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From Shore-to-ship to smart ports: Balancing demand and supply and optimizing capital expenditures

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INTRODUCTION

As a standard procedure, during their stay in port, ocean-going vessels generate electrical power using their diesel engines. However, marine engines are not known for their environmental friendliness and dockside emissions (SOx, NOx, PM and CO2). Also, noise and vibration are increasingly subject to regulatory scrutiny – especially as ports are often located in sensitive marine environments or large, densely populated cities.

Indeed, of the top 10 environmental priorities that the European Sea Ports Organization (ESPO) has identified for major ports to take into account, the first three places feature the management of air quality, energy efficiency and noise.

To reduce emissions when a ship is at berth, port authorities often provide a shore-to-ship power connection. However, ultra-large container vessels can consume as much as 7.5 MVA and large cruise ships up to 20 MVA. If several high consumption vessels are connected at the same time, the increase in port grid energy consumption is significant.

The supply of high power levels has a substantial impact on the port electrical infrastructure in terms of technical solution complexity, capital expenditures and operational costs, and is considered to be one of the main barriers to shore-to-ship power large scale implementation.

Due to the complexity of the solution and related constraints, such as limited space availability, a shore-to-ship power installation in a port grid requires an engineering perspective that shall consider the broader impact into the complete port electrification, where the interaction of several electricity consumers and producers shall be taken into consideration. For this reason, a strong port grid is a critical ingredient, and the choice of a centralized frequency conversion system that can minimize the impact on the existing grid is fundamental to maintain a successful balance between demand and supply.

THE EVOLUTION OF PORT ELECTRICAL GRID

Over the last decades, electrical demand in the most advanced ports has constantly increased to allow the management both of an extensive logistics of goods and the increased transport of passengers: it is a fact that the electrification of several ports facilities, including cranes, refrigerated container storage areas and terminal buildings made ports energy intensive customers for the Distribution and Transmission Service Operators.

The port electrical grid is evolving from the traditional model, which encompasses a one-way electricity supply from a centralized production plant to the port traditional loads, to a multi-directional power flow scenario where electricity consumers and producers are spread around the port area.

![ABB logo]

Traditional grid

– Centralized power generation
– One-directional power flow
– Generation follows load
– Top-down operations planning
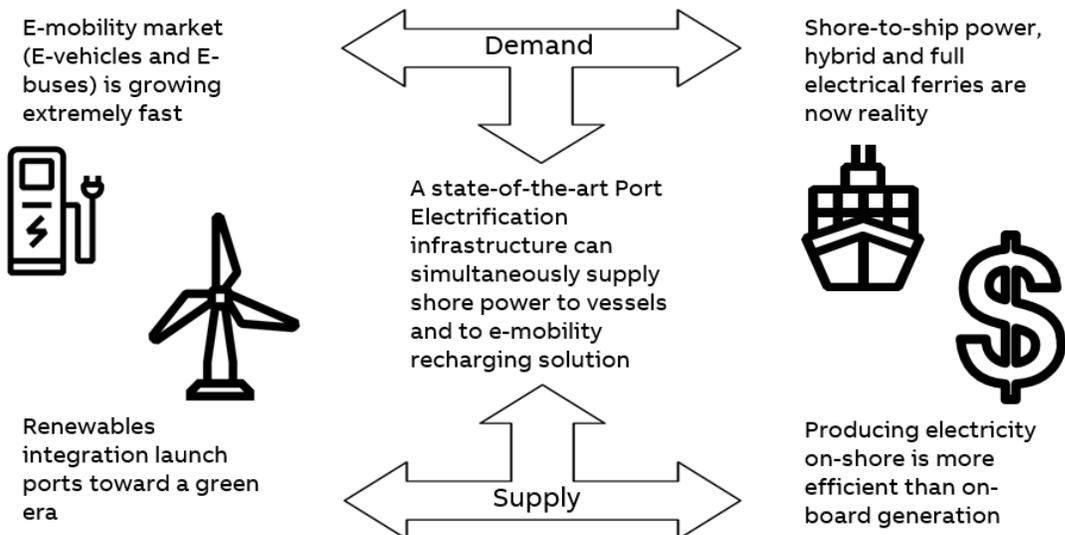– Operation based on historical experience
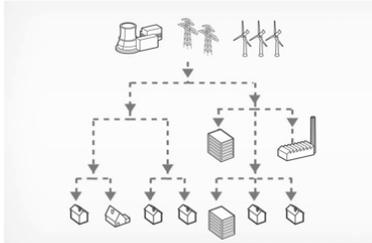
Smart grid

– Centralized and distributed generation
– Multi-directional power flow
– Intermittent renewable generation
– Consumption integrated in system operation
– Operation based on real-time data
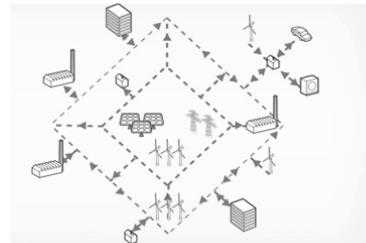
In addition, the electrical system must evolve to adapt to new customers/producers scenarios: localized renewable power generation (solar, wind, cogeneration and tidal) and new consumers pertaining to e-mobility area (e-vehicles and e-trucks), down to the shore-to-ship power connection are generating the need of a comprehensive load management policy in ports areas, based on the balance of demand and supply.

E-mobility market (E-vehicles and E-buses) is growing extremely fast

Renewables integration launch ports toward a green era

Demand

A state-of-the-art Port Electrification infrastructure can simultaneously supply shore power to vessels and to e-mobility recharging solution

Supply

Shore-to-ship power, hybrid and full electrical ferries are now reality

Producing electricity on-shore is more efficient than on-board generation

Amongst the critical loads that need specific management in a port network, shore-to-ship power systems play a key role especially when high consumption vessels needs to be supplied: this is the case of cruise and container vessels.

	HV or LVSC – Low Power		HVSC – High Power		Special Application
Characteristics	RORO/Ferry	Container	Cruise	LNG / Tanker FSU / FPSO	Shipyards / Navy
Voltage	11 kV or low voltage	6,6 kV	6,6 & 11 kV	6,6 kV	6,6 kV, 11 kV or low voltage
Max Power consumption	6,5 MVA	7,5 MVA	16/20 MVA	Approx. 10 MVA	Case by Case
Frequency	60 & 50 Hz	60 mainly	60 mainly	60 Hz	50 & 60 Hz
Plugs/cables (per connection)	1	2	4+1	2/3	Case by case
Transformer	onboard	onshore	onshore	onshore	Case by case
Layout	Not critical	critical	critical	critical	Not critical
Load profile	Partially controlled	Partially controlled	Flat profile	Not controlled	Case by case
Protect selectivity	critical	Not critical (If P=7,5 MVA)	critical	Case by case	Case by case
Cable management system	mid cost	low cost	high cost	Mid cost	Case by case

Although shore-to-ship power connections and interface equipment include standardized components readily available on the market, the critical issue occur when the ship frequency (typically 60 Hz) differs from the supply system frequency (typically 50 Hz): in this specific case Static Frequency Converters (SFCs) shall be designed and optimized for the specific requirements of the vessel to be connected, and this in turn requires a high level of customization of shore-to-ship power solutions.

CENTRALIZED OR DE-CENTRALIZED SHORE-TO-SHIP POWER CONNECTIONS

When designing a tailor made shore-to-ship power solution for a commercial port, two are the typical configurations to be applied when frequency converters are required: decentralized (one-to-one) and centralized.

With a de-centralized system, the SFC is dedicated to one vessel only. In this case, the sizing of the frequency converter has to be performed taking into consideration the highest power demand for the biggest vessel typically berthed in one location.

More precisely, a single-berth/single-vessel solution is characterized by the selection of a SFC that not only complies with the vessel's nominal power requirement but that also accommodates the overload arising from the startup of large direct-on-line motors and the energization of onboard transformers, as well as the needed selectivity to isolate faults on the vessel's electrical network.

This solution is typically applicable to a cruise terminal, where the consumption of a single vessel can be as high as 20 MVA.

Cables between vessel(s) and ACS6000
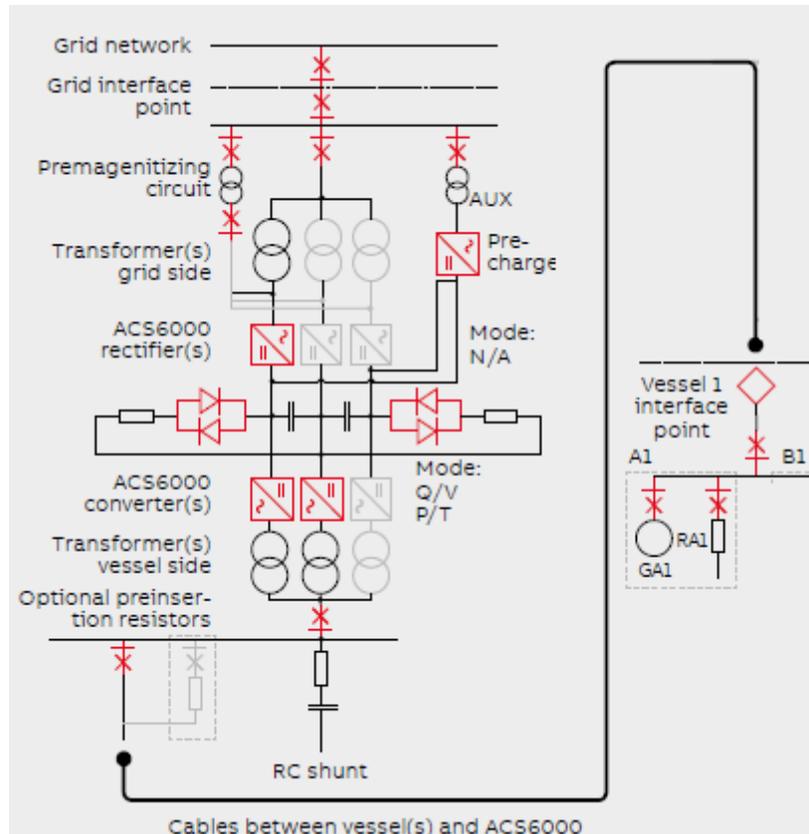
With a centralized system, instead, the SFC is devoted to supplying power to multiple vessels simultaneously. In this case, the sizing of the frequency converter has to be performed taking into consideration the sum of the power demands for all vessels connected at a certain time. The capacity of the total installed shore power can be therefore optimized taking into account the overall system utilization factor (not all vessels have the same consumption) and the contemporaneity factor (not all vessels are berthed at the same time).

In addition to the CAPEX optimization, a multi-berth installation can have a lower overall OPEX since a single frequency conversion substation can be used to feed several vessels at the same time. An additional assessment of the specific load of a single vessel should be performed to make sure that the substation capabilities match the overall load, taking into account the pre-magnetization needs of the onshore transformer that ensures the galvanic isolation between the vessels.

This solution is typically applicable to a container terminal, where, although the peak consumption of a single vessel can be as high as 7.5 MVA, the average consumption is usually lower, since it is strictly dependent on the vessel size and on the number of refrigerated containers on board.
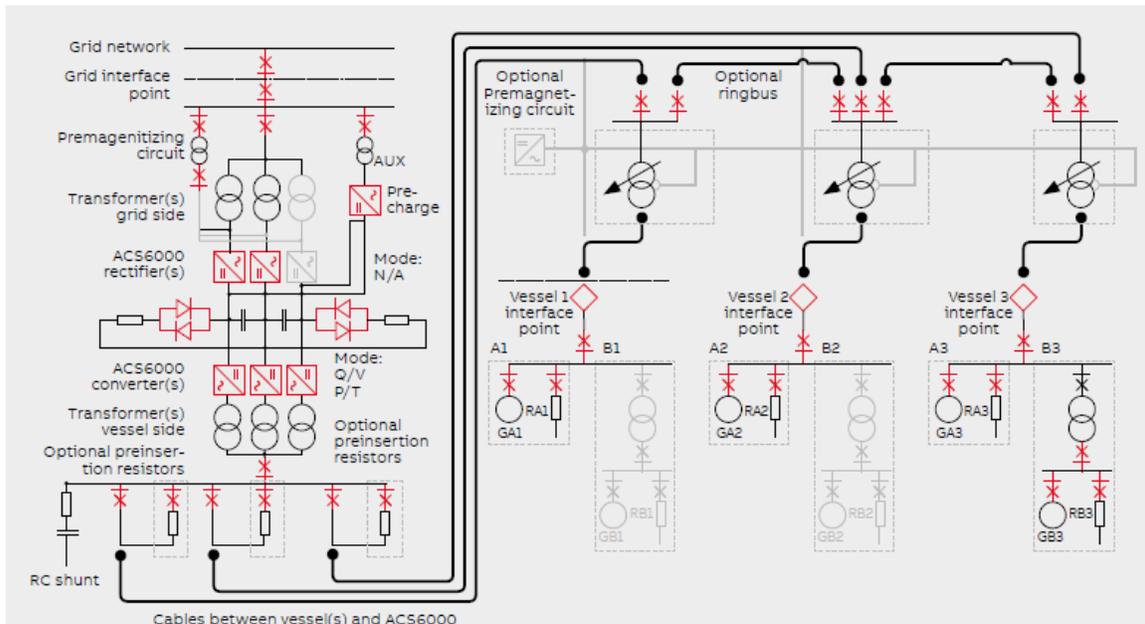
The table below shows a qualitative comparison of the two solutions.

Configuration	Advantages	Disadvantages
Decentralized	– Autonomous system for each vessel – Planned/unplanned maintenance in one system does not affect other vessels – Can be located directly at berth / movable (in case of low power requirements)	– Overall space requirement is considerable (n times the single footprint) – The system shall be dimensioned on the vessel peak power for the single berth (partial load) – Large amount of components required → higher cost
Centralized	– Reduced overall footprint required – Optimized number of components → lower costs – Optimized dimensioning considering utilization / contemporaneity factor	– Planned/unplanned maintenance in one system will make shore power unavailable to multiple vessels – Requires double- busbar switchgears for simultaneous 50 Hz and 60 Hz operation – Might require dedicated vessel isolation transformers (i.e. cargos)

A CASE STUDY ON A CONTAINER TERMINAL

IEC/ISO/IEE 80005-1 international standard for High Voltage Shore Connection states the following: "Two parallel cables with three pilot conductors each shall be used for HVSC systems up to a maximum power demand of 7.5 MVA."
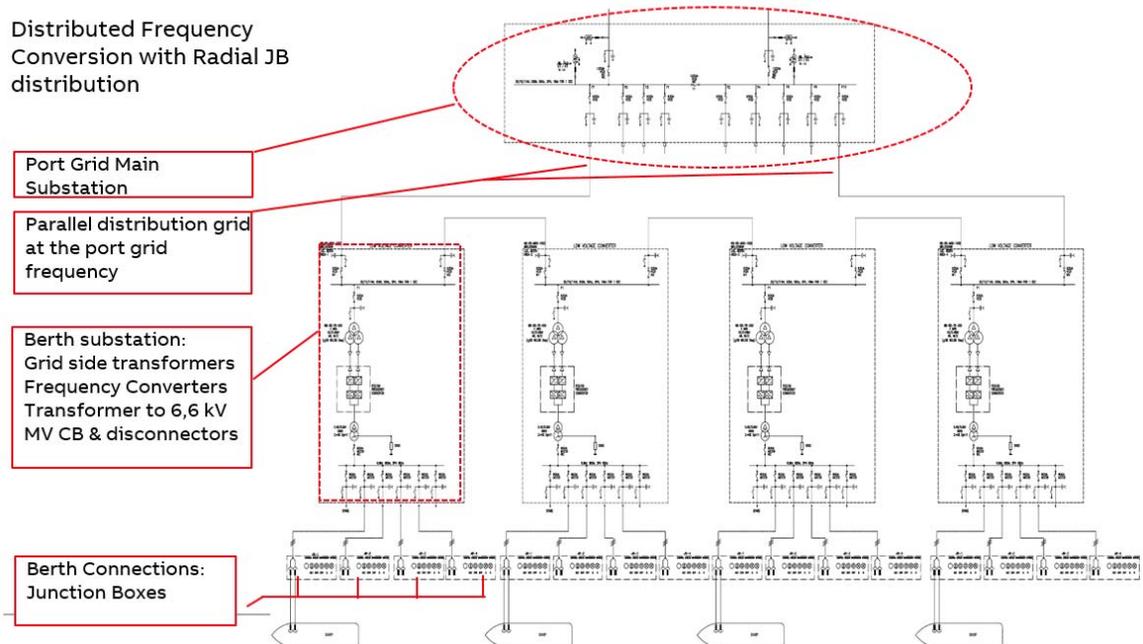
The maximum consumption of 7.5 MVA is theoretically calculated as follows:

- Hoteling services are estimated to be 1-1.5 MVA maximum
- Average consumption for each of the 20 feet refrigerated containers is evaluated as 4kW at 0.8 power factor (i.e. 5 kVA each)
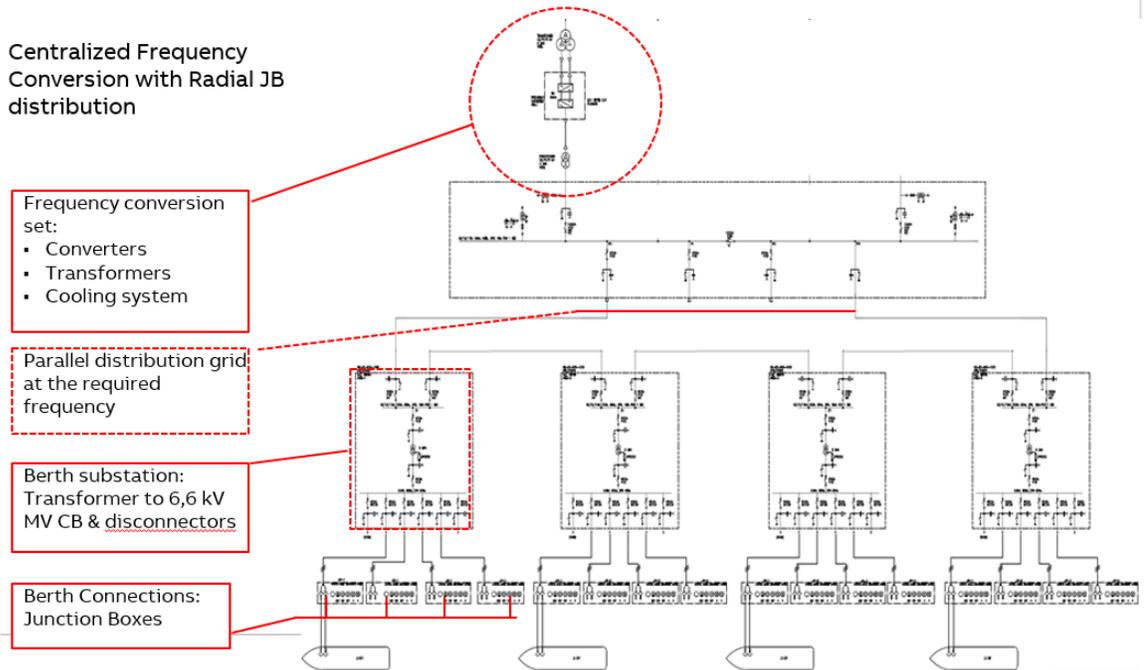
Whilst 7.5 MVA represents the maximum consumption of a container vessel, the real power absorbed during the stay at berth is therefore a function of the number of refrigerated containers simultaneously powered up.

This study will consider an average loading factor of 5 MVA per container vessel. If we consider a container terminal with 4 vessels docked at the same time, we could therefore provide two different solutions:

- Four decentralized shore-to-ship power connections rated 7.5 MVA each

- One centralized shore-to-ship power connection rated 20 MVA

Centralized Frequency Conversion with Radial JB distribution

Frequency conversion set:
- Converters
- Transformers
- Cooling system

Parallel distribution grid at the required frequency

Berth substation:
Transformer to 6,6 kV
MV CB & disconnectors

Berth Connections:
Junction Boxes

Looking at the main components costs (per unit) as per below table:

Component	Rating	Quantity	Cost p.u.	Rating	Quantity	Cost p.u.
MV input switchgear	~300 A (@11 kV)	4	0,1*4= 0,4	~1000 A (@11 kV)	1	0,1*1= 0,1
Step-down transformer	7,5 MVA	4	0,15*4= 0,6	18 MVA	1	0,4*1= 0,4
Frequency converter	7,5 MVA	4	0,5*4= 2,0	18 MVA	1	1,0*1= 1,0
Step-up transformer	7,5 MVA	0	0	18 MVA	1	0,4*1= 0,4
MV output switchgear	N/A	0	0	~1000 A (@11 kV)	1	0,1*1= 0,1
Isolation transformer	N/A	4	0,15*4= 0,6	7,5 MVA	4	0,15*4= 0,6
MV vessel feeder	~650 A (@6,6 kV)	4	0,1*4= 0,4	~650 A (@6,6 kV)	4	0,1*4= 0,4
TOTAL	—	—	4 p.u.	—		3 p.u.

As an outcome of this case study, with a centralized frequency conversion solution, and only considering components pricing, expected savings of 25% are therefore achievable.

CONCLUSIONS

When designing a shore-to-ship power solution for a port, several factors shall be taken into account, including:

- Overall power availability at port substation
- Type of vessel to be supplied
- Nominal power supply for each vessel
- Average power for each vessel (utilization factor)
- Multiple vessel operation (contemporaneity factor)

A careful planning of the shore-side infrastructure will therefore be performed in order to allow the maximum number of connections in line with the overall port grid capacity: this will in turn minimize the total cost for investment (CAPEX) and optimize system operation costs (OPEX), thus allowing operators to decrease the barriers towards the application of shore-to-ship power supply in many commercial ports.

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