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Hybrid Microgrids: Why the time is now.

Microgrids that combine renewable energy with diesel or gas generator sets and energy storage capability can deliver clean, cost-effective electricity to remote locations with limited or no access to reliable utility power.

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Introduction

Cost-effective electric power has been a challenge for communities and industrial or commercial installations without access to a strong utility grid. They have had to rely on engine- or turbine-driven generator sets that, while highly reliable, typically produce power at much higher cost than a large utility.

Now a better model is emerging that combines newly cost-effective renewable energy from wind or solar sources with conventional diesel or gas-fueled generation. These installations, called hybrid microgrids, also employ energy storage to add power system stability and enable further energy cost reduction.

Enabled by sharp declines in the cost of wind and solar energy, as well as lower energy storage costs relative to the price of fuel, hybrid microgrids are well suited to a host of applications: individual buildings, resorts, mine sites, remote villages, small islands and others. The most promising applications are those with total power demand from 100 kW to 20 MW.

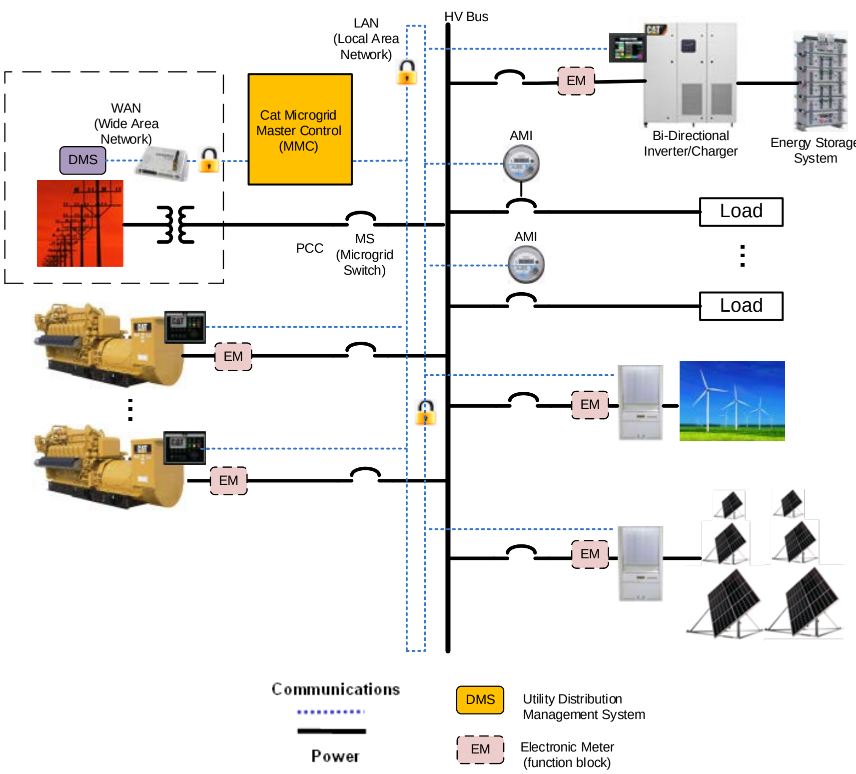


Figure 1.Typical single-line diagram of a hybrid microgrid

The basic concept is simple. Wind or solar energy reduces reliance on generator sets' produced energy, saving on fuel and, to a lesser extent, on maintenance costs. The generator sets firm the renewable sources and follow the load. Sophisticated digital controls tie the system together. Energy storage enhances system economics while also helping the generator sets respond smoothly to significant fluctuations in output from the renewable resources and maintaining consistent voltage and frequency (Figure 1).

The hybrid microgrid concept is quickly becoming the preferred approach to delivering low-cost, reliable power in settings beyond the reach of electric utility infrastructure.

Hybrid microgrid defined

The formal definition of a microgrid is a group of interconnected loads and distributed generation sources within a clearly defined electrical boundary that acts as a single controllable entity. Microgrids themselves are not new, as diesel and gas generator sets have been sold for several decades to power remote applications. These systems are continuously becoming more fuel-efficient as engine combustion and generator technologies improve.

What is new is an increase in hybrid microgrid systems that include renewable energy sources. Improvements in the costs and capabilities of photovoltaic PV systems, energy storage and telematics, along with advances in technology and communications now economically justify hybrid applications that previously would have required special support or incentives. The integration of renewable technologies reduces operating expenses when compared to purely conventional generation, while also optimizing system reliability, efficiency and flexibility.

The concept has become increasingly attractive as the cost of energy from wind and solar photovoltaic generation has declined, while the cost of diesel fuel – usually the most available fuel for remote locations – has risen (Figure 2). In 2000, the levelized life-cycle energy cost of wind generation was similar to that of diesel, while solar energy was nowhere near competitive.

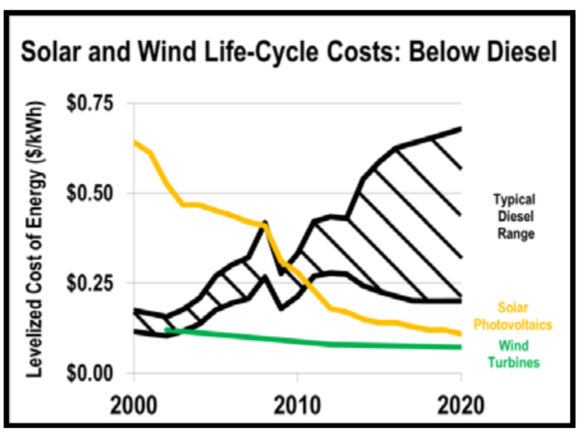


Figure 2. Life-cycle cost trends: Diesel vs. Renewables
Sources: International Energy Agency, Lawrence Berkeley National Laboratories, National Renewable Energy Laboratory, U.S. Energy Information Administration, Clean Edge, Caterpillar

Since then, diesel fuel prices have mostly trended upward, while wind power prices trended slightly down and solar PV prices fell dramatically. Conservative projections place the price of wind energy at US$0.09 per kWh by 2020, and the price of solar energy only slightly higher. This gives renewable energy a meaningful long-term price advantage over diesel-generated power.

In addition, advances in energy storage, system control and power conditioning, and connected load-side management have helped drive down the total cost of ownership (TCO) of hybrid microgrid systems.

Complementary technologies

The hybrid microgrid combines the benefits and offsets the weaknesses of renewable and conventional generation. The basic cost equation (Figure 3) is that in return for higher capital cost, a hybrid microgrid delivers lower long-term operating cost and thus lower TCO than pure conventional power generation.

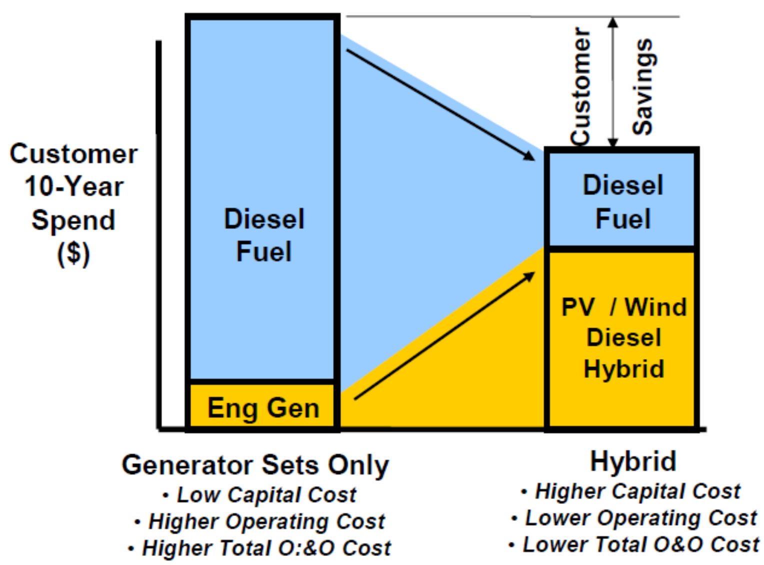


Figure 3. Basic hybrid microgrid economics

In a hybrid microgrid, renewable energy capacity can account for any percentage of the total peak load. In general, the greater the contribution from renewables, the greater the potential fuel and operating cost savings (Table 1).

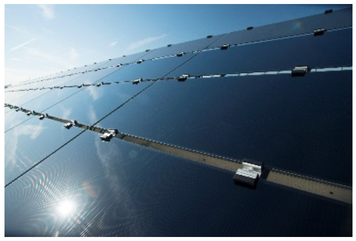
Fuel savings objective	 **Renewable energy capacity**	 **Energy storage function**
30-100%	Greater than generator set capacity	Power stability and energy time shifting
10-30%	Equal to generator set capacity	Power stability only
5-10%	<15-20% of generator set capacity	No energy storage
Baseline	 **Diesel or gas prime power generator sets**	

Table 1. Microgrid renewable component vs. fuel savings chart

In a hypothetical system with a 3 MW peak load served by three 1 MW generator sets, a conservative approach would limit the renewables component to a small share of capacity – for example, 300 kW (10 percent). In this scenario, the renewables limit fuel cost, but by far less than 10 percent because the renewable energy, being intermittent, is able to offset only a small share of generator set run time.

An intermediate approach would increase the renewables to 1 MW (33 percent). Here, at times when the renewables produce at full capacity, one generator set could shut down, saving significant fuel. If the renewable output declined suddenly (as when a cloud shades a PV array), energy storage could provide short-duration intermittent power, achieving good system stability.

Optimally, renewables would total the full 3 MW, or more. In that event, under ideal wind or sun conditions, the renewables could carry the entire load and at times inject the excess energy into storage, for use later when wind or sun conditions are less favorable. This would result in long periods when no fuel is burned in running the generators.

Technology virtues

Each component of a hybrid microgrid brings advantages that strengthen the system as a whole.

Renewables

Wind and solar, while requiring higher capital and significant space, have minimal operating and maintenance costs once installed. They displace greenhouse gases and other pollutants and contribute strongly to sustainability initiatives.

Two basic types of solar PV systems can serve microgrids. Inexpensive thin-film technology has an energy conversion rate of about 20 percent and is well suited for hot, humid and dusty environments where its performance does not degrade at the same (higher) rate as silicon panels. More costly silicon technology is also more efficient, at 25 percent energy conversion, under ideal light and temperature conditions. It also requires less space.

Generator sets

Reciprocating engine-generator sets deliver reliable energy and are fully dispatchable while renewable sources are offline or producing at less than rated capacity. Units in ratings from 350 kW to 15 MW and larger can be added in modular fashion to create systems of substantial size. Multiple units add ample flexibility for variable load conditions.

Generator sets offer high power density, simple-cycle electrical efficiencies from 40 to 48 percent, high part-load efficiency and excellent capability to follow loads. They tolerate a wide range of ambient temperatures and high altitude without derate. Diesel units in particular accept loads rapidly, with start times to full load as fast as 10 seconds and ramp-up time from 25 percent to 100 percent load in as little as 5 seconds. They tolerate unlimited starts and stops per day with limited impact on service life or maintenance requirements. The technology is thoroughly proven reliable with hundreds of gigawatts of capacity installed and qualified service technicians readily available worldwide.

Generator sets also offer potential for combined heat and power. Indeed, settings where microgrids are economically attractive – communities, resorts, industrial facilities – tend to have significant heat requirements. Heat captured from engine exhaust or cooling circuits, or both, can be converted to steam, hot water or chilled water (by way of absorption chillers) or used in water desalination plants, in each case greatly enhancing project economics. In temperate climate zones, it is very attractive to combine CHP and Solar energy because of their complementary nature. The CHP is typically operated during the cooler period when the solar contribution culminates during the sunnier months; energy storage helping balancing any surplus.

Energy storage

Energy storage is a key enabler of hybrid microgrids, and that technology is advancing rapidly. The conventional energy storage system consists of banks of deep-cycle lead-acid, lithium-ion or nickel-metal hydride batteries. Two other technologies – flywheel energy storage and researchable air-metal – are now gaining favor.

Flywheel storage offers low operating costs through low maintenance, a significantly smaller footprint than battery-based storage, and slightly greater efficiency. Mechanical energy storage is predictable and fail-safe, has a nearly unlimited life with no fall-off in performance, and tolerates a broad operating temperature range up to 104 degrees F (40 degrees C) without derate.

Air-metal energy storage originated with hearing-aid batteries, providing long life in a safe and non-toxic package. More recently, a rechargeable technology has been adapted to the zinc-air energy storage technology already common in applications such as backup power for cellular communication towers. The batteries can be 95 percent discharged and can be recharged with no cycle limit. Rechargeable metal-air (Zinc-air) provides the most economical electricity storage, and includes integrated controls and monitoring at the cell level.

The batteries do not overheat or discharge hazardous gases, and they operate in a range from freezing temperatures to 122 degrees F (50 degrees C) without derate. Life expectancy is twice as long as for lead-acid batteries. The next generation of zinc-air storage will be offered in capacities at megawatt scale, well suited for the hybrid microgrid concept and providing attractive TOC.

The range of energy storage technologies above are applied today in microgrid applications. A fully flexible offering enables a combination of these technologies, depending on the application.

System integration

Control over a hybrid microgrid is simpler than controlling combined renewables and conventional generation in a major utility. On a utility grid with wholesale deployment of wind or solar energy, the intermittent nature of the renewables would make the grid unstable absent massive energy storage.

On a microgrid, digital controls and smaller-scale energy storage enable consistent voltage and frequency and reliable kVAR control. In the event of a voltage dip, for example, the flywheel or energy storage can rapidly feed back into the system to provide stability. Energy storage also supports the generator sets in accepting block loads without fluctuations in frequency. This capability makes it possible to deploy renewable resources in proportions far greater than a utility grid could support – up to and exceeding total system demand.

A successful hybrid microgrid deployment depends on a fully integrated system. Ideally, a single party assumes responsibility for designing the microgrid, supplying all major components (generator sets, solar PV panels or wind turbines, energy storage and controls), and assumes responsibility for commissioning and long-term maintenance.

Today, the major components are available as factory-built, factory-tested, containerized modules that can be shipped to the site and installed with plug-and-play simplicity. This minimizes on-site construction work and shortens lead times.

Analysing costs

The key question is whether a hybrid microgrid is appropriate to a given site. Analytical tools are available that make it relatively easy to check economic feasibility. An initial high-level analysis requires little more than basic information about:

- The load profile of the community or facility to be served
- The site latitude and longitude and the historic solar and wind conditions
- The cost of fuel for the primary power units (generator sets)
- The remaining life of the primary power units (if existing units are to be reconfigured for microgrid duty)
- The cost of capital

The results of this analysis will indicate whether the project should be abandoned or a deeper investigation is warranted. In the latter case, Homer Microgrid Analysis Software can be used to perform a much more rigorous analysis on which to base a final go/no-go decision. The software:

- Simulates one year of system performance
- Uses site-specific solar and wind energy data
- Predicts annual generator set hours of operation and fuel use

The resulting data can be used to develop an operating protocol that enables financial optimization of the system.

Conclusion

One way to simplify a project is to select a partner with deep experience in power systems and in hybrid microgrids specifically. The chosen partner should demonstrate experience installing and integrating such systems and should employ locally based service technicians who can provide support ranging from basic planned maintenance to comprehensive long-term service agreements. The ideal organization should be qualified to manage whole-project engineering, procurement and construction, and supply all major components and ancillary equipment.

Another strong attribute is diverse financing capability with intimate knowledge of the special needs of power projects. This can include capability to finance the entire 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.

The low and declining cost of solar PV and wind energy opens new possibilities for clean, reliable, affordable electric power in hybrid microgrid configurations. Microgrids can be quickly and cost-effectively implemented in remote locations beyond the reach of the utility grid or where the grid is unstable. These are opportune times to investigate the hybrid microgrid concept as an alternative to conventional power generation.

Sidebar

Case Study: Power for a tropical island

A power company serving a tropical island wanted a hybrid microgrid to help reduce its costs; by adding solar photovoltaic energy to its diesel-fueled generation system.

The power generation equipment consisted of diesel generator sets fueled by No. 2 diesel distillate supplied by Caterpillar. The table presents a summary of the generating system. The chart (Figure 1) shows the daily load profile.

Island Generating System Before Microgrid

Total generation capacity	10.7 MW
Average demand	1.6 MW
Peak demand	4.5 MW
Annual historic energy production	13,900,000 kWh

Profile of Island Power Generation System

Figure 1. Island Power System: Daily Load Profile

Evaluating renewable energy

To identify the optimal system design for the island's needs, planners used the NASA EOSWEB database for global solar irradiation data, combined with the Homer software tool. This enabled an estimate the performance of a micro-grid system incorporating renewable energy. The NASA data estimated the average annual solar irradiation to be 5.32 kWh/m^2/day.

The analysis evaluated the site with a 670 kW solar PV system distributed over various roof tops. The system analysis was offered with and without energy storage to illustrate the financial benefits of the energy storage.

Hybrid Microgrid System Analysis With and Without Energy Storage

MICROGRID OPTIONS	PV capacity (kW)	Fuel savings (%)	Fuel savings (gallons/yr)	Simple payback (Years)
Baseline (as is)	0	0	0	0
Rooftop PV with grid stabilization	670	5%	53,373	6.4
Rooftop PV with grid stabilization & Energy Storage	670	7%	69,927	4.9

Hybrid Microgrid Economic Analysis

The analysis results showed a 6-year payback simply from combining PV with the diesel, but the payback fell below 5 years with the integration of a 250 kW energy storage system, even though that system meant a higher total capital expense.

The system demonstrates the value of the microgrid concept in combining the benefits and offsetting the limitations of both renewable and conventional generation. The system with integrated energy storage delivers rapid economic benefits along with enhanced power system stability and availability.

The systems include rooftop-mounted PV panels because ground space was too scarce and too valuable for that purpose. The system includes 2,316 solar modules and the racking structure needed to roof-mount the panels in various locations. String inverters are included.

The energy storage system consists of one Caterpillar BDP250 bidirectional energy storage inverter and two strings of batteries. The inverter interacts with the power system frequency and voltage to add power when needed to compensate for energy fluctuations. The grid stabilizer helps the overall power plant maintain system frequency and voltage in a narrower control band.

The system readily compensates for fluctuations in output from the solar panels. Figure 2 compares solar PV output for the array on a clear day and a cloudy day. During cloudy periods, solar energy generation can vary from 50 to 100 percent of the array capacity over short periods (10 seconds or less). A sharp drop in PV output causes a sharp rise in the power required from the diesel generator sets. This causes drop in system frequency and voltage as the diesel generators respond to the load.

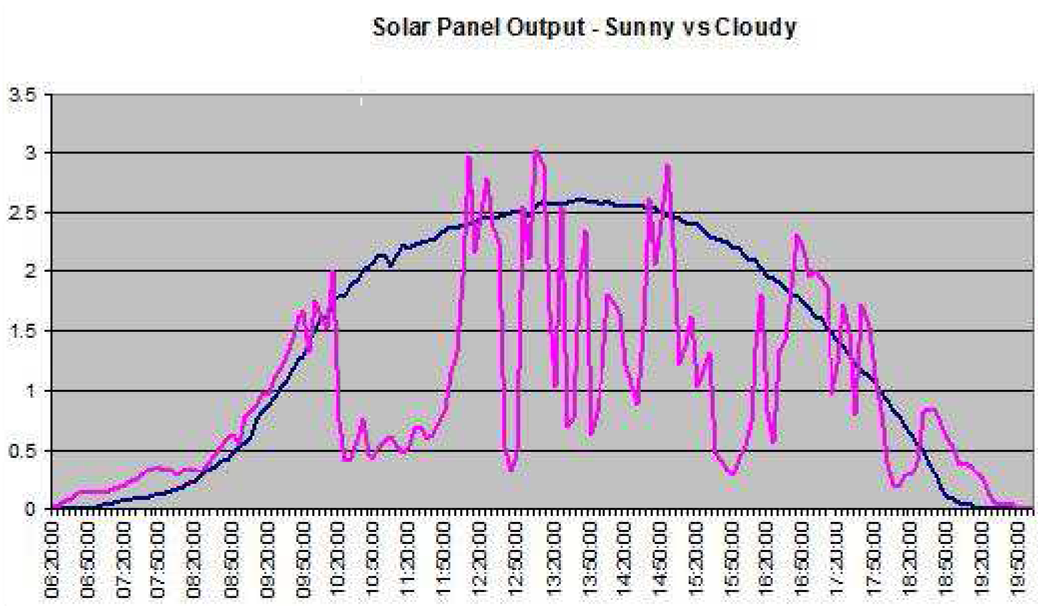


Figure 2. Solar Panel Output: Sunny vs. Cloudy

The benefit of energy storage is that when the bus frequency dips, the energy storage inverter outputs power to assist the generator set in responding to the transient, reducing the magnitude of frequency and voltage dip. The energy storage inverter can provide 250 kW continuously, up to the storage capacity of the battery. In transient operation, the inverter has higher power capability (150 percent for 30 seconds, or 200 percent for 3 seconds). The battery capacity can power the inverter for 10 minutes at 250 kW.

An additional benefit of the energy storage inverter is overall improvement in diesel power efficiency. The energy storage system can supply operating reserve (spinning reserve) for the power plant. As power plant load rises, additional generator sets are usually started when the operating load reaches 80 to 90 percent of the running generator sets' capacity. This provides extra capacity to respond to transient loads. Using the storage energy as operating reserve allows the system operator to wait to dispatch additional generators until the power system load is 95 to 100 percent of the running units' capacity. The overall average load of the diesel generators sets is therefore higher, resulting in higher overall power plant efficiency.

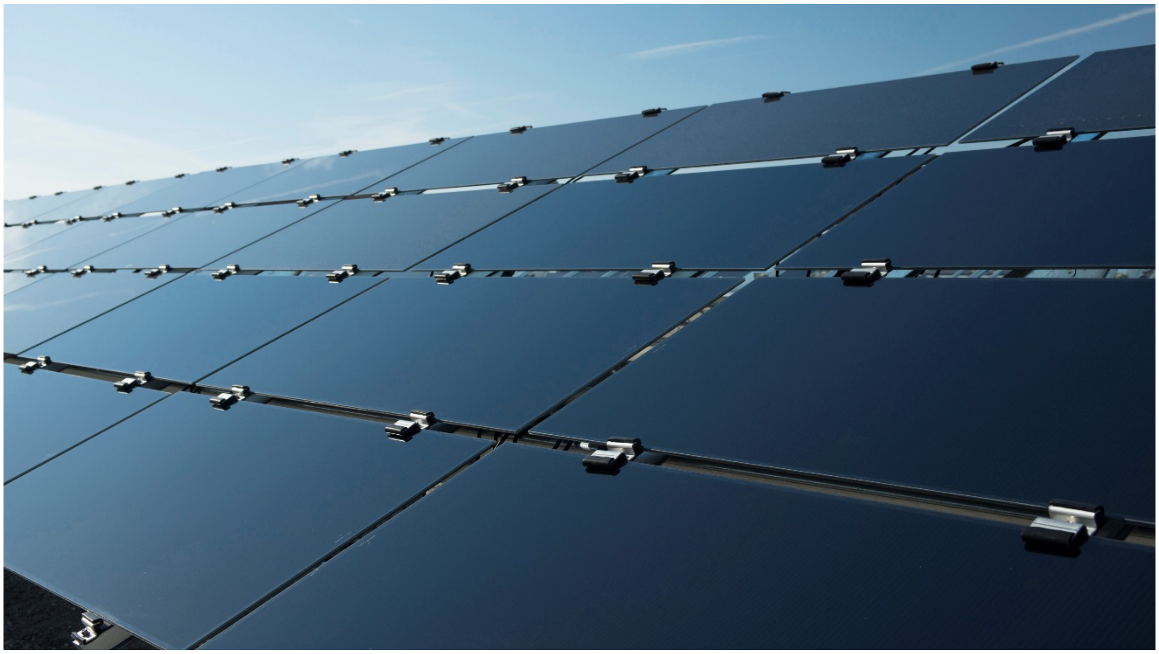


Figure 3. Typical thin film PV array on racking system and clips.

The CAT microgrid control system can be used with or without energy storage in an existing power plant to control the network and integrate with all energy sources to provide coordinated control of the generator sets, energy storage, and PV panels. This is important because with high reliance on renewable generation, voltage on some power feeder circuits may rise. The microgrid controls automatically adjust to maintain system voltage and power quality within specifications. The controller monitors generator set operation and maintains minimum load levels on the diesel generator sets in response to set points determined by the operator.

Where fuel consumption information is available, the microgrid controller can be used to dispatch the most efficient generator set, or combination of generator sets, for a particular operating mode.

About

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