Enabling Grid Firming in India for a Renewable Rich Future

India Gate, New Delhi

gepower.com

Thermal hybrids using aeroderivative gas turbine technology from GE can provide cleaner, less expensive and higher quality power while helping to meet the objectives of stabilizing grid frequency and balancing voltage control—thus enabling high penetration of cleaner renewable power into the Indian grid. Aeroderivative turbines offer a blend of flexibility, modularity and scalability without compromising reliability, availability and environmental goals.

Energy Systems in Transition

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

India is committed to the goal of reducing greenhouse gases by 2030 by adding 450 GW of renewables. With a higher penetration of renewables such as wind and solar, the Indian grid would face complexities of frequency and voltage fluctuations due to the unanticipated sudden loss of generation and reduced system inertia. The future grid will need more dispatchable synchronous generation as spinning reserve to provide load following and frequency response services.

Given the nature of each application and the dynamic power supply and demand situation, it is prudent for grid operators to identify the technology that will best help them manage the grid and support their long-term needs. Operators must clearly identify the pros and cons of the different technologies available to support such dynamic requirements and select the most appropriate solution.

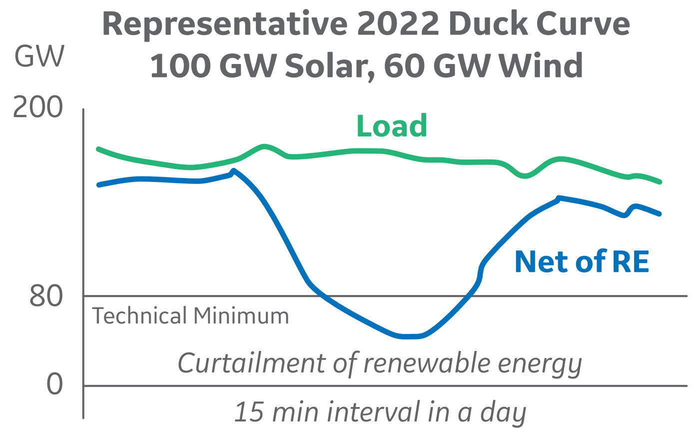
Gas thermal hybrids using aeroderivative technology are GE's solution to this grid firming challenge. Aeroderivative turbines derived from the advanced aviation technology can provide cleaner, cheaper and higher quality power to help meet the objectives of stabilizing grid frequency and balancing voltage control and enable high penetration of cleaner renewable power into the Indian grid. Aeroderivative turbines offer a blend of flexibility, modularity and scalability without compromising reliability, availability and environmental goals. GE's 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 meet specific energy needs.

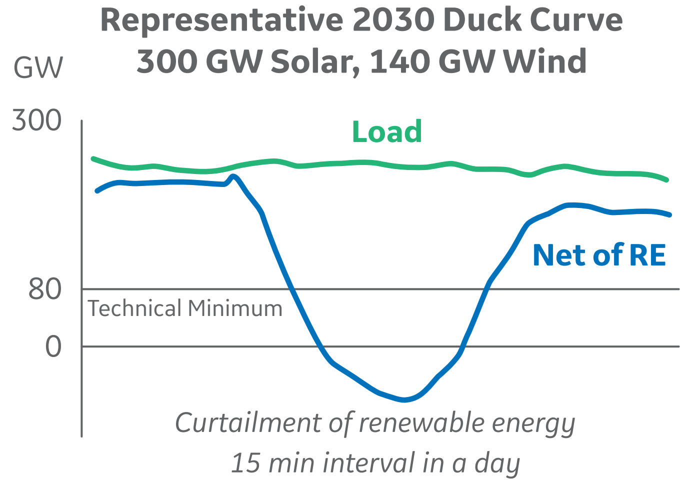
Impact of renewables on the Indian grid

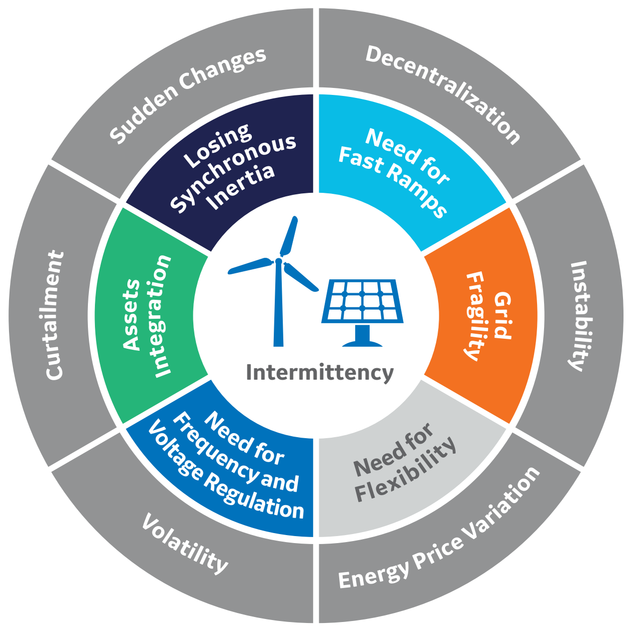
Higher renewable penetration in the energy mix results in big changes in the net load profile of the system due to the inherent seasonal and daily variability of wind and solar energy. At any given time, net load is the total system load minus the load served by renewable sources. On a typical day in India, the net load takes the shape of the familiar "duck curve" due to reduced solar generation (valley of the curve) and increasing residential demand (peak of the curve) in the evening. With increasing solar penetration and overall demand growth due to rising population, GDP growth and overall per capita electricity need, the valley of the curve deepens and the peak rises—resulting in a large increasing slope. This indicates a steep ramp need from non-renewables, primarily thermal energy sources. This will be more pronounced in a country like India because most solar capacity additions will be taking place in a relatively thin longitudinal band and, after accounting for the high seasonal variability of hydro power, steep slopes of net ramp requirement across the western, southern and northern regions may result.

Renewable energy curtailment is a thoughtful reduction in generation that can be due to many reasons such as oversupply, local area transmission constraints, insufficient energy storage capacity or lack of flexible energy resources like gas turbines. This results in underutilization of resources, which increases the cost of energy served in the system. With growing renewable energy production in India, the problem of curtailment is could become severe in coming years.

Another problem to be tackled with increased renewable penetration, especially wind resources, is the intermittency of the power production. Even with advanced forecasting techniques, precise prediction of wind energy production, especially at low wind speeds, is difficult due to high temporal and spatial variations. Because the wind rich sites are already installed with older technology turbines, new wind capacity is being added in low wind areas. The power system will need additional reserve margin for tackling the intermittency problem in the grid.





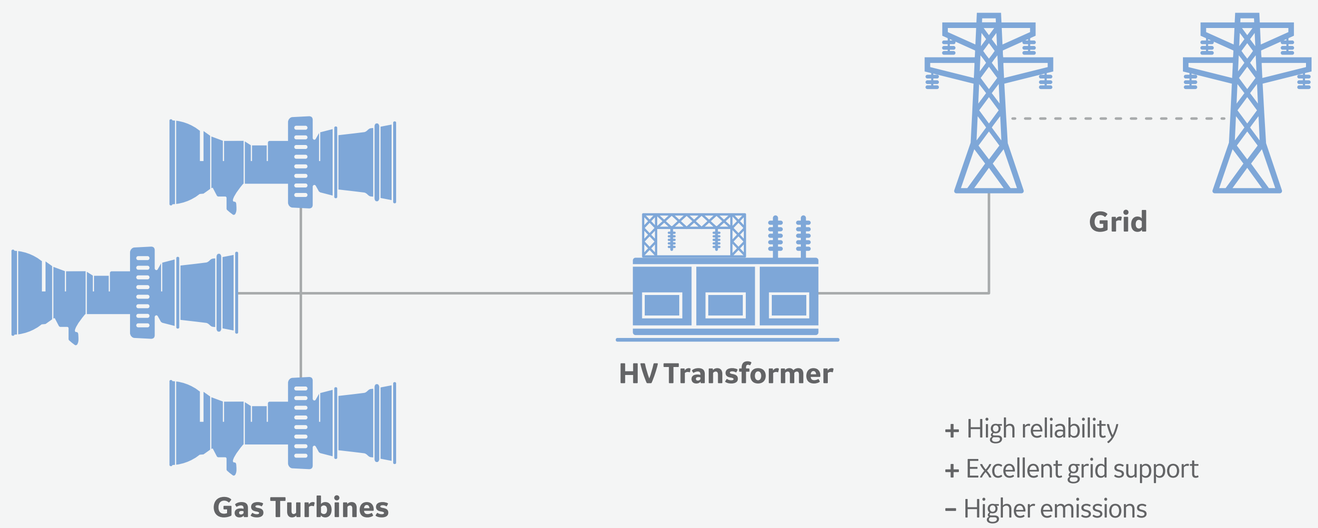


Renewables integration challenges

Which mix is the right one?

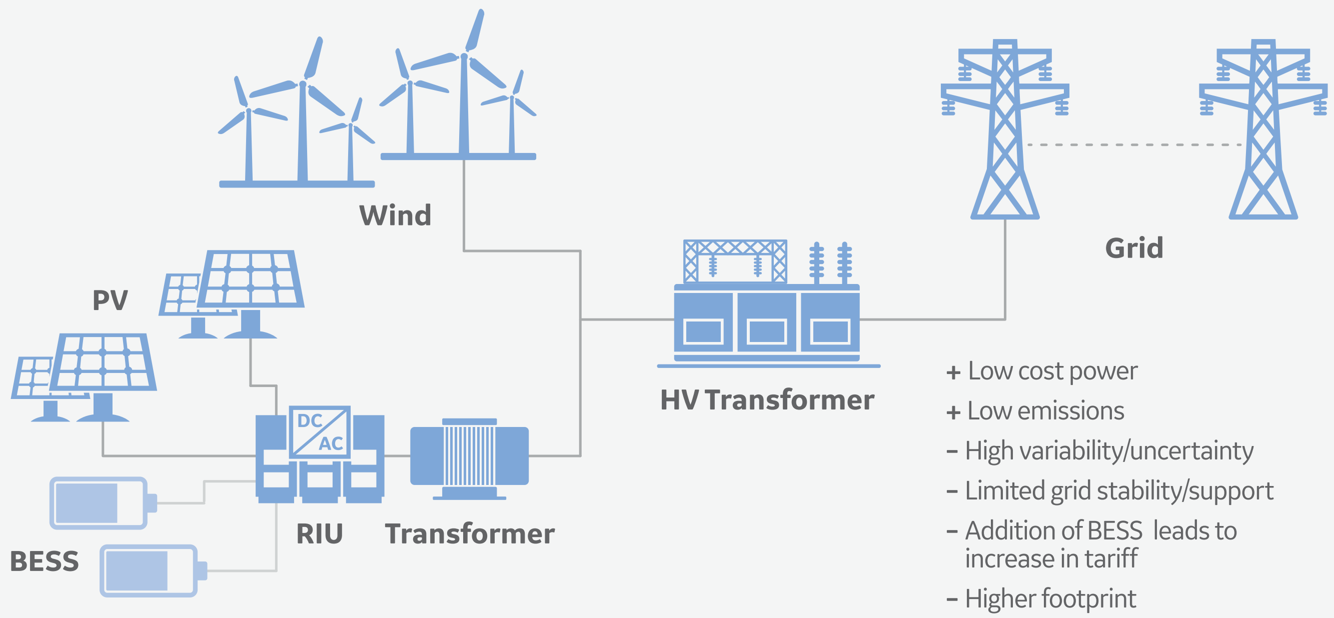
Multiple paths exist to achieving high renewable capacities. The diagrams below highlight various options available, with the pros and cons of each.

100% Thermal



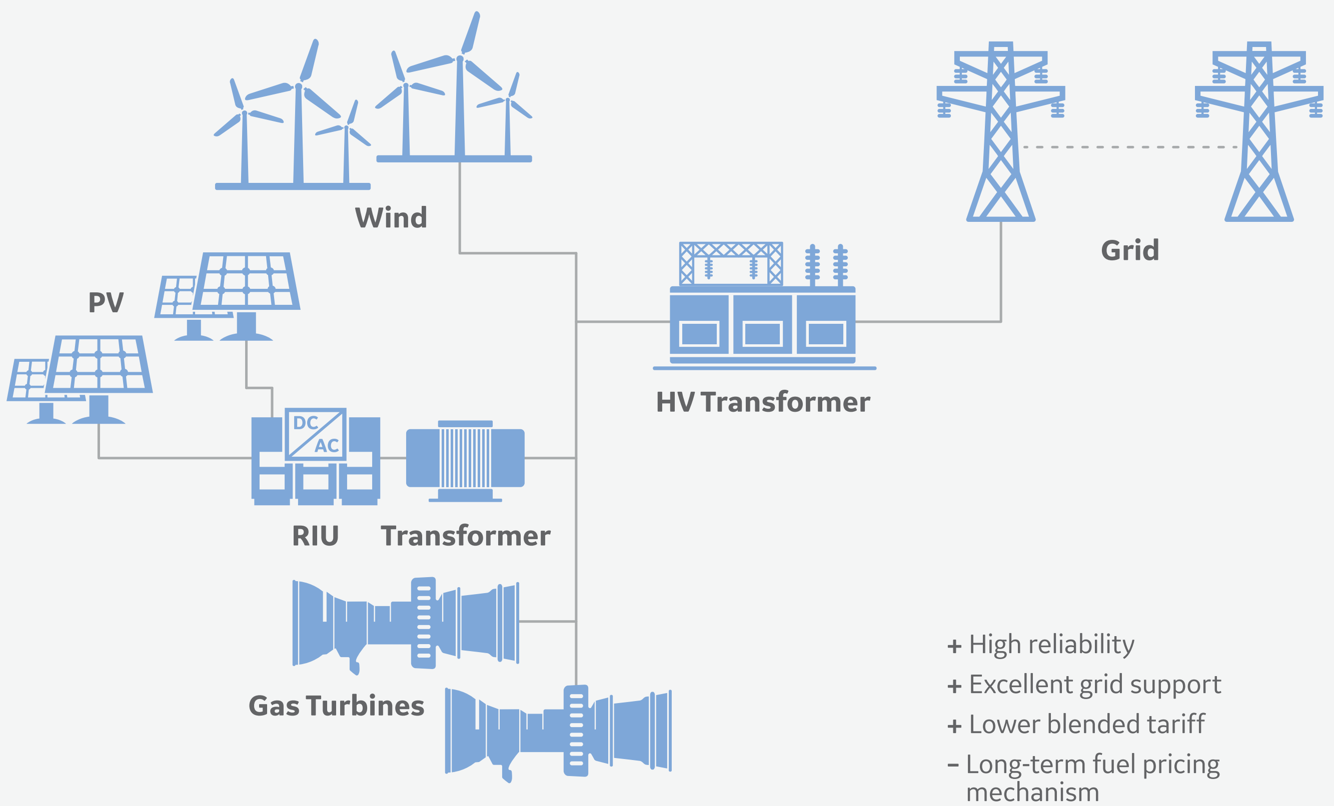
+ High reliability
+ Excellent grid support
– Higher emissions
– Fuel price variability/availability

100% Renewable



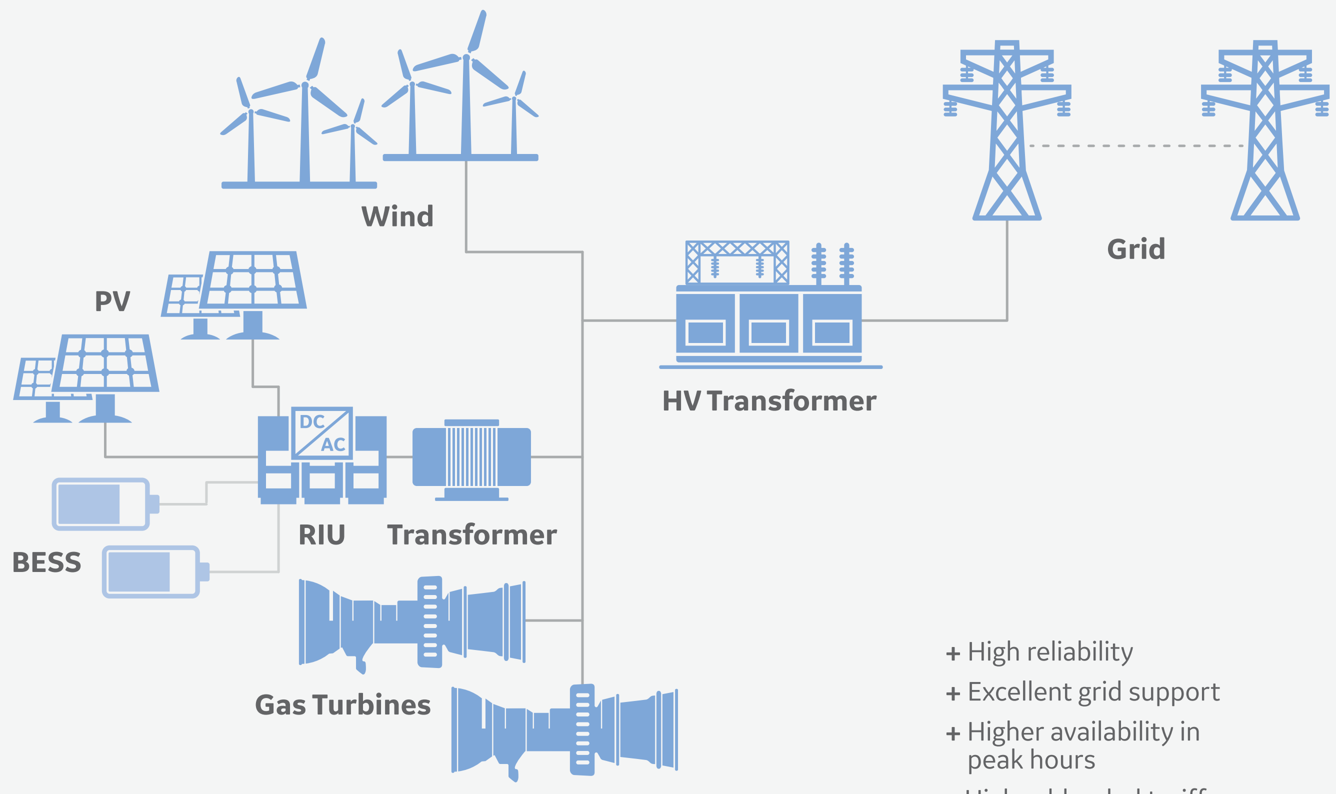
+ Low cost power
+ Low emissions
– High variability/uncertainty
– Limited grid stability/support
– Addition of BESS leads to increase in tariff
– Higher footprint

RE hybrid with aeroderivative gas turbines system



+ High reliability
+ Excellent grid support
+ Lower blended tariff
– Long-term fuel pricing mechanism

RE hybrid with Battery Energy Storage System (BESS) and aeroderivative gas turbines system



+ High reliability
+ Excellent grid support
+ Higher availability in peak hours
– Higher blended tariff

Grid firming with gas-based thermal hybrid plants

As of 2020, about 60% of India's power generation is coming from coal power plants, thus contributing the bulk of emissions generated in this sector. In addition, the dropping plant load factors (PLFs) of these coal-based thermal plants increasingly make them economically unsustainable. Major coal power producers in India and around the world are phasing out older plants, and additional investment in new plants is happening at a relatively slow rate. Although coal may continue to play an important role in India's overall energy mix for the foreseeable future, the injection of must-use renewable energy, limitations on ramping and flexibility will present challenges to a balanced grid that cannot be suitably handled by coal-based thermal plants. For a successful renewable transition, wind and solar must be complemented by an alternate technology that can offset their dispatchability and availability disadvantages and help to firm and stabilize the grid.

Gas-based power can provide such a solution. Gas power plants uniquely provide the following additional benefits:

- Fast ramp up and ramp down capability
- Fast and reliable starts (fast MWs when renewables ramp down)
- Higher efficiency for lower consumer costs and smaller carbon footprint
- No maintenance penalty from cyclic operation
- Deep turndowns, enabling higher renewable energy absorption
- Better grid support attributes

Multiple initiatives have been taken by the government to increase the production, distribution and consumption of natural gas, all with an aim of increasing NG in India's primary mix from 6% to 15 % by 2030. Huge investments continue in building gas network and new gas import facilities to link all states with currently six gas terminals operational. Pipeline operations are underutilized and sufficient to meet existing and new investments in gas power plants. As of 2020, India's regasification capacity terminals in operation are nearly 39.2 MMTPA with capacity under development of 17.3 MMTPA. Also, available natural gas pipelines total about 17,016 km with pipelines under construction at nearly 15,543 km (refer to Figure 1).

The Natural Gas Exchange was inaugurated on June 2020 and is envisaged to play an important role in connecting producers and consumers. Long term investment decisions like in gas-based power plants need certainty in availability and pricing of gas and to move towards higher gas usage, a spot-market for natural gas with the ability to hedge risks is certainly a positive step. Recent changes in Natural gas marketing policy (October 2020), where producers can opt for e-bidding mechanism for natural gas sales from newly discovered fields, will bring more transparency in price discovery. The Petroleum and Natural Gas Regulatory Board has also published a draft amendment proposing unified tariff for the national gas grid system in India, which, if approved, would move away from the current distance-based zonal tariffs to a unified tariff rate applied across major pipelines in India. The new tariff structure would be beneficial for buyers further away from the gas source as they would be paying lesser tariffs compared to previously. As per the recent Thermal RTC (round the clock) guidelines amendment issued November 2020, Ministry of Power has allowed for other sources of power generation "including Gas" to support renewable intermittency. With conducive policy environment, growing power demand and need for a reliable partner to renewables, natural gas based power is surely positioned for growth in India. Please refer to page 10 for a detailed analysis on the role of Gas Power in addressing the RTC requirement.

Figure 1: Gas pipeline and LNG infrastructure in India

New gas pipelines (approximately 17,000 km operational and 15,500 km under construction) and terminals (39 MMTPA currently installed and 17 MMTPA under construction) continue to be added to help ensure that gas demand is adequately met.

Liquefied natural gas (LNG) receiving station

GE's Aeroderivative Gas Turbines

Built on an Aviation Legacy

2,800 ACTIVE UNITS / **>150 MILLION** OPERATING HOURS

PRODUCT DIFFERENTIATION

- High simple-cycle efficiency gas turbines
- High reliability
- Fast start
- Load following
- Fast power plant to commission
- Flexible maintenance

APPLICATIONS / SEGMENTS

- Utility and industrial cogeneration
- District heating
- Renewables support
- Grid stability
- Mobile/fast power
- Marine
- Airports
- Oil & gas power generation
- Pipeline compression

Figure 2: Aeroderivative gas turbines and their rich legacy

Features and Benefits

Proven technology and high availability and reliability

- Fleet experience of more than 2,800 active units and more than 150 million operating hours
- Aviation turbine technology for high availability (>98%) and reliability (>99%)

Higher renewable penetration enablement and grid support

- Fast starts:
  - 5-minute start to full load from cold iron without any preheating
  - Faster Plant startup due to fewer installed units and lesser time for sequential start compared to an alternate technology with smaller unit size
- Higher ramp rate: From 30 to 500 MW/min on an individual unit basis enabling smaller installed capacity to achieve desired ramp up requirement of the grid
- Cyclic operation: Flexibility with multiple starts and stops per day with no maintenance penalty
- Frequency response:
  - Wide frequency operation range with fast frequency response and no under-frequency tripping
  - Ride through rate of frequency change (RoCoF) without tripping
  - Capability to maintain power within wide frequency range with no impact on life
- Load rejection: Full load rejections while maintaining connectivity with the grid
- Higher inertia (H constant): To support the grid
- Synchronous condensing: Option to switch from power generation to synchronous condensing in 5 to 10 minutes while running or from cold iron standby mode
- Spinning reserve: Excellent spinning reserve capacity to provide full load power from minimum emission-compliant load within 15 to 20 seconds in response to an under-frequency event
- Ride through capacity: For low voltage with little to no impact to MWe

Fuel flexibility

- Can operate on 100% gas to 100% liquid fuels without need for any pilot liquid fuel
- Fuels include natural gas, LNG, LPG, diesel, naptha, methanol, hydrogen and many others
- Can switch between fuels without stopping and without a power reduction
- Can switch between economically preferred fuels for reliable power generation capabilities coming from different sources

Lower operating costs and maintenance events for higher availability

- Fewer maintenance events as aero engine can be swapped out overnight through a lease or exchange program
- About 200 times lower lube oil consumption compared to an alternate technology
- About four times lower operating anpower and 30 times lower maintenance manpower compared to an alternate technology

Faster installation and relocation

- Lightweight, modular and scalable configuration for fast installation and commissioning in as little as seven days
- Smaller and simpler civil foundation with equipped enclosure for much faster site installation and relocation if needed

Lower exhaust and noise emissions

- Excellent combustion systems offering 15 or 25 ppm NOx emissions without after-treatment
- Green hydrogen-ready (upto 80% concentration with select variants)
- Four times lower NOx, 10 times lower CO, and six times lower PM and VOC emissions compared to an alternate technology
- Less than half of global warming potential (CO_2 equivalent) compared to an alternate technology—the equivalent of taking 50,000 cars off the road for a 100 MW base load plant

Round-the-Clock (RTC) Case Study:

RE Hybrid vs. RE Gas Thermal Hybrid

This case study explores the techno-economic attributes of the renewable energy (RE) hybrid and gas thermal hybrid solutions for the round-the-clock (RTC) application.

A representative simulated case (subsequently referred to as the "base case") for the recent 400 MW RE RTC award by the Solar Energy Corporation of India Limited (SECI) was created by validating the first-year tariff using GE's inhouse Hybrid Architect software. Input variables for each subsystem (wind and photovoltaic) were carefully constructed as per standard industry assumptions. Those variables included hourly profile and ambient data for a typical site as well as operational, financial and commercial factors. Hourly outputs—such as utilization of each subsystem over the lifetime of the project, curtailment and annual outputs (including capacity utilization factor, availability, LCOE and cash flow proformas)—were retrieved for comparison with the proposed gas thermal hybrid solution.

In addition to addressing availability during peak hours, the case study was modified by considering the BESS solution, which would support the grid during evening hours when the sun is not shining and wind is not blowing as fast.

GE's aeroderivative gas turbine-based thermal hybrid case was constructed with the same photovoltaic and a lower wind capacity as shown in Figure 3.

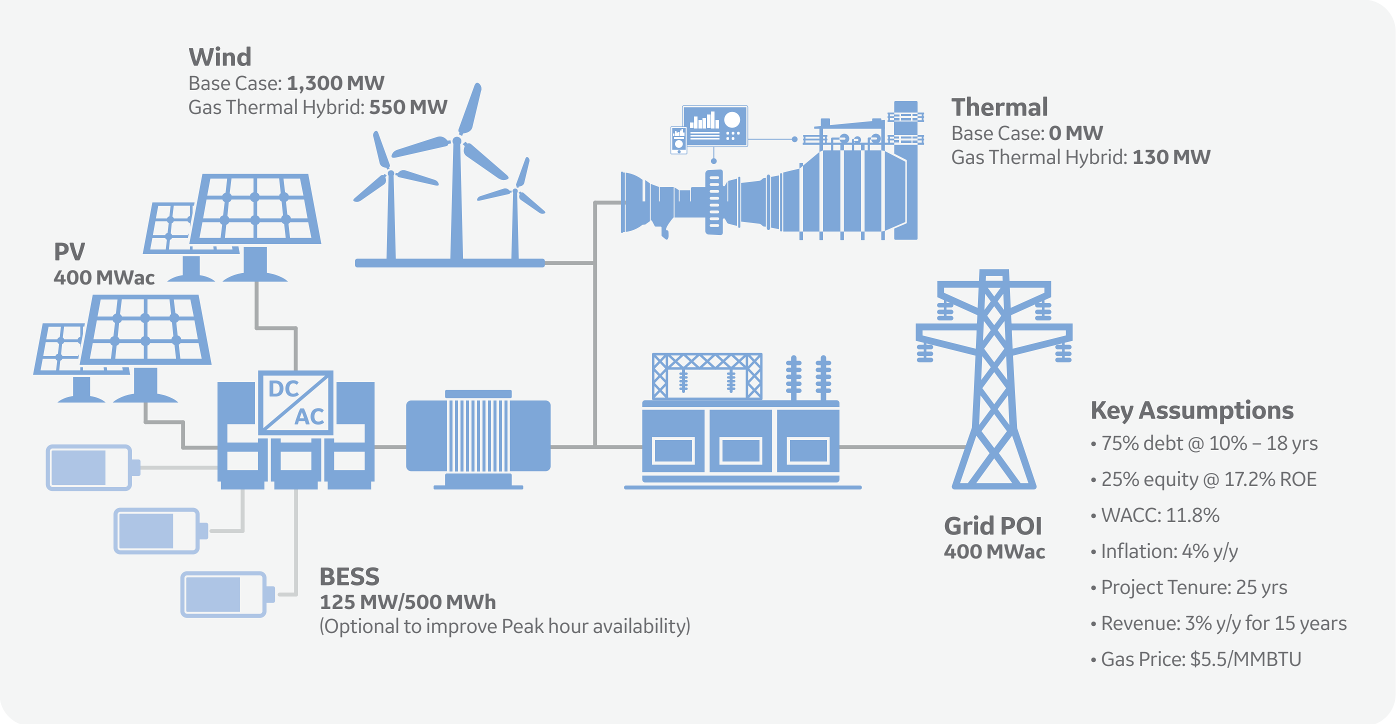


Figure 3: Renewable energy hybrid vs. gas thermal hybrid

The detailed comparison is tabulated below:

	RE RTC	RE + Gas Power @ 5.5 $/MMBTU	RE + BESS + Gas Power @ 5.5 $/MMBTU
Assumptions	• Wind 1,300 MW, PV 400 MW • Total 1,700 MW • Equity IRR -17.2% • Excess power revenue @ ₹2.00/kWh	• Wind 550 MW, PV 400 MW, Gas 130 MW • Total 1,080 MW (36.5% lower) • Gas 19% of AEP, 55% PLF, 600 cycles/year • Equity IRR -17.2% • Excess power revenue @2 Rs/kWh	• Wind 550 MW, PV 400 MW, Gas 130 MW + BESS 125 MW • Total 1,080 MW (36.5% lower) + 500MWh • Gas 19% of AEP, 55% PLF, 600 cycles/year • Equity IRR -17.2% • Excess power revenue @2 Rs/kWh
Capacity Utilization Factor (CUF)	+ Approx. 86% for 400 MW RTC capacity	+ Approx. 89% for 400 MW RTC capacity	+ Approx. 87% for 400 MW RTC capacity
Minimum Monthly CUF	− 70%	+ 78%	+ 85%
1st-Year Tariff (revenue from excess energy sale considered)	+ ₹2.90/kWh	+ ₹2.89/kWh	− ₹3.12/kWh
Annual availability	+ 80% of RTC demand served for 80% time	+ 83% of RTC demand served for 80% time	+ 82% of RTC demand served for 80% time
Curtailment/excess energy	− 41.4 %	+ 9.5%	+ 8.5%
Dispatch - Full RTC power (10% tolerance, subject to seasonality)	− 10-12 hours/day (intermittent) 5,963 hours/year	+ 10–12 hours/day (contiguous blocks) 4,530 hours/year	+ 14–16 hours/day (contiguous blocks) 5,700 hours/year
Financial closure risk	− Higher risk • @40% non-committed energy sales • Impact of uncertainty (lower "P")	+ Lower risk • Reduced curtailed power • Reduced uncertainty impact (high "P")	+ Lower risk • Reduced curtailed power • Reduced uncertainty impact (high "P")
Capital Expenditures (CapEx)	− Higher CapEx for oversized Wind MW ($1,180 million)	+ 40% Lower CapEx - optimized Wind MW ($714 million)	+ 27% Lower CapEx - optimized Wind MW ($860 million)
Footprint	− Larger footprint (4,050 acres)	+ 33% reduced footprint (2,700 acres)	+ 33% reduced footprint (2,700 acres)

A representative simulated case using GE's inhouse Hybrid Architect software

Table 1: Advantage of gas thermal hybrid over pure renewable energy hybrid

The gas thermal hybrid shows significant advantages on most of the parameters including capacity utilization factor (CUF), availability, curtailment, financials and CapEx. It is to be noted that the above base cases assume sale of excess energy, at ₹2.00/kWh in open market. This excess energy in the base case is about 40% of the overall production and not covered under any power purchase agreement (PPA), which poses a significant financial risk over a 25-year project life.

The addition of a small BESS in the system helps ensure peak hour availability at a nominal increment in tariff.

The financial risk is significantly less in the thermal hybrid case for two reasons:

- **Substantial reduction in excess energy due to lower installed base.** If revenue from excess energy sales is not considered, the current base case tariff increases by 37% from ₹2.89/kWh to ₹4.00/kWh compared to an increase of only 5.5% from ₹2.90/kWh to ₹3.06/kWh for a gas thermal hybrid solution.
- **Reduction in uncertainty of energy generated** due to lower wind capacity and addition of firm thermal power.

Table 1 compares the merits of a gas thermal hybrid solution on key parameters over the base case, and it can be inferred that the thermal subsystem helps meet or exceed most of the key metrics despite low overall installed capacity. Also, the gas thermal hybrid solution scores well on overall financial metrics like DSCR and cash flows throughout the project tenure.

Firm Availability:

The Real Spirit of Round-the-Clock

Time-based availability is important for the grid of the future as increasing renewable energy is connected.

As seen in Figure 4, the thermal hybrid solution has much better power availability for longer durations over the year compared to the base case, thus serving to the spirit of RTC power tenders. Gas-based thermal hybrids provide 3% additional availability of round-the-clock (RTC) demand vs. the renewable energy (RE) hybrid for 80% time and additional grid support attributes. If the thermal hybrid solution is supplemented with BESS, the overall availability—including during peak hours—improves to 87%.

The thermal hybrid solution offers 10–12 hours of contiguous blocks of full RTC power (10% tolerance) compared to intermittent power from an oversized RE base case on a typical day. For instance, even on a low renewable day, as shown below, the gas thermal hybrid case offers significant improvement in availability over the base case (refer to Figure 5).

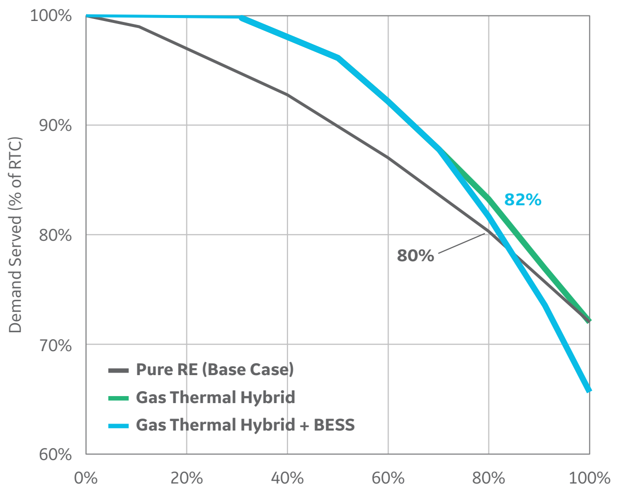


Figure 4: Overall hourly availability comparison – RE hybrid vs. gas thermal hybrid

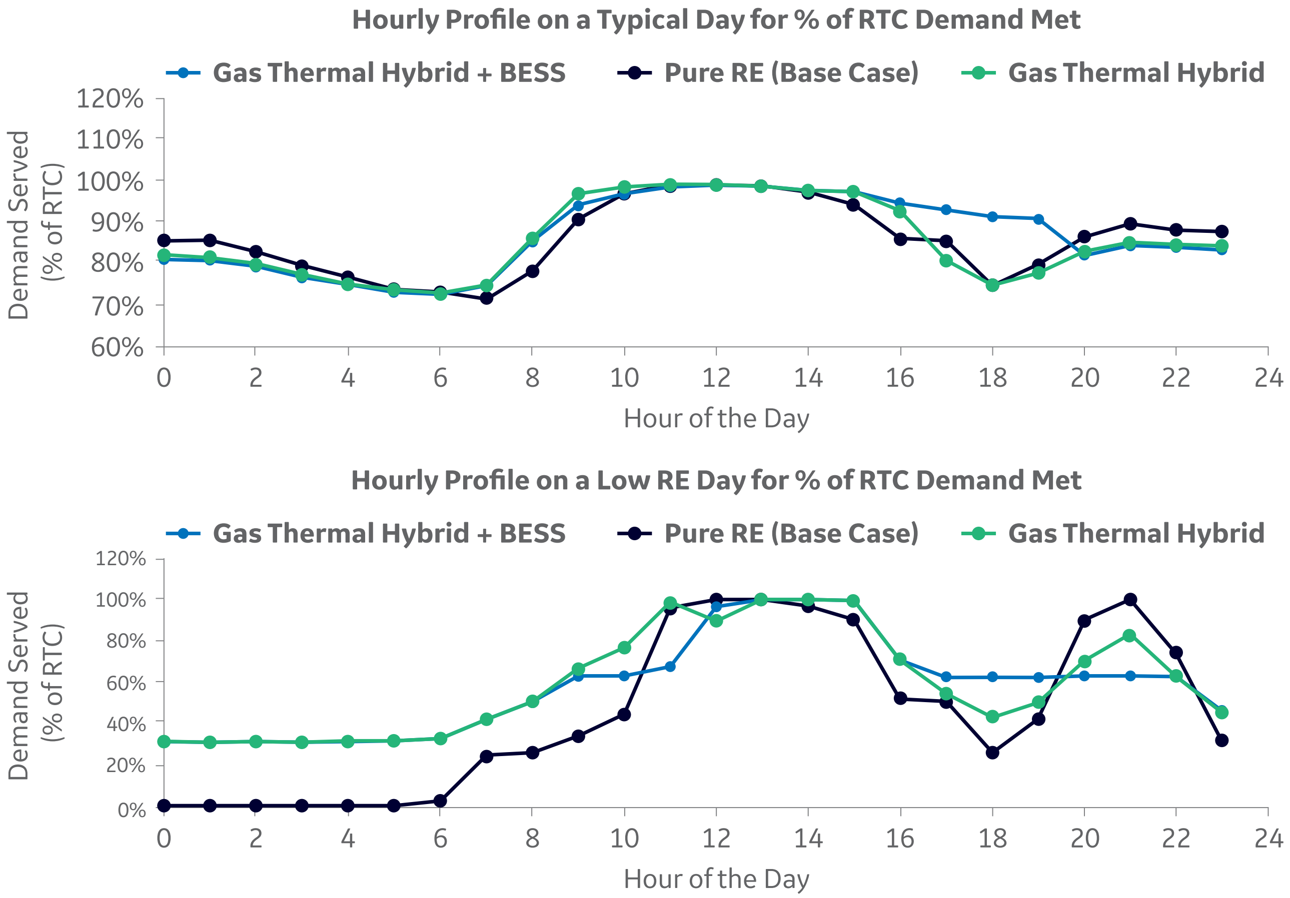


Figure 5: The thermal hybrid provides more availability than a pure RE solution on both a typical day and a low RE day.

Bandra Worli Sea Link viewed from Bandra Fort, Mumbai

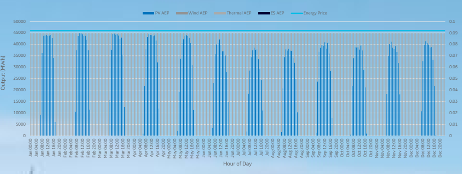
Aeroderivative Thermal Hybrid Experience:

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 manufacturers and suppliers 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



Typical hybrid annual energy production operation

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 engineered 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.

Aeroderivative support of renewable energy generation

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 Architect 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 can reduce the engineering cycle from weeks to hours.

The Architect can be used for:

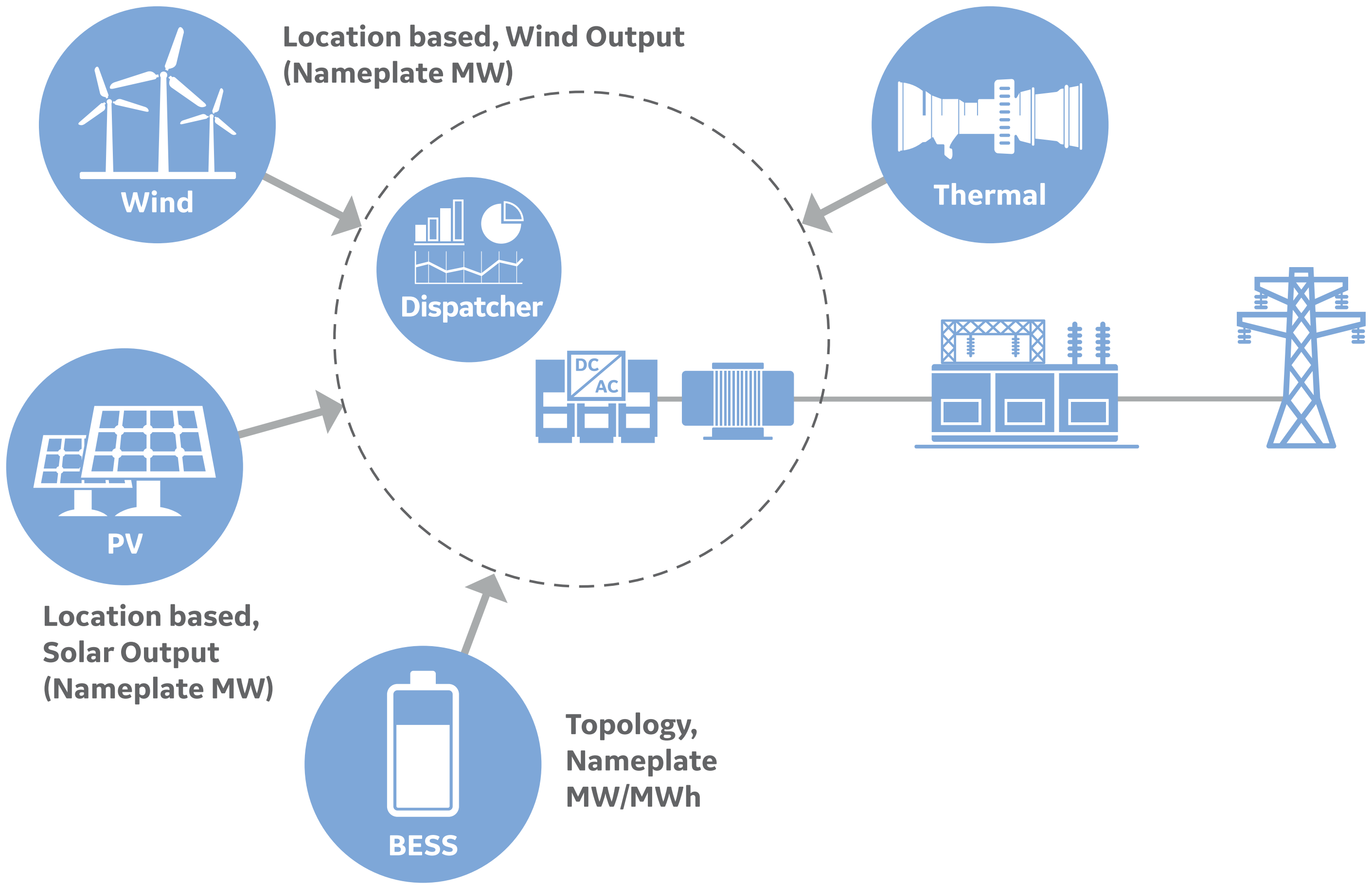
- Energy shifting
  — Merchant/structured purchase power agreement
- Load following/firming
- Capacity payments
- Renewable Energy Certificates (REC) for revenue
- Curtailment
- Frequency response

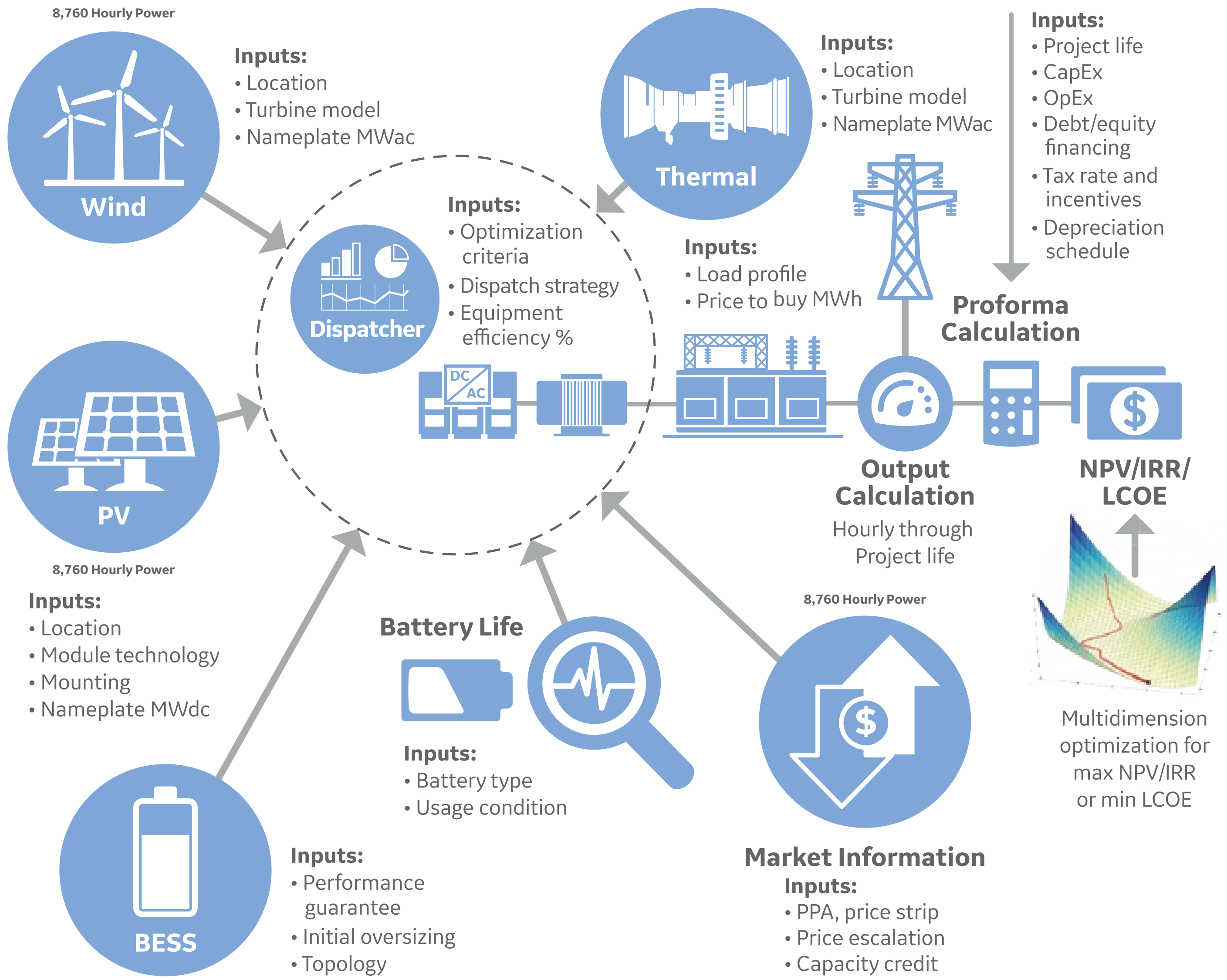
User Input

- 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

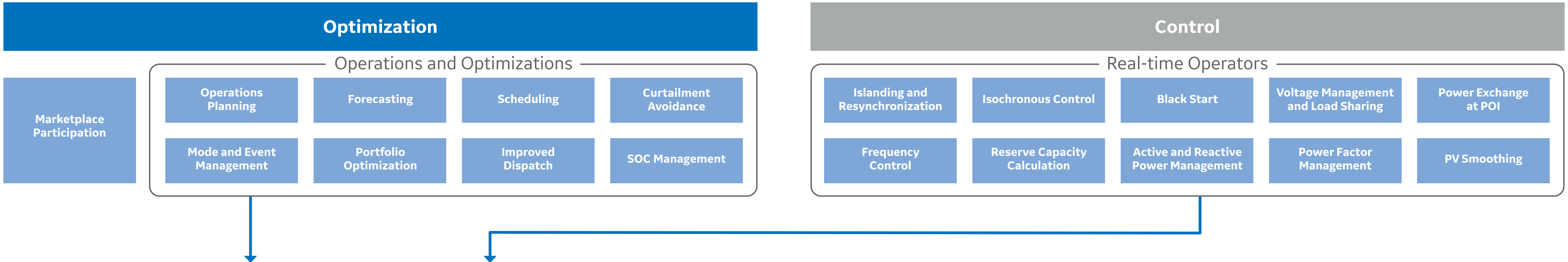


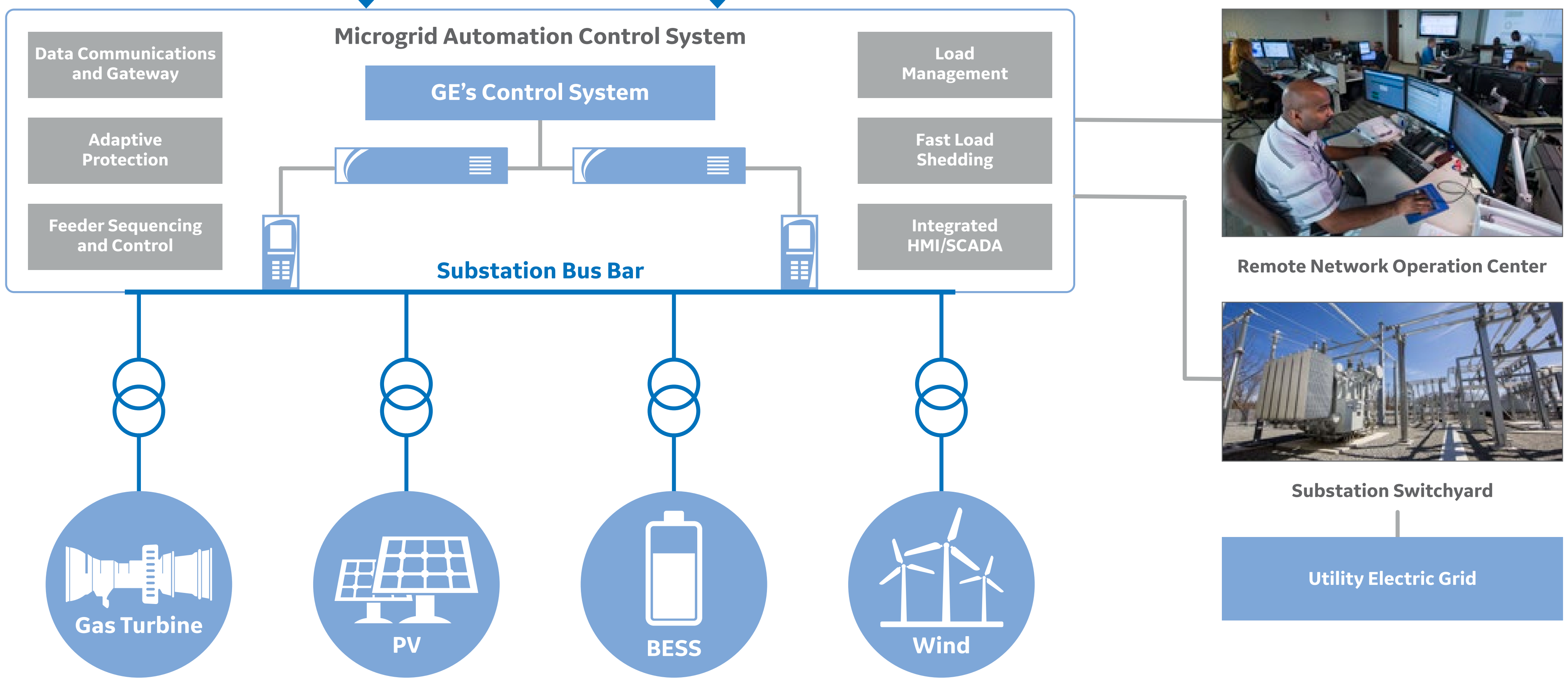


GE's Solution Enablers

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.





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
- Improved 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

GE In India for India

GE has had a strong local presence in South Asia for more than 110 years. In the region, we have more than 18,000 employees across Aviation, Power, Healthcare, Renewable Energy and Digital, and an installed fleet of more than 300 utility and industrial gas turbines. GE has 15 manufacturing sites in India, including a multi-modal manufacturing facility in Pune. GE also has five technology and engineering centers—including the India Technology Center (ITC) in Bengaluru, the largest integrated multidisciplinary research and development center outside the US. At ITC, more than 650 engineers dedicate their expertise to conducting research studies on key power industry domains such as combustion technologies, emission technologies, component level testing, rotor dynamics and vibration, plant engineering, and aerodynamics. These ITC engineers have developed 1,200-plus patents in the last 20 years.

- **18,000+ employees in India**
- **More than 300 gas turbine installed fleet in South Asia**
- **Present in South Asia for 110+ years**
- **15 manufacturing sites, including multi-modal factory**
- **5 technology and engineering centers**

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GEA34658 (12/2020)