Survey of High Voltage Shore Connection
Analiza visokonaponskog priključka s kopna

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Abstract

Shipping is a significant source of pollution in the modern world. In ports, during berthing, activities such as loading, unloading, and hospitality operations rely on auxiliary engines. The combustion of marine fuels during these activities significantly contributes to air pollution. This pollution can spread up to 400 km around the port area. Naturally, the consequences include environmental damage near ports, respiratory issues, and an overall negative impact on human health. Globally, ship emissions account for 3% of CO_2, 15% of NO_x, and 6% of SO_x emissions. These gases have a key impact on human health and the environment. Pollution also depends on the type of fuel that ships use and the size of the ship. Oceangoing ships are major polluters, but they are not always in port. Therefore, pollution in the port depends on all the ships that are in the ports. Tugs that direct ships entering and leaving the port contribute greatly to port air pollution. Marine vessels have been required to use cleaner fuels (MARPOL Annex VI). Shore power connection can reduce the negative impact of ship activities in the port environment. A significant number of international documents regulates this area. Most of them emphasize the importance of shore power connections as a potential solution to environmental problems. We must preserve the planet for future generations as well as ensure continuity maritime activities. The problem is that the infrastructure in small ports is weaker in comparison with large ports, so introducing a high voltage shore connection is challenging.

KEY WORDS
shore power connection
greenhouse gas emission
environmental protection

Sažetak

Pomorski promet predstavlja značajan izvor onečišćenja u modernom svijetu. U lukama, tijekom pristajanja, aktivnosti poput ukrcaja, iskrcaja i ugostiteljskih usluga ovise o pomoćnim motorima. Sagorijevanje brodskih goriva tijekom navedenih aktivnosti značajno doprinosi zagađenju zraka. Ovo zagađenje može se širiti do 400 km oko područja luke, uzrokujući štetu na okolišu u neposrednoj blizini luka, respiratorne probleme i općenito negativan utjecaj na ljudsko zdravlje. Na globalnoj razini, emisije brodova čine 3% emisija CO_2, 15% emisija NO_x i 6% emisija SO_x. Ovi plinovi imaju ozbiljan utjecaj na ljudsko zdravlje i okoliš. Zagađenje također ovisi o vrsti goriva kojim se brodovi koriste i veličini brodova. Brodovi na otvorenome moru glavni su zagađivači, ali nisu stalno prisutni u luci. Stoga zagađenje u luci ovisi o svim brodovima koji se u njoj nalaze. Tegljači koji usmjeravaju brodove koji ulaze i izlaze iz luke značajno doprinose zagađenju zraka u luci. Plovila su obvezna koristiti se čišćim gorivima (MARPOL Prilog VI). Priključak s kopna može smanjiti negativan utjecaj brodskih aktivnosti na okoliš u luci. Značajan broj međunarodnih dokumenata regulira ovo područje te ih većina naglašava važnost priključka s kopna kao potencijalno rješenje ekoloških problema. Moramo očuvati planet za buduće generacije i istovremeno osigurati kontinuitet pomorskih aktivnosti. Nedostatak je nerazvijenost infrastrukture u malim lukama za razliku od velikih pa uvođenje visokonaponskog priključka s kopna predstavlja veći izazov.

KLJUČNE RIJEČI
priključak s kopna
emisija stakleničkih plinova
zaštita okoliša

1. INTRODUCTION AND MOTIVATION / *Uvod i motivacija*

Traffic and electricity production are the major cause of greenhouse gas (GHG) emissions into the Earth's atmosphere. A large number of ships use fossil fuels for propulsion. Newer ships run using electric propulsion system, but the generators that produce electricity on-board run on fossil fuels (such as diesel). The use of fossil fuels greatly contributes to the total emission of carbon dioxide, thereby affecting global

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warming, climate changes and air pollution. The shore power connection can have a positive effect on GHG emission in the atmosphere, the reduction of noise and vibrations, and the preservation of clean air at ports. It is a proven technology for 20 years [1].

Ships come to ports for different needs, therefore cargo ships load or unload cargo, or load fuel, cruise ships visit ports depending on what kind of trips they organize, load fuel, etc. While the ships are in port, their drive is running because of the constant electricity supply. If it is possible to connect to a shore power connection, the CO_2 emission into the surrounding air is reduced. Since emissions from ships are a major contributor to global GHG emissions (3% of global CO_2, 15% of global NO_x, and 6% of global SO_x emissions), every shutdown of the ship's engine contributes to cleaner air in the port. The air pollution is released 400 km around the port area [2].

The problem of GHG emissions has been gaining more attention in the past few decades. Environmental pollution has become one of the main problems. In addition to water, special attention is paid to the cleanliness of the air. Maritime transport is the fifth responsible for total GHG emissions. In addition, the number of ships is constantly increasing, which means that emissions from ships are constantly increasing. The complexity of climate change policy for the international maritime transport sector requires that a wide range of considerations be taken into account that require policy makers [3].

That is why it is important to write about this topic. The concern for the environment and the planet Earth should be one of the basic concerns of humanity. Environmental protection and care have become a part of all parts of life.

The advantages of using shore power connection are highlighted in some recent works. An additional advantage is the case when the electricity that supplies such a connection is produced from renewable energy sources, at least in a significant percentage [4, 5].

Paper [6] provides an overview of shore connection technology. The paper highlights the advantages of using shore connection from the point of view of the environment and the reduction of harmful emissions, but also raises the question of economic profitability and the implementation of such systems in a large number of ports.

Paper [7] specifically deals with the implementation of the HVSC system in Croatian ports. The question of investment in the infrastructure of the electric power system arises. Projects require significant financial resources that can be secured if they are operated at the local, regional, national and international level. The optimal synergy between stakeholders is necessary to achieve the projects goals [7].

Paper [8] deals with regulations and standards related to the use and safe implementation of the HVSC system. These are actions that carry significant risks due to the involvement of high voltage. Therefore, it is necessary to determine in advance the steps that must be followed when using the HVSC system. Process diagrams for key operational phases, based on IEC/IEEE 80005-1 specifications and evaluation criteria are presented. The part of IEC/IEEE 80005 describes high-voltage shore connection (HVSC) systems, onboard the ship and on shore, to supply the ship with electrical power from shore. This document is applicable to the design, installation and testing of HVSC systems. These recommendations are general.

A special topic related to the installation of HVSC connections is ensuring the safety of these connections. This is addressed in the paper [9].

Additional requirements may be set by the national administration, the port authority or the body that owns the ship or the owners or bodies responsible for the operation or distribution system [10, 11].

IRCLASS has issued guidelines for the use of HVSC 2020, outlining the requirements that must be met when designing the system, the necessary equipment for its use, and additional requirements that apply to different types of ships [12].

American Bureau of Shipping releases guide for the design and operation of high voltage shore connection [13]. It addresses connections of 6.6 kV and 11 kV because these are the high voltage values most often used on standard ships [14].

2. SHORE POWER CONNECTION / *Priključak s kopna*

Shore power connection is, as the name suggests, the electrical connection of the ship to the land connection.

Sources for the electricity production on ships are mostly fossil fuels. It is known that this method of electricity production causes emissions of greenhouse gases into the atmosphere and air pollution. The idea, which was implemented for the first time in the world in 2000, was to connect the ship to the land electrical connection. In such a case, the electricity generators on the ship are turned off while the ship is in port [15, 16, 17, 18].

Ships are major consumers of electricity, and electrical power is directly proportional to voltage. Higher power corresponds to higher voltage. Therefore, shore connections are always high-voltage shore connections.

High voltage shore connection (HVSC) is also called Cold Ironing or Alternative Marine Power (AMP). The ship's power system operates at a frequency of 60 Hz. In countries where the power system operates at 50 Hz, a frequency converter is mandatory, which is part of the HVSC. Pulse Width Modulation (PWM) has a high-power factor and good quality of electric energy, so it is the best choice [19].

When the ship arrives in the port and moors, it connects to the HVSC. The main switchboard is linked to the shore connection, allowing the ship's generators to be turned off. This reduces the emission of greenhouse gases into the atmosphere. Figure 1 provides a graphic representation of the connection [15].

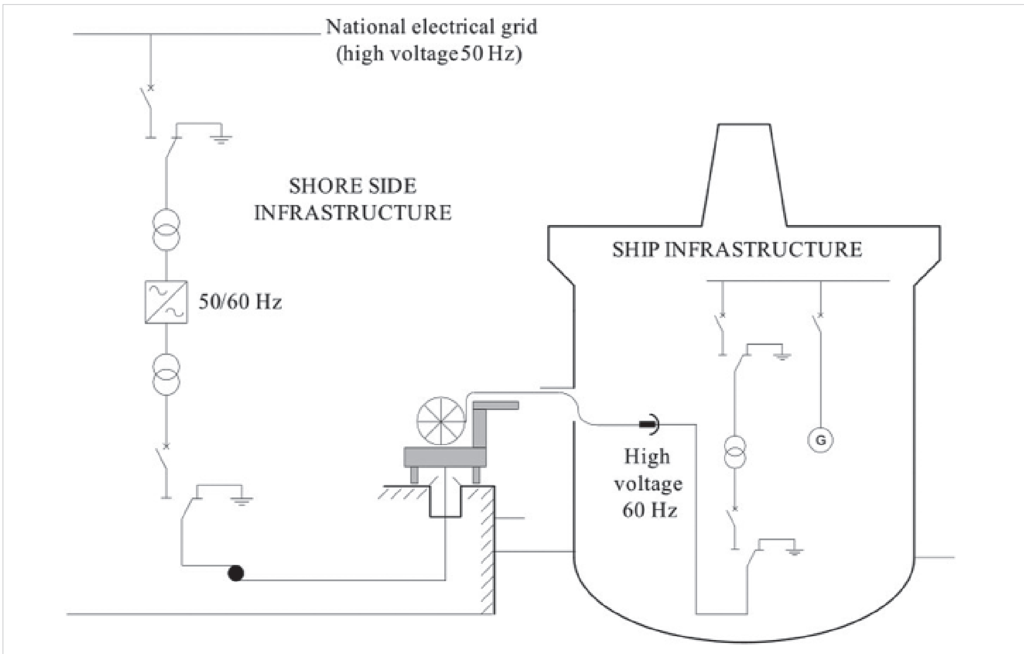

Figure 1 High Voltage Shore Power Connection [15]
Slika 1. Visokonaponski priključak s kopna

3. SHORE POWER CONNECTION ADVANTAGES THROUGH EXAMPLES / *Prednosti priključka s kopna na primjerima*

There are several more than good reasons for the increasing implementation of the HVSC system in more ports. One of the first Shore Power Connection system is implemented in the port of Göteborg in 2001 [16].

The EU Directive 2005/33/EC requires the use of expensive marine gas with a low sulfur content. The average price of marine gas oil is over 1000 US$/ MT, and it has continuous rising trend [17]. It is not economically profitable.

A Shore Power Connection has been installed at the Port of Vancouver. When the ship arrives in the port, it can connect to the HVSC and turn off its diesel engines. Since the electric power network is characterized as low-carbon (it has a large number of hydroelectric power plants), the emission of GHG into the surrounding air is reduced. The engine noise and vibrations are reduced, too. It has been calculated that, thanks to HVSC connections, more than 30,000 tons of greenhouse gas emissions have been prevented until today [18, 20].

Although the first HVSC system was installed in the year 2000, following installations took place somewhat later.

The third system in the world, and the first in Canada, is the HVSC system in the Port of Vancouver, which was installed in 2009. The first system was installed in its Canada Place cruise terminal, and the second two additional terminals, the Centerm and Deltaport container terminals until today [20].

The Port Authority implements the Eco Action Program, which offers a 75% discount on harbour dues to ships that use the shore power connection. This encourages ships that are more quiet and more environmentally friendly to their port.

Arguments against shore-based electricity supply are related to the origin of shore-based electricity, the cost of infrastructure investment, and issues of safety and efficiency of port operations. Studies have shown that switching from marine diesel power generation to shore-based coal-fired

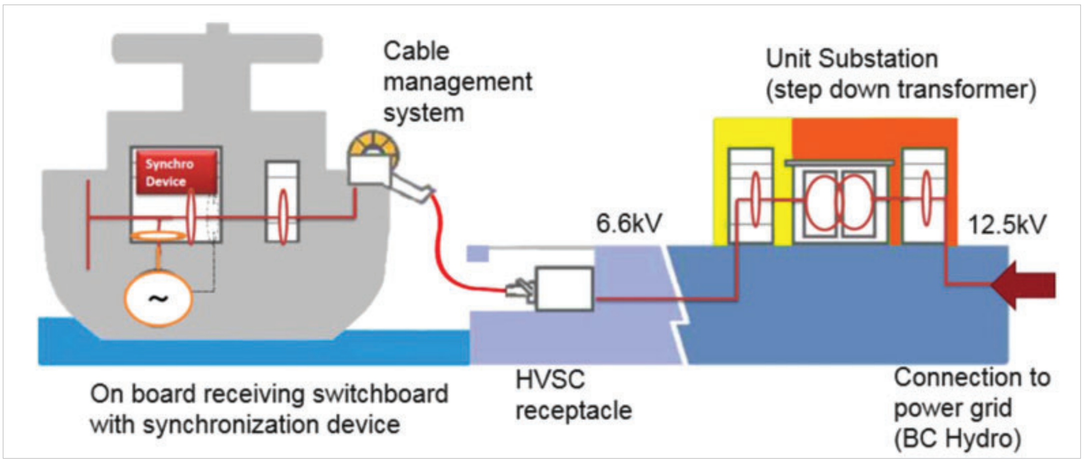

Figure 2 High Voltage Shore Power Connection [20]
Slika 2. Visokonaponski priključak s kopna

power has negligible environmental benefits (with an increase in particulates and, potentially, sulphur oxides). With any other type of power supply, the benefits are considerable, for example renewable energy sources, especially improve the environmental footprint of port operations [21, 22].

Most of today's new cruise ships have a 6600 V electrical network. The generators of such ships have a power of up to 6.5MW. This is not a small amount of power, and such a quantity must be supplied through the shore power connection. The required amount of electricity must be produced in the land network, as well as brought to the port through transmission lines. Producing the necessary electricity is one challenge, while an additional, and sometimes greater, challenge lies in the power lines and the entire required infrastructure. An additional problem arises, especially for small and medium-sized ports, when more than one cruise ship requests an electrical a shore-power connection simultaneously.

4. THE HVSC CONFIGURATIONS / *Konfiguracije visokonaponskog priključka s kopna*

There are three different shore power connection configurations that can be applied in ports. In all three configurations, there is a transformer located on each side of the connection due to necessity as well as safety. Schemes of all three configurations are shown in Figure 3.

If the voltage of the land network does not have the amount required by the ship's network, the transformer will convert it to the required amount. By means of a transformer at that point in the system, galvanic separation was achieved between electrical shore network and ship electrical system. Also, the possibility of failure is reduced. In addition, if a fault occurs on the shore electrical network, the ship's electrical network can be protected [21, 23].

The first configuration is called Frequency converter placed on the link. A scheme of that configuration is shown in Figure 3, a). It is most similar to the configuration recommended by the European Union. This high voltage connection system is decentralized.

As can be seen from Figure 3, a separate radial power supply of the frequency converter is placed on each connection. The frequency converter and the transformer on the armature jointly form a sine curve. Therefore, an additional transformer is needed to shape the voltage required for the frequency converter. Since the voltage decreases, the number of current increases, which is neither desirable nor acceptable because of the high heat that can be generated, which results in high losses. For this reason, another step-down transformer is needed (which can be seen in Figure 3, a)). The frequency converter must be dimensioned according to the highest power that can appear in the system [21, 23].

The second configuration is called Central inverter(s). The scheme of that configuration is shown in Figure 3, b). A frequency conversion installation with a suitable double bus switchgear is centrally located. Further, the system was developed according to the needs of a certain port or ship. One or more frequency converters are connected in parallel. A step-down transformer must be installed in front of the converter, and a step-up transformer behind it. Also, it is necessary to enable parallel powering ships at frequencies of 50 Hz and 60 Hz. For this reason, an additional bus is integrated, which is

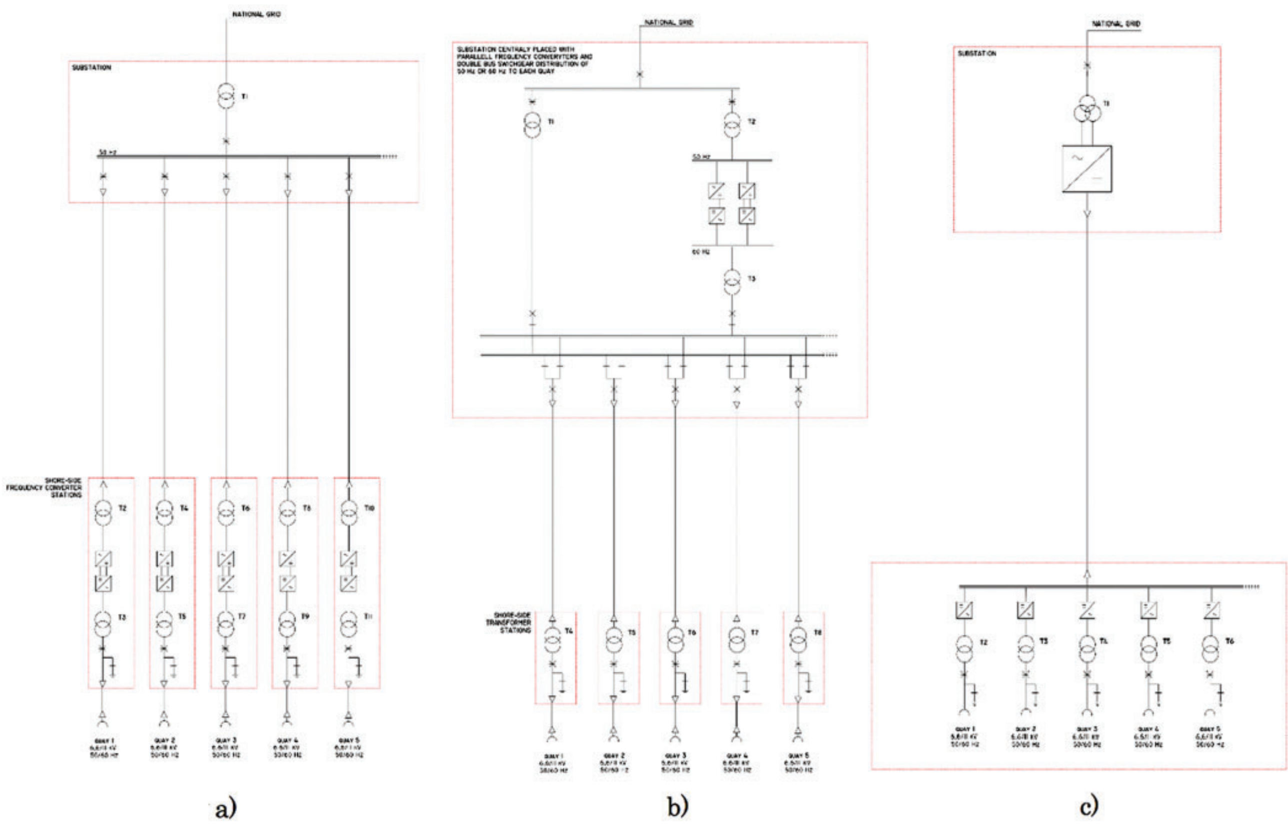

Figure 3 Three Configurations: a) Frequency converter placed on the link, b) Central inverter(s), c) DC distribution [23]
Slika 3. Tri konfiguracije: a) frekventni pretvarač postavljen na mreži, b) centralni inverter, c) DC distribucija

directly connected to the power grid via a transformer. Each link is connected to the central bus through the switch. An individual sub can be turned on and off, depending on the current need, using a switch. The advantage of this configuration is that the role of the frequency converter is only its basic role, frequency conversion from 50 Hz to 60 Hz [21, 23].

The third configuration is called DC distribution. The scheme of DC distribution is shown in Figure 3, c). The basic characteristic of this configuration is that it works on direct voltage. The rectifier is centrally placed. It changes alternating voltage (AC – alternating current) to direct voltage (DC – direct current). The DC voltage is then distributed via the DC bus.

Depending on the needs of the ship, a bus with the required frequency is chosen. The specificity of this configuration is the power transmission in one direction only. It is similar to a high-voltage direct current lighting plant. The advantage of this configuration is the reduction of cable losses [21, 23].

5. ENVIRONMENTAL IMPACTS / *Utjecaji na okoliš*

There are several good reasons for proposing to connect the ship to shore power connections.

There are positive reactions and feedback from ports where HVSC systems have been implemented. The port of Göteborg, where the HVSC was installed in 2001, is taken for example. More than 20 years have passed, which is a sufficient time frame for an appropriate and realistic assessment [16].

It has already been mentioned that emissions from maritime transport contribute 3% of total emissions. Some estimates put this percentage even higher, ranging from 3% to 5% today, and by 2050 it will amount to 15%. Air pollution is affected by many factors. If air pollution occurs, it is important what the current weather conditions are, how the wind is blowing, what currents are in that part of the atmosphere, whether there is humidity or precipitation. It is also important how close the sensitive area is to the polluted site. It can be concluded that air pollution from the sea has a smaller impact on human health and the environment than pollution from land. But this is not always true. There are too many external factors that are currently changing for such a statement to be made [21, 24, 25, 26].

Polluted air can travel hundreds of kilometres. This is especially true for sulphur and nitrogen compounds. Ships have the lowest GHG emissions far from land, when they are just sailing. Near land, and in ports, they perform their specific activities. Almost 70% of emissions from shipping are emitted in an area no more than 400 km from the coast. Coastal areas of the Earth are therefore particularly exposed to air pollution. In port cities, the air quality is generally very poor, and the main reason for this is gas emissions from ships. Many ships still use fuel oil with a high sulphur content for economic reasons because it is not expensive. In some countries, the use of fuel oil has been banned and reduced, but not in all. It is important to emphasize, in order to understand the problem, that the sulphur content of standard marine fuel is 2700 times higher than the sulphur content of ordinary diesel used in cars [21, 26, 27, 28].

The use of heavy fuel oil in ships is responsible for emissions of various gases such as:

- Fine particles
- Carbon monoxide (CO)
- Carbon dioxide (CO_2)
- Nitrogen oxides, NO_X (NO and NO_2)
- Sulphur dioxide (SO_2)
- Volatile organic compounds (benzene, toluene, ethyl benzene, and xylene, a volatile aromatic compound commonly found in gasoline and diesel fuel).

Also, the number of emissions of harmful gases and substances into the air produced by marine engines is directly related to the total consumption of heavy fuel oil, which also depends on various factors: mainly the shape of the hull, load conditions and engine operating conditions [21, 26, 27, 28].

Here is an example for Dubrovnik region, in Dubrovnik – Neretva County. There is a Pre-Feasibility Study for Dubrovnik Port Authority where there are explanations of the advantages and disadvantages of HVSC in Dubrovnik Port [29]. A simple calculation of GHG emissions reduction in case of having HVSC in Dubrovnik Port is presented. Most of the energy power plants are low carbon emissions in Dubrovnik – Neretva County (wind power turbines, hydro power plants, solar panels etc.). Diesel engine has a specific CO_2 emission 266,5 gCO_2/kWh [30]. Dubrovnik – Neretva County electricity grid has hydropower (80%), wind generator (10%) and solar power (10%) which are total specific CO_2 emission of 24 gCO_2/kWh [31, 32]. That leads to cutting emissions for 242 gCO_2 per 1kWh of produced energy.

The positive impact on the environment is unquestionable when talking about HVSC connections.

Another topic is the price of such connections, the need to upgrade the existing electrical energy systems, the need to build new power plants for the production of electricity, etc. [29]. In Dubrovnik, the necessary investment in the electricity network infrastructure would be in the millions of euros. This raises the question of the profitability of such systems in small ports. On the other hand, the issue of preserving air quality and the environment is of crucial importance for life. It is necessary to carefully evaluate the importance of preserving the environment and invest additional efforts in making decisions that will positively affect the quality of life of future generations.

The Republic of Croatia has a very specific geopolitical position. It borders two EU member states and 3 other countries, and has access to the sea. On the map of Europe, Croatia has the possibility to become a hub for trade in energy products and other goods that are transported by sea. Apart from the port of Rijeka, which is a commercial hub, the ports of Split and Dubrovnik are interesting for cruise ships traveling the Adriatic Sea. For this reason, high air pollution can be expected in the vicinity of the mentioned ports in the future. The European Union (EU) Directive prescribes (for now advises) the introduction of HVSC to protect air quality in the future [33].

6. STANDARDS / *Standardi*

The International Maritime Organization (IMO) is an organization that issues, laws and recommendations related to the safe work of seafarers, safe navigation, as well as the impact of ships and maritime traffic on the environment, sea, and air. MSC.1/Circ.1675, the Interim guidelines on the safe operation shore power supply service in port for ships engaged on international voyages is released by IMO in June 2023 [34]. Shore power supply is known by a variety of names: Onshore Power Supply (OPS), "Alternative Maritime Power (AMP)", "Cold Ironing", "Shoreside Electricity" and "On-shore Power Supply". Wherever HVSC connection has been introduced, GHG emissions into the surrounding air have been reduced, air quality in the port and surrounding cities has improved, noise and vibration levels have been reduced, and thus people's lives have improved both on ships and in the surrounding areas. The international standard "ISO/IEC/IEEE 80005-1:2012 Utility connections in port – Part 1: High Voltage Shore Connection (HVSC) Systems – General requirements" was published on 13 July 2012 and addresses the connection between ship and shore and the procedures for safe operation. This standard revises "IEC/PAS 60092-510:2009 Electrical installations in ships – Special features – High Voltage Shore Connection Systems (HVSC-Systems)" [33, 35].

7. CONCLUSION / *Zaključak*

High Voltage Shore Connection is a great solution for bigger ports.

It is the most favorable from the point of view of environmental protection, GHG gas emissions in the atmosphere, and reducing noise and vibrations in ports. All that is positive both for the staff working on the ships and for the passengers on the ships (if they are cruise ships), as well as for the people who live and work near large ports where such ships dock.

Also, it is important to emphasize that HVSC systems are excellent for ports that are connected to a power system that can handle these large additional demands for electricity, as well as for systems in which electricity is obtained from so-called green energy sources.

On the other hand, the need to introduce an HVSC connection can be an incentive for some medium or smaller ports to upgrade their power system. It can be a stimulus for the entire region to develop and turn to renewable energy sources, to build additional plants for the production of electricity that do not emit large amounts of GHG gases into the atmosphere, etc. It has to be acknowledged that all relevant decisions related to investments depend on the public opinion in the local community, and above all political will to implement long term changes that will contribute to sustainable port management.

High voltage brings with it some additional handling hazards. The process of switching the ship`s network from the ship's generators to the shore connection must be carried out very carefully and following the rules for handling high voltage. The first step was taken because certain maritime associations created guidelines for the use of high-voltage connections. These guidelines are in accordance with all international safety standards. The next step would be to introduce legal regulations for the use of HVSC.

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