Power Generation

TYING MULTIPLE POWER SYSTEMS TOGETHER WITH INTELLIGENT CONTROLS

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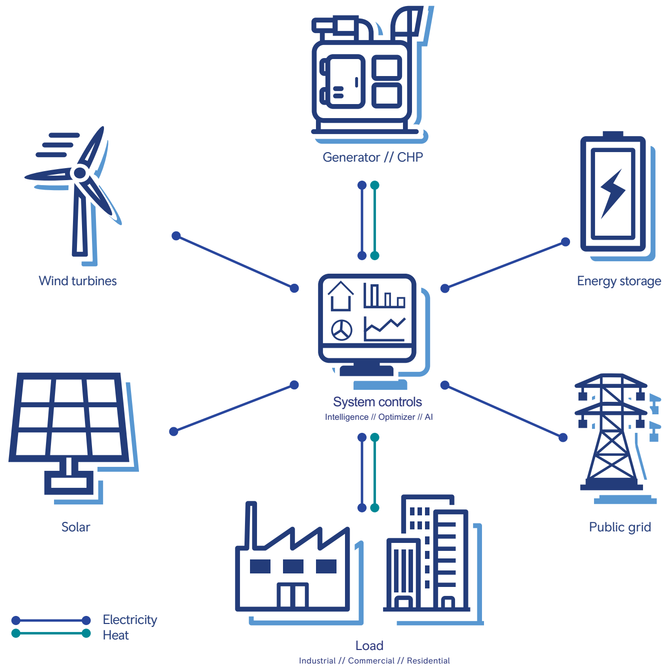
The control system is the most essential component of a microgrid. It manages a microgrid's distributed energy assets to cost-effectively produce energy while maintaining grid stability. To deliver the right energy mix for a customer's needs, the system must be predictive, intelligent and automated. After specifying a few key parameters, a control system can calculate exactly which energy sources will be needed to ensure efficient and reliable operation of a microgrid.

The need for dispatchable generation

Whether it's powering a residential high-rise in a major city or a mining operation in a remote area, every microgrid is designed to support an electric or thermal load. A wide range of distributed energy sources can be installed to optimize load management. The options could be renewable, such as solar panels and wind turbines, or conventional, such as diesel- or natural gas-powered generator sets combined with battery energy storage systems and intelligent controls to optimize these various assets.

A Rolls-Royce solution



Components of a microgrid

Intelligent control systems can bundle a microgrid's distributed energy resources and loads together for on-grid (parallel mode) or off-grid (island mode) energy consumers. A control system works as an optimization tool to harness a microgrid's various assets. Microgrids in environments with unlimited grid access allows optimum load management (peak shaving and load shifting) and enables operators to participate in the power balancing market. For off-grid applications, the microgrid becomes the sole energy source. Intelligent controls help lower fuel consumption and maintenance requirements to reduce overall operating costs, cut exhaust and noise emissions and ensure the availability of reserve power. A well-designed microgrid system allows energy users to optimize all of these functions into one system.

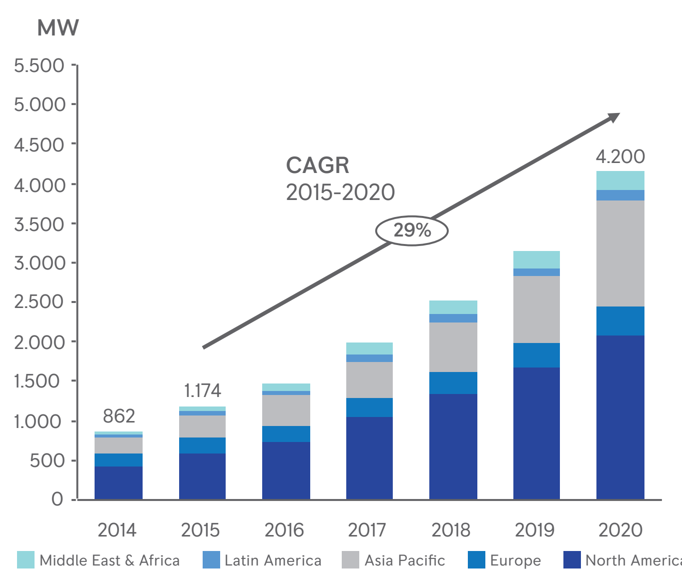
Why use a microgrid?

- Cost optimization
- Peak shaving
- Reduced environmental footprint
- Increased energy efficiency
- Increased resiliency/reliability
- Defer need for investment
- Flexible solutions
- Additional revenue streams for customer
- Grid services
- Energy arbitrage

New opportunities

As more customers realize the benefits of microgrids, the market continues to expand. Specifically, North American and Asia Pacific regions are showing the most growth potential for the future. With the growing demand for energy independence, renewable energy sources and on-site combined heat and power (CHP) systems, along with advancements in battery technology, interconnectivity and intelligent controls, the implementation of microgrids will continue to grow.

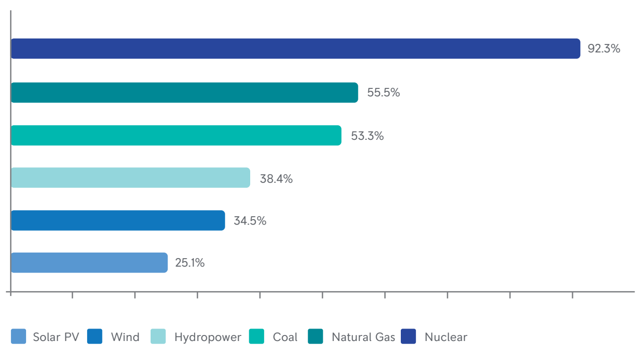
Annual total installed capacity by region, base scenario, world markets: 2014-2020



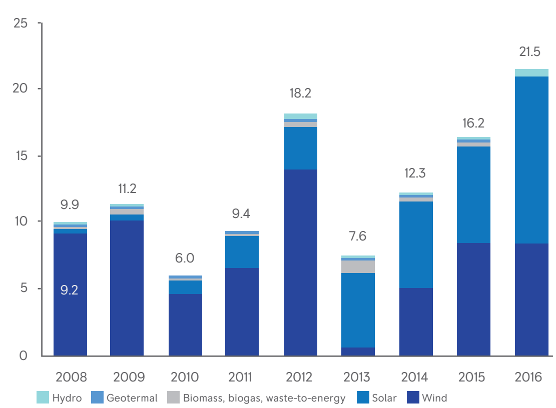
The growing need for dispatchable generation

The world continues to shift toward renewable energy sources such as solar, wind and biogas-powered components. More than 60% of new power plant installations are devoted to renewable energy. Renewable capacity has increased 70% since 2008. However, renewable energy is a variable source and not dispatchable. The maximum capacity factor (time a facility is able to produce maximum power) for wind and solar is 35%. This low capacity factor creates a risk of instability and the need for flexible generation assets, such as reciprocating engines and battery energy storage, paired with renewable sources. With a microgrid on-site, an energy user has a diverse mix of dispatchable power "behind the meter" at their command. Through flexible generation assets—whether it's engines, solar panels or battery storage—power can be instantaneously available and financially optimized at all times with intelligent controls.

Maximum Capacity Factors



Renewable Energy Usage



Soutrce: US energy overview: Renewable energy capacity build by technology (GW) [2]

Controls

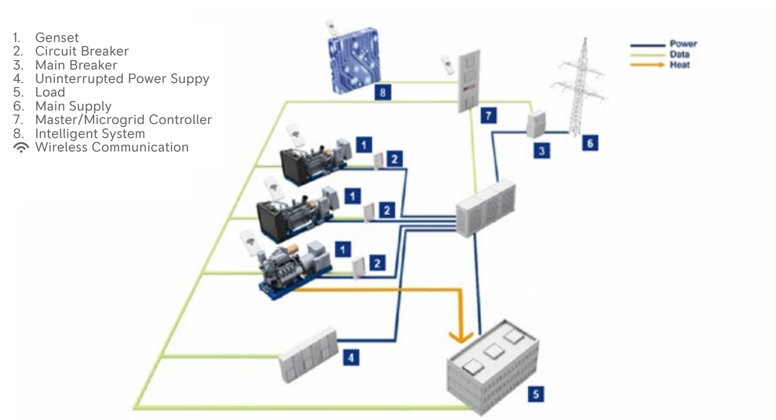
Intelligent control systems must be in place in any microgrid to balance distributed energy sources. Every piece of equipment must be integrated to safely and cost-effectively produce energy while minimizing environmental impact. At a site with multiple generator sets powering loads with electrical switchgear (shown below), a genset master controller keeps individual engines in sync with each other to seamlessly handle the load. All units work together to produce the exact power needed. A genset master controller's sole task is to monitor power generation assets.

Genset Master Controller functions

- High-level controller interfacing with individual genset controllers for multi-unit installation
- Start/stop selection and power setpoint of the gensets according to power or heat requirements
- Load sharing
- Leveling of engine run hours across units
- Synchronizing/control of main and tie breakers
- Island operation logic
- Visualization and data tracking of multiple units
- Remote access

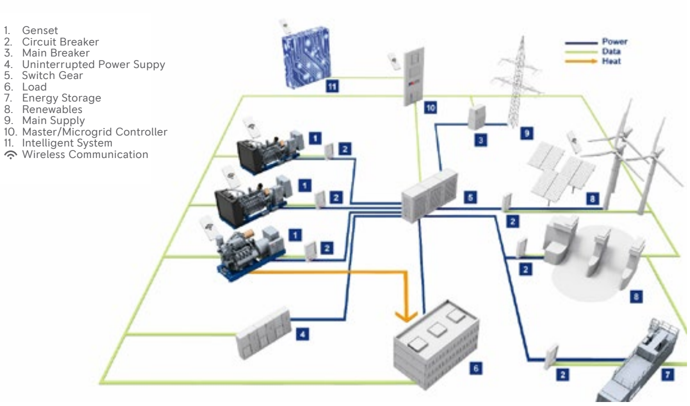
Genset master controller

As power generation systems get more complex, so do the control



systems. A microgrid controller manages many more assets than a genset master controller. In the microgrid application shown below, the control system must not only manage how diesel or gas generator sets interact with each other, but also how they integrate with renewable sources (which produce efficient yet variable power), the grid and battery energy storage systems. Adding to the complexity, on-grid or off-grid applications present different challenges. Either way, a microgrid controller must perfectly balance all assets to reduce the total cost of energy produced, optimizing the installation's financial and energy solution.

Microgrid controller



Microgrid controller functions

- Control of gas/diesel generators, solar, wind, battery storage, spinning reserves
- Grid parallel and grid forming operation in island mode
- Optimization of assets – technical and financial
- Modular platform for scalable solution
- Visualization and data tracking of multiple units
- Remote access

Grid design

The architecture of a microgrid controller is organized by function. Like a generator set controller, there are primary control functions to stabilize engine assets. Secondary controls are associated with transitioning between grid parallel mode and island mode. If there is a power outage, operation parameters must be restored between phases. Tertiary control's main objective is financial optimization—focusing on which mix of assets minimize the cost of energy.

Hierarchical control of hybrid power system

Primary Control

- Stabilize the voltage and frequency
- Offer plug-and-play capability for DERs
- Share the active and reactive power
- Mitigate circulating currents

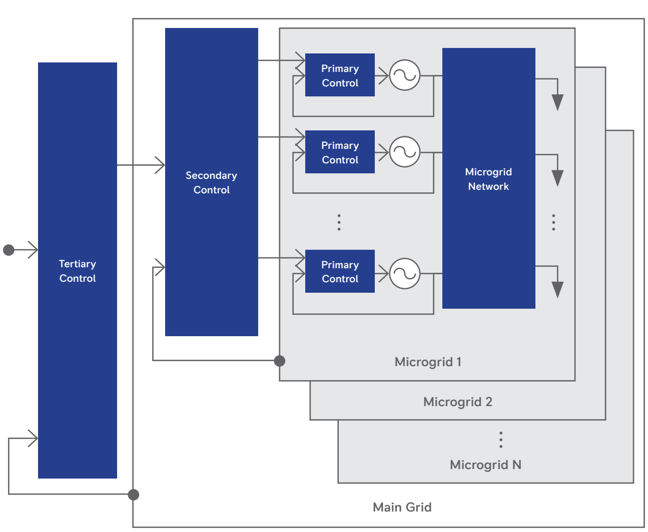
Secondary Control

- Frequency restoration
- Voltage restoration

Tertiary Control

- Optimal operation
- Power flow management

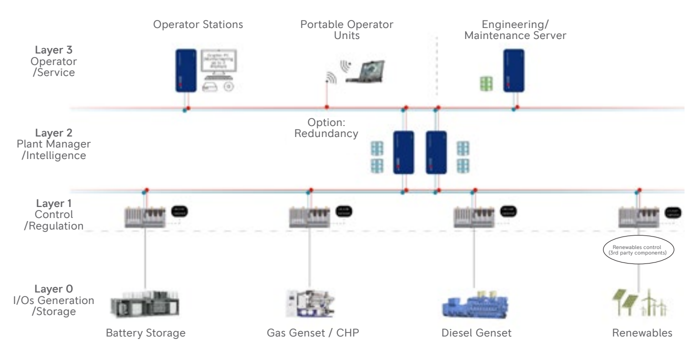
Control architecture



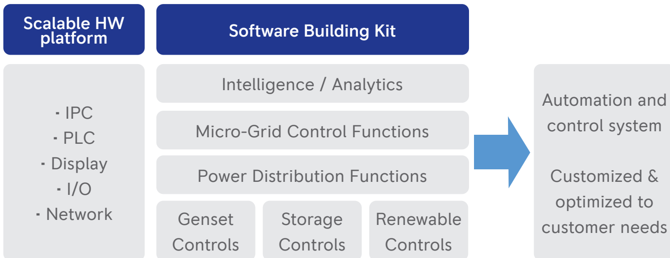
An ideal automation and control system is a fully integrated platform throughout all layers of control—from very basic functions like hardware I/O control or field device interfacing all the way to high layer SCADA functions like trending, reporting and system overview visualization.

Each layer is scalable to a customer's needs. For example, computing power can be adjusted by adding or removing industrial PCs. If you need very high availability, redundancy on all layers can be provided, from controller redundancy through network redundancy, all the way to I/O redundancy. Based on a system-wide user management, according to your role or on your individual account, you can always access all general information and control functions throughout the system, with the option of personalized profiles for access to additional functions. No matter if you are working locally at a power unit, sitting in a control room or reviewing reports at your desk, any type of interface to this automation and control system features the same user experience. This is a fully integrated, fully customizable, high performance automation and control solution with full redundancy on demand.

Layers of control



A flexible, scalable solution



Every microgrid—and customer—has different needs. A microgrid controller must provide complex functions throughout the system with user-friendly engineering tools. It functions as an automation system building kit with two parts: hardware platform and software building kit. Hardware is scalable with built-in redundancies, with functions that can be used in a wide range of Industrial PCs or controllers in a very flexible and efficient way. Hardware components provide calculation power, communication and I/O. A software building kit brings these two worlds together to intelligently dispatch multiple assets to financially optimize the system. Using analytics and artificial intelligence, hardware and software work in tandem as a powerful automation and control solution that is not limited to predefined controller devices, but is customized to a customer's exact specifications.

Operational modes

Microgrid design varies depending on whether the microgrid is connected to the main grid in grid parallel mode or isolated from the grid in island mode. In any case, a microgrid control system ensures the most reliable, economical and environmentally responsible operation possible.

Grid parallel mode

There is growing interest from on-grid energy consumers (industry, service providers and municipal services) in the development of partial or complete self-supply. The motivating factors for these customers are: independence from nationwide network providers, security of supply, cost optimization, and a "green" image.

Functions

— Active Power Control – Set active power (kW) import/export to the grid
— Reactive Power Control – Set reactive power (KVAR) import/export to the grid
— Optimize utilization of renewable generation to reduce usage of gensets/grid
— Optimize load factor/running hours of gensets
— SOC Limits – Control State of Change (SOC) boundaries of battery storage (scheduled or fixed values)

Island mode

Consumers without grid connections run self-sufficient island operations (traditionally based on conventional diesel generators). Installations include mines in remote regions, inhabited islands, and remote hotel resorts. Common goals are the development of microgrids, consisting of regenerative energy (PV, wind), battery storage, and backup generators in connection with intelligent energy management systems.

Functions

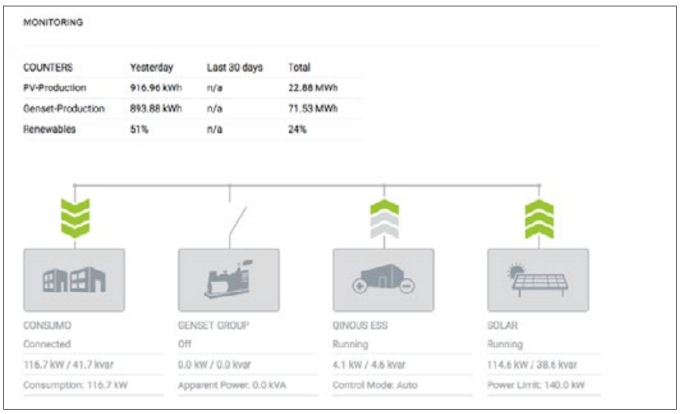
— Utilize Battery Energy Storage System (BESS) to improve power quality by supporting generators during transient load changes
— Optimize usage of renewable generation with BESS to avoid curtailment of these assets
— Renewable curtailment should power production exceed consumption

Control & monitoring functions

A microgrid controller forms an interface between a complex network of distributed energy sources, battery and load. Through user-friendly displays accessible on desktop and mobile platforms, an engineer can monitor live data and performance history while the system automatically manages the microgrid efficiently and reliably.

Example: Control System Functions

System Overview (Home screen)



Functions

- Live data overview showing flow of energy being produced, consumed and stored
- Performance history for all subcomponents
- Alarm list and history

Capacity Management (System)

Functions

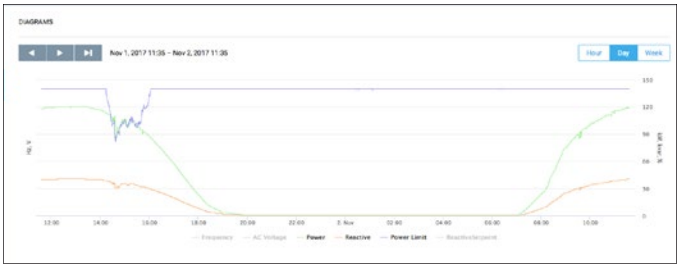
- Reduce utilization of generator sets
- Optimize genset starts
- SOC schedule to store energy from renewables for nighttime use
- Avoid solar curtailment
- Ensure stability of electrical system with sufficient stored energy

Capacity Management (Genset Group)

Functions

- Optimize genset starts
- Add/subtract genset capacity to ensure optimal load factor
- Pre-programmed generator start times/load acceptance capability to intelligently manage assets

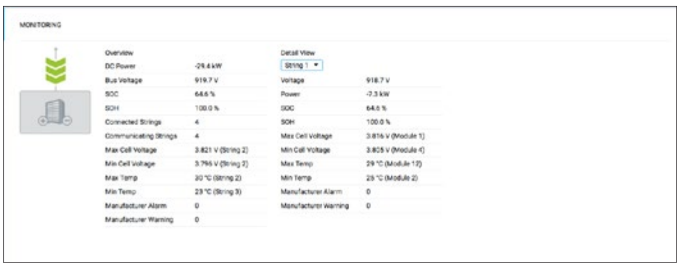
Capacity Management (Solar)



Functions

- Reliable solar curtailment, factoring in BESS SOC, BESS power limits and inverter power limits
- Avoid curtailment through analysis of solar capacity in power management

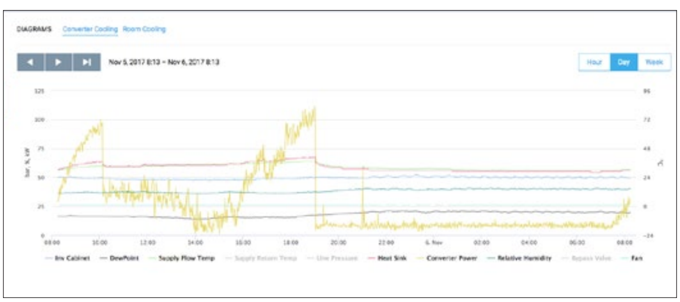
BESS Management



Functions

- Overview of battery parameters
- Monitoring to avoid undesirable SOC rest states: BESS remaining deeply discharged for prolonged time
- Full utilization of battery capacity
- Thermal monitoring

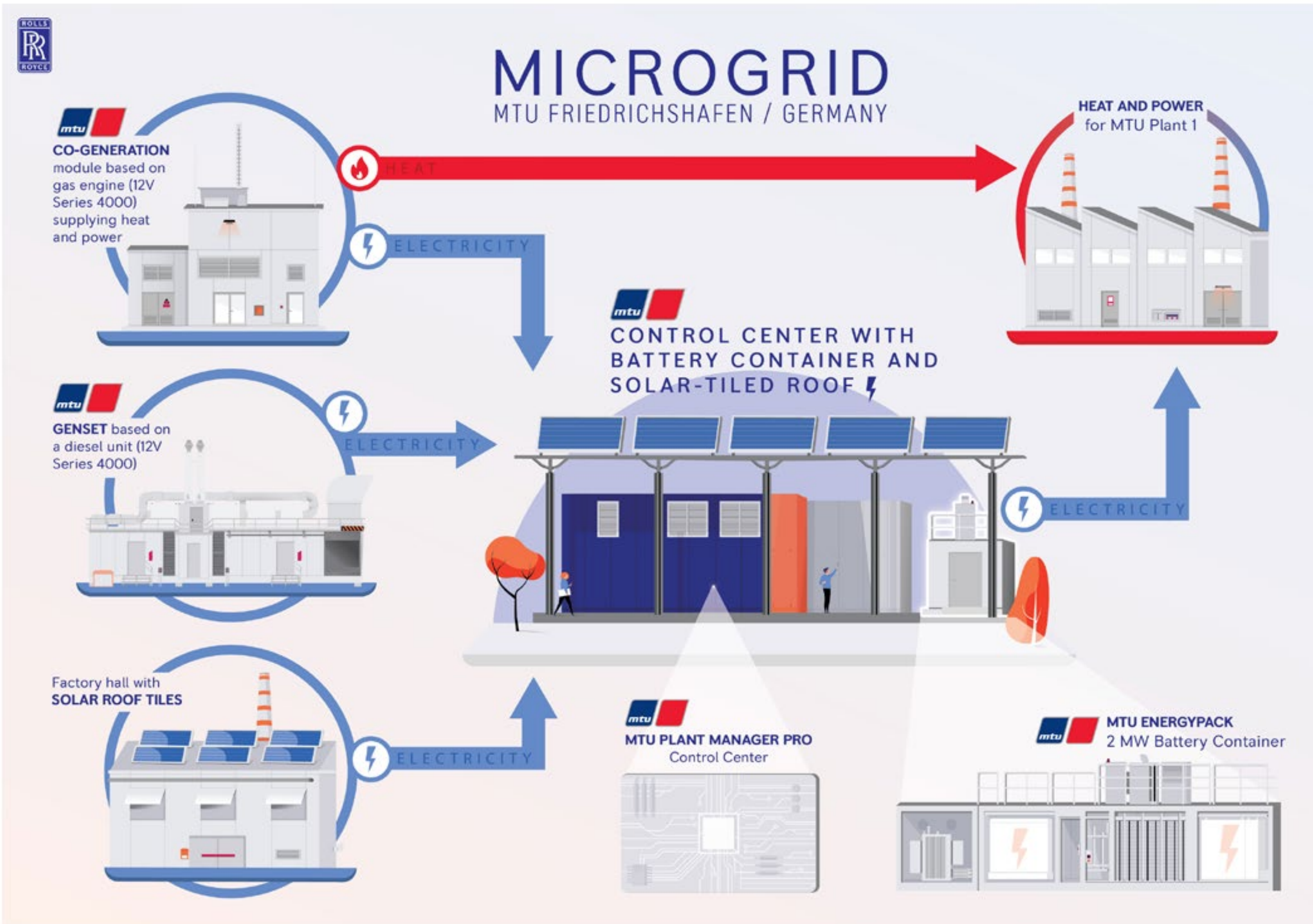
BESS Management (Thermal)



Functions

- Overview of HVAC system
- Monitor ambient and battery temperatures
- Track invertor power
- Detect overheating to prevent battery fire

Simulation tool



Every microgrid is unique. Modeling real-world applications can ensure a microgrid and its control system is designed optimally. The MTU Microgrid Validation Center in Friedrichshafen, Germany offers highly flexible simulation and testing capability. Equipped with diesel and co-generation standby generator sets, solar panels, battery storage and integrated MTU automation system, the self-sustaining center can simulate a wide range of conditions, including off-grid operation. It's an effective proving ground for customers to apply a software model to just about any real-world installation.

There are several parameters to consider when optimizing a microgrid. The facility's load profile, solar and wind conditions, fuel costs, remaining life of primary power units and the CAPEX investment on renewables, energy storage and plant power components must all be thoroughly analyzed. The process starts with a high-level analysis, to indicate whether the project should be abandoned or investigated further. These calculations simulate one year of system performance, using site-specific solar and wind energy data. The data helps predict annual generator hours of operation and fuel use. The second part of the process is financial optimization, to make sure the right equipment is selected to cost-effectively and efficiently produce power. A real-world example of this process is outlined on the next page.

Example #1:
Off-Grid Greenhouse – California

Site details
— 160,000 sq. ft. European-designed facility
— Limited three-phase power available for office area only
— Abundant natural gas available
— Cooling loads are the major challenge

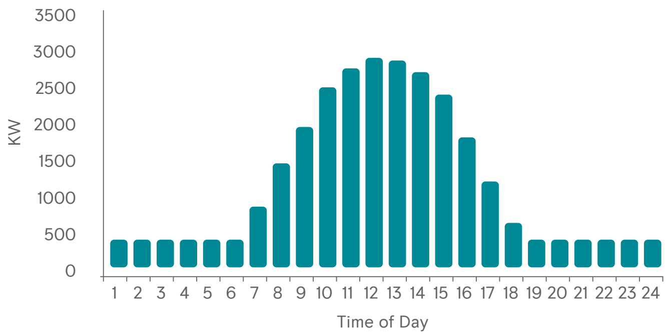
Scope of supply
— 2 x MTU 8V4000L32 natural gas generators rated at 762kW
— 2 x MTU 16V4000L32 natural gas generators rated at 1550kW
— MTU/Qinous Qlarge 700kVA/753kWh
— Site controller/Microgrid energy management system

Consumption
On a typical summer day, the facility needs a peak of over 3,000 kW. In the winter, with shorter days and less sunlight, more electricity is needed (4,000 kW). Over a 12-month period, more than 13 million kWh are required to power facility.

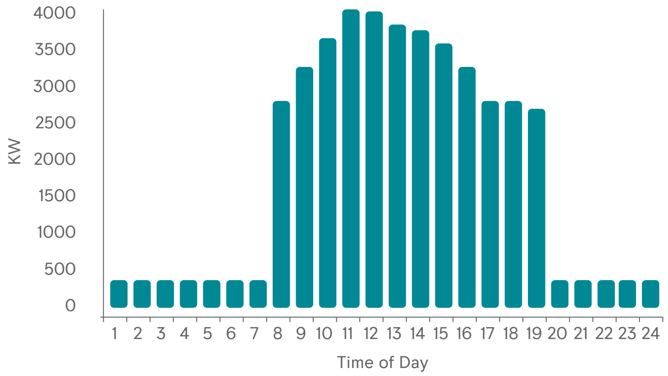
Consumption Summary

Component	Consumption (kWh/yr)	Percent
AC Primary Load	13,848,830	100
DC Primary Load	0	0
Deferrable Load	0	0
Total	13,848,830	100

Summer



Winter



Production summary

Run hours will spread across engine models leveling annual run time and extending maintenance intervals using controller.

Component	Production (kWh/yr)	Percent
Generic flat plate PV	352,777	2.54
MTU 8V4000 GS L32 60Hz	3,178,966	22.9
MTU 8V4000 GS L32 60Hz (1)	277,064	2
MTU 16V4000 GS L32 60Hz	6,059,779	43.7
MTU 16V4000 GS L32 60Hz (1)	4,012,275	28.9
Total	13,880,862	100

Engine plant statistics

Natural Gas Consumption Statistics

Quantity	Value	Units
Total fuel consumed	3,417,265	m^3
Avg fuel per day	9,362	m^3/day
Avg fuel per hour	390	m^3/hour

(1) MTU 8V4000 GS L32 60Hz Statistics

Quantity	Value	Units
Hours of Operation	6,520	hrs/yr
Number of Starts	868	starts/yr
Operational Life	9.66	yr
Capacity Factor	47.6	%

(1) MTU 16V4000 GS L32 60Hz Statistics

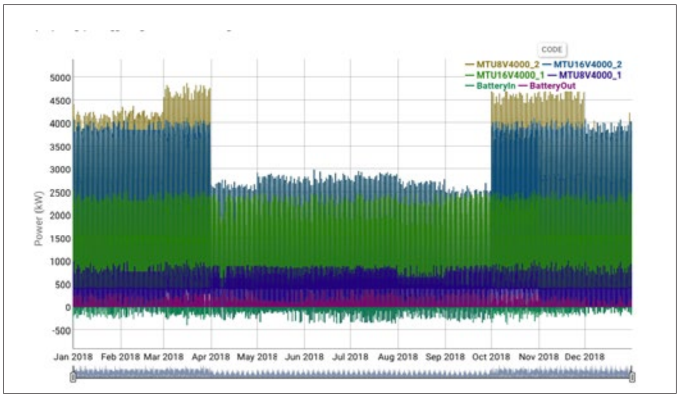
Quantity	Value	Units
Hours of Operation	3,969	hrs/yr
Number of Starts	365	starts/yr
Operational Life	15.9	yr
Capacity Factor	44.7	%

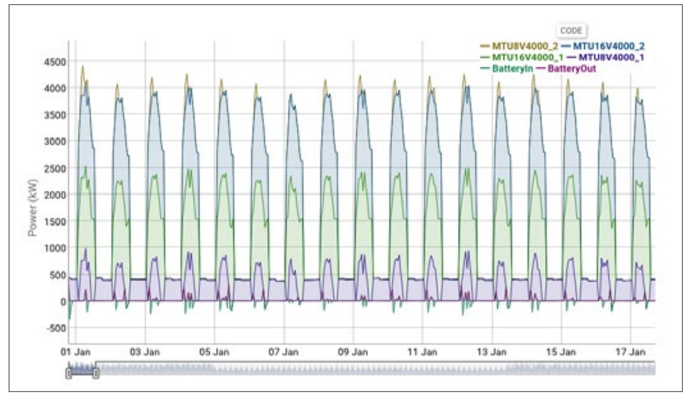
(2) MTU 8V4000 GS L32 60Hz Statistics

Quantity	Value	Units
Hours of Operation	597	hrs/yr
Number of Starts	194	starts/yr
Operational Life	106	yr
Capacity Factor	4.15	%

(2) MTU 16V4000 GS L32 60Hz Statistics

Quantity	Value	Units
Hours of Operation	2,854	hrs/yr
Number of Starts	396	starts/yr
Operational Life	22.1	yr
Capacity Factor	29.6	%





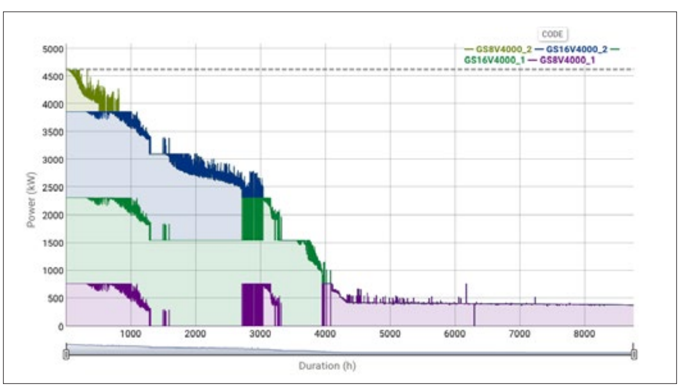
Highlights the distribution of the power demand throughout the different microgrid components. The power output or input (storage) is staged together and the covering line shows the demand timeline.

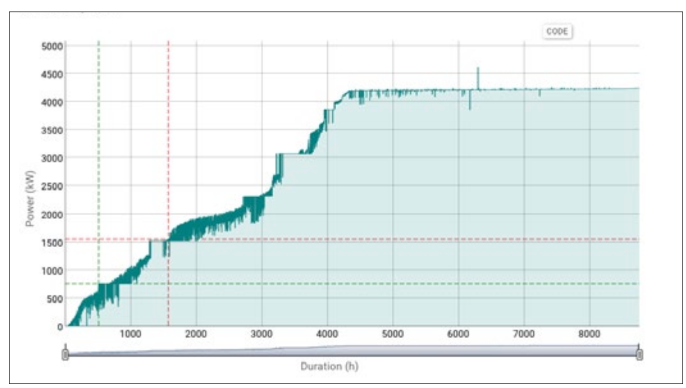
Duration curve plot

The duration curve is staged together from each genset power supply. This enables a view on how often and for how long each combination of gensets is running. The white space between the duration curve and the dashed limit line is the pure genset system reserve.

Availability calculation

An MTU generator set with service agreement has a technical availability of 96%. If the genset reserve is below the rated power of a unit, a failure will cause a blackout. The green dashed line above represents the operating hours per year the MTU 8V4000 GS must not fail, because of a lower reserve than its rated power of 762 kW. The red dashed line shows the operating hours per year that the MTU 16V4000 GS must not fail, because of a lower reserve than its rated power of 1549 kW.





Trends in intelligent controls

As we move toward a future with a growing prevalence of microgrids, energy sources will certainly diversify. Historically, throughout the world, power generation has always followed the load. Highly stable power generation facilities such as coal facilities and nuclear plants were the only source. Through these methods, the sources had to be always available since power had to be instantaneously created and consumed.

But the energy market is changing. As we look to the future, utilization of renewable sources will continue to grow. The costs are coming down and the efficiencies are going up. However, diverse assets cause a variable creation and consumption of power. To optimize wind, solar and all other assets, you'll need intelligent controls to make sure the load is always supported, whether it's connected to the grid or operating in island mode.

Conclusion

A microgrid is a technical solution that satisfies local energy demand in an economical manner, customized to a customer's specific needs and local boundary conditions. A microgrid enhanced by an active management of the loads or a flexible change of addressed value streams is called a smart grid. A hybrid system is the combination of a generator set with an energy storage system and therefore a subset out of a microgrid configuration. Energy demand includes both pure electrical and combined electrical and thermal.

Microgrids comprise distributed energy resources, energy storage systems and loads under one control system. The system can be operated two ways—interconnected to the grid or in island mode. It can take advantage of different value streams, depending on the concrete technical design and subject to applicable regulations. By integrating multiple energy assets through an intelligent control system, a microgrid can cost-effectively produce energy while maintaining grid stability.

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