IAEA Nuclear Technology Review 2009
Attachment 5

Interfacing Nuclear Power Plants with the Electric Grid: the Need for Reliability amid Complexity

A. Introduction

For a country that does not yet use nuclear power, the introduction and development of nuclear power is a major undertaking. It requires the country to build the necessary infrastructure so it can construct and operate a nuclear power plant (NPP) in a safe, secure and technically sound manner. A major part of the necessary infrastructure is the electric grid to which the NPP will connect. While most countries already have an electric grid system, it may require significant development to be suitable for the connection of an NPP. The safe, secure and reliable operation of the NPP requires that the grid to which it connects is also safe, secure and reliable. This paper explains the characteristics of the electric grid, its relationship with the NPP, and the reasons that a reliable grid is so important to the NPP.

The grid is the electrical highway through which all electricity traffic passes as it moves energy from the supplier (‘generation’) to the customer (‘load’). Interconnected electric grids can encompass several countries and are probably the largest machines in the world. They consist of hundreds of power suppliers, thousands of kilometres of transmission and distribution lines and millions of different electrical loads. Rapid economic development in the 20th century made the electric grid system a critical part of the economic infrastructure in industrialized countries and a permanent feature of the landscape.

NPPs are unique and powerful generators compared to other electricity generating plants. Moreover, they are both electricity generators and customers. They thus maintain a symbiotic relationship with the electric grid at all times. NPPs supply large amounts of energy to the grid as well as relying on it to receive power for crucial safety operations, especially during emergency conditions. The safe startup, operation and shutdown of NPPs require a reliable and stable power supply from the electric grid, referred to generally as ‘off-site power’.

The grid does much more than transport electricity from the power plant to customers. A reliable, balanced and well maintained electric grid is crucial for bringing new nuclear power plants online and operating them both safely and cost-effectively. In particular, the grid plays an important safety role by providing a reliable source of electricity to power the plant’s cooling system to keep nuclear fuel cool after a reactor has been shut down (although NPPs also have on-site back-up power available for emergency situations). The fewer instabilities and interruptions there are in NPP–grid interactions, the more productively and consistently the NPP can supply full power to consumers. Siting decisions must therefore take into account the local grid conditions and usage, and, because of the grid’s role in plant safety as well as plant economics, integration of NPPs into an electric grid poses a complex set of regulatory as well as engineering challenges.

Countries expanding or introducing nuclear power programmes are advised to consider their electric grids as part of their planning process, particularly as the grid impacts the size and type of reactor that can be deployed. Specific issues that should be considered in the early phases of a nuclear power programme include grid capacity and future growth, historical stability and reliability, and the potential for local and regional interconnections. Assessment of the current grid and plans for improving the grid should therefore be developed to be consistent with plans for nuclear power.

B. Vulnerability of the Electric Grid

The grid must maintain a precise frequency of alternating current; a relatively small imprecision can cause disproportionate damage. The electric power received at a house or a factory is the result of hundreds of distant, widely dispersed generators sending electricity through a maze of circuits, wires and transformers, and under varying weather conditions, at a single synchronized precise frequency without missing a beat.

Section G.1 describes how such synchronization is normally maintained, but this section outlines what can happen when things go wrong. Even a well balanced grid is subject to events that can potentially lead to large scale disturbances or even to a collapse of the grid if the grid operates near its capacity with no margin for faults. A small shift of power flows caused by a sudden increase or decrease of electricity generation or the load can trip protective circuit breakers which send larger power flows to neighbouring power lines, possibly triggering a chain reaction of failures.

The grid systems in developed countries are normally designed and operated with a contingency margin. That is, they are operated so that no single fault on the system can lead to unacceptable problems such as abnormal voltage, abnormal frequency or disconnection of demand. However if this margin is not maintained, or multiple faults happen close together in time, a major failure can still occur.

Much of the north-eastern United States of America and part of Canada were plunged into darkness in August 2003 when a disruption in the electric grid’s intricate balance caused a massive blackout (Figure V-1). This was an example of cascading events resulting in the complete shutdown of the grid. The blackout affected an estimated 10 million people in Ontario and 40 million people in eight US states.

The collapse of the grid was caused in this case by a combination of human errors and technical challenges: power plant outages, overextended controllers, transmission line failures, the overheating of alternate transmission lines causing lines to sag into trees, an insufficient ability to repair or replace sensors and relays quickly, poor maintenance of control room alarms, poor communications between load dispatchers and power plant operators, insufficient understanding of transmission system interdependencies, and the grid operating very near its transmission capacity. As a consequence, nine NPPs in the USA and eleven NPPs in Canada were disconnected from the grid because of electrical instabilities.

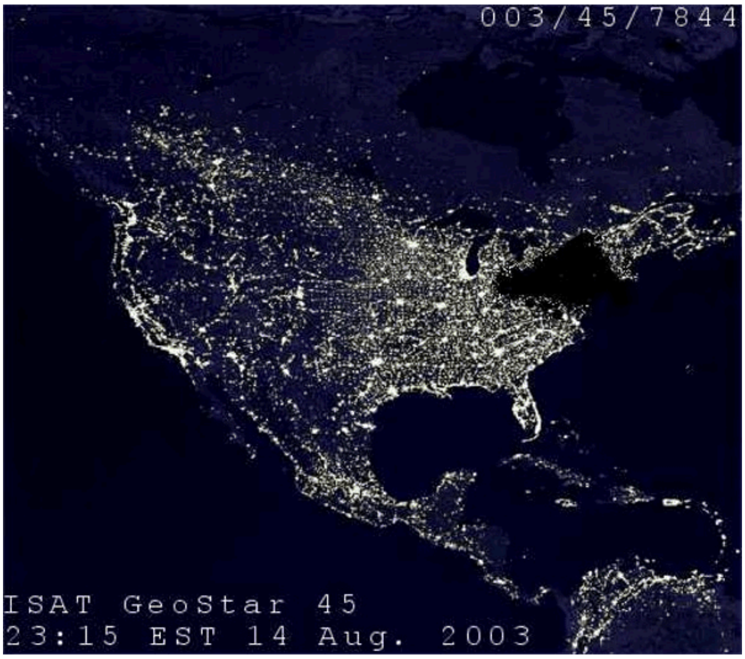


FIG. V-1. Blackout in the north-eastern USA and Ontario, Canada, August 2003 (not an actual satellite photo)

The North American blackout was in fact only one of seven blackouts in a six-week period in 2003 that affected more than 120 million people in eight countries: Canada, Denmark, Finland, Italy, Malaysia, Sweden, UK and USA. In Sweden, in September, a nuclear power plant tripped (i.e. rapidly shut down), resulting in the loss of 1200 MW(e) to the grid. Five minutes later a grid failure caused the shutdown of two units at another nuclear power plant with the loss of a further 1800 MW(e). To respond to this loss of 3000 MW(e) (about 20% of Sweden's electricity consumption) the grid operators isolated the southern Sweden–eastern Denmark section of the grid, but the voltage eventually collapsed due to the insufficient power supply. At the time of the original reactor trip two high-voltage transmission lines and three links to neighbouring countries were out of service for normal maintenance work and four nuclear units were off-line for annual overhauls. Their unavailability severely limited the options of the grid operators.

Electric grids are also vulnerable to natural disasters such as tornadoes, hurricanes, earthquakes and ice storms. One well known example is the North American ice storm of 1998. In January 1998, a massive ice storm struck a relatively narrow area from eastern Ontario via southern Quebec to Nova Scotia in Canada as well as bordering areas from northern New York to south-eastern Maine in the USA. Freezing rain coated the area with 7–11 cm of ice. It caused massive damage to trees and power lines throughout the area, leading to widespread long term power outages (Figure V-2). Trees and electrical wires fell, and utility poles and transmission towers came down causing massive power outages, some for as long as a month. It was the most expensive natural disaster in Canada. Over four million people in Ontario, Quebec and New Brunswick lost power. 130 power transmission towers were destroyed, and more than 30 000 utility poles fell.

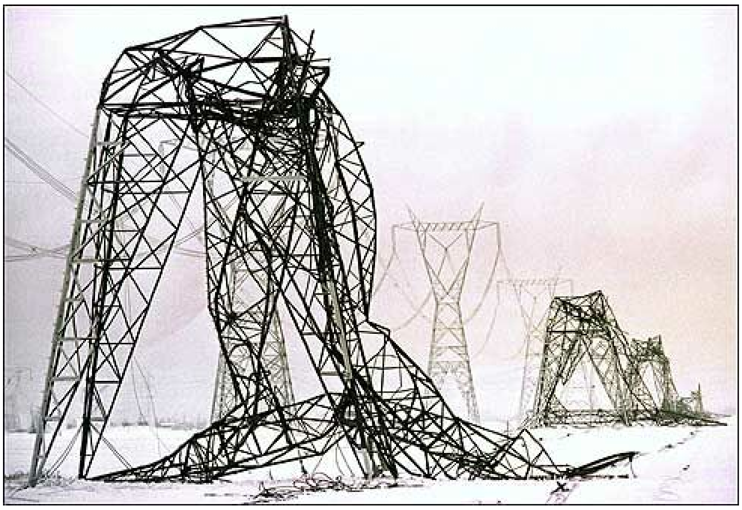


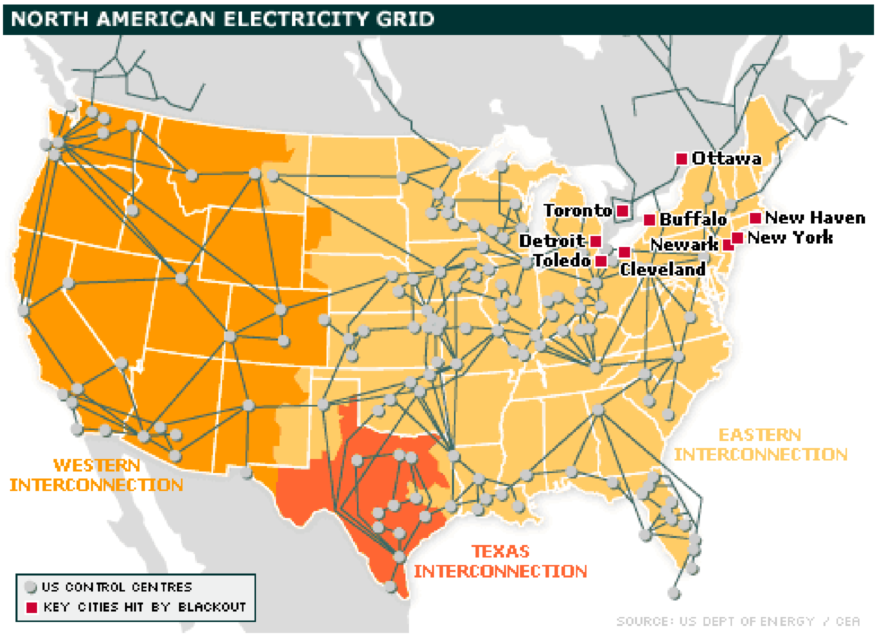
FIG. V-2. Freezing rain caused extensive damage to transmission lines in Quebec, Canada, January 1998

C. Structure of the Electric Grid

The electric grid consists of two separate infrastructures. The electric power lines that are most visible are the high voltage transmission system carrying electricity for large distances with relatively low current. Electricity is generated by power plants at a relatively low voltage (ranging from 2 kV to 50 kV, depending on the size of the power station) and must be transformed into high voltage electricity by step-up transformers at the stations' switchyards. The high voltage (from 100 kV to 800 kV) allows the transmission lines to carry electric power at low current, therefore minimizing electrical losses over long distances. Losses in electricity are generally due to the electrical resistance and consequent heating of the cables. Typical losses for the UK and USA are around 7% of the energy passed through the transmission and distribution networks.

The second system is the low voltage distribution system that draws electricity from the high voltage transmission lines and distributes it to individual customers. At the interface between the high voltage transmission lines and the distribution systems, an electrical substation uses transformers to 'step down' the transmission line voltage to the lower voltage of the distribution system. Substations also include electrical switches and circuit breakers to protect the transformers and the transmission system from electrical failures on the distribution lines. Transformers are located along the distribution lines to further step down the line voltage for household use (120 V to 380 V) and are protected by circuit breakers that locally isolate electrical problems, such as short circuits caused by downed power lines.

The transmission grid, with multiple generating stations and distribution system connections, functions as one entity potentially stretching for thousands of kilometres. Physically and administratively divided smaller networks are often connected together forming a large electric grid. For example, in North America there are three loosely coupled networks covering the USA and Canada (Figure V-3). Within each network, power flows through alternating current (AC) lines, and all power generators are tightly synchronized to the same cycle in terms of frequency. The three networks are joined by transmission lines carrying direct current (DC), so the coupling and the need for frequency and phase synchronization are more relaxed than within the individual networks. The capacity of the DC transmission lines connecting the networks is also much less than that of the AC transmission lines within them.



SOURCE: US DEPT OF ENERGY / CEA

FIG. V-3. Electric grids covering the USA and Canada

In North America, prior to electricity deregulation, regional and local electric utilities were regulated vertical monopolies. A single company controlled electricity generation, transmission, and distribution in a given geographical area. Each utility generally maintained sufficient generation capacity to meet its customers' needs in its service area, and long distance energy shipments were usually reserved for emergencies, such as unexpected generation outages and transmission line failures. In essence, the long range connections served as insurance against a sudden loss of power. This limited the use of long distance connections to aid system reliability because the physical complexities of power transmission rise rapidly as distance and the complexity of interconnections grow.

D. Grid Operation

Stability in the grid system is maintained by matching the electricity generation with the ever changing demand. The electricity from many power generating stations is 'pooled' in the transmission system, and each customer draws from this pool. Power entering the system flows along all available paths to the distribution systems. This pooling of electricity also means that power is provided from a variety of generating stations of different sizes, including nuclear, coal, oil, natural gas and renewable energy sources such as wind, solar, biomass and hydropower, which must all be synchronized to the same 'rhythm' with millisecond accuracy. For a power grid to remain stable, the frequency and phase of all power generation units must remain synchronous within narrow limits. A generator that loses synchronism with other generators but stays connected to the grid will experience large electrical currents, which will lead to overheating and large mechanical forces that will rapidly destroy the generator. So protective circuit breakers disconnect (trip) a generator from the grid when the generator loses synchronism.

Electric power takes the path of least resistance from its source to the load, which generally means the shortest route but may also include parallel flow paths through other parts of the system. When a utility agrees to send electricity to a customer, the utility increases the amount of power generated while the customer increases its load. The power then flows from the utility to the customer along as many of the paths that connect them as it needs to make the trip with the least impedance possible. This means that changes in generation and transmission at any point in the system will change loads on generators and transmission at every other point, which is not easily controlled. To avoid system failures, the amount of power flowing through each transmission line must remain below the line's capacity. Exceeding capacity can cause overheating. Overhead lines which overheat will sag, and may cause electrical flashover to trees or the ground. Underground cables which overheat can damage their insulation. Exceeding capacity can also create power supply instability such as phase and voltage fluctuations.

The transmission grid, with multiple generating stations and distribution system connections, functions as one entity potentially stretching for thousands of kilometres. The grid must accommodate changing electricity supply and demand conditions, planned or unexpected outages of generating stations, transmission lines, and customers, as well as extreme weather conditions. The balance between electricity supply and demand must be maintained at any time by increasing or decreasing the output of the operating power plants or turning power plants on or off. Nuclear power plants are rarely operated in this 'load following' mode. Rather they provide a constant 'baseload' supply of electricity to the grid. Thus having a baseload nuclear plant on a grid means that other plants must be 'load following', i.e. able to increase or decrease their output to balance changes in electricity demand.

E. Interfacing Nuclear Power Plants with Electric Grids

Both nuclear power plants and electric transmission grids (Figure V-4) are fascinating engineering achievements on their own. When they are connected together in a highly controlled, dynamic and distributed network, further complexity is created. This complexity of engineered systems is a consequence of several factors: the sheer size and interconnectivity of the electric grid, the nuclear safety requirements imposed on NPPs, the need to balance electricity supply and consumption throughout the grid at all times, and the nature of electricity — that it is generated as it is used. Unlike other commodities, it is difficult to store electricity. This means the electric grid system requires continual surveillance and adjustment to ensure supply always matches demand. Unlike nuclear power plants, the inherent, natural and passive safety feedback systems based on physical laws are rather weak. Hence electric grids require continuous control and balancing actions based on engineered systems.

Nuclear power plants are operated usually in baseload mode (i.e. steady-state operation at full power) and less frequently in load following mode. The integration of large NPPs into an electric grid brings nuclear safety requirements that impose additional requirements on the grid design, operation and stability. Specifically, when NPPs are not generating electricity, they, like other power plants, still need electricity from the grid to support maintenance work, operate other equipment, keep the plant ready to restart, and, very importantly, operate critical safety systems. In NPPs the source of energy (the nuclear chain reaction) can be turned off in a few seconds. However, significant heat is still generated from the long term decay of highly radioactive fission products. This residual heat has to be removed from the reactor core indefinitely in order to prevent overheating of the reactor fuel and its consequent damage. The reactor cooling systems must be therefore powered by a long term stable source of electricity. In addition, to prevent fuel rod damage, sufficient and reliable power is needed to maintain conditions in the coolant system and containment and to run vital safety related instrumentation, control, monitoring and surveillance systems. Electric power is also needed for heating, ventilation and air conditioning (HVAC) systems used for assuring operable environments for equipment and personnel. This stable source of power comes either from the grid (off-site power), or from on-site emergency back-up power, such as batteries, diesel generators or gas turbines.

FIG. V-4. Power lines coming into the Callaway NPP.

The reliability of off-site power is usually assured by two or more physically independent transmission circuits to the NPP to minimize the likelihood of their simultaneous failure. Similarly, the reliability of on-site power is enhanced by sufficient independence, redundancy and testability of batteries, diesel generators, gas turbines and the on-site electric distribution systems to perform safety and other functions even if a single failure occurs. Because of the importance of reliable off-site power, the electric grid is an important factor in NPP site selection, which must take into account the plant's position within the grid as well as its proximity to centres of electricity demand, population density and other factors.

In addition to assuring that the electric grid will provide reliable off-site power to NPPs, there are other important factors to consider when an NPP will be the first nuclear unit on the grid and, most likely, the largest unit. If an NPP is too large for a given grid, the operators of the NPP and the grid may face several problems.

- Off-peak electricity demand might be too low for a large NPP to be operated in baseload mode, i.e. at constant full power.
- There must be enough reserve generating capacity in the grid to ensure grid stability during the NPP's planned outages for refuelling and maintenance.
- Any unexpected sudden disconnect of the NPP from an otherwise stable electric grid could trigger a severe imbalance between power generation and consumption causing a sudden reduction in grid

frequency and voltage. This could even cascade into the collapse of the grid if additional power sources are not connected to the grid in time.

F. Operational Modes of Nuclear Power Plants

Most NPPs are baseload plants operating normally at 100% power. Startup, shutdown and load changes are very infrequent, usually dictated by NPP requirements such as refuelling, inspections and internal restrictions. Baseload operation of NPPs is more economic for the system as a whole because fuel costs are lower for NPPs than for fossil fuel plants and because turning NPPs off and on is more complex and expensive than it is for fossil fuel plants. However, there may be other reasons to consider some operational flexibility and load following for an NPP. For example, in a developing country with a small grid, off-peak electricity demand may be too low for baseload operation, or NPPs may need to do some load following as the share of nuclear power is increased by additional NPPs coming on line.

NPPs operating in a load following mode can be further divided into two categories. Firstly, scheduled load following plants that normally operate at 100% power but may, at certain predetermined times, operate at partial power according to grid requirements. These plants can follow a predetermined daily pattern, e.g. operating at 100% power for 12 hours, then, over the next three hours, reducing to 50% power, operating at 50% power for six hours, and then increasing back up to 100% over the next three hours. Secondly, arbitrary load following plants that operate in their upper power range and are expected to meet the daily grid load requirements, including rapid power changes of up to 10% per minute. Some disadvantages of operating NPPs in a load following mode are that plant components will be exposed to many thermal stress cycles and that more sophisticated instrumentation and control systems will be needed. Both add costs.

G. Disturbances Affecting the Interaction between Nuclear Power Plants and Electric Grids

Grid interconnectivity and redundancies in transmission paths and generating sources are key elements in maintaining reliability and stability in high performance grids. However, operational disturbances can still occur even in well maintained grids. Similarly, even an NPP running in baseload steady-state conditions can encounter unexpected operating conditions that may cause transients or a complete shutdown in the plant’s electrical generation. When relatively large NPPs are connected to the electric grid, abnormalities occurring in either can lead to the shutdown or collapse of the other.

The technical issues associated with the interface between NPPs and the electric grid include:

- The magnitude and frequency of load rejections and the loss of load to NPPs.
- Grid transients causing degraded voltage and frequency in the power supply of key safety and operational systems of NPPs.
- A complete loss of off-site power to an NPP due to grid disturbances.

- An NPP unit trip causing a grid disturbance resulting in severe degradation of the grid voltage and frequency, or even to the collapse of the power grid.

G.1. Influence of grid disturbances on nuclear power plants

G.1.1. Load rejection and complete loss of load

A load rejection is a sudden reduction in the electric power demanded by the grid. Such a reduction might be caused by the sudden opening of an interconnection with another part of the grid that has carried a large load. An NPP is designed to withstand load rejections up to a certain limit without tripping the reactor. An NPP's ability to cope with a load rejection depends on how fast the reactor power can be reduced without tripping and then how fast the reactor power output can be increased back to the original level when the fault is cleared. Load rejections of up to 50% are accommodated by a combination of several actions: rapidly running back the steam turbine to the new lower demand level, diverting the excess steam from the turbine to the main steam condenser unit or to the atmosphere if this is permitted by licensing regulations, and reducing reactor power via insertion of control rods without tripping the reactor.

A *loss of load* is a 100% load rejection, that is, the entire external load connected to the power station is suddenly lost, or the breaker at the station's generator output is opened. Under this severe condition, it may still be possible to 'island' the NPP so that it powers only its own auxiliary systems. During this 'house-load' operating mode, the reactor operates at a reduced power level that is still sufficient to assure enough electricity for its own needs, typically 5% of full power. Once the grid disturbance has been eliminated, the NPP can be re-synchronized to the grid and its production quickly raised again to full power. This operational characteristic of the NPP is important when the loss of load is expected to last for just a short time.

G.1.2. Degraded grid voltage or frequency

Electric grids are controlled to assure that a particular frequency, either 50 or 60 Hz, is maintained within a small tolerance, typically within ± 1%. When the grid develops an imbalance between generation and load, the grid frequency tends to 'droop' if the load exceeds generation and increase if generation exceeds the load. A reduction in frequency can be caused by several events, such as insufficient available generation, a major electrical disturbance such as a circuit fault, or the trip of a major generator unit. A small droop in the grid frequency caused by the loss of generation can be controlled by:

- automatically changing output by speed governors on generating units providing 'spinning reserve'[1],
- manually changing (i.e. through operator intervention) output from the grid's available 'spinning reserve',
- starting up additional generation capacity, such as gas turbines or hydroelectric power, and
- disconnecting selected loads (i.e. customers) from the grid (load shedding).

Isolating the section of the grid with the NPP from the rest of the grid ('system islanding') can also help maintain the proper frequency in the islanded system. System islanding may reduce the load on

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[1] Spinning reserve is any unused capacity that is already connected and synchronized to the grid ('spinning') and can be activated immediately on the decision of the grid operator, reaching its full capacity within 10 minutes.

the NPP, requiring that its generation be reduced accordingly by a quick set-back to an intermediate power level. Proper islanding prevents the NPP from tripping because of the lower frequency, but may further aggravate the power imbalance in the rest of the grid. A plant trip including reactor shutdown should be regarded as a last resort. During a trip the plant is subject to rapid changes in power, pressure and temperature, which shorten the lifetime of the plant. Moreover, if the NPP is immediately disconnected from the grid, the lost generation will exacerbate the already degraded conditions on the grid.

Any change in the grid frequency affects an NPP's operation by changing the speed of the NPP's turbogenerator and the speed of pumps circulating coolants through the reactor and the secondary coolant circuits. The main reactor circulating pumps, steam generator feedwater pumps and long term decay heat removal systems rely on stable electric power to function properly. The speed of the reactor's main coolant pumps is directly proportional to the frequency of the electric power supply. Therefore, if the frequency of the power from the grid drops far enough, the pumps will slow, which will lead to inadequate core cooling, and the reactor will trip.

Other AC motors in the NPP may also trip due to rising currents and consequent overheating caused by reduced frequency. The performance of AC motors is directly affected by the voltage and frequency of their power supplies. If electric grid voltages are not sufficient, motors cannot develop sufficient motor torque to start, and if the frequency drops below a certain value, the start and operation of AC motors would require higher operating voltages. If the voltage is insufficient, it results in excessive current being drawn by the motor that in return would lead to overheating and the opening of protective breakers.

The frequency and voltage ranges in which large AC motors can operate are relatively narrow. Thus, in severely abnormal conditions, safety systems in nuclear power plants are required to take protective actions such as tripping the reactor and turbine, separating the plant electrical systems from the degraded conditions present on the grid, and switching to on-site emergency power sources until the grid voltage and frequency are restored to acceptable values. These actions protect the NPP by safely shutting it down and keeping it cooled. However, any sudden automatic shutdown of a large baseload nuclear unit during periods where there is already a mismatch between generation and load on the grid can only further degrade the grid's condition, potentially leading to a partial or full collapse.

G.1.3. Loss of off-site power

Any loss of off-site power would be caused by external events beyond the NPP's switchyard, such as transmission line faults and weather effects like lightning strikes, ice storms and hurricanes. A loss of off-site power interrupts power to all in-plant loads such as pumps and motors, and to the NPP's safety systems. As a protective action, safety systems will trigger multiple commands for reactor protective trips (e.g. turbine and generator trip, low coolant flow trip, and loss of feedwater flow trip). The reactor protection system will also attempt to switch to an alternate off-site power source to remove residual heat from the reactor core. If this fails, in-plant electrical loads must be temporarily powered by batteries and stand-by diesel generators until off-site power is restored. However, diesel generators may not be as reliable as off-site power from the grid in normal conditions. Diesel generators may fail to start or run 1% of the time. However, the probability of failure can be significantly reduced by installing independent trains of diesel generators. Batteries can provide power only for a limited time.

G.2. Influence of NPP disturbances on the grid

G.2.1. Trip of an NPP causing degraded grid frequency and voltage

Even at steady state conditions, when the generation and loads on a grid are in balance, if a large NPP (e.g. 10% of the grid’s total generating capacity) trips unexpectedly, the result can be a significant mismatch between generation and load on the grid. Unless additional power sources are quickly connected to the grid, this can degrade the grid’s voltage and frequency and thus the off-site power supply to the NPP. As discussed in Section G.1, degraded voltage and frequency on the grid can potentially result in the NPP protection system disconnecting the degraded off-site power to the NPP. This will force the NPP to switch to on-site emergency power to run safety and core cooling systems until off-site power is restored. This should be done as soon as possible for safety reasons: the possible concurrent failure of the NPP’s on-site power system and delayed recovery of off-site electric power would make it nearly impossible in most NPPs to cool the core, a situation that must be avoided under all conditions. The introduction of new reactor designs that use passive cooling would alleviate this problem. Therefore, in unreliable grid systems, it is recommended to consider NPP designs with passive safety systems.

The grid’s response over time to the sudden loss of the NPP can be modelled by computer simulations, conditioned by the capacity and interconnectivity of the grid and the size of the lost NPP generation, as well as the timing of switching additional power sources to the grid. Large interconnected electric grids can usually meet the requirement of providing reliable off-site power to NPPs connected to the grid. However, in some scenarios involving poorly interconnected or controlled electric grids, the sudden shutdown of a large NPP, or any other large generating station elsewhere on the grid, might result in severe degradation of the grid’s voltage and frequency, or even to the collapse of the overall power grid. Similarly, when an NPP is sited on a well maintained but small and isolated grid of limited generating capacity (e.g. on an island), the sudden loss of its generation may lead to the same outcome.

Complex computer models are used to decide whether the loss of the largest operating unit on the grid could result in the loss of grid stability and of off-site power. In simulation studies, the consequences of various single faults (e.g. the sudden loss of key transmission lines or a power generating unit) are explored. The output of the simulations provides the time dependent response of the grid (in terms of voltage and frequency) to the event, including protective actions, such as automatic load shedding, emergency disconnects and starting up additional power sources that can start quickly.

Results show that isolated grids are inherently less stable than equivalent grids of the same size with supporting grid interconnections. Therefore the design and licensing basis for ‘poorly sited’ NPPs should include provisions for more reliable on-site power, i.e. additional capacity for the on-site power system beyond the normal requirements (e.g. more diesel generators and fast-starting gas turbine engines). This would compensate for less reliable off-site power by providing more reliable on-site power, and it would assure that the degradation or collapse of the grid would not make an NPP’s decay heat removal systems inoperable.

H. Conclusions

As noted at the outset, countries expanding or introducing nuclear power programmes are advised to consider their electric grids as part of their planning process:

- The electric grid should provide reliable off-site power to NPPs with a stable frequency and voltage.
- Any potential lack of reliability in off-site power from the grid must be compensated for by increased reliability of on-site power sources.
- Enough reserve generating capacity should be available to ensure grid stability to replace NPP generation during planned NPP outages.
- The grid should also have a sufficient ‘spinning reserve’ and standby generation capacity that can be quickly brought online in case the NPP were to be disconnected unexpectedly from the grid.
- The off-peak electricity demand should preferably be large enough for the NPP to be operated in a baseload mode at constant full power.
- If there is any possibility of the NPP being operated in a load following mode, any additional design requirements to ensure safe load following operation should be discussed in advance with the NPP designer or vendor company.
- If baseload operation will not be possible, the NPP should have additional design margins to compensate for the increased exposure to thermal stress cycles, and more sophisticated instrumentation and control systems.
- The national grid should have enough interconnections with neighbouring grids to enable the transfer of large amounts of electricity in case it is needed to offset unexpected imbalances of generation and demand.
- In preparation for the introduction of an NPP, if grid reliability and the frequency and voltage stability of the existing grid are insufficient, they should be made sufficient before the NPP is brought online. Any improvements will not only allow the grid to incorporate the new NPP but will have additional benefits for all customers and other generators.
- Communication is critical, in this case between the NPP operators and grid dispatchers. Effective communication protocols will need to be developed.