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Events Related to Emergency Diesel Generators

Summary Report of a European Clearinghouse Topical Study

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1. INTRODUCTION

The nuclear power plants worldwide have a configuration of emergency power supply (EPS) systems which includes, as minimum, two redundant trains of safety buses, each powered by an emergency diesel generator (EDG) when regular power supply is lost to an individual safety bus or following loss of off-site power (LOOP). 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. The Stress Tests conducted [1] following the Fukushima accident in the European Union countries showed the importance of EDGs as the vital stand-by source of emergency alternating current (AC) power. The external events such as grid disturbance, earthquakes, floods, severe weather conditions, etc. can cause a LOOP condition at nuclear power plants (NPPs). The availability of EDG is therefore crucial during the plant operation as well as during outages.

This Summary Report presents the main findings of a study [2] performed by the European Clearinghouse on Operating Experience Feedback of NPPs with the support of Gesellschaft für Anlagen und Reaktorsicherheit (GRS) mbH and Institut de Radioprotecton et de Sûreté Nucléaire (IRSN). The referenced study focuses on analysing specific operating experience related to EDGs at NPPs.

The selected operating experience was analysed in detail in order to: (i) identify type of failures, attributes that contributed to the failure, failure modes potential or real, affected components, circumstances of failure; (ii) discuss risk relevance; (iii) summarize important lessons learned; and (iv) provide recommendations.

2. SCOPE AND METHODOLOGY

2.1. Scope

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 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 databases were screened for EDG related events over a time period of roughly 20 years: the GRS database, the IRSN database, the International Reporting System (IRS) database operated by the International Atomic Energy Agency (IAEA) and the Licensee Event Reports (LERs) database operated by the U.S. Nuclear Regulatory Commission (U.S. NRC).

Table 2-1 summarizes the number of relevant events and the time span considered for each of the four databases.

Table 2-1. Screened databases, number of events and relevant time period

	GRS database	IRSN database	U.S. NRC LERs	IRS database
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

A total of 676 events were considered and analysed for this study.

In general, the selected events for all 4 databases 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 failure types, components involved, failure mode, etc. The main categories in which EDG failures were classified are the following: the type of the failure; the failure modes; the main causes for the failure; the affected components; the manufacturer and type of the diesel engine (wherever possible).

After the identification, screening and analysis of EDG related events challenging issues and lessons learned related to EDG performance were identified. Subsequently, generic recommendations on how to tackle challenging issues related to EDG performance at NPPs were compiled. The lessons learned are presented in the Annex and the recommendations in Section 4.

3. RESULTS AND MAIN FINDINGS

The topical study [2] comprises the results of EDG related events evaluation. For each of the selected events for detailed analysis, in-depth information is given on the component involved, risk relevancy to the plant operation, associated failure mechanism / phenomenon and corrective measures taken. It should be noted that no comparison of the results among the four different cases i.e. databases analysed was performed due to the different reporting criteria specific for each database.

This chapter summarizes the results of the database trend analyses from the topical study. Due to length constraints for this summary, only case-specific results, for each of the four different cases, are presented as an illustration. The complete results are presented in the tropical study [2]. They did not reveal significant database singularities and led to the main findings which are summarized at the end of this section.

3.1. German results

In Germany, the emergency power supply system comprises at least 5 EDGs. The modern Konvoi-PWRs have 8 EDGs. On average, there are 6,5 EDGs in German NPPs. Usually 2 EDGs are required for emergency power supply.

Figure 3-1Figure 3-1 illustrates the number of all reported events and proportion of EDG related events per calendar year.

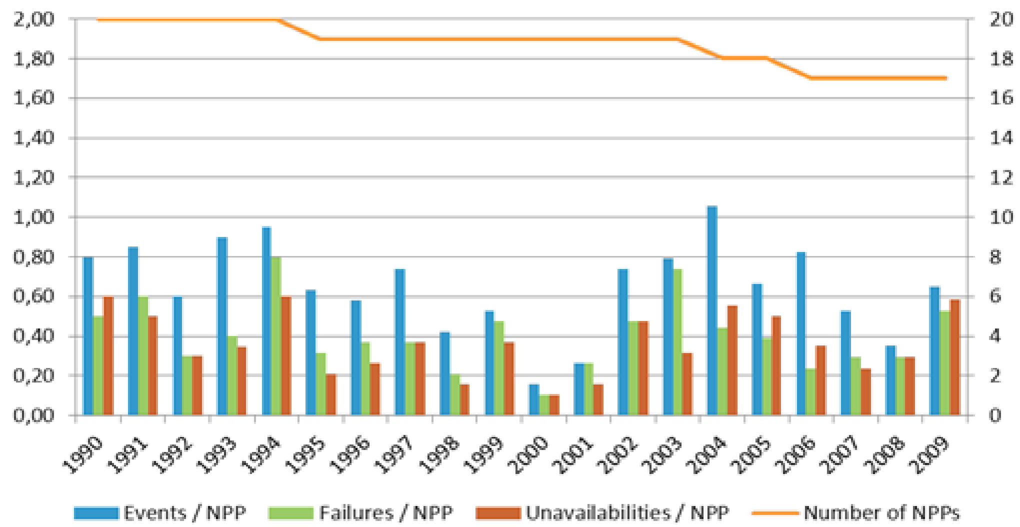

Figure 3-1. Chronological distribution of the EDG related events (GRS)

On the left-hand side vertical axis there are events, failures and unavailability per NPP units. On the right-hand side axis there is the number of NPP (units) in operation.

Figure 3-2 depicts an overview about how often particular components/systems were involved in the events. This has been done because for almost every event different components were affected. The failures were classified into different categories, whether they belong to diesel engine or generator systems and components. As it can be seen on Figure 3-2, there are no substantial differences in the number of failures among EDG systems/components. The distribution of failures in the main component parts is fairly equal. It can be concluded that there were no major deviations among EDG component failures that would implicate significant contribution of individual component group to overall EDG failures.

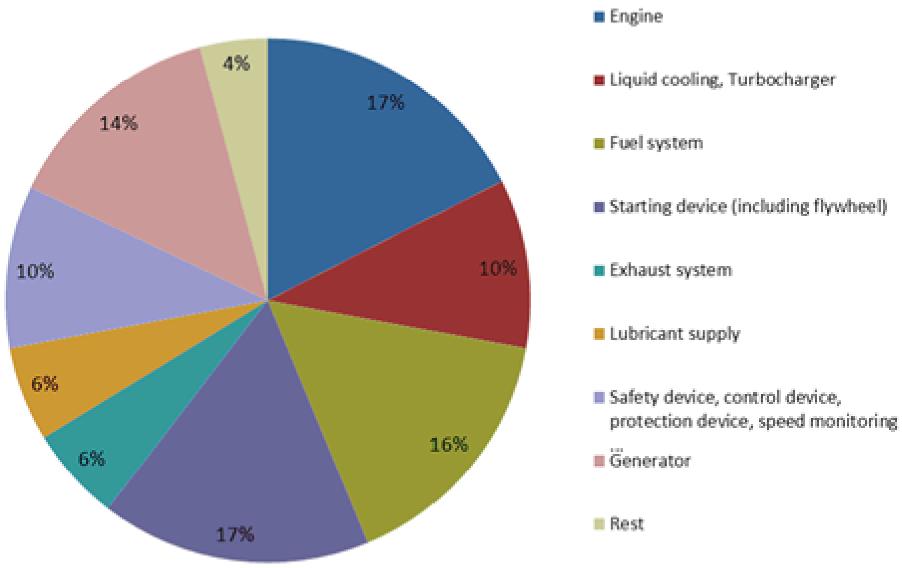

Figure 3-2. Distribution of affected components/systems in EDG events (GRS)

3.2. French results

The following EDGs were considered in the French database analysis:

- 116 EDGs (each of the 58 French NPP units contains two EDG);
- 7 additional EDGs (additional EDG are installed only in 7 NPP sites of the French 900 MWe series).

Figure 3-3 represents a proportion of reported events considering the time duration necessary to recover the capability of EDG/Additional EDG. More than half of the reported events (53,3%) were related to failures that could have been repaired fast (category "Fast recovery"), i.e. within one hour. Events that are classified in the category "Slow recovery" are related to failures of EDGs/Additional EDGs for which more than one hour was necessary to recover their safety function. There was only one event for which the recovery time of EDG function remained unknown.

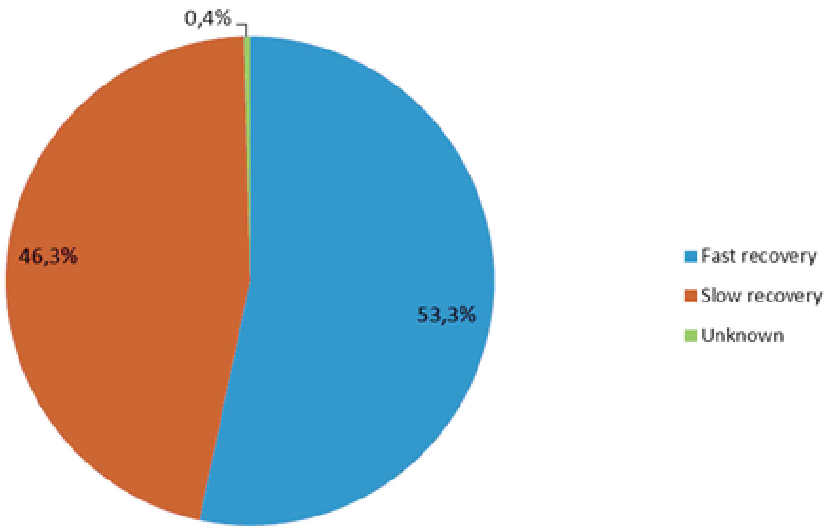

Figure 3-3. Recovery time of EDG/Additional EDG (IRSN)

Table 3-1 presents the comparison between the type of failure and the main cause of failure. Less than half of the reported events (44%), which were mainly caused by human error, led to a complete failure whereas 53,3% led to a potential failure and 2,7% led to a degraded function. A similar proportion can be noticed for events caused mainly by design/manufacturing error. A third of the events for which the main cause was not determined led to a complete failure and two thirds led to a potential failure.

Table 3-1. Comparison between the type of failure and the main cause of failure (France)

	Human error		**Design/manufacturing**		**Unknown**	
Total percentage	58,8%		40%		1,2%	
	Number of events	Percentage	Number of events	Percentage	Number of events	Percentage
Complete failure	66	44,0%	44	43,2%	1	33,3%
Degraded ability	4	2,7%	3	2,9%	0	0,0%
Potential failure	80	53,3%	55	53,9%	2	66,7%

Figure 3-4 shows the proportion of reported events considering the actual detection mode. It shows that large majority of reported events (97,6%) occurred during test, inspection and maintenance activities.

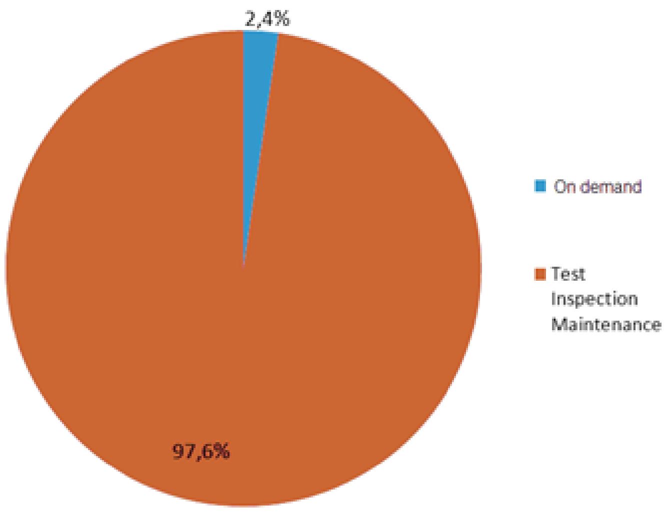

Figure 3-4. Detection of failures (IRSN)

This result underlines the importance of preventive maintenance and surveillance testing which is carried out to confirm EDG functionality. Similar to other systems important to safety, EDG are in a stand-by mode during operation. Any degradation or latent failure is difficult to identify unless regular preventive maintenance and tests are performed.

3.3. U.S. results

The following figure, Figure 3-5, presents the chronological distribution of EDG related events reported as LERs to the U.S. NRC.

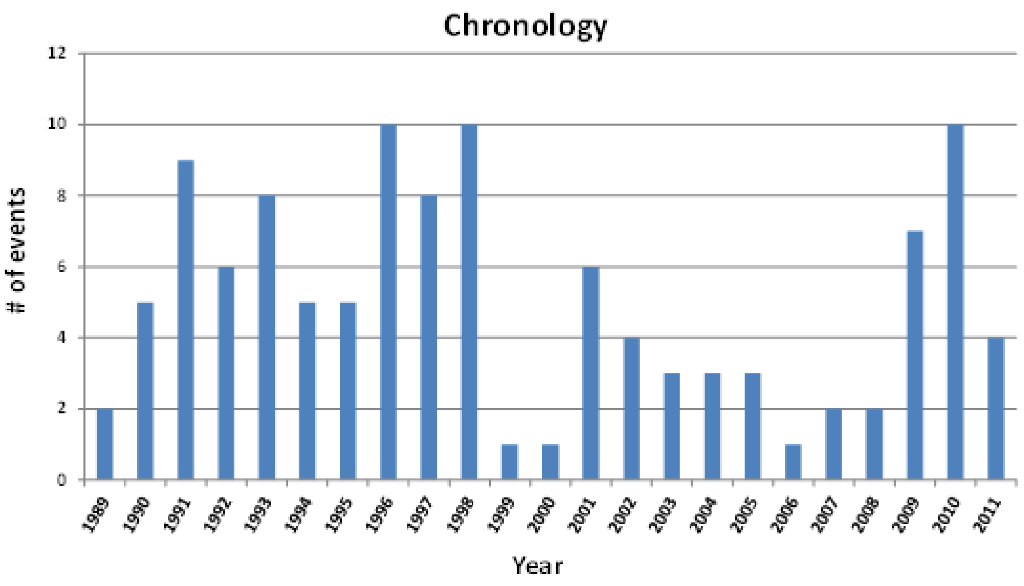

Figure 3-5. Chronological distribution of the EDG related events (U.S. NRC)

This chart should be seen as number of events per year without trying to establish relevant trend. The amount of data is relatively poor for one to be able to give a fair assessment of the trend. However, similar to the German results presented earlier within this study, a decreasing of the amount of events seems to be more likely than an increasing.

Analysis regarding the extent of the EDG related failure was also conducted. Figure 3-6 presents the distribution of the studied EDG related failures among 3 different types of failure. As obvious from the figure, one third (33%) of the studied events led to a complete failure, while 27,8% led to a potential failure. The bigger part, i.e. 39,1% of the studied events led to a degraded ability of the related EDG.

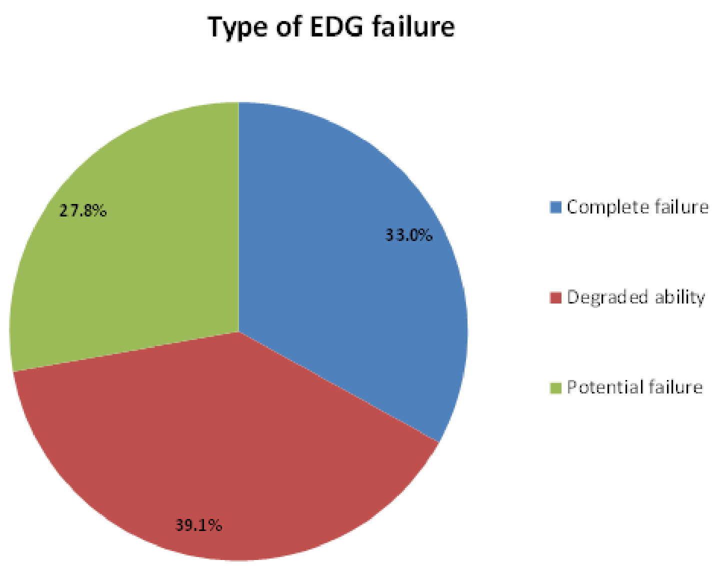

Figure 3-6. Extent (magnitude) of EDG failure (U.S. NRC)

3.4. IRS results

For the purpose of the topical study [2], the IRS database [3] was searched by specific guide words, contained in IRS Guidelines [4]. All operation modes, i.e. on power, hot shutdown conditions, and cold shutdown (reactor sub-critical and coolant temperature) were considered.

Apparently, the threshold for reporting the events into IRS is higher, compared to IRSN and GRS event databases, which allow searching the failures at the component/sub-component level. For that reason, it was not always possible to keep the same structure and level of details, as the reader can see in the previous sections for French, German or U.S. operating experience. Nevertheless, IRS database provides number of interesting events, which without any prejudice, could provide some interesting insights and trends.

Figure 3-7 shows the proportion of failure modes during which EDG failed. Modes "Fail to start" and "Fail to run" corresponds to EDG failures on demand and operation, respectively. There are also other failure modes, such as "potential fail to start / run", which correspond to the cases when EDG could potentially fail to start or run if the malfunction is not detected and fixed on time.

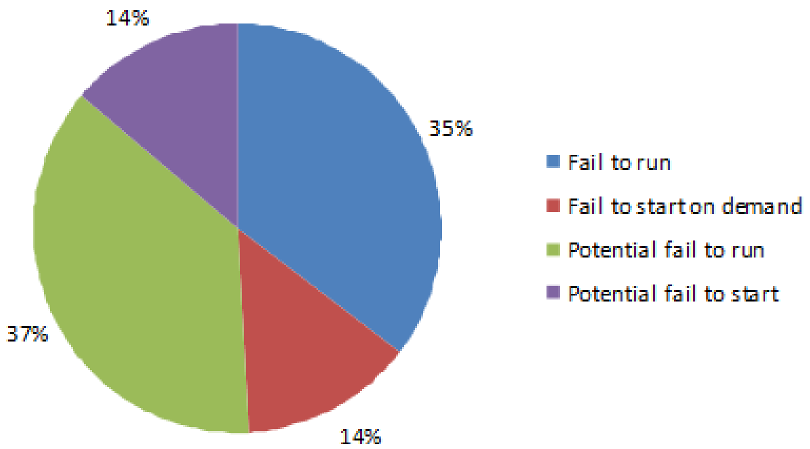

Figure 3-7. Failure modes associated with EDG failure (IRS)

Figure 3-8 shows the proportion of type of failures associated with EDG events. A number of events that lead to EDG failure were individual malfunctions. A small number were recurrent events. Two of the analysed IRS events are related to failures due to fires. One of these events is related to small fire of the EDG set that has occurred at five different plants. More specifically, in one of these five cases the fire was caused due to oil spill on the exhaust manifold gaskets implicated by bolts not properly tightened.

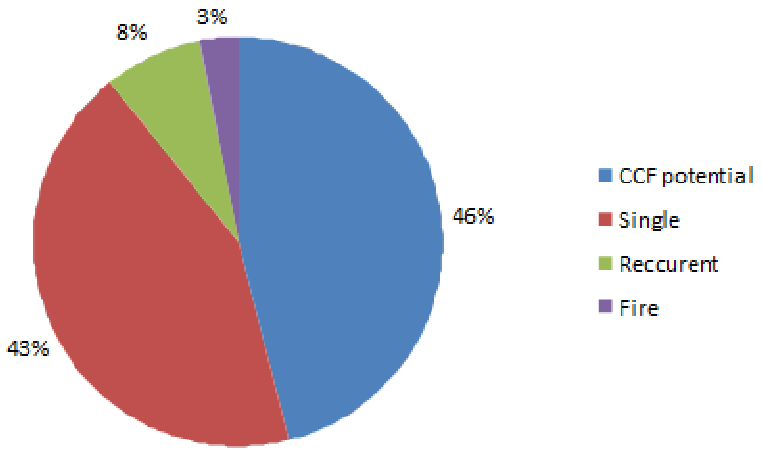

Figure 3-8. Type of failures associated with EDG events (IRS)

The number of events which have potential to common cause failure (CCF) type of failures however requires attention. These events are particularly related to problems with the plant essential service water cooling systems, use of biodiesel fuel, design error and protective device. Safety consequences of EDG CCF type failures are obvious, especially when LOOP is quite frequently reported event.

3.5. Main findings

Based on the analysis performed on the selected failure events screened from the four different databases considered (GRS, IRSN, IRS, U.S. NRC), the following main findings can be summarized:

- There is no single EDG component/ system that can be delineated as dominantly affected;
- No significant trend of increase and/or decrease of the number of reported events can be defined;
- There are a significant number of events that have a CCF potential;
- The EDG failure modes "fail-to-run" and "potential fail-to-run" were found to be relatively high, i.e. can be delineated as EDG dominant failure modes;
- The safety consequences differ depending on the type of failure:
  - medium – in case of a single component failure;
  - significant, in case of CCF;
- Most of the failures were detected during test/inspection/maintenance;
- Tests performed on EDG reduced power output level were proven to be ineffective in detecting some problems.

4. RECOMMENDATIONS

Based on the analysis performed on the selected EDG related events from all the four databases and consequently the lessons learned, recommendations how to tackle the challenging issues were compiled. These recommendations are brought to the attention of regulators, operators, as well as manufacturers. They are grouped into 6 main categories as follows:

1) Preventive maintenance and testing
   - The maintenance, surveillance, periodic testing of EDGs should be consistent at various NPPs of same design. This ensures the availability of the entire EDG sets, including starting compressed air, water cooling, lube oil and fuel systems, as well as the protections and the speed governor.

- The plant operating and maintenance personnel should be properly trained to use rigorous procedures and practices when maintaining, testing, or repairing EDG. Quality of maintenance activities should be properly oversight by management staff.
- Each EDG has to be clearly labelled in their room in order to avoid mixing between the plant redundant equipment.
- One NPP experienced several common mode failures during EDG start-up. All EDGs had to start in all instances simultaneously to achieve a synchronous supply of the emergency bus bars. The lesson learned showed that EDG was able to supply only one safety bus bar which had to be isolated from the plant buses. This "coupled" start-up procedure was eventually abandoned. Currently, there is no need for simultaneous start-up of all EDG, because no synchronization is required.
- EDG run test, which is typically performed every four weeks, should last at least one hour in order to avoid carbon deposits at fuel injection nozzles. The closer analysis of the carbon deposits revealed that the diesel engine is not sufficiently warmed up during the short test run, despite the preheating of the lubrication oil.

2) Manufacturing and spare parts

- The plant should improve attention to preventive maintenance programs in order to better anticipate the expiration dates of consumables and to prevent non-compliance of the replacement parts on the stock.
- Licensees should inform manufacturers of spare components about any non-conformance noticed on EDG parts in order to improve EDG reliability.
- The plant should follow on available spare parts at the market so that to better anticipate the components' obsolescence with regard to available spare parts.
- Before replacing the original component with a spare component, the conformity of the spare part with the original design specifications has to be ensured.
- Each non-conformance noticed during the operation of an EDG should be communicated to the manufacturer, and the manufacturer should consider it.

3) Operating Experience Feedback

- The evaluation of operating experience is an applicable and powerful tool to identify important safety issues and changes in the reliability of EDG. These issues may be important precursors to more serious events.

- When non-conformity is detected on EDG components, these components should be re-inspected on all EDG sets of the same or similar design.
- The plant should analyse operating experience regularly in order to detect specific system / component failures and implement corrective measures in order to prevent recurrence of similar errors.
- The OE implies the need for attention that should be paid to the generic character of some failures and the risk of common cause failure among multiple EDGs for the same NPP unit. In particular, activations of non-priority protections should be recorded and analysed. Even if they do not cause the trip of the EDG in case of emergency operation, they reveal the risk of failure of the EDG in that situation.
- The plant design basis should ensure that induced failures due to internal and external disturbances in the plant electrical systems, which can cause voltage transients (such as voltage drop, overvoltage, short circuit, lightning into the overhead power lines or plant buildings) and the resulting electromagnetic effects should not either propagate inside the plant electrical systems important to safety or compromise performance of these systems. The following is recommended:

    a) Relevant operating experience from NPP as well as conventional plants should be reviewed in order to identify any electrical disturbances / transients that could have impact on the plant design basis;

    b) The effects of electrical disturbances / transients should be compared with current protective measures of the emergency power supply system considering the state-of-the-art technology. This applies in particular to correct selectivity settings of the electrical protective devices. Reviews may involve the use of analytical methods as well as experimental investigations. If necessary, simulations can be used to determine possible effects. Failures of individual protection devices of the main power output, main generator, grid connection, and back-up power supply should be considered;

    c) Any weakness identified in the previous step should be assessed for their safety impact and particularly those which may lead to CCF. Necessary corrective measures should be timely implemented.

4) Protective devices [e.g. emergency stop button, low lube oil pressure protection, generator overspeed protection, generator differential overcurrent protection, etc.]

- Prior to every EDG periodic test the main systems and components, necessary for the EDG operation, should be checked. This involves control and monitoring devices, checking the functionality of individual components of the diesel engine, etc.
- EDG protective devices should be inspected periodically. Correct value settings should be maintained and properly documented according to their safety significance.
- Protective devices of the associated EDG safety bus should also be inspected periodically (including correct settings). It is important to verify a function of a bus load shedding, i.e. disconnecting all loads before connecting the EDG, in order to avoid EDG overloading. The sequencer setting should ensure that EDG is properly loaded in time. The sequence of equipment connected to the EDG bus shall comply with results of DBA.
- Devices that are required to start the EDGs and to engage and connect loads should be supplied from uninterruptible power supply (UPS) in order to improve the EDG reliability.

5) Reliability

- In order to prevent spurious disconnection of EDG in case of real demand, the EDG electrical and diesel engine protections, which in some instances have a higher priority than the reactor protection system, should be highly reliable. To achieve this high reliability, a protection input signals should have 2 or 3 inputs, with a voting logic 2 out of 2 or 2 out of 3. It is recommended to check all EDG, whether the important parts of the EDG protection system, which have a higher priority than the reactor protection system, are built with multi-channel input signals with a voting logic. If not, EDG protection system should be upgraded.
- Specific attention should be paid to the definition and setup of the limiting values of EDG support equipment governing parameters. Namely, by correctly setting the values of the alarm governing parameters, events in which the unavailability is considered only by definition and has no consequences on the technical availability of the EDG can be avoided. Thereby, the possibility of unnecessary and unwanted automatic declaration of the EDG as unavailable will be minimized / eliminated.
- Identical procedures should be applied for the preventive maintenance and surveillance testing of EDG at different NPP sites operating the same or similar EDG sets. This ensures the availability of the entire EDG sets, including starting compressed air, water cooling, lube oil and fuel systems, as well as the protections and the speed governor.

6) External events

- To review regularly (e.g. once per 10 years) the plant design basis for any potential risk from external events (flooding, earthquake, severe weather conditions). The original assumptions used in initial safety analysis to determine the plant design basis may be either too old, or may become insufficient (or inaccurate). This may lead to a situation where the emergency power supply systems, including essential supporting systems may not be sufficiently qualified to anticipate external events than originally envisaged. Regular surveillance testing and maintenance cannot however reveal potential design deficiencies to external events.

5. CONCLUSIONS

The analysis of almost 700 events confirmed that EDGs have a significant potential to lead to CCF and that tests, inspections and maintenance activities are of paramount importance in order to reduce the risk of EDG failures. The study showed also that in addition to tests, inspections and maintenance, it is necessary to adopt a structured and comprehensive approach to assess risks related to EDG, including the manufacturing stage and the supply of spare parts, the EDG reliability, and the protection against external events, and to update this approach regularly considering the operating experience.

6. LIST OF ACRONYMS

AEG	Allgemeine Elektricitäts-Gesellschaft
BHB	Betriebshandbuch
BWR	Boiling Water Reactor
CCF	Common Cause Failures
DIN	Deutsches Institut für Normung
DBA	Design Basis Accident
EDF	Électricité de France
EDG	Emergency Diesel Generator
EFWS	Emergency Feedwater System
ENER	Directorate General for Energy (European Commission)
ENSREG	European Nuclear Safety Regulators Group
ESFAS	Engineered Safety Feature Actuation System
ETSON	European Technical Support Organization
EU	European Union
GRS	Gesellschaft für Anlagen- und Reaktorsicherheit mbH
IAEA	International Atomic Energy Agency
I&C	Instrumentation and Control
IET	Institute for Energy and Transport

INES	International Nuclear Event Scale
IRSN	Institut de Radioprotection et de Sûreté Nucléaire
JRC	Joint Research Centre
KTA	Kerntechnischer Ausschuss
kW	Kilowatt
KHD	Klöckner-Humboldt-Deutz AG
KWU	Kraftwerk Union AG
MAN	Maschinenfabrik Augsburg-Nürnberg
MMB	Maybach-Motorenbau GmbH
MW	Megawatt
MWe	Megawatt Electric
MCC	Motor Control Centre
MOV	Motor Operated Valve
MTU	Motoren- und Turbinen-Union
NPP	Nuclear Power Plant
OECD/NEA	Nuclear Energy Agency
OEF	Operating Experience Feedback
PWR	Pressurized Water Reactor
SACM	Société Alsacienne de Constructions Mécaniques
SEMT	Societe d'Etudes de Machines Thermiques
SBO	Station Black Out
TOER	Topical Operational Experience Report
US NRC	U.S. Nuclear Regulatory Commission
VERA	Vertiefte Auswertung

7. REFERENCES

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[2] Topical Operation Experience Report on Events related to Emergency Diesel Generators, European Clearinghouse on NPP Operational Experience Feedback, DG-JRC, IET Petten, 2013.

[3] The International Reporting System for Operating experience jointly operated and managed by OECD Nuclear Energy Agency (OECD/NEA) and International Atomic Energy Agency (IAEA).

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APPENDIX: LESSONS LEARNED

This following table summarizes the lessons learned from the selected events analysed in details within the topical study [2].

CATEGORY	LESSONS LEARNED
Mechanical components (engine-related)	- The OE shows that when replacing reportedly identical components, particular attention must be paid to the qualification of these parts; - Additionally, an emergency stop button should be installed outside the EDG/additional EDG compartments in order to trip the engine in case of fire; - Periodic tests at 30% load cannot reveal malfunction which may likely to occur at 100% load. This creates a risk of possible unavailability between two annual tests at 100% load. Consequently, it becomes questionable whether the tests at 30% load are always sufficient after maintenance regarding to this risk; - Specific attention should be paid to the EDG scavenging air blower, especially during surveillance testing involving fast starts. Potential repairs may take longer that the allowed outage time (AOT) which, in turn, may implicate unscheduled shutdown.
Diesel engine air starting system	- Attention should be paid to the proper testing of the solenoid pilot valves of the air starting system. Namely, the valves should be tested at both the design basis low voltage and low pressure conditions; - Special attention should be paid to the seismic qualification of the non-safety related tubing of the air staring system. Potential failure of the air starting tubing due to seismic event would render the related EDGs inoperable. In case where the air starting tubing is related to multiple air start headers corresponding to multiple EDGs, its potential failure due to seismic event would implicate CCF of all the EDGs.

CATEGORY	LESSONS LEARNED
Diesel engine cooling system	– Special attention should be paid to the thermostatic valves of the diesel engine cooling system. There are several events reported that are related to anomalies concerning the EDG thermostatic valves of the cooling system. The surveillance of these valves should be enhanced. The post-maintenance quality assurance should be improved, i.e. it should include inspections of the retaining rings (these rings ensure the connection of the internal part of the valve between the servomotor and the valve) conformity mounting in the valve internal parts; - The maintenance procedures should provide adequate level of detailed instructions on proper installation of the gasket between the exhaust belt and the coolant inlet bypass fitting. More specifically, the procedures should provide guidance and details how to tighten the adjusting fastener without impacting the gasket joint compression; - Special attention should be paid to the effects that the humid salt-laden atmosphere could have on EDG structural support component, especially the radiator flat tubes. In that aspect, engineering personnel training programs should be established in sites where this or similar events related to the effects of salt-laden atmosphere are applicable. Also, the preventive maintenance program and procedures should be complemented and/or revised in order to incorporate cleaning instructions and time-based criteria for the EDG radiators.
Diesel engine exhaust system	- Clear instructions, which will guarantee adequate implementation of the work control process regarding the field welding of the flange to pipe connections of the EDG exhaust system, should be provided by the vendor.

CATEGORY	LESSONS LEARNED
Diesel engine lubrication system	- A particular attention should be paid to the effects that the ambient temperature has on the diesel engine lube oil viscosity and ultimately lube oil pressure. A low-lube-oil-pressure alarm may render the EDG unavailability by an automatic trip. Areas of external lube oil piping (e.g. the main lube oil filter, main lube oil strainer, the associated interconnecting piping, sensing lines for the lube oil pressure switches) should be identified. Lube oil piping temperatures should be recorded. In this aspect, vendors should assess the actual heating demand in the EDG room, and consequently, depending on the outcome different coping solutions should be envisaged (e.g. placing different temporary area heaters) ; - The EDG lube oil system check valves are specific component that requires special attention. Surveillance/maintenance procedures should comprise a requirement for verification that these lube oil check valves have seated correctly by performing a verification that a differential temperature exists across the check valve. The potential consequences of an eventual lube oil leakage from these valves can be significant. Namely, as a result of a check valve leakage, lube oil will be distributed to the engine head which could then seep into the engine combustion chamber. Accumulation of lube oil in the engine combustion chamber could cause substantial damage upon engine start because of hydraulic lockup.

CATEGORY	LESSONS LEARNED
Diesel fuel and fuel supply system	- The potential impacts of B5 type fuel should be evaluated so that the EDG operation remains within the design and licensing bases. Specific attention should be paid to the following: • Prevent build-up of the sediment discussed by: cleaning the fuel oil storage tanks before putting B5 in them; adding and/or upgrade the filters in the fuel oil system; • Prevent the formation of dirty water and the subsequent growth of algae by: using a moisture dispersant and biocide in fuel oil storage tanks containing B5; adding a fuel/water separator to the fuel oil system; • Avoid damage caused by fuel degradation, licensees may consider not using B5 if it has been stored for an extended period of time (approximately 3 to 6 months or longer); • Avoid using zinc linings, copper pipes and fittings, and brass regulators with B5; • Evaluate and ensure adequate low temperature protection for all diesel generator system components; - Similarly, licensees should evaluate the potential impacts of the new ultra-low-sulphur diesel (ULSD) fuel oil so that the EDG operation remains within the design and licensing bases; - Attention should be paid to the lubrication of the bearings of the EDG fuel transfer pumps. A preventive maintenance activity for lubrication of these bearings should be developed in cases where there is not one; - Attention should be paid whether the start of the electric driven fuel oil pump during performance of the monthly EDG load test could mask early detection of a potential failure of the EDG engine driven fuel oil pump. Namely, the EDG monthly load test procedures should be such to eliminate pressurizing of the fuel oil line prior to start-up by turning off the electric driven fuel oil pump; - Fire protection isolation should be ensured for all supporting equipment going through pre-designated fire areas.

CATEGORY	LESSONS LEARNED
Electrical failures	- The EDG circuit breakers that comprise tension rings require specific attention. Namely, the usual testing concept, which consists only of the test switching, is not sufficient to detect early failure of the pretension devices. Therefore, a periodic measuring of the spring characteristics should be incorporated within the preventive maintenance procedures for this type of EDG circuit breakers as a way to detect breaker early failure; - The OE shows that the EDG field diode rectifier bridges are highly susceptible to high voltage transients. Maintenance procedure should be, where possible, accordingly adapted/revised in order to assure that the motor-operated potentiometer (MOC) is left in mid-position to assure any residual energy in the MOC coil has a dissipation path; - The OE has also shown that the EDG automatic voltage regulator (AVR) is a sensitive component, which very often can render the EDG inoperable. Moreover, identification of the failure cause and subsequent repair can often breach the corresponding LCOs implying a necessity for unscheduled unit shutdown. Therefore, surveillance testing and preventive maintenance for the AVR should be given a special attention.
Maintenance	- The nut which holds the fuel flow limiter adjuster needs specific attention. A spurious tightening of this nut during post-maintenance assembly of the fuel flow limiter may potentially render the EDG unavailable. The fuel flow limiter manufacturer should provide specifications regarding the tightening torque; - All the specification of the EDG supporting equipment related to the conduct of specific preventive maintenance should be followed and satisfied in details. Maintenance personnel's lack of attention / failure to torque the cooling fan bearing bolts till the exact extent specified by the vendor may render the EDG inoperable; - During maintenance work on tubings (air, oil) connected to the EDG support systems , special attention should be paid to the post-activity configuration of the tubings (geometry, fixation..) , as an improper configuration combined with the EDG normal vibration can lead eventually to the damage of the tubings.

CATEGORY	LESSONS LEARNED
Human error	- Special attention should be paid to the labelling in the EDG room. A distinct and sufficient labelling should be used in order to create barrier preventing crossing over to active systems or trains. Procedures should be revised as necessary to require the use of barrier tape as an aid to restrict access to operable equipment whenever work activities involve closely located similar equipment. Distinctive labelling and/or protective covers/plastic seals should be implemented on "emergency stops"/"stop" buttons in order to avoid spurious activation by e.g. caused by cleaning activities carried out in vicinity; - The OE has once more emphasized the importance of the annual overload (110%) test. E.g. the incorrect adjustment at the control linkage of the fuel injection system can be detected by this type of testing; - In general, for any work close to the EDG compartments the associated risks should be analysed and necessary protections measures should be made. In specific, it should be ensured that electro-welding, particularly with high-frequency ignition, is not carried out close to EDG. If during power operation electro-welding cannot be avoided, it should be ensured through analysis of the planned workflow and associated risks that remaining EDG redundancies are available; - The OE shows that the extent of the damage that sand-particles polluted air can implicate on the EDGs, and consequently, render their degraded ability and/or their unavailability. Therefore, licensees should undertake corresponding measures to prevent EDG room air pollution with hard particles, e.g. by sealing the air openings of the EDG room when carrying out sandblasting activities in the vicinity; - The OE proves the high importance of the annual full-load test. Attention should be paid to the correct mounting of the fuel injection mechanisms seal clamps. Incorrect mounting of these clamps will limit the fuel injection to the diesel engine and render the EDG degraded ability, something that cannot be identified by the periodic 30%-load tests. The plant procedures should be augmented so that to carry out the operating tests on full power every year after any intervention on the EDG;

CATEGORY	LESSONS LEARNED
Human error	- The EDG room openings, which allow the admission of external air for the operation of the diesel engine as well as the cooling of the EDG premise, should be regularly controlled. These openings should be equipped with position indicator in order to eliminate any inadvertent total closure by the personnel which, in turn, will render the corresponding EDG unavailable; - A special attention should be paid to the EDG wiring labelling. Test and maintenance personnel should perform labelling modifications after every single design change that takes place.
External events	- The influence of the environmental conditions and their coupling with eventual extreme values of some of the EDG control parameters has to be considered. Special attention should be paid to the EDG prolonged starting time due to very cold intake air in the charger air cooler concurrent with a cold cooling water temperatures in cases of EDGs without internal pre-heated engine cooling water circuits; - Specific attention should be paid to all the anchoring screws of all the EDG supporting equipment. Their slightest loosening may progress in time (e.g. due to vibration during operation) and eventually be decisive in case of external events influences (e.g. earthquake) which can then render the EDG unavailable.

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Abstract

The availability and operability of the EDGs is acknowledged as crucial for NPP safety during plant operation as well as during outages. The Stress Tests conducted in the European Union Countries following the Fukushima accident showed the importance of EDG as the vital stand-by source of AC electrical power. In that direction, a Topical Operation Experience Report on Events related to Emergency Diesel Generators [2] was generated. This topical report aims at analysing operating experience for the past twenty years and identifying events that involved failures of EDG due to various types of failures. The selected operating experience contained in event reports was further analysed in order to identify type of failure, attributes that contributed to the failure, EDG failure mode potential or real, discuss risk relevance, provide recommendations and summarize important lessons learned.

A time span of about 20 years was used to identify EDG related events. Four different databases (GRS, IRSN, IRS and U.S. NRC) were screened for relevant EDG related events. Based on the different statistical analysis performed, a list of general recommendations related to specific issues identified by analysing the OE was generated. These recommendations were grouped in 6 main areas: preventive maintenance and testing; manufacturing and spare parts; operating experience feedback; protective devices; reliability; external events. At the end of the report, a table summarizing specific lessons learned is provided.

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