# The SSE-ID Card of Ships in the Sustainable Maritime Framework

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***Abstract*—Nowadays, the worldwide implementation of shore-to-ship connection paradigm is hindered by the large variability of requirements on the ships to be powered. In order to solve this issue, a standardized form must be conceived for defining all the characteristics. The paper wants to presents the shore-side electricity (SSE) related information as encoded in an electronically registered ID card (the SSE-ID) of all the ships subjected to cold ironing obligation. As finalized in the IEEE 45.1, the format of SSE-ID is anticipated to facilitate the SSE-connectivity procedures in all the equipped ports.**

***Keywords—Shore-to-ship interconnections, electrification of ships, SSE, sustainability, electrification of ports, cold ironing.***

## I. Introduction

At the present day, humanity having become sensitive on the adverse environmental impact of all activities, has taken significant resolutions to eliminate the negative impact on climate change. Within this context in the European Union, Paris convention has made the way to the European Green Deal, which in turn led up to the introduction of 'Fit-for-55" packages of directives [1]. The latter are expected to be finalized and be energized by the end of 2023.

The maritime transport could be considered among the pioneers in the Global decarbonization efforts via the corresponding resolutions of the International Maritime Organization (IMO). Since 2010 its Marine Environment Protection Committee (MEPC) has released a long series of resolutions in an attempt to drastically reduce the environmental footprint of almost all sea-going vessels. Electrification of several systems installed onboard, including propulsion, energy harvesting, power transmission etc. appear to be favorable solutions to this notable end.

Moreover, as ships tend to contribute to atmospheric pollution not only during sailing but also while at berth in ports, electrification has been considered as a most appealing means towards decarbonization. Thus, the so-called Shore-Side Electricity (SSE) interconnection often met as Alternative Maritime Power (AMP), Cold Ironing (CI) or Onshore Power Supply (OPS), refers to the electrification of a ship while the latter is at berth within the port at full operating mode and not at a docking stage [2]. More specifically, when the ship lays in a port, the onboard generator sets are shut down, therefore the switchboard is connected with the shore grid which covers all her power demands [3].

As summarized in the following, this measure has multiple benefits, not only as climate consequences, but also when thinking about the quality of life in the port nearby. To give a short list, it is possible to observe: i) the port and the city around it are relieved from the atmospheric pollution provoked due to ship emissions, ii) the noise in the port area due to the operation of ship generators is reduced to a significant extent, iii) the electricity supplied by the inland grid can be generated from Renewable Energy Sources (RES), then minimizing environmental adverse impact. By focusing on the important benefits here expressed, SSE interconnection is thus favorably promoted while starting to extensively implement it in a significant amount of ports around the world. Although from the standardization point of view, several guidelines already exist referring to both SSE [IEC, EMSA] and the ships, there are still several challenges that need to be further considered [4], [5].

This paper wants to highlight the importance that the SSE related information of all ships subject to cold ironing obligation is properly collected and recorded. This information is called "SSE-ID of the ship" herein after and includes critical electrical characteristic data of the ships some of which are strictly necessary. To give some examples, it is possible to enumerate operating voltage, frequency, power demands at berth etc, while some others like the synchronization procedure protocols are less mandatory. Anyhow, the efforts to introduce the SSE-ID ship card within the "Sustainable Maritime" Industry Connections Activity (ICA) are described, as well as the final result included in the set of proposed amendments of the standard IEEE 45.1 [6].

## II. The Challenges of the Shore-to-Ship Interconnection

As a matter of fact, cold ironing can greatly reduce the carbon footprint of marine transportation. Evidently, such an important result is ensured by a strong port electrification. The implementation of the beneficial green measure of SSE which transforms ports into sustainable energy hubs is a major challenge when considering the following aspects:

## A. Custom Design

Each ship is a custom design on her own. The design configuration of the ship, and, consequently, her power system including propulsion and service/auxiliary sub-systems, is strongly related to the mission and profile the ship owner has specified. The fact that the ship power system is an autonomous one, up to the mandatory implementation of the shore connection, no compatibilities were supposed to occur with other external systems, with the exception of maintenance procedures (e.g. dry-docking in shipyards).

The power demand of a ship at berth depends on its characteristics like size, type, operating profile, and may vary from hundreds of kW up to a few MW. Considering that a port hosts a random variety of ships, the estimation of the SSE demand is critical for the Port Authorities and also for all the energy-related Authorities operating in the area [7].

## B. Electrical Characteristics

As a consequence of the custom design, the nominal electrical characteristics of each ship can greatly vary among ships. For instance:

- the rated operating voltage can be 115 V, 380 V, 400V, 440 V, 690V, 1.1 kV, 3.3 kV, 4.17 kV, 6.6 kV 11 kV, 13.8 kV. Nowadays, the most frequently met nominal voltage values comprise 440V. Differently, 690 V is for Low Voltage systems while 6.6 kV or 11 kV for High Voltage systems;
- the nominal system frequency can be either 50 Hz or 60 Hz with the latter being the most frequently met;
- for fail safe purposes and in order to keep the network operating in case of short-circuit faults, the system earthing is either "ungrounded" (or IT system), or "High Resistance Grounded-HRG". Configurations, short-circuit withstand capabilities, nominal capacity of circuit breakers are important information in this regard.

On the other hand, it is worth noting that in inland grids, the nominal voltage and frequency could vary from those of the ships to a significant extent. As an example, the main characteristics of the low voltage distribution networks of different geographical areas, as highlighted in Fig. 1, are:

- most countries in Europe, Africa, Oceania and few in South America operate their grids at 220-240 V/50 Hz;
- in the continent of America most countries operate at 100-127 V/60 Hz. The same also in South Arabia;
- few countries in South America, Asia and Oceania operate at 220-240 V/60 Hz;
- Japan operates at 100-127 V/50 Hz.

Last but not least, it is noted that in almost all continental grids, the so called "Low Resistance Grounding – LRG" is implemented regarding the earthing scheme. Taking into account the various mismatches between the ship and the inland grids and the fact that a port hosts different types of ships with various characteristics, the implementation of shore-to-ship interconnection in each port is a project with a series of challenges that need to be appropriately addressed.

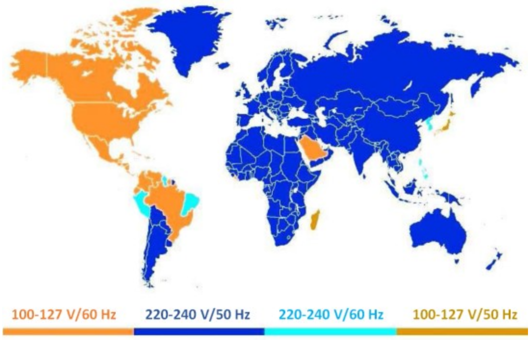


Fig. 1. Worldwide operating voltage (line-to-ground) and frequency.

# III. Standards and Guidelines

Although from the standardization point of view, several guidelines already exist referring to both SSE [IEC, EMSA]

## A. The SSE configuration

Taking into account the aforementioned incompatibilities between the shore and the ship grid technical characteristics, the SSE interconnection comprises at least three distinct sub-systems [8], as you can see in Fig. 2:

- the shore side part consisting of a power transformer (matching the voltage of the shore with that ship), a frequency converter (matching the corresponding differences in operating frequencies) and an isolation transformer (of Dye connection with an earthing resistor) used to match the different grounding schemes (the shore and the ship ones);
- the ship side part consisting mainly of the switchboard, where the interconnection plugs are connected. The switchboard is also used to temporarily synchronize the ship generator sets with the shore grid so that a black-out does not take place;
- the actual interconnection interface between the ship and the shore, i.e. a sophisticated cable management system. The interconnection cables comprise one or more 3-phase flexible power cables along with a flexible cable connecting the earthing resistor of the isolation transformer with the common earthing point on the ship's hull.

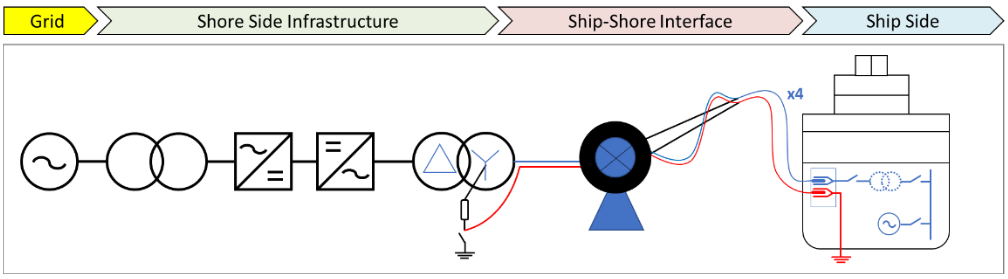


Fig. 2. Typical SSE configuration (adapted from [8])

*B. Standards for SSE interfaces 80005 series*

The SSE interconnection is recommended to comply with IEC/ISO/IEEE 80005 series of standards on "Utility Connections in Port", which is a result of a joined effort among the three standardization bodies IEC, ISO and IEEE and their Joint Working Group, namely JWG 28. There are three Parts of this standard:

- Part 1: High Voltage Shore Connection (HVSC) systems – General requirements [9]
- Part 2: High and low voltage shore connection systems – Data communication for monitoring and control [10]
- Part 3: Low Voltage Shore Connection systems – General requirements [11]

Taking into consideration the current trends to make mandatory the SSE at least in the ports of the main transport corridors, the *JWG28* keeps updating and amending the existing versions e.g. by adding specifications for new ship types while developing new sections, in particular for DC interconnections [12].

It also worth mentioning that the interconnection plugs and sockers must comply with IEC 62613, Part 1 [13] and Part 2 [14]

*C. Standards for ship electrical installations*

Concerning ship electrical installations, IEC has released a number of standards, the most important of which are collected in the IEC 60092 "Electrical installation in ships" series, as follows:

- Part 201: System design – General. [15]
- Part 202: system design – Protection. [16]
- Part 301: Equipment – Generators and motors. [17]
- Part 501: Special features – Electric propulsion plant. [18]
- Part 503: Ship special features – AC supply systems with voltages in the range of above 1 kV up to and including 36 kV. [19]
- Part 504: Automation control and instrumentation [20]

The main reference for the calculation of short-circuit currents is the standard IEC 61363 "Electrical installations of ships and mobile and fixed offshore units. Part 1: Procedures for calculating short-circuit currents in three-phase a.c."[21]

In addition, there are some IEC standards not dedicated to ship networks, but strongly related to the nature of the circuits already discussed, namely:

- IEC 60502-2 on power cables [22]
- IEC 60947-5-1 on the low voltage switchgear [23]
- IEC 61936-1 on the power installations exceeding 1 kV ac [24]
- IEC 62271-200 focused on high voltage switchgear and control-gear [25]
- IEC 60146-11-2 on semiconductor converters [26]
- IEC 60332-1-2 that reports the tests on electric and optical fiber cables under fire conditions [27]
- IEC 60364-4-41 on LV electrical installations safety [28]

On the other hand, IEEE has elaborated the IEEE 45 series of standards with the general umbrella-title "Recommended Practice for Electrical Installations on Shipboard". The IEEE 45 series is subdivided in the following:

- IEEE 45.1: Design [29]
- IEEE 45.2: Control and Automation [30]
- IEEE 45.3: Systems Engineering [31]
- IEEE 45.4: Marine Sector & Mission Systems [32]
- IEEE 45.5: Safety Considerations [33]
- IEEE 45.6: Electrical Testing [34]
- IEEE 45.7: AC Switchboards [35]
- IEEE 45.8: Cable Systems 0

Furthermore, regarding SSE related issues, IEEE 45.1, in its current of version makes reference to "shore-to-ship interconnection" in a number of sections, which are enlisted below:

- Section 9.3 *"Shore connection"*
- Section 9.10.7 "*Shore connection boxes"*
- Section 22.2 "*Electric plant load analysis (EPLA)"*
- Section 25.7 *'Stray current protection'*
- Section B.1 *Operating conditions.*

Despite the great number of existing standards, there are certain topics interrelated to SSE that are not covered yet. Thus, among other, it would be good if certain pieces of electrically related information of each ship visiting a port is well known. This gap was identified within the framework of the "Sustainable Maritime" Industry Connections Activity, which is briefly outlined in the next section accompanied by the solution developed.

## IV. SUSTAINABLE MARITIME

The transportation of goods and people on ships is not only responsible of air pollution, but also it can largely increase the greenhouse gas production, with the consequent effect on climate change. Focusing on this criticality, the IEEE has realized, that the global maritime industry (comprising both ships and ports) is facing significant challenges in moving towards more sustainable operational practices to align with international sustainable development goals.

To this end, a new Industry Connections Activity entitled "Sustainable Maritime", No ICA-13-22 was officially launched in October 2022. In more detail, IEEE has a number of committees and programs associated with maritime technical issues, each working on specific topical areas in their respective domains. The goal of this Industry Connections activity is to bring together these areas of domain expertise and build a collaborative IEEE community of interest around maritime issues, and investigate opportunities for new standards, reports, events and thought leadership to support these ambitious goals of the maritime industry.

### A. Identified gaps in SSE standards

Within this context, several gaps and missing links in the maritime related technology chain have already been identified. Some of them are strongly related to SSE and are listed below. The topic a) is then described in more detail.

a) SSE related information of ships is not known.
b) SSE related information of ports is not known either.
c) SSE related investments in ports and the subsequent energy demands have not been foreseen by electric grid authorities (e.g. Distribution System Operators – DSO's etc).
d) SSE related energy transactions have not been included nor foreseen in the electric energy market.

### B. SSE related information of ships

When a ship is reaching a port, certain data must be exchanged between the ship and the Port authority so that the proper berthing location (in terms of voltage, frequency, power capacity, etc.) is selected.

It would be much better if the compatibility of the equipment onshore and onboard could be checked and verified beforehand, which would save time of the interconnection procedure and minimize the operation of ship engines in the port area (and consequently their emissions).

The missing SSE-related information outlined above gave the idea for the development of an electronic registry (a database) that would include critical information of each ship, like operating voltage, frequency as well as power demands at berth etc. In this way, each ship will be registered via her SSE ID card.

## V. THE SSE-ID CARD OF SHIPS

The contents of this SSE-ID have been discussed in depth within the IEEE 45.1 WG (preparing the amendment of IEEE 45.1). This section presents the results of this discussion.

### A. Attached information on ID card

The SSE-ID card of the ship should accompany her IMO No. To guarantee the correct recognition of each ship, the card should contain the quantities for each identification symbols in the following:

1) rated voltage, symbol [$V$];
2) rated frequency, symbol [$f$];
3) range of power demands at berth, particularly:
   - average active, reactive, apparent power and power factor, whose symbols are [$P_{ave}$, $Q_{ave}$, $S_{ave}$, $pf_{ave}$];
   - maximum active, reactive, apparent power, represented by symbols [$P_{max}$, $Q_{max}$, $S_{max}$];

It is worth noting that typically this kind of information must be available via the Electric Power Load Analysis (EPLA). However, it is strongly recommended that the values behind each symbol are confirmed at least by the ship personnel or an independent authority (e.g. a surveyor or an auditor). Additional pieces of information are also useful as they facilitate the interconnection procedure:

4) levels of harmonic distortion
   - average value of voltage THD (<5%);
   - maximum value of voltage THD (<5%);
   - average value of current THD;
   - maximum value of current THD;
5) levels of equipotential bonding potential;
6) touch voltage (must be less than 30 V);
7) (online) ground check monitoring system availability;
8) Short-circuit current values calculated according to IEC 61363 (including contribution of generators and induction motors) must be available and compatible with IEC/ISO/IEEE 80005 prescriptions (max permissible current and corresponding interval e.g. 20 kA for 1s);
9) existence of HRG on each generator of the ship or on the generator used to be synchronized with the shore side;
10) capacity of ship-side circuit breaker (bus-tie):
    - making capacity, symbol [$I_p$];
    - breaking capacity, symbol [$I_{sc}(t=T/2)$];
11) position of the shore-connection switchboard (starboard/port side);
12) maximum cable length required (this means the cable from SSE hatch to the switchboard);
13) synchronization procedure between ship and shore:
    - via temporary black-out;
    - automatic synchronization;
      - f-P control;
      - V-Q control;
    - manual synchronization
      - f-P control;
      - V-Q control;
14) load flexibility (demand side management): the ship will be able to adjust to some extent its load demands contributing, in this way to the demand response of the entire port:
    - Load shedding system;
    - Preferential tripping.

| SSE ID CARD | | |
|---|---|---|
| **Ship IMO No** | | |
| **Ship name** | | |
| **Ship type** | | |
| **Rated voltage** | | |
| **Rated frequency** | | |
| **Power demand at berth** | Active Power [MW] | Power Factor |
| Average | | |
| Maximum | | |
| Frequency converter onboard | | |
| **Harmonic Distortion** | THD [%] | Max IHD [%] (order) |
| Voltage | | |
| Current | | |
| **3-phase short-circuit current** | Peak [kA] | Steady state [kA] |
| At the shore connection switchboard (according to IEC 61363) | | |
| **Earth fault (single-phase-to-ground)** | | Steady state [kA] |
| At the shore connection switchboard (according to ________________) | | |
| **Existence of High Resistance Grounding (HRG)** | [yes/no] (one answer only) | |
| On each generator separately | | |
| On the common generator busbar | | |
| On the sole gen. used for synch. with shore | | |
| **Capacity of ship-side circuit breaker** | [kA] | |
| Rated making capacity | | |
| Rated breaking capacity (@T/2) | | |
| **Position of shore connection cubicle** | [yes/no] | Cable length [m] |
| Starboard | | |
| Port | | |
| **Synchronization procedure** | [yes/no] | |
| Via black-out | | |
| Automatic synchronization | | |
| f-P control mechanism | | |
| V-Q control mechanism | | |
| Manual synchronization | | |
| f-P control mechanism | | |
| V-Q control mechanism | | |
| **Demand flexibility** | [yes/no] | |
| Load shedding | | |
| Preferential tripping | | |
| Demand response | | |

Fig. 3 Indicative format of the SSE-ID card

### B. ID card template

An indicative example of the form of this SSE-ID card is shown in Fig. 3. The SSE-ID of each ship is to be filled in only once (e.g. after the corresponding SSE retrofitting in case of an existing ship or at the virgin trip in case of new builds). The info is to be registered in a proper electronic database which can be accessed by authorized personnel of port authorities, ship owners, classification societies etc. When the SSE-ID card is completely filled, the efficient terrestrial powering of ships is possible. Partial information can only facilitate the interconnection, without any warranty on the final aim.

### C. Pilot implementation

The result of the work (SSE-ID card) as presented herein has been tested on a pilot basis for cruise ships visiting the port of Piraeus, Greece, within the framework of CIPORT research project (full title : Cold Ironing in the Port of Piraeus - Taking the Final step) co-financed by the European Climate Infrastructure and Environment Executive Agency (CINEA), project code No: 2020-EL-TM-0062-S. The testing interval was the hot season of the touristic period of 2022, but it is planned to be repeated within 2023. Some of the preliminary results are summarized below:

- All cruise ships (of medium size and above) operate at 60 Hz (mostly due to the fact that the rotating machinery is of smaller dimensions)
- The operating voltage of all cruise ships (of medium size and above) is 6.6 kV and mostly 11 kV
- A significant amount of cruise ships have already installed or planned to install SSE switchboards. However, only a limited number of cruise ships can take the SSE cable from both the port and the starboard side.
- The power demands at berth of all cruise ships rarely exceed 11 MW. This can be attributed to the energy saving initiatives undertaken by most cruise ship owners including for instance installation of LED lighting, Power electronic converters supplying the electric driven rotary equipment, energy saving devices in galleys, energy harvesting and waste heat recovery units

The aforementioned data has enabled a more thorough conceptual design of the distribution network supplying the SSE facilities within the port of Piraeus, but also the expansion plan of the (sole) Distribution System Operator of Greece, HEDNO. Thus, the peak power demands of the entire cruise ship terminal based on the recorder traffic were estimated on a more accurate basis. More specifically, despite the rated capacity of the SSE equipment as stipulated in IEC/ISO/IEEE 80005-1, [9], i.e. that of 16 (or even better 20) MVA for each ship, the long term load forecasting of HEDNO used a lower average peak power demand of the cruise terminal. Thus, it can be seen that the SSE-ID card can help not only to the short term load forecasting of the power demands in a port terminal etc but it can assist to the long term load forecasting of DSO's and the development of their Grid Expansion Plan.

## VI. CONCLUSIONS

This paper has discussed about the importance of the shore-side electricity (SSE) related information for all ships subject to cold ironing obligation. This technology is expected to increase its application taking into account the more cogent requirements for navigation in the Sustainable Maritime Framework. This information on ships is to be registered for later ensuring the necessary analysis for the correct powering, while it can be even further useful. Within this context, a corresponding identification card format the "SSE-ID of the ship" is introduced and presented, as it has been incorporated in the set of proposed amendments of the IEEE 45.1 Std.

## ACKNOWLEDGMENT

The financial support of the European Climate Infrastructure and Environment Executive Agency (CINEA) to the project CIPORT (full title: Cold Ironing in the Port of Piraeus - Taking the Final step, project code No: 2020-EL-TM-0062-S) is gratefully acknowledged. The authors wish, also to thank the chairman of IEEE 45.1 WG, Dr Norbert Doerry for the substantial support in forming the final draft of the under development amended version of IEEE 45.1.

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