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Events related to emergency diesel generators in the nuclear industry: Analysis of lessons learned from the operating experience

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ABSTRACT

This study focuses on specific operating experience related to emergency diesel generators (EDG) at nuclear power plants. The study aims at analysing operating experience for the past twenty years and identifying events that involved failures of EDG or its supporting systems.

The selected operating experience was analysed in order to identify type of failures, attributes that contributed to the failure, failure modes, discuss risk relevance, summarize important lessons learned and provide recommendations. For the purpose of this study EDG failure is defined as EDG fail to function on demand (i.e. fail to start, fail to run) or during testing, or an unavailability of an EDG, except of unavailability due to regular maintenance.

The Gesellschaft für Anlagen und Reaktorsicherheit mbH (GRS) and Institut de Radioprotection et de Sûreté Nucléaire (IRSN) databases were screened to select all the events between 1990 and 2010 related to this topic. Besides IRSN and GRS operating experience, the operating experience contained in the IAEA/NEA International Reporting System for Operating Experience as well as the U.S. Licensee Event Reports were also analysed.

The selected events were analysed in depth. Causes, root causes, contributing factors, consequences and lessons learned were determined. The events were classified into categories in order to establish main conclusions on the topic. A trend analysis was performed wherever possible, by assigning the reported events into different categories regarding chronology of occurrence, failure types, components involved, failure mode, failure causes, failure detection, etc. Subsequently, generic recommendations related with the analysed EDG failures were compiled.

The focus of this paper is on the lessons learned from the analysed operating experience as well as on designating generic recommendations for the specific EDG-related issues encountered rather than presenting selected statistical results.

1. Introduction

The Stress Tests (Peer review report of the, 2012) conducted in the European Union countries following the Fukushima accident showed the importance of EDG as the vital stand-by source of alternating current (AC) power. The external events such as grid disturbances, earthquakes, floods, severe weather conditions, etc., can cause a loss of off-site power (LOOP) condition at nuclear power plants (NPPs). In this case, the safety buses are switched to stand-by EDG as a preferred source of power supply. Similarly to other safety-related systems that are typically in stand-by mode, EDG is "waiting" for demand, and therefore must be prepared to start at any time it is required. In order to ensure EDG operability, a surveillance testing is regularly conducted to confirm the EDG operability. Moreover, after each outage the endurance tests under rated power are conducted to verify EDG capability to provide load for required period of time.

An emergency diesel generator selected for use in an onsite electric power system should have the capability to start and accelerate a number of large motor loads in rapid succession, while maintaining voltage and frequency within acceptable limits, provide power promptly to engineered safety features if a LOOP and a design-basis event occur during the same time period and supply power continuously to the equipment needed to maintain

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the plant in a safe condition if an extended LOOP occurs (U. S. NRC, March 2007, Institute of Electrical and Electronics Engineers, International Atomic Energy Agency, 2004).

Although LOOP event is within the plant design basis, partial or full failure of EDG may lead to loss of individual safety bus or even to station blackout (SBO), which is for many plants limiting case in term of safety margins due to short coping time for power recovery. Given that many safety systems required for reactor core decay heat removal and containment heat removal are dependent on AC power, the consequences of a station blackout could be severe (U. S. NRC, August 1988). The functionality of the EDGs is therefore crucial during the plant operation as well as during outages.

A topical report study, aimed at analysing operating experience for the past twenty years and identifying events that involved EDG failures, was conducted (Topical Operation, 2013). This study was prepared by the European Clearinghouse on Operating Experience (OE) in cooperation with IRSN and GRS who have comprehensive event databases that are suitable for trending analysis, and which allow identifying representative EDG related events (Topical Operation, 2013).

Besides IRSN and GRS operating experience, the operating experience contained in the IAEA/NEA International Reporting System (IRS) (The International Reporting) as well as the licensee event reports (LERs) reported to the U.S. Nuclear Regulatory Commission (U.S. NRC) were also analysed.

The selected operating experience contained in event reports was further analysed in order to identify type of failure, chronology of occurrence, attributes that contributed to the failure, EDG failure mode, failure causes, failure detection, discuss risk relevance, etc. Based on this thorough analysis, the associated lessons learned related to specific EDG-issues were identified. Consequently, six different categories of generic recommendations on how to tackle these specific EDG issues were compiled.

2. Scope and methodology

2.1. Scope

For the purpose of this study an EDG failure is defined as EDG fail to function on demand (i.e. fail to start, fail to run) or during testing, or an unavailability of an EDG, except of unavailability due to regular maintenance. The failures considered are related to the whole EDG set together with all the supporting equipment.

The EDGs considered in the scope of this study are as follows:

- Main EDGs (stand-by) that are connected to the plant electrical safety buses;
- Additional EDGs to stand-by EDGs, typically installed at multi-unit sites (French design);
- EDGs that are considered for specific events e.g. seismic event (e.g. EDGs in bunkered systems for safe plant shut down as in KWU design, etc.);
- Mobile EDGs used for specific purpose; e.g. accident management.

2.2. Methodology

Four different data bases were screened for EDG related events over a time period of roughly 20 years: the GRS data base, the IRSN data base, the IRS data base operated by the International Atomic Energy Agency (IAEA) and the LERs database operated by the U.S. NRC.

The identification of EDG related events, components involved and their associated failure modes was performed through the following activities:

- Searching the operational experience databases for at least the past 20 years in order to identify any “EDG related events” for this study;
- Analysing those events that involved EDG failures:
  - Any mechanical, electrical or I&C failures (including failure to synchronize to the safety bus bars) occurring during a start-up on-demand, operation or surveillance testing;
  - Failures related to EDG voltage and frequency control system;
  - Failures related to EDG support systems (compressed air, cooling, fuel, etc.);
- Determining the most frequent failure modes for which the malfunction prevented EDG to function;
- Determining the most frequent causes for the EDG failures;
- Discussing the most common degradation mechanisms that attributed to EDG failures;
- Performing a chronological trend analysis wherever possible to show whether the occurrence of events caused by EDG related effects is increasing, decreasing, or steady;
- Performing analysis aimed at designating the circumstances under which the EDG failure was detected;
- Performing trend analysis related to the manufacturer and the type of the EDGs;
- Discussing whether the existing plant could be an effective tool to timely detect degradation of EDG components before its failure;
- Identifying any challenging issues related to EDG performance, which resulted from operational experience lessons learned;

Table 1 summarizes the number of relevant events and the time span considered for each of the four databases.

A total of 676 events were considered and analysed for this study. It should be noted, however, that no comparison of the results among the four different cases i.e. data bases analysed was performed due to the different reporting criteria specific for each data base.

After the identification, screening and analysis of EDG-related events, lessons learned were compiled for different types of EDG components/systems concerned (diesel engine-related mechanical components; diesel engine air starting system; diesel engine cooling system; diesel engine exhaust system; diesel engine lubrication system; diesel fuel and fuel supply system; electrical failures) and related activities (maintenance; human error) as well as external events affecting EDG performance. Subsequently, a set of generic recommendations addressing issues challenging EDG performance has been identified and grouped into six generic categories.

2.2.1. German (VERA) database screening

The German database VERA is a GRS database, which contains reportable events that occurred in German NPPs. This database, used for systematic evaluation of operating experience, includes about six thousand events, which have been reported since 1975 in a complete manner. Older events, since the end of the 1960s, have not been reported with so much detail than those reported after 1975.

Table 1
Screened data bases, number of events and time period considered.

	GRS data base	IRSN data base	U.S. NRC LERs	IRS data base
No. of analysed events	241	255	115	65
Time period	1990–2009	1990–2010	1989–2011	1988–2012
No. of years considered	20	21	23	25