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Analysis of loss of offsite power events reported in nuclear power plants

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HIGHLIGHTS

- Loss of offsite power events were identified in four databases.
- Engineering analysis of relevant events was done.
- The dominant root cause for LOOP are human failures.
- Improved maintenance procedures can decrease the number of LOOP events.

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ABSTRACT

This paper presents the results of analysis of the loss of offsite power events (LOOP) in four databases of operational events. The screened databases include: the Gesellschaft für Anlagen und Reaktorsicherheit mbH (GRS) and Institut de Radioprotection et de Sûreté Nucléaire (IRSN) databases, the IAEA International Reporting System for Operating Experience (IRS) and the U.S. Licensee Event Reports (LER).

In total 228 relevant loss of offsite power events were identified in the IRSN database, 190 in the GRS database, 120 in U.S. LER and 52 in IRS database. Identified events were classified in predefined categories.

Obtained results show that the largest percentage of LOOP events is registered during On power operational mode and lasted for two minutes or more. The plant centered events is the main contributor to LOOP events identified in IRSN, GRS and IAEA IRS database. The switchyard centered events are the main contributor in events registered in the NRC LER database. The main type of failed equipment is switchyard failures in IRSN and IAEA IRS, main or secondary lines in NRC LER and busbar failures in GRS database.

The dominant root cause for the LOOP events are human failures during test, inspection and maintenance followed by human failures due to the insufficient or wrong procedures. The largest number of LOOP events resulted in reactor trip followed by EDG start.

The actions that can result in reduction of the number of LOOP events and minimize consequences on plant safety are identified and presented.

1. Introduction

The operating nuclear power plants have safety systems that require electrical energy for their activation and operation (Park et al., 2014). The electrical systems of the nuclear power plants are designed to be reliable and protected from the relevant hazards. Therefore the design of the electrical systems in nuclear power plants implements diversity, redundancy, physical separation and functional independence.

The NPP electrical system can be generally divided into offsite and on-site power systems (IAEA, 2012).

The offsite power system is the transmission power system where the nuclear power plant is connected. A minimum of two power interconnections with proven independence is expected between the offsite and on-site power system.

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The loss of offsite power (LOOP) initiating event occurs when all electrical power to the plant from offsite power system is lost. The electrical power after the LOOP is expected to be provided either by the plant generator or, in case of unsuccessful transfer to house load operation, by the emergency diesel generators (EDG). Station blackout event (SBO) is when all alternate power sources are lost.

The LOOP events were analysed in several reports (NRC, 1988, 1996, 1998b, 2003). Results of the latest study (NRC, 2003) show that major contributor to the LOOP during the power operation mode are grid related events. The decrease of the LOOP frequency compared to previous periods and studies and increase of LOOP duration was identified (NRC, 2003).

The European Clearinghouse on Operational Experience Feedback (OEF) for Nuclear Power Plants (NPP) was established in 2009 by the European Nuclear Regulators. The main objectives of the European Clearinghouse are to enhance nuclear safety through strengthening and sharing the competences in operational experience feedback, to establish European best practice for assessment of operational events and to support European Commission policy needs (Ballesteros et al., 2015).

On the 2013 annual meeting of the European Clearinghouse the nuclear regulators requested topical study on events related to Station Black Out (SBO) and Loss of Offsite Power (LOOP).

This paper presents the results of LOOP events analysis identified in four databases of operational databases. The analysis is done with the classification of the events in the predefined categories. The results of statistical analysis of the events that include assessment of LOOP frequency and trend analysis are presented in (Volkanovski et al., 2016).

The description of the database screening methodology and events classification is given in Section 2. The results of the analysis of identified events are given in Section 3. Main observations and actions based on the identified events are listed in Section 4. The conclusions are given in Section 5.

2. Events identification and classification methodology

The four databases of operational events analysed in this study are: the "Support a l'Analyse des Problemes, Incidents et Difficultes d'Exploitation" (SAPIDE), owned and managed by IRSN; the "Vertiefte Auswertung meldepflichtiger Ereignisse" (VERA), owned and managed by GRS; the LER database of the Nuclear Regulatory Commission (NRC); the IRS of the International Atomic Energy Agency (IAEA, 2010b).

The database searching and events screening methodology is described in details in Kančev et al. (2014) and Volkanovski et al. (2016). The IRSN SAPIDE and GRS VERA database were reviewed for LOOP events reported in time period 1992–2011. The NRC LER and IAEA IRS databases were searched for events reported in the period 1990–2013. All operating nuclear power plants in the analyzed period and countries were considered in the study. No differences resulting from design were identified between pressurized and boiling water reactors and therefore LOOP events for both designs were considered together in the study. The events from the IAEA IRS considered in the study excluded those reported from France, Germany and United States.

The 228 LOOP events from the IRSN SAPIDE database and 190 from GRS VERA were selected as relevant for the analysis. Different reporting criteria are used in France and Germany, resulting in different types of events to be reported and inserted in the databases. The 120 LOOP events from LER and 52 from IRS were identified as relevant and considered in the analysis. The widespread grid disturbance which happened on August 14, 2003, affected nine NPPs sites with eleven reactors is considered in the study. In IAEA IRS the largest number of events was identified for Russian Federation with 9 events followed by Canada with 5 events.

The selected LOOP events were classified into eight categories considering: plant status, circumstances, type of event, type of equipment failed, direct cause, root cause, consequences of the event and event duration. Each event was classified into single best matching category with the exception for the characteristic related to the type of equipment failed and the consequences, which can be multiple.

In the "Plant status" category events were classified considering the operational mode of the plant before or during the event into: On power, Hot shutdown and Cold shutdown.

In the "Circumstances" category events were classified based on the conditions at the NPP when the event started: Normal operations, Shut-down or Start-up operations, Planned or preventive maintenance, Repair (corrective maintenance), Inspections and functional testing, Fault finding, Modifications and Others.

In the "Type of event" category the events were classified considering the type of loss of electrical power: Partial loss of external power, Total loss of external power (with EDG start), Loss of power supply (with EDG failure) and Physical loss of electrical busbars. Events that induced the loss of voltage on busbars due to damage or degradation of the busbar are classified into "Physical loss of electrical busbars". To make a difference between the auxiliary and emergency busbars, two sub-groups are created: "Loss of power to emergency busbars" and "Loss of power to auxiliary busbars". Events were classified into these two sub-groups otherwise were considered into "Physical loss of electrical busbars".

The category "Type of equipment failed" classified events based on the type of the equipment that failed or concerned resulting in LOOP: Main or second interconnection, Breaker or Switchyard, Transformer, EDG/SBO-EDG, Busbar, Inverter, Generator and Others. Transformers include all type independent of function (main, auxiliary, startup or other). Busbar category includes the main distributing busbars in the plant for alternate and direct current, non-interruptible alternate current system and connected circuit breakers. The distinction between EDG and SBO-EDG is made considering the terminology used in the analysed databases and design features of the nuclear power plants.

In the "Direct cause of event" category the events were classified in three main groups considering the cause location: Electrical grid deficiency, Switchyard deficiency and Plant related events. Each group is divided in the following subgroups: Mechanical deficiency, Electrical deficiency, Instrumentation and Control (I&C) deficiency, Environmental, Human factor, Unknown and Others.

In "Root causes" category events were classified based on the causes resulting in the occurrence of the event into: Human performance related root causes, Equipment related root causes, Others and Unknown.

The direct and root causes are analysed separately because "Direct cause of event" should answer the question "how did it happen?" while "Root causes" answers to the question 'why did it happen?' (IAEA, 2010a).

In "Consequences" category events were classified in the following groups: Non-compliance with operational technical specifications, Internal line switching, House load operation, Offsite line switching/external system connection switching, Starting EDG without connecting, Starting and connecting EDG, Starting SBO-EDG, Reactor trip, Material degradation and Others. Internal line switching includes events, where a switching between different busbars or trains of the same busbar within the unit took place including an emergency supply provided by a neighboring unit in case of French NPP.

In "Event duration" category events are classified according to their duration into: Longer than 2 min, Shorter than 2 min and Undefined. The classification is based on the criteria in NUREG/