Emergency Diesel Generator Reliability Study

1 EDG SYSTEM DESCRIPTION

This analysis focused on the ability of the EDG train to start and load its associated safety-related bus for a specified mission time. For the purposes of this study, an EDG train is a diesel engine, electric generator, and the associated support subsystems necessary to power and sequence the electrical loads on the safety-related bus. Typically, two or more EDG trains constitute the onsite emergency ac power system.

All but one of the plant designs in this study include the capability for at least two EDG trains to supply power to the plant using independent safety-related buses. The one exception is at Millstone 1 where one EDG train and a gas turbine generator train supply ac power to the emergency ac power system. In some cases, a *swing* EDG train is used that can supply power to more than one plant (but not simultaneously) such that two plants will have a total of only three EDG trains: one EDG train dedicated to each specific plant and the third, a swing EDG system, capable of powering either plant. Each EDG train uses combinations of one or two diesel engines powering one ac electrical generator. The typical EDG train comprises one diesel engine per generator. In this study, two diesel engines powering one generator were considered as one EDG train.

Diesel engines used for fire pumps, specific Appendix R purposes, or non-class 1E backup generators, were not included in the study. Neither was the high-pressure core spray (HPCS) EDGs included in this study. The HPCS EDGs are a dedicated power source for the HPCS system and do not have load/shed sequencers. Because sequencers are absent in the HPCS EDG system and they have a special function, these data were not included in the study. HPCS EDGs are included in a separate HPCS system study.

1.1 EDG Train

1.1.1 EDG Operating Characteristics

The EDG train is part of the standby emergency onsite ac power system and is required to be available as a reliable source of ac power in the event of a loss of normal ac power during all plant modes (operating or shutdown). Normally, each plant has two safety-related buses that power the electrical loads required for safe shutdown and emergency conditions. These buses typically receive power from either the auxiliary or the startup transformers, which are powered from the main generator or offsite power. In the event of the loss of offsite power or the failure of the normal power to the individual safety-related buses, an EDG train will provide a backup source of power to its associated safety-related bus. The EDG train has sufficient capacity to power all the loads required to safely shut the plant down or supply emergency core cooling system (ECCS) loads on a loss-of-coolant accident (LOCA). Plant-specific technical specifications identify the requirements for the emergency ac power system operability under various plant conditions.

Instrumentation is provided in the control room to monitor EDG operation following an automatic start signal. Control switches are also available to control EDG operation or manually

start the EDG if necessary. In addition, local manual controls are available in or near the EDG room. Generally, any automatic start of the EDG train is considered an emergency start regardless of whether the start was planned (i.e., surveillance test) or unplanned (i.e., low-voltage condition). An EDG train is required to automatically start upon indication of the following:

- A loss-of-coolant accident (safety injection signal)
- A low-voltage condition on the safety-related bus.

A safety injection signal without a loss of offsite power will automatically start the EDG; however, the EDG output breaker will not close. The EDG train will not supply power to the safety-related bus for safety injection events unless a low-voltage condition exists. The EDG will remain at rated speed and voltage with the output breaker open until manually stopped. Should a LOCA occur during loss of offsite power, the bus is first stripped of all loads (automatic load shedding), except for selected feeds for motor-operated valves, and isolated from offsite power sources before the loading sequence begins. After the bus is stripped of loads, the EDG output breaker automatically closes, and the load sequencer automatically restarts selected equipment at a preset time interval onto the affected safety-related bus.

A low-voltage condition on the safety-related bus requires automatic starting of the EDG and closing of the output breaker to supply electrical power to designated equipment on the affected bus. Should a loss of offsite power on any safety-related bus occur, the bus is stripped of loads by a load-shedding scheme. Automatic loading of the safety-related bus begins after the EDG has obtained rated speed and voltage and the EDG output breaker has closed. During an under-voltage condition, the EDG train operates independently without being in parallel with any other electrical power source. When normal power again becomes available, the EDG train can then be paralleled with the grid, unloaded, secured, and returned to standby condition.

For most testing purposes, the EDG train is manually started, brought up to speed, synchronized to the plant power system, and loaded. Normally, voltage is regulated automatically. If offsite power is lost during parallel operation with the plant electrical system, the EDG output breaker will open automatically via an under-frequency relay. The under-frequency relay protects the EDG from an over-load condition during parallel operation. The under-frequency relay opens only the output breaker and is interlocked to operate only in parallel operation. Once the output breaker has been opened by the under-frequency relay, an under-voltage condition on the affected bus will exist, causing the output breaker to reclose automatically. Operation of the EDG train from this point is similar to the loss-of-offsite-power or under-voltage condition discussed earlier.

1.1.2 EDG Support Subsystems

Support subsystems are necessary for successful EDG train operation. Instrument and control subsystems function to start, stop, and provide operational control and protective trips for the EDG. Heating and ventilation subsystems maintain the EDG room environment and supply engine combustion air. Controls for the diesel engines are a mix of pneumatic and electrical devices, depending on the manufacturer. These function to control the voltage and speed of the EDG. Various safety trips for the engine and generator exist to protect the EDG. During the *emergency start* mode of operation, some of these protective trips associated with the diesel engine are bypassed.

The cooling subsystem is a closed-loop water system integral to the engine and generator and has some external cooling medium, generally emergency service water. The lubrication oil subsystem is a closed-loop system integral to the engine and generator consisting of a sump, various pumps, and a heat exchanger. The fuel subsystem provides fuel oil from large external storage tanks, having a capacity for several days of system operation, to a smaller *day* tank for each engine. The day tank typically has capacity to operate the engine for 4 to 6 hours. Day tank fuel oil is supplied to the cylinder injectors, which inject the fuel to each individual cylinder for combustion. The engine governor maintains correct engine speed by metering the fuel oil to each cylinder injector. An air start subsystem provides compressed air to start the engine. The generator, exciter, and output breaker all function to deliver electrical power to the safety-related bus.

Automatic load shedding and sequencing controls the order and timing of emergency loads that are loaded onto the safety-related bus. The purpose of this equipment is to prevent instantaneous full loading (ECCS loads during a LOCA event) of the engine when the output breaker is closed. The load sequencer consists of at least two redundant, physically separated, and electrically isolated sets of circuitry, one set for each EDG train. Each sequencer functions independently and is associated with the sensors and safety equipment of a particular division. Each EDG train has its own independent automatic load sequencing equipment to load the generator. The load sequencer can either be a centrally located solid state configuration or a distributed sequencer with associated relays and timers located in the respective load centers on the safety-related buses. The solid state sequencer is normally used in plants designed after 1980. However, some older plants may have been backfitted with this type of sequencer. The pre-1980 plants typically have the distributed sequencer.

1.1.3 EDG Train Boundaries

The EDG train boundaries selected for this study are shown in Figure 1. These boundaries are consistent with the boundaries identified in similar studies: NUREG-1032, *Evaluation of Station Blackout Accidents at Nuclear Power Plants* and NUREG-2989.

The boundary of the EDG train includes the diesel engine, electrical generator, generator exciter, output breaker, load shedding and sequencing controls, EDG room heating/ventilating subsystems (including combustion air), the exhaust path, lubricating oil (with the device that physically controls the cooling medium, i.e., the nearest isolation/control valve to the EDG boundary that is actuated on a start signal), fuel oil subsystem (including all storage tanks permanently connected to the engine supply), and the starting compressed air subsystem. All pumps, valves, valve operators, the power supply breakers for the powered items, and associated piping for the above support subsystems are inside the boundary of the EDG train.

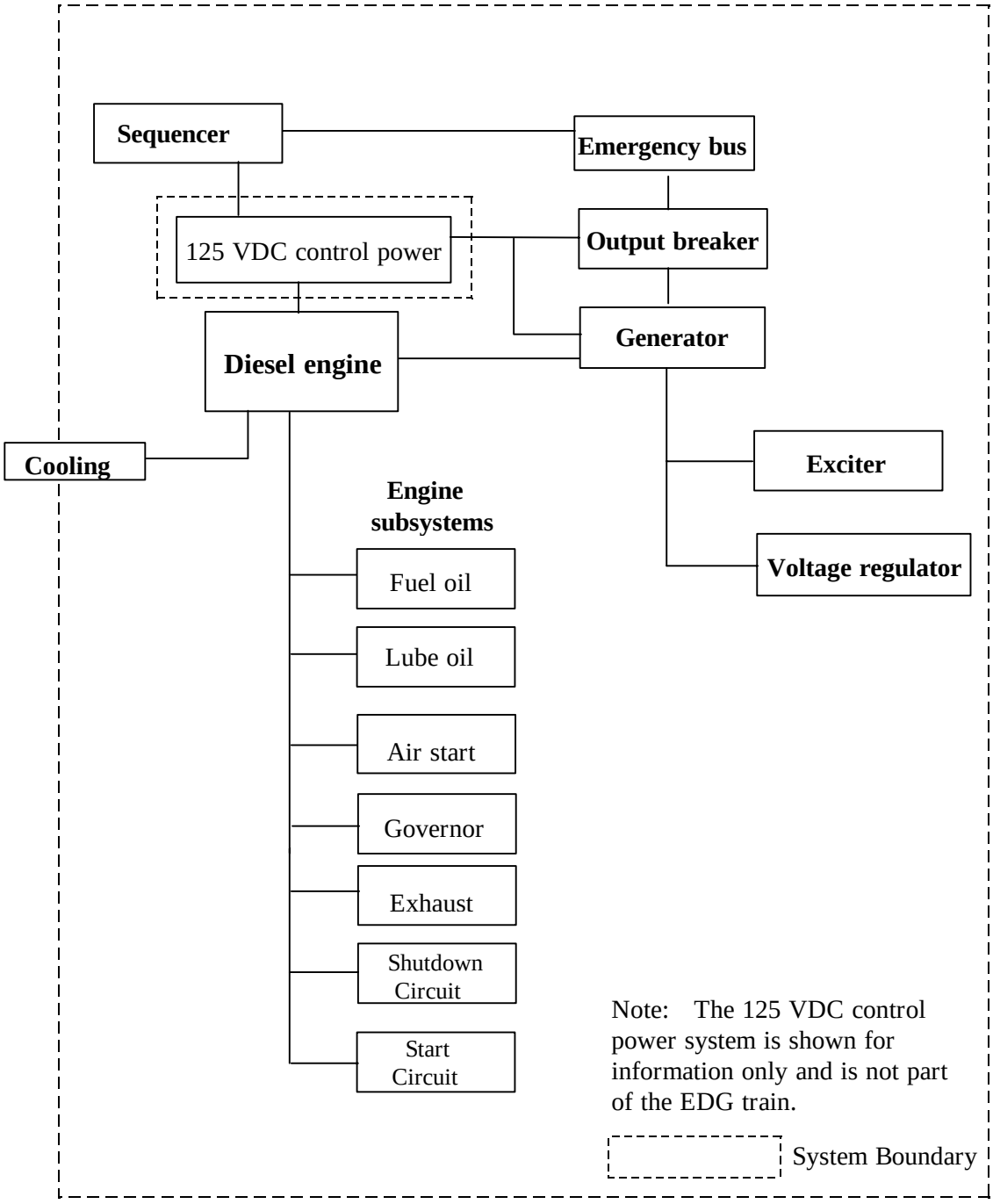

Figure 1. Simplified EDG train schematic.