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TEST AND MAINTENANCE OF THE EMERGENCY POWER SUPPLY IN THE NUCLEAR POWER PLANT BIBLIS

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ABSTRACT

Besides design and construction test and maintenance play an important role for the availability of the emergency power supply. As an example test and maintenance provided for the emergency power supply in a german 4-loop PWR will be desribed. In general one has to differentiate between test and maintenance performed during power operation of the plant and those carried out during the refuelling outage. For both periods of operation detailed information will be given including type, extent and frequency of test and maintenance work. The results of test and maintenance up to now will be discussed.

1. Introduction

The paper deals with test and maintenance on the components of the emergency power supply. Main emphasis is be put on emergency diesel generators and batteries, since for these components the scope of the tests as well as the number of defects is the largest. Besides the results of the tests the experience gained and the measures resulting from it are presented.

2. General Information on the Nuclear Power Plant Biblis

The NPP Biblis has two units and is located 10 km north of the city of Worms on the east bank of the Rhine River. Operator of the plant is the Rheinisch-Westfälisches Elektrizitätswerk. The two units have a design output of

- 1204 MWe (unit A) and
- 1300 MWe (unit B)

The reactors are 4-loop pressurized water reactors which have been delivered as turnkey plants by Kraftwerk Union (KWU). First power to the grid was produced on

- unit A: August 25, 1974 and
- unit B: April 25, 1976

Gross power production since commissioning until May 31, 1985:

- unit A: 76702 GWh and
- unit B: 65087 GWh

3. Concept of the Emergency Power Supply System

Each unit is provided with a complete self-contained emergency power supply, which consists of four emergency diesel generators in agreement with the design concept incorporating 4 x 50% trains for emergency core cooling. The redundant trains are functional and physical separated. Each diesel generator is associated with one train. During normal operation, the 10 kV emergency switchgears are fed by the switchgears of the normal power supply system.

The major loads responsible for the emergency cooling and decay heat removal of the reactor are connected to the emergency switchgears. Each of the four 10 kV A.C. emergency switchgears feeds its own 380 V A.C. emergency switchgears (see figure 1).

A voltage drop of more than 20% in one of the 10 kV emergency switchgears causes an automatic starting of the associated diesel generating set and separation of the affected power section from the normal power supply system. Once the emergency diesel has run up to full speed, it is loaded in accordance with technical requirements, but with such time staggering of load groups that intolerable speed drops and generator voltage drops are avoided.

Each emergency diesel set is provided with a protection, consisting of five protection criteria. The individual criteria are listed in the following table.

Emergency Diesel Trip Signal	Trip Logic	Effective for Design Basis Accident
Low Lube Oil Pressure	1/1	No
High Lube Oil Temperature	1/1	No
High Cooling Water Temperature	1/1	No
Over Speed	2/2	Yes
Over Current	2/2	Yes

If one of the protection signals is initiated during test or loss of normal power supply without a simultaneous accident, the affected diesel generator is tripped. In the case of an accident the trip-signals in a 1 out of 1 logic are blocked. Thus the availability of the emergency diesel sets will be increased for an accident in connection with loss of normal power supply, because failures of an one-channel protective design do not lead to a trip of an emergency diesel generator.

4. Technical Data of the Emergency Diesel Generators

The important technical data of the diesel engines and the diesel generators are given in the next table:

	Unit A	Unit B
Diesel Engine		
Manufacturer	MTU	MTU
Rated Output	2950	3550
Number of Cylinders	16	16
Operating Mode	continuous and short-time	
Starting System	Air-to-cylinder cranking	
Year of Construction	1973	1974

Generator

Manufacturer	Siemens	Siemens
Continuous Rating (kVA)	3380	3900
Voltage (kV)	10	10
Rated speed (Rpm)	1500	1500

The operating hours and the number of starts of the individual diesel sets from the commissioning until June 1985 are shown in the next table. It may be seen that despite frequent tests the average number of 500 operating hours is very small.

	Unit A		Unit B	
	Operating Hours	Starts	Operating Hours	Starts
Emergency Diesel 1	501	515	502	510
Emergency Diesel 2	534	580	536	510
Emergency Diesel 3	555	485	470	485
Emergency Diesel 4	499	500	445	455

5. Test and Maintenance on the Emergency Diesel Sets

Concerning test and maintenance one has to distinct between

- recurrent tests which are executed in periodic intervals independent of the state of the plant

and

- preventiv maintenance causing unavailability of a diesel and recurrent tests which are executed only during refuelling outage

The content of these tests and maintenance work as well as the respective test and maintenance intervals are summarized in the following table.

Interval	Plant Status		Type of Test/Maintenance
	Operation	Refuelling Outage	
monthly	x		Test run of the emergency diesel sets including automatic reconnection of the loads
bi-annually	x		Full power test run of the emergency diesel sets
bi-annually	x		Examination of diesel fuel in the fuel tanks
annually		x	Maintenance on diesel engines (small inspection)
every 4 yr		x	Maintenance on diesel engines (large inspection)
every 4 yr		x	Maintenance on diesel generators
every 4 yr		x	Test of protection, instrumentation and control of the emergency diesel sets
upon delivery			Quality test of fuel upon delivery

5.1 Recurrent Tests

Two types of recurrent tests of the emergency diesels and one quality test of the diesel fuel are performed.

Test 1: Test of the emergency diesel set including its auxiliary systems as well as the automatic reconnection of the loads

The test is either started by simulating the loss of power signal on one of the four emergency power buses by a test switch in the reactor protection system or by opening the connection of the emergency bus to the main 10 kV bus. Thus the unit auxiliary bus is disconnected from the corresponding emergency power bus in one train.

The test sequence is identical to the sequence in the case of loss of on-site power, except for the difference that the test is not performed simultaneously in several trains. Figure 2 shows the automatic start-sequence for an emergency diesel set.

The functions which are tested in this test run are as follows:

- switch-off of the circuit breakers between the main bus and the emergency bus
- switch-off of all loads from the emergency bus
- switch-on of the pre-lube oil pump
- opening of the starting air valve
- switch-on of the fuel pump
- switch-on of the excitation
- run up of the emergency diesel set to full speed
- rise of the generator voltage to nominal voltage
- switch-on of the diesel circuit breaker to the emergency bus
- time-staggered automatic reconnection of the loads to the emergency bus.

The tests are performed monthly i.e. each week one of the four trains is being tested. In this test a load of some 30% is observed. The run time of the diesel is approximately 80 min.

Test 2: Full power diesel test

The test is performed by synchronization of the diesel generator with the unit auxiliary power grid. Each emergency diesel set has a synchronizing and parallel switching device of its own. By the speed adjusting device of the diesel engine the power output to the grid may be governed steadily up to 100%. The test interval is bi-annually. The test run time is 4 hours.

The next table summarizes some data of the tests performed until now. One can see that with some 1100 tests only 8 failures of emergency diesel units are recorded.

	Monthly Test	Bi-annual Test
Runningtime of Diesels during Test (h)	1,5	4
Load on Diesels (%)	30	100
Number of Tests Performed 1)	960	160
Number of Failures	5	3

1) Sum for all 8 emergency diesels in unit A and unit B

Apart from the tests on the emergency diesel units periodic tests are performed on the diesel fuel. Here the fuel in the tanks is subject to a quality analysis as well as each delivery prior to its filling into the fuel tanks according to a given specification. In the tests performed so far no irregularities have been observed.

5.2 Preventive Maintenance of the Emergency Diesel Sets

The preventive maintenance works on the diesel engines and the adjacent auxiliary equipment are being performed during refuelling outage. Content and intervall of the preventive maintenance are widely based on recommendations from the diesel manufacturer. The works themselves are performed by the manufaturer of the engines and the generators.

Details of the maintenance work on the diesel engines are given in the next table.

Maintenance Work	Intervall	
	annually	every 4-years
Control of Lubricant and Coolant	x	x
Cleaning of Filters and Heat Exchangers	x	x
Leak Test of Compressed Air System Revision of Air Compressors and Starting-Air Valves	x	x
Revision of Lube Oil and Fuel Pumps	x	x
Visual Inspection of Engine Bearings and Clutch	x	x
Revision and Test of Standby Heaters	x	x
Hydrostatic Pressure Check of Fuel Injection Nozzles	x	x
1h - Run with Control of all Operating Data	x	x
Demounting and Control of two Cylinder Bushings Including Pistons		x
Control of the two Accessible Connecting-rod Bearings		x
Change of Lube Oil		x
45h - Test Run with Changing Loads		x

Preventive maintenance on the diesel generator is performed every 4 years and includes

- visual control of stator winding
- insulation test of stator winding
- visual control of stator stack of sheets
- visual control of rotor winding
- insulation test of rotor winding
- visual control of rotor stack of sheets
- visual controll of bearings, change of lubricant
- visual control of slip-rings, exchange of brushes if necessary
- check of generator instrumentation

6. Operating Experience with the Emergency Power Diesel Sets

In the first years of operation a number of failures occurred during recurrent tests as well as in test runs after maintenance. Besides 5 start-up failures and 3 operating failures some other failures occured which would have allowed a continuation of operation only for a limited period (about 12 hours) without remedial action. Such disturbances were declared longtime failures.

The observed failures predominantely occurred on peripheric installations and auxiliary systems of the diesel engines, such as

- leaks on coolant pipes
- leaks on fuel pipes
- failure of tachometer
- failure of check valve in the starting-air valve
- failure of standby heater
- failure and drifting of temperature sensors.

The reason for the comparably high number of defects in the first years of commercial operation of the plant was the small overall operating time of the emergency diesel sets.

Each emergency diesel only had acceptance tests of 12 h, six of which took place at the manufacturer and six at the site. Until 1978 for each unit the operating time has been increased by some 80-100 h.

An overall operating time of this order of magnitude is definitely too short to detect weakpoints. In particular, leaks on coolant, fuel and air pipes which may be traced back to inadequate design can only be detected by longer test runs. The KTAstandard 3702 in the meantime requires for German plants a running time of the emergency diesel sets of 200 h prior to first criticality of a plant.

For integral control and detection of further weakpoints all 8 emergency diesel sets were subject to a long time test with changing loads in 1977/78. The running times amounted to 150 h per diesel. After termination of the test runs a revision was made to remedy the deficiencies and add some improvements. Since this time the frequency of defects is considerably smaller (see figure 3).
For an early detection of developing failures the following rules were set up:

- prolonged running times in the monthly tests from approximately 15 min to 80 min. During the test the diesels are controled for leaks, quietness and other irregularities.

- after failure and renewal of components subjected to changing loads a 45 h run is performed. These 45 h correspond to more than 4×10^6 revolutions of the crankshaft. With this load changing frequency the fatigue strength is reached.

7. Technical Data of the Batteries and Rectifiers

The 24-V and 220-V batteries are consisting of stationary cells with large surface plates in narrow seat design according to DIN 40738. The abbreviated battery notation for this is GroE. The cell vessels are made of glasclear plastic and are capped with tight plastic covers. Degassing is accomplished through porous ceramic plugs.
Batteries and rectifiers work in compensating charge operation. Technical data of the batteries are:

- density of acid: 1.22 + 0.01 kg/dm^3 at 20°C
- compensating charge voltage of one cell: 2.20 - 2.30 V
- number of cells per battery: 24 V = 13 cells
220 V = 108 cells

8. Tests on Batteries and Rectifiers

As on the emergency power diesels likewise intensive recurrent tests are performed in particular on the batteries. They stretch from daily visual controls of the batteries and battery rooms, where particular attention is paid to a possible vessel damage and subsequent vessel leakage, up to an every-four-years capacity test including measurement of the associated drop of voltage and of the current at the connectors.
Scope and interval of the tests are based on the recommendations of the manufacturer and widely on operating experience. Details of the recurrent tests on batteries and rectifiers are summarized in the following table:

Recurrent Test	Intervall				
	daily	monthly	bi-annually	annually	every 4-years
Visual Control	x				
Control of Temperature of Battery Rooms	x				
Control of Electrolyte Level on all Cells		x			
Measurement of Cell-voltage on all Cells			x		
Measurement of Acid Density of all Cells			x		
Visual Control of Plates (Color, Formation of Crystals, Deposits)				x	
Visual Control of Pole Penetrations (Pole Corrosion)				x	
Filling up of Cells to Maximum Level				x	
Functional Test of Charging Devices					x
Capacity Test of Batteries					x
Measurement of Voltage Drop at Cell Connectors					x
Measurement of Current on Parallel Cell Connectors					x

9. Operating Experience with Batteries and Rectifiers

The batteries work in compensating charge operation, i.e. with an undisturbed state of the plant no request is made for the batteries. A difficulty results from the fact that it is hard to determine from the outer appearance as well as from measured data if a battery will supply the required power on demand. Therefore a consequent performance of the described tests is indispensable in our opinion.
The defects observed on the batteries in both Biblis reactors are listed in the next table.

Finding	Number of Affected Batteries	Measures Taken
Plate Short-circuit	2 (1 cell in each battery)	exchange of cells (construction fault)
Pole Corrosion	8	exchange of batteries for batteries with tight pole penetrations
Cracks in Battery Vessels	8	exchange of batteries for batteries with greater vessel wall thickness

In the following the failure modes observed in the Biblis plant are discussed in some more detail:

a) Plate Short Circuit on two Battery Cells

Detection was made due to low acid density and too low cell voltage. Both cells were exchanged.

b) Pole Corrosion on eight 24-V Batteries

Pole corrosion was detected by visual control. The corrosion starts at the penetration of the positive poles just below the cell covers causing heavy corrosion of the lead pole. With a copper inlay even this copper is attacked by the acid in a short time. Complete corrosion of the pole beneath the cover is possible. Since the resulting corrosion products are very voluminous, pending on the construction of the pole sealing, the damage may become apparent as follows:
if flowable material is used for sealing (e.g. vaseline), this is pushed outwards from the sealing and thus makes visible the corrosion. If the pole penetrations are provided with a solid coat of plastic, the volume increase may lead to a cracking of the cover.
The 8 batteries were exchanged for new ones for which, according to the information from the manufacturer, pole corrosion may no longer occur due to an improved construction.

c) Cracks in Battery Vessels

Vessel cracks develop favorably on large vessels (batteries with high capacity). They are observed at the edges of the interior wall of the vessels and run downwards. In unit A on a total of 8 batteries such vessel cracks were detected with the crack depth having reached partially 50% of the wall thickness (see figure 4). All batteries had to be exchanged. The cause for these cracks is too high stress on the plastic material from the weight of the positive lead plates, which are fixed to supporting edges of the vessel, as well as from the weight of the acid. This stress causes strong buckling of the side walls and subsequently crack formation in the edges. The new vessels have stronger walls. In addition, the vessel construction was changed such that all edges were rounded off and thus are less susceptible to crack formation. As a very effective countermeasure has proved the placing of the battery vessels into so-called earthquake-protected rack arrangements. Apart from their seismic design the racks have the advantage that they enclose the vessels tightly and thus preclude bulking.

d) Increased Contact Resistance at Cell Connectors

Measurement of voltage drop at cell connectors has also proved important (see figure 5). With this method a number of bad soldered joints could be detected (defects during construction).
Capacity measurements showed good values this far on all batteries. None of them fell short of nominal capacity. With charging devices good experience has been made as well. No remarkable defects have been observed on these devices.

11. Summary

The emergency power supply systems of both units of the nuclear power plant Biblis work reliable.

Scope and intervals of the recurrent tests and preventive maintenance measures have proved necessary and appropriate. They largely correspond to the KTA-standards 3702 (emergency power supply facilities with diesel units) and 3703 (emergency power supply facilities with batteries and rectifiers).
Extensive test runs with diesel units are essential prior to plant acceptance by the operator to detect deficiencies and weakpoints and to remove them.

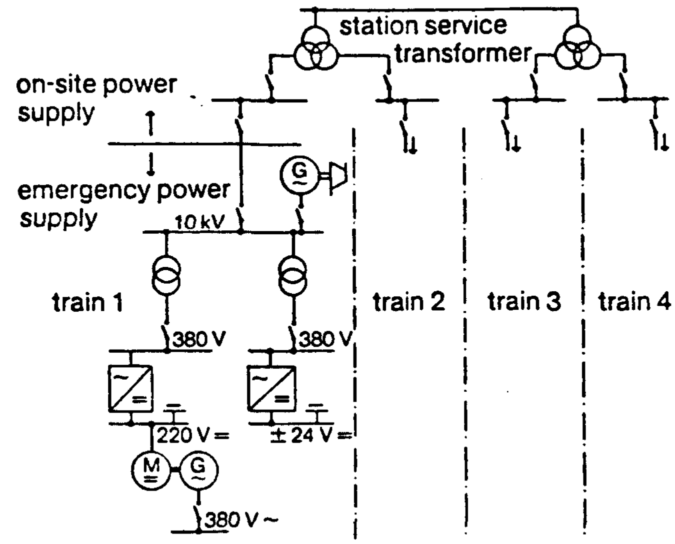

Fig.: 1 EMERGENCY POWER SUPPLY OF NPP BIBLIS B - SIMPLIFIED DIAGRAM

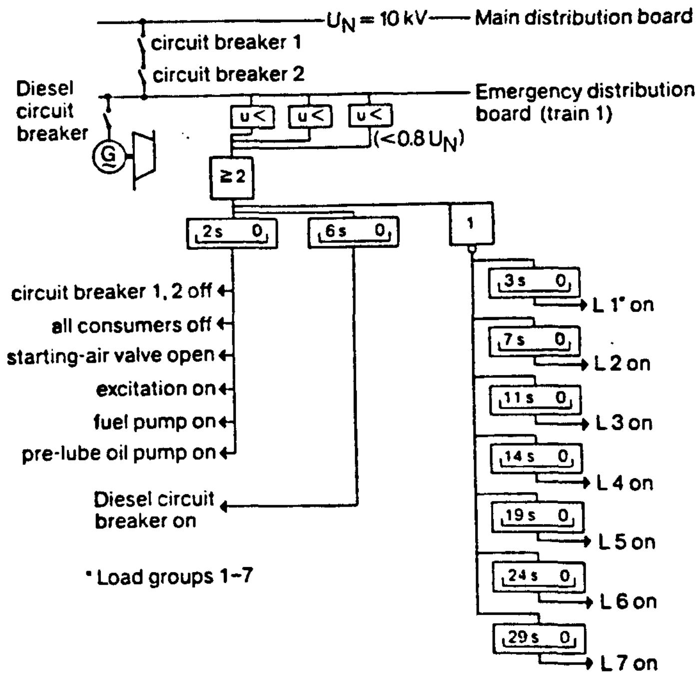

Fig.: 2 DIESEL GENERATOR - AUTOMATIC START SEQUENCE

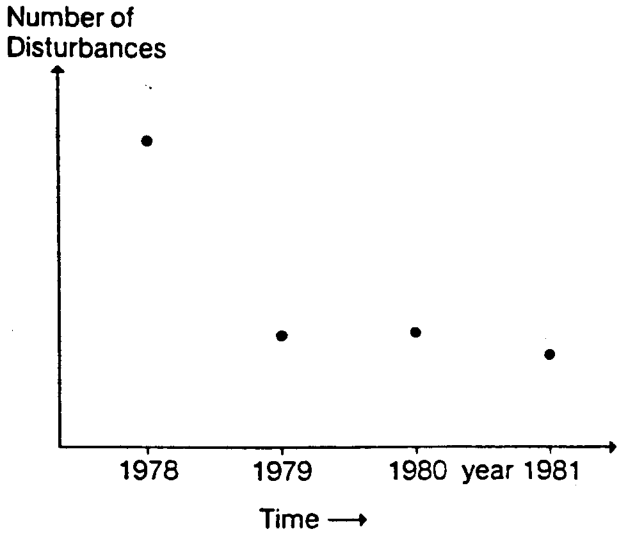

Fig.: 3 NUMBER OD DISTURBANCES AFTER LONG TIME TEST IN 1977/78

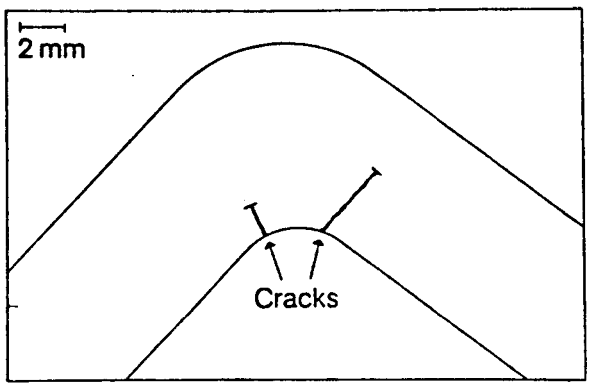

Fig.: 4 BATTERY VESSEL CRACKS

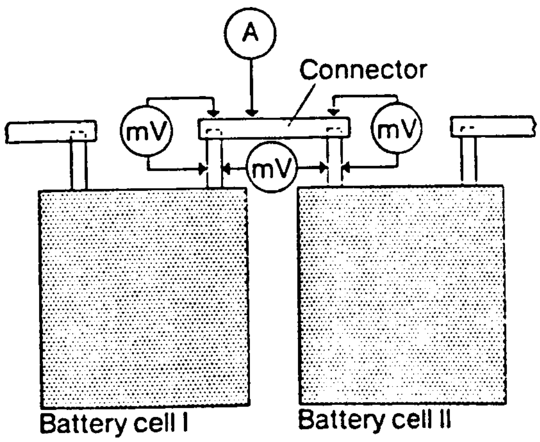

Fig.: 5 VOLTAGE DROP MEASUREMENT AT BATTERY CONNECTORS