The ports as smart micro-grids: development perspectives

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Abstract— **The deregulation of the electric power systems in conjunction with the high penetration of renewable energy sources regardless of their capacity has lead to the extensive deployment of the smart grids, as they offer certain advantages such as exploitation of non-pollutant power sources and smoothing of peak power demands. On the other hand, the general concern throughout the Globe about reducing the Green House Gases (GHG's) of the waterborne vessels has lead up to a number of alternatives outlined by the International Maritime Organization (IMO) and the European Union (EU). Among these measures, an appealing one is the alternative maritime power or 'cold ironing' according to which, when the ship enters a port and stays at berth (i.e. there is no demand for propulsion), she shut downs her generators and is interconnected to the mains grid. Based upon the infrastructure of 'cold ironing', the ports can be transformed into energy hubs. In this paper, the new development perspectives of the ports are analyzed from the energy point of view. Finally, this paper includes a short presentation of the ongoing EU-funded ELEMED project and an implementation of the cold ironing technology at the port of Kyllini.**

Keywords—smart grids, cold ironing, shore supply, alternative maritime power, ELEMED

I. OVERVIEW

In this paper the appealing advantages of ship-to-shore interconnection between ashore grid and ships at berth are presented. The combination of smart micro-grids, renewable energy sources, smart interfaces and smart measuring devices enabling the surveillance, monitoring and control of bidirectional power flow can be used as a means to this end [1]. Within this framework, the ports can become energy hubs with a key-role not only in decreasing the atmospheric pollution provoked by ships, but also to the National Energy Policy. Last but not least, the paper includes a short presentation of the ongoing EU-funded ELEMED project, which incorporates the aforementioned applications

The general concern throughout the Globe about reducing the Green House Gases (GHG's) of the waterborne vessels has lead up to a number of alternatives outlined by the International Maritime Organization (IMO) and the European Union (EU) [2]. Moreover, the areas where emissions are well confined and monitored are the Emission Controlled Areas (ECA's), the most common of which are the broader areas of the ports. Cold ironing is measure with appealing perspectives as discussed in this paper.

II. METHODOLOGICAL APPROACH

A. The concept of Cold ironing (alternative maritime power)

Cold ironing, a term initially used by U.S. Navy, refers to connecting a ship to a shore-side power supply in port with the ship's machinery shut-down on the assumption that the port has the infrastructure and the "greener" energy (e.g. renewables) to support the effort.

Cold ironing does away with the need of burning fossil fuel all together on board ships at port. This shore sourced power serves the ship's cargo handling machinery and hotelling requirements. This brings immediate relief from pollution by shipboard emissions and allows a more holistic maintenance schedule to be followed by ship operators – they are typically hard-put to maintain planned maintenance schedules due to commercial operating pressures [3],[4].

B. ISO/IEC/IEEE Standards

The international standard IEC/ISO/IEEE 80005-1 sets out the requirements for High Voltage Shore Connections (HVSC) and is applicable to ships requiring 1 MW or more or ships with HV main supply, while IEC/ISO/IEEE 80005-3 (pre-standard) deals with Low Voltage Shore Connections (LVSC) (International Electrotechnical Commission, 2014) for vessels with a lower power demand [5],[6],[7].

The standards propose similar configurations for both the HVSC and the LVSC systems. The main difference bettween the two configurations consists of the earthing equipement and its relevant interlocks used in the High Voltage systems to avoid residual charges. Figure 1 illustrates the port side configuration for a LVSC system presented in IEC/ISO/IEEE 80005-3.

Both the HVSC and the LVSC systems use a dedicated isolated transformer as the last power component before the interconnection between the ship and the port. The term dedicated transformer means only one ship connection to one transformer to satisfy the galvanic isolation requirements, in order to protect the ship power system from abnormalities in the shore power system. Many power system grounding problems and stray currents associated with other port facilities can affect the ship power-supply ground fault protection, unless the shore power system has its own grounding zone provided by a dedicated transformer with a neutral grounding resistor. The continuity of the neutral earthing resistor shall be continuously monitored. In the event of loss of continuity the shore-side circuit-breaker shall be tripped.

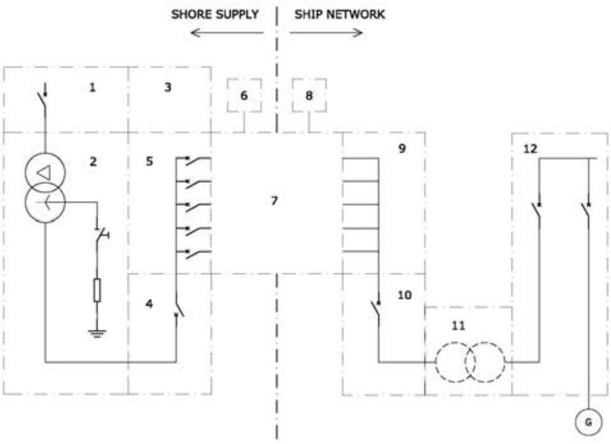

Fig. 1. Port side configuration for a LVSC system presented in IEC/ISO/IEEE 80005-3 [7]

C. Shore-side alternative configurations

When designing an effective shore connection system, it is important to take into account the right dimensioning criteria and choose the best architecture.

The typical architectures of the shore connection systems can be classified according to different criteria such as:

- the voltage level of the shore connection. LVSC systems (usually 440 V) are suitable for systems with power demand less than 1 MW, while HVSC systems (usually 6.6 or 11 kV) are more appropriate for ships with higher power demands or with HV main supply;
- systems with or without frequency conversion. Systems without frequency conversion are suitable for North American ports, while systems with frequency converters for ports located in Europe or Asia.

The shore supply systems which include a frequency conversion unit, can be further classified into the following categories:

- cold ironing systems using rotary frequency converters or cold ironing systems using static frequency converters;
- the frequency converter(s) can be dedicated to each shore connection point (decentralized solution) or installed in main central substation (centralized solution).

In the decentralized solution presented in figure 2 a dedicated frequency converter is placed on each berth and radially feed from a common substation. The transformer at each berth in this configuration serves the additional function of forming, together with the frequency converter, a sinusoidal curve shape.

The main advantage of this configuration is that consist of a free-standing system at each berth. If a fault takes place in one of the frequency converters then this berth can be disconnected without any influence on the other supplied vessels. Moreover ships with different voltage levels can by supplied simultaneously with appropriate adjustment of the converter output or the taps of the isolating transformers. On the other hand, it requires big footprint at every berth and the frequency converter is in use even if a 50 Hz vessel is connected, which results in slightly lower efficiency and higher harmonic distortion. Moreover, Large amount of transformers is required, due to the need of a step-down and a step-up transformer for each frequency converter.

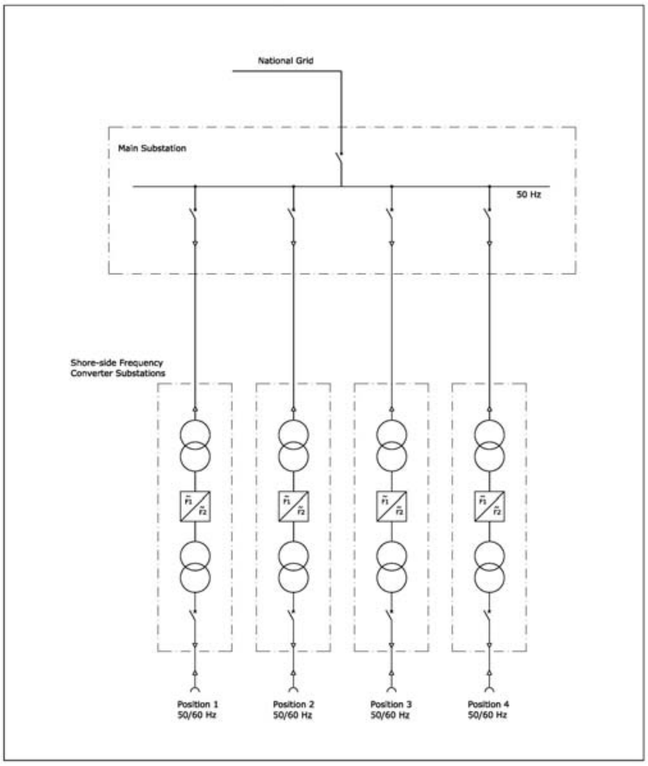

Fig. 2. Decentralized frequency converter configuration.

In the centralized configuration (figure 3), a centrally placed frequency converter, or several frequency converters in parallel, supply a double busbar arrangement which can be used to selectively provide either 50 Hz or 60 Hz to the berths. Each substation at berth, which contains only the isolation transformer and the appropriate low voltage switchgear, is fed through a breaker and a change-over switch. The change-over switch makes it possible to select which busbar shall be connected to the berth in every occasion.

The frequency converter, in this configuration, can be dimensioned by means of the highest power demands among the ships that intend to be connected and the number of the vessels that will be supplied simultaneously. This can result in lower total installed capacity of the frequency converter system, especially in the case that a large number of identical berths that will not be supplied at the same time, which can lower the cost of the investment. Another advantage of the centralized solution is the small footprint needed at every berth, which can become a crucial factor when the available space at the terminals is restricted. Moreover, the frequency converter is not in use if a 50 Hz vessel is going to be supplied, so a higher efficiency can be achieved with this facility. Though, considering todays frequency converters have a high efficiency (98%), this is not a key factor in the configuration selection.

On the other hand, the system is more vulnerable in the case a fault occurs in the frequency converter, since the facility will not be able to supply 60 Hz to any berth and the price of the switchgear equipment is slightly higher due to the double busbar system.

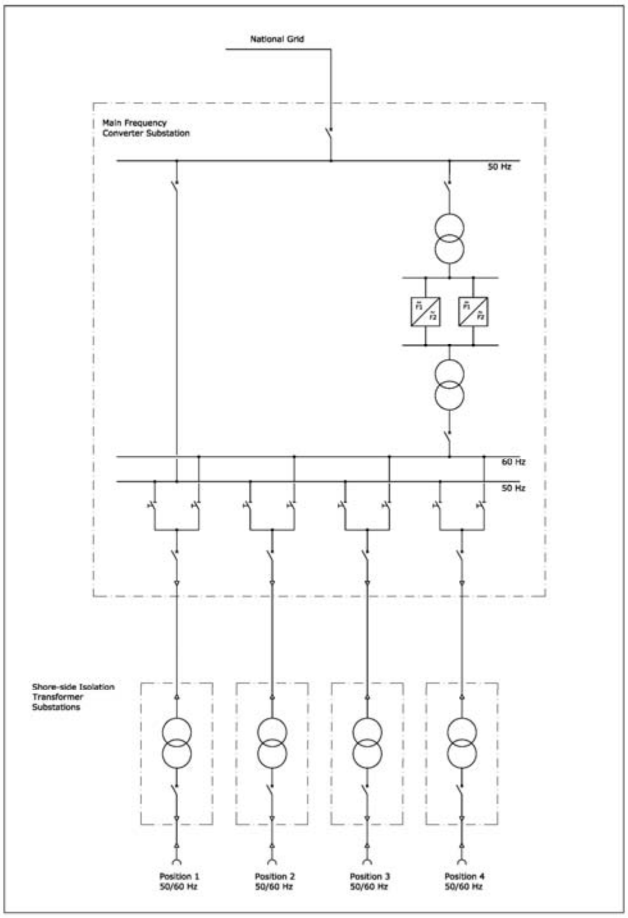

Fig. 3. Centralized frequency converter configuration.

D. *The concept of Smart Grids*

The concept of “smart-grids” engages more efficient energy transactions between energy producers and consumers. It has been under development in the last decade in parallel with the deregulation of inland grids and the deployment of smaller or larger scale electric energy production plants based mainly on renewable energy sources.

In smart-grids, distribution field devices become nodes on communication networks and act as intelligent remote agents to operations, control and asset management centres. These devices are enabled to make localized decisions, coordinate with peers, self monitor their own health, monitor changing local system conditions, communicate warnings to the control centres, request operations changes and maintenance actions, and take action to protect and reconfigure the delivery grid to minimize problems and optimize reliability. Control Centres also become closely integrated with the field devices. All the above require increased operational complexity, two way communication capability, distributed computing/intelligence, large communication infrastructure and finally large initial investments.

E. *Further development of ports as energy hubs*

Taking into account the aforementioned characteristics, the infrastructure of ports can be further enhances in manner like those mentioned next:

- Constructions of hybrid electric driven shuttle ferries (for short sea transportation: battery based+ back up energy unit).
- Selective-collective co-operation of energy storage units deployed in port (and in ships interested).
- Interim solution of supplying islanded networks with electric energy based on environmentally friendly fuel (eg LNG): applicable to islands where the LNG network has not been deployed yet.
- Emergency supply of inland grids (e.g. in black-out situations of National Grids in Force Majeur cases).

III. THE ELEMED PROJECT

The Electrification of Eastern Mediterranean Corridor (ElEMed) is an initiative aiming at the cultivation of cold ironing perspective in the Eastern Mediterranean region of Europe. It is coordinated by Lloyd’s Register while several partners take part in including major ports like Piraeus and Killini (Greece), Koper (Slovenia) and Limassol (Cyprus).

A. *Cold Ironing implementation at the port of Kyllini*

The port of Kyllini is a four berth Roll-On Roll-Off (RoRo) ferry terminal. The topographical top view of the port is presented in figure 4 along with the berthing positions and the major port distances.

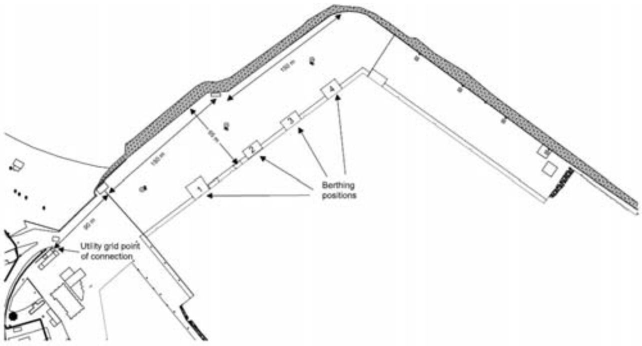

Fig. 4. Topographical top view of the Kyllini port

There are, currently, five ferries which visit the port of Kyllini in daily basis. Four of them have an electrical system operating at 440 V, 60 Hz, while, one of them operates at 380 V, 50 Hz. Their electrical power demands at berth vary shortly from around 300 kVA to 450 kVA.

Figure 5 below presents the instant power demand (kW) and the power factor of a typical vessel visiting the port of Kyllini over a period of 1.5 h while in berth, as recorded after site measurements. The average load demand is approximately 257 kW, with a peak around 375 kW (450 kVA) and a minimum around 200 kW.

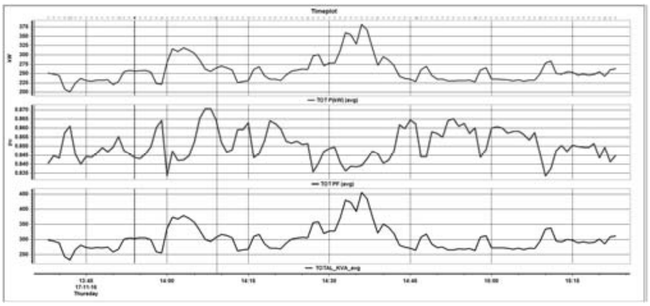

Fig. 5. Instant power demand (kW) and power factor of a typical ferry while in berth

The cold ironing implementation in the port of Kyllini will consists of two shore supply positions (figure 6) at berth points 1 and 2 (figure 4) which are going to be constructed in two individual stages.

The first shore supply position will be constructed within the framework of the ELEMED project and more specifically activity 13 “Pilot: Shore Power Installation in the Port of Kyllini”. The project is anticipated to be completed before October 2018.

The complete shore – side installation for Kyllini AMP project will consist of two shore side substations one per supply position. The first substation shall include:

- one medium Voltage Switchgear
- one Step Down Power Dyn Transformer of Dyn
- one Incoming Low Voltage Switchgear
- one static Frequency Converter
- one Isolation Transformer dyn, 1:1 ratio which will provide galvanic isolation from other connected ferries and consumers;
- one Neutral Earthing Resistor (NER) installed at the neutral point of the isolation transformer for limiting the ground fault current between the shore box and the vessel’s infrastructure;
- one Outgoing Low Voltage Switchgear which will supply the shore socket outlets;

The second shore side substation will be identical to the first one except the medium voltage Switchgear. Each supply point shall consist of two standardized socket-outlets The interconnection cables between the supply point on shore and the receiving point on the vessel shall consist of two XLPE parallel cables, 185mm2, 3 Phases + Earth + 4 Pilot wires.

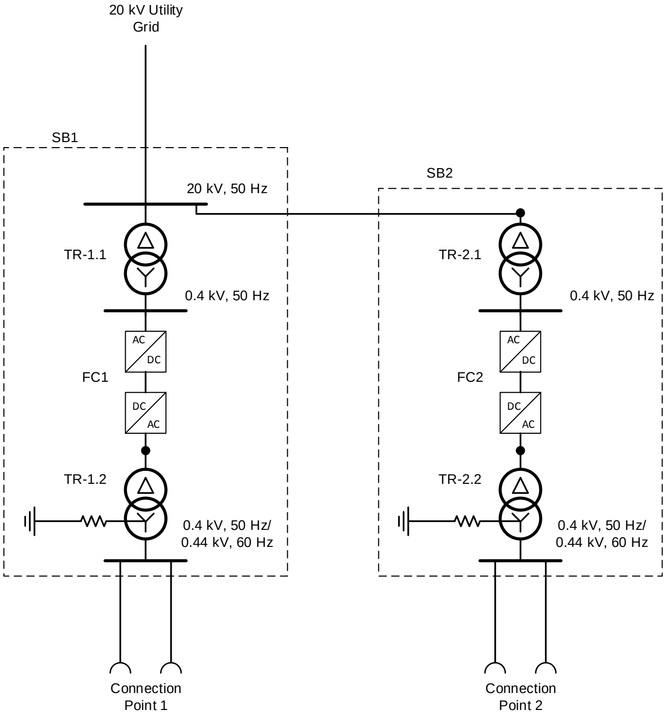

Fig. 6. Kyllini cold ironing simplyfied single line diagram

Table I, presents the cost estimation for the pilot implementation (one shore-side power supply position) and the complete cold ironing solution (two shore-side power supply positions) for the Kyllini project.

B. *Deployment of renewable sources at the port of Kyllini*

In order to deploy fully the advantages of Cold Ironing technology the electricity supplying the vessels should come from zero emission sources such as photovoltaic panels and wind generators, especially if combined with a battery storage system (figure 7).

TABLE I. KYLLINI PROJECT COST ESTIMATION

De Description	Pilot Project Cost (€)	Complete Project Cost (€)
Civil Works	27.000	53.500
Electrical Utilities	37.500	63.500
Shore Box Equipment	272.000	522.000
Socket Outlets and Plugs	7.500	15.000
Earthing System	7.500	14.000
Cable management system	100.000	200.000
Sum	451.500	868.000
Total cost (Subcontractor profit 18%, Uncertain expenses 15%, VAT 24%)	780.000	1.475.000

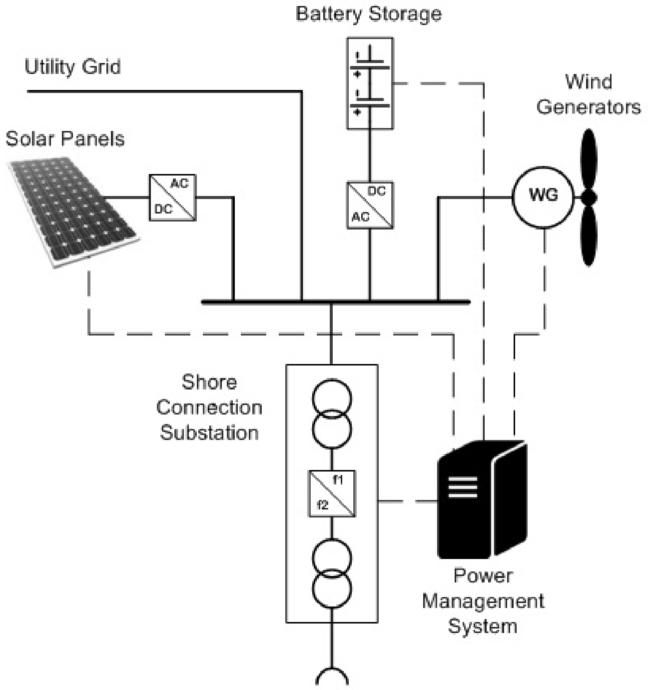

Fig. 7. Combination of smart grids, renewable sources and cold ironig

The battery storage system can be charged through the installed solar panels and wind generators when no vessel is supplied from the port’s grid and act as supplementary to the renewable sources when the demand of the supplied vessel exceeds the power generated from renewable sources. All the measured data are gathered in a central power management system server which controls the functions of the local micro-grid.

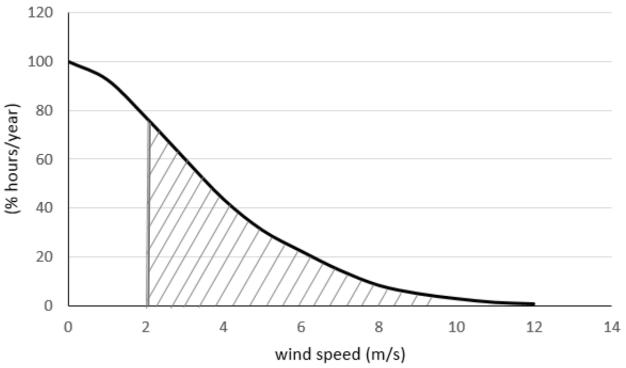

Fig. 8. Cumulative distribution of the hourly average wind speed at the port of Kyllini

An investment on renewable source depends on the available space at the port area and the local weather conditions. In order to determine the available power generation resources, the meteorological data from the port’s weather station were collected. Figure 8 depicts the cumulative distribution of the hourly average wind speed over a period of one year, while table II presents the average monthly solar irradiance.

As observed in figure 8, in no more than 20% of the hours of the year the wind speed is less than 2m/s which is the cut in wind speed for vertical axis wind turbines. As expected, the solar irradiance is more intense in the summer which is extremely beneficiary for cold ironing implementations since during summer months the vessels power demand reaches a maximum due to the extensive utilization of air condition systems.

TABLE II.

	Solar irradiance kWh/m^2	Temperature °C
January	69.8	10.70
February	84.9	11.00
March	131.0	11.80
April	159.1	14.00
May	199.0	18.70
June	220.6	23.20
July	228.4	25.10
August	208.7	25.60
September	159.5	22.90
October	120.5	18.70
November	79.5	15.20
December	62.0	11.80
Year	**1723.2**	**17.43**

IV. CONCLUSIONS

Both environmental and economic forces affect the decision to develop ports to become energy hubs. The deployment of smart grid, renewable sources and battery storage technologies offers ports the potential to participate in electricity markets through the demand side response by regulating the port’s electricity consumption according to market price signals.

Moreover, ports can supply a percentage of the electric power demand of the vessels that employ cold ironing with energy produced by the ports renewable sources, contributing in the effort of reducing the Green House Gases without affecting the local utility grid. Finally, berthed vessels are able to supply the local loads acting as small power plants (reverse cold ironing) in case of emergencies such as black outs.

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