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NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

Comparison of Methodologies for the Simulation of Electrical Systems in Nuclear Power Plants

Working Group on Electrical Power Systems Activity 3 Report

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COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

The Committee on the Safety of Nuclear Installations (CSNI) is responsible for the Nuclear Energy Agency (NEA) programmes and activities that support maintaining and advancing the scientific and technical knowledge base of the safety of nuclear installations.

The Committee constitutes a forum for the exchange of technical information and for collaboration between organisations, which can contribute, from their respective backgrounds in research, development and engineering, to its activities. It has regard to the exchange of information between member countries and safety R&D programmes of various sizes in order to keep all member countries involved in and abreast of developments in technical safety matters.

The Committee reviews the state of knowledge on important topics of nuclear safety science and techniques and of safety assessments, and ensures that operating experience is appropriately accounted for in its activities. It initiates and conducts programmes identified by these reviews and assessments in order to confirm safety, overcome discrepancies, develop improvements and reach consensus on technical issues of common interest. It promotes the co-ordination of work in different member countries that serve to maintain and enhance competence in nuclear safety matters, including the establishment of joint undertakings (e.g. joint research and data projects), and assists in the feedback of the results to participating organisations. The Committee ensures that valuable end-products of the technical reviews and analyses are provided to members in a timely manner, and made publicly available when appropriate, to support broader nuclear safety.

The Committee focuses primarily on the safety aspects of existing power reactors, other nuclear installations and new power reactors; it also considers the safety implications of scientific and technical developments of future reactor technologies and designs. Further, the scope for the Committee includes human and organisational research activities and technical developments that affect nuclear safety.

Foreword

Working under the mandate of the Committee on the Safety of Nuclear Installations (CSNI), the objective of the Nuclear Energy Agency (NEA) Working Group on Electrical Power Systems (WGELEC) is to advance the current understanding and address safety issues related to electrical systems of nuclear installations. The aim of the working group is to enhance the safety performance of nuclear installations and improve the effectiveness of regulatory practices in NEA member countries.

WGELEC was launched following a workshop organised by the CSNI in April 2014, and one of the major conclusions of this workshop was that simulation of electrical systems has not been adequately discussed at the international level despite the fact that it is used more and more frequently for the safety demonstration of NPPs. Performing a survey on the simulation of electrical systems thus became one of the activities proposed in the initial WGELEC programme of work.

To perform this activity, a detailed 18-page questionnaire was circulated to CSNI members to ascertain the state of the art in the use of simulation of electrical systems for the safety demonstration of NPPs. This questionnaire is consistent with the content of standard IEC 62855 relative to the analysis of electrical distribution systems as well as the paper, "Verification of Simulation Tools", presented during the ROBELSYS workshop under reference P016. Nineteen answers were received originating from regulators, technical support organisations or licensees, representing a total of eleven countries.

A first compilation of information was discussed among WGELEC members and this led to clarification and additional information. Following this discussion, the collected information was analysed and summarised to be presented in this report.

Acknowledgements

This paper has been prepared by a task force for the WGELEC Activity 3. The NEA wishes to express its particular gratitude to Pascal Regnier and Pauline Deschryver (IRSN) and to Thierry-Victorin Richard (EDF-SEPTEN) for their extensive efforts in compiling and analysing the information provided by the member countries.

The NEA wishes to thank the 11 member countries who responded to the questionnaire, enabling the WGELEC to complete this report. Further, Kevin Pepper (ONR), the Chair, and Ju Yeop Park (NEA), the Secretariat of the WGELEC, provided valuable input for various chapters and contributed significantly to editing the report.

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List of abbreviations and acronyms

AC	Alternating current
AVR	Automatic voltage regulation
CAPS	CSNI Activity Proposal Sheet
CSNI	Committee on the Safety of Nuclear Installations
DC	Direct current
EDG	Emergency diesel generator
GIC	Geomagnetic induced current
HV	High voltage
IAEA	International Atomic Energy Agency
IEC	International Electrotechnical Commission
LV	Low voltage
MV	Medium voltage
NPP	Nuclear power plant
OPC	Open Phase Conditions
TSO	Transmission System Operator (NB: in this report "TSO" is not used to designate "Technical Support Organisations")
UPS	Uninterruptible Power Supply

Executive Summary

Background

The Nuclear Energy Agency (NEA) Working Group on Electrical Power Systems (WGELEC) was launched following a workshop organised by the CSNI in April 2014.

One of the major conclusions of this workshop was that simulation of electrical systems has not been adequately discussed at the international level despite the fact that it is used more and more frequently for the safety demonstration of NPPs.

Performing a survey on simulation of electrical systems thus became one of the activities proposed in the initial WGELEC programme of work.

Objective

The aim of this work is to undertake an identification and a comparison of good practices among member countries concerning the methodologies and tools used to simulate the behaviour of electrical systems of NPPs.

For this first study, the scope was as large as possible, encompassing all voltage levels, DC and AC current systems, all equipment of the electrical distribution including the electrical part of electrical sources, and electrical phenomena ranging from a few microseconds to steady-state operation.

Process

A detailed 18-page questionnaire was circulated to CSNI members to ascertain the state of the art in the use of simulation of electrical systems for the safety demonstration of NPPs.

This questionnaire is consistent with the content of standard IEC 62855 relative to the analysis of electrical distribution systems as well as the paper "Verification of simulation tools" presented during the ROBELSYS workshop under reference P016.

Nineteen answers were received originating from regulators, technical support organisations or licensees, representing a total of eleven countries. A first compilation of information was discussed between WGELEC members and this led to clarification and additional information. The collected information was finally analysed and synthetised to be presented in this report.

The main insight from this work is that from a safety point of view, simulation studies are now considered indispensable because they enable verification of the correct behaviour of the electrical distribution system, or the impact of a modification, in situations that cannot be tested in real conditions (e.g. incidents and accidents). Noticeably, simulation studies have been submitted as part of the licensing cases in most, if not all, reactors under construction.

The other major insights are as follows:

Involvement of various stakeholders in simulation

Nuclear power plant designers use simulation throughout design stages, starting in the early stages and introducing more precise data into their models used for simulation as plant studies progress.

Regulators do not perform simulations themselves, but most of them nowadays expect to find justifications based on simulations in a licensee's safety case.

Some safety authorities use technical support from external companies to perform some simulation activities as part of their regulatory assessment. Some regulators require their support company to use a simulation tool that is different from those used by the plant designer and the licensee.

Comparison of simulation practices

Five different types of electrical studies were identified in the report: load flow studies, transient studies, short-circuit studies, protection's co-ordination and selectivity studies, and miscellaneous studies.

Study of transients on AC current systems appears to be the most common type of study performed

About two thirds of the respondents performing simulations have developed asymmetric models that allow them to address open phase issues.

Studies of transients on DC current systems are not common as they are performed by only a few of the respondents.

In the models developed for studies of electrical systems:

- for the medium voltage part, all components (transformers, motors and lines) are taken into account,
- for the low voltage part, in the majority of cases equivalent models are used except for the transformers.

Several members have experienced difficulties in obtaining access to detailed characteristics of some equipment because such data was considered as proprietary by the equipment manufacturer.

About two-thirds of the respondents performing simulation studies use a qualified software tool previously submitted to some verification and functional validation. However the various practices to perform such a qualification have not been addressed and may be an interesting topic for further work.

Only one-third of the respondents seem to have a formalised guidance for building and validating the models used for simulation also leaving room for potential further exchanges in the short term.

Possible next steps

Transient studies are a priority topic for further discussions because, in addition to being the most common type of study performed by member countries, the relevance of such studies relies on multiple assumptions on which sharing of best practices would be valuable.

Performing a benchmark on simulation, as mentioned in the initial WGELEC integrated plan still appears as the next major step but will require some significant preparatory work as none of the respondents appears to have a case study with enough technical details that would be ready to use for such a purpose.

WGELEC will use the results of this report to promote further international collaborative efforts within the framework of the CSNI.

1. Introduction

1.1. General

In April 2014, the Committee on the Safety of Nuclear Installations (CSNI) task group on the robustness of electrical systems (ROBELSYS) held a workshop gathering more than one hundred people from 25 countries. One of the major lessons of this workshop was that simulation of electrical systems is used more and more in the safety demonstrations of nuclear power plants (NPPs). It was also underlined that despite a significant number of organisations from various countries performing such simulations, those organisations have not yet had any international opportunity to share their practices. The need for further development and improvements in the analysis and simulation of some specific issues was also pointed out, in particular the simulation of open phase conditions.

Hence, when the Nuclear Energy Agency (NEA) Working Group on Electrical Power Systems (WGELEC) was created, performing a survey on simulation of electrical systems was one of the activities proposed in the initial programme of work.

1.2. Objective and Scope of the work

The aim of this work is to undertake identification and a comparison of good practices among member countries concerning the methodologies and tools used to simulate the behaviour of electrical systems of NPPs.

Understanding the behaviour of electrical systems involves the consideration of different types of electrical phenomena each requiring modelling. An individual simulation study is often dedicated to a specific characteristic of this behaviour. Lastly, a simulation may encompass the whole distribution system or be focused on a specific part of it. Therefore, even considering only safety analyses, there is quite a broad range of simulation activities that is needed to be performed on electrical systems to ensure that the electrical power system remains rugged under anticipated operational transients including electrical faults of varying nature. At the beginning of this survey, various types of simulation were considered, and then as explained in section 2, the work focused on the main types of simulation presently used.

Additionally, during the ROBELSYS workshop the importance of the methodology used to perform a simulation was highlighted, in particular the validation of the software tool used. Therefore, this aspect is also included in the present work

Lastly, this work is focused on power reactors only (excluding all other types of nuclear installations). WGELEC considers that while simulation of electrical systems is equally relevant for other types of nuclear installations, contributions to the review were focused on power reactors.

1.3. Format of the report

This report is divided into two main parts:

The first part discusses the various kinds of simulation activities considered and gives an overview of how the various stakeholders (plant designers, licensees, safety authorities, etc.) presently use simulation.

The second part is devoted to the analysis of the results of the survey performed (see next section on the process followed in the work).

Since the objective of the work was not to compare the scope or depth of analysis undertaken by each country or provide a comparison, the working group considered it appropriate to anonymise the results. Therefore, with the exception of section 1.4 of this report, which mentions the answers received by each organisation in each country, the report is anonymised while pointing to the benefits of the various simulations and its applicability.

The set of section headings in the report is, consequently, as follows:

- Executive summary
- Introduction
- Simulation activities considered in this report
- Involvement of various stakeholders in simulation
- Lessons learnt from the comparison of simulation practices
- Review of results
- Conclusion
- References
- Appendix 1 Questionnaire sent to member countries

1.4. Process followed in the work

The work presented in this report is one of the three initial activities carried out by the newly created WGELEC. The group therefore had to learn and apply typical CSNI processes. The process selected is inspired by those recently used for WGRISK activities. It should be noted that as a newly created working group, WGELEC is still on the learning curve.

After the approval of the CAPS[1], the activity leaders produced a draft questionnaire, which was sent to the working group members for review. The comments received were discussed during the 3rd WGELEC meeting and the questionnaire was then officially sent to working group members and to other CSNI member countries as well. Because the aim was to capture each respondent's activities with as much detail as possible, this questionnaire, given in Appendix 1, was deliberately designed to contain a significant set of direct and specific questions.

1. CSNI Activity Proposal Sheet.

The answers received were as indicated in the following table.

Table 1. Answers to the questionnaire (in alphabetical order)

Bruce Power, Licensee, Canada
CAPSIM, Consultant for Licensee, France
EDF, Licensee, France
EDF Energy, Licensee, UK
Forsmark, Licensee, Sweden
Fortum, Licensee, Finland
GRS, Regulator (technical support), Germany
Hitachi, Licensee, Japan
IRSN, Regulator (technical support), France
KINS, Regulator, Korea
MHI, Licensee, Japan
NPC, Licensee, India
NRC, Regulator, US
Oskarshamn, Licensee, Sweden
Ringhals, Licensee, Sweden
SSM, Regulator, Sweden
STUK, Regulator, Finland
Tractebel Engineering, Licensee, Belgium
VTT, Research Laboratory, Finland

Note that in some countries the respondent made a synthesis of the activities performed by the different organisations in the country, whereas in other countries each of the different organisations provided its own answer.

The analysis of these answers was used to produce a draft for chapter 5 of the report. Additionally, based on the informal exchanges between members during the WGELEC meetings, a draft for chapters 3 and 4 of the report was established.

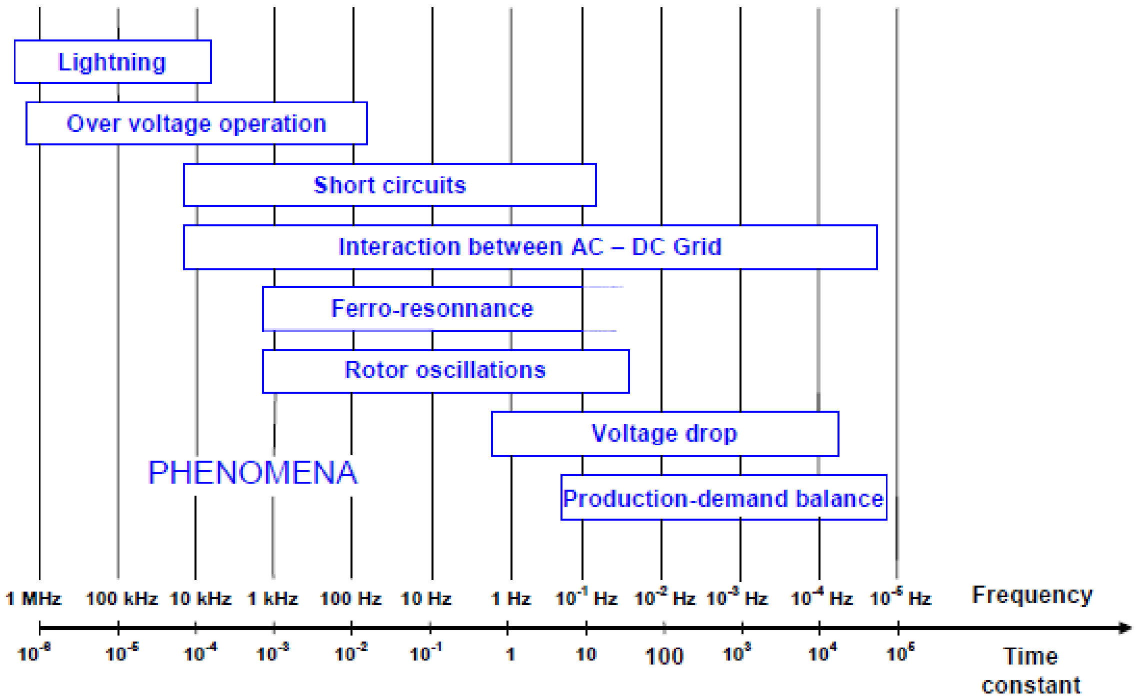
The draft report was then sent out to members for two rounds of comments before going through the standard CSNI review process.

2. Simulation activities considered in this report

As stated in the introduction, the goal of this report is to present a first overview of the use of simulation of electrical distribution systems for safety purposes in the nuclear industry. At a high level, the potential scope of such simulation activities encompasses:

- all voltage levels from several hundred kilovolts (at the interface between the plant and the grid) to a few hundred or a few tens of volts (low voltage power supplies);
- DC and AC current systems;
- all equipment of the electrical distribution (transformers, circuit breakers, cables, etc.) as well as electrical loads (motors, solenoids, I&C cabinets, etc.) and the electrical part of electrical sources (generators, batteries);
- all time constants involving electrical phenomena, ranging from a few microseconds (lightning waves) to steady-state operation as shown in figure 1.

Figure 1. Time constants of the relevant electrical phenomena



Simulation of electrical systems may be used for various purposes. All purposes that may contribute to the safety of NPPs have been considered. The following examples help to explain how common analyses are used practically:

- Load flow studies (to verify the steady-state operation).
- Short-circuit calculation [to verify that the maximum values of the short-circuit current (peak currents Ip and breaking currents Ib) must be within the rated capability of circuit breakers and switchboards (to isolate the faults with minimum collateral damage)].
- Simulation of transients (to verify the global behaviour of the electrical distribution typically expected during and after electrical transients).
- Selectivity studies (in particular to verify that the breaker nearest to the electrical fault opens first to limit the propagation of an electrical fault or to assess what happens if the primary protection fails to operate – single failure).
- Miscellaneous other studies can be developed, depending on the different issues considered (for example lightning, open phase condition or GIC studies).

Historically, simulation of electrical systems of NPPs for safety purposes seems to have started in the mid-1970s as some NPP licensees report having performed at that time short-circuit current computations and studies related to electrical transients. The tools used were first based on internally developed software, but then in the 1990s commercial tools started being used. Then shortly after, the idea for the need of specific requirements for the selection, verification and validation of simulation tools arose. When the computational capability of a PC advanced, the simulation software became more advanced and available; the regulatory requirements were anticipated in power system modelling.

3. Involvement of various stakeholders in simulation

Based on the answers received to the questionnaire and on internal WGELEC discussions, it appears that simulation of electrical systems has now become an essential tool for the safety demonstration.

More specifically simulation studies have been submitted as part of the licensing cases in most if not all reactors under construction and most regulators have specific expectation, some of them requiring access to the model data for independent verification.

The following sections detail how each of the various organisations involved in nuclear safety either directly performs or recommends the use simulation.

3.1. Nuclear power plant designers

Nowadays for nuclear power plant designers (or their subcontractors[2]) simulation of electrical power systems is current practice. Indeed, to the knowledge of the contributors to this report, such simulation is performed by designers in every new reactor project.

Simulation is often used throughout the design stages starting in the early stages. As the plant studies progress, more precise data may be fed into the simulation. The typical uses are in the following:

<u>Basic design</u>

At this stage the electrical distribution is essentially defined by a general single-line diagram. Simulation is used to determine a first set of basic parameters, in particular for the pre-sizing of the main components of the distribution system (main generator and transformer, auxiliary transformer).

<u>Detailed design</u>

The detailed design stage usually progresses through formalised steps; each step ending with the various plant systems being in a coherent state. At an early step a simulation study may be performed using data available in the technical specification documents (eg. starting current for motors) and decoupling assumptions (voltage within the standard steady-state range). At a later step a second study may be performed using the data provided by the manufacturer of the pieces of equipment being built and the respective protection and co-ordination settings.

Figure 2 illustrates how this process may be iterative as design modifications affect the overall plant configuration.

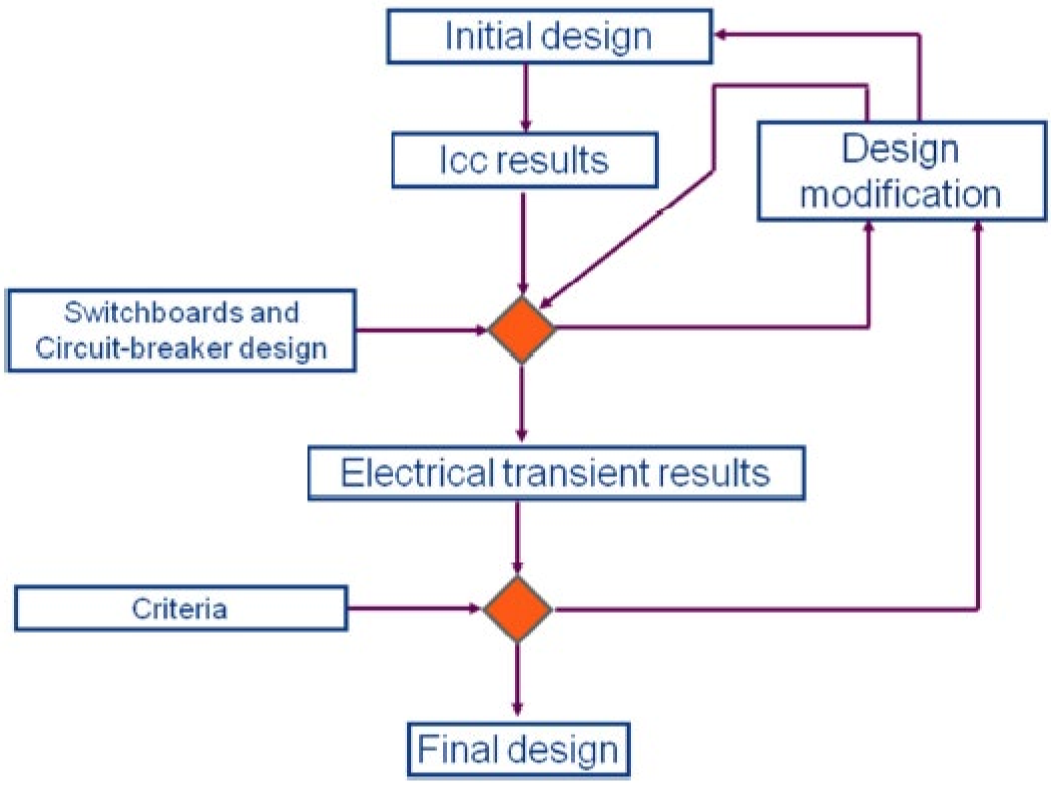
2. Depending on the project organisation, there may be a dedicated subcontractor which is the supplier of the electrical equipment. In such a case this subcontractor is responsible for most simulation studies.

From the initial design, at first software is used to calculate the maximum values of short-circuit currents at different HV and LV switchboards. The results are then compared with the design of circuit breakers and switchboards. If the design is within the code/design requirements, the transient studies are carried out, otherwise it is required to either replace the equipment with higher ratings (Switchgear, breakers etc.), adding transformers or alternate power supply, change the initial design (e.g. adding a HV/LV transformer) or change the range for circuit breakers and / or scenarios (e.g. cut the power supply to the MFW pump).

When the results of the above mentioned short-circuit studies are satisfactory, the transient phenomena are studied (often using different software).

The results are then compared with acceptance criteria (e.g. time to restart the auxiliaries), when the results are not consistent with expectations it is necessary to modify the design then to recalculate the short-circuit currents and electrical transients until the design is validated.

Figure 2. Illustration of a detailed design process



Procurement (Manufacture and Factory Testing)

Manufacturers of the main components of the electrical system may use simulation for their own development purposes.

Once a manufacturer has developed one of those major components, he is required to perform some manufacture and factory testing. Those tests are an opportunity to get some actual characteristics of the components built that will be useful for simulation: starting time for a motor, transformer winding resistance, etc.

The values obtained through those tests are then used to make simulations more precise and ensure the results are not overly pessimistic leading to excessive over-engineering. In particular those values may be used to determine the settings for protection relays.

Note that emergency diesel generators, including their generators with their I&C control systems, often require specific transient studies which are usually performed by the diesel supplier. These specific studies do not include any detailed model of the low voltage plant network nor the plant actuators supplied by the diesel generator.

The transient stability analyses of main generator, including their generator and its regulations (automatic voltage regulation [AVR] and speed regulation), are usually performed by the supplier (They may also be performed by the transmission system operator (TSO), see §3.4).

At the very end of the design, simulation using actual equipment characteristic is used to determine the settings for protection relays so that electrical protections trigger only when necessary.

Commissioning tests

Commissioning tests results are especially useful for simulation activities as they allow adjusting the parameters (bench marking) of the models with the actual plant data.

For example commissioning tests allow verifying:

- the start-up of motors, especially the largest ones;
- bus transfer sequences (such as main to auxiliary transformer);
- load shedding sequence and its impact on voltage (even though it is not possible to start all loads during a test sequence).

3.2. Nuclear power plant licensee

The power system model needs to be maintained (updated) similar to design drawings with all the design changes and equipment information to assess the continued ruggedness of the electrical power system. Simulation of electrical distribution systems should be performed all throughout the operating life of an NPP and it is necessary to support plant modifications, equipment replacements, Periodic Safety Reviews, or following exceptional events which highlight phenomena previously not considered (OPC, Forsmark transients, etc.).

Simulation activities are then performed by the licensee or a subcontractor, which in some cases may be the original plant designer.

Those activities are performed using mostly the models developed and validated during the design stage including, as mentioned above, the feedback incorporated as bench marking from the commissioning tests.

Simulation is typically used for:

- Fine tuning of settings (especially protection relays settings);
- Incident analysis (root cause identification);

- Design of significant evolutions involving electrical equipment (simulation plays a role similar to the one played during the initial plant design).

From a safety point of view, simulation studies are now considered as indispensable because they allow verifying the correct behaviour of the electrical distribution system, or the impact of a modification, in situations which cannot be tested in real conditions (e.g. incidents and accidents).

More specifically the following experience has been reported by working group members.

Several member countries have used simulation to analyse the consequences on their plants of events corresponding to those which have occurred at Forsmark in 2006 and Olkiluoto in 2008.

More recently a few member countries have used simulation to analyse the consequences of OPCs on their plants. It should be noted that, without simulation, the analysis of the effects of OPCs would be drastically limited.

Some members countries have also used simulation for the assessment of post Fukushima Daiichi measures. The role of simulation was to support the demonstration that those measures are sufficient, but also that they would not jeopardise the existing safety systems (non-regression).

Presently or in the near future, several countries in Europe will have to apply 2016 European Grid code. This new version of the grid codes allows (temporary and permanent) grid operation within wider frequency and voltage ranges than the previously permitted. Depending on the implementation decision taken nationally, some European countries may use simulation to analyse the impact/consequences of this new grid code.

Lastly, simulation may also be used during NPP decommissioning in particular to support the change in loads that could be envisaged on the system. For example, while the same motors may be used, the running load may be lesser; or alternatively the loads on each board may change which means the protection should be reviewed to ensure adequate protection. Only one member country reported using simulation for this last stage of a plant lifecycle.

3.3. Regulators and their Technical Supports

Regulators do not usually perform simulation activities themselves, but rather use the services of a Technical Support Contractor, who is familiar with various software tools.

In one member country the regulator stated that in case of an exceptional event, it could start investigations related to the event and in this case, very likely, purchase the necessary tools.

However if regulators do not perform simulation themselves most of them nowadays expect to find justifications based on simulation in a licensee's safety case. In some cases, such requirement is more or less directly mentioned in the regulation[3].

Several of them routinely use a technical support company to undertake independent analyses of the assessments of new reactor designs. These independent analyses may

3. For example in Canada, section 5.6.6.1 of CSA N290.5 (Requirements for electrical power and instrument air systems of CANDU nuclear power plants).

require the technical support company to develop its own model and perform its own simulation on some critical characteristics of the electrical distribution system. The support company may also be required not to use any simulation tool that would have already been used by the plant designer and the licensee.

Certain regulators are requiring power system model data on a common software platform along with the license application for the regulatory assessment on the ruggedness of the design. Some other regulators ask, not for the model itself but for data equipment that will allow them or their subcontractor to build a specific model.

In some member country simulation models developed by licensees such as voltage study, co-ordination, etc., for the plant distribution system may be inspected by the regulators even though they are not kept by the regulators.

Some regulators also promote the use of simulation by funding other organisations or suggesting them to perform simulation studies. Those other organisations may be their technical support or research laboratories (see next section).

Some technical supports do perform simulation activities themselves. The main reasons why those technical supports invest on simulation are:

- to build the capacity to perform, to some extent, their own simulations, not solely relying on the licensees' computations and results;
- to ensure that their staff has the necessary detailed technical know-how to perform relevant technical assessments of electrical systems and contribute to the establishment of international standards and documents;
- to explore new uses of electrical simulations in order to enhance safety (research goal).

Those technical supports usually do not have the manpower to explore all simulation topics. Among the few organisations on the Regulator side that perform simulation activities, the main topics addressed are:

- OPCs.
- Lightning overvoltage.
- Adaptive operation of NPPS.

One technical support reported the following experience which is at the border of the scope of this report but nevertheless mentioned for the sake of completeness. This technical support organisation has developed a specific tool which enables the user to know what safety actuators are lost when such or such electrical switchboard is lost during a plant event. All the reactor series in operation in the country have been modelled and the tool is used by the crisis centre for exercises as well as during real events.

3.4. Transmission System Operators (Grid operators)

Even though in some member countries the TSO and the NPP operator belong to the same company, transmission companies are out of the scope of the CSNI and therefore out of the scope of the WGELEC and of this particular report. However this section was considered necessary to complete the overall picture of the stakeholders involved.

The transmission companies conduct the grid studies for transients (slow and fast) and remedial actions are also managed by them. The nuclear stations specify the power requirements for the off-site power that is relied on as the first choice for accident mitigation. If by some reason, the off-site power is degraded, the transmission company is required to notify the nuclear station and corresponding tech spec action statement is entered.

Those studies require close co-operation between the NPP licensee and the grid operator.

In some member countries, to get the agreement to connect a new plant to the grid, the NPP licensee (as any other operator) must perform a set of simulations to verify that the performance of the turbine generator regulations (AVR and speed regulation) complies with the grid code.

3.5. International organisations (IAEA and standards organisations)

Even though international organisations are not users of simulation, they nevertheless play a role by promoting the use of simulation in the document they produce.

IAEA

The International Atomic Energy Agency (IAEA) develops international standards that present international good practices, and increasingly they reflect best practices, to help users striving to achieve high levels of safety.

In order to support the design and safety evaluation of the electrical power systems, the IAEA has published a new specific safety guide SSG-34 entitled "Design of Electrical Power Systems for Nuclear Power Plants" [1]. This safety guide provides recommendations on the necessary characteristics of electrical power systems for nuclear power plants and of the processes for developing these systems, in order to meet the safety requirements of SSR-2/1 (Rev. 1) [2]. It reflects revisions that have been made to SSR-2/1 and, in particular, to Requirement 68 on Design for withstanding the loss of off-site power. In this new safety guide simulation is mentioned as a means for performing load flow studies and transient studies.

The SSG-34 has been complemented by two technical reports that provide for the application guidance on several topics in this safety guide; these are TECDOC-1770 on Design Provisions for Withstanding the Station Blackout [3], and the Safety Report Series No. 91 on Impact of Open Phase Conditions on Electrical Power systems of Nuclear Power Plants [4].

Specifically, the Safety Report Series No. 91, which addresses the safety concern of the open phase conditions in the electrical systems, develops an understanding of the behaviour of electrical systems to address OPC vulnerabilities in electrical systems used to start up, operate, maintain and shut down nuclear power plants. It also provides a detailed technical basis for the concerns about OPCs discussed in [SSG-34] and provides guidance for the implementation of detection and protection schemes. More specifically this Safety Report contains a section 4.2 titled "calculation and simulation" which recognises the benefits of simulation. It also contains an annex I which gives an example of a calculation method for validating purposes.

IEC

Subcommittee 45A of the International Electrotechnical Commission (IEC) is dedicated to "Instrumentation, control and electrical systems of nuclear facilities". In 2013 this subcommittee created its working group 11 dedicated to "Electrical power systems: architecture and system specific aspects."

Quite noticeably, the first standard produced is focused on simulation. Indeed this IEC 62855 standard published in 2016 and entitled “NUCLEAR POWER PLANTS – ELECTRICAL POWER SYSTEMS – ELECTRICAL POWER SYSTEMS ANALYSIS” [5] is about the various analytical studies that are necessary to “validate the robustness and adequacy of design margins and demonstrate the capability of electrical power systems to support plant operation for normal, abnormal, degraded and accident conditions.” The typical studies addressed by this standard are the following:

- transient stability analysis;
- load flow studies;
- transient and dynamic studies;
- short-circuit studies;
- electrical protection and co-ordination and selectivity;
- lightning protection studies.

In the first page of its first section, this standard mentions that those analyses may be performed by tests, by hand calculation, or using “simulation tools (software and hardware) that have been verified and validated”.

Lastly this standard mentions that those studies should be used during the initial design of the plant but also:

- in case of major replacements or modifications of the electrical power system either off site or on site;
- in case of licence renewal or periodic safety review.

Some other IEC standards, not dedicated to power system simulation but applicable for power systems, are listed in references [6]-[8].

IEEE

The Institute of Electrical and Electronics Engineers (IEEE) has not produced a standard for power system simulation. The software developed in the US maintains compliance to the system design and electrical code requirements. The variety of applicable standards for the power systems are listed in references [9]-[17].

3.6. Research laboratories

Research activities regarding the development of simulation tools and methods in the field of electrical systems in general is a topic which has not been addressed by the working group.

Research activities in the field of electrical systems dedicated to the safety of nuclear installations has been discussed to a limited extent within the working group. From those discussions it appears that only a few member countries have reported an involvement of research laboratories (either public or private, financed by regulators, technical support organisations, or licensees).

Regarding the major categories of simulation activities (transient simulation and short-circuit studies), commercially available tools seem to suit the present need as no research activity dedicated to the development or enhancement of such tools has been reported.

Research laboratories seem to be involved mainly in very applied research activities which consist in making prototype studies using commercial tools. The aim of those prototype studies may be to establish a specific methodology that will then be used by a licensee (or a subcontractor) to perform actual studies contributing to the safety demonstration. If the action is funded by a Safety Authority or a technical support organisation, then the aim may be an investigation of specific scenarios or phenomena to support a safety analysis report.

One experience is about simulation of DC currents and OPCs.

3.7. Conclusion

From the above sections it appears that the main points concerning the involvement of various stakeholders in simulation are the followings:

- Simulation of electrical systems has clearly now became an essential tool for the safety demonstration.
- In particular simulation studies are now considered as indispensable because they allow verifying the correct behaviour of the electrical distribution systems, or the impact of a modification, in situations which cannot be tested in real conditions (e.g. incidents and accidents).
- Nuclear power plant designers use simulation throughout design stages, starting in the early stages and introducing more precise data into their models used for simulation as plant studies progress.
- Simulation studies have been submitted as part of the licensing cases in most if not all reactors under construction.
- If regulators do not perform simulation themselves, most of them nowadays expect to find justifications based on simulation in a licensee's safety case.
- More precisely, certain regulators are requiring power system model data on a common software platform along with the license application for the regulatory assessment on the ruggedness of the design. Some other regulators ask, not for the model itself, but for equipment data that will allow them or their subcontractor to build a specific model.
- Some safety authorities use technical support from external companies to perform some simulation activities as part of their regulatory assessment. Some regulators require their support company to use a simulation tool which is different from those used by the plant designer and the licensee.

4. Lessons learnt from the comparison of simulation practices

As mentioned in the introduction, a questionnaire (see Appendix 1) was sent to NEA member countries. Nineteen answers were received. The following sections present a first level synthesis of those answers using tables.

4.1. Types of studies performed

The following table gives a synthetic view of the types and the aims of simulation studies performed by NEA member countries.

The later tables then present in a more detailed way the answers received for each type of studies.

	Used to justify the safety demonstration	Load flow studies	Transient studies	Short-circuit current	Protection's co-ordination and selectivity studies	Miscellaneous studies	Could provide some information for a benchmark
1	X	X	X	X	X	X	Not likely
2	X	X	X	X	X	X	Maybe
3	X	X	X	X	X	X	No
5	X		X		X	X	?
6	X	X	X	X	X	X	No
7	X	X	X	X	X	X	Yes
8			X				Not likely
9	X	X	X	X	X	X	?
10	X	X	X	X	X		No
11	X	X	X	X	X	X	?
12	X	X		X			Not likely
13	X	X	X	X	X	*Planned for new NPPs (Harmonic)*	Maybe, partially
14	X	X	X	X	X		*The data we have is what we have in the simulation programme.*
15	X	X	X	X	X		*Concept for electrical plant analysis may be shared.*
16		X				X	?
18		X			X		?
19	X	X	X	X	X	X	Not likely
	14 /17	15/17	16/17	15/17	14/17	10/17	

The following explanation may ease the understanding of the above table:

- Respondent 4 and 17 do not appear on the table because they do not perform any simulation. They were thus 17 respondents performing simulation studies as it appears in the last row of the table.
- An 'X' mark in blue cells means that, for example the studies will be performed as part of the safety demonstration.

4.1.1. Load flow studies

No studies undertaken: 4, 5, 8, 17

	Load flow studies for AC networks	**Load flow studies for DC networks**	**Software used**
1	X (except Alternate AC power source)		ETAP, SKM Powertools
2	X (except Alternate AC power source)	?	EDSA
3	X (except Alternate AC power source)	X Except for UPS	*No information*
6	X	X Except for UPS	ETAP, PowerFactory
7	X (except Alternate AC power source)		EUROSTAG, ETAP
9	X (except Alternate AC power source)	X Rectifier and batteries only	NEPLAN
10	X (except Alternate AC power source)	X	ETAP, PSCAD
11	X	X Except for UPS	ETAP
12	X (except Alternate AC power source)	X	ETAP
13	X		PSS/E (Off-site power system) ETAP (On-site power system)
14	X (except Alternate AC power source)		PowerFactory
15	X	X Except for UPS Rectifier and batteries (other)	PSS/E ; Simpow
16	X (except Alternate AC power source)		PowerFactory
18	X (except Alternate AC power source)		IPSA
19	X	X	PSS/E, PSLF, Powerworld (AC) ETAP (DC)
	15/15 5/15 for Alternate AC power source	8/15 3/15 for UPS	14/15 6/14 ETAP 3/14 PSS/E and PowerFactory

Explanations:

- The cell with a question mark means that the analysis of the answer provided did not allow to establish whether DC load flow studies were performed.
- The right row indicate, when known, which software tool is used to perform load flow studies. 14 users among 15 use software tools, and in particular 3 member countries use the PSS/E software and 3 others the PowerFactory software.

4.1.2. Transient studies

No studies undertaken: 4, 12, 17

	Transient stability analyses of main generator	Slow transient studies (AC)	Fast transient studies	Transient studies of DC networks and UPS	Software used
1	performed by grid analysis, not in the frame of NPP safety	Limited scope			??
2	X	Except for behaviour of the auxiliaries during frequency & voltage dip	X		EDSA
3	Except for changes in network topology & voltage step	X	X		PSS/E, Matlab
5	?	X	X	X UPS only	PSCAD, Fast Transient Aalto university in house tool
6	X	X	X	X	PSIM, Matlab (AC&DC) ETAP, PowerFactory, EMTP (only AC)
7	X	X	X		Slow EUROSTAG Fast EMTP-RV
8		X			Matlab/Simulink
9	Except for voltage step of AVR set point	X	X		NEPLAN
10	X	X	X		PSCAD, ETAP
11	Except for changes in network topology & voltage step	X	X		ETAP, ATP-EMTP
13		Except for behaviour of the auxiliaries during frequency deviation			PSS/E, ETAP
14	Except for changes in network topology	X	X		PowerFactory
15	Except for short circuit on the grid eliminated by the protection	Except for behaviour of the auxiliaries during frequency deviation	X		PSS/E
16	Except for changes in network topology & voltage step	Except for behaviour of the auxiliaries during frequency & voltage dip	X	X UPS only	PSS/E, Simpow, Power Factory, PSCAD/EMTDC
18	X	X			IPSA
19	X	X	X		Powertech
	12/16 8/12 for voltage step, 8/12 for changes in network topology	16/16 11/16 frequency 14/16 voltage dip	12/16 5/12 for Interaction AC/DC grid with the generator	3/16	15/16 4/15 PSS/E, ETAP 3/15 Power Factory, Matlab, EMTP

Information in blue cells gives details on the scope of the studies performed.

4.1.3. Short-circuit current

No studies undertaken: 4, 5, 8, 17

	Maximum short-circuit current		Minimum short-circuit current		Software used
	AC network	DC network	AC network	DC network	
1	X		X		ETAP
2	X (3-phase only)	?			EDSA
3	X	X (single phase only)	X	X (single phase only)	Paladin design base (former EDSA), PSCAD
6	X	X (single phase only)	X	X (single phase only)	ETAP, PowerFactory
7	X		X		CC909, ETAP
9	X		X		NEPLAN
10	X (except Two phase)		X (except Two phase)		ETAP, PSCAD
11	X (3-phase only)	X (??)			AC: ETAP DC: ETAP, ATP-EMTP
12	X (??)	X (single phase only)			ETAP
13	X (3-phase only)				ETAP
14	X		X		PowerFactory
15	X		X		Simpow
16	X (3-phase only)	X (3-phase only)	X Except single-phase	X Except single-phase	PowerFactory, Simpow
18	X		X		IPSA
19	X	X			PSS/E
	15 / 15 4/15 (3 – phase only)	6/15 3/15 (1 – phase only)	10/15	3/15	15/15 7/15 ETAP , 3/15 PowerFactory, 2/15 Simpow, EDSA and PSCAD

4.1.4. Protection's co-ordination and selectivity studies

No studies undertaken: 4, 8, 12, 17

	Voltage study	Current study	Frequency study	Software used
1	X	X		ETAP
2	X			EDSA
3		X		Paladin design base (former EDSA) Current study only
5	X	X		?
6	X	X	X	ETAP, PowerFactory
7	X Study methodology under development	X		ETAP for current study, EMTP for voltage study
9	X	X	X	NEPLAN
10		X		ETAP, PSCAD and RTDS
11		X		ETAP for current study only
13	X	X		ETAP Except for Frequency study
14	X	X		For the future PowerFactory
15	?	?	?	This studies is made manually
16	?	?	?	This studies is made manually
18		X		Amtech Software
19	X	X		ETAP
	9/15	12/15	2/15	12/15 7/12 ETAP 2/12 PowerFactory & EDSA

4.1.5. Miscellaneous studies

No studies undertaken: 4, 8, 10, 12, 13, 14, 15, 17, 18

	Lightning protection study	Electromagnetic compatibility	Harmonic study	Ferro-resonance study	GIC study	Software used
1		X Not with a dedicated software				
2			X			EDSA
3	X	X			X	
5	X					
6			X	X		ETAP, PowerFactory for harmonic study & EMTP, PSIM for Ferro-resonance study
7	X	X	X	X	X Study subcontracted to BGS	EMTP, EURISGIC
9			X			NEPLAN
11			X			ETAP
16	X				X	EMTP ATP for lightning protection study Power Cast for GIC study
19	X	X	?	?	X	
	5/10	4/10	5/10	2/10	4/10	6/10 3/6 EMTP, 2/6 ETAP

4.2. Software tools used

4.2.1. List of software tools used for the various studies

	Load flow studies	Transient studies	Short-circuit current	Protection's co-ordination and selectivity studies	Miscellaneous studies
Amtech				X	
CC909			X		
EDSA	X	X	X	X	X
EMTP		X	X	X	X
ETAP	X	X	X	X	X
EURISGIC					X
EUROSTAG	X	X			
Fast Transient Aalto university		X			
IPSA	X	X	X		
Matlab/ Simulik		X			
NEPLAN	X	X	X	X	X
Power factory	X	X	X	X	X
Powertech		X			
Powerworld	X				
Power Cast for CIG					X
PSCAD	X	X	X	X	
PSLF	X				
PSIM		X			X
PSS/E	X	X	X		
RTDS				X	
Simpow	X	X	X		
SKM Powertools	X				

4.2.2. Tool qualification

No studies undertaken: 4, 5, 6, 11, 12, 17

	Qualification of the tools	**Functional verification**	**Functional validation**	**Organisation to maintain the qualification**
1		X	X	X
2	X	X		X
3		X	X	
7	X	X	X	X
8	X	X	X	
9	X	X	X	X
10	X		X	
13	X	X	X	X
14	X	X	X	
15	X	X	X	X
16	X	X	X	X
18	X	X	X	X
19	X	X	X	X
	11/13	12/13	12/13	9/13

4.2.3. Tool documentation

No studies undertaken: 4, 5, 6, 12, 17

	User manual	Note of Methodology	Note of Assumptions	Note of input data
1	X		X	X
2	X	X	X	X
3	X		X	X
7	X	X	X	X
8	X		X	X
9	X	X	X	X
10	X		X	X
11	X	X	X	X
13	X			X
14	X		X	X
15	X	X	X	X
16	X	X	X	X
18	X			X
19	X	?	?	X
	14/14	6/14	11/14	14/14

4.3. Models developed for transient studies

4.3.1. Level of detail of models developed for AC transient studies

No studies undertaken: 1, 4, 12, 17

		2	3	5	6	7	8	9	10	11	13	14	15	16	18	19	
Type of models	Symmetrical	?	X	?	X	X	X	X	X	X	X	X	X	X	X	X	13/15
	Asymmetrical	?	X	X	X	X	X	X	X			X	X	X		X	11/15
Transmission system	Simplified model	?	X	X	X	X	X		X	X	X	X	X	X	X	X	13/15
	Regional model	?		?				X	X			X		X	X	X	6/15
	National model	?		?								X		X			2/15
Turbo-generator set	Generator	X	X PSSE	?	X PM	X PM	X PM	X PM		X PM	X IEEE	X PM	X PM	X PM	X PM	X PM	13/15 10/13 Park Model
	Turbine	?	X Sp	?	X St&Sp	X St&Sp	X Sp	X Sp				X St&Sp	X St	X Sp	X St	X Sp	10/15
	Valves control chains	?		?		X Sp						X Sp				?	2/15
	Excitation system	X St	X Sp	?	X St&Sp	X Sp	X St	X Sp		X St&Sp	X Sp	X St&Sp	X St	X St	X St&Sp	X	13/15
	Voltage regulation	?	X Sp	?	X St&Sp	X Sp	X St	X Sp		X St&Sp	X Sp	X St&Sp	X St	X St&Sp	X St&Sp	X Sp	12/15
	Speed regulation	X St	X Sp	?	X St&Sp	X Sp		X Sp		X Sp	X Sp	X St&Sp	X St	X Sp	X St	X Sp	12/15
	Upstream turbine				?										X St	?	1/15

Explanations :

- « PSSE » is used to indicate that the generator model is developed with PSSE software.
- « PM » means a Park model is used for the generator.
- « IEEE » means an IEEE standard model is used to model the generator Sp means Specific.
- « St » means Standard.

		2	3	5	6	7	8	9	10	11	13	14	15	16	18	19	
Standby AC power source / Emergency generator	Generator	X	X	?	X	X		X		X		X	X	X	X	?	10/15
	Diesel / process	?		?	X	X						X	X	X	X	?	6/15
	Combustion turbine process	?		?	X	X		X					X		X	?	5/15
	Excitation Sys&voltage regulation	X	X	?	X	X		X		X		X	X	X	X	?	10/15
	Speed regulation	X	X	?	X	X				X		X	X	X	X	?	9/15
Transfo	HV/MV	X	X	?	X	X	X	X		X	X	X	X	X	X	X	13/15
	MV/LV &LV/LV	X	X	?	X	X	X	X		X	X	X	X	X	X	?	12/15
Lines/cables		?	X	?	X	X		X		X	X	X	X	X	X	?	10/15
Auxiliaries	Induction motor MV	?	X	?	X Si &Co	X Co	X Co	X Si		X Sp	X Co	X Co	X Si	X Si	X Si&Co	?	11/15
	Induction motor LV	X	X Si	?	X Si &Co	X Co	X Co	X Si		X Sp	X Co	X Si &Co	X Si	X Si	X Si&Co	?	12/15
	Static loads	X	X	?	X	X	X	X		X	X	X	X	X	X	?	12/15
Level of detail of the SLD MV part	Transfo Buses	?	All	?	All or Gr	All	All	All or Gr	All	All	All	All	All	All	All or Gr	All	13/15
	Cables	?	Pa	?	All or Pa	All		All or Pa	All	All or Pa	All	All or Pa	All	All	All or Pa	All	12/15
	Motors	?	Gr	?	All or Gr	All	All	All or Gr	All	All or Gr	All	All or Gr	All	All	All or Gr	All	13/15
Level of detail of the SLD LV part	Transfo Buses	?	Gr	?	All or Gr	All	All	All or Gr	All	All	All	All	All	All	All or Gr	All	13/15
	Cables	?	Pa	?	All or Pa	All or Pa		All or Pa	All or Pa	All or Pa	All or Pa	All or Pa	All or Pa	All or Pa	All or Pa	All	12/15
	Motors & Static load	?	Gr	?	All or Gr	All or Gr	All	All or Gr	All or Gr	All or Gr	All or Gr	All or Gr	All or Gr	All or Gr	All or Gr	?	12/15

Explanations :

- « Si » means Simplified
- « Co » means Completed
- « Sp » means Specific
- « Gr » means Grouped
- « Pa » means Partly

4.3.2. Level of detail of models developed for DC and UPS transient studies

No studies undertaken: 1, 2, 3, 4, 5, 7, 8, 10, 12, 13, 14, 15, 17, 18, 19

		6	9	11	16	
Type of models	Symmetrical	X	X	X	X	4/4
	Asymmetrical	X	X			2/4
Upstream network (AC)	Simplified model	X	X		X	3/4
DC source	Inverter / UPS	X Sp	X Sp			2/4
	Rectifier	X Sp	X Sp	X Sp		3/4
	Battery	X Sp	X Sp	X Sp		3/4
Cable		X	X RLC	X RLC		3/4
Auxiliaries	Static loads	X	X	X	X	4/4
	Motor DC	X	X	X		3/4
Level of detail of the single-line diagram of DC and UPS networks		X All, or Pa or Gr Eq	X All, or Pa or Gr Eq	X All buses Gr Eq	X Equiv. static load	4/4

Explanations :

- « Eq » means Equipement

5. Review of results

In summary, the main lessons learnt from this work are the following:

5.1. General results

- Response analysis shows that, among the 19 respondents, 17 perform studies.
- 14 use these studies to justify the safety demonstration.

The scope of these studies is close to the scope described in IEC 62855.

5.2. Types of studies

From now on, only the 17 respondents performing simulation studies are considered in the analysis.

Response analysis shows that:

- AC studies are carried out by almost all respondents to the questionnaire :
  - ✓ 15/17 perform load flow studies;
  - ✓ 16/17 perform transient studies;
  - ✓ 15/17 perform short-circuit currents calculation.
- DC studies are not very common. Among the few respondents performing DC studies:
  - ✓ Most studies only concern load flow (8/17 respondents) and maximum short-circuit currents calculation (6/17);
  - ✓ UPS transient studies are rather uncommon (3/17).
- Protection's co-ordination and selectivity studies:
  - ✓ 9/17 take into account voltage deviation;
  - ✓ 12/17 take into account current co-ordination and selectivity studies;
  - ✓ 2/16 take into account frequency deviation.
- Miscellaneous studies :
  - ✓ 5/17 respondents perform lightning and harmonic studies;
  - ✓ 4/17 respondents perform EMC and GIC studies;
  - ✓ 2/17 respondents perform ferro-resonance studies.

5.3. Software tools

Response analysis shows that:

- The number (22) of software tools used is important, however:
  - ✓ only five software tools covers almost the whole scope of studies;
  - ✓ among these five software tools only two are used by at least three respondents.
- Tool Qualification and Documentation
  - ✓ 2/3 use qualified software, which was subject to verification and functional validation;
  - ✓ 2/3 use a User Manual, and Notes of Assumptions and Input Data;
  - ✓ 1/3 use notes of methodology.

5.4. Level of detail of the models developed

As mentioned in §4.3.1, 4 respondents do not realise models for simulation studies, so only the 15 respondents concerned are considered in the following analysis. Response analysis shows that:

- 13/15 develop symmetric models
- 11/15 also develop asymmetric models
- 14/15 model the transmission system (simplified model for 13/15)
- 13/15 model the turbo-generator set with its voltage and speed regulation
- 10/15 model the Standby AC Power Sources generator, its voltage regulation and excitation system
- 6/15 only model the process
- 13/15 model transformers
- 12/15 model auxiliaries
- 10/15 model cables
- 13/15 model all transformers and all buses (HV&LV)
- 13/15 model all MV motors
- 6/15 use equivalent models for MV cables & motors
- 11/15 use equivalent models for LV cables & motors

5.5. Access to proprietary data

Developing and validating a model that closely represents the behaviour of electrical equipment may require having access to proprietary data. Such proprietary data may either be detailed design documentation or test results.

Those data are usually the property of the manufacturer of the equipment, or sometimes of a company that has invested in specific tests of the equipment.

From discussions within the working group and additional inquiries, it appears that in several countries various stakeholders including operators and plant designers have experienced difficulties in obtaining detailed technical characteristics for some equipment.

Examples of data that has proved to be difficult to obtain are:

- algorithms for the regulation of generators;
- model for the process of a diesel engine;
- model for a UPS;
- asymmetric data for different equipment.

For safety authorities and TSOs, access to such proprietary data may also be problematic. Indeed, depending on the legal status of those organisations in each member countries, the transmission of data which may be the property of private companies based abroad may require to establish dedicated agreements.

5.6. Open questions raised by this study

The analysis of the answers to the questionnaires leads to the following questions:

- What are the reasons why very few transient studies are being performed for DC networks? Are real tests used rather than simulations? Are UPS and battery models difficult to get?
- Is the impact of the DC network insignificant when considering transients affecting the whole distribution system? And hence is it or is it not useful to model the DC network for simulation of the whole distribution system?
- What is the origin of the difficulties in taking into account the frequency variation of the transmission system in the studies? Is this due to the use of a simplified grid model? Or is it due to the small impact on electrical equipment?
- What are the reasons why only half of the users have a “note of methodology” also called a formal procedure? Is it due to a lack of knowledge of its content and role? Or is it because only very few people are involved in such studies?
- What are the reasons why only 1/3 of the users model the process and the speed regulation of emergency diesel generators (EDGs) for the load sequencer studies? Are these behaviour models difficult to obtain? Or are the corresponding studies performed by the manufacturer of the diesel generator set?
- Is the development of asymmetrical models due to the completion of a study on the OPC? Are these models used for other kinds of studies?
- For AC networks, how are the levels of detail defined for the MV part and LV part of the SLD? What is the number of components in the models and why? (e.g. what assumptions are made to define the relevant level of detail?)

Note: It appears that the methods for performing short-circuits studies are well established and detailed in existing IEEE and IEC standards and hence do not call for specific further exchanges within the WGELEC.

5.7. Conclusion about the review of the results

From the above sections it appears that the main lessons learnt are the followings:

- Study of transients on AC current systems is the most common type of study performed. This involvement of many member states added to the fact that this type of study relies on multiple assumptions makes it a priority topic for further discussions.
- About two thirds of the respondents performing simulations have developed asymmetric models that allow them to address open phase issues.
- Studies of transients on DC current systems are not common as they are performed by only a few of the respondents.
- Regarding the models developed for studies of electrical systems:
  - For the medium voltage part, all components (transformers, motors and lines) are taken into account.
  - For the low voltage part, in the very large majority of cases equivalent models are used except for the transformers.
- Several members have experienced difficulties in obtaining access to detailed characteristics of some equipment because such data was considered as proprietary by the equipment manufacturer.
- About two thirds of the respondents performing simulation studies use a qualified software tool previously submitted to some verification and functional validation. However the various practices to perform such a qualification have not been addressed and may be an interesting topic for further work.
- Only one third of the respondents seem to have a formalised guidance for building and validating the models used for simulation also leaving room for potential further exchanges in the short term.
- Miscellaneous studies (including lightning, electromagnetic interferences, harmonics, ferro-resonance) are performed by less than one third of the respondents who perform simulation studies and appear as a possible topic for medium term further exchanges.

5.8. Possible next steps

This study was the first opportunity to review how various member countries undertake the analysis of electrical systems of NPPs. It has opened several paths for further exchanges on technical practice for enhancing the safety of NPPs.

First, there is the set of open questions raised in the previous section that calls for some investigation.

Second, a discussion could be held on the scope of slow transient studies addressing:

- working assumptions;
- the methodology used;
- methods for model validation:
  - ✓ through unit tests (based on real test reports) to validate each model of AC components: transformers, lines or cables, motors;
  - ✓ through a representative and documented case study (if possible by means of real tests) making it possible to compare the results obtained between the various tools at the MV and LV level of electrical systems.

Performing a benchmark on simulation, as mentioned in the initial WGELEC integrated plan still appears as the next major step but will require some significant preparatory work as none of the respondents appears to have a case study with enough technical details that would be ready to use for such purpose.

Third, and rather in the mid or long term, a work programme could be proposed (still to be defined by the working group) on the remaining work to be done especially on the following areas:

- modelling of EDGs;
- protection's co-ordination and selectivity studies;
- modelling of DC current systems;
- miscellaneous studies:
  - ✓ lightning;
  - ✓ EMI;
  - ✓ harmonics;
  - ✓ ferro-resonance;
  - ✓ and GIC;
  - ✓ ….

Finally, defining the appropriate content for a "methodology note" that could also be an interesting path forward. The overall goal of such a note would be to obtain identical simulation results no matter who performs the study. Typical topics addressed by such a note could be:

- what minimum input is needed (aka completed SLD, …);
- what assumption to perform for missing data;
- the need for the type of study (bus transfer, load sequencer, ...);
- models adapted and validated with respect to the electrical phenomena to be studied;
- how to describe the single-line diagram in the simulation tool;
- spreadsheets to be used for conversion of input data into required format for tools;
- ...

6. Conclusion

From a safety point of view, simulation studies are now considered indispensable because they allow verifying the correct behaviour of the electrical distribution system, or the impact of a modification, in situations that cannot be tested in real conditions (e.g. incidents and accidents).

Most of the studies performed by member countries address AC distribution networks and are dedicated to slow transients. Such studies are a priority topic for further discussions because, in addition to being the most common type of study performed, their relevance relies on multiple assumptions on which sharing of best practices would be valuable.

Short-circuit studies, even though they are also being performed by many member countries, rely on well-established methodologies that are quite detailed in existing Institute of Electrical and Electronics Engineers (IEEE) and International Electrotechnical Commission (IEC) standards. Hence those studies do not call for specific further exchanges within the Nuclear Energy Agency (NEA) Working Group on Electrical Power Systems (WGELEC).

This first overview has also raised a set of open questions and possibilities for further work on topics such as slow transients (including open phase conditions) and validation of tools and models.

Performing a benchmark on simulation, as mentioned in the initial WGELEC integrated plan, still appears as the next major step but will require some significant preparatory work as none of the respondents appears to have a case study with enough technical details that would be ready to use for such a purpose.

Additionally, DC current systems and miscellaneous studies have been identified as potential topics for mid or long term discussions.

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[9] IEEE, Recommended Practices for Electric Power Distribution for Industrial Plants, IEEE Std141.

[10] IEEE, Recommended Practice for Grounding of Industrial and Commercial Power Systems, IEEE Std 142.

[11] IEEE, Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems, IEEE Std 242.

[12] IEEE, Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications, IEEE Std 446.

[13] IEEE, Recommended Practice for Powering and Grounding of Electronic Equipment, IEEE Std 1100.

[14] IEEE, Recommended Practice for Calculating AC Short-Circuit Currents in Industrial and Commercial Power Systems, IEEE Std 551.

[15] IEEE, IEEE Standard Criteria for Diesel-Generators Units Applied as Standby Power Supplies for Nuclear Power Generating Stations, IEEE Std 387.

[16] IEEE, IEEE Standard for Criteria for the Protection of Class 1E Power Systems and Equipment in Nuclear Power Generating Stations, IEEE Std 741.

[17] IEEE, Recommended Practice for Nuclear Power Generating Station (NPGS) Preferred Power Supply (PPS) Reliability, IEEE Std 1792.

8. Appendix 1 Questionnaire sent to members countries

WGELEC Activity 3
"Comparison of methodology for simulation of electrical systems" questionnaire

1. Introduction

In June 2016 during its 59th meeting, CSNI approved the activity number 3 proposed by the Working Group on Electrical Power Systems (WGELEC).

The objective of this activity entitled, "Comparison of methodology for simulation of electrical systems", is to undertake, by the means of a survey, a comparison and identification of good practices in the methodologies and tools used by member countries for the simulation of electrical systems. Further definition of this activity is given in the associated CAPS, which was approved by CSNI

The following questionnaire has been established as the basis for this survey. The main points covered are:

- the types of studies performed in member states regarding the simulation of electrical systems;
- the type of software and the environment used to perform those simulations;
- the overall methodology used to validate those tools (including functional verification of the basic models offered by the tool);
- the kind, size and level of details of the models developed to perform those studies.

Even though this questionnaire may at first glance seem quite long, it mostly consists of "yes or no" questions. In addition, a "no" answer leads to skipping many of the following questions. It is therefore expected that despite its length the questionnaire will only require a reasonable amount of time to fill in.

In case of a "no" answer, you are welcome to elaborate your position. A few other specific questions call for worded answers if needed. In particular at the end of each sub section you may use the specific place entitled "additional comments" if you consider that the yes/no answers insufficiently reflect your activities.

Please note that this questionnaire is consistent with the content of standard IEC 62855 relative to the analysis of electrical distribution systems as well at the paper, "Verification of simulations tools", presented during the ROBELSYS workshop under reference P016

- Name:
- Telephone No.:
- Email:
- Organisation:

2. Types of studies performed (including those in progress)				
Are you presently performing any studies on electrical distribution systems?			Yes	No
	If no	**Reason why? (no interest/ interest but…)** **Do you have any mid/ long term perspective to launch such studies?** If you are not performing any studies you have reached the end of the questionnaire.		
	If yes	**What is the overall purpose of those studies?**		
		In particular, are those studies used to justify the safety demonstration?	Yes	No
		What is the status of those studies? To which extent are your models and/or the results of your studies public or proprietary? What could be shared within WGELEC members? Do you have a set of data that could be used as a basis for defining a future benchmark for the WGELEC?		
2.1 Load flow studies Are you performing load flow studies?			Yes	No
If yes	In those studies, the auxiliaries are supplied by:			
	2.1.1 AC networks		Yes	No
	If yes	Auxiliary Transformer(s)	Yes	No
		Standby Transformer	Yes	No
		Standby AC Power Source or Emergency Generator	Yes	No
		Alternate AC power source	Yes	No
		Other (please specify)		
	2.1.2 DC network and UPS (uninterruptible power supply)		Yes	No
	If yes	Inverters (UPS)	Yes	No
		Rectifier and batteries	Yes	No
		Batteries	Yes	No
		Other (please specify)		
	2.1.3 Standards used			
	Any Additional comments regarding 2.1 (Load Flow studies)			

2.2 Transient studies Are you performing transient studies?				Yes	No
If yes	*2.2.1 Transient stability analyses of main generator*			Yes	No
	If yes	Short circuit on the grid eliminated by the protection		Yes	No
		Changes in network topology		Yes	No
		Voltage step of AVR setpoint		Yes	No
		Other (please specify)			
	2.2.2 Slow Transient studies (AC)			Yes	No
	If yes	House load operation		Yes	No
		Bus transfer or Source switching		Yes	No
		Start of the largest motor		Yes	No
		Load sequencer		Yes	No
		Behaviour of the auxiliaries during frequency deviation		Yes	No
		Behaviour of the auxiliaries during voltage dip		Yes	No
		Overvoltage following AVR failure		Yes	No
		Phase opening on grid side		Yes	No
		Transformer inrush current		Yes	No
		Other (please specify)			
	2.2.3 Fast Transient studies			Yes	No
	If yes	Switching overvoltage		Yes	No
		Interaction between AC – DC grid with the main generator		Yes	No
		Other (please specify)			
	2.2.4 DC network and UPS			Yes	No
	If yes	Inverters (UPS)		Yes	No
		Rectifiers / batteries		Yes	No
		Batteries		Yes	No
		Other (please specify)			
	2.2.5 For each kind of study and each type of network (AC, DC, and UPS) can you specify which standard you use to model and simulate				
	Any Additional comments regarding 2.2 (Transient studies)				
2.3 Short-circuit current				Yes	No
If yes	*2.3.1 Maximum short-circuit current*			Yes	No
	If yes	**AC network**		Yes	No
		If yes	Three-phase	Yes	No
			Two-phase	Yes	No
			Single-phase	Yes	No

			Other (please specify)		
	If yes	**DC network and UPS**		Yes	No
		If yes	Three-phase	Yes	No
			Two-phase	Yes	No
			Single-phase	Yes	No
			Other (please specify)		
	2.3.2 minimum short-circuit current			Yes	No
	If yes	**AC network**		Yes	No
		If yes	Three-phase	Yes	No
			Two-phase	Yes	No
			Single-phase	Yes	No
			Other (please specify)		
	If yes	**DC network and UPS**		Yes	No
		If yes	Three-phase	Yes	No
			Two-phase	Yes	No
			Single-phase	Yes	No
			Other (please specify)		
	2.3.3 For each short-circuit calculation, can you precise the standard you use				
	Any additional comments regarding 2.3 (short circuit current studies)				
2.4 Protection's co-ordination and selectivity studies				Yes	No
If yes	*2.4.1 Voltage study*			Yes	No
	2.4.2 Current study			Yes	No
	2.4.3 Frequency study			Yes	No
	2.4.4 For each kind of study, can you precise the standards you use				
	Any additional comments regarding 2.4 (co-ordination and selectivity studies)				
2.5 Miscellaneous studies				Yes	No
If yes	*2.5.1 Lightning protection study*			Yes	No
	2.5.2 Electromagnetic compatibility			Yes	No
	2.5.3 Harmonic study			Yes	No
	2.5.4 Ferro-resonance study			Yes	No
	2.5.5 Geomagnetic induced current (GIC) study			Yes	No
	2.5.6 For each study, please mention any standard used				
	Any additional comments regarding 2.5 (Miscellaneous studies)				

3. Software tool used for the studies				
3.1 AC network			Yes	No
	3.1.1 Load flow	If yes, please mention the tool, the step (fixed or variable) and environment used		
	3.1.2 Transient studies		Yes	No
	• *Stability analyses*	If yes, please mention the tool, the time step (fixed or variable) and environment used		
	• *Slow Transient*	If yes, please mention the tool, the time step (fixed or variable) and environment used		
	• *Fast Transient*	If yes, please mention the tool, the time step (fixed or variable) and environment used		
	3.1.3 Short-circuit current		Yes	No
	• *MV*	If yes, please mention the tool and environment used		
	• *LV*	If yes, please mention the tool and environment used		
	3.1.4 Protection's co-ordination and selectivity studies		Yes	No
	• *Voltage study*	If yes, please mention the tool and environment used		
	• *Current study*	If yes, please mention the tool and environment used		
	• *Frequency study*	If yes, please mention the tool and environment used		
3.2 DC network and UPS			Yes	No
	3.2.1 Load flow	If yes, please mention the tool and environment used		
	3.2.2 Transitoires	If yes, please mention the tool and environment used		
	3.2.3 Calculs Icc	If yes, please mention the tool and environment used		
	3.2.4 Protection's co-ordination and selectivity studies		Yes	No
	• *Voltage study*	If yes, please mention the tool and environment used		
	• *Current study*	If yes, please mention the tool and environment used		
3.3 Miscellaneous studies			Yes	No
	3.3.1 Lightning protection study If yes, please mention the tool and environment used			
	3.3.2 Electromagnetic compatibility If yes, please mention the tool and environment used			

	3.3.3 Harmonic study *If yes, please mention the tool and environment used*				
	3.3.4 Ferro-resonance study *If yes, please mention the tool and environment used*				
	3.3.5 GIC study *If yes, please mention the tool and environment used*				
3.4 Qualification (refer to P016 "Verification of simulations tools") *You may duplicate this section if you are using different tools that require different answers.* Is the software tool you are using for your studies qualified?				Yes	No
	3.4.1 Functional verification			Yes	No
If yes	This functional verification				
		has been performed by the software designer ?		Yes	No
		can be demonstrated through certification or report of Quality Assurance		Yes	No
		Other (please specify)			
	3.4.2 Functional validation			Yes	No
If yes	This functional validation				
		has been performed by the engineers that are using the software ?		Yes	No
		can be done by comparing simulation results with			
			Theorical calculation	Yes	No
			Another verified and validated software tool	Yes	No
			Real tests	Yes	No
			Other (please specify)		
	3.4.3 Organisation to maintain the qualification			Yes	No
If yes	Do you have in your organisation a designated person who is:				
		Responsible for the qualification		Yes	No
		Responsible for the Use		Yes	No
		Other (please specify)			
	Any Additional comments regarding 3.4 (other practices for the qualification)				
3.5 Associated documentation You may duplicate this section if you are using different tools which require different answers. Is there any specific documentation associated to the software tool?				Yes	No
	3.5.1 User manual			Yes	No
If yes	written by				
	If yes	The software designer ?		Yes	No
		The engineers that are using the software ?		Yes	No

		Other (please specify)	Yes	No
	3.5.2 Note of methodology		Yes	No
If yes	written by			
	If yes	The engineers that are using the software ?	Yes	No
		Other (please specify)	Yes	No
	3.5.3 Note of assumptions		Yes	No
If yes	written by			
	If yes	The engineers that are using the software ?	Yes	No
		Other (please specify)	Yes	No
	3.5.4 Note of input dta		Yes	No
If yes	written by			
	If yes	The engineers that are using the software ?	Yes	No
		Other (please specify)	Yes	No
	3.5.5 Other documents (please specify)			

4. Models developed for transient studies of AC networks

If you are performing different types of studies (in the meaning of § 1.2.1, 1.2.2, 1.2.3), you may either: answer for you most significant study or as more appropriate duplicate the section or make a grouped answer.

4.1 Modelling Are you developing any model for transient studies of AC networks?			Yes	No
If yes	*4.1.1 Symmetrical*		Yes	No
	4.1.2 Asymmetric		Yes	No
4.2 Transmission system			Yes	No
If yes	• *Simplified model*		Yes	No
	If yes	Infinite bus	Yes	No
		Resistance	Yes	No
		Reactance	Yes	No
		Other (please specify)		
	• *Regional model*		Yes	No
	• *National Model*		Yes	No
	• *Other (please specify)*			
4.3 Turbo-generator set			Yes	No
If yes	*4.3.1 Generator*		Yes	No
	• *Park model*		Yes	No
	If yes	3 windings	Yes	No
		4 windings	Yes	No
	• *Other model (please specify)*		Yes	No
	• *Saturation*		Yes	No
	If yes	Saturated values	Yes	No

		Non-saturated values and no-load curve	Yes	No
	• *Other (please specify)*			
	4.3.2 Turbine		Yes	No
	• *Standard model*		Yes	No
	If yes	Precise references (IEEE, KTA, …)		
	• *Specific model*		Yes	No
	If yes	Developed by the supplier	Yes	No
		Developed by your engineers	Yes	No
		Developed from the physical equations	Yes	No
		Developed from real tests	Yes	No
	• *Shaft line model*		Yes	No
	If yes	the turbine and the generator are represented by a single mass model	Yes	No
		the turbine and the generator are represented by a multi-mass model	Yes	No
	• *Cylinder of the turbine*		Yes	No
	If yes	HP cylinder	Yes	No
		IP cylinder	Yes	No
		Other (please specify)		
	• *Superheater*		Yes	No
	• *Other (please specify)*			
	4.3.3 Valves control chain		Yes	No
	• *Standard model*		Yes	No
	If yes	Precise references (IEEE, KTA, …)		
	• *Specific model*		Yes	No
	If yes	Developed by the supplier	Yes	No
		Developed by your engineers	Yes	No
		Developed from the physical equations	Yes	No
		Developed from real tests	Yes	No
		HP valves	Yes	No
		IP valves	Yes	No
		Other (please specify)		
	• *fast valving*		Yes	No
	• *Other (please specify)*			
	4.3.4 Excitation system		Yes	No
	• *Excitation system type*		Yes	No
	If yes	Static	Yes	No
		Dynamic	Yes	No
		Other (please specify)	Yes	No
	• *Standard model*		Yes	No
	If yes	Precise references (IEEE, KTA, …)		
	• *Specific model*		Yes	No

	If yes	Developed by the supplier	Yes	No
		Developed by your engineers	Yes	No
		Developed from the physical equations	Yes	No
		Developed from real tests	Yes	No
	• *Excitation transformer*		Yes	No
	• *Other (please specify)*			
	4.3.5 Voltage regulation		Yes	No
	• *Standard model*		Yes	No
	If yes	Precise references (IEEE, KTA, …)		
		Power System Stabiliser	Yes	No
	• *Specific model*		Yes	No
	If yes	Developed by the supplier	Yes	No
		Developed by your engineers	Yes	No
		Developed from the design	Yes	No
		Developed from real tests	Yes	No
	• *Other (please specify)*			
	4.3.6 Speed regulation		Yes	No
	• *Standard model*		Yes	No
	If yes	Precise references (IEEE, KTA, …)		
	• *Specific model*		Yes	No
	If yes	Developed by the supplier	Yes	No
		Developed by your engineers	Yes	No
		Developed from the design	Yes	No
		Developed from real tests	Yes	No
	• *Other (please specify)*			
	4.3.7 Upstream turbine		Yes	No
	• *Standard model*		Yes	No
	If yes	Precise references (IEEE, KTA, …)		
	• *Specific model*		Yes	No
	If yes	Developed by the supplier	Yes	No
		Developed by your engineers	Yes	No
		Developed from the design	Yes	No
		Developed from real tests	Yes	No
	• *Other (please specify)*			
4.4 Standby AC power source or emergency generator			Yes	No
If yes	***4.4.1 Generator***		Yes	No
	• *Park model*		Yes	No
	If yes	3 windings	Yes	No

		4 windings	Yes	No
	• *Other model (please specify)*		Yes	No
	• *Modelling of the Saturation*		Yes	No
	If yes	Saturated values	Yes	No
		Non-saturated values and no-load curve	Yes	No
	• *Other (please specify)*			
	4.4.2 Diesel process		Yes	No
	• *Standard model*		Yes	No
	If yes	Precise references (IEEE, KTA, …)		
		Behavioural	Yes	No
		Thermodynamical	Yes	No
	• *Specific model*		Yes	No
	If yes	Developed by the supplier	Yes	No
		Developed by your engineers	Yes	No
		Developed from the physical equations	Yes	No
		Developed from real tests	Yes	No
		Behavioural	Yes	No
		Thermodynamical	Yes	No
	4.4.3 Combustion turbine process		Yes	No
	• *Standard model*		Yes	No
	If yes	Precise references (IEEE, KTA, …)		
		Behavioural	Yes	No
		Thermodynamical	Yes	No
	• *Specific model*		Yes	No
	If yes	Developed by the supplier	Yes	No
		Developed by your engineers	Yes	No
		Developed from the physical equations	Yes	No
		Developed from real tests	Yes	No
		Behavioural	Yes	No
		Thermodynamical	Yes	No
	4.4.4 Control chain of isolation valves		Yes	No
	• *Standard model*		Yes	No
	If yes	Precise references (IEEE, KTA, …)		
	• *Specific model*		Yes	No
	If yes	Developed by the supplier	Yes	No
		Developed by your engineers	Yes	No
	4.4.5 Excitation system		Yes	No
	• *Excitation system type*		Yes	No
	If yes	Static	Yes	No
		Dynamic	Yes	No
		Permanant magnet generator	Yes	No
		Other (please specify)		

	• *Standard model*		Yes	No
	If yes	Precise references (IEEE, KTA, …)		
	• *Specific model*		Yes	No
	If yes	Developed by the supplier	Yes	No
		Developed by your engineers	Yes	No
		Developed from the physical equations	Yes	No
		Developed from real tests	Yes	No
	• *Other (please specify)*			
	4.4.6 Voltage regulation		Yes	No
	• *Standard model*		Yes	No
	If yes	Precise references (IEEE, KTA, …)		
	• *Specific model*		Yes	No
	If yes	Developed by the supplier	Yes	No
		Developed by your engineers	Yes	No
		Developed from the design	Yes	No
		Developed from real tests	Yes	No
	• *Other (please specify)*			
	4.4.7 Speed regulation		Yes	No
	• *Standard model*		Yes	No
	If yes	Precise references (IEEE, KTA, …)		
	• *Specific model*		Yes	No
	If yes	Developed by the supplier	Yes	No
		Developed by your engineers	Yes	No
		Developed from the design	Yes	No
		Developed from real tests	Yes	No
	• *Other (please specify)*			
4.5	**Transformers**		Yes	No
If yes	***4.5.1 HV/MV***		Yes	No
	• *High frequency model*		Yes	No
	• *Low frequency model*		Yes	No
	• *Copper losses*		Yes	No
	• *Iron losses*		Yes	No
	• *Magnetising current*		Yes	No
	• *Short-circuit reactance*		Yes	No
	• *Short-circuit resistance*		Yes	No
	• *No-load tap changer*		Yes	No
	• *Tap changer (if any))*		Yes	No
	• *Tapping range of the tap changer (if any)*		Yes	No
	• *Saturation*		Yes	No
	• *Coupling between primary and secondary windings*		Yes	No
	• *Phase shift between primary and secondary windings*		Yes	No

	• *Coupling between secondary windings*		Yes	No
	• *Core confirguration*		Yes	No
		Shell type	Yes	No
		Core type		
	• *Earthing arrangement*		Yes	No
	• *Other (please specify)*			
	• *Input data*			
	Source	Theory	Yes	No
		Design	Yes	No
		Test report	Yes	No
		Other (please specify)		
	4.5.2 MV/LV and LV/LV		Yes	No
	• *High frequency model*		Yes	No
	• *Low frequency model*		Yes	No
	• *Copper losses*		Yes	No
	• *Iron losses*		Yes	No
	• *Magnetising current*		Yes	No
	• *Short-circuit reactance*		Yes	No
	• *Short-circuit resistance*		Yes	No
	• *No-load tap changer*		Yes	No
	• *Saturation*		Yes	No
	• *Coupling between primary and secondary windings*		Yes	No
	• *Phase shift between primary and secondary windings*		Yes	No
	• *Core confirguration*		Yes	No
		Shell type	Yes	No
		Core type		
	• *Earthing arrangement*		Yes	No
	• *Other (please specify)*			
	• *Input data*			
	Source	Theory	Yes	No
		Design	Yes	No
		Test report	Yes	No
		Other (please specify)		
4.6	**Lines or cables**		Yes	No
If yes	***4.6.1 HV***		Yes	No
	• *Line model*		Yes	No
	If yes	High frequency model	Yes	No
		Low frequency model	Yes	No
		Pi model	Yes	No
		Other (please specify)		
	• *Wave propagation*		Yes	No
	• *Magnetic coupling*		Yes	No
	• *Resistor*		Yes	No

	• *Inductor*		Yes	No
	• *Capacitor*		Yes	No
	• *Other (please specify)*			
	• *Input data*			
	Source	Theory	Yes	No
		Design	Yes	No
		Test report	Yes	No
		Other (please specify)		
	4.6.2 MV		Yes	No
	• *Cable or line model*		Yes	No
	If yes	High frequency model	Yes	No
		Low frequency model	Yes	No
		Pi model	Yes	No
		Other (please specify)		
	• *Magnetic coupling*		Yes	No
	• *Resistor*		Yes	No
	• *Inductor*		Yes	No
	• *Capacitor*		Yes	No
	• *Other (please specify)*			
	• *Input data*			
	Source	Theory	Yes	No
		Design	Yes	No
		Test report	Yes	No
		Other (please specify)		
	4.6.3 LV		Yes	No
	• *Cable model*		Yes	No
	If yes	High frequency model	Yes	No
		Low frequency model	Yes	No
		Pi model	Yes	No
		Other (please specify)		
	• *Resistor*		Yes	No
	• *Inductor*		Yes	No
	• *Capacitor*		Yes	No
	• *Other (please specify)*			
	• *Input data*			
	Source	Theory	Yes	No
		Design	Yes	No
		Test report	Yes	No
		Other (please specify)		
4.7 Auxiliaries			Yes	No
If yes	***4.7.1 Load type***			
	• *Rotating*		Yes	No
	• *static*		Yes	No

	• *Other (please specify)*			
	4.7.2 Induction motor MV		Yes	No
	• *Motor model*		Yes	No
	If yes	Simplified model (5 parameters)	Yes	No
		Complete model (including skin effect)	Yes	No
	• *Skin effect*		Yes	No
	If yes	Simple cage rotor with deep-bar rotor	Yes	No
		Double squirrel-cage rotor bars	Yes	No
	• *Flux decay*		Yes	No
	• *Switch from and to generator and motor mode*		Yes	No
	• *Saturation*		Yes	No
	• *Starting type*			
		Direct	Yes	No
		Wye-delta	Yes	No
		With power electronics device	Yes	No
	• *Inertia*		Yes	No
	• *Other (please specify)*			
	• *Input data*			
	Source	Theory	Yes	No
		Design	Yes	No
		Test report	Yes	No
		Other (please specify)		
	4.7.3 Induction motor LV		Yes	No
	• *Motor model*		Yes	No
	If yes	Simplified model (5 parameters)	Yes	No
		Complete model (including skin effect)	Yes	No
	• *Skin effect*		Yes	No
	If yes	Simple cage rotor with deep-bar rotor	Yes	No
		Double squirrel-cage rotor bars	Yes	No
	• *Flux extinction*		Yes	No
	• *Switch from and to generator and motor mode versa*		Yes	No
	• *Saturation*		Yes	No
	• *Starting type*			
		Direct	Yes	No
		Wye-delta	Yes	No
		With power electronics device	Yes	No
	• *Inertia*		Yes	No
	• *Other (please specify)*			
	• *Input data*			
	Source	Theory	Yes	No
		Design	Yes	No
		Test report	Yes	No

		Other (please specify)		
	4.7.4 Load of motors		Yes	No
	• *Inertia*		Yes	No
	• *Resistive torque Tr*		Yes	No
	If yes	Tr = k x N² Fonction of the square of the speed	Yes	No
		Constant Tr = K	Yes	No
		Other (please specify)		
	• *Coupling*		Yes	No
	• *Mechanical gear*		Yes	No
	• *Inertia storage*		Yes	No
	• *Other (please specify)*			
	• *Input data*			
	Source	Theory	Yes	No
		Design	Yes	No
		Test Report	Yes	No
		Other (please specify)		
	4.7.5 Statics loads		Yes	No
	• *Load type*		Yes	No
		Impedance	Yes	No
		Constant power	Yes	No
		Other (please specify)		
	• *Evolution of the active and reactive power*		Yes	No
	If yes	As a function of voltage	Yes	No
		Other (please specify)		
	• *Other (please specify)*			
	• *Input data*			
	Source	Theory	Yes	No
		Design	Yes	No
		Test report	Yes	No
		Other (please specify)		
4.8 Level of detail of the single-line diagram of AC networks				
	4.8.1 MV		Yes	No
	• *Lines*		Yes	No
	If yes	All	Yes	No
		Partly	Yes	No
	• *Transformers*		Yes	No
	If yes	All	Yes	No
		Grouped (equivalent transformer)	Yes	No
	• *Buses*		Yes	No
	If yes	All	Yes	No
		Grouped (equivalent bus)	Yes	No
	• *Motors*		Yes	No

	If yes	All	Yes	No
		Grouped (equivalent motor)	Yes	No
	• *Static loads*		Yes	No
	If yes	All	Yes	No
		Grouped (equivalent static load)	Yes	No
	• *Other (please specify)*			
	4.8.2 LV		Yes	No
	• *Cables*		Yes	No
	If yes	All	Yes	No
		Partly	Yes	No
	• *Transformers*		Yes	No
	If yes	All	Yes	No
		Grouped (equivalent transformer)	Yes	No
	• *Buses*		Yes	No
	If yes	All	Yes	No
		Grouped (equivalent buses)	Yes	No
	• *Motors*		Yes	No
	If yes	All	Yes	No
		Grouped (equivalent motor)	Yes	No
	• *Static loads*		Yes	No
	If yes	All	Yes	No
		Grouped (equivalent static load)	Yes	No
	• *Other (please specify)*			

5. Models developed for transient studies of DC and UPS networks

If you are performing different types of studies (in the meaning of § 1.2.4, 13.1, 1.3.2), you may either: answer for you most significant study or as more appropriate duplicate the section or make a grouped answer.

5.1 Modelling Are you developing any model for transient studies of DC and UPS networks?			Yes	No
	5.1.1 Symmetrical		Yes	No
	5.1.2 Asymmetrical		Yes	No
5.2 Upstream network (AC)			Yes	No
If yes	• *Simplified model*		Yes	No
	If yes	Infinite bus	Yes	No
		Resistance	Yes	No
		Reactance	Yes	No
		Other (please specify)		
5.3 Models			Yes	No
	5.3.1 Inverter / UPS		Yes	No

	• *Standard model*		Yes	No
	If yes	Precise references (IEEE, KTA,…)		
		Behavioural	Yes	No
	• *Specific model*		Yes	No
	If yes	Developed by the supplier	Yes	No
		Developed by your engineers	Yes	No
		Behavioural	Yes	No
		Developed from the design	Yes	No
		Developed from real tests	Yes	No
	5.3.2 Rectifier		Yes	No
	• *Standard model*		Yes	No
	If yes	Precise references (IEEE, KTA,…)		
		Behavioural	Yes	No
	• *Specific model*		Yes	No
	If yes	Developed by the supplier	Yes	No
		Developed by your engineers	Yes	No
		Behavioural	Yes	No
		Developed from the design	Yes	No
		Developed from real tests	Yes	No
	5.3.3 Battery		Yes	No
	• *Standard model*		Yes	No
	If yes	Precise references (IEEE, KTA,…)		
		Behavioural	Yes	No
	• *Specific model*		Yes	No
	If yes	Developed by the supplier	Yes	No
		Developed by your engineers	Yes	No
		Developed from the design	Yes	No
		Developed from real tests	Yes	No
		Behavioural	Yes	No
5.4 Cable				
	• *Cable model*		Yes	No
	If yes	Pi model	Yes	No
		Other (please specify)		
	• *Resistance*		Yes	No
	• *Inductance*		Yes	No
	• *Capacitance*		Yes	No
	• *Input data*			
	Source	Theory	Yes	No
		Design	Yes	No
		Test report	Yes	No
		Other (please specify)		

5.5 Auxiliaries			Yes	No
	5.5.1 Load type		Yes	No
	• *Rotating*		Yes	No
	• *Statics*		Yes	No
	• *Other (please specify)*			
	5.5.2 Motor DC		Yes	No
	• *Motor model*		Yes	No
	If yes	Simplified model	Yes	No
		Complete model	Yes	No
	• *Inertia*		Yes	No
	• *Other (please specify)*			
	• *Input data*			
	Source	Theory	Yes	No
		Design	Yes	No
		Test report	Yes	No
		Other (please specify)		
	5.5.3 Load of motor		Yes	No
	• *Inertia Inertie*		Yes	No
	• *Resistive torque Tr*		Yes	No
	If yes	Tr = k x N^2 Fonction of the square of the speed	Yes	No
		Constant Tr = K	Yes	No
		Other (please specify)		
	• *Coupling*		Yes	No
	• *mechanical gear*		Yes	No
	• *Other (please specify)*			
	• *Input data*			
	Source	Theory	Yes	No
		Design	Yes	No
		Test report	Yes	No
		Other (please specify)		
	5.5.4 Statics load		Yes	No
	• *Load type*		Yes	No
		Impedance	Yes	No
		Constant power	Yes	No
		Other (please specify)		
	• *Evolution of the active and reactive power*		Yes	No
	If yes	As a function of voltage	Yes	No
		As a function of frequency	Yes	No
		Other (please specify)		
	• *Other (please specify)*			
	• *Input data*			
	Source	Theory	Yes	No
		Design	Yes	No

		Test reports	Yes	No
		Other (please specify)		
5.6	**Level of detail of the single-line diagram of DC and UPS networks**			
	• *Cables*		Yes	No
	If yes	All	Yes	No
		Partly	Yes	No
	• *Buses*		Yes	No
	If yes	All	Yes	No
		Grouped (equivalent bus)	Yes	No
	• *Motors*		Yes	No
	If yes	All	Yes	No
		Grouped (equivalent motor)	Yes	No
	• *Static loads*		Yes	No
	If yes	All	Yes	No
		Grouped (equivalent static load)	Yes	No
	• *Other (please specify)*			

6. General comments

Any general comment?

Congratulations, you finally reached the end of the questionnaire, thank you!