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# Reliability analysis of Diesel Generator power supply system of Prototype Fast Breeder Reactor

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## HIGHLIGHTS

- The unavailability of DG success is 4.75E−3 for 2/4 and 1.47E−3 for 1/4.
- Modeling includes sub systems like CB, SSWS, Fuel oil system & 220 V DC.
- DG-FR, DG-FR-CCF and DG maintenance is major contributors of DG unavailability.
- Uncertainty analysis has been carried out through Monte Carlo simulations.
- Sensitivity analysis identifies DG mechanical FR as most sensitive part.

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## ABSTRACT

The unavailability of Diesel Generator power supply system has been evaluated using Fault tree method with ISOGRAPH reliability software and is found to be 4.75E−3 for 2/4 (DG success) and 1.47E−3 for 1/4 (DG success). Common cause failures contribute significantly to the unavailability of the system. Statistical analysis indicates that the DG unavailability is uncertain by Error Factor 4.4 (90% confidence bound) for 2 out of 4 DG system (system success) and by Error Factor 4.1 (90% confidence bound) for 1 out of 4 DG system (system success). Support systems namely Safety related service water system, Fuel oil system and circuit breaker control power supply dependency have been modeled. Results of importance analysis and sensitivity study are used to identify significant contributors to unavailability. DG fails to run, DG fails to run due to CCF and DG maintenance out of service is identified as dominant and important contributors of DG unavailability. Uncertainty analysis has been carried out through Monte Carlo simulations.



## 1. Introduction

The availability of electrical power is essential for the safe operation of nuclear power plants in prevention and mitigation of accidents. Offsite power supply from the electric grid (Class IV) is the main source of electric power to which the plant is connected. During loss of offsite power, Diesel Generators (DG) provides onsite electrical power (Class III) (NUREG-CR-5500, 1987). A total loss of power called "Station Blackout" (SBO) occurs as a result of complete failure of both offsite and onsite power supply (Ramakrishnan et al., 2008; USNRC RG 1.155, 1988). Unavailability of electrical power can lead to a significant undesirable impact on plant ability to achieve and maintain safe shutdown conditions (Wong, 1984). Based on concerns about SBO risk, reliability analysis of Diesel Generators has been performed in this paper. In order to obviate the concerns, a comprehensive analysis including System Modeling, Fault Tree Analysis (FTA) and common cause failure (CCF) analysis have been performed to ensure the reliability of Diesel Generators (DG) of Prototype Fast Breeder Reactor (PFBR).

Several studies exist for reliability analysis of Diesel Generator power supply system (NUREG/CR-2989, 1983, NUREG-CR-5500,

*Abbreviations:* PFBR, Prototype Fast Breeder Reactor; FBTR, Fast Breeder Test Reactor; CB, Circuit Breaker; SBO, Station Blackout; FTA, Fault Tree Analysis; CCF, common cause failure; DG, Diesel Generators; EMTR, Emergency Mean Transfer Relay; SSWS, Safety related service water system; EF, Error Factor; RCB, Reactor Containment Building; PCC, Power Control Centres; MTTR, mean time to repair; NICB, Nuclear Island Connected Building; LT, low tension; PSA, probabilistic safety assessment.

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1987, Wong, 1984; Harry et al., 1996). Volkanovski et al. (2009) demonstrated the reliability analysis of power supply system using Fault tree method. NUREG CR-5994 (1994) has demonstrated maintenance and failure unavailability and their risk impacts on Diesel Generator. Lilleheier (2008) demonstrated analysis of common cause failures in complex safety instrumented systems. van der Borst et al. (2001) demonstrated procedure for importance analysis.

As such there is no difference between Diesel Generator of Light Water Reactors and Fast Reactors. This study is for sodium cooled, Tank Type Fast Breeder Reactor.

DG subsystems failure often makes significant contribution to system unavailability. This study is significant because it includes explicit addition of sub systems like Circuit Breakers (CB), Safety related service water system (SSWS), Fuel oil system and 220 V DC Power Supply. Unavailability due to preventive maintenance has been considered in this analysis. The data used in the quantification of the unavailability of Class III power system is taken from generic source. Importance analysis has been performed to identify significant contributors to unavailability. Sensitivity analysis of DG components has also been performed. Results for unavailability have been computed and compared with existing DG unavailability.

In present analysis, details about Class III and Class IV power supply system is provided. The schematic of DG configuration has been outlined. Unavailability of DG has been estimated for 2/4 failure and 1/4 failure. Success criteria of DG have been included at both 6.6 kV and 415 kV Bus levels. CCF analysis has been done for DG components. Human error has been assumed for manual closing of intra division tie Circuit Breaker between bus sections in a division. Uncertainty analysis has been carried out through Monte Carlo simulations.

## 2. System description

### 2.1. PFBR brief description

The Prototype Fast Breeder Reactor (PFBR) is a 500MWe, sodium cooled, pool type, mixed oxide fuelled reactor (PFBR-FSAR rev-0, 2010). There are two Primary Sodium Pumps (PSP) in the primary circuit. They maintain the sodium flow in primary circuit. The heat from primary sodium is transported from Intermediate Heat Exchangers (IHX) to steam generators (SG) by two secondary sodium loops. Each secondary sodium loop is provided with one Secondary Sodium Pump (SSP). Each secondary sodium loop is connected to four steam generators. Totally eight steam generators produce steam to run the turbine. Reactivity control and decay heat removal are the important safety functions in any reactor. The reactivity control in PFBR is carried out by two independent fast acting diverse Shut Down Systems (SDS). There are two decay heat removal systems in PFBR namely Operating Grade Decay Heat Removal System (OGDHRS) and Safety Grade Decay Heat Removal System (SGDHRS). The shutdown system and decay heat removal systems are the frontline safety systems in PFBR. The frontline safety systems depend on several support systems like power supply systems, service water system and compressed air system. In the present analysis reliability analysis of Diesel Generator power supply system of PFBR is performed.

### 2.2. Class III power supply

Class III buses receive power from Class IV supply under normal conditions of operation. Diesel Generators are the source of onsite power to Class III buses under loss of Class IV power (FSAR Chapter-9, 2014). The Class III power supply system is provided with two independent divisions located in Electrical Building 1 and Electrical Building 2 respectively. Class III power supply scheme is shown in Fig. 1 (PSAR Chapter-9 2004). Each division is having its own 6.6 kV bus arranged in two sections. The two sections of the division -1 receive the normal power supply (Class-IV) feeder from the unitbus-1 and station bus-1 respectively. Similarly the two sections of the division -2 receive the power supply (Class-IV) from the unit bus-2 and station bus-2. Each section is having an incomer from an independent DG. The two DG sets of a division are located in two different DG buildings. The Class III 6.6 kV buses are normally supplied from the unit buses and station buses with the bus couplers of Class III 6.6 kV buses open. When a feeder from the unit bus trips due to cable fault (feeder fault), the feeder from the station bus will feed the Class III 6.6 kV bus by auto closing the bus coupler breaker. The change over time is about 500 ms. The bus change over is a normal operation in any power plant. The bus changeover is carried out through numerical check synchronizing relay. There are 4 DG sets and one each is connected to one section of Class III power supply bus at 6.6 kV level. The DGs are not designed for operation in parallel in order to have redundancy in the supply capacity (USNRC RG 1.6, 1971). Each DG is capable of taking 50% (2.25 MVA) of its capacity as first step load and subsequently DG is capable of taking 25% (1.125 MVA) load steps after every 4 s. When, one out of two primary sodium pumps is not available for operation, the other primary sodium pump main drive motor is to be run at 40 percent of the rated speed for decay heat removal. Each DG is rated to supply emergency loads connected to the respective Class III bus and the power required to run one primary sodium pump (420KVA) at a speed of 40% of the rated speed.

The 4 DGs are housed in two independent DG building. The two units housed in one DG building are physically segregated from one another by fire barrier wall and each DG is also functionally independent from the other. The two DG building are separated from one another. One DG building is located on the eastern side of the Nuclear Island Connected Building (NICB) and the other is located on the western side of the NICB. The cooling water systems for the two DG buildings are also independent. All the auxiliaries of a DG set are fed from the same section of the 415 V system bus to which the DG set is connected. The main and standby air compressors of all DG sets are fed from Class III.

A schematic diagram of Class III power system is shown in Fig. 1 (PSAR Chapter-9 2004). At 6.6 kV level, there are two divisions of Class III buses with two bus sections per division with 1 DG connected to each section. Bus sections within a division are connected by inter-sectional bus-couplers (auto). There is an inter-divisional tie line and Circuit Breakers which can be closed manually to provide power to a bus (when its normal supply is lost) from a bus in the other division. Further details regarding Class IV and Class III power supply systems are available in Reference (PSAR Chapter-9 2004).

### 2.3. System boundary

Diesel Generator boundary is shown in Fig. 2. These boundaries are consistent with the boundaries identified in similar studies (NUREG-1032, 1988, and NUREG/CR-2989, 1983). The boundary of the EDG includes combustion air intake and exhaust system, lubricating oil, fuel oil system (including day tank) and the starting compressed air system. DG oil storage capacity planned is adequate to meet the emergency load demand for 7 days either with 4 DGs running or 2 DGs running. In line with the location of DGs, two storage tanks are located on the eastern side of NICB and the other two on the western side. The fuel oil storage tanks and the oil transfer pump for the two DG buildings are independent. Each DG has a day tank of sufficient capacity to run DG for a period of 4 h at rated capacity with 10% required margin. A number of aux-