Thermal Hybrids

GE's Solution for Grid Firming

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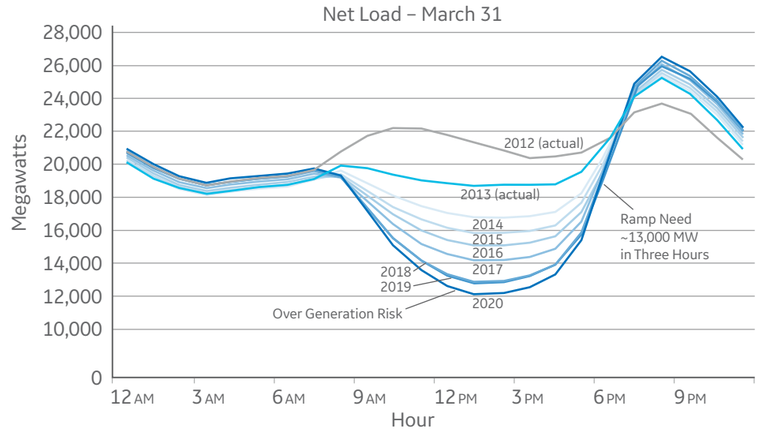
The global energy system is transforming at a scale and pace never experienced before. Integrating intermittent renewables and distributed energy into an aging grid requires flexible and resilient technologies, able to ramp up or down rapidly and dynamically adjust to real-time grid signals.

Thermal hybrids are GE's solution to the grid firming challenge. These applications—involving the interfaced operation of a thermal asset with a renewable and/or an energy storage asset—are expanding the possibilities of electricity generation.

GE has more than 125 years of experience integrating the latest innovations in electricity generation and delivery—and hybrid power technology is no exception. Our hybrid energy system portfolio, backed by the experts whose equipment generates about one-third of the electricity in the world, can be customized and scaled to help meet your specific needs. Our wing-to-wing hybrid solutions range from upgrading and improving the capabilities of an existing facility to incorporating hybrid technologies into a new generation facility or transmission and distribution network.

The Impact of Renewables

As more and more renewables come into play, grid operators and regulators are faced with significant operational challenges. Essentially, the steep load ramps associated with wind and solar operations could be fully satisfied through demand management, energy storage and the use of efficient fossil fuel sources.

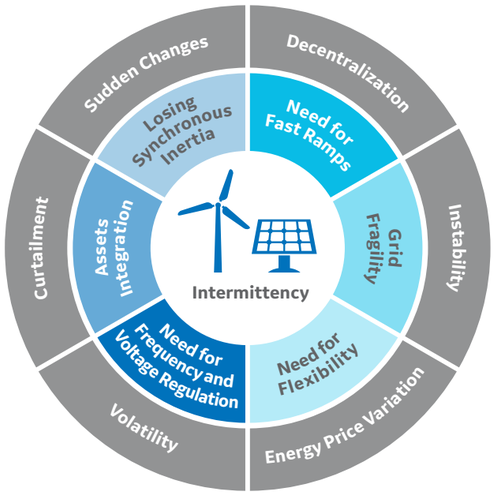


Increasing Reliance on Renewables Can be Seen as a Duck-Shaped Graph.

Why Hybrid Energy Now?

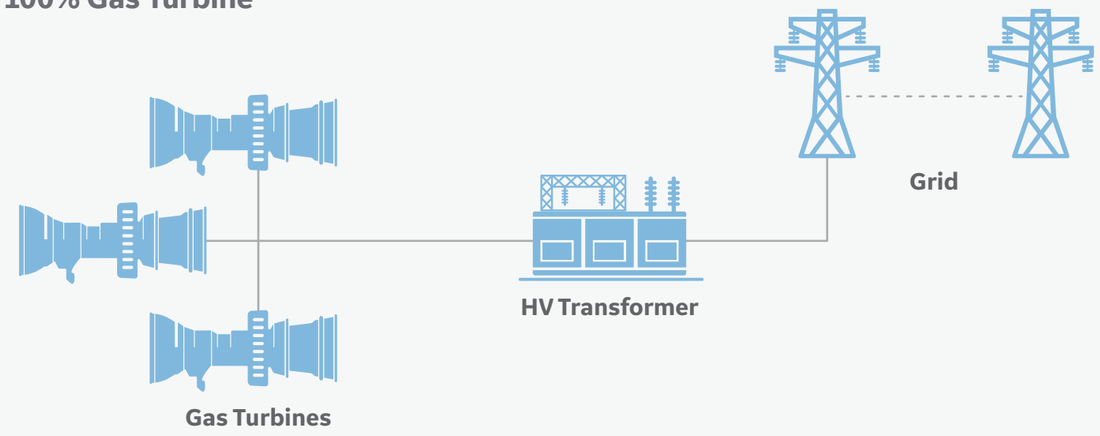
A number of trends are driving a shift to hybrid energy:

- Steady deployment of intermittent renewable wind and solar photovoltaic (PV) power resources
- Exponential reductions in the cost of batteries for energy storage
- The growth of digital power solutions that enable better integration of generation assets and real-time interaction with the grid
- Implementation of environmental goals by a wider range of countries, cities, communities, and businesses

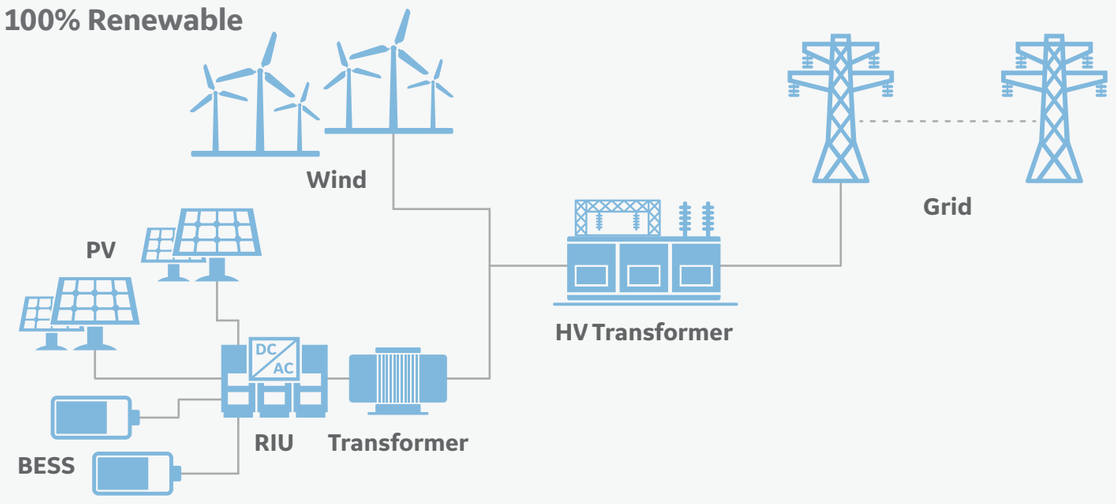


Which mix is the right one?

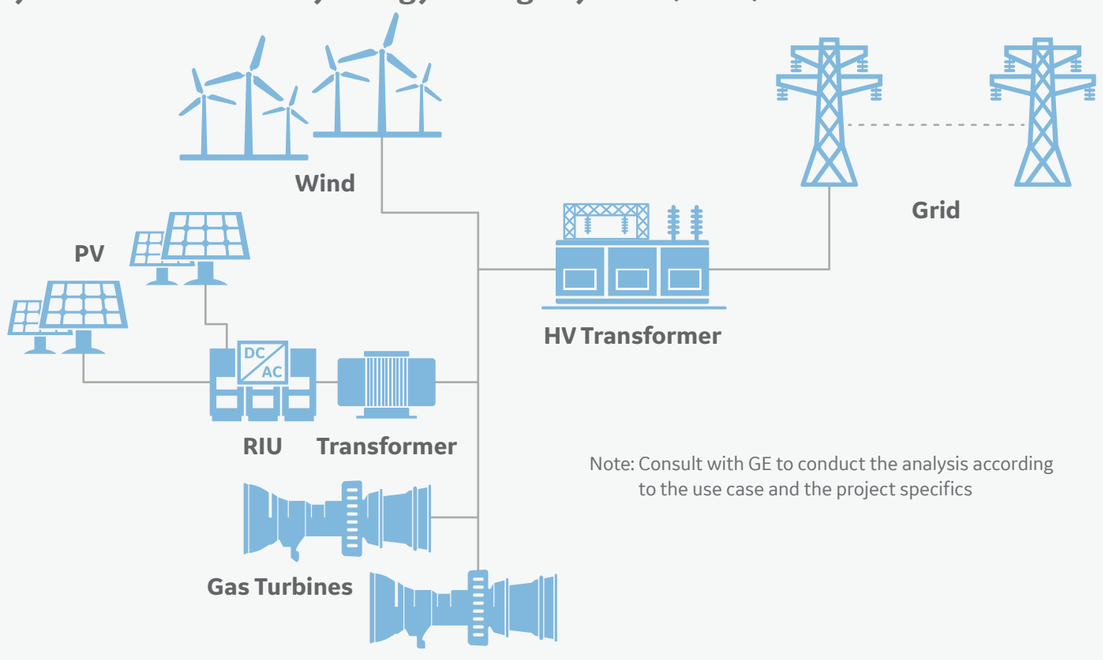
100% Gas Turbine



100% Renewable

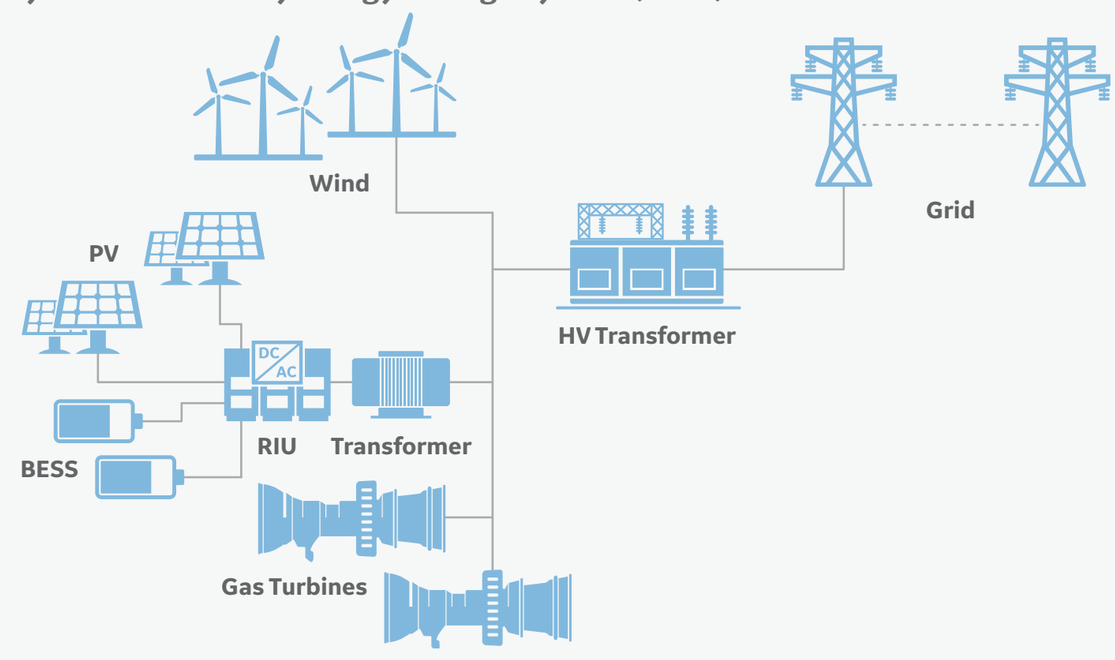


Hybrid Without Battery Energy Storage System (BESS)



Note: Consult with GE to conduct the analysis according to the use case and the project specifics

Hybrid With Battery Energy Storage System (BESS)



GE's Thermal Hybrid Solutions:

Simple Cycle Gas Turbine
Turbine + BESS + Digital Controls = EGT*

Enhancing peaking and grid following

Battery storage systems can be integrated with existing or new simple cycle gas turbine power plants to enhance the peaking and grid-following attributes that are typical of today's simple cycle gas turbines. Hybrids also offer reduced system operating costs, creating value for both power providers and rate payers. The upgrade to an enhanced gas turbine (EGT) enables contingency (spinning) reserve without fuel burn between demand events.

This technology also enables high-speed regulation, primary frequency response, and voltage support with the combined response of the gas turbine and battery storage system. Finally, the solution can be used to enhance peaking megawatts with the additional capacity of the battery and provide black start capability to the site.

These hybrid solutions can be applied to aeroderivative and heavy-duty gas turbines in many size ranges. Our gas turbines are integrated with packaged storage solutions and a proprietary control system. The control system manages gas turbine output, battery storage output and system rate of charge to continuously provide better outcomes from the hybrid installation. These systems can be customized to your site-specific needs and industry conditions for advanced benefits.

Case in Point

In 2017, Southern California Edison (SCE) installed the world's first battery storage and gas turbine hybrid system, the LM6000 Hybrid EGT, at two sites in response to California's changing regulations and grid requirements. The system ultimately will support increased renewable energy capacity on the grid.

Features of an LM6000 Hybrid:

- 10 MW/4.3 MWhr lithium-ion battery
- GE's Brilliance inverters
- OpFlex* hybrid upgrade package
- Mark*VIe control system
- GE's proprietary hybrid turbine controls

Benefits without Fuel Burn

- Instant, always-ready response
- 50 MW of operating reserve
- +10 MW of peaking power
- Primary frequency response
- -8 to +5 MVAR voltage support
- Black start capability
- Demand charge savings
- Spinning reserve enabled

Benefits with Fuel Burn

- 50 MW peaking power for local contingency
- 25 MW of high-speed frequency regulation
- Self-managed BESS state of charge

GE's Thermal Hybrid Solutions:

Combined Cycle Gas Turbine + BESS

Improving combined cycle flexibility and utilization with battery storage

GE's hybrid solution couples the latest advances in battery storage technology with our proven combined cycle power plant—delivering the reliability you expect from a manufacturer with more than 60 years of gas turbine experience. Our hybrid battery storage solution can be added to existing combined cycle plants, integrated with new combined cycle plant installations during construction, or even included as a complete upgrade package to convert from simple cycle operation to combined cycle plus battery storage.

As the single OEM, GE can help ensure that all components are optimally integrated to work together seamlessly, providing higher performance at a lower cost.

Case in Point

In a 2 X 6F.01 installation with a 55 MW/18 MWh battery, GE's hybrid solution can provide full combined cycle output (162 MW) within 13 mi nutes of engine start. A standard 2 X 6F.01 without battery storage would take approximately 30 minutes to achieve full combined cycle output.

In a primary frequency respon se application, a 9F.03 combined cycle gas turbine with a 9 MW/2.5 MWh battery can provide the same capabilities as an appropriately sized standalone battery solution—at a 30% lower capital cost.

Benefits

- Faster combined cycle startup
- Simple cycle flexibility with combined cycle efficiency
- Lower capital expenditure (CAPEX) than standalone storage solutions
- Black start capability without the need for a backup diesel genset
- Enhanced grid frequency regulation
- Additional peak capacity during periods of high energy demand/high pricing
- Increased ramp rate with lower thermal stress
- Increased load following capability

GE's Thermal Hybrid Solutions:

Gas Turbine + Renewable Energy

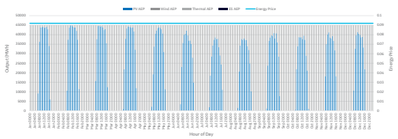
GE's gas turbines can play a valuable role as reliance grows on a larger renewables mix. As one of the world's largest manufacturer and supplier of gas turbine technology, GE offers a wide array of equipment options and models to help meet your most challenging energy requirements. We build our heavy-duty and aeroderivative gas turbines to be efficient, versatile and reliable, with individual output ranging from 34 MW to 571 MW. They are proven performers in simple and combined cycle operation for pure power generation, cogeneration, mechanical drive, and waste-to-power applications.

Benefits

- Reduced renewable energy curtailment
- High capacity factors at lower capital expenditures compared to battery storage utilization
- Lower levelized cost of energy (LCOE) compared to pure thermal operation
- Decreased greenhouse gas emissions
- Lower variable cost

Case in Point

GE's aeroderivative technology is enabling CPV Sentinel (CPVS) to help meet California's ambitious renewable energy goals and maintain grid reliability. The 800 MW CPVS energy project is a natural gas power plant in Riverside County, California, that runs only during periods of peak electricity demand. The power plant is equipped with eight natural gas-fired LMS100 combustion turbine generators (CTGs) that are designed to start in 10 minutes and can be operated at a 43% simple cycle mode, helping the plant meet environmental challenges and also aid in reducing CO_2 emissions. The world's largest facility using GE's intercooled aeroderivative combustion turbine is located adjacent to a high wind area in the vicinity of 3,000 wind turbines.



Typical Hybrid annual energy production operation

GE's Solution Enablers

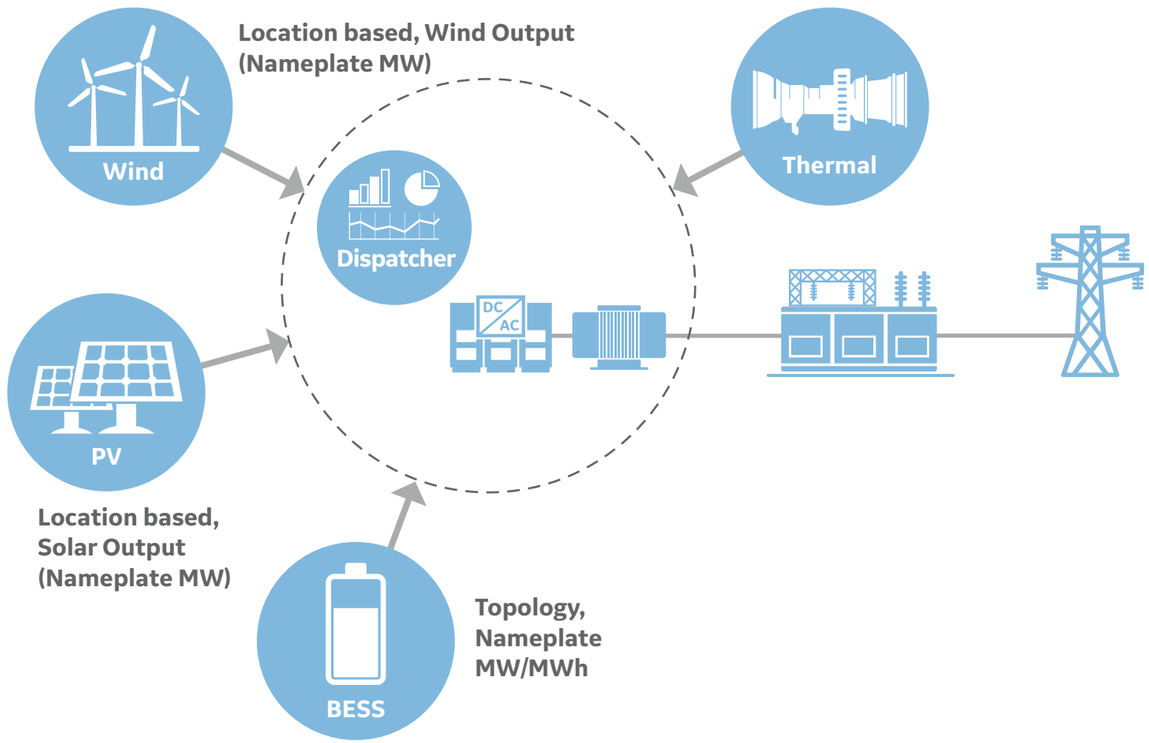
GE's Hybrid Architect for Better Decision-making, Improved Results

GE's Hybrid Architect was developed to calculate net present value (NPV), internal rate of return (IRR) and levelized cost of electricity (LCOE) of a hybrid power generation system incorporating a combination of solar, wind, gas turbines and battery energy storage. The Hybrid Architecture also can help improve the hybrid system configuration, such as the photovoltaic direct current nameplate, the size of the energy storage system, and the number of wind and/or gas turbines.

An easy-to-use tool, the Hybrid Architect reduces the engineering cycle from weeks to hours.

The Architect can be used for:

- Energy shifting
  — Merchant/structured purchase power agreement
- Load following/firming
- Capacity payments
- Renewable Energy Certificates (REC) for revenue
- Curtailment
- Frequency response

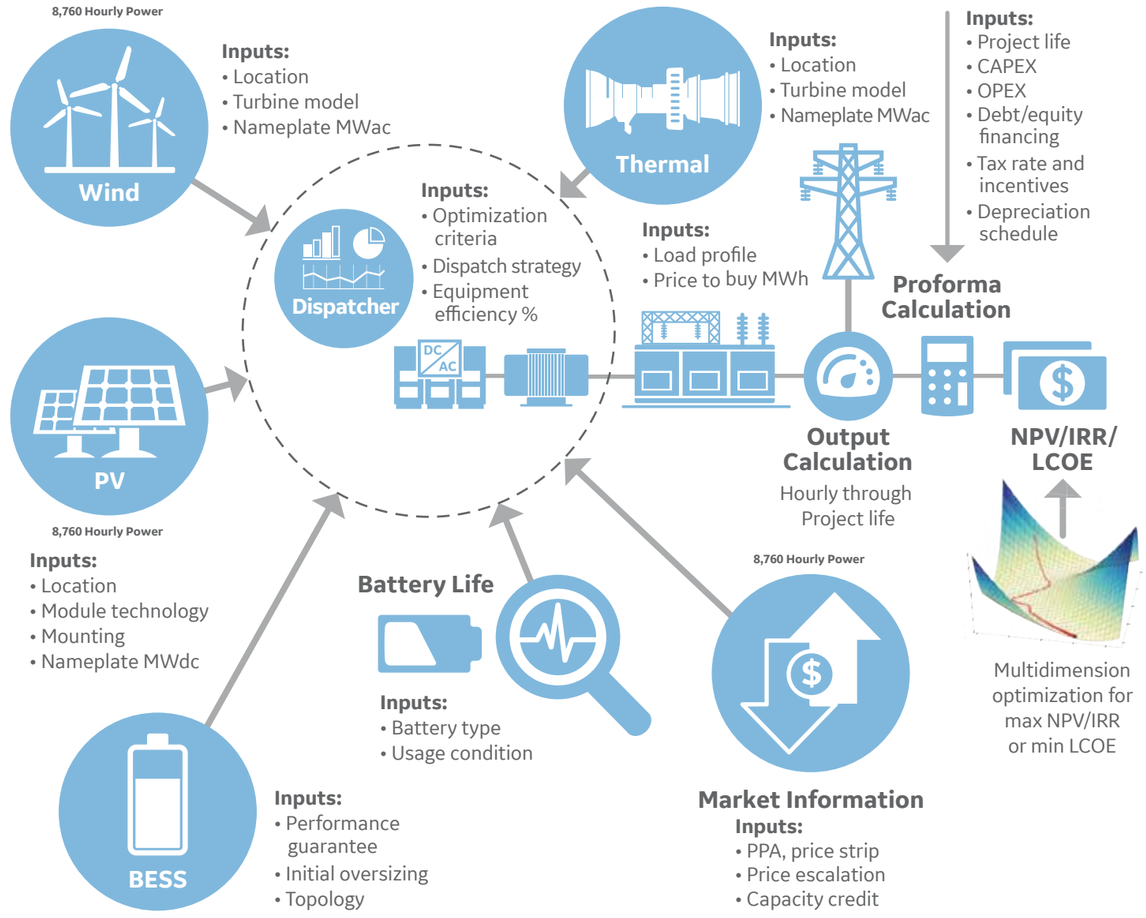


User Input

- Location, generation equipment, revenue and power output
- Weather data including solar irradiance as well as wind profile yearly data
- Finance, Capex, Opex, equipment efficiency and degradation

Output

- Improved hybrid system engineering configuration
- Multi-year proforma w/LCOE, NPV, IRR
- Curtailment analysis
- Battery capacity addition strategy for local incentives
- PowerPoint summary
- Modeling computations to analyze improved performance of hybrid assets, providing a preliminary feasibility assessment of a hybrid operation



GE's Solution Enablers

Increased Reliability with Control Solution and Software from GE

GE Renewable Energy provides resiliency, reliability, and renewables enablement through our control solution and software package, which includes real-time control, energy optimization, and marketplace participation capabilities.

Optimization

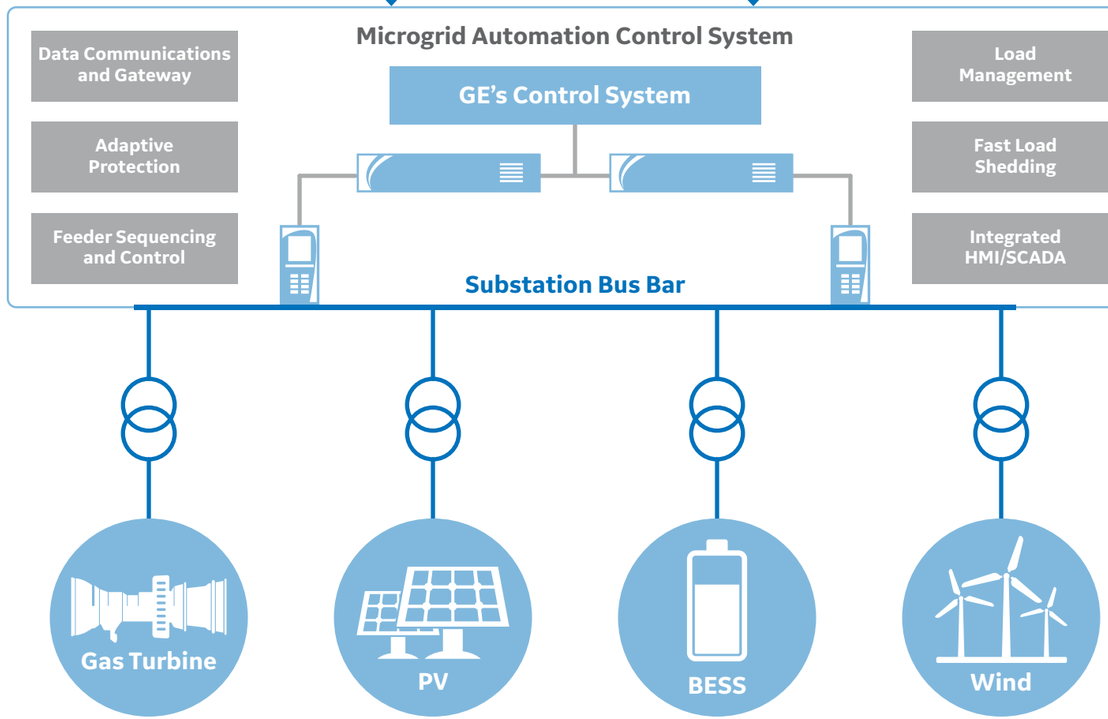
Operations and Optimizations

- Marketplace Participation
- Operations Planning
- Forecasting
- Scheduling
- Curtailment Avoidance
- Mode and Event Management
- Portfolio Optimization
- Optimal Dispatch
- SOC Management

Control

Real-time Operators

- Islanding and Resynchronization
- Isochronous Control
- Black Start
- Voltage Management and Load Sharing
- Power Exchange at POI
- Frequency Control
- Reserve Capacity Calculation
- Active and Reactive Power Management
- Power Factor Management
- PV Smoothing



Remote Network Operation Center

Substation Switch Yard

Utility Electric Grid

Advanced Software Features

- Planned and unplanned islanding
- Power exchange management at point of installation
- Re-synchronization
- Black start
- Load sharing
- Frequency control and regulation
- State of charge management
- Optimal energy dispatch
- Photovoltaic smoothing
- Forecasting
- Reserve capacity management
- Fast load shedding
- Active and reactive power management
- Isochronous control
- Peak shaving
- Curtailment avoidance
- Power and ramp rate firming

System Functionality

- Adaptive protection control
- Cold load pickup management
- Feeder control and sequencing
- Ability to integrate into utility Document Management System (DMS)
- Marketplace participation and ancillary services management

Services

- Feasibility and planning studies
- Engineering studies
- Configuration and integration
- Commissioning and testing

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