A practical path to decarbonization and implementing change

MANAGING ENERGY AT PORTS

GE VERNOVA

FOREWORD

How can a port 'green' critical operations that require reliable power, 24/7/365, when power demands are simultaneously increasing?

With peaks that can exceed baseload by multiples of ten, and in a dynamically changing environment, the challenge is on to find solutions whilst maintaining environmental and financial sustainability.

Ports are essential to our economies and our lifestyles. Around 55,000 marine vessels carry over 90% of global trade by sea. On the other hand, nearly 3% of greenhouse gas emissions worldwide are generated by the shipping industry, and up to 90% of emissions[1] at ports embedded in our cities are caused by vessels activity at port.

Ships' hoteling, maneuvering and cruising operations in port areas generate a large share of local pollution. Associated costs and health issues can also affect the port facilities and local communities. Hence, regulation on pollution, emissions and noise in ports is becoming more stringent.

Stakeholders are also looking for assurance that operators have plans to reduce emissions. As the energy transition develops, ports are having to navigate options, suddenly needing to become energy experts!   So, what are the options?

Recognizing that no one port is the same, this white paper sets out to demystify paths towards both net zero and energy surety. Through practical considerations for ports' roadmaps, it highlights options for integration of cleaner energy configurations that can evolve to meet shifting energy needs. We look at simple measures, right up to the potential to benefit from alternative fuel production and use at the port.

Based on GE Vernova's expertise in energy *and* maritime domains, we give insights into how ports can satisfy operational needs while navigating the energy transition as affordably, reliably and sustainably as possible. Of course, this period of transition is not without its challenges, and we work with customers by providing practical advice about their electrification and energy needs.

Whether simply helping to optimize existing assets and increase energy efficiency, implementing shore-to-ship connections or even scalable microgrids and on-site clean fuel production, considerations for ports span energy from its generation, management and use. Being so critical to operations we evaluate equipment and software solutions that can help to assure safe, secure connections.

Olivier Jamart
Executive Director, Microgrids and Digital

[1] OECD, "Ocean Shipping and Ship Building." Available: https://www.oecd.org/ocean/topics/ocean-shipping/

INTRODUCING THE GE VERNOVA BUILDING BLOCKS

With more than 130 years' innovating in electricity generation, distribution and application, GE Vernova is a leading player delivering end-to-end, clean electricity solutions, from wind farms and other renewables through efficient power generation and storage to electrification solutions, both at grid level and for the consumer. We understand the operator's perspectives of safety-first, reliability, flexibility and investment viability.

~30%
World's electricity generated with the help of our **technology**

2,200GW
Global **Installed Base**

30%
Global utilities served by our **software**

1st
Enhanced Electric Gas Turbine (EGT) Aero + Storage + Hybrid Control

1st
Small Modular Reactor commercial contract signed in North America

54K
Wind turbines installed in >50 countries... **#1 Onshore Wind in US**[a]

Driving the energy transition forward

With or without a grid interconnection, GE Vernova's suite of port solutions comprises **clean energy, power generation, electrification and energy management.** Microgrid controllers and management systems can operate assets seamlessly and optimize the energy feeding your applications. Complementary digital platforms can cover mission-critical, off-grid operations, local, real-time load balancing (to prevent blackout) and coordinate power converters for high power quality. Here's some of our portfolio of energy capabilities:

Grid Solutions, providing protection and interconnection to the regional electricity grid, assuring a reliable, secure and efficient process. High and medium voltage primary substation equipment, as well as associated automation, controls, and intelligent sensors that enable real-time visibility and advanced asset management for efficient power plant operation.

Solar and Storage Solutions, help to improve capacity with solutions to design, supply and service power plants co-locating wind, solar, battery and/or thermal assets, with integrated controls. This team has developed digital tools to optimize plant configuration during project planning and to optimize power forecast and output during operation.

Power Conversion business for shore-to-ship power supplies and energy management systems and controls. Modular, low- and medium-voltage static frequency converter solutions, helping to assure electric power quality. Complementary ship's electric grid systems and extensive maritime sector experience.

Gas Power business, bringing aeroderivative, multi-fuel capable turbines, demonstrates a strong fit to meet an affordable and sustainable energy supply model as part of a port's net zero roadmap. Through captive generation - complementing renewables or utilizing a mixture of renewable fuels - it provides flexibility for future growth. Turbines can meet peak demand that exceeds baseload, provide resilience, and serve as backup power.

Onshore and Offshore Wind Power, with energy solutions for enhanced performance, optimized for site conditions.

SHORE POWER SYSTEMS:
Making An Impact On Emissions Reduction

Shore-to-ship power supply systems allow vessels to plug into an onshore power supply and shut down their auxiliary engines while berthed. The ship's power load is seamlessly fed by the shore-side power supply without disrupting onboard services. This substantially reduces fuel consumption, greenhouse gas emissions, noise and vibrations, which greatly improves the environment of the port.

With ports operating as logistics hubs connecting the sea and land, with important, multi-modal infrastructure and multi-fuel operations, installing a shore power system for visiting vessels may just be one aspect of a port's energy considerations. But, especially for large vessels, it can significantly impact ports' power requirements.

Considering shore power supply solutions triggers strategic planning around electrification needs, related assets and energy efficiency. Challenges can arise.

Firstly, as ports electrify their own activity and prepare to deliver electricity to vessels, peak power needs grow by multiples of ten and can even exceed those of the surrounding town and businesses. Also, ports are having to plan long-term investment decisions based on a still-emerging view of future fuels and energy technologies.

Meanwhile, ports cannot neglect critical operational factors. A one-size-fits-all approach won't succeed, with considerations like space, infrastructure and traffic. Robust and adaptable technologies are needed to respond to the differences among power supply types, maximum power consumption and ship types, and voltage and frequency in different regions.

Shore-to-ship customer requirements

Having facilities for a vessel to plug into electric power from the port itself enables port owners and operators to improve the environmental footprint of the facility and reduce noise emissions whilst maintaining efficiency. It's also becoming an increasingly important port service for the port's customers who need to manage their own energy-efficiency and emissions compliance.

Power and performance demands for shore to ship power supply systems vary for different types of vessel. We also have to consider that multiple vessels will need to be supplied concurrently.

IEEE 8005.1 TYPICAL POWER REQUIREMENT AT BERTH

Vessel	Voltage (kV)	Power (MVA)
Cruise ship	6.6/11	16-20
Container ship	6.6	7.5
LNG carrier	6.6/11	10.7
Ro-ro vessel	11	6.5
Tanker	6.6	7.2

An onshore power solution comprises three main systems:

1. **Power conversion system, to manage power safely**
2. **Cable management system (CMS), the connection interface with vessels**
3. **Control system, for effective user management (also known as SCADA)**.

Connecting a vessel causes events on the grid and operators are not necessarily electricians; the system must assure safety and performance during load transfer without specialist know-how (potential reactive power, assure power quality despite harmonics, prevent blackouts).

In most cases, vessels have 50Hz or 60Hz power networks, so the shore power system requires **power frequency conversion**. However, even when ports and vessels are both at 60Hz, or frequency conversion is only occasionally needed, there are still advantages in installing frequency conversion technology: it assures a higher degree of electrical isolation and faster protection response. In summary, it can prevent grid fluctuations to the vessel, it can better prevent reactive power to the grid, and transmission of harmonics from the vessel to the grid.

GE Vernova's system deploys technology and know-how deployed at both grid and operator level, including extensive experience of vessel electrification and shore connections.

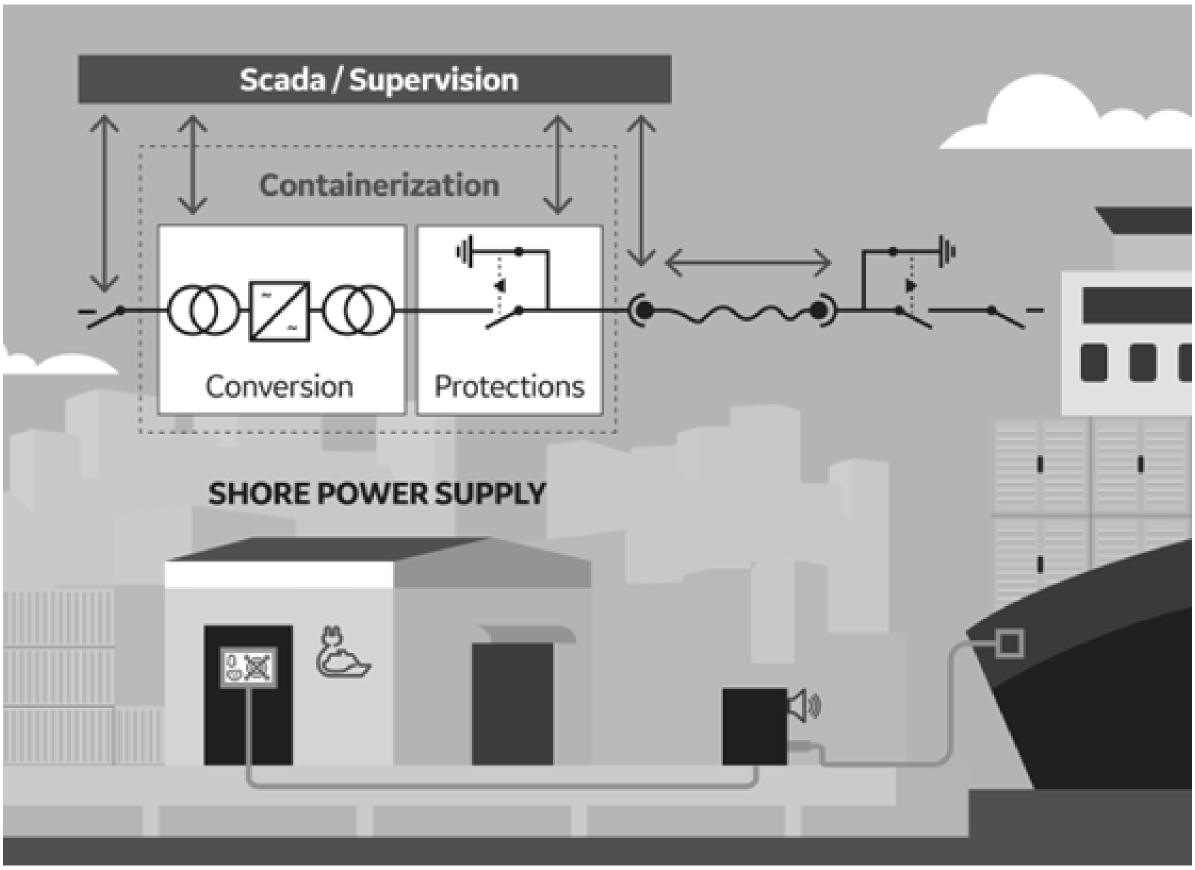
It has a full, integrated, turnkey system capability. With specialism in the core power system and controls, the company works with its preferred partners for cable management or can work with local partners preferred by port customers.

Lifecycle considerations

Compared with more traditional applications of the power components involved in an onshore power system (e.g., industrial applications), at the port the systems will be magnetized and demagnetized repeatedly, connected and disconnected many times, so products need to be fit for purpose, proven and robust.

Suppliers typically provide not only equipment but also training. There is also important scope for a general or EPC contractor on a shore power supply project, to plan and manage implementation at an infrastructure and installation level.

Finally, a solution represents an important investment that should operate for 20 to 30 years, **so total cost of ownership** – including reliability and maintenance – should be an upfront consideration when evaluating different providers' solutions.



Technology considerations, power equipment

The **power conversion equipment** is not the biggest cost item in a shore power solution, but its functionality is critical. With the latest power electronics and controls, it creates **a safe interface between operators and the shore power system** and is effectively the hub for system functionality.

Apart from its critical power quality and safety functionality, it manages the sequence of connections to vessels, it manages metering, and it can provide automatic billing reports. It can also log consumption to forecast future, long-term energy management at the port, and the long-term opportunity is for the port to digitize and integrate operational systems to improve efficiency, optimize costs and reduced emissions.

To reduce project risk, power conversion capability for shore-to-ship applications is best delivered as a complete system, including power electronics technology, frequency conversion technology, monitoring technology, communication technology and metering technology.

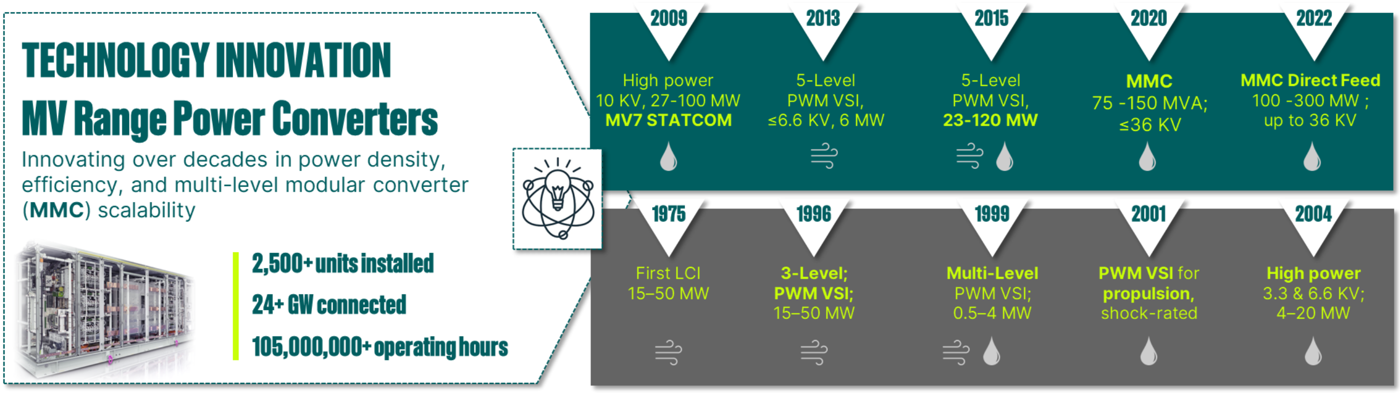
For flexibility and value, ports may want to select power conversion technology that is built on standard technology blocks that can be configured and adapted to the port's vessel traffic requirements:

- Designed for industrial applications (marine class available)
- Scalable solutions ranging from 1 up to 50 MVA
- Selectable frequency setting (50 to 60 Hz)
- Two or four quadrants operation
- High efficiency under full and partial-load conditions
- Optimized footprint (high power density 1.5 MVA/m3, compact design even in dense urban areas)
- High availability (reliability, low maintenance)
- 24/7 support, remote diagnosis.

Medium-High Voltage

To optimize for reliability for the port application, GE Vernova would recommend moving to a MV solution at system **power demands above 4MVA**. Compared with connecting multiple low voltage converters, this reduces complexity, cabling requirements and maintenance needs and increases system efficiency, improving energy consumption.

As an industry-leading example, the Power Conversion business converter is based on the latest generation of SFC using voltage source inverter (VSI) technology. It uses proven and mature SeaPulse™ MV7 drive technology, widely deployed in maritime and industrial sectors. MV7 provides a modular approach to achieve a customized solution across different applications. It is a high-performance converter, with high power density, N+1 redundancy, low losses, remote support capabilities, and grid monitoring that improves power quality to meet grid requirements and ship power supply and provides higher availability.



Low Voltage

GE deploys a high-density converter modular concept, based on flexible **1.35MVA power blocks**. The latest generation has a heritage of thousands of systems deployed in maritime, industrial and wind sector applications where rugged but high-performance operation is required.

With a compact, reduced footprint, the customizable system is conceived with operations in mind: access options, removable assemblies, pulse width modulated (PWM) filter and flexible power modules. The drive has an enhanced cooling design to provide high reliability, with IP44 cubicles.

MICROGRID CONFIGURATIONS FOR PORTS:

Navigating options for energy sources, power generation and connections

As demand for electric power at ports goes up, opportunities are growing to add new, cleaner energy sources and create port on-site microgrids, even unlocking potential new energy revenue streams. A smart, digital energy management system will help maximize power availability and energy efficiencies.

Benefits of a microgrid for ports:

- helping to achieve net zero operations – through deep electrification and local energy production from clean sources
- helping to improve resilience and security of power supplies for port operations, especially if power demand is growing to exceed main grid connections.

Each customer's project is unique to the location and operations or business model, and we recognize these technology, performance and investment decisions can, understandably, sit outside of the normal knowledge base of the port's technical, financial and operations experts.

Microgrids at port – challenges and solutions

With the context of considering different types of energy sources, we need to consider practical energy usage demands.

Power requirements

Depending on traffic at the port, peak power needs can exceed baseload demand by a factor of 10 to 20 or even more if, for example, multiple ships are berthed simultaneously. This adds to already increased demand at ports through electrifying operations (cranes, vehicles) and from multi-modal transportation into and out of the port.

Many ports cannot quickly or reliably secure increased grid capacity to meet this growth in peak demand, especially as more energy-use applications are electrified around port locations (like industry and transport networks). Even when augmented grid connection is feasible, reserving such peak capacity with the local distribution system operator may be economically or socially unviable. So, having the flexibility to generate power and manage it locally, and/or the flexibility to address a net zero roadmap, can be an attractive option.

GE Vernova has *scalable* technology blocks required to adapt for each port project, and the ability to provide objective advice including investment considerations. A practical solution will depend on the factors mentioned here: power demands, multi-modal considerations, available space and infrastructure, and planning considerations.

With ports having to rapidly acquire energy and power system knowledge to inform decisions, we recommend working with an energy expert, like GE Vernova, to identify the optimized configuration of energy and power, including renewable assets, considering loads profile, available resource (wind speed, solar irradiation), available land area and safety considerations, and of course practical budget requirements.

We outline here some of the options and their functionality in a local, microgrid power network.

Evaluating energy sources and power network technology options

Grid connected: For ports receiving prime power from the grid, alternative configurations are determined based on peak needs and regulation.

Captive generation: For sites with weak grids or high electricity prices a solution option is based on 'captive (site) generation' where renewable generation can be maximized and/or an aeroderivative turbine acts as the sole source of thermal power, independent of the grid.

Back-up and power export: The port receives its prime power from the electricity utility while using, for example, turbines as backup, or for peaks. Thanks to the fast starts of the power plants, units can start and take on loads in five minutes. Moreover, given the role that turbines have long played in the utility industry to serve grid peak loads and ancillary services, this configuration enables ports to utilize power plants, when not needed for peak power or as backup, to **deliver excess electricity to the grid and generate revenue** (if regulation allows), which improves return on investment while providing service to local system operator and community.

A simple example of a rapid-response hybrid solution integrates the GE Vernova multi-fuel turbine with BESS (Battery Energy Storage System) and digital controls. Trailer-mounted solutions can be deployed for temporary resolution of power needs until the customer's utility feed is available, and leasing options can facilitate temporary configurations. GE Vernova's proposed technology solutions integrating the multi-fuel aeroderivative turbine (hydrogen-capable) offer the flexibility to operate as a simple cycle system or, more efficiently, as combined cycle or with heat recovery options.

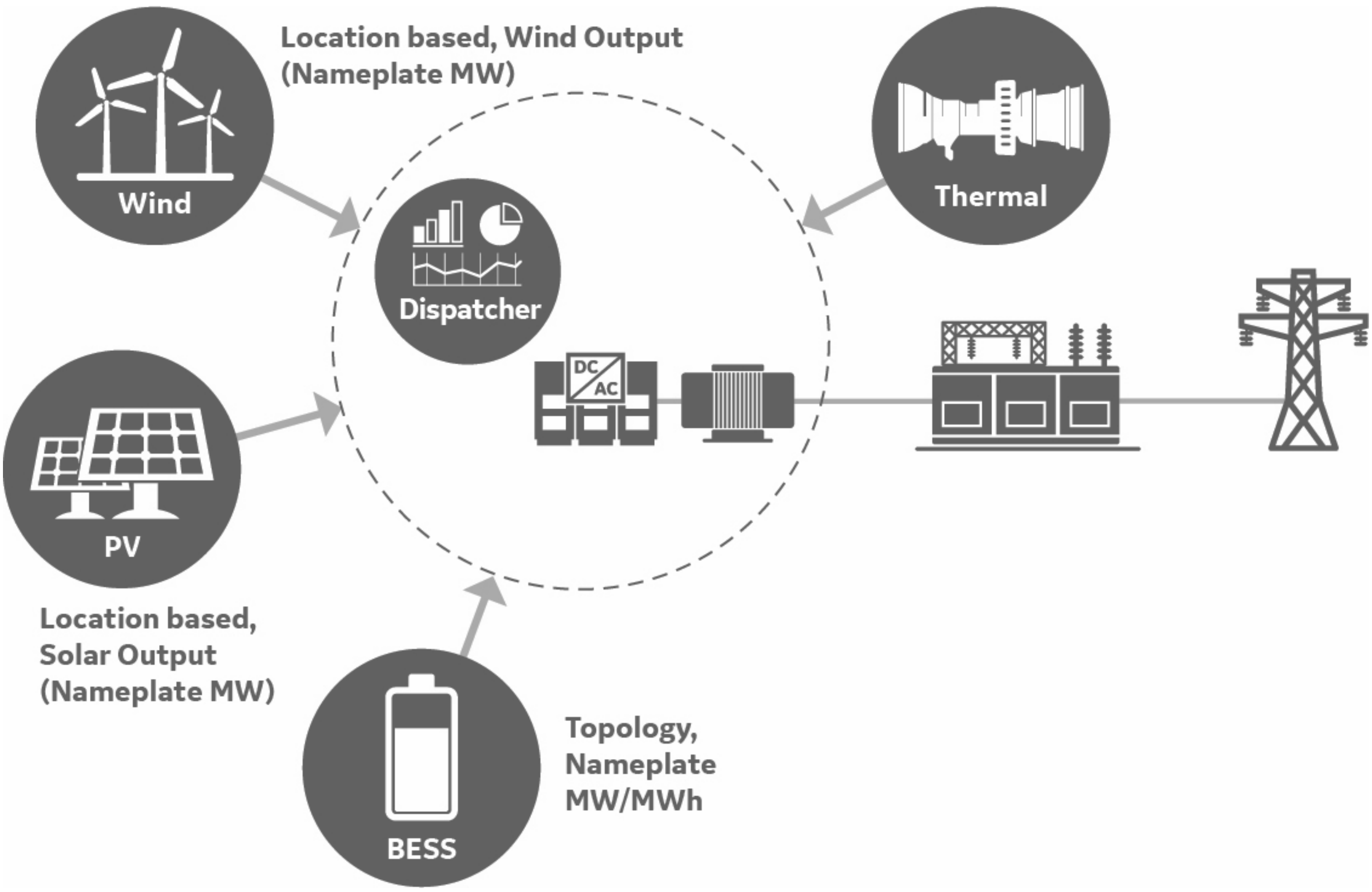
Scalable technology blocks

Wind and solar, coupled with battery storage: an excellent choice when conditions and the environment are feasible. Due to resource (e.g., wind speed), space constraints or zoning limitations, the potential to deploy renewable generation at ports can sometimes be limited, especially to meet peak power demands.

Renewable-thermal hybrid if there is an objective to integrate or *transition* to local renewables and maximize renewable self-supply, but a supplementary local power plant is required for secure baseload or peaking operation, an option is a **renewable-thermal hybrid**. This configuration integrates thermal *and* renewable hybrid generation assets, parametrized so the renewable energy-derived power system generates at its maximum capacity while turning down the thermal asset and hence reduces the curtailment, fuel burnt, provides a lower blended LCOE (Levelized Cost of Electricity) as well as lower emissions.

Renewable-Thermal Hybrid with hydrogen and alternative fuels: The renewable energy system can generate at its maximum capacity, reducing curtailment and fuel burned while also ensuring reduced levels of blended Levelized Cost of Electricity (LCOE) and CO2 emissions. The next step is cutting-edge configuration to **integrate green hydrogen** production and consumption in a renewable-thermal hybrid configuration, further providing customers with optionality in their emissions reduction journey.

GE Vernova can work with ports on a roadmap to reconfigure and operate engines on alternative, carbon neutral or renewable fuels as these become available to the port for combustion.



Technology notes: simple or combined cycle generation

Aeroderivative turbines can provide benefits in terms of fast installation and scalable capability to match growth in load. Both emissions and noise sound levels are favorable when compared to reciprocating engines (like diesel engines), even when vessels berthed are powered by dual-fuel engines combusting liquid natural gas (LNG). Moreover, aware of space constraints at ports, turbines present a compact footprint with excellent power density.

Simple cycle configurations provide fast starts and ramping as well as smooth load following capability. On the other hand, they exhibit lower efficiencies when compared to combined cycle and heat recovery options. The optimum configuration is determined together with the port, aiming to achieve competitive LCOE and high reliability.

Technology notes: Battery Energy Storage System (BESS)

The BESS, which is part of the GE Vernova portfolio of products, including LFP (lithium ferrophosphate) batteries and FLEXINVERTER, operates in milliseconds to take on essential loads while the turbine ramps up to take over the total load. GE Vernova has a proven track record in its EGT (enhanced gas turbine) design where the power plant unit with the BESS and digital controls are transformed into a single resource when the two assets are interfaced via a Mark VIe hybrid controller to manage the operational profile.

ENERGY & MICROGRID MANAGEMENT AT PORTS: Helping to do more with the energy you have

Through energy management, most effective use can be made of available energy at a port, helping to optimize efficiency and availability, managing hybrids of distributed energy resources (DER) and interconnected loads.

Energy management systems' (EMS) digital front ends also help to improve situational awareness of demand and supply profiles and decision-making, with operator-friendly dashboards.

Energy management considerations

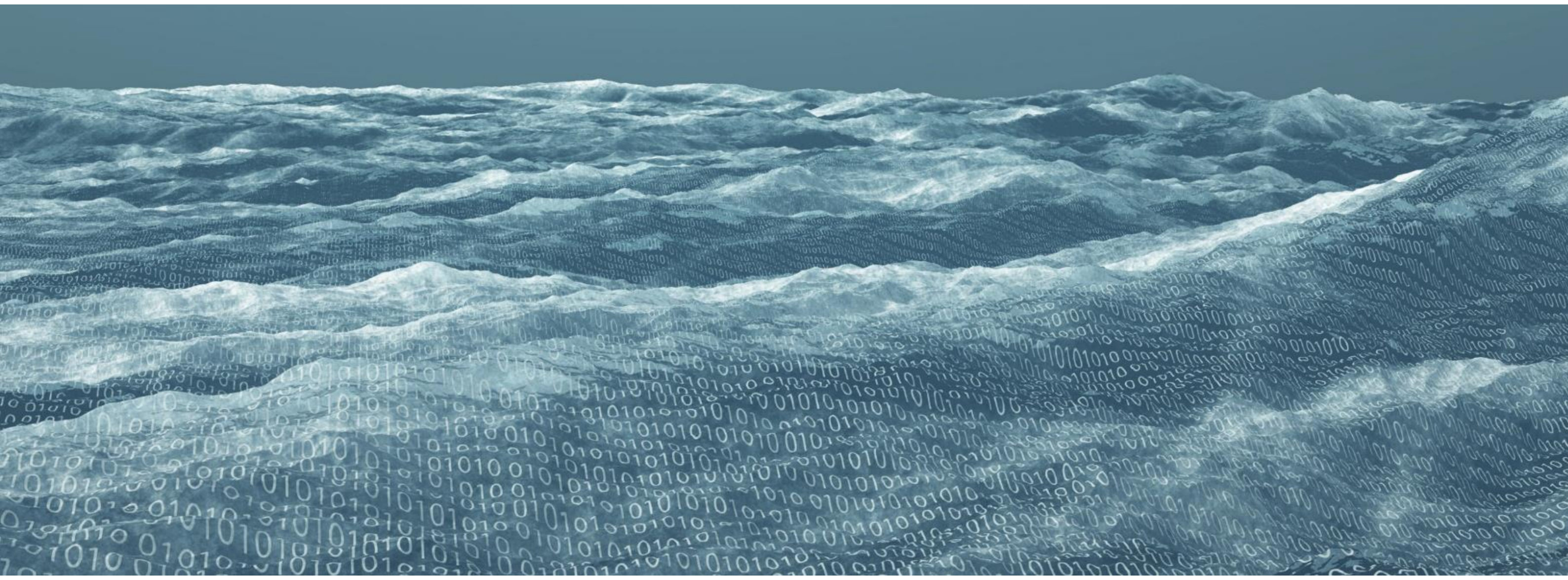
At a port, the power consumers' (loads) profile is usually highly fluctuating, especially at large transport terminals. Consumption is high per berth when ships load and unload (cranes, stackers/reclaimers, GSU, reefer cooling, cold ironing…), lower once the ship has sailed.

Moreover, due to numerous electrically-powered apparatus to be charged (electric vehicles (EV), including trucks, or dockside-charged tugs), the port's overall load profile is directly dependent on real-time port activity. Energy demand and provision must be managed in close coherence with the port's **logistics management and integrated port community systems**.

Moreover, since all above mentioned loads are electrical, energy management can support power quality. This consideration is especially significant when variable renewable energy supplies and/or storage and/or H2 are used to power the port. **This all leads to higher requirement for integrated controls** to share and manage available sources**.**

At a microgrid level this means enabling clearly defined electrical boundaries but with the ability to act as a single, controllable entity with respect to the grid. Through control and management, a microgrid can connect and disconnect from the grid to enable its operation in both grid-connected and islanded mode.

A port **energy management system** can include predictive features, for smooth operations and to avoid blackout risks as well as, when grid-connected, over-consumption (for example, vs. agreed billing-based capacity).



Microgrid energy management solutions

Microgrid digital solutions essentially support seamless interfacing of all involved assets, where the assets are brought together by communicating with each control system and consolidating it into one controller; ultimately all the assets operate as a fully integrated single entity. Some of the key functionalities that improve the load-side output include synchronization, load sharing, firming capacity and frequency and voltage control.

This microgrid solution can also leverage an optimization engine that further enhances management of distributed energy resource (DER) and assets for improved sustainability, reliability and economics while continually maintaining system resiliency as a primary objective.

Microgrid control technologies

A crucial element in microgrid control and energy management systems are digital solutions. GE Vernova's microgrid portfolio is inter-operable with its Distributed Energy Resource Management System (DERMS) and integrated to manage grid resiliency.

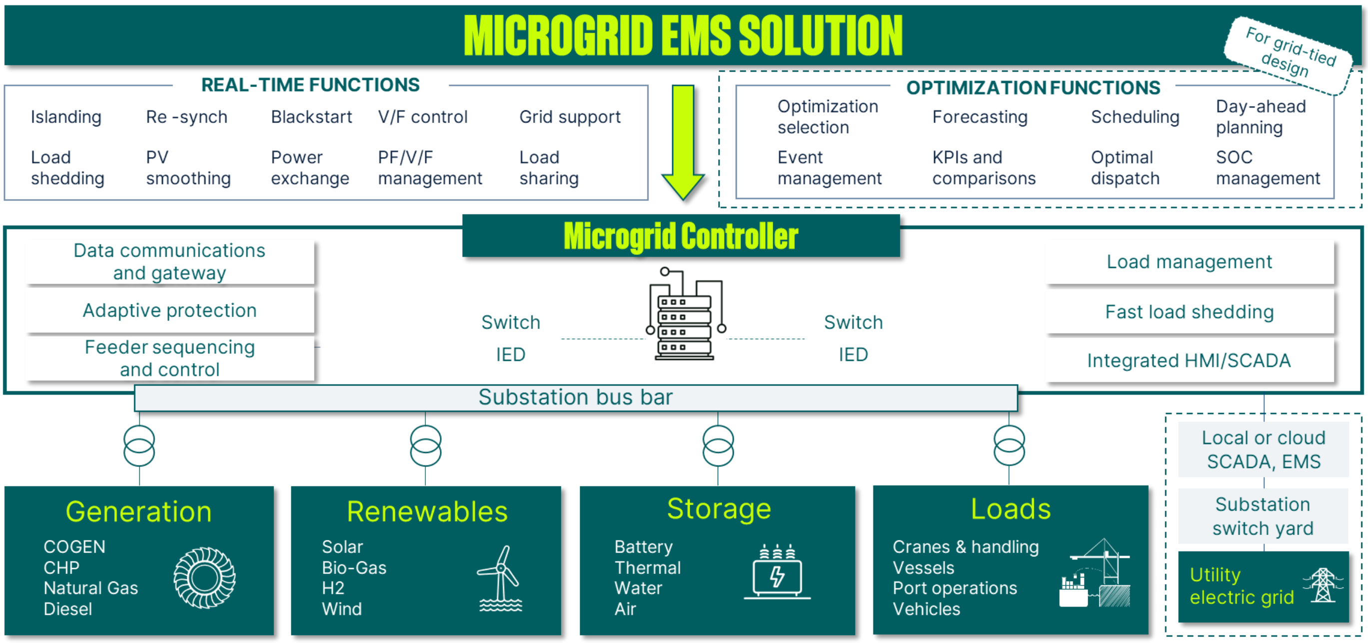
Operators can benefit from control systems based on common platforms, and selected for customer and projects needs. Complementary functionality needs for a microgrid might include, for example:

- Dispatching power and energy resources in a hybrid through supervisory, model-predictive control, such as GE Vernova's FLEXIQ.
- Real-time control, automation and energy optimization at scale with flexibility to accommodate grid-connected and islanded modes, such as the GridNode solution.
- Process-focused energy management system controls to support local load balancing (to prevent blackout) and power quality through management of power converters, for example.

Customizing for different ports: energy demand profiles and cycles

Each site requires an in-depth study to correctly analyze needs, to evaluate blackout risks and mitigation measures, to determine the acceptable risk ratio for each customer, considering associated capital expenses and technical-economic tradeoff.

Leveraging GE Vernova's experience in providing solutions for demanding transmission system operators and for mission-critical operations at sea (on vessels and energy platforms) or in remote locations, its existing, proven solutions are configured always with the customer's operating mode and business model as the starting point.



CONCLUSIONS: Collaborating to De-Risk Projects

Demand for energy at ports is increasing, especially demand for electrical power to reduce greenhouse gas and noise emissions, in line with regulation and stakeholder expectations.

Apart from ports' own needs for power – for operations and logistics - port multi-modal customers have expectations that they can access clean power-as-a-service, making provision of power a necessity for ports as future-ready transport and energy hubs.

Energy transition is a journey; it is possible to map out scalable solutions that achieve immediate emissions reductions and benefits for the operation and surrounding community while assuring safe, reliable, affordable operations on the path to net zero.

Four key considerations for ports:

1. Having sufficient **energy availability and surety** to accommodate both port *and* customer power demands. And being better informed to understand, and predict, what the 'duty cycle' for those power demands might be.
2. As energy provision becomes front-and-center as a user-service, ensuring that energy and power are **accessible, connectable, safe** and of the right 'quality' for different users.
3. Balancing meeting growth in power demands with a viable but **cleaner mix of energy** and power supplies, as part of 'net zero' roadmaps.
4. Without the benefit of a 'crystal ball', being **adaptable** for future scale and/or technology insertion. Above all, a solution that is relevant for different ports' **budget, location and traffic**.

Helping to overcome challenges

As an energy business, at GE Vernova we work with many different industrial and maritime companies, and hear two key things: Most are facing very *similar* challenges in energy transition and investment, but equally no one organization is the *same*. However, with a broad range of energy and power solutions in the market, there are energy-efficiency, supply, surety and decarbonization measures appropriate for any type of operation to help create viable roadmaps.

At GE Vernova we believe in the value of energy, port and infrastructure specialists working together to understand options and help to de-risk decisions. Whichever energy specialist you engage with, you may benefit from:

- Experience with a range of solutions, from more simple energy storage, digital optimization or shore power options to full 'energy park' or microgrid know-how; that can help to avoid having just one option pushed.
- Understanding of both the energy and power sectors, right up to grid connection level and beyond to power generation and renewables (especially with ports' increased engagement with the offshore wind sector).
- And understanding of the characteristics of different types of energy, from physical and environmental to performance and operating characteristics, scale and all-important capex, opex, LCOE (levelized cost) and return on investment.
- Expertise in technology, but with a focus on both system-level integrity (how it all works together) and the user experience: it's going to be a critical part of *your* operations.

In this white paper, we've outlined three examples of approaches to managing energy at ports: impacting emissions through shore power connections; supplementing or replacing grid electrical connections with an on-site capability; and more effective knowledge and management of energy usage and ways to optimize it. We welcome continuing the discussion with you.

GE VERNOVA

GEA34918