Safety Requirements to Face Nuclear Power Plants Blackout Using Standby Gas Turbine Generator

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ABSTRACT

The main function of nuclear power plant safety systems is to prevent damage to the reactor and the release of radioactive materials into the surroundings following an occurrence that interrupts normal power plant operation. Recent nuclear regulations concerning the emergency power generating facilities in nuclear power plants consider diesel engines only for the application which isn't the best choice for stand by generation needs. In this paper the main goal is to determine the main characteristic of Diesel Generator (DG) and Gas Turbine Generator (GTG) and justify the main general requirements for a station blackout power sources using gas turbine generator instead of commonly used diesel generators to bring multiplicity to the design of the nuclear unit.

Key Words: Gas Turbine Generator, Diesel Generator and Nuclear Power Plants.

INTRODUCTION

The availability of alternating current (AC) power is essential for safe operations and accident recovery at profitable nuclear power plants. Off-site power sources normally supplies this AC power by means of the electrical grid also it can be supplied by onsite sources such as Emergency Diesel Generators (EDG) or Emergency Gas Turbine Generator (EGTG) (1).

Since 2008, the US nuclear regulator (NRC) has been examining Mitsubishi Nuclear Energy Systems’ US-APWR design for license approval in the USA. According to Mitsubishi Nuclear Energy System (MNES), gas turbines are simpler than diesel engines, with fewer components, easier cooling requirements (air rather than water) and simpler support systems. It is also more reliable and compact (2).

Gas turbines have been much developed over the last two decades. Whereas gas turbines represented only 20% of the power generation market twenty years ago, they now maintain approximately 40% of new capacity additions. Some forecasts predict that GTG may furnish more than 80% of all new U.S. generation capacity in coming decades.

Gas turbines have been long used by utilities for peaking capacity. They are now used for base load power with the changes in the power industry and increased efficiency. Much of this growth can be accredited to large combined cycle plants that exhibit low capital cost and high thermal efficiency (1, 3).

New reactors provides guidance on the implementation of emergency gas turbine generator (EGTG) used as AC power sources to supply power to safety-related equipment or equipment important to safety for all operational events and during accident conditions.

This paper provides the advantage and disadvantage of EDG and EGTG and overall requirements of EGTG system design to ensure that it is consistent with the intent of 10 CFR Part 50.
Main Contrast in Diesel and Gas Turbine Generator:

There are many similarities between a DG and a GTG. First, the generators are quite similar. Possibly they are identical with the exception of a few parameters defining the control systems due to the increased rotational inertia with the gas turbine-driven system. The fuel supply systems are relatively similar in case that the gas turbine can run on diesel fuel.

The lubrication system would also be quite similar. The power capability of a gas turbine and diesel engine depends on the local pressure and temperature level. However, the functional relationship is somewhat different. Contrast in the operation, design and maintenance of gas turbine and diesel engine results from the difference in their designs. The most obvious difference is that the gas turbine is made up of different components. It is composed of a compressor, a combustor and a turbine. It does not contain a turbocharger and a flywheel which are the components of a diesel engine. It also will not include a jacket water system for cooling. Different components will result in different design considerations.

There is a conceptual difference that distinguishes a gas turbine from a diesel engine. The diesel engine is a cyclic device, whereas the gas turbine is a steady state device. This allows for easier monitoring of gas turbine operations. The gas turbine design can incorporate more accurate instrumentation, which allows more precise determination of the operational state of the gas turbine. The efficiency of the various processes can be determined by direct measurements of temperature, pressure and vibration. This then allows for a better management of system operation and maintenance. Operational measurements can be used to schedule overhauls and anti-fouling operations rather than calendar time. Many potential trip signals resulting from measurability of operational parameters can be used to stop gas turbine operations [4].

A gas turbine comes in many sizes. The size that might be considered for application as a standby emergency power source at a NPP will often use roller bearings. This is in contrast to the use of journal bearings in a diesel engine. A roller bearing requires lubrication, but it does not need pre-warming and pre-filling of the lubrication lines that are typical operations in a diesel engine designed for standby operation. The vibration level is much higher in a diesel engine than in a gas turbine due to cyclic explosions which occurs in the diesel engine. This allows for using the vibration level as a diagnostic in a gas turbine system. In theory, the vibration level can indicate when the bearings are going bad. However, in practice this is not always accomplished due to the rapid nature of bearing failure. A gas turbine typically operates at a speed above the first resonance. Thus, the system must be designed to accelerate past the first resonance to obtain operational speeds.

The gas temperatures within the turbine are not as high as in the diesel engine. Thus, the cooling system is much simpler and less critical. Typically water cooling is not used. A gas turbine generally has an air cooling system that passes air through the gas turbine enclosure and an air cooler to provide cooling for the lubrication system.

A gas turbine may run on a variety of fuels and it is capable of using more than one fuel. Diesel fuel must be atomized in case of using it in the gas turbine, while in a diesel engine the spray is a steady flow and need not be timed to the cylinder position.

The repair of a gas turbine is a significantly different process from what is typically done for a diesel engine. Replacement of the complete compressor, combustion and turbine assembly with a new or rebuilt cartridge is involved when a gas turbine overhaul occurs. Hence, few operations are performed on site resulting in a much shorter down time for an overhaul.
A contrast between a diesel engine and a gas turbine is presented in table 1 which shows that weight and size of gas turbines are known to generate lots of power while offering less space and weight than a diesel engine of the same output. Exhaust gas emissions are the real advantage of the gas turbine due to its friendliness as far as Sulphur Oxides (SO$_x$) and Nitrogen oxides (NO$_x$) emissions are concerned. The SO$_x$ release from gas turbines is nearly zero and NO$_x$ exhaust gas is also small. Therefore the gas turbine is clean. The gas turbine unit requires a longer starting time. This time is within the core starting time. This starting time for the GTG is acceptable because the advance accumulator design of the US-APWR.$^5$.  

**Table (1): Gas Turbine and Diesel Engine Contrast.**

<table>
<thead>
<tr>
<th>Point of Contrast</th>
<th>Diesel Engine</th>
<th>Gas Turbine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vibration</td>
<td>It is reciprocating facility, and big vibration.</td>
<td>It is rotary machine, and small vibration.</td>
</tr>
<tr>
<td>Installed cost ($/kWh)</td>
<td>800 - 1500</td>
<td>700 - 900</td>
</tr>
<tr>
<td>O&amp;M cost ($/kWh)</td>
<td>0.005 - 0.008</td>
<td>0.002 - 0.008</td>
</tr>
<tr>
<td>Availability</td>
<td>90 - 95%</td>
<td>90 - 98%</td>
</tr>
<tr>
<td>Start-up time</td>
<td>10 sec</td>
<td>40 sec</td>
</tr>
<tr>
<td>Fuels</td>
<td>Diesel and residual oil</td>
<td>Natural gas, biogas, propane, distillate oil</td>
</tr>
<tr>
<td>NO$_x$ emissions (Ib/MWhr)</td>
<td>3 - 33</td>
<td>0.3 - 4</td>
</tr>
<tr>
<td>output (Btu/kWh)</td>
<td>3400</td>
<td>3400 - 1200</td>
</tr>
<tr>
<td>Usage percent</td>
<td>60%</td>
<td>40%</td>
</tr>
</tbody>
</table>

**Performance Characteristics of the Gas Turbine:**

The GTG system consists of gas turbine, generator, fuel transport system, starting system and control instrumentation system as shown in Figure1.  

The gas turbines are extremely simple. They have three major parts: compressor, combustion area and turbine. The compressor compresses the incoming air to high pressure combustion area where the fuel is burnt and produces high pressure, high velocity gas, turbine that extracts the energy of the gas flowing from the combustion chamber in the engine which has high pressure and high velocity, air is absorbed from the compressor. The compressor is a cone shaped cylinder with small fan blades arranged in rows. The pressure of the air rises when it is forced through the compression stage.

As a result, the Gas Turbine is a very simple rotating engine with few components. In a gas turbine, a pressurized gas spins the turbine. The engine of recent gas turbines generates its own pressurized gas by burning its fuel. The heat that comes from burning the fuel expands air, and the high speed of this hot air rotates the turbine.$^6$. 
Fig. (1): Emergency power system using gas turbine generator in nuclear power plants.

The ambient conditions such as output power and efficiency have an effect on the operation of the gas turbine. The power and efficiency decrease when inlet air temperature is high and vice versa. The power decreases due to the decreased air flow mass rate (the density of air declines as temperature increases) while the efficiency decreases because the compressor requires more power to compress air of a higher temperature. The variation in power and efficiency for a gas turbine as a function of ambient temperature compared to the reference International Organization for Standards (ISO) condition of sea level at 59°F is shown in Figure 2. At inlet air temperatures close to 100°F, the output power can drop to 90% of the ISO-rated power for typical gas turbines. At lower temperatures of about 40 to 50°F, the output power can increase to 105% of the ISO-rated power (7).

Fig. (2): Effect of inlet temperature on performance of gas turbine.
At altitudes above sea level, the density of air decreases so the output power decreases. The effect of altitude on performance of gas turbine is shown in Figure 2 (8).

![Figure 2](image)

**Fig. (3):** Effect of altitude on performance of gas turbine.

**General Design Criterion for Emergency Power Systems Using Gas Turbine Generator:**

The Emergency Power Systems (EPSs) shall be designed to supply the necessary power in any operational state during or after accident conditions (9). The EPSs should be designed to the safety classifications for the electrical equipment and systems that are essential for emergency such as: shutdown of the reactor systems, containment isolation, reactor core cooling systems. Also, EPSs are essential to preventing a significant release of radioactive material to the environment, Class 1E requirements. The EPSs should be seismically qualified to ensure: (a) for anticipated operational occurrences: Provision of power to those systems whose functioning is necessary to keep radioactive releases within authorized limits. Predictable operational occurrences include those occurrences that primarily and directly affect the plant’s electrical power systems, like the loss of off-site power or the loss of power generation at the plant. (b) For design basis accidents and certain severe accidents: Provision of power to those systems is necessary to keep radioactive releases within authorized limits over the total accident recovery period, with account taken of the consequential effects of the loss of power generation at the plant and/or the loss of off-site power over this period (10&11).

General Design Criterion 17, “Electric Power Systems,” of Appendix A, “General Design Criteria for Nuclear Power Plants,” to Title 10, Part 50, of the Code of Federal Regulations (10 CFR Part 50), “Domestic Licensing of Production and Utilization Facilities”, requires that onsite electric power systems have sufficient independence, capacity, capability, redundancy, and testability to ensure that specified acceptable nuclear fuel design limits and design conditions of the reactor coolant pressure boundary are not exceeded as a result of anticipated operational occurrences and the core is cooled and containment integrity and other vital functions are maintained in the event of postulated accidents (assuming a single failure) (12).

GDC 18, “Inspection and Testing of Electric Power Systems,” of Appendix A to 10 CFR Part 50 requires that electric power systems important to safety be designed to permit appropriate periodic inspection and testing to assess the continuity of the systems and the condition of their components (13-19).

Criterion III, “Design Control,” and Criterion XI, “Test Control,” of Appendix B, “Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants,” to 10 CFR Part 50 require that measures be provided for verifying or checking the adequacy of design through design reviews, the use of alternative or simplified calculation methods, or the performance of a suitable testing
program, and a test program be established to ensure that systems and components perform satisfactorily and that the test program include operational tests during NPP operation (14-19).

An EGTG selected for use as standby emergency power source for the onsite electric power system should have the capacity and capability to (1) start and accelerate a number of large motor loads in rapid sequence, while maintaining voltage and frequency within acceptable limits, (2) provide power punctually to engineered safety feature (ESF) if a loss of offsite power (LOOP) and a design-basis events (DBEs) occur during the same time period, and (3) supply power continuously to the equipment needed to maintain the plant in a safe condition if an extended (e.g., 30-day period should be considered with refueling every 7 days) LOOP occurs (19&20).

CONCLUSION

This paper provides reasonable assurance that GTG is highly reliable and dependable and very well suited to perform their safety functions as required by the US codes and Standards, (Code of Federal Regulations, Regulatory Guides, Branch Technical Positions, NUREG-Series Publications, IEEE-Standards).

The GTG system requires no cooling water system. GTG is a very simple rotary engine which is much simpler than a diesel engine. There are also far fewer components, such as valves, pumps and pipes in the GTG support systems, compared to the support systems for a DG. Starting time of GTG is required within 40sec as standard by safety design and analysis of US-APWR specification. The probability of failure to start of GTG is lower than of DG as reported in NURG/CR-6928. Thus, GTG is expected high reliability.

REFERENCES


