Note:
This is a translation of the RSK recommendation entitled "Ein- oder zweiphasiger Ausfall des Haupt-, Reserve- oder Notstromnetzanschlusses".
In case of discrepancies between the English translation and the German original, the original shall prevail.

RSK recommendation
(467th meeting of the Reactor Safety Commission (RSK) on 26.06.2014)

Faults in one or two phases of the main, standby or emergency grid connection

Contents

1 Introduction

In the years 2012 and 2013, events from several nuclear power plants outside Germany were reported that were due to the faults in one or two phases of the high-voltage grid connection and involved the unavailability and several failures of components of the operational systems and the safety system, as described in GRS Information Notice 2013/05 [1].

On 30.01.2012, an insulator on the high-voltage side (345 kV) of the auxiliary power transformers failed in the Byron-2 plant (Illinois, USA) during full power operation, which resulted in the loss of one phase. This caused an asymmetric voltage situation in two redundancies in the plant's auxiliary power supply, which in turn, led to switch-off by overcurrent protection and unavailability of various consumers, some of them with safety significance. The installed measuring and monitoring devices were not capable of detecting the actual loss of the auxiliary power supply and thus did not trigger the necessary actions (initiation of grid disconnection and activation of the emergency diesel generators). The plant could only be restored to normal condition by manual actions.

On 30.05.2013, the Swedish nuclear power plant Forsmark, Unit 3, was in an outage for refuelling and maintenance, auxiliary power was supplied from the main grid, and the standby grid was disconnected. During maintenance work, the electrical protection was actuated so that the high-voltage circuit breaker received an OPEN command. In two of three phases, the breaker on the high-voltage side of the generator transformer then opened on demand, but one phase remained connected with the main offsite power supply. As in Byron, the resulting asymmetric conditions in the plant's auxiliary power supply resulted in the unavailability of various safety-related consumers due to switch-off by overcurrent protection. Some non-safety-related consumers were destroyed by thermal overload. The installed measuring devices also did not detect the instability in this case and thus the unavailability of the auxiliary power supply and did not trigger any automatic protective actions; normalisation was again only possible by means of manual actions.

Despite the sometimes considerable differences in the auxiliary power supply systems between the affected and the German nuclear power plants, transferability of the observed phenomena and failure mechanisms to German plants is given. A more detailed description of both events as well as four additional events under the aspect of "open phase condition" (OPC) can be found in [1].

For all events, the difficulties were related to the detection of these open phase conditions (OPCs), i.e. the resulting asymmetric voltage conditions. Due to the magnetic coupling of the three phases within transformers, there is a voltage on the low-voltage side for all three phases – although asymmetrical – up to the level of the nominal voltage (depending on the consumer load) despite the failure in one or two phases on the high-voltage side, but also on the high-voltage side there might only be a slightly changed voltage at all phases due to the aforementioned magnetic coupling effect within the transformer. The magnitude of these voltages depends on the load of the transformer. This applies, in particular, to transformers in a star-delta connection. A reliable detection of such situations therefore depends on the load of the transformer and, in addition, of its neutral treatment (grounded or non-grounded neutral). The voltage measurements currently installed in German NPPs are not capable of ensuring reliable detection and control of an OPC in all phases of operation and at all power levels.

OPC has not been taken into account in the designs of nuclear power plants worldwide so far, even though it has the potential that all safety systems may be affected simultaneously. Accordingly, the RSK derives a need for action from it.

At its 467th meeting on 26.06.2014, the RSK discussed the draft recommendation submitted by the RSK Committee on ELECTRIC INSTALLATIONS (EE) and approved it after amendments.

2 Assessment criteria

The RSK investigated which requirements exist in international and national regulations for the management of OPCs. It was concluded that phase faults have to be postulated, identified and controlled (see [2], Section 3.9 (1)). Specific requirements detailed on a technical level, in particular regarding their implementation, are not included in the regulations.

3 Assessment

The investigations of the RSK focus on OPCs in the grid connections due to the fact that several redundancies can only be affected simultaneously from the grid during power supply. Of particular importance for the impacts of asymmetries are transformers since magnetic coupling of the individual phases occur in the transformers.

Consumers on the low-voltage side, such as solenoid valves, pumps, drives and controller drives, may be affected by asymmetric voltage conditions, i.e. they may either be switched off through protective devices or even damaged by load unbalances.

An OPC as an initiating event or in connection with a transient as an independent additional failure or due to a certain probability results from a failure of operational installations that may also be located outside the nuclear facility. The RSK derives the requirements regarding the detection of the OPC and for the measures to be taken from the safety requirements for nuclear power plants (*Sicherheitsanforderungen an Kernkraftwerke*) [2] in combination with the reference values for the frequency of occurrence of events according to the RSK's understanding of safety philosophy (*RSK-Verständnis der Sicherheitsphilosophie*) [3].

Due to the frequency observed, the RSK assigns an OPC as an initiating event to the second level of defence. The requirements for installations to detect and control the effects are to be specified according to the safety requirements for nuclear power plants [2]. In this context, it has to be checked whether the event sequence "OPC in combination with failure of the monitoring system provided" is to be assigned to the third level of defence due to the effects.

Events where the OPC is postulated as an additional fault independently or conditionally with a certain probability are to be assigned to the respective level of defence according to the frequency of the event itself and under consideration of the additional OPC. The RSK considers the probability to be very low that independently an OPC occurs simultaneously in addition to any initiating event of the second or third level of defence due to a random failure of conductors. There are no reliable figures for OPCs during switching operations (e.g. resulting from reactor trip/turbine trip).

The RSK currently assumes that there will be scenarios with frequencies that would have to be classified as level of defence 3. The RSK therefore holds the view that for equipment for detection and control of OPCs the requirements according to [2] for level of defence 3 are to be met, unless it is demonstrated by the operator that less stringent requirements may be applied due to the frequency or permissible effects.

First of all, a distinction can be made between single- and two-phase faults. A single-phase fault results in the interruption in one phase of the three-phase grid connection (main, standby or emergency grid connection (third grid connection)). In the event of a two-phase fault, only one phase remains connected to the grid. From operating experience, different causes are known for such asymmetric faults: single- or two-phase faults may be due to a failure of passive components (conductor rupture, insulator breakage) as well as of active components (failure of individual switch poles of circuit breakers). Both types of fault are to be treated equally with regard to the potential effects.

In its recommendation, the RSK considers the following:

- Single- and two-phase fault resulting from
  - conductor rupture, insulator breakage
  - switch pole failure

- OPC as initiating event
  - plant in power operation
  - plant in non-power operation mode, supply from the main grid (400/220 kV), or standby grid connection (110/220 kV)

- OPC as an independent additional failure

- OPC in the time sequence subsequent to reactor trip/turbine trip

- OPC in the standby grid connection in standby

These scenarios are of a general character and do not refer to a specific failure analysis taking into account all possible plant configurations (i.a. transformer neutral treatment, location of the failure, failure type, grid connection concept).

Furthermore, the RSK generically compiled the possibilities already available in the plants for detection and control of phase failures and discussed their effectiveness. The following issues were considered:

- Synchronisation monitoring (monitoring of the synchronous behaviour of all switch poles of a three-phase breaker)

- Trigger communication (simultaneous automatic opening of the high-voltage- and low-voltage-side breaker of a grid transformer)
- Generator load unbalance protection
- Auxiliary power changeover
- Overvoltage protection
- Voltage monitoring of the auxiliary power and emergency busbars
- Signalling in the reactor protection system
- Undervoltage protection
- Voltage monitoring for static or rotating inverters

Despite the large number of existing monitoring capabilities, an OPC cannot be detected reliably in all cases.

For the derivation of recommendations, the RSK formulates basic requirements for the identification and control of asymmetric conditions with respect to current or voltage. On this basis, recommendations are made, taking into account the following operational states:

- Generator connected to the main grid (400/220 kV) during power operation
- Refuelling and maintenance outage with supply from the main or standby grid connection
- Standby transformer in idle mode (standby operation)
- Emergency grid connection in idle mode (standby operation)
- Main grid connection in idle mode (standby operation)
- Power plants in standstill operation mode/post-operational mode/residual operation mode

Furthermore, recommendations are made for interim measures.

4 Recommendations

The effects of OPCs on the auxiliary power and emergency power supply depend on the plant-specific conditions (transformer parameters, neutral treatment, short-circuit power at the grid node, cable lengths, busbar load, etc.). The plant-specific conditions must therefore be considered in the implementation of recommendations E_2 to E_8.

The RSK notes that, for example, methods based on symmetric components (evaluation of positive, negative and zero sequence) are suitable to detect asymmetries due to phase failures.

E_1 In the KTA safety standards, the issue of phase asymmetry is only dealt with indirectly. To meet the requirements based on the safety requirements for nuclear power plants, Section 3.9 (1) and their interpretations, it is necessary to reliably detect and control OPCs. After final clarification of the technical details, the relevant standards should be revised accordingly (e.g. KTA 3701, Section 4.1.2 (3), supplement to include OPCs).

E_2 To detect asymmetric voltages in the phases of the three-phase system, all phase-to-phase voltages are to be measured in all grid connections and monitored for deviations by alarm limits. The limit values are to be defined plant-specifically.

E_3 To protect against impairment by asymmetries, additional protection is to be installed for the detection of an unbalanced load through a reliable

- current measurements on redundant high-power operational consumers of the 10 kV-power system (e.g. absolute measurement of the unbalanced load current), or

- current measurement on all supply breakers of the 10 kV busbars (e.g. ratio measurement negative to positive sequence current).

For a PWR in operation, disconnection from the main grid is to be actuated by the signals derived from these measurements (e.g. resulting in load rejection to auxiliary power or actuation of auxiliary power changeover) and in case of supply by the standby grid, changeover to emergency diesel generator supply of the affected redundancy is to be actuated (i.e. opening of the section switch between auxiliary power and emergency busbar).

For boiling water reactor SWR 72, opening of the section switch is to be actuated in case of operation by the main grid since standby grid connection is actuated by reactor protection signals via measurements of the low voltage and frequency at the emergency busbars. In case of supply by the standby grid, measurements are to be installed between standby grid bus bar and emergency busbar.

For implementation of recommendation E_3, measures technically equivalent to the aforementioned current measures may also be applied as e.g. measurement of the negative sequence voltage.

E_4 Unavailabilities of the standby grid connection in standby mode due to single- or two-phase faults must be detected by technical devices in order to initiate corrective measures.

E_5 Unavailabilities of the emergency grid connection due to single- or two-phase faults must be detected by technical devices in order to initiate corrective measures.

E_6 Unavailabilities of the main grid connection due to single- or two-phase faults before reconnecting the main grid transformers, e.g. after maintenance, must be detected by technical devices to ensure that there is no OPC before returning to main grid supply.

E_7 For facilities in standstill operation mode/post-operational mode/residual operation mode, the same requirements apply as for power plants during outage mode. Should less requirements result regarding the availability of safety-relevant consumers considering different grace times for event control, less stringent requirements for the detection of OPCs and corresponding measures may be derived from it. This is to be documented and justified accordingly.

E_8 Due to the potential for redundancy-wide failures of safety installations, the RSK considers it necessary that equipment is provided that reliably detects OPCs and initiates measures in time so that redundancy-wide failures of safety installations are not to be feared.

To the RSK's knowledge, the equipment suitable for this purpose does not have a qualification according to the nuclear rules and regulations for reactor protection devices. Against this background, the RSK concludes that diverse operationally proven equipment should be used. It is to be demonstrated that this design will be appropriate in the long term with regard to effects on process-engineering systems or due to a very low frequency of occurrence of hazard states.

As interim measures for the protection against simultaneous failure of safety installations by asymmetries, the following measures are recommended until implementation of the measures according to E_2 to E_8:

E_9 It should be immediately ensured that in the event of an OPC at least one subsystem remains functional for coolant injection and residual heat removal.

E_10 In order to prevent hazards initiated by OPCs, written procedures are immediately to be developed that describe the plant specific possibilities and criteria for detection of OPCs. In addition, the measures to be derived from it (manual switchover to the standby grid or opening of the section switch between auxiliary power and emergency busbar) are to be described (supplement to the operating manual).

5 References

[1] GRS, Information Notice (Weiterleitungsnachricht – WLN) 2013/05 “Unzureichend detektierte Ausfälle einzelner Phasen der Fremd- bzw. Reservenetzanbindung in mehreren ausländischen Anlagen”)

[2] “Sicherheitsanforderungen an Kernkraftwerke” of 22 November 2012, published on 24.01.2013 in the Federal Gazette: BAnz AT 24.01.2013 B3

[3] RSK statement “RSK-Verständnis der Sicherheitsphilosophie”, 460th meeting of the RSK on 29.08.2013, published in the Federal Gazette AT 05.12.2013 B4