Advanced Control Technologies for Customer's Business Continuity Plan for Engine Power Generation that Powers Social Infrastructure

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The importance of business continuity plan (BCP) power sources has been increasing as a measure to deal with the risk of long-term power outages due to large-scale natural disasters. Mitsubishi Heavy Industries Engine & Turbocharger, Ltd. (MHIET) manufactures engine generators, which are widely used as BCP power sources, and supports social infrastructure in terms of providing countermeasures against disasters by improving the value of engine generators used as BCP power sources through power generation technologies such as independent parallel operation control of continuous and emergency generators and high-speed synchronization control of multiple generators. This report presents an overview of MHIET's technologies for BCP.

1. Introduction

Japan experiences frequent natural disasters such as earthquakes, typhoons, and heavy rains, and these disasters can seriously damage social infrastructure. For this reason, companies and public/medical institutions have been implementing business continuity plans (hereinafter referred to as BCP), and securing stable emergency power sources (hereinafter referred to as BCP power source(s)) is one of the most important issues.

Engine generators are widely used as emergency power sources. To improve their value as BCP power sources, however, engine generator technologies for BCP, such as operation and control technologies are important. Mitsubishi Heavy Industries Engine & Turbocharger, Ltd. (hereinafter referred to as MHIET) contributes to the stable supply of BCP power sources by designing and manufacturing highly reliable engine generators and providing high-value products based on technologies for BCP.

2. MHIET's engine generator product line

MHIET produces diesel engine emergency generators and natural gas continuous generators.

(1) Diesel engine generator

Diesel engine generators are mainly used as a standby power source. The output ranges between 200 kVA and 3,500 kVA.

Due to their short startup time and the diesel fuel's suitability for stockpiling, our diesel engine generators contribute to the improvement of power security as emergency and hazard-resistant power sources for a variety of applications.

(2) Natural gas generator

Due to its high efficiency, natural gas power generation is mainly applied to continuous generators with the following output ranges.

・0 Hz generators: 500 kW to 2,000 kW (GSR and GNB), 3,800 kW to 5,750 kW (KU)
・60 Hz generators: 450 kW to 1,200 kW (GSR), 3,650 kW to 5,500 kW (KU)

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Our natural gas generators contribute to energy conservation and low-carbon emissions as high-efficiency cogeneration systems that supply both heat and power, and in recent years, there has been a growing need for these generators as BCP power sources.

3. Examples of technologies for BCP

This chapter describes MHIET's engine generator technologies for BCP.

3.1 Blackout start

Generators used as emergency power sources are required to be able to start up without commercial power (blackout start) to start operation and supply power to the load in the event of a commercial power outage.

Diesel engine generators, which are mainly used for emergency applications, use engine-powered auxiliary equipment (cooling water pumps, etc.) necessary for engine startup, and can start up during a power outage.

On the other hand, natural gas generators, which are mainly used for continuous applications, use electric-powered auxiliary equipment and require a power source for the auxiliary equipment when starting up. Natural gas generators of less than 2,000 kW (GSR, GNB) can also serve as general emergency systems for BCP, because they can start up during a power outage due to the equipment system that quickly operates the auxiliary equipment with the power generated by themselves after startup. Since they can also transmit start supplying power within 40 seconds from engine start, they can be applied to continuous and hazard-resistant systems that operate as a continuous generator during normal operation and supply power to hazard-resistant equipment during a power outage (**Figure 1**).

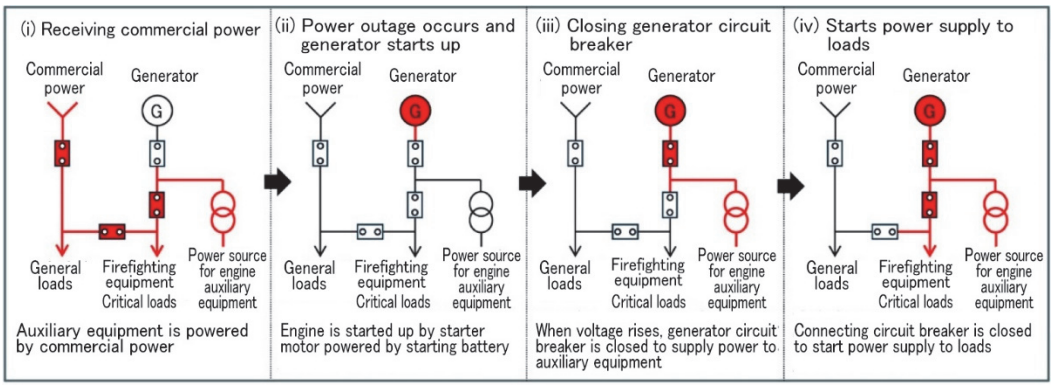

Figure 1 Startup of natural gas generator when power outage occurs (example of continuous and hazard-resistant system)

3.2 High-speed synchronization control

To operate multiple generators in parallel, it is necessary to synchronize them (i.e., connection after matching the frequency, voltage, and phase between the power sources) so as not to apply stress to them.

A typical synchronization control method adjusts the frequency and voltage of the generators and, on the condition that the frequency and voltage differences from those of the power supply to the bus line to be connected are within the allowable values, closes the circuit breaker at the point where the voltage phases match (synchronization point). In the case of this method, it takes a certain amount of time to complete the synchronization and circuit breaker closing because it is necessary to adjust the voltage and frequency of the generator and the period of appearance of the synchronization point is $1/\Delta f$ (for example, a 10-second period for a frequency difference of $\Delta f = 0.1$ Hz). To solve this problem of time required for synchronization and circuit breaker closing, MHIET has developed a high-speed synchronization control method to operate emergency generators in parallel in a short period of time.

Table 1 compares a typical synchronization control method with the high-speed synchronization control method, which synchronizes the generator to the dead bus line and can be applied to the parallel operation of multiple generators of the same capacity during commercial power outages, etc.

Table 1 Comparison of synchronization control methods

Method	Typical synchronization control	High-speed synchronization control
Target	Synchronization control with **voltage-carrying bus line** (LIVE BUS SYNCHRONIZING)	Synchronization control with **no-voltage bus line** (DEAD BUS SYNCHRONIZING)
Application	Applicable for synchronization control with commercial power supply or other generator power supply	Applicable to **synchronization control of multiple generators of the same capacity** during commercial power outages (not applicable to synchronization with commercial power).
Control summary	Adjust the frequency and voltage of the started generator to match those of the bus line to be connected, and then close the circuit breaker at the point where the voltage phases match (synchronization point).	Close the circuit breaker with the generators de-energized, connect the output terminals of multiple generators, and then start energizing all generators at the same time.
Synchronization time required	Synchronization control between generators tends to take a long time (30 to 180 seconds) to complete the synchronization and closing the circuit breaker due to the lower stability of the power supply to the bus line caused by load fluctuations, etc.	Synchronization of generators is completed within a few seconds after starting energization of them. **Power supply to loads from all of the multiple generators is possible within 40 seconds after their startup.**

Figure 2 shows the operational procedure for the high-speed synchronization. At the startup of the generators, the output terminals of all generators are connected without energization (no generator voltage present), and after reaching the rated speed, the energization of all generators is started simultaneously. When the generators are connected without energization, their phases differ from each other, so a current flows between generators when generator energization starts, and this current acts as a synchronizing force to match the phases of the generators and the synchronization is completed. **Figure 3** shows an example of actual equipment behavior during the high-speed synchronization.

The high-speed synchronization method actively utilizes the characteristics of the generators to be synchronized, and this synchronization method enables synchronized parallel operation in a short time after the generators are started up. This method is particularly effective for use in continuous and hazard-resistant natural gas systems that are often required to supply power to loads using multiple generators in parallel due to the limited amount of the load to be connected, and in emergency diesel generators for data centers that are required to have high capacity and high start-up capability.

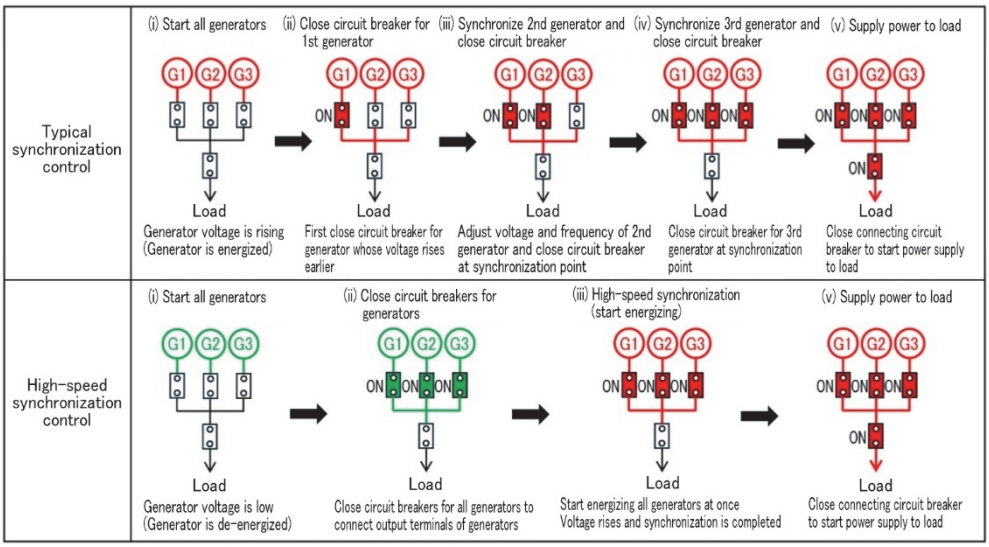

Figure 2 Operational procedure for high-speed synchronization

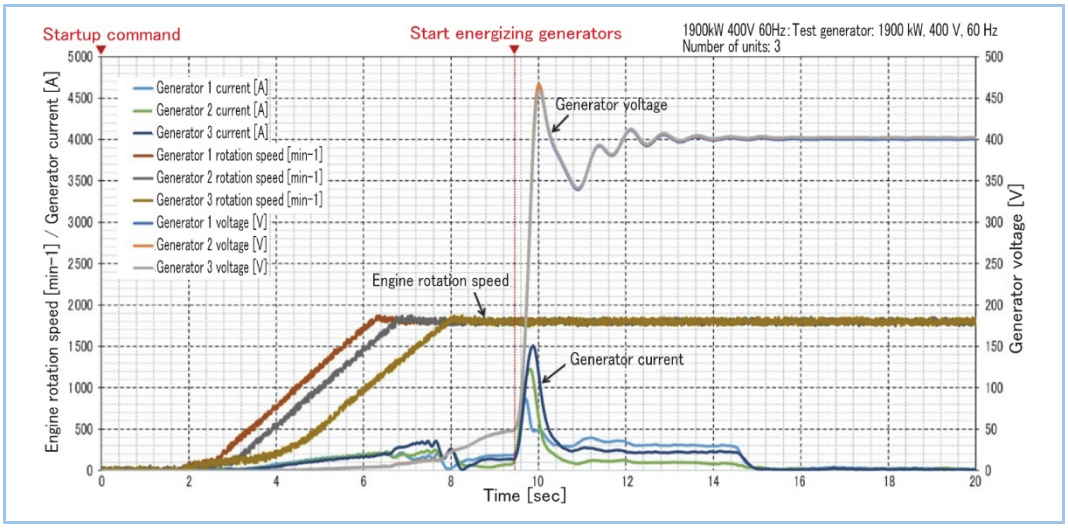

Figure 3 Behavior during high-speed synchronization

3.3 Independent parallel control of different types of engines

Large office buildings often have emergency generators (mainly gas turbine or diesel generators) that supply power to hazard-resistant and security loads in the event of a power outage, and continuous generators (mainly natural gas generators) that supply both heat and power with high generating efficiency. In such cases, the BCP power source can expand and extend the duration of power supply by operating the continuous-use and emergency generators in an independent parallel operation during power outages.

Normally, the type of prime movers and manufacturers differ between the continuous and emergency generators. Therefore, independent parallel operation of such different types of generators with different engine characteristics requires special engineering for their operation control. MHIET has extensive experience in the independent parallel operation of continuous natural gas generator (hereinafter referred to as CGS) with emergency generator (hereinafter referred to as EG).

The procedure for shifting to independent parallel operation of different types of generators is as follows: when a commercial power outage occurs, the EG with high load-following capability starts supplying power to the load first, and then the CGS is synchronized with the EG and connected for independent parallel operation.

During independent parallel operation, maintaining an appropriate load allocation between the CGS and EG is necessary. The load allocation is performed by adjusting the output of the CGS. The load allocation ratio between the CGS and EG is determined mainly by considering the following points.

(i) Load allocation control considering engine characteristics

Since the EG is superior in load-following capability, the following load fluctuation is mainly performed by the EG, while the CGS is basically operated with constant output.

(ii) Avoid light-load operation

Basically, the CGS is operated at 50% or more of the generator's rated output to provide load allocation suitable for long-time operation of the engine.

(iii) Prevention of generator reverse power

The CGS is operated at constant output with a target value that takes the minimum load of the EG into account, thereby preventing reverse power to the generator when the site load is light.

Figure 4 shows an example of load allocation between the CGS (GSR/GNB class) and EG in independent parallel operation.

As such, the synchronization control and load allocation adjustment between the CGS and EG are performed by the CGS, so building special control is not necessary for the EG, which only requires the preparation of status signal outputs, such as active power value signals, circuit breaker status signals, etc.

Figure 5 shows the behavior of actual equipment when load fluctuations occur during independent parallel operation of CGS and EG. The behavior during load fluctuations in independent parallel operation varies depending on the combined engine types, characteristics, and generator

capacities, but the EG with high load-following capability responds to load fluctuations first, followed by the CGS.

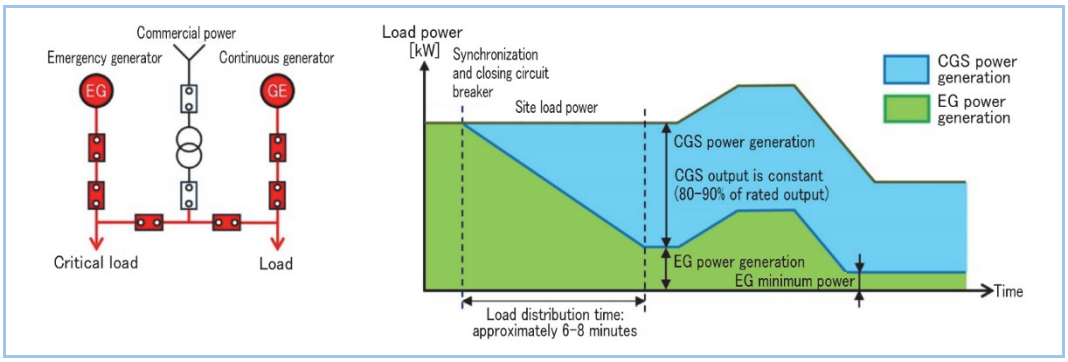

Figure 4 Example of load distribution between CGS and EG

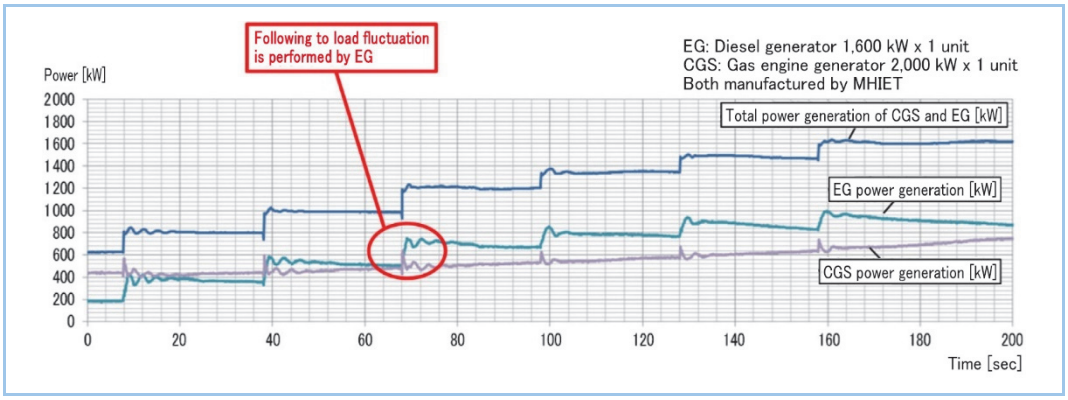

Figure 5 Behavior of actual equipment when load fluctuations occur during independent parallel operation

3.4 Uninterruptible power supply to critical loads through power flow control

Normal continuous generators are operated in connection with commercial power supply to maximize the effective use of power generated by the generators to save energy costs. On the other hand, in cases where commercial power supply abnormalities (power outages, instantaneous voltage drops, etc.) have a significant impact on users' production lines and facility operations, continuous generators are sometimes installed to improve the security of power supply to critical loads.

In such cases, as shown in **Figure 6**, a bus line circuit breaker is installed between the generator and commercial power supply and the critical loads are placed on the generator's side of the bus line circuit breaker. When a commercial power supply abnormality occurs, the abnormality is detected by a fast-operating undervoltage relay or similar device, and the generator and critical loads are disconnected from the commercial power supply system by opening the bus line circuit breaker to allow independent power supply to the critical loads from the generator system.

When shifting to independent power supply by the generator, if the load fluctuation is large (especially when the power generation before the system isolation is smaller than the critical load power), a sudden increase in load exceeding the capacity of the generator may make it impossible to continue operation, or cause extremely large frequency and voltage fluctuations. To prevent such a problem, the output of the generator is controlled so that the power at the bus line circuit breaker (which is opened at the transition to independent operation) becomes zero (or a small value in the direction from the generator to the commercial power supply) when the system is operated in connection with the commercial power supply, to ensure reliable transition to the independent operation and to minimize generator voltage and frequency fluctuations.

In addition, in regions where lightning and typhoon damage occur frequently, when the risk of commercial power outages increases according to weather information and other factors, the power supply to critical loads is switched from the commercial power supply to the generator power supply in advance.

In systems that can switch the power supply to critical loads to uninterruptible power supply, when the risk of commercial power outage decreases, the power supply to critical loads can be

switched back to the commercial power supply uninterruptedly by synchronization and closing the bus line circuit breaker that has been opened.

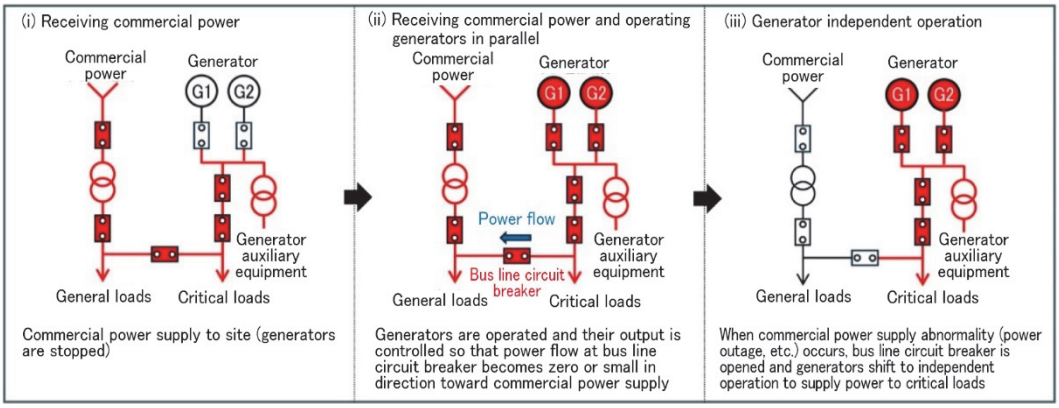

Figure 6 Uninterruptible power supply to critical loads

3.5 Redundant system

Emergency generators for data centers and other facilities require a high level of power supply security and are therefore required to have redundancy as well as large capacity and high startup capability. MHIET provides systems that can be made redundant, as well as diesel generators with high output performance for data center applications.

The basic approach to the redundancy is to prepare a backup unit to construct an n+1 system (the required number of units plus a spare unit). Eliminating single points (where a single failure affects the operation of the entire generator) is also important. Thus, measures such as duplicating control sections common to the system and eliminating common sections themselves in the system are necessary. To ensure such power supply redundancy, it is necessary to take measures including power receiving and transforming facilities and load facilities, etc., and we build the most appropriate system for each customer's facility.

4. Conclusion

Engine generators are expected to continue to play an important role as a means of securing BCP power sources for commercial facilities, etc. To make effective use of engine generators, technologies for BCP, such as operating and controlling technologies optimal for the customer's facilities, are important. MHIET provides highly reliable engine generators as appropriate, such as diesel generators and gas generators, for emergency and continuous use, and will further improve the utilization value of engine generators through technologies for BCP, such as blackout start, high-speed synchronization, independent parallel control of different types of engines, uninterruptible power supply to critical loads through power flow control, and redundant systems.

There has been a growing adoption of renewable energies to achieve carbon neutrality. Renewable energies, including solar power, are unstable power sources with fluctuating output, which causes load fluctuations from the perspective of engine generators in the event of a commercial power outage. Therefore, for interconnected operation with emergency generators, current solar power generation needs to be limited in its maximum output, which means that it cannot be effectively utilized as a BCP power source. MHIET has commercialized EBLOX, a hybrid power generation system that combines an engine generator, solar power generation, and storage batteries. We aim to expand the application of EBLOX, which enables effective use of renewable energy as a BCP power source and improves power quality by reducing frequency and voltage fluctuations.

Reference

(1) M. Tanaka et al., Demonstration Testing of Triple-Hybrid Power Generation System toward Era of Distributed Power Sources - Development of "EBLOX" and "COORDY" -, Mitsubishi Heavy Industries Technical Review Vol.56 No.2 (2019)