trespassed and no interlock. However Forsmark’s experience led to improving discrimination of limit values in UPS safeguards.
- During normal operation (not during start- up) turbine lube oil is fed by a mechanically driven pump connected to the turbine.
- Another type of excitatory should bring less voltage overshoot during fast power reductions (the plant has been live tested on full power LOOP and 50% RCP loss).

After said short term check a more in depth analysis was requested from NPP Borssele, reflecting to possible near or underlying weaknesses. The following non-limited list of topics was mentioned by KFD.

- evaluation of incidents and deviations in Borssele's emergency power systems, at least since 1997,
- possible common mode effects on emergency generators, rectifyers and inverters,

- selectivity in short current safeguards and fuses especially for emergency power, DC current and UPS,
- automatic actions after initiation of UPS protection,
- behavior of the turbo generator on load drop/ loss of offsite power,
- sensitivity of condenser and auxiliarities for load drop which may lead to turbine and reactor trip,
- response on various disturbances in the external grid (like Forsmark's two phase short cut)
- reliability of various initiations of fast and delayed switch over from house load to start-up transformers,
- response of emergency power generators to such a switch over,
- verification of the design basis for redundancy in emergency power (n+1, n+2).

At NPP Borssele a report is available now confirming the first mentioned conclusion.
October 2006 the Dutch Parliament was informed by ministerial letter telling that the Forsmark event is not probable in Dutch installations. We informed also Greenpeace on request and publicised the results on the VROM website. In the KFD’s annual incidents reports of 2007 and 2008 the Parliament has been informed.

6.11 Slovak Republic

Response to the Forsmark Unit 1 event on the nuclear installations in the Slovak republic

- Interest for access to the IRS web for experts from regulatory body, Nuclear Research Institute and NPPs has increased
- Presentation on event named „Skrat v rozvodni 400 kV a zlyhanie štartu DG na JE Forsmark (Švédsko)“ performed on regulatory body Operating Events Feedback Group OEFG meeting

Analysis of the WWER 440 features:

- inherent safety of the WWER in case of LOOP
- WWER 440 design
- robustness of the WWER design in case of LOOP

Inherent safety of the WWER in case of LOOP – conclusion of the regulatory body and the NPP operators

- relatively good heat sink at the secondary side and core cooling function
- total volume of coolant (more than 200 tons) in the 6 horizontal steam generators (SGs) can prolong time of electric voltage restoration at hours after LOOP
- heat sink function guaranteed by qualified SG safety and relief valves
- „bleed“ of coolant from the SGs can maintain Safety Critical Function „heat sink“
- no necessity of feedwater supply for a few hours due to sufficient coolant volume in the SGs
- F&B (Feed and Bleed) on secondary side using Super-emergency Feedwater System and SG safety and relief valves

Robustness of the WWER design in case of LOOP – conclusion of the regulatory body and NPP operators

- Emergency Diesel Generators (EDGs) are independent on unit uninterruptable power systems (UPS) and unit accubateries (the highest importance 1. category)
- 3 EDGs on 1 unit, 3 redundancies of 2. category UPS
- generators switchers – generator can feed electrical systems independently on distributing grid in case of LOOP (isle regime)
- independent stand by 110 kV line for each unit can supply all 6kV systems with 150% capacity for unit own consumption (reactor coolant pumps (RCPs), emergency core cooling system (ECCS), condensate and feedwater pumps, SEF pumps ...)
- each stand by 110 kV line can be connected to neighbouring unit
- hydrogenerator (14 MW) on near hydrodam for beyond design accidents purposes with manual control

Basic engineering of the MO34 NPP - Perspective design for new planned units at the MO34 NPP

- additional EDGs for beyond design accidents purposes manually controlled
- standard 3 EDGs controlled by ESFAS
- standard 3 redundant safety trains (6kV, 0,4kV, 220V, ECCS, containment SS...)
- additional source of electric energy (hydroalternator) „3rd source“ for beyond design accidents purposes manually controlled

Corrective actions implemented in the NPP Bohunice from event in the NPP Forsmark/1

- Request the main generator and exciting equipments producer for the viewpoint
- The overvoltage in the distribution of the station internal power consumption of the NPP Bohunice can increase up to maximum 110% Unom.
- Verification the emergency operating procedures (EOPs) contain solutions of the similar event
- The EOPs contain similar script which happened at the NPP Forsmark (EOP ECA 0.0 Total loss of power supply).
- Verification possibilities the simulation of the similar event at the simulator
- No. The simulation of this process will be done after an innovation of the simulator.
- Determine configurations of the switches in the switchboard, which have influence to the electrical protections sensitivity in the ground short circuit
- The electrical protections of the switchboards are independent from the state of the switches. The state of the switches does not have any influence to the electrical protections sensitivity.
- Determine the operational state of the equipments in the switchboard, which have influence at the protections
- The operational states of the equipments in the switchboard, which have influence to the operation of the protections, have been defined.

- Verification the overvoltage on uninterruptable power systems (UPS) has a potential impact on function of the supply distributors and equipments
- In the expected voltage changes of the NPP internal grid in the range 80% - 150% Unom:
    - it is not necessary to do modifications of the inverters
    - it is necessary to do modification the rectifiers PROFITEC-S according to the producer recommendation (the modification was ordered in the producer)
    - it is necessary to modify the transducers 220/24 DC for the supply RPS and RLS (the producer reviews it in this time)
- Revise the agreements between the NPP and off–site grid operating organisation in the purpose ensuring the reliable source of the off–site electric power supply for the NPP
- The agreements between the NPP and off–site grid operating organisation are revised according to the recommendations from the event WANO SOER 1999-1 and its attachment (from the year 2004) in this time.
- Determine technical requirements which should be ensured by the off–site grid operating organisations in the purpose ensuring the reliable supply for the NPP
- The technical requirements were determined and submitted to the department, which is responsible for the development and contracting the agreements with the off–site grid operating organisation.

Corrective actions implemented in the NPP Bohunice from event in the NPP Forsmark

- Design new operating procedures for the control of the operating state equipments, which have influence to the operation of the electrical protections
    - The operating procedures were designed.
- Mark the control switches for manual start–up of the diesel generators with the technological marking of the relevant EDG
    - Marking was realised.

6.12 Slovenia

Shortly after the Forsmark-1 event, the Slovenia Nuclear Safety Authority (SNSA) performed in-depth analysis of the Forsmark event and its applicability. The Krško plant is two-loop PWR designed by Westinghouse with electrical output of 700 MWe and commissioned in 1983. It has two redundant safety trains, each able to provide the plant electrical systems with 100% capacity. The following areas were reviewed in detail:

- Maintenance and surveillance procedures for the plant electrical systems, i.e. switchyard, inverters, generator, protection devices, alternate current as well as direct current power distribution system;
- Final test reports and the check lists of the plant electrical systems (switchyard, inverters, generator, protection devices, A.C. and D.C. power distribution system;
- SNSA inspection reports.
- A comparison of Krško NPP and Forsmark-1 design features showed major differences in the plant electrical system configuration, the safety buses voltage levels, and UPS design.

- The Slovenian Elektro Institute Milan Vidmar (EIMV) carried out an independent review of the Forsmark-1 event and provided the SNSA with number of recommendations.

The Krško plant, based on SNSA request analysed the Forsmark-1 event, seeking for its potential impact to the design of the plant electrical systems. The plant came to following conclusions:

- The plant uninterruptible power supply configuration is different; batteries are separated from the inverters (In case if inverters are inoperable, the DC power distribution system remains operable).
- The owner of the 110 kV/400 kV switchyard was the utility (NEK). All administrative, maintenance and surveillance procedures of the Krško NPP switchyard were developed by the plant personnel. Since November 2007, the owner of the switchyard is a grid operator Elektro – Slovenija (ELES).
- The plant management will revise the existing procedures and prepare a strategy to keep the surveillance on modifications which will be performed in 110 kV/400kV switchyards. In future all modifications in 110 kV/400kV switchyards will be performed by ELES.
- The plant contacted the designers of the inverters and battery chargers in order to check, how inverters and battery chargers respond on the input over voltage. The designer response was that it cannot guarantee that inverters and battery chargers will work properly in case of similar voltage transients that occurred at Forsmark-1. This issue will be solved with additional analysis.
- Electrical circuit breakers type EB, EHB and direct current distribution panel will soon reach the end of their design lifetime and will be replaced.
- Electrical protections of the DS breakers at direct current distribution system will not work properly in case of station blackout. The DS breaker must be exchanged and also the power supply of the protection of DS breaker must be solved.
- Electrical circuit breakers, disconnect switches, buses protection devices, etc. at the 110 kV and 400 kV switchyards will be either replaced or refurbished (most of the electrical systems were installed 25 years ago).
- Some maintenance and surveillance procedures need to be revised too.

Based on the review results, and the comparison of Krško NPP and Forsmark-1 design features, SNSA concluded that the Forsmark-1 event is not directly applicable to the Krško NPP as well as the plant personnel maintains the plant electrical systems adequately.

6.13 Spain

The Spanish Nuclear Safety Authority (CSN) sent a Technical Instruction in October 2006 to all Spanish NPPs requiring an analysis determining if an event like Forsmark could happen in Spain.

There are eight units operating in Spain; only one, a German design, has the possibility of house load operation. This plant can be transferred automatically to house load operation in specific situations.

The offsite grid configurations, the main generator (just one generator in all cases) and the onsite switchyard configuration are site dependent. Some plant designs include a generator breaker; others disconnect the main generator in the switchyard. In some plants, the main generator feeds onsite electrical distribution systems during power operation, with automatic transfer to start-up power lines (offsite sources available); other plants have preferred keeping safety buses continuously fed from start-up lines. In this case no automatic transfer would take place in case of loss of normal power supply.

The Forsmark-1 incident information allows us to consider capability for house load operation as a factor, followed by other failures (turbine trip, delayed generator breaker opening). The house load operation mode is not foreseen at Spanish NPPs in general the grid faults lead to instantaneous main generator trip and to plant power supply transfer to start-up supply.

Although Spanish NPPs cannot enter into house load operation (excepting one plant), an event involving the main generator and/or switchyards causing voltage/frequency perturbations could occur, challenging hot shutdown achievement.

There are two factors at Spanish NPPs that make similar event to the Forsmark very unlikely. Such two factors are the following:

- Overvoltage could cause the rectifiers to trip, but inverters would remain operating, because they are fed from battery backed DC buses; bypass connections that generally exist at the plants would reenergise vital AC buses. If inverters are also lost, power supply will be ensured through emergency buses transfer to start-up lines, or EDG buses.
- Diesel generator breakers have no dependence on AC power for emergency connection to safeguard buses; then, even considering inverters loss, automatic DG connection will safely take place and emergency buses will be immediately reenergised.

Spanish NPPs are not equipped with a gas turbine for backup power supply, because the offsite power source configuration, as well as EDGs, could provide a sufficient level of safety in all considered states.

The plant analysis included review of switchyard maintenance procedures as well as design of electrical protection. Generally, all Spanish NPPs concluded that no urgent or significant corrective measures were needed. Nevertheless, some improvements were considered and implemented.

In 2009, two inspections were programmed to check some specific aspects regarding Forsmark event. These aspects were included in inspections of the type called “Surveillance Requirements”, that is, no Forsmark dedicated inspection was made.

One of the inspections was carried out in the only plant having house load operation capability (It is of interest to mention that automatic actuation demand has never occurred). This plant is a NSSS KWU design.

It was confirmed that rotating inverters (MG sets, d.c. to a.c.) have no overvoltage trip. In case of an overvoltage event, battery chargers would trip, and the MG sets would keep running.

Battery charger-inverter configurations are only used to feed plant computers (i.e., not safety related equipment). In any case, trip on inverters for overvoltage is established 10 V higher than the one for battery charges.

Regarding actuations/transfers due to under-frequency, it was confirmed that they are as follows (in successive steps, of frequency value and/or time delay, if frequency is still decreasing):

- When 400 kV disconnects, house load operation starts.
- With identical under-frequency setting, but with some delay, the unit would trip and general transfer to 220 kV in the normal (not safety related) 10 kV buses takes place.
- In case of a faster frequency decrease, general transfer is anticipated by individual transfers in the normal buses.
- Interconnections between normal buses and 10 kV safeguard buses open and EDGs start.
- Finally, auxiliary feedwater system (AFWS) EDGs start and connect to 380 V buses, with a greater time delay.

The other inspection was carried out in the plant with solid-state UPSs similar to those of Forsmark. This plant is a GE design, BWR-3, Mark I containment.

There are three UPS units in this boiling water reactor (BWR) plant (two of them are safety related; the third one is for control instruments). One design modification was installed during the 2009 refuelling outage in the UPS units, which is considered below.

Previously, rectifiers did trip for overvoltage. In case of overvoltage events, battery and inverter would trip, and that would create an under-voltage condition downstream the inverter that would transfer the UPS to its internal bypass.

The design modification includes a relay upstream of the rectifier in each UPS unit, which would make its a.c. electric supply trip in case of overvoltage. Such a relay would also trip if the card that monitors the d.c. voltage upstream of the inverter detected an overvoltage.

Additional protection (RC circuit) has been added in the internal bypass to prevent large variations in voltage over time from creating parallel coupling of unsynchronised feeds and subsequently blowing the fuse in the circuit.

The design modifications also involved some additional changes in the under-voltage protection, not addressed here.

In 2010, the following actions are being carried out by the Spanish regulatory body (CSN) and nuclear power plants (NPPs):

1. Due to the operation authorization renewal requested by Almaraz NPP in 2010, some requirements have been established by the CSN related to Forsmark.

   First of all, Almaraz NPP must implement a trip on class 1E 125V DC battery chargers for output overvoltage during the next refueling outage in 2012. Almaraz NPP will send the documentation about this matter to the CSN to be evaluated; the CSN will check that the protection set point value on the battery chargers is lower than that of the inverters; that is, that rectifiers would trip before inverters.

   The second requirement is a procedure modification to make possible the unit trip due to the opening of the breakers which connect the 400 kV bus bars to the unit in every operating condition where auxiliary services are fed by the unit auxiliary transformer. This improvement will avoid house load operation in a NPP that has not been designed to work in that mode. It will have to have been carried out by the first of October, 2010, at the latest.

   The last requirement refers to improvements in building protection against atmospheric discharges. They basically consist of installing additional lightning rods in some buildings and increasing the number of conductors which connect these elements to the grounding grid. These measures must be implemented before the 31st of August, 2012 (this requirement is related to the Forsmark event because lightning can create very fast overvoltage; with these measures, overvoltage can be diverted to ground before reaching equipment).
   The first and the last requirements have been requested through Technical Instructions, according to CSN procedure for operation authorization renewal.

2. Because of the operation authorization renewal requested by Vandellós II NPP in 2010, the licensee has been required to develop and implement a design modification, already in process at the time of the request, to protect against lightning all buildings within the double fence which still don’t have proper protection. It must be carried out before the 30th of June, 2011.

   This requirement has been requested through a Technical Instruction, according to CSN procedure for operation authorization renewal.

6.14 Switzerland

The Swiss nuclear safety authority HSK made a comprehensive analysis of the Forsmark-1 event. The analysis focused on two aspects of the Forsmark-1 event such as whether (i) the technical and organisational precautions against the results of such disturbance exists in Swiss NPP, and (ii) what consequences a comparable disruptive incident would have had on a Swiss plant. It was also checked whether and which measures have to be taken at Swiss NPPs as lessons learnt from the Forsmark-1 event.

After immediate measures had been taken by the HSK, based on the initial information received about the event in August 2006, namely to see whether a similar occurrence was at all possible in the Swiss nuclear power plants, the HSK then checked in detail, on the basis of the preliminary report from the Swedish regulator, those aspects that had been identified through the event analysis as being significant.

Above all, it was checked to see which technical and organisational measures were in place in the Swiss plants in order to deal with consequences of similar types of events and what the consequences would have been if a similar event had happened. Furthermore, it was checked to see if any measures taken in Forsmark-1 could be applicable to Swiss NPPs. For this, investigations were made concerning:

- The electrical power supply and its relevant protection measures;
- The approach use concerning changes to safety relevant electrical equipment ;
- The emergency operating procedures, as well as the simulator training of the shift personnel.
- Furthermore, the operational experience of the Swiss nuclear power plants with similar events was evaluated.

As a result of these investigations, it can be stated that, compared to those areas in Forsmark 1, which were identified as weak spots and which had contributed significantly to the complex run of events, there are no gaps in the technical and organisational measures in the Swiss nuclear power plants. The Swiss plant's behaviour (according to design under similar events) has been confirmed many times in practice.

The Swiss authority recommended, however, that when training shift personnel on the simulator, additional losses of redundancies of safety systems or of the power supply, as well as the loss of information systems and signals in the control room, should also be trained periodically.

Furthermore, the HSK expects that the necessary resources are made available from the operators of the Swiss nuclear power plants in order that events and operational experiences in foreign plants can be evaluated. (Reference is made to "Der Störfall vom 25. Juli 2006 im schwedischen Kernkraftwerk Forsmark 1 und die Auswirkungen auf die Kernkraftwerke in der Schweiz" HSK-AN-6132 available at www.ensi.ch.

A member of the Swiss authority participated in the task group that prepared the DiDELSYS-report and its recommendations. So far he was familiar with the corresponding contributions received from the international community and checked their applicability to Swiss NPPs. In some cases these contributions have led to slight improvements. Examples are preventive adjustments of existing electrical protection equipment and helpful insights that could be applied in the context of the Swiss authorities release concerning the exchange of an UPS. The same member of the Swiss authority participates in the follow-up task group DiDELSYS2.

6.15 Sweden[1]

The Forsmark Event in 2006

The Forsmark event occurred on 25 July 2006 at 13:20 on Unit 1 at the Forsmark NPP[2] facility. Former SKI[3] was informed 10 minutes later. This event was classified as a “category 1 event”, according to the Swedish classification system, meaning that the licensee needs permission to restart the plant.

Shortly after the Forsmark event, SKI requested all Swedish licensees to provide evidence and analysis showing that their units (10 totally) did not have similar weaknesses as Forsmark Unit 1. The licensee for Oskarshamn NPP[4] facility was unable to provide this information to SKI in such a short period of time for Unit 1 and 2. Therefore they shut these units down. On 19 September 2006, SKI granted OKG permission to restart the Oskarshamn Unit 2. OKG informed SKI that some modification needed to be implemented on Unit 1, which would require more time. Forsmark unit 2 who has the same design as Forsmark Unit 1, was at the time shut down for yearly outage and was not allowed to restart.

After a review of an application from FKA to restart Forsmark Unit 1 and 2, based on an event analysis, SKI decided on 14 September that the licensee had to implement the following immediate corrective measures before a decision regarding restart:

- modify the UPS voltage protection in such a way that the UPS can withstand an overvoltage up to 130%
- make sure that start of diesels generators and powering of the emergency diesel bus bar shall be independent of the corresponding UPS
- verify the function for the alternate AC power source (gas turbine) to safely feed the Forsmark nuclear installations
- make sure that the visual presentation in the main control room regarding the status of the electrical systems provides an adequate situational picture at loss of power, that does not mislead the operators
- review and improve emergency procedures for operating the electrical equipment.

[1] The detailed Swedish response can be found in the IRS report 7788.

[2] Licensee is Forsmark Kraftgrupp AB, FKA

[3] On 1 July 2008 a new authority, The Swedish Radiation Safety Authority, SSM (Strålsäkerhetsmyndigheten) was established. This new authority is a merger between SKI (The Swedish Nuclear Power Inspectorate) and SSI (The Swedish Radiation Protection Authority).

[4] Licensee is Oskarshamn Kraftgrupp AB, OKG

The SKI decision on 28 September 2006 that granted permission to restart Forsmark unit 1 and 2 also put the licensee under enhanced SKI supervision as a condition for continued operation of unit 1, 2 and 3. These conditions included requirements on the licensee to:

- provide SKI with minutes from operational meetings on a daily basis
- provide SKI with documents related to internal decision making to restart a unit after any planned or unplanned outage or reactor trip.

The restart permission also included the following requirements on the licensee:

A. To develop an action plan which shall show how the licensee will:
   - improve the plant staff´s capability to judge, classify, evaluate and take appropriate measures when the reactor behaves in an unexpected manner
   - improve the process of maintenance and periodic supervision of installed components and systems
   - improve the procedures regarding the plant design changes
   - review, assess and boost the safety culture of the company management and all staff employees involved in operations and maintenance.

B. To review and update the Final Safety Analysis Reports (FSARs) for Forsmark units 1, 2 and 3 respectively, to include requirements for the plant design base, concerning transients resulting from malfunctions and disturbances in the power supply.

C. To provide SKI with the directives/orders from the company board to the CEO, regarding the priorities between safety and production.

From restart in September 2006 until June 2010

In December 2006 the licensee notified SKI of an update of the FSARs for Forsmark unit 1 and 2 respectively. The update on design base was a general requirement, that electrical equipment important to safety shall be able to withstand over-voltages up to 130%.

In April 2010 the licensee notified SSM of a renewed update of the FSARs for Forsmark unit 1 and 2. An update of the Forsmark unit 3 FSAR will follow year 2010.

The FSAR update is a complete renewal of the design base general requirements concerning over-voltages and frequency variations. The notification of the updated FSARs has many attachments with analysis reports, reports of measures taken to fulfil the new design base requirements etc.

FKA has since the FSARs update in the end of 2006 until 2010, continued to make very thorough investigations and analysis on a wide and deep basis, with the main goal to achieve robust electrical power supply systems within the plant. The work is done in a project called the “600 investigation”.

As these FSARs update still are under review and assessment at SSM the summary of measures taken by the licensee, given below, ***is only preliminary****.*

The summary also includes measures taken by Svenska Kraftnät (SvK) at the substations at the Forsmark plant. Svenska Kraftnät is a state utility which administers and runs the national electrical power grid including power lines for 200 kV and 400 kV as well as substations (switchyards), interconnectors to neighboring countries and IT systems. Svenska Kraftnät is also the authority responsible for Sweden´s power supply contingency planning.

Forsmark power plant

The "600 investigation" has so far resulted in FSAR design base requirements with mainly three categories of requirements.

- *Overvoltage limitations* Protection measures and operation/functional limitations to avoid and limit possible over-voltages over a certain level. At this stage the investigation findings imply that possible over-voltages are limited to be not greater than 142%.

- *Overvoltage hardiness*, Electrical equipment important to safety shall withstand different overvoltage levels, each level for a specified duration time, starting from 142% (shortest time) down to 110% (in continuity). New equipment shall withstand up to 150% overvoltage in a maximum specified time. This category of requirement also includes a prerequisite of a maxim rise time per second for the overvoltage.

- *Frequency hardiness,* Electrical equipment important to safety shall with high reliability fulfil their intended functions at frequency variations defined in SvK regulations SvKFS 2005:2 3 §2, table 2 and in addition at frequency variations that could arise in case of load rejection at full load (frequency rise to 55 Hz and thereafter a linear decrease to 50 Hz in 90 seconds).

Malfunctions and disturbances in the power supply, that equipment important to safety shall be protected from, can be originating from systems such as, the national power grid 400 kV (including substation), 70 kV regional grid (including 70 kV substation and gas turbine) and the plant equipment itself, including generators and transformers.

Updated requirements are also implemented which concerns selectivity of failure isolation depending on the type of failure and where it is located. Examples are that a short circuit shall be disconnected as near as possible to the fault and the upstream distribution board shall not be disconnected. The disconnections of a downstream distribution board shall be realised as near as possible to the feeding point.

FKA has made investigations about which over-voltages could appear from different postulated failures and which of these shall be considered to be the dimensioning FSAR requirements. In one of the analysis that was performed by Alstom it was found that some worst case failure combinations could be found in the generator excitation subsystem. This was further analysed using simulation and modelling (PSS/E) analysis performed by a subcontractor (Gothia Power). In this type of modelling the unit-specific parameters for the power grid, substation, generators and transformers are used.

These simulations showed that in some rare failure combinations could result in overvoltage of about 160% due to failure in generator excitation equipment. FKA have taken actions to limit these failure possibilities by disabling certain excitation functions. The simulations and analysis reports have resulted in different limitation actions. After this the maximum possible overvoltage that can appear according to the analysis is 142%.The equipment important to safety shall be designed to withstand this overvoltage level.

To fulfil the new FSAR requirements, FKA has made systematic analysis of the impact on all electric equipment important to safety to find out if the equipment withstands the new requirements. The analyses are to be finalised this year.

The analysed equipment comprises:

- different substations, substation equipment and bus bars
- cables
- motors
- transformers
- batteries
- rectifiers
- UPS equipment
- electric heaters
- fuses.

For equipment supplied from batteries, UPSs and rectifiers, findings have resulted in modifications. All analysis and tests are at present time still not finished.

Svenska Kraftnät

SvK has a running upgrade and modernisation program for the 400 kV lines in the national power grid and its substations at all Swedish nuclear power plants. The main task is to match the power uprate at the nuclear plants and to keep a stable and reliable Swedish power grid.

A secondary task which is communicated to the nuclear power plant owners is the modernisation of the substations and its equipment for 400 kV. The modernisation comprises simplification of substations and the introduction of new Disconnecting Circuit Breakers (DCBs). When used in a substation, the DCB replaces the conventional combination of circuit-breaker and separate disconnectors. *These new DCBs,* which also are over dimensioned, *have all significantly shorter disconnection time than the circuit breakers used earlier,* reducing the impact of power grid failures on the NPPs.

6.16 United Kingdom

The UK Nuclear Installations Inspectorate (NII) has ensured that the licensees are aware of the event; the licensees have been, and are still, engaged in the OECD working group, which is specifically investigating the implications of the 'Forsmark event'.

In response to a letter and enquiries from NII, British Energy and Magnox (our operating NPP licensees) have outlined their intentions as follows:

Magnox:

Magnox consider that the inherent design and protection systems of their plant mean that the effects of a 'Forsmark event' at its sites is extremely unlikely. However, as a prudent measure Magnox are looking at the implications of an abnormally high voltage on essential supply systems.

British Energy:

Protection against the effects of transmission disturbances is provided at all British' Energy's (BE) nuclear power plants; BE consider that the effects of a 'Forsmark event' on BE sites is extremely unlikely. Nonetheless BE has proposed to undertake the following assessments at each of its NPP:

- Review existing analysis models of plant and grid connections;
- Undertake transient analysis to determine maximum credible over voltage at the various essential systems;
- Review the over voltage protection of transformers, rectifiers, battery chargers, motor-generator sets and static UPS systems;
- Confirm that over voltage protection on the above essential plant is appropriately set;
- Confirm independence of standby diesel and gas turbine generators.

At this stage NII is content that NPP licensee's are responding appropriately to the issues raised by the event and NII will continue to monitor progress by the licensees in the undertaking of the work to address their intended commitments.

6.17 United States of America

On July 25, 2006, a significant event occurred at Forsmark Unit 1 in Sweden, which initiated with a fault in the 400 kV switchyard. This event drew the attention of nuclear regulatory agencies around the world as the details of the sequence of events became more clear. In the U.S., the event produced a number of NRC actions, including internal and external communications on the event, efforts to evaluate the event vis a vis the potential for a similar occurrence in U.S. designed plants, and a number of interactions within the agency and between the agency and external agencies and international regulators.

Below is a summary list of the actions taken by USNRC staff. Some of the actions include; internal and external NRC communications including Generic Communications, participation in other government agency and industry meetings, Regulatory Conferences, WGOE meetings, NUREG updates, and Agency lessons-learnt reviews.

Licensee actions included factoring the event into their corrective action programs for determination of applicability and any possible lessons learnt, and the Industry, through the Institute for Nuclear Power Operations (INPO), also issued a Significant Event Report and Significant Event Notification. Several staff evaluations and several NRC briefings were conducted on the event.

The detailed list of agency activities is provided below, listed in rough chronological order:

1. NRC staff and its supporting contractor laboratories developed and published NUREG/CR-7007on Diversity Strategies for Nuclear Power Plant Instrumentation and Control Systems (ML100541256) NUREG highlights the event involving several Common Cause Failure (CCF) issues that occurred on July 2006 at Forsmark Unit 1 in Sweden. (Document date: 2/18/2010).
2. The Division of Engineering in the Office of Nuclear Reactor Regulation (NRR) developed an internal staff report to document and explained the differences between the Forsmark design and US designs. (September 5, 2006)

3. The USNRC Office of Nuclear Reactor Regulation participated in the December 2006 Committee on Nuclear Regulatory Activities Meeting and Bilateral Meetings with nuclear safety regulatory agencies in France and Switzerland to discuss this, and a number of other topics. Subsequent bilateral visits by NRC staff and management to Sweden and the Forsmark plant were conducted as recently as April 2010. NRC Staff responded to a management action item, known as a Yellow Ticket (number 020060267) for CNRA Members to meet with their Delegates Prior to Next Meeting to Review the Agenda and Provide Input on WGOE Plan of Work. A special in-depth session was held on the incident at Forsmark NPP as part of this meeting.
4. NRC staff included reference to the Forsmark event in the agency’s Standard Review Plan NUREG-0800 Section 8.2 (ML0636004100), which is the technical review guidance and tool used by NRC staff in the conduct of staff review of License amendment and other licensing actions requested by industry.
5. NRC Staff attended a meeting at Swedish Nuclear Inspectorate (SKI) and Participated in a Scandinavian Symposium on Nuclear Technology Conference (Kärnteknik 2006) In Stockholm, Sweden, in which the Forsmark event was reviewed and discussed.
6. Several Licensees incorporated the facts associated with the Forsmark event into their corrective action programs. NRC reviewed one of the licensees’ programs in the CLINTON POWER STATION NRC PROBLEM IDENTIFICATION AND RESOLUTION INSPECTION REPORT 05000461/2007007 (ML071220208)
7. NRC Operating Experience staff conducted a Quarterly Operating Experience (OpE) Summary 2nd Calendar Quarter 2006 briefing of NRR management for recent notable OpE, which included a discussion of the Forsmark event.
8. NRC Operating Experience Branch Chief participated in the periodic Joint IAEA/NEA Technical Meetings to Exchange Experience on Recent Events in Nuclear Power Plants and the Joint IAEA/NEA Technical Meeting on the Incident Reporting System Activities. These meetings included discussion of the Forsmark Event.
9. The NRC’s Operating Experience Branch (IOEB) posted an internal OpE communication on August 2, 2006, describing the Forsmark event and thereby communicating the event to a widespread internal audience within the agency. IOEB screened the event in for further evaluation as an ”Issue for Resolution” (IFR) on Friday, August 4, 2006. Titled: Issue for Resolution (IFR) 2006-026 - Forsmark 1 - EDGs Failed to Start When Unit Disconnected from Grid.
10. On January 23, 2007, NRC staff conducted a “JOINT MEETING OF THE NRC AND THE FEDERAL ENERGY REGULATORY COMMISSION” in which a discussion with FERC on Forsmark event took place. This meeting was to identify any implications of the event for possible action by FERC.
11. The Electrical Engineering Branch (DE/EEEB) in NRR provided technical expertise and input for an Operating Experience IFR evaluation of the Forsmark event, that was finalised in June, 2007. (The purpose of this evaluation was to determine the significance of the event, its generic applicability to US nuclear plants, and provide recommendations based upon lessons learnt. In their technical evaluation, electrical engineering technical staff concluded that this issue is a safety concern, but it is not generic to U.S. domestic plants.
12. On November 2, 2006, staff conducted an Operating Experience (OpE) Significant Topics Briefing to management. OpE Briefing 2007-01, "Significant Loss of Safety-Related Electrical Power at Forsmark Unit 1," provided an overview of the event and a discussion of why the event is not applicable to domestic plants. The NRC staff issued an Information Notice (IN) on this issue. IN 2006-18: “Significant Loss of Safety-Related Electrical Power at Forsmark Unit 1, in Sweden”, was issued on August 17, 2006, and is available in ADAMS under Accession number (ML062220339).

13. NRC LESSONS-LEARNT OVERSIGHT BOARD: SUMMARY OF THE MEETING HELD ON MARCH 28, 2007 (ML070990252) The Lessons-Learnt Oversight Board (LLOB) Meeting was held on March 28, 2007

14. The purpose of the meeting was (1) to discuss LLOB selected recommendations from an Office of Inspector General (OIG) Audit Report, agency documents, and external reports, and (2) to discuss suggestions for improving the Lessons-Learnt Program (LLP). Based on information received subsequent to issuance of IN 2006-18, which was issued based on information available at the time, staff recommended that the IN be supplemented to include additional considerations to emphasise the importance of the following items:

    (a) The plant Class 1E auxiliary system of the future advanced reactors (likely to be designed for house load operation), may be adversely impacted by the voltage transients due to delayed fault clearing in the switchyard (due to reasons such as a failed/stuck breaker). The impact should be adequately evaluated down to the level of UPS buses.

    (b) The low frequency protection of generators may be phase dependent, which should be verified.

    (c) The equipment for providing the important control room indications (such as control rod position indication) should be preferably fed or backed-up by DC power or fed from dual UPS sources.

The supplement to IN 2006-18 became publicly available on August 10, 2007. This updated report is also available through the NRC Public Website, at the following http address:
http://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/2006/in200618sup1.pdf

15. The NRC has issued three recent Generic Communications on the subject of grid reliability, Offsite power, and switchyard issues:

    a. Regulatory Issue Summary (RIS) 2004-05 (Issued prior to the Forsmark event): Grid Reliability and the Impact on Plant Risk and the Operability of Offsite Power was issued to advise Nuclear Power Plants (NPPs) of the requirements in Title 10 of the Code of Federal Regulations (10 CFR) Section 50.65, 50.63, and Part 50, Appendix A. In addition, the NRC issued two Temporary Instructions that instructed the regional offices to perform follow-up inspections at NPPs on the issues identified in the RIS.
    b. Generic Letter 2006-02: Grid Reliability and the Impact on Plant Risk and the Operability of Offsite Power was issued following the RIS to request further information from licensees. The requested information included the interfaces between the NPPs and the grid operators and offsite power restoration procedures.
    c. Information Notice 2007-14: Loss of Offsite Power and Dual-Unit Trip at Catawba Nuclear Generating Station was issued to inform NPPs of an event that occurred at Catawba due to current transformer (CT) failures and improper switchyard bus differential relay settings.

16. The staff of the Offices of Nuclear Reactor Regulation and Research conducted a second briefing to NRC Management on the lessons learnt from the Forsmark event. The briefing was entitled “Operating Experience Brief 2008-02 – Forsmark Lessons Learned” and occurred on December 6, 2007.

17. The NRC participated in the "International Workshop on Defense in Depth Aspects in Electrical Systems of Importance for Safety." Sponsored by CSNI This included the “Working Material IRS Topical Study Analysis of Events Related to Interaction Between the Grid and the Nuclear Power Plants” In addition, NRC staff have participated in the series of meetings and work to produce the Defense in Depth of Electrical Systems (DiDELSYS) report. The report is currently available at http://www.nea.fr/html/nsd/docs/2009/csni-r2009-10.pdf

18. NRC/RES continues to participate in CSNI sponsored follow up activity to identify guidelines to conduct periodic review of hazards from grid generated voltage and frequency transients.
19. NRC staff briefed the Nuclear Power Engineering Committee of IEEE and the committee has authorised revisions to two IEEE standards to incorporate the lessons learnt from the Forsmark event.

Communication with Industry on the Forsmark Event:

The industry in the United States was provided with the information on this event via a number of sources, including the NRC Information Notices, news media information, participation in the Regulatory Information Conferences in which this topic was discussed and through reports issued to the industry by the Institute of Nuclear Power Operations (INPO). The INPO reports are not publicly available, but are fully distributed throughout the utility members of this organisation. All U.S. nuclear utilities are members of INPO.

APPENDIX A. DIDELSYS RECOMMENDATIONS IN DETAIL

The following text is an excerpt from the Defence in Depth of Electrical Systems and Grid Interaction Final DiDELSYS Task Group Report, NEA/CSNI/R(2009)10, issued 9 November 2009.

4.2 Recommendations

The DiDELSYS [Defence in Depth of Electrical Systems and Grid Interaction] Task Group performed: a review of recent operating experience related to nuclear power plant electrical system failure events, held fact-finding discussions with representatives of several European utilities, directly involved members on the working group who are active in the IEEE, IEC, and KTA standards setting bodies, and reviewed current good safety practices originating from regulatory bodies and WANO [World Association of Nuclear Operators]. The group observed that practices implemented in one country to address their specific operating experience were not necessarily being communicated or adopted in counterpart organisations in other countries, or to international design standards bodies such as IEEE or IEC.

The process of changing accepted electrical design standards is recognised as being a 3 – 5 year long process from the time of creating a working group to the time the standard is adopted and published for use. It must also be noted that creation of a new standard does not necessarily imply its adoption or use in upgrading nuclear safety related equipment unless the national regulator makes the new standard obligatory. The DiDELSYS Task Group was not chartered to carry out new electrical systems analyses or define specific numerical values for qualifying safety related electrical equipment. This is the proper responsibility of design and operating organisations. The task group did make substantive observations where specific practices had "gaps" and where design standards need to be upgraded. These are summarised in the following subsections.

4.2.1 Recommendations related to preventing electrical grid and plant generated electrical faults

The task group recognises that WANO SOER 99-1 and their 2004 Addendum offers a number of practical approaches to reduce electrical grid challenges and these should be addressed by nuclear power plant operating organisation. These include, but are not limited to:

- Establishment of Binding Agreements between nuclear power plant operators and transmission system operators for communication and coordination of planned activities such as major upgrades.
- Jointly planning and coordinating electrical circuit test and maintenance activities,
- Requiring transmission system operators to provide nuclear power plant operators with early warning of any on-going electrical grid problems that may become more severe. Examples would include degradation in voltage or frequency, sudden loss of major production units, or problems that might require de-energising a critical circuit or substation.
- Requiring nuclear power plant operators to provide transmission system operators with early warning of any operational limitations that might impact nuclear power plant output. Examples would include: technical specification limitations that might require a power reduction or controlled shutdown.

- Assuring that transmission system operator procedures recognise that nuclear power plants are priority load centers that must be avoided when load shedding is necessary and which need priority during restoration activities given blackout.

While the WANO SOER 99-1 and 2004 Addendum recommendations are recognised as being very important, it was recognised that WANO is a voluntary organisation, and that not every OECD member country was in conformance with these recommendations.

4.2.2 Recommendations related to robustness of nuclear power plant electric power systems

The DiDELSYS Task Group review found that many critical nuclear power plant safety systems are directly connected to the preferred power source (offsite power transmitted to plant safety systems via a transformer connection). A large rapid surge can propagate to these systems in some cases faster than alarms or active protective devices can respond. This presents the possibility for a common cause failure such as has been observed in the 2006 Forsmark event. Nominally a value of 120% voltage is assumed as an upper limit and used as the basis for qualifying many safety related electrical systems. The task group found this 120% value commonly used in IEEE, IEC, and German KTA standards. As examples: IEEE Std. 944 (1986) in Section 5.7.1 (4) only requires qualification testing of UPS units to 120% rated voltage.

Additionally IEEE Std. 741 (1997) in Annex A states:
"In an overvoltage condition, an alarm is generally adequate, without automatic tripping, because such a condition would be expected to only cause gradual component loss of component life."

Other standards contain similar limitations not based upon an assessment of actual hazard levels. Recognising this, the task group performed a review of selected IEEE, IEC, and KTA standards utilised in the design of nuclear power plant electrical systems. This review is documented in tables with specific suggested action items in Appendix B to this [DiDELSYS] report. The DiDELSYS task group thus recommends that nuclear power plants need to:

- Conduct a Hazard Review to determine the plant-specific range of possible voltage surge transients (considering: voltage and frequency content, rate of change, and duration) including: anticipated lightning surges, symmetric and asymmetric faults, switching faults, generator excitation system malfunctions and develop a design specification to be used as a basis to qualify existing or replacement equipment. Such a Hazard Review should consider the impact of such faults in conjunction with a single failed or delayed protective device operation. This is because operating experience indicates that recent events have been directly caused by initiating events not properly considered in plant electrical system design bases which were compounded by reliability issues associated with infrequently tested protection devices.
- Conduct a review of plant safety systems to confirm their capability to withstand the worst case power frequency overvoltage transients (including events such as: asymmetric or single phase faults, failure of the generator voltage regulator and excitation system with its maximum output). This is because operating experience has demonstrated that more serious current/voltage transients have occurred than were used as the design basis.
- Review the potential voltage degradations, their rate of change, and duration, and evaluate its impact on voltage sensitive devices such as local power supplies, MOVs [motor operated valves], SOVs [solenoid operated valves], contactors, etc.
- Review solid state device-based equipment such as: UPS, local power supplies, for their response (e.g. risk of tripping) to design basis voltage transients for an increasing and decreasing voltage in response to anticipated transients.

- Review the possible impact of voltage surge transients propagating through UPS, rectifiers, and other power supplies, causing detrimental effects on safety system loads.
- Consider the need for additional protection or equipment upgrade if the protective system response is not fast enough.

In making these recommendations to carry out further technical investigations it is recognised that the analytical tools such as Failure Modes and Effects Analyses are hindered by the lack of qualified electrical system simulation models for evaluating issues such as voltage/current surges potential and the impacts on local components to voltage/current surges. It would be the equivalent of attempting to understand the magnitude of LOCA [loss of coolant accident] blowdown loads or fuel rod heatup during a LOCA without qualified system simulation codes. Clearly there is a need to select and qualify suitable electric power system simulation codes and benchmark these models against actual plant events.

4.2.3 Recommendations related to improving training, procedures, and information capabilities

The DiDELSYS Task Group recognised that the reason events such as the 2006 Forsmark event did not become more serious was because operators were well trained and followed procedures as best they could (given complicated nature of the event presented to them - and which was compounded by the unavailability of substantial portions of safety related displays). The DiDELSYS task group thus recommends that nuclear power plants:

- Review the existing reliability and diversity of power supplies needed to support Operator Information Systems important to safety.
- Given that the investigative processes recommended in Section 4.2.2 may require some time to fully implement, consider recovery procedures for events involving more than one safety related electrical supply until any corrective actions are completed.
- Review and confirm that WANO SOER 99-1 and 2004 Addendum recommendations related to electrical system recovery at the nuclear power plant have been carried out.

4.2.4 Recommendations related to coping capability of nuclear power plants

The DiDELSYS Task Group recognised the need to assure that while upgrades and improvements are being made to prevent electric power system common cause failures that events could occur that could fail one or more redundant trains of safety related equipment. The DiDELSYS task group thus recommends that nuclear power plants:

- Review RPS [reactor protection system] and ESFAS [engineered safety features actuation system] logic circuits for undesirable failure modes from loss of power, air, hydraulic pressure etc., (such as automatic depressurisation in BWRs [boiling water reactors], or actuation of automatic switchover to sump recirculation in PWRs [pressurised water reactors]) given loss of power to safety related electrical divisions or more than one train/channel of control and protection systems.
- Develop procedures and/or design modifications to address concerns arising from such undesirable failure modes.

4.2.5 Recommendations related to electrical system recovery

- For BWRs and PWRs that are designed with only electric power driven decay heat removal systems: evaluate a diverse means for promptly supplying power to core cooling systems (e.g., diesel driven pump, or fast starting gas turbine, etc.).
- Confirm existence of, or immediately develop a protocol for requiring offsite power to the nuclear station as a high priority and that transmission system operator procedures recognise that nuclear power plants are priority load centres which need priority during restoration activities given blackout.
- Review plans for grid recovery from brown and blackout events to assure adequate priority is given to NPPs and other essential high priority facilities.