Development, features and prospects of application of AMP / cold ironing marine power systems

A V Ignatenko, D V Migel, G V Deruzhinsky, N A Kravchenko

Admiral Ushakov Maritime State University, 93 Lenin Ave., Novorossiysk, 353924, Russian Federation

E-mail: iscander@hotmail.co.uk

Abstract. The evolution and current state of the technology for supplying ships from the shore under high voltage - alternative power from the shore (APS), known as “Alternative Maritime Power® (AMP®), cold ironing (CI) and high voltage shore connection (HVSC) are described. The structure of the system and existing methods of implementation, mandatory components, depending on the system version are considered. The need for national adaptations of the international versions, the unification of existing technical solutions and their development trends, taking into account high-voltage technologies is emphasized. Advantages and challenges of environmental impacts, expected phased tightening of environmental regulations, including the maritime legislation (the MARPOL convention), as well as promising initiatives in the context of global decarbonization trends are described. The need to take into account purposes and cargo capacity and regions of operation of ships, to develop the port infrastructure, and make clean electricity available is emphasized.

1. Introduction
Since the entry into force of MARPOL Annex VI, the requirements aimed at reducing air emissions from ships have been tightening. On January 1, 2020, the requirements of the UN International Maritime Organization on the global sulfur content in marine fuel up to 0.5%, and in areas with emission control - with a limit of up to 0.1% came into force [1]. The shipowners should choose between fuels with lower sulfur content, install an additional exhaust gas filtration system, or use alternative fuels such as natural gas, oil gas, ammonia, biofuels, etc. Each of these alternatives implies the need to use new technologies and increases the associated costs, taking into account a number of factors - readiness of the world fleet to implement technical solutions, the cost of fuels and their availability, the infrastructure of bunkering bases, safety [2]. Along with these alternatives, there is a joint technical solution for ships and ports, whose equipment allows the ship to be supplied with power from the shore in volumes adequate to the needs of the ship's technological complex when using its technological complex. Both shipowners and port authorities are interested in using the Alternative Maritime Power (AMP), the terms Cold Ironing (CI) and High Voltage Shore Connection (HVSC).

2. Problem statement
In 1989, the port of Gothenburg equipped the terminal for servicing ferries with an onshore feeding system. In the ports of North America, the power supply system was first applied in 1991 in Pittsburgh.
(California, USA). The Pohang Iron and Steel Company (POSCO) installed an onshore ship power system. At the same time, four bulk carriers plying between South Korea and San Francisco began to use shore power for cargo operations.

The AMP / CI idea proposed by Stora Enso committed to being green. The offer was approved in Gothenburg. A special partnership was established between Colbelfret and Wagenborg Shipping and ASEA Brown Boveri (ABB). Part of the funds were allocated by the Swedish government. In January 2001, the first successful use of a new high-voltage connection of the ship’s power grid with the coastal grid was recorded. It prevented harmful emissions and decreased the level of noise and vibration during the ship stay in the port.

In 2002, five Princess cruise ships, each requiring about 7MW of power while docked in port, were upgraded to use the AMP technology at the ports of Juneau, Alaska and Long Beach. In 2004, the sixth Princess Cruise vessel using the AMP technology was built, taking into account the power of 9 MW.

The German port Lubeck is in the process of agreeing on technical requirements for onshore power supply in the Baltic ports. Lübeck also plans to implement an onshore electricity project for ferry and passenger terminals. The main goal is to reduce SO\textsubscript{2} emissions in winter. The port plans to use electricity from wind generators, and is developing an extensive plan for supplying ships from shore under the Baltic 21 Plan, covering all port cities in the Baltic [3].

3. **Structures of AMP systems and layout options, taking into account port peculiarities**

At present, two standards for supply voltage from the shore of the AMP technology have been adopted - 11 kV and 6.6 kV [4], while the frequency and voltage of the ship network are not decisive: the coastal power supply complex and equipment of the ship electric power system provide the transformation and compliance with voltage and frequency compliance requirements.

There are four main ways to place power and conversion equipment:

- on a barge;
- at the berth;
- stationary on board;
- semi-stationary on board.

The barge is used when it is not possible to place the equipment at the berth. The idea of using barges evolved into the use of “floating generators”. Such vessels can supply the required power to the berth, while using natural gas. The use of such sources can overcome several problems:

- lack of required power in the electrical network supplying the port;
- lack of space for placing additional equipment at the port;
- improvement of the environmental friendliness of the power generation process (in comparison with oil fuels).

A typical scheme of the ship power supply from the shore using the AMP technology is shown in Figure 1. Onshore substation 1 is connected to high-voltage network 5. The frequency of the current depends on the norms applied in a country. To connect to power plant of ship 2 at berth 3, cable 2 is used. The cable section is reduced due to the use of high voltage. The current frequency and voltage in network 6 may differ from the parameters of the onshore network. For frequency matching, converters, including semiconductor frequency converters, including rectifier 10 and inverter 12 stages, connected by direct current link 11, are used. The voltage of most existing transport ships is 440V, while transformers 7 will be used to match the voltages.

To perform technological processes, the transition to shore power should be carried out without interruption in the power supply, for which the coastal network is synchronized with the ship, where only one generator 8 remains in operation. Its load is represented by powerful technological electric drives 9 and other consumers 15. They are protected against abnormal modes (e.g., short circuit) using automatic circuit breakers 13 in the coastal network and automatic breakers 14 in the ship’s network.
Placing equipment at the berth is the most common method. The main emphasis of manufacturers is placed on the improvement of berthing facilities, as well as their compatibility with ship equipment, and maximum automation of the process. The number of personnel has been minimized: the procedure is performed by one person of the ship electrical personnel.

If it is not possible to mount the switching equipment on the berth, it is placed on board during cargo operations. There is an option to install the cable reel separately and in a container. Figure 2 shows a variant of the system in a "semi-stationary on board" configuration [5]. The container with equipment 2 is installed on board in the port for the duration of cargo operations. Using high-voltage cable 1, it is connected to the connector on the quay. The container module is connected to main switchboard 6 through the shore power connection panel 3.

Depending on the parameters of the ship network, the voltage value is either reduced by means of transformer 4, or remains unchanged and supplied directly through high-voltage connection 5. The development of this idea led to the development of container-type generators using natural gas.

4. Current application of the AMP technology in the world
Despite the ongoing debate about economic feasibility, the use of AMP is growing dynamically. The port of Los Angeles and potential shippers are using the AMP for new ships. Since 2006, the ports of Los Angeles and Long Beach have implemented the project intended to improve the environment, including by the use of AMP technology.
Figure 3 shows the dynamics of growth in the number of container ships at the port of Los Angeles, during which the transition to shore power was carried out, while the 80% milestone was originally planned to be overcome in 2020, and the project was implemented in 2018 [7,8].

The concept of development of European ports reflects the need for the technology and reinforces the requirement according to which by the end of 2025 all European ports must provide the technical capability of high-voltage power supply to ships. This is one of the milestones in reducing greenhouse gas emissions by 2050. The transport sector emits about a quarter of all greenhouse gases in Europe; by 2050 the goal is to reduce the emissions by 60%. Natural gas does not solve the problem of CO₂ emissions, reducing them by only by 20%. Therefore, despite the small share of emissions, the use of electricity from renewable sources looks promising. The Long Beach and Los Angeles ports are examples of US ports connected to the national power grid. In these ports, electricity is generated by coal-fired power plants, which raises the issue of environmental friendliness of the project. However, California authorities are only tightening the rules: all new vessels should be phased in with shore-powered equipment in the coming years. By 2029, the tanker fleet should meet these requirements.

In major Chinese ports such as the Waigaoqiao cruise terminal in Shanghai and the Shenzhen port, electricity is generated by national thermal power plants, which also leaves significant potential for greening by using electricity from alternative and renewable sources. The port of Shenzhen was connected to the Hong Kong city network, where the possibility of consuming electricity received from the wind park was realized. Power Hong Kong Limited and Hong Kong Electric Company provide this option when distributing electricity with a capacity of up to 720 MVA at a voltage of 34.5 kV[9]. More and more research aimed to ensure zero emissions from ports is being conducted; a combination of AMP technology and alternative energy sources is promising [10, 11]. The port of Baku plans to use the AMP using renewable energy [12]. The Port of Seattle is powered by government-owned hydroelectric power plants, which significantly reduce the cost of electricity for shipowners.

The economic efficiency of the AMP technology has remained controversial: the main capital investments are associated with the installation of equipment, while a decrease in shipowner's costs is directly related to the cheapness of “onshore electricity”. However, when calculating the payback of projects, one should take into account significant penalties for environmental pollution and various incentive programs. Thus, the port of Long Beach exempts incoming ships from port dues if a number of conditions are met. One of them is the connection of Cold Ironing, but there are sanctions for emissions into the atmosphere. California law provides for a fine of $ 1,000 to $ 75,000 for each pollution incident, and there is a concept of “multiple casualties,” whose number is set by the authorities, and simple calculations suggest that the amount of fines can be catastrophic for the shipowner.

As of 2017, the AMP technology has already been used in more than twenty-five ports whose list is presented in Table 1, and in 2020 the number of ports was 66 [13], which is shown in Figure 4.
Table 1. AMP application in world ports in 2017

| Application year | Port name  | Country | Application year | Port name       | Country  |
|------------------|------------|---------|------------------|-----------------|----------|
| 2000             | Gothenburg | Sweden  | 2010             | Karlskrono Ve    | Sweden   |
|                  |            |         |                  | rko              |          |
| 2000             | Zeebrugge  | Belgium | 2010             | Amsterdam       | Netherlands |
| 2001             | Juneau     | USA     | 2011             | Long Beach      | USA      |
| 2004             | Los Angeles| USA     | 2011             | Oslo            | Norway   |
| 2005             | Seattle    | USA     | 2011             | Prince Rupert   | Canada   |
| 2006             | Kemi       | Finland | 2012             | Rotterdam       | Netherlands |
| 2006             | Kotka      | Finland | 2012             | Auckland        | USA      |
| 2006             | Oulu       | Finland | 2012             | Ystad           | Sweden   |
| 2006             | Stockholm  | Sweden  | 2012             | Helsinki        | Finland  |
| 2008             | Antwerp    | Belgium | 2013             | Trelleborg      | Sweden   |
| 2008             | Lubeck     | Germany | 2014             | Riga            | Latvia   |
| 2009             | Vancouver  | Canada  | 2015             | Bergen          | Norway   |
| 2010             | San Diego  | USA     | 2015             | Hamburg         | Germany  |
| 2010             | San Francisco | USA  | 2015             | Civitavecchia   | Italy    |

Figure 4. AMP Application in World Ports in 2020.

4. Prospects and problems of application of AMP technology in the ports of Russia

Taking into account the increasing involvement of the Russian Federation in the global sustainable development, the use of this technology is relevant [14].

For example, in the Vostok Oil project, 200-300 billion rubles should be allocated for the generation and distribution of about 2.5 GW of electricity. It would be logical to apply the technology of feeding ships from the shore. Transferring the capacities of the port of St. Petersburg to Ust-Luga with the aim to transfer part of the capacities to the port of Lavna in Murmansk region, it is also of interest. Lavna is the northernmost non-freezing port of the Russian Federation suitable for traffic along the Northern Sea Route. The use of the technology in the Arctic region is promising to reduce the environmental load from shipping.

Offshore feeding of foreign ships is also of interest in terms of electricity exports. The port of Vanino is a promising platform for implementing the technology at the design stage. In the near future,
some of the terminals of NCSP can use “green” electricity from wind generators, and the use of AMP is a logical step towards the development of the port.

The additional reduction in CO$_2$ emissions is a significant contribution to the transport industry, since the transition to NGF is not the final solution to achieving zero emissions.

The vessel traffic control system in a modern Russian port makes it possible to track vessels and planned operations on-line, and the main purpose of this monitoring is to ensure safety of maritime navigation. Typical information includes such data as the number in the register of the International Maritime Organization, main dimensions, deadweight, ports from which the vessel proceeded and to which the vessel sailed, the nature of operations in the ports of Novorossiysk. The authors obtained two sets of statistical data. Table 2 shows information on the movement of ships in the Novorossiysk Bay from the Spardeck system (www.spardeck.ru) [15].

| Year | 2017 | 2018 | 2019 | 2020 | 2021 (upto June 30) |
|------|------|------|------|------|---------------------|
| Number of records in the Spardek system | 5675 | 5490 | 5252 | 5375 | 2700 |

The second data set was compiled according to the data of one of the operators of container terminals - Novorossiysk Nodal Freight Forwarding Enterprise: from 01.01.2018 to 31.12.2018, 345 calls of container ships moored to berth 39 were registered (Table 3).

| Year | Less than 101 meters | 101 – 150 meters | 151 – 200 meters | > 200 meters |
|------|----------------------|------------------|------------------|-------------|
| Length of the container carrier | 63 | 54 | 161 | 67 |

Information on the size of ships, power of the main and auxiliary power plant, and the staying time can be provided. This serves as the basis for calculating emissions (and their potential reduction), the required capacity of the AMP system for each vessel and terminals taking into account the mooring of vessels, determining the capacity deficit at the terminal and the need for infrastructure development.

The authors of the State Maritime University named after Admiral F.F. Ushakov are interacting with the Government of the Russian Federation with the aim to implement the technology in the ports of Russia. The technology implementation process sets the following tasks:

• selection of a supply voltage standard or readiness for any accepted standards;
• selection of designated terminals for receiving ships equipped with the AMP system;
• reliability of the onshore power supply system, power quality and availability of “clean electricity”;
• in terms of design and operational requirements, it seems necessary to revise the current standards, add new ones;

• in the current scenario, when the term "import substitution" is relevant, it will be useful to analyze existing foreign technical solutions and develop own ones taking into account the existing experience;

A separate large-scale task is the spread of technology to the sea shelf of the Russian Federation, taking into account different conditions - the distance and capacity of offshore infrastructure facilities will require different technical solutions.

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