Elaborating Sustainable Port services for Greener Shipping *

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Synopsis

The paper deals with the new development perspectives of modern smart ports in an attempt to offer premium services to ships, passengers, commercial business, the environment even the society fully exploiting the smart grid concept. Besides highlighting the courses of actions towards such reformation, it is discussed that of major importance is the proper design of a centralized energy management system providing supervisory monitoring and control of all energy transactions among providers and consumers as well as their optimized co-operation.

Keywords— green shipping, smart ports, smart grids, sustainability.

 http://doi.org/10.24868/icmet.oman.2019.018

1. Introduction

Lately, the maritime industry, following the IMO and EU directives towards minimizing atmospheric emissions of ships, has been focused on designing and building greener vessels or greening existing ones via alternate retrofitting techniques (Prousalidis et al. 2011; Smith et al. 2015). Furthering this concept, modern ports playing a key role in the transportation chain are also facing challenges in terms of providing innovative services of superior quality without adverse environmental and societal impact (Ericsson 2008; Paul & Haddian 2009; Gialketsi et al. 2012; Acciaro et al. 2014; Buiza et al. 2015; Coppola et al. 2016) Thus, all ports re-establish their strategic priorities being into smart energy hubs where electric energy systems tend to predominate. In particular, the port facilities and services related to this target include the installation, operation and management of systems like Cold Ironing, Reefer power supply, Renewable Energy Sources, Port Lighting, Cargo handling cranes and Energy storage systems (Prousalidis et al. 2019).

Within this framework, the paper deals with a discussion of the sustainable growth reformation of ports in alignment to green shipping demands on the one hand and the smart grid concept on the other. Thus, it is shown that it is of major importance to design, and develop a centralized energy management system of SCADA type in the port area that can integrate, monitor and control all available energy sources (RES's, Grid Supply, batteries) as well as all loads served which comprise ships in cold-ironing mode, battery ships in charging mode, cargo handling equipment, refrigerating reefers etc. In this way, all energy transactions can be performed in an optimum manner from the techno-economical point of view. For instance, energy can be stored from RES's or from the Grid when the latter provides it in low price, or even from cranes operating in regenerative mode and provided to loads and consumers upon demand.

2. Port major electric clients

Within the framework of greener shipping established by IMO resolutions, modern ports being the transportation hubs become confronted with significant challenges in terms of providing innovative services of superior quality and high financial, environmental and societal impact. To this end, all ports tend to re-synthesize their master-plan according to which they are subjected to a transformation into smart energy hubs where electrification plays a key-role. In particular, the port clients subject to penetration and sophisticated management of electric energy are, see also Fig.1:

- Bidirectional ship-to-shore (Cold Ironing)
- Regulated reefer power supply
- Smart Port Lighting
- Efficient cargo handling cranes
- Smart Energy storage systems

the characteristics of which are discussed next highlighting the important role of a central Power Management System (PMS).

2.1 Bidirectional ship-to-shore (Cold Ironing)

Ship-to shore power interconnection or alternate maritime power is one of the most appealing ways of eliminating the aerial emissions (and noise) produced by ships being at berth, as their engines are shut-down and they are supplied electric energy from the port infrastructure (Khersonsky et al. 2005; Ericsson 2008; Paul & Haddian 2009; Prousalidis et al. 2011; Gialketsi et al. 2012; Smith et al. 2015; Sulligoi et al. 2015; Michalopoulos et al. 2016; Parise et al. 2016; Prousalidis et al. 2017; Patil & Sahu 2017; Prousalidis et al. 2019) (Fig. 2).

An extension of this interconnection type consists in charging battery-driven ships via shore power facilities. Furthermore, the same infrastructure utilized for shore-to-ship can be exploited for the reverse power flow; i.e., from the ship to the shore grid (Prousalidis et al. 2017; Vlachokostas et al. 2019). This "reverse cold ironing" can be used in case of emergency such as environmental disasters but since it can be treated as an energy transaction between the ship and the port it can be exploited in many ways. Thus, in certain cases it

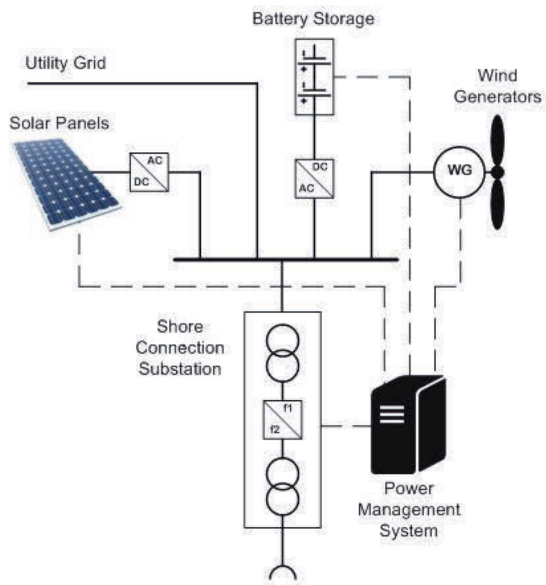
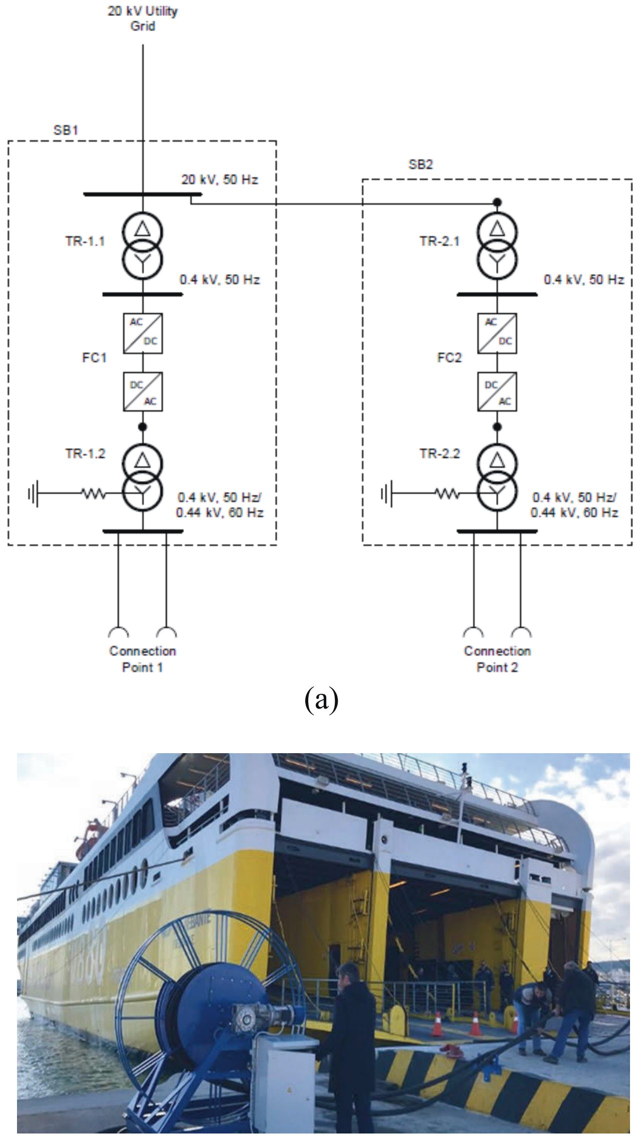


Figure 1. Major port energy sub-systems

might be more beneficial from environmental and economical point of view for this approach with a typical example being the non-interconnected



(a)

(b)

Figure 2. a) Kyllini cold ironing simplified single line diagram b) Kyllini Cable management system

islands the power of which in most cases is strongly dependent on oil with all its subsequent side-effects (in terms of cost and pollution). In such a case it has been proven appealing from many points of views to procure electric energy from ships the electric power of which is based on greener fuels like LNG (Lyridis et al 2019, Prousalidis et al 2017, Vlachokostas et al 2019).

2.2. Regulated reefer power supply

One of the most advantageous characteristics of reefers is that they are able to keep their thermal condition almost constant for fairly long intervals on the order of 6-12 hours, even if there is no power supply, which provides some freedom in controlling the energy supply to them, (Kanellos, 2019).

2.3. Smart Port Lighting

Modern lighting devices based mainly on LED technology provide significant reductions in energy demands (in terms of kW) still offering equivalent levels of luminance, Fig. 3). It is worth noting though, that LED lighting devices introduce harmonic distortion problems which have to be taken into consideration (Prousalidis et al., 2019).

2.4. Efficient cargo handling cranes

Cranes are particularly useful for cargo handling of container-ships and car-carriers. The energy profile of one port crane during operation is shown in Fig. 4. The most critical issue is the negative power noted during lifting down of a load which corresponds to the regenerative nature of the braking of the related motor. This regenerated power can either be stored to battery systems of the port, supplied to ships in cold ironing mode or supplied to the central Grid, (Prousalidis et al., 2019).

2.5 Renewable Energy Sources (RES's)

As it is well-known, Photo-Voltaic units (PV's) or Wind-Generators (WG's) produce energy. Hence, taking into account meteorological data, clusters of PV's and WG's can be deployed in certain available locations within the port jurisdiction. Based on economical criteria, the green energy produced can be stored in energy storage units or distributed to the port consumers or even sold to the main Grid.

*2.6 Efficient Parking station*s

The modern services offered in the port jurisdiction could include parking stations for electric or hybrid-electric vehicles (Prousalidis et al., 2019):

- Belonging to passengers

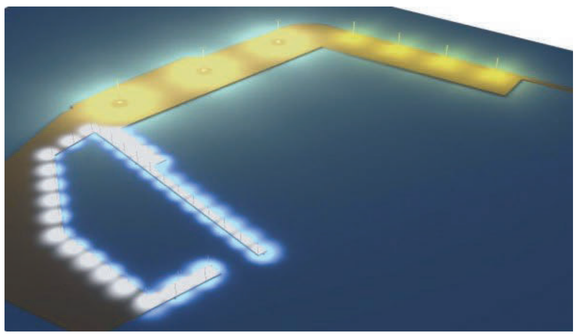


Figure 3. Luminance of the Kyllini port (LED lights have been placed only in the fishing docks)

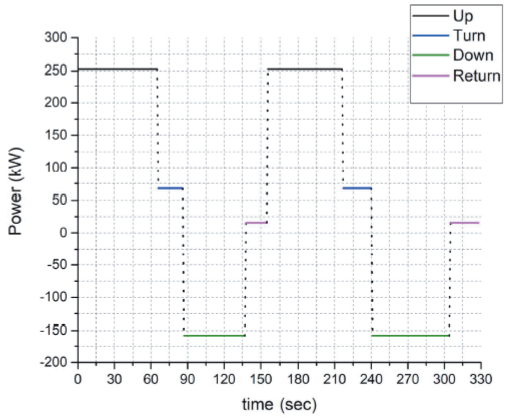


Figure 4. Operating profile (two full cycles of operation) of one single port crane

- Belonging to the Port Authority and used for internal transportation needs (e.g. moving passengers between terminals etc).
- In combination with PV's (eg. Solar panels on top of the parking stations on the port side)

2.6 Smart Energy storage systems

The battery units installed in the port jurisdiction can serve the following two-fold goal:

- Provide **energy buffering** i.e. storing electric energy which is
  - o purchased from electricity providers when electricity price is low
  - o generated by RES's deployed in the port area produced by regenerative braking of cranes battery swapping (ships and ports)

- Facilitate **energy bunkering** i.e. electric energy is provided to battery driven ships such as short-sea shuttle ferries. This bunkering can be performed either via:

  - o direct charging through DC to DC ship-to-shore interconnection, or

  - o battery swapping, i.e. battery modules which be easily transferred from shore to ship and vice versa while they can be charged in port, (Fig. 5).

2.8 The next step: Energy Clouding

The energy transactions of all electrical sub-systems described above are figuratively depicted

Figure 5. Battery modules storage system

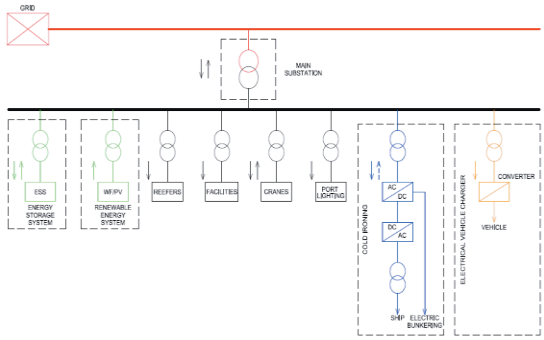


Figure 6. Energy transactions within the port.

in Fig. 6.

Furthermore, following the current trends of smart micro-grids, ports via its electrified facilities can be transformed into energy hubs buying and selling electric energy in bulk. The next step is that all energy sources in the port area including vessels (with batteries) at berth, battery stacks, RES's can store or provide energy upon demand. Within this framework, energy is not well located in certain providers but is rather distributed throughout a cloud with which transactions can be bi-directional.

3. The key-role of PMS

The Power Management System (PMS) of the Port is to have an overall supervisory monitoring and control of the energy transactions in the port network, remote-control of energy flow, protection, visualized inspection of critical operating parameters along with automatic meter reading, meter data management and asset management for operation, maintenance and billing purposes. Moreover, the SCADA type PMS must have capabilities of providing energy to all loads by all available sources in an optimized manner so that the ultimate target i.e. the minimized atmospheric pollution by any thermal energy source in the port area is achieved. To this end, the PMS is to comprise the following components:

- Optimal scheduling of the intermittent operation of reefers: since the temperature in their content is kept unchanged for long long intervals, their supply is to be scheduled during off-peak time slots.

- Optimal exploitation of energy produced within the port jurisdiction (by energy generation sources like the RES's, the cranes operating in regenerative braking mode, ships in reverse cold-ironing mode, buffering/storing)

- Optimal Operation Scheduling of Shore Power Supplies including reverse cold ironing
- Optimal charging of battery driven ships

To this end, efficient algorithms for global optimized operation have already been developed. For instance, in (Kanellos 2017; Kanellos 2019), the Port Authority acts as the Manager and all energy sources and loads are considered to be agents. According to this "win-win" co-operation scheme, the operation scheduling of each agent as well as the electricity price for the energy transaction between each agent and the Port are finalized after a series of iterative negotiations between them.

4. Programming a sustainable reformation of a port

Taking into account the aforementioned development perspectives of the ports, the following courses of action can be taken by the Port Authorities:

i. A thorough auditing is performed focused on the perspectives for sustainable energy development. Thus, the capacity and the weaknesses of the port electric energy system are traced, the perspectives of deploying RES's are investigated (based on meteorological data and possible installation locations), the possibility of installing large battery units is sought etc.
ii. The Master-plan of the port (as an enterprise) is revised and reformed taking into consideration critical parameters such as environmental friendliness, green shipping, blue growth and energy smart grid management transactions).
iii. Data are collected from all major agents engaged i.e. port energy clients and producers (as outlined in the previous sections)
iv. Feasibility studies and Cost Benefit Analyses (CBA's) are preformed for the investments regarding the related infrastructure expansion (e.g. installation of cold ironing facilities, deployment of RES's, batteries, smart energy management systems)
v. The investment actions in sustainable development are prioritized so that the most economically appealing ones are selected.
vi. Funding schemes and instruments are investigated and critical decisions for the most feasible investments are made. Applications for funding are made.

5. Conclusions

The paper deals with the new development perspectives of modern smart ports in an attempt to offer premium services to ships, passengers, commercial business, the environment even the society fully exploiting the smart grid concept. The key factor towards this reformation which has to be very carefully and thoroughly planned is an energy management system providing supervisory monitoring, control and optimized operation of all energy providers and consumers.

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