On-site Power for Data Centers: New Possibilities in a Changing Marketplace

Critical facilities have more choices than ever for ensuring an uninterrupted electricity supply. Here is a look at various solutions for achieving the required reliability with the best combination of low initial and lifecycle cost, long-term efficiency, and operating flexibility.

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Introduction

The designers of a new data center received the standard proposal for electric power protection – dual utility feed with diesel-engine-driven emergency standby generators – but then decided to look deeper. They asked:

- Could the emergency generators in some way serve as a source of revenue?
- What is the risk of a catastrophic storm that could cut off both utility feeds, block access to diesel fuel, and jeopardize business continuity?
- What are the local emissions regulations and what are the costs to comply?
- Is a 10-second maximum generator startup time actually necessary?

Based on the site-specific answers, they built the data center with natural-gas-fueled generator sets enrolled in the local utility's demand response program. Besides standby service, the units are expected to carry the entire facility's load for about 200 hours per year during times of peak demand on the utility grid, in return for rate incentives that will yield an attractive payback.

The gas units are augmented by diesel-driven generator sets to be used strictly for emergency backup and therefore not requiring costly emission controls. The multiple fuel arrangement provides insurance against an interruption of either the natural gas or diesel fuel supply. The generators are configured in a parallel system with a battery UPS and designed for soft loading in the event utility power is lost.

The data center just described is hypothetical, but the concepts are fully realistic. In today's electric power markets, and with today's on-site power generation technologies, data center developers have multiple choices for providing emergency power to ensure continuity of critical operations. An innovative power system – one that goes beyond traditional standby – can help a data center differentiate itself and gain a competitive edge.

By carefully considering site conditions and business needs and asking and answering the right questions, it is possible to devise the emergency power configuration that best supports the desired reliability while optimizing capital investment, lifecycle cost, efficiency, and operating flexibility. Options can range from basic diesel-driven standby, all the way to full-time on-site gas reciprocating engine or turbine power generation with utility power as backup. Combined heat and power (CHP) may even come into play in certain applications. Here are several key considerations that can guide the design of the ideal power security solution for a given site.

Parallel or Distributed?

There are two basic backup power configurations for data centers: Parallel and distributed (also referred to as "pod" or modular design). Each has advantages and drawbacks depending on the application.

A traditional parallel system (Figure 1) arranges multiple generator sets in parallel by way of switchgear. An advantage of this configuration is that it provides complex integration and a fine degree of control over the system, including capabilities such as load addition and load shedding. Furthermore, if one in a bank of engines should fail, the remaining units can continue to carry the most critical loads (though some less critical loads may need to be shed). As an alternative, one or more additional generator sets can be included for redundancy and greater certainty of power supply.

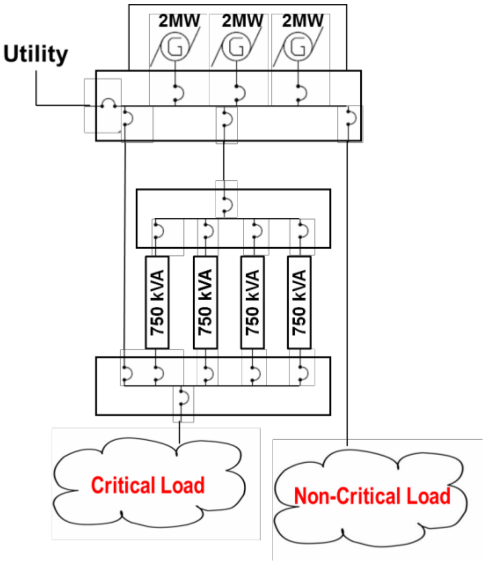

Figure 1: Traditional paralleled system with generators feeding the critical load from a common buss through battery-based UPS.

These systems typically use battery-based UPS because the time to parallel the generators requires a slightly longer ride-through. The UPS can be separated into smaller blocks to provide additional redundancy. Quick-connect for load banks and rental generators can be integrated to improve maintainability and continuity of power. One caveat with a parallel system is that the initial cost tends to be higher than for a distributed system. Still, it is easy to add generators as load grows – so long as the entire, long-term paralleling network has been planned for and the basic infrastructure installed up front. Without such preparation, system expansion becomes difficult once the facility is live.

A distributed system (Figure 2) deploys a single generator serving each of several discrete critical loads through a UPS. Each pod is isolated from disturbances or failures elsewhere in the facility. Systems can also be physically isolated for even greater protection. Distributed systems allow for easy data center expansion – new pods can be added almost indefinitely without affecting any other operating systems. Rapid startup is possible because units start independently – there is no delay while multiple units parallel. Distributed systems therefore can use shorter ride-through solutions such as a UPS with flywheel energy storage, as 20 to 25 seconds of ride-through provides ample time to bring generators online.

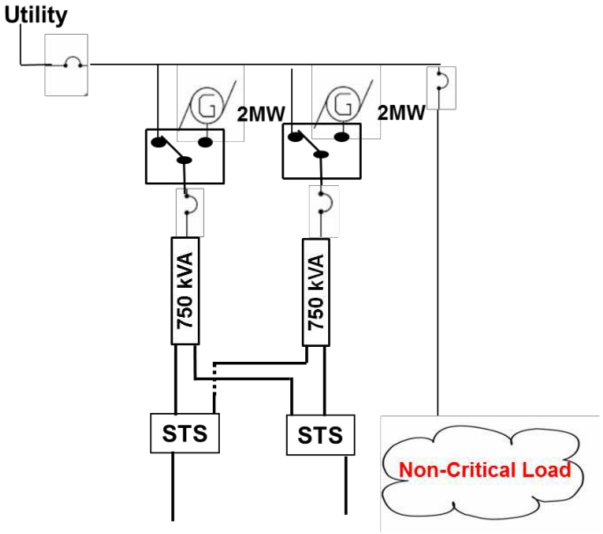

Figure 2: Distributed system with generators feeding directly through a UPS to the critical load. Non-critical loads may be covered by the generator as well, though typically not through the UPS.

On the other hand, the failure of a generator set in a distributed system means a block of critical load is lost (although redundant units can be deployed against that possibility). Inability to parallel means no capability to add or shed loads. And critical loads must be capable of segmenting into small enough blocks to be supported by isolated systems.

Choice of Prime Movers

The choice of generating technologies is wider than many data center designers imagine. Diesel engine generator have been and remain the default choice for standby power, but local power pricing structures, utility power instability, emission regulations, and other factors may warrant bringing natural gas engines or gas turbines into the discussion.

Data Center On-Site Power Generation Technology Summary

	Tier 2 Diesel Engine	Tier 4 Diesel Engine	Gas Engine	Gas Turbine
Annual hours of non-emergency operation	100 hours or less	100+ hours	100+ hours	Continuous
Application	Pure standby	Standby, prime, continuous or load management	Standby, prime, continuous, load management or CHP	High-hour load management with CHP
Installed cost	Lowest	Higher	Higher	Highest
Efficiency	Lower	Lower	Best electrical	Best thermal
Starting	Fastest	Fastest	Slower	Slowest
Load acceptance	Fastest	Fastest	Slower	Slowest
Limitations due to air permitting*	Restricted to <100 hours	Minimal	Minimal	Minimal

** Emission regulations allow all these types of prime movers to operate for unlimited hours during power outage emergencies. Tier 4 diesel and gas units have no restrictions on annual operating hours under federal regulations may be limited under state or local provisions.*

Diesel Reciprocating Engines

Stationary emergency (Tier 2 emissions level) qualified diesel engines are eminently suitable for standby power. They offer the highest power density and the lowest installed cost per kilowatt; in extremely limited standby duty, fuel and operating costs are not an issue. They perform at high ambient temperatures and high altitudes without significant derating. A simple design makes maintenance and service easy. The engines can be online and fully loaded within 10 seconds (compliant with NFPA 110). They also have excellent transient capability for rapid response to increased loads and the ability to accept and recover from a 100 percent block load.

Stationary emergency diesels with limited or no exhaust aftertreatment can comply with most localities' emissions regulations so long as they operate according to the stationary emergency requirements. These generator sets are allowed to run for unlimited hours during an outage or emergency, but are allowed to operate for no more than 100 hours per year for maintenance, testing, and all other non-emergency duty.

In general, these emissions regulations mean stationary emergency diesel units are limited to standby applications – more extended operating hours call for lower-emission power sources. Run times can be extended by using EPA Tier 4 certified diesels.

Figure 3: Cat 3516C Tier 4 certified diesel unit.

Tier 4 certified diesel generator sets must come certified from the manufacturer, and most Tier 4 certified products include some form of exhaust aftertreatment to meet the emissions targets set by the U.S. EPA. Aftertreatment can include selective catalytic reduction (SCR), diesel oxidation catalysts (DOCs), and diesel particulate filters (DPFs). Depending on the engine size, one or a mix of these technologies, may be required to comply with the Tier 4 interim and Tier 4 final requirements. Tier 4 certification or significant aftertreatment will increase the package cost of the diesel generator set and negate the initial cost savings over natural gas generator sets.

Gas Reciprocating Engines

Gas engines are gaining attention for data center standby service for their potential to log more annual duty hours, help reduce utility power costs, and even generate revenue. With their lower emissions, gas units can be readily deployed for 100, 200, 500 annual hours or more, even outside emergency duty. The longer the annual hours of operation, the greater the advantage over diesels from gas units' higher electrical efficiency (40 to 44 percent) and lower fuel costs. When compared to diesel generator sets running a similar number of annual hours, gas units offer longer service intervals, resulting in less downtime and lower maintenance costs.

Gas engines can operate on a variety of “opportunity” fuels, including landfill gas, wastewater treatment digester gas, and agricultural biogas. Where available, these fuels can substantially reduce operating costs. One disadvantage of gas engines versus diesels is that they are subject to higher power derate at altitude or in high ambient temperatures.

While by reputation gas-engine-driven generators are slower than diesels to come online and accept full load, current gas engine technology is closing the gap significantly. Gas engines are inherently slower to respond than diesels because of physical differences in how they accept load (see sidebar). In practice, however, the speed of response depends on factors that include the size and operating speed of the engine, the nature of the loads, and how the loads are applied.

For example, an engine-generator rated at 2.5 MW and larger may need up to 120 seconds to accept full load, and possibly longer for a lower-speed (1,200 rpm) engine. On the other hand, some smaller, higher-speed (1,800 rpm) units can go from start to full load in 60 seconds, or in some cases significantly faster, with fully acceptable voltage and frequency dips, if ramp-loaded rather than block-loaded. Continued advances in standby gas engine technology are pushing times for full acceptance of ramped loads toward 30 seconds from the start signal.

Figure 4: Cat® G3516H NSPS compliant gas generator set.

Gas Turbines

Turbines share some of gas engines’ advantages, including high operating efficiency, low emissions, and fuel flexibility. They are ill-suited for short annual hours, intermittent duty, or variable loads. However, they are highly efficient in continuous, base-load operation where there is a need for high quality heat. They are lightweight and have a compact footprint, producing three to four times the power in the same space as reciprocating engines of similar capacity.

Their design is simple – there is no liquid cooling system to maintain, no lubricating oil to change, no spark plugs to replace, and no complex overhauls to perform (only combustor replacement after about 60,000 hours (about seven years) of duty. Turbine emissions can be extremely low, especially with the latest advances, such as lean-premixed combustion technology. Turbines achieve maximum efficiency and economic performance where their high-quality exhaust heat can be recovered and used. Startup time is slower than for diesel or gas engines, at four to 10 minutes.

Innovative Solutions

New approaches to standby power are gaining attention as the electric utility industry undergoes profound changes. The U.S. Energy Information Administration projects that tightening emission regulations and other factors will lead to retirement of 60 GW of existing coal-fired generating capacity in the continental United States by 2020.[1]

The consensus among industry observers is that power prices are likely to rise as relatively inexpensive coal is replaced by more costly natural gas or renewables. Grid reliability also could be compromised. Meanwhile, as peak power demand grows faster than base load, utilities increasingly look for help to manage both daily and seasonal peaks. Many are willing to offer rate incentives in return for the help they need. This environment can encourage innovation in dual peaking and standby power systems.

Peak Shaving/Demand Response

Standby gas engine-generators can fit well in a variety of peak-time power generation scenarios. They can be operated to help offset a data center's own peak-time demand and energy charges. Or, more commonly, they can be enrolled in utility load management (demand response) programs. Here, the units are installed at the data center but dispatched at the utility's direction to help offset extreme peak demands on the utility grid, such as during the hottest summer and coldest winter days. In return, the utility pays generous incentives, often in the form of preferential energy or demand charges, or as payments for the actual kilowatt-hours of energy or kilowatts of demand reduced.

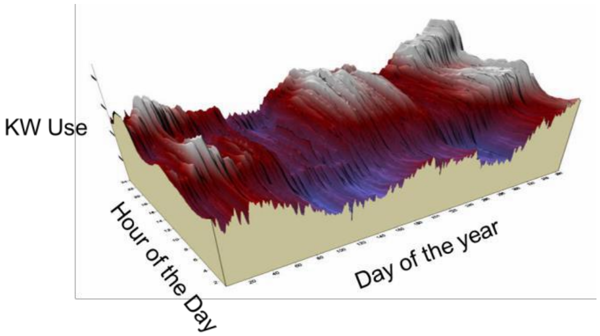

Figure 5: Annual utility load profile with summer and winter peaks.

Chart used with permission from Black Diamond Solutions Inc.

Emergency diesel units may participate in demand response programs, although to a lesser extent. Subject to specific rules, they are allowed to operate for up to their full allotment of 100 annual hours of non-emergency service under such programs. The units may operate only when requested by the utility, and by rule, owners are not allowed to export the power to the grid for direct compensation.

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[1] Annual Energy Outlook 2014, U.S. Energy Information Administration.

Microgrids

Gas-fueled units are also well suited to microgrid configurations, taking the place of the second utility feed and capable of powering the entire data center on a continuous basis for extended periods. Today, such installations more often apply to developing countries where utility power is unreliable or of inconsistent quality. However, the concept can be workable in specific settings in North America, such as in remote sectors of a utility grid where power quality may be suspect or distribution is severely constrained, or a second utility feed would be impractical or too costly. Gas reciprocating engines and gas turbines can perform reliably and cost-effectively in microgrid systems.

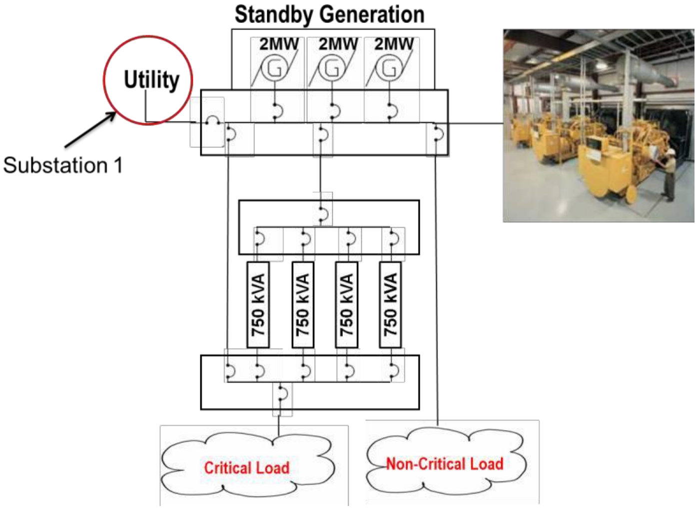

Figure 6: Gas generator sets as dual feed for data center and secondary standby source.

A Place for CHP?

In the majority of installations, CHP is not an economic benefit for operation in mission-critical data center standby applications. However, in cases where a heat load is available on site or nearby, the production of steam, hot water or hot air can enhance a facility's economic picture.

While pure standby duty will not economically justify CHP, installations involving longer annual hours, up to and including microgrids, clearly can in the right circumstances. A data center itself can provide some heat load. For example, recovered heat can be fed to absorption chillers to cool the server rooms and the office spaces. Another favorable scenario is to locate the data center in an industrial or commercial area near a resort, food processing plant, greenhouse, district heating system, or other heat-intensive operation that can purchase hot water, steam or chilled water. Demands for electricity and heat need to be coincident, so that when the generators are operating, the heat load can be satisfied.

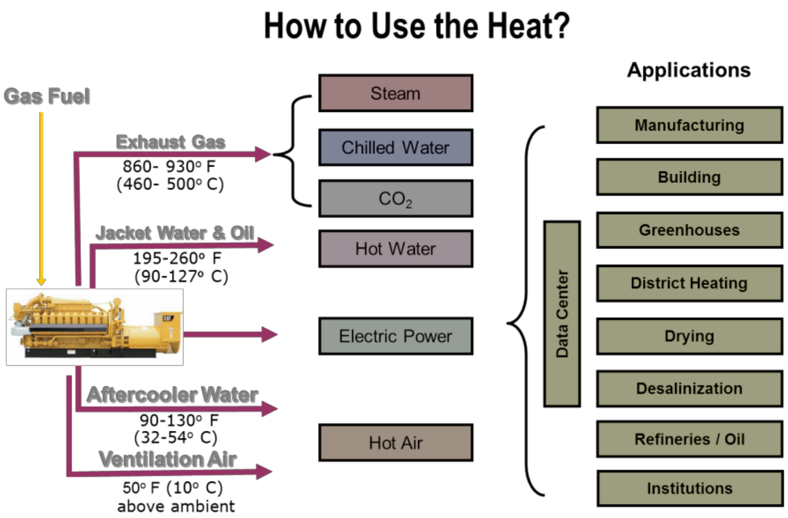

Figure 7: While the power is being used at the data center, the heat can be used for many local applications

Heat can be recovered from gas engine exhaust, coolant and lube oil; turbine exhaust is an extremely high-quality heat source. A common misconception is that a cost-effective CHP system must operate full-time. In reality, CHP can be beneficial wherever the economic benefit of the heat outweighs the cost of the heat-recovery equipment. For example, a simple heat exchanger in the engine coolant loop is quite inexpensive and can easily supplement building space and water heating.

Site and Business Considerations

Standby power must be designed in the context of the data center owner's business model and the specific location. Here is a look at several important considerations.

Loads Characteristics

As in any generator set application, the user needs to know the types of loads the generator will be expected to pick up. Is it a resistive load? Will significant UPS and non-linear loads be involved? What is the expected power factor? Must the engine accept block loads? What load size steps are expected? Can the engine be ramped up rather than block loaded? What voltage and frequency dips will be experienced in the acceptance and rejection of loads? What recovery times are allowed or acceptable? The generator must be sized to have enough copper to accept the loads at the prevailing power factors, while the engine must be large enough to be able to pick up the load in the time allowed – without being oversized to the point where it will impose excessive costs in fuel, maintenance and oil consumption).

Long-Term Plans

The intended use and design life of a data center helps dictate the design of the critical infrastructure and the emergency power system, as well. For example:

- If the data center is to operate for 10 years or less, capital costs generally would be kept to a minimum. Generator sets, with much longer expected life, might be installed to allow removal with relative ease for relocation or sale at a later date.

- If multiple data centers are planned, a single, standardized design facilitates moving equipment between sites and limits the cost of training personnel who may be transferred from one site to another.
- If a single location is to serve for the long term, the ultimate size should be considered carefully and the power infrastructure designed and planned accordingly.

Utility Capabilities

Emergency power system designs may be driven in part by the utility's ability to deliver consistently reliable, high-quality power. While utility limitations are more often an issue in the developing world, they can be a factor even in the U.S. and Canada, especially as distribution systems become more constrained and as power intensive businesses develop on the fringes of their utilities' territories. For example, while data centers typically have redundant utility power feeds from two separate substations, a data center may seek to locate on a grid sector with economical access to only one substation. A standby power system then in effect substitutes for the second utility feed, and must be designed accordingly, with the appropriate redundancy and startup capability.

Optimizing Costs

In a typical standby power application, the bulk of costs are incurred up front, since the units operate rarely and generally for short intervals. For pure emergency standby, the installed cost for diesel units is roughly 25 to 35 percent less than for a similarly rated gas unit. The cost picture changes as annual operating hours increase.

For example, while a stationary emergency diesel engine without exhaust aftertreatment may suffice for pure standby, voluntary operation beyond 100 hours per year may require Tier 4 certified generator sets, negating the installed cost advantage over gas (although the benefits of faster startup and better load response would remain). In addition, the greater the annual operating hours, the more fuel efficiency and maintenance and service costs come into play. Of course, for critical duty, reliability trumps all other considerations: Availability to operate when needed outweighs economic gains from differences in efficiency between generator models.

Startup Requirements

The default specification and customer expectation for mission critical facilities calls for the emergency power source to be fully online and accept full load within 10 seconds. Most data center customers ask for 10-second start capability, even though many facilities with paralleled emergency power systems do not actually require it. Typical operation in facilities with minutes of battery UPS backup involves a slow ramp transition from UPS discharge to the generator set. This usually takes 10 to 30 seconds, depending on the application and the user's needs. Natural gas units can make sense in applications where the loading and unloading of the generator sets can be managed and controlled. Facilities with shorter ride-through solutions (such as flywheel UPS) will typically require 10-second start and load acceptance and therefore most likely will need diesel generator sets. However, flywheel UPS can be sized to accommodate longer ride-through times (at higher cost), and in such cases, gas generator sets may be a workable choice.

If size UPS so 30 to 40 second ride through time, could use gas if quick starting unit. Sizing the U.S. solution for under 20 seconds, chances are will want the diesel but flywheels can be sized for longer ride-through times and in those cases a gas unit may be an acceptable choice.

A thoughtful plan for bringing emergency power online can help in forming decisions such as the power system configuration (parallel or pod), the generation source (gas or diesel) and the UPS type (battery or flywheel).

Switchgear and Paralleling Technology

There are numerous ways to manage and control a standby power system. They include paralleled systems with multiple units on a common bus and much simpler transfer switch-based strategies in which a single unit serves a discrete set of loads. A transfer switch system can enable a robust, highly capable pod-based design with limited investment in controls.

More complex paralleling systems requires sequencing and speed control synchronization to bring each unit online. Diesel generator sets give users the ability to comply with NFPA110, and to accept load in one step (block load). Gas generator sets require a soft-load transition, and the generator set's transient capability must be managed by loading and unloading of the units from UPS discharge.

Generator Set Ratings

Generator set ratings for diesel engines are based on the application and operation of the unit. These ratings support operation in settings from stationary emergency standby all the way through continuously operated Tier 4 emissions applications.[2]

Gas engines are rated based on the exhaust gas temperature and the engine detonation limits. These limits typically come into play before the physical pressure (from power) limit of the engine is reached. Consequently, there typically is only one rating for a gas engine, whether it is used in standby, prime or continuous service. A user may choose to install a lesser generator (higher temperature rise) based upon the intended use of the unit.

Eye on Emissions

Emission requirements can vary greatly with the locality and its status as an attainment or non-attainment area under U.S. EPA regulations. For diesels, local and federal regulations will determine the permissible operating hours and the emissions limitations. For gas engines, some localities my require NOx emissions as low as 0.5 gram/bhp-hr. Local requirement need to be researched carefully and discussed with permitting authorities.

Managing the Risks

The role of a data center power system is to limit business risk – a failure may place critical functions in jeopardy, with severe consequences for financial performance, customer satisfaction, and company reputation. From design through operation, a variety of risks must be managed effectively.

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[2] For more information about diesel generator set ratings, refer to the Caterpillar white paper, "Demystifying Generator Set Ratings," LEXE0549.

Financing

An emergency power system represents a substantial investment that entails risk at various project phases. These include technology (equipment track record, efficiency, reliability), environmental permitting, construction (quality, cost, conformance to schedule), debt service/cash flow, and casualty (physical damage, liability). Whether the project is financed in- house or externally, these risks must be addressed through contracts that assign each risk to the party best qualified to manage it.

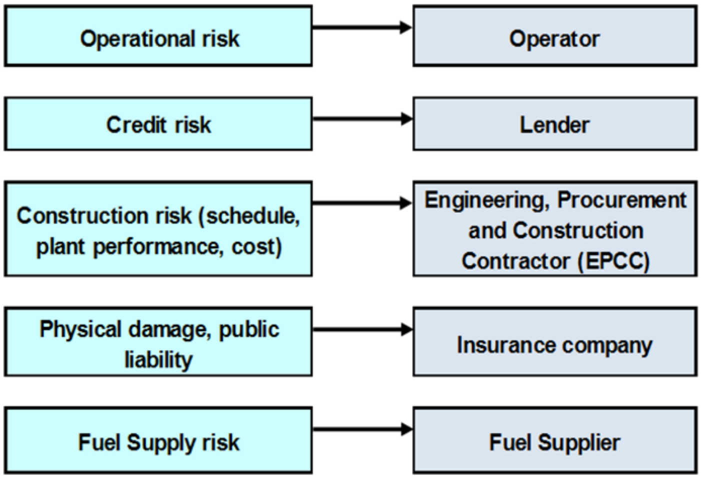


Figure 8: Project risk assignment.

Disaster Preparedness

While most utility outages last only seconds, a disaster plan is essential for outages that may last days or weeks, such as after storms or floods. Questions to ask in disaster planning include:

- Is there a contingency plan for backup rental generator sets?
- Has a quick-connect been integrated to allow fast hookup of a rental unit?
- Is a right of first refusal or other arrangement in place with a rental equipment supplier?
- Is there a need for temporary chiller capacity?
- Are adequate supplies like lube oil, oil filters and fuel filters available on or near the site?
- Is a process in place to ensure a reliable fuel supply?

The criticality of data and the corresponding reliability requirement in large part determine the level of backup power redundancy. Some facilities opt for limited redundancy. Others may choose an N+1 (one spare generator set) or N+2 (two spare units) configuration, depending on the facility and the tolerance for the potential loss of power. Facilities may even opt for a 2N configuration – two complete standby facilities that are mirror images, possibly using different fuels. Rental (co-location) data centers may have sectors with differing levels of redundancy to site specific tenants' needs and enable market-competitive pricing.

Recent catastrophic storms have led emergency planners to explore multiple-fuel-sourced (natural gas and diesel) standby power configurations. After Superstorm Sandy in late 2012, flooded roadways largely cut off diesel fuel supply routes, and some facilities dependent on diesel-driven emergency power ran dry of fuel in a few days. The added cost of a standby system that can power the most critical loads with either diesel or gas is often justified by greater resiliency. An ideal multiple-fuel configuration combines diesel units for pure standby with gas units enrolled in a demand response program – the utility incentives often can recover the investment in the gas units within just a few years.

Equipment Reliability

The reliability of any standby technology depends on rigorous planned maintenance. The most common reasons why emergency generator sets fail to start – discharged or dead starting batteries, units not set in the automatic mode, lack of fuel or poor-quality fuel, low fluid levels, filter contamination – all trace back to neglected maintenance.

Maintenance must span the equipment lifecycle. Periodic testing is essential to ensuring that the standby system will run when needed. Diesel-driven emergency power systems in pure standby duty with extremely limited hours of operation many need little maintenance beyond annual lubricating oil, fluid and filter changes and periodic exercising. On the other hand, gas engines in higher-hour peaking, demand response or micro-grid (continuous) duty require more intensive service, which must be budgeted.

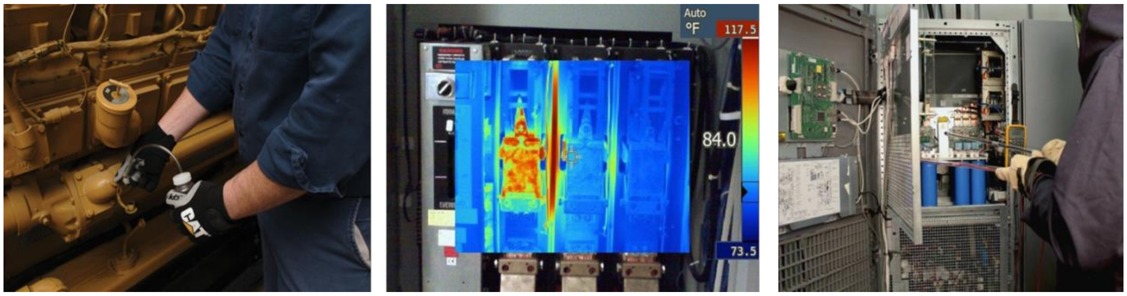


Figure 9: Proper equipment service is critical to insure that the generator sets are available for service in the event of a main source power outage.

For systems that operate for extended annual hours, condition monitoring and trending can enable repairs to be made on a planned basis. In general, a good practice is to work with the engine or turbine manufacturer’s local dealer/distributor who can perform maintenance and other service as required, often under a structured program with fixed, predictable monthly costs. This ensures that timely service is performed in accord with best practices that maximize availability and limit unplanned downtime.

Putting it all Together

One way to simplify a project is to work with a partner with deep experience in emergency power systems. One logical choice is a dealer for an engine-generator manufacturer offering a full range of technology choices and the expertise to deploy them to maximum advantage in critical power applications.

The chosen partner should demonstrate broad experience installing and servicing emergency power system and employ locally based service technicians who can provide support ranging from basic planned maintenance and overhauls to comprehensive long-term service agreements.
Ideally, the organization should be able to manage whole-project engineering, procurement and construction, and supply all engines and generators, plus transformers, switchgear, UPS, fuel treatment systems, and other ancillary equipment.

Another strong attribute is diverse financing capability with intimate knowledge of the special needs of data center power projects. This can include capability to finance the entire emergency power infrastructure, rather than generating equipment only, and to offer flexible programs to suit specific needs. Especially helpful is project construction financing, which provides a bridge loan while the project is being built and not yet producing cash flow, then converts to long-term financing when the project is substantially complete.

Pure diesel-powered standby is not the only game in town for data center backup power. Careful choices among diesel and gas technologies can help owners develop the optimum solution. In some cases, a mix of diesel and natural gas generation will provide the most robust, reliable and flexible solution – with the added benefits of saving on energy costs and generating revenue.

Independent of the power generation technology, a proactive maintenance plan and a strategic disaster preparedness plan are critical to minimizing the risk of unplanned shutdown and will allow for quick response in case of a failure or other event that could lead to facility downtime.

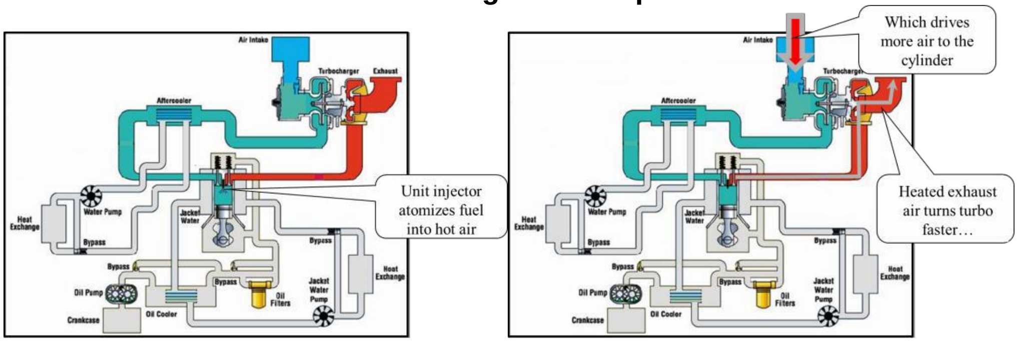
Addendum

How Diesel and Gas Engines Accept Load

Gas and diesel engines are similar in most respects, but they differ in how they accept load and therefore in how rapidly they can come online at full power in emergencies.

In diesel engines, fuel is directly injected into the cylinders. Thus when the system calls for more power, the injector rack opens wider to let more fuel in. Excess air is already present in the cylinder to mix with the fuel for combustion. Hotter exhaust goes through the exhaust manifold to the turbocharger. The turbocharger spins faster, increasing airflow in the engine, and the process begins again, now with a larger air charge to make more power.

How Diesel Engines Accept Load



Unit injector atomizes fuel into hot air

Which drives more air to the cylinder

Heated exhaust air turns turbo faster…

Figure 10: Increasing injector fuel volume (left) increases exhaust energy to drive increasing amounts of air into the cylinder to be mixed with fuel for combustion (right).

Gas engines, in contrast, are carbureted: The fuel must be mixed with air in the correct ratio before delivery to the cylinders. When the system calls for more power, the throttle opens to let in more air/fuel mixture. This mixture then must pass through the turbochargers, the aftercooler, the throttle and the intake manifold before reaching the cylinders. A spark starts combustion, and the mixture burns. Hotter exhaust goes through the exhaust manifold to the turbocharger. The turbocharger spins faster, increasing air flow in the engine. A fuel control valve increases the amount of fuel delivered to match the increased airflow, and the process begins again, now with a larger air/fuel charge to make more power. This process takes more time, and as a result the engine requires more time to accept load then does a diesel unit.

How Gas Engines Accept Load

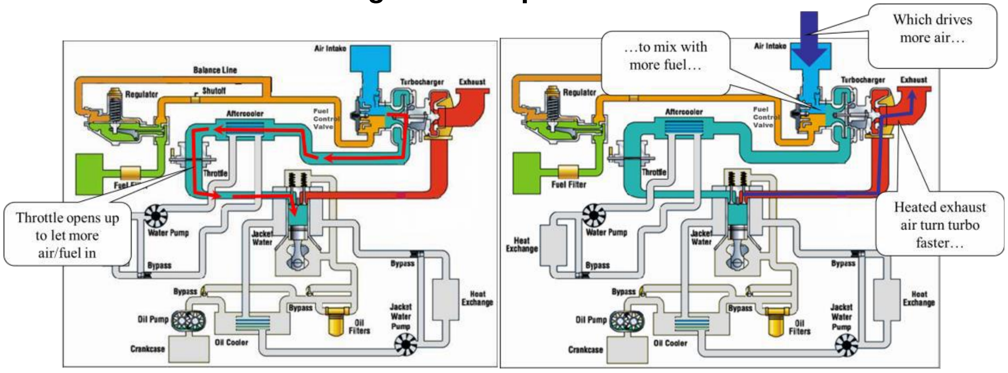


Figure 11: Increasing air and fuel volume by opening the throttle (left) increases combustion and exhaust energy to drive increasing amounts of air into the carburetor to be mixed with fuel for combustion (right).

Service references
SEBU6400-05
SEBU8554-03
SEBU7681-17

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