GRID INTERFERENCE ON OPERATIONS

RAPPORT 2015:132

NUCLEAR

Energiforsk

Grid interference on operations

Mapping of R&D needs

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ISBN 978-91-7673-132-1 | © 2015 ENERGIFORSK

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Preface

Disturbances in the external grid can occasionally affect the onsite power system in nuclear power plants. In this study, interviews with experts at Swedish and Finnish nuclear power plants, The Swedish Radiation Safety Authority and Svenska Kraftnät (National Grid) have been conducted to identify R&D needs within external grid disturbances. The study has been conducted by Erica Lidström, Daniel Wall and Jonas Persson at Vattenfall AB.

A reference group consisting of Ari Kanerva from Fortum, Ismo Sandback from TVO, Jonas Jönsson from OKG, Magnus Knutsson from Ringhals, Per Lamell and Thomas Smed from Forsmark have assisted in the project.

The feasibility study has been financed by the stakeholders of the Energiforsk Nuclear Energy Research program:

Sammanfattning

Syftet med denna förstudie är främst att uppmärksamma störningar som uppkommer i det yttre nätet och som negativt påverkar det interna nätet vid kärnkraftverk. Interna störningar är också beaktade men har inte varit främsta fokus. Utifrån intervjuer och en workshop med representanter från kärnkraftverken i Oskarshamn, Olkiluoto, Forsmark och Ringhals har fem prioriterade områden identifierats för fortsatt samarbete.

Nedan följer titlar och prioritering av de områden som har bedömts vara signifikanta:

- Kartläggning av störningar som uppkommit i det yttre nätet med fokus på motverkande vidtagna insatser
- Subsynkron resonans samt modellerande och simuleringar
- Kartläggning av nya typer av elektriska komponenter samt jämförelse med befintliga installerade komponenter
- Kartläggning av metoder för att verifiera att de yttre jordlinenäten vid kärnkraftverken är intakta
- Generisk modell för de nordiska kärnkraftverken för att studera ledningsbundna åskincidenter

Resultatet av förstudien ska främja ett samarbete mellan kärnkraftverken för att undvika att var och en för sig arbetar med respektive område. Dessutom kan resultatet förväntas blir mer omfattande och användbart om flera aktörer får möjlighet att påverka vad som ska undersökas samt hur arbetet ska utföras. För att ytterligare bredda perspektivet på förstudien har även Strålsäkerhetsmyndigheten och Svenska Kraftnät intervjuats, dock har uppgiftsprioriteringen skett endast med hjälp av representanter från kärnkraftverken.

Energiforsks områdesstyrelse Kärnkraft kommer slutligen att besluta om något eller några av de identifierade områdena lämpar sig för fortsatt arbete och hur detta ska genomföras.

Summary

The purpose of this study is primarily to pay attention to external disturbances affecting the onsite power system in the nuclear power plants. Internal disturbances are also considered but are not the primary focus. Five priority areas have been identified for further cooperation on the basis of interviews and a workshop with representatives from the nuclear power plants in Oskarshamn, Olkiluoto, Forsmark and Ringhals.

Below follows the titles and prioritization of the tasks that have been identified as significant for further work:

- Survey of operational events from the offsite power system with focus on retrofit of mitigating actions
- Subsynchronous resonance phenomenon and modelling combined with hybrid simulations
- Survey on new electrical devices with different technology compared to existing electrical devices
- Survey of methodologies to verify that the outer grounding line network in the nuclear power plants is intact
- Generic lightning model of the Nordic nuclear power plants to study lightning incidents due to conducting

The results of this pre-study will encourage cooperation between the nuclear power plants to avoid individual work within each area. In addition, the results are expected to become more comprehensive and useful if several actors have the opportunity to influence what to include in each task and how the work should be performed. To further broaden the perspective of the pre-study, also the Swedish Radiation Safety Authority (Strålsäkerhetsmyndigheten) and the Swedish TSO (Svenska Kraftnät) have been interviewed. However, the list of the identified tasks have been prioritized only with the support of the representatives from the nuclear power plants.

Finally, the Energiforsk Research Area Board Nuclear will decide if any of the identified areas are suitable for further work and how this could be implemented.

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1 Introduction

1.1 Background

Energiforsk have an annual strategy meeting with the Research Area Board Nuclear. The intention is to look ahead and discuss what new areas to explore in the near future. At the previous meeting in August 2014, impact of disturbances in the offsite power systems on the onsite power system was discussed. It turned out that Vattenfall also had conferred the issue previously. Therefore it was decided to run the pre-study within Energiforsk and also include other actors in the field instead of running it as an internal study within Vattenfall. Thus, Energiforsk wants to create a forum where representatives of the nuclear power plants in Oskarshamn, Olkiluoto, Forsmark and Ringhals can come together to map mutual needs, highlight issues and suggest potential cooperation areas between the nuclear power plants.

The project is defined as a pre-study for upcoming activities generated within this forum. In order to support the pre-study and ensure the quality of the work a reference group was established consisting of representatives from the four nuclear power plants in the forum.

1.2 Purpose

The objective of the pre-study is to find synergies, concerns and cooperation areas related to external disturbances affecting the onsite power system in the Nordic nuclear power plants in order to form tasks for further work. Additionally, Energiforsk will be provided with an overall description of each task in order to decide if some of them are suitable for further work. The outcome of the pre-study will hopefully avoid overlapping of activities performed within this area by the participating nuclear power plants.

1.3 Method

Initially, a form with questions covering areas of interest was developed in consultation with the reference group. The following topics are handled in the form: grid code, transformers, disturbances and analysis, relay protection and components.

Thereafter, interviews with representatives from the nuclear power plants were performed at each plant. The questions in the form were discussed in detail to identify the needs experienced by the power plants. To get a more extensive documentation and a broader perspective of the project, also the Swedish Radiation Safety Authority (Strålsäkerhetsmyndigheten) and the Swedish TSO (Svenska Kraftnät) have been interviewed.

After summarizing the answers from each interview, potential cooperation areas were discerned. Subsequently, a workshop was held in Stockholm where each potential cooperation area were presented followed by discussions in the reference group. During the workshop the most prioritized tasks were highlighted. Further on, each highlighted task is described in more details to be presented at the Energiforsk Research Area Board in March 2015.

2 Results

2.1 Identified task and overall descriptions

During the workshop five individual tasks were identified by the reference group as the most important areas for further work. Moreover, in this chapter each prioritized task is described in more details and suggestions on what the final report for each task should include is outlined.

The title and prioritizing of each task is as follows:

- Survey of operational events from the offsite power system with focus on retrofit of mitigating actions
- Subsynchronous resonance phenomenon and modelling combined with hybrid simulations
- Survey on new electrical devices with different technology compared to existing electrical devices
- Survey of methodologies to verify that the outer grounding line network in the nuclear power plants is intact
- Generic lightning model of the Nordic nuclear power plants to study lightning incidents due to conducting

2.1.1 Survey of operational events from the offsite power system with focus on retrofit of mitigating actions

The aim of this investigation is to provide power plants with information of relevant disturbances that is needed to handle and to support the actors involved in the decision process with a toolbox of mitigating actions. The toolbox will handle the impact of disturbances and also the possibility how to reduces the exposure. The mitigating actions should also be suitable for retrofitting in an existing plant.

The first phase of the project is to summarize events that has occurred around the world with some emphasis on events in Sweden and Finland. Previous work in this area such as DIDELSYS and ROBELSYS should be utilized in order to make this phase more efficient. After collecting the data, an assessment of the most relevant types of disturbances should be performed and impact on vital equipment in the plants should be compiled.

The second phase of the project is to assemble mitigating countermeasures that have been retrofitted into existing plants. Examples of such mitigating measures could be adjustment or modification of relay protection, but it could also include more ambitious countermeasures such as new sources of electrical power supply or insulating devices such as motor generator sets or power electronic devices etc.

Subjects to be covered in a final report include:

- Description of relevant disturbances
- Root cause for the disturbances
- Impact of the disturbance
- Lessons learned and implementation of mitigating measures

2.1.2 Subsynchronous resonance phenomenon and modelling combined with hybrid simulations

Subsynchronous Resonance Phenomenon
Subsynchronous resonance (SSR) is not a single phenomenon, but can be divided into three types.

- Induction generator effect (IGE)
- Torsional interaction (TI)
- Torque amplification (TA)

In 1970 and -71 the Mohave generator in Nevada, USA, experienced a gradually growing vibration that eventually led to a fracture of the shaft section between the generator and the rotating exciter. Investigations determined that an electrical resonance at 30.5 Hz produced a torque at 29.5 Hz (the 60 Hz compliment frequency, 60–30.5 = 29.5 Hz), which interacted with one of the torsional modes of the turbine-generator shaft at 30.1 Hz. The phenomenon was identified as an interaction between the series capacitors in the network and torsional system. It came to be known as “subsynchronous resonance” or SSR.

Induction generator effect is a purely electrical phenomenon that is due to the fact that, when subsynchronous currents flow in the armature circuit of a synchronous generator, the generator appears as a negative-resistance circuit at the prevailing subsynchronous frequencies. If the apparent negative resistance is greater than the inherent positive resistance of the circuit at one of the natural frequencies of the electrical circuit, growing subsynchronous voltages and currents will be expected in the system and in the generator.

Torsional interaction is an interaction and exchange of energy between the series compensated electrical system and the spring-mass mechanical system. It can lead to growing shaft torque oscillations at one of the natural mechanical frequencies of the turbine-generator spring-mass system. Torsional interaction can occur when the generator is connected to a series compensated electrical system that has one or more natural frequencies (resonance frequencies in the grid), which are the synchronous frequency complements of one or more of the spring-mass natural frequencies.

Torque amplification refers to the phenomenon that occurs when a fault on a series compensated power system, and its subsequent clearing, results in high-energy storage in series capacitor banks. The energy discharge through a generator is in the form of a current having a frequency that corresponds to one of the natural frequencies of the turbine-generator spring-mass system. Unlike torsional interaction and induction generator effect, the growth rate for torque amplification is high.

Forsmark 3 has a SSR protection which has been successively included with new parameter value after renewal of the low-pressure turbine. At the outage in 2015 a new protection equipment will be installed with new parameter value because of a new generator and high-pressure turbine.

The aim of this project is to increase the knowledge of the subject at the Nordic power plants and study if it can be a problem depending on location of series capacitor and critical torsional modes.

Modelling and Hybrid Simulations
A Canadian consultancy business[1] have developed a set of tools applicable to PSCAD and PSS/E. The first tool, E-TRAN, is a software that converts PSS/E models to PSCAD models and also large part of the standard dynamic models that comes with PSS/E. There are two add-ons to E-TRAN that quite recently were released.

The first one is E-TRAN Plus for PSS/E and is basically an interface to PSS/E which provides several possibilities.

- Having a part of a PSS/E model in PSCAD allowing for more detailed modelling of that part. The simulation is then run from PSCAD. Several “PSCAD-islands” may exist.
- Using it only as an interface between two PSS/E models for example Norway and Sweden or Sweden and Ringhals (then Ringhals is not included in the model of Sweden). Additionally, the different PSS/E models can be run in different PSS/E versions.
- The models do not need to exist on the same computer.

The second is E-TRAN Plus for PSCAD and allows for breaking up PSCAD models into several smaller models which then can be run on the same computer or different computers within the same network.

An interesting feature is named “Multi-Vendor Simulation Setup” by Electranix. It allows models from different parties (for example wind turbines and HVDC connection) to be used in the same simulation, but the performer running the simulation only sees the parts of the model that he/she has access to. The only feature that is visible from other models is the interaction with the rest of the system.

If Ringhals as an example would like to study their plants interaction with the Nordic power system a possible setup would be that Ringhals has a model of their plant on one computer and SvK has a computer containing the Nordic system except Ringhals. The computers need to be connected to the same computer network but Ringhals cannot see SvK’s model, only how it interacts with the model of Ringhals.

This concept could allow nuclear power plants studying their interaction with the rest of the system, which is not possible today due to security issues for SvK’s model. This means that today SvK needs to do many of the studies which can be time consuming. Currently, the presented simulation set-up can only be used with PSS/E. Perhaps the possibility to develop the same functionality between other simulation softwares can be investigated.

[1] Electranix Corporation, http://www.electranix.com/, accessed 030915

Subjects to be covered in a final report include:

- Describe phenomenon and what technical information needed to do SSR calculations.
- Determine if the network include any critical frequency/electrical resonance
- Present how the turbine-generator critical frequencies/torsional modes can be calculated
- Evaluate and conclude the study, also what to proceed with.

2.1.3 Survey on new electrical devices with different technology compared to existing electrical devices

A nuclear power plant consists of a large number of electrical devices. Due to a long–term operation expectancy of a nuclear power plant a lot of equipment needs to be replaced one or several times during the life time of the plant. As a natural progress, development of electrical equipment is constantly ongoing. This implies that the new equipment not only may have a different design but also a different technology and thus different electrical behavior. It can be challenging to get an overview of how well the properties of new equipment interact with the existing electrical power system and of the alternatives available on the market.

The project aims to gain a better knowledge of what the market offers regarding certain types of equipment, such as circuit breakers, and what equipment that is preferable. This will denote that future changes of specific equipment can be done with better knowledge of the individual behavior and characteristics in the plant.

The project shall investigate the alternatives and characteristics of several types of equipment. What equipment to include in the survey shall be decided in the initial stage of the project, primarily through literature studies from both a technical and an economical perspective and specific needs from the operating nuclear power plants.

Subjects to be covered in a final report include:

- Results from literature study/benchmark
- Description of which equipment is included in the survey such as circuit breakers, surge arresters etc.
- Sources used for the survey
- Pros and cons for technologies within each type of equipment category
- Conclusions and recommendations

2.1.4 Survey of methodologies to verify that the outer grounding line network in the nuclear power plants is intact

The grounding line network in nuclear power plants consists of an outer and an inner grounding line network. The outer grounding line network is mainly placed in the ground and is therefore not possible to easily check, test and verify. The inner network is installed on cable ladders and trays in all cable raceways throughout the different units. A methodology to verify that the design is working properly is an area where additional knowledge needs to be added. Specific requirements regarding grounding and connection to the grounding network of the power plant are specified in specific installation instructions.

The outer grounding line network consists of bare copper conductors, located in a grid pattern in the ground. The grounding network covers the total area of the nuclear power plant including the switchyards. A number of additional grounding conductors are also located in the cooling water intake ducts. The network is in several locations connected to down conductors coming from the buildings (every 5-20 m). At many locations there are also connections to building reinforcement.

The objective of the task is to study methodologies investigating to what extent the outer grounding line network might have deteriorated due to the environment in the ground as well as the water. Focus for the survey is to analyze procedures for the copper conductors but also analyzing any degradations of the joints between different conductors/sections in the network. The intention of the project is also to make recommendations of one or several appropriate method. Additional, if possible, field studies could be performed in Barsebäck if well suited within the scope.

If the corresponding grounding system in Barsebäck is designed in the same way, several tests regarding the condition of the grounding line network could be performed in connection with the dismantling of the power plant which has been shut down. In Ringhals there are both joints performed with C clamps and welded connections (Cadweld or similar). Hence it would be desirable to examine both types if they exist in Barsebäck. Thereafter, the tests on-site in Barsebäck would hopefully give valuable knowledge how to make adequate assessments/statements of the condition on the grounding line network in other nuclear power plants with similar grounding design.

As a second stage of the task the internal grounding line network could be studied. It would also be interesting to have a methodology to verify that individual connections still have low transition impedance.

Subjects to be covered in a final report include:

- Results from literature study/benchmark
- Description of the grounding line network in the Nordic power plants
- Description of relevant methodologies
- Results from the on-site tests in Barsebäck
- Lessons learned from Barsebäck which can be applied on other nuclear power plants
- Recommendation of an appropriate testing method to be used for the earth grid evaluation

2.1.5 Generic lightning model of the Nordic nuclear power plants to study lightning incidents due to conducting

A power system will inevitably be subjected to transient overvoltages, as lightning strikes. The lightning strike has different frequency and magnitude. The main types of lightning strikes are:

- Positive first strike
- Negative first strike
- Negative subsequent strike

These transients overvoltages may harm sensitive equipment without sufficient protection. It can also have negative consequences as thermal demolitions, fire, melting, electrodynamic effects, forces, isolation damage, danger for employees, eletromagnetic influence, failures etc. In the end it will influence the availability and reliability of the technical facilities.

By making a lightning model of the plant it is possible to check stress due to overvoltage at all points in the plant for different types and location of lightning strikes in the external grid. In this case, practical tests in the real power system is impossible. The result of the simulations can be evaluated towards different withstand voltage of the components, which is standard manufacture tests performing for example lightning impulse test, switching impulse test etc. Also to be evaluated is the possibility of standing waves in the system, which can largely influence the overvoltages. Additionally, the transfer function and models for frequency range up to 5 MHz is mostly unknown.

The different components to be modelled are:

- The lightning strike itself
- Overhead lines and towers
- Insulators
- Surge arrester with the cable to ground connection
- Transformers, generators and motors
- Cables and ducts

The approach of the task is to:

- Define the position for the lightning with highest impact (most sensible point). Both in the main grid and the start-up grid. The study must also include how the lightning will strike at the external grid in the overhead power lines.
- Creation of component models, valid in a high frequency range up to 5 MHz.
- Put together the component models to develop a complete plant model.
- Formation of only one (generic) model to reduce the amount of analyses, which has to represent all Nordic nuclear power plants.
- Implementation of the generic plant model into a software program.
- Performing simulations and find out the worst case scenarios depending on the type of lightning strikes etc.
- The result is a high frequency voltage transient, that present the maximum voltage stress (peak and duration) after a lightning strike. Furthermore, a discussion of the results will be presented.

Subjects to be covered in a final report include:

- Description of the installed safety devices handling overvoltage in case of a lightning strike
- Description of the use case defined for the simulations
- A generic model for analysis of lightning including description of each component
- Results from the simulations
- Recommendations of improvements regarding the results gained

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