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PRIMJENA VISOKONAPONSKIH KOPNENIH PRIKLJUČAKA U HRVATSKIM LUKAMA

HIGH VOLTAGE SHORE CONNECTION IMPLEMENTATION IN CROATIAN PORTS

SAŽETAK

Stroge ekološke norme i rast cijena goriva promiču upotrebu visokonaponskih kopnenih priključaka. Ta relativno nova tehnologija postaje sve atraktivnija brodovlasnicima, jer pruža ekonomski isplativu alternativu trošenju propisanog skupog goriva s niskim udjelom sumpora u brodskim električnim centralama za vrijeme boravka u lukama Europske unije i posebno nadziranim područjima ispuštanja plinova. Mogućnost implementacije ove tehnologije u Republici Hrvatskoj analizirana je korištenjem dostupnih statističkih podataka i razvojnih planova na primjerima luka Rijeka i Dubrovnik. Procijenjena je maksimalna potrebna snaga po priključku od 15 MVA za luku Dubrovnik i 7,5 MVA za luku Rijeka. Analiza je pokazala da se u hrvatskim lukama, ponajviše zbog nužnosti primjene pretvarača frekvencije i nedovoljnih kapaciteta postojećih napojnih vodova, mogu očekivati relativno visoki troškovi implementacije. Kako bi se odredila ekonomska isplativost takve investicije, neophodno je uzeti u obzir i posredne troškove koji predstavljaju vrijednost štete pričinjene lokalnoj zajednici zbog emisija štetnih tvari s brodova, za što je potrebno pripremiti registar brodskih emisija te odrediti njihov udio u odnosu na ostale izvore prema preporukama Europske okolišne agencije.

Ključne riječi: *visoki napon, kopneni priključak, luka, onečišćenje, ekologija*

SUMMARY

Strict environmental regulations and increasing fuel oil price encourage the use of High Voltage Shore Connection, also referred to as Cold Ironing. It is becoming very attractive to the ship owners, offering an alternative for burning expensive low sulphur fuel in the European Community and Emission Control areas ports. The possibility of High Voltage Shore Connection implementation in Croatian ports is analysed on the example of Dubrovnik and Rijeka, using the available data from port statistics and development plans. The required power per berth is determined to be 15 MVA in Dubrovnik and 7.5 MVA in Rijeka. Due to the requirement for frequency converters and insufficient capacity of the existing power supply lines in the harbours, relatively high implementation costs can be expected. To determine the justifiability of High Voltage Shore Connection installation, external costs, which present a monetary equivalent of the harm done to the local community by ship emissions, has to be known. Therefore, it is necessary to implement proper pollutant measurement techniques in harbour areas, in order to determine the share of ship emissions in national emission inventory in accordance with the recommendations of the European Environment Agency.

Key Words: *high voltage shore connection, cold ironing, ship, port, pollution, ecology*

1. UVOD

Međunarodne morske luke i putnički terminali imaju važnu ulogu u svjetskom transportu robe i ljudi. Oko 90 % ukupne svjetske trgovinske razmjene ostvaruje se putem usluga međunarodnih brodarskih kompanija i prateće pomorske infrastrukture. Tijekom posljednja dva desetljeća prisutan je značajan rast ukupne tonaže tereta koji se prevozi morskim putem (8 milijardi tona 2009., u usporedbi s 4 milijarde tona 1990. godine) uz očekivano udvostručenje do 2020. godine [1], pa se od luka očekuje proširenje postojećih kapaciteta kako bi se mogle nositi s rastućim zahtjevima brodara za skladištenje i prekrcaj tereta. Unatoč neospornoj važnosti za gospodarstva obalnih država, proširenje lučkih kapaciteta i povećanje prometa također imaju i značajni negativni utjecaj na okoliš, povećavajući rizik od sudara, ispuštanja nafte i ulja, zagađenja zraka itd. [1] [2].

Luke su vrlo često dominantan izvor onečišćenja u obližnjim gradskim područjima te zajedno s drugim izvorima zagađenja, kao što su cestovni promet i okolna industrijska postrojenja, stvaraju kumulativan nepovoljan učinak na okoliš [3]. Tijekom boravka u luci, brodovi za proizvodnju električne energije potrebne za rad brodskih sustava koriste vlastite dizelske ili turbogeneratore. Uobičajen doprinos brodskih emisija štetnih tvari koncentraciji dušikovih oksida (NO_x) kreće se u granicama između 0,5 i 5 %, ali u područjima s relativno niskim pozadinskim zagađenjem može narasti i do 10 %. Relativni doprinos koncentraciji sumpornog dioksida (SO_2) je neznatno viši s istom prostornom raspodjelom [4].

Procijenjeno je da će do 2020. godine količina emisija štetnih tvari, povezanih s međunarodnim pomorskim prometom dužeuropskih obala dostići ili čak premašiti ukupnu količinu emisija kopnenih izvora [5]. Emitirane štetne tvari imaju izrazito negativan učinak na ljudsko zdravlje, usjeve i obalne ekosustave. Između 19 000 i 64 000 preuranjenih smrtnih slučajeva godišnje, većinom od raka pluća i kardiovaskularnih bolesti, povezano je s povećanom koncentracijom čestica iz brodskih ispušnih plinova [6] [7]. Povećane koncentracije SO_x i NO_x spojeva uzrokuju zakiseljenje obradivih površina, šuma i izvora pitke vode u područjima izloženim brodskim emisijama [4].

1 INTRODUCTION

International cargo and passenger ports have a major role in a worldwide transport of goods. Approximately 90% of the world trade is transported and handled by international shipping and port industry. During the past two decades, a huge growth in seaborne trade is present (8 billion tons in 2009 compared to 4 billion in 1990), and is estimated to double by 2020 [1]. It creates increased demands toward ports to expand their capacities and handle additional traffic. Despite its importance for the economies of the coastal countries, expanding port capacities and its throughput can also cause considerable negative effects for the environment, increasing the risk of collision, oil spill, air pollution, etc. [1][2].

Very often, ports are the dominant source of pollution in nearby urban areas, producing combined environmental effect with other emission sources, such as traffic and surrounding industrial plants [3]. While in port, ships use their diesel or turbine powered generators to produce energy required for hotel operations, cargo handling machinery, heeling pumps, cooling of cargo, etc. The contribution to nitrogen oxide (NO_x) concentration from port emissions is typically between 0.5 and 5 %, but it can be more than 10 % in areas with the low background pollution. Relative contributions for sulphur dioxide (SO_2) are slightly higher with the same spatial distribution [4].

It is estimated that the emissions related to international trade shipping along the European coastal areas will reach, or even exceed total emissions coming from on shore sources by 2020 [5]. These emissions have a pronounced effect on people's health, crops and coastal ecosystems. Between 19,000 and 64,000 premature mortality cases every year, mostly from lung cancer and cardiopulmonary diseases, are related to the increased concentrations of fine particulate matter (PM) coming from ship exhaust gasses [6] [7]. The ship related SO_x and NO_x emissions are also causing acidification of land, forests and fresh water sources in coastal countries [4].

In order to minimize the above mentioned effects and to ensure sustainable development of ports around the world, it is necessary to implement additional protective measures. One of the most effective methods for reducing emissions coming from ships in ports is the implementation of High Voltage Shore Connec-

Kako bi se minimizirali navedeni štetni učinci i osigurao održivi razvoj svjetskih luka, neophodno je provesti odgovarajuće mjere zaštite. Jedna od najučinkovitijih metoda za smanjenje količine emisija s brodova tijekom njihovog boravka u lukama je uvođenje visokonaponskih (VN) kopnenih priključaka. Osnovni zadatak ove tehnologije je omogućiti jednostavno i brzo spajanje brodske električne mreže na kopnenu bez prekida u napajanju brodskih sustava.[1]

Nakon što se brodski sustav sinkronizira na kopnenu mrežu, gase se svi brodski generatori čime prestaje i ispuštanje štetnih tvari. Brod se na kopnenu mrežu spaja pomoću visokonaponskog kabela s ugrađenom optičkom linijom putem koje se omogućuje komunikacija i prijenos podataka između brodske i kopnene infrastrukture. Upotreba visokog napona neophodna je kako bi se smanjila ukupna struja napajanja i omogućila lakša manipulacija kabelima. Sustav za upravljanje kabelima može biti smješten na brodu ili na lučkom terminalu, a mora omogućiti brzi uklop i isklop napajanja s kopna te biti potpuno siguran za posadu, putnike i lučko osoblje [8].

Složenost sustava VN kopnenih priključaka se vrlo često podcjenjuje. Među mnogim čimbenicima koji značajno otežavaju njihovu implementaciju treba svakako posebno izdvojiti različitost sustava distribucije električne energije u svijetu, ali i različitost naponskih razina na brodovima. Unatoč brojnim otegotnim okolnostima broj luka s uvedenim VN priključcima, posebice u Europi i duž zapadne obale Sjedinjenih Američkih Država kontinuirano se povećava.

Međunarodni standard za sustave VN kopnenih priključaka EC/ISO/IEEE 80005-1 prihvaćen je i potvrđen od najvažnijih pomorskih zemalja, te je službeno objavljen u kolovozu 2012. [9] [10], što će značajno pojednostaviti proces njihove implementacije kako za brodare, tako i za lučke operatore.

U ovome se radu analizira mogućnost i problematika uvođenja VN kopnenih priključaka u hrvatskim lukama sa stanovišta gospodarstva i stanovišta zaštite okoliša na primjerima luka Rijeka i Dubrovnik. Ove luke odabrane su zbog jasno definiranih razvojnih planova i činjenice

[1] Treba naglasiti da se visoki napon koji se ovdje spominje (1 – 15 kV) odnosi na pomorske tehnologije, dok je na kopnu to srednjonaponska razina.

tion (HVSC), also referred to as Cold Ironing or Alternate Marine Power.[1]

The aim of this technology is to allow the connection of the ship's electrical system to the shore side electrical grid without any power supply interruptions. The use of high voltage is necessary in order to reduce the supply of current and to allow an easier cable manipulation. After the ship's system is synchronised to the land grid, all onboard generators can be stopped, thus reducing the emissions to almost zero. The ship is connected to the shore supply via special power cable with embedded fibre optic line for shore to ship communication. The cable management system, which can be located onboard ship or at the berthing terminal, should provide a fast connection and disconnection of the shore supply and be completely safe for the ship's crew and harbour personnel [8].

The complexity of High Voltage Shore Connection implementation is often underestimated. There are still many factors that make its implementation quite difficult. The most influential ones are different electrical systems around the world and a variety of voltages used onboard merchant ships. Despite those challenges, the number of ports with HVSC is increasing, especially in Europe and the USA West Coast.

International standards for high voltage shore connection systems IEC/ISO/IEEE 80005-1 is accepted and validated by main shipping countries and officially published in August 2012 [9][10]. It will provide firm rules for ship and port owners and certainly simplify the process of the HVSC implementation.

In this paper, challenges and opportunities for the HVSC implementation in Croatian ports is analysed, from the environmental and economic perspective on the examples of Rijeka and Dubrovnik. These ports have been selected because of the clearly defined development plans and the fact that the reconstruction and upgrade projects for both ports are in progress. Due to the unavailability of relevant data, the ports of Split, Ploče, Zadar and Šibenik are not taken into consideration so far.

[1] It should be emphasised that the high voltage mentioned here (1-15 kV) refers to marine technologies, while on the shore side electrical grid it is a medium voltage level.

da su projekti rekonstrukcije i nadogradnje obje luke u tijeku. Uslijed nedostupnosti relevantnih podataka, luke Split, Ploče, Zadar i Šibenik za sada nisu uzete u razmatranje.

2. ODREDBE O ZAŠTITI OKOLIŠA

Rezultati mnogobrojnih studija o utjecaju na okoliš provedenih tijekom posljednjeg desetljeća, prisilili su vlade i nadležne institucije da razmotre alternativne mehanizme i donesu odgovarajuće političke odluke usmjerene ka kontroli emisija štetnih tvari **s** brodova. Međunarodna pomorska organizacija (IMO) je 2008. godine revidirala i postrožila pravila o kontroli brodskih emisija definirana u Aneksu VI Međunarodne konvencije o sprječavanju onečišćenja s brodova (MARPOL). Izmijenjeni Aneks VI stupio je na snagu u srpnju 2010. i prihvaćen je od strane 53 države, koje pokrivaju 81,88% ukupne svjetske brodske tonaže [11].

U Aneksu VI definirana su dva različita skupa pravila: opća pravila i postrožena pravila koja se odnose na područja s posebnom kontrolom štetnih emisija (ECA – Emission Control Areas).

Dozvoljene granične vrijednosti za NO_x emisije donesene od strane IMO-a, poznati kao Tier I-III standardi, primjenjuju se na brodske dizelske motore, a propisane vrijednosti ovise o nominalnom broju okretaja motora (Tablica 1.). Tier III standardi odnose se samo na ECA područja.

U svrhu smanjenja emisija sumpornih oksida (SO_x), pravila iz Aneksa VI MARPOL konvencije nalažu ograničenje udjela sumpora u brodskom dizelskom gorivu koje se mora provesti u tri faze, a najkasnije do 2025. godine. Također, od siječnja 2010. godine, sukladno EU Direktivi 2005/33/EC, svi brodovi koji borave u lukama Europske unije (EU) moraju koristiti gorivo s ukupnim udjelom sumpora manjim od 0,1 %, (Tablica 2.). Ista Direktiva, međutim, kao alternativnu opciju preporučuje korištenje VN kopnenih priključaka [12].

Nakon studije o korisnim učincima upotrebe VN kopnenih priključaka na okoliš, Europska komisija izdala je preporuku za korištenje napajanja s kopna u lukama Europske unije (2006/339EC). Ta preporuka potiče države članice da razmotre mogućnost instalacije VN pri-

2 ENVIRONMENTAL REGULATIVE

The results of various environmental studies during the last decade have forced policy makers and relevant institutions to consider alternative policy mechanisms for the ship emissions control. In 2008, the International Maritime Organization (IMO) revised and tighten ship emission control rules defined in Annex VI of the International Convention on the Prevention of Air Pollution from Ships (MARPOL). The revised Annex VI entered into force on July 2010 and has been ratified by 53 countries, covering 81.88% of the global ship's tonnage [11].

Two different sets of rules are defined in Annex VI: global rules and more stringent rules for the emission control areas (ECA).

The NO_x emission limits set by the IMO are commonly referred to as Tier I-III standards. Those standards are applied to ship's diesel engines and their legislation values depend on the rated engine speed (table 1). Tier III standards are applied only for ECA.

In order to reduce the SO_x pollution, Annex VI regulations set limits on sulphur contents in marine fuel which has to be reduced in three stages, not later than 2025. In addition to this, from January 2010, the EU Directive 2005/33/EC requires that all ships at berth in European Community ports and on inland waterways should use fuel with less than 0.1% of sulphur content by mass (table. 2). The same directive allows the use of onshore power supply as an alternative option [12].

Furthermore, after studying the environmental benefits of using shore side power supply, the European Commission issued a recommendation on the promotion of using shore side electricity by ships at berth in European Community ports (2006/339EC). This recommendation encourages the member states to consider the installation of shore connections, especially in ports situated near residential areas, to promote the development of harmonised international standards for shore side electrical connection and to offer economic benefits to operators which use shore side electricity [13].

Tablica 1. TIER standardi za NO_x emisije
Table 1 *TIER standards for NO_x emissions*

		NO_x limit (g/kWh) depending on the engine speed		
	Date	n < 130 rpm	130 ≤ n < 2000 rpm	n ≥ 2000 rpm
Tier I	2000	17	$45 \cdot n^{-0.2}$	9.8
Tier II	2011	14,4	$44 \cdot n^{-0.23}$	7.7
Tier III (only for ECA)	2016	3,4	$9 \cdot n^{-0.2}$	1.96

Izvor / ***Source:*** *International Maritime Organization*

Tablica 2. Ograničenja udjela sumpora u brodskom gorivu
Table 2 *Sulphur limits for marine fuel*

Sulphur content limits for marine fuel (% by mass)					
IMO global limit		*IMO limit for ECA/SECA*		*European Community ports (Directive 2005/33/EC)*	
Effective from	*Limit*	*Effective from*	*Limit*	*Effective from*	*Limit*
2000.	*4.5 %*	*July 2010.*	*1 %*	*January 2010*	*0.1%*
January 2012.	*3.5%*	*January 2015.*	*0.1%*		
*January 2020.**	*0.5 %*				

* Alternativni datum je 2025. godine (ovisno o rezultatima procjena IMO-a 2018. godine)
* *Alternative date is 2025 (depending on the results of IMO assessment in 2018)*

Izvor / ***Source:*** *International Maritime Organization*

ključaka, poglavito u lukama koje su smještene blizu gusto naseljenih područja te da podrže razvoj ujednačenih međunarodnih standarda za kopnene električne priključke i daju poticajne ekonomske mjere operatorima koji koriste električnu energiju s kopna [13].

3. EKONOMSKI ČIMBENICI

Implementacija VN kopnenih priključaka zahtijeva znatne investicije i modifikacije na brodu i lučkoj infrastrukturi. Direktni troškovi uvođenja (unutarnji troškovi) ovise o više faktora od kojih su najutjecajniji frekvencija električne mreže, smještaj i veličina luke, dostupnost i kapacitet postojeće infrastrukture u njenoj blizini, ukupna instalirana snaga po priključku i vrsta broda.

Procijenjeni prosječni troškovi implementacije VN priključaka za kontejnerske terminale u lukama Europske unije kao rezultat ENTEC-ove studije 2005. godine prikazani su u tablici 3. [14]. Stvarni troškovi za teretne brodove kreću se u rasponu od 300 000 $ do 4 milijuna $, ovisno o smještaju luke, snazi priključka i vrsti broda. Neke od najnovijih studija pokazuju da troškovi implementacije za putničke brodove mogu doseći i 6 milijuna $ po vezu [15].

3 ECONOMIC FACTORS

The implementation of HVSC requires considerable investments and modifications, both on the port infrastructure and onboard ship. Direct implementation costs (internal costs) depend on several factors. The most influential are: operational frequency of supply network, port location and size, availability and capacity of the existing electrical infrastructure near the port, total installed power per berth and type of the ship.

The estimated average HVSC implementation costs for container terminals in the EU community ports, as a result of the early ENTEC study in 2005, are given in table 3 [14]. The actual costs for cargo ships may vary between \$300,000 and \$4M per berth, depending on the port location, power requirements and ship's type. Some of the recent studies indicate that the implementation costs for cruise ships can be as high as \$6M per berth [15].

When only the internal costs are considered, electricity from ashore is generally more expensive as compared to electricity generated onboard, but only if the ship's generators are running on a relatively cheap heavy fuel oil (HFO) [16].

Tablica 3. Procijenjeni prosječni troškovi implementacije VN kopnenih priključaka za kontejnerske terminale EU luka prema ENTEC-ovoj studiji iz 2005. godine
Table 3 *Estimated average implementation costs for HVSC at container terminals in the EU community ports according to the 2005 ENTEC study*

	Implementation costs per berth (€)			*Total annual costs per berth (€/per year)*		
	Ship size			*Ship size*		
	Small	*Medium*	*Large*	*Small*	*Medium*	*Large*
Low cost ports	*569,157*	*612,907*	*656,657*	*42,615*	*45,834*	*49,053*
High cost ports	*1,112,586*	*1,156,336*	*1,200,086*	*64,236*	*67,455*	*70,674*

Izvor / ***Source:*** Autori prema [14] / *Authors according to* [14]

Kada se u obzir uzmu samo unutarnji troškovi, električna energija s kopna je općenito skuplja od one koja je proizvedena na brodu, ali samo ako se za pogon pomoćnih motora koristi relativno jeftina teška nafta [16].

Studija ekonomske isplativosti VN kopnenih priključaka mora međutim obuhvatiti i tzv. vanjske troškove, koji predstavljaju novčani ekvivalent štete koju efekti brodskih emisija nanose društvu. Upotrebom napajanja s kopna, ti se troškovi mogu smanjiti za 15 do 75 puta [17].

Poseban fokus stavljen je na putničke terminale iz razloga što su oni obično locirani u neposrednoj blizini urbanih centara. Vanjski troškovi koji se povezuju s putničkim terminalima u Barceloni, Napulju i Pireju izračunati su u studiji o utjecaju putničkih brodova za kružna krstarenja, provedenoj 2009. godine za potrebe Europske komisije. Procijenjeni su troškovi od preko 35 milijuna € za Barcelonu, 23 milijuna € za Napulj i 19 milijuna € za Pirej [18].

Europska komisija prepoznala je negativne učinke brodskih emisija i potiče upotrebu VN kopnenih priključaka kroz Direktivu 2003/96/EG. Prema toj Direktivi upotreba VN kopnenih priključaka se subvencionira ukidanjem poreza na električnu energiju brodarima i lučkim operatorima koji koriste ovu tehnologiju. Ovisno o početnoj investiciji i godišnjim troškovima implementacije, VN kopneni priključci postaju ekonomski opravdani kada je cijena goriva veća od 600 do 1000 $ po metričkoj toni (MT) [14].

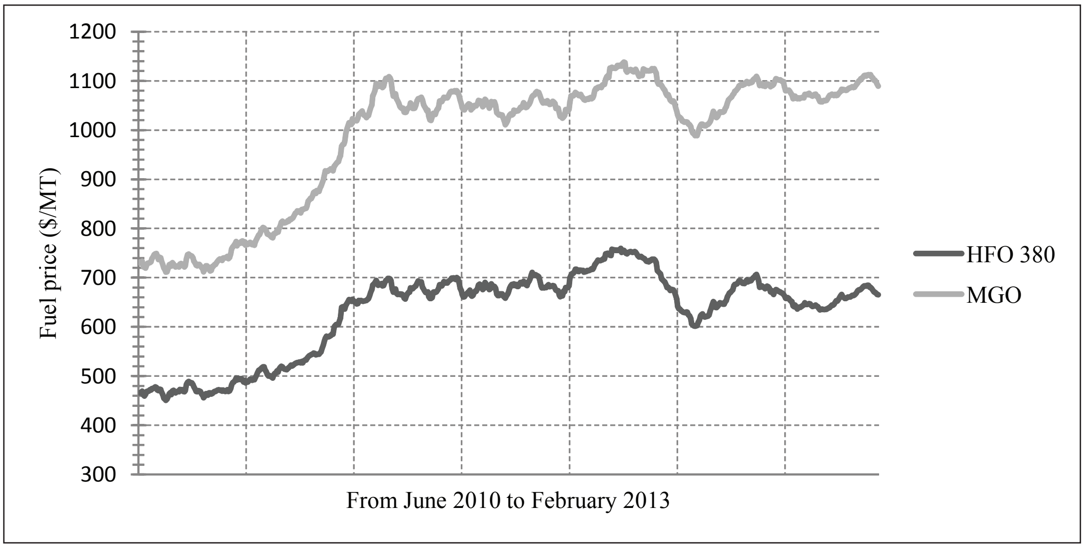
Dijagrami na slici 1 prikazuju prosjek cijena goriva u $/MT u glavnim svjetskim lukama koje pružaju uslugu dobave brodskog goriva [19]. Zbog zahtjeva Direktive 2005/33/EC, pri računanju troškova proizvodnje električne energije na brodu treba u obzir uzeti samo cijenu goriva

On the other hand, the economic feasibility study of HVSC must also include external costs which present a monetary equivalent of damage to the society by the effects of ship emissions. These costs can be 15 to 75 times lower when shore side electricity is used [17].

Special focus has been put to cruise ship terminals because they are usually located close to the city centres. External costs related to cruise ship emissions for the ports of Barcelona, Naples and Piraeus are calculated in the study on the cruise tourism made for the European Commission in 2009. Those costs are estimated to be over 35 million Euros per year, namely, for the port of Barcelona 23 million, for the port of Naples 23 million and 19 million for the port of Piraeus [18].

The European commission has recognized the negative impact of the ship emissions and has promoted the using the shore supply in ports through the directive 2003/96/EG. According to this directive, the use of shore side power supply is subsidized by the cancellation of electricity taxes for port operators and ship owners. Depending on the initial investment and annual costs, HVSC becomes economically justified when the price of the fuel is higher than $ 600-1000/MT [14].

Diagrams on figure 1 present the average of marine fuel prices in US Dollars per Metric Ton ($/MT), taken from the main bunkering ports around the globe [19]. Because of the requirements of the EU directive 2005/33/EC, when calculating the electricity production costs in the European Community ports, only the price of low sulphur marine gas oil (MGO) should be taken into account. It can be seen that HVSC has already become profitable in the EU ports, considering the current MGO prices.



Slika 1. Prosječne cijene brodskog goriva između lipnja 2010. i veljače 2013. godine
***Figure 1** Average prices of marine fuel oil between June 2010 and February 2013*

Izvor / *Source:* Autori prema [19] / *Authors according to* [19]

s niskim udjelom sumpora (MGO), što pokazuje da su VN priključci već postali isplativi u većini luka Europske unije.

4. PERSPEKTIVA UVOĐENJA VISOKONAPONSKIH KOPNENIH PRIKLJUČAKA U HRVATSKIM LUKAMA

Planiranje i implementacija VN kopnenih priključaka je dugotrajan proces. Kako je već spomenuto, prilično je teško odrediti isplativost investicije njihovog uvođenja u pojedinoj luci bez provedene opsežne studije koja obuhvaća unutarnje direktne troškove i troškove povezane s utjecajem brodskih emisija na stanovništvo i ekosustav. Unatoč skorom ulasku u EU (1. srpnja 2013.) još nema provedene takve studije za hrvatske luke.[2]

Uvođenjem VN priključaka, zahtjevi luke za električnom energijom višestruko se povećavaju, što za posljedicu ima značajan utjecaj na lokalnu električnu mrežu. Potrošnja nekoliko velikih brodova, poglavito brodova za kružna krstarenja i velikih kontejnerskih brodova, može doseći snagu prosječne termoelektrane. To znači da bi manje države s nekoliko većih

[2] Ovdje autori primarno misle na putnički terminal u Dubrovniku i budući kontejnerski terminal luke Rijeka, gdje su projekti rekonstrukcije u tijeku.

4 PERSPECTIVE OF HVSC INSTALLATIONS IN CROATIAN PORTS

The planning and implementation of HVSC is a long term process. As already mentioned, it is very hard to determine the justifiability of the HVSC installation for a particular port without comprehensive study that includes both the internal and the external costs. Despite Croatia's forthcoming entry into the EU on 1st July 2013 and large investments in the construction and expansion of port capacities, no such study has been made for its ports so far.[2]

With the HVSC, harbour power demands are multiplied, having a significant effect on the local electric grid. The consumption of few larger ships, particularly cruise liners and container ships, can reach the amount of power generated by an average power plant. It means that smaller countries with few large ports, as Croatia is, will probably have to make some changes in their energetic strategy in order to use the HVSC.

The port of Dubrovnik has a clear strategy to become one of the major cruise ships destinations in the Mediterranean. During the last decade, a strong positive trend in the number

[2] Here, the authors primarily refer to the cruise ship terminal in Dubrovnik and future container terminals in Rijeka where the reconstruction projects are in progress.

luka, u kakve spada i Republika Hrvatska, ukoliko bi se odlučile za uvođenje VN priključaka u svojim lukama, vjerojatno morale provesti odgovarajuće izmjene u svojoj energetskoj strategiji.

Luka Dubrovnik ima jasnu strategiju postati jedna od vodećih destinacija za kružna krstarenja na Mediteranu. Posljednjih nekoliko godina prisutan je izuzetno jak trend povećanja broja posjeta, kako na terminalu Gruž, tako i na vanjskom sidrištu. Da bi se udovoljilo potrebama za povećanjem broja vezova i prihvata putnika neophodno je izgraditi adekvatnu infrastrukturu. Projekt rekonstrukcije i nadogradnje operativne obale je u tijeku i ulazi u svoju završnu fazu, te bi prema sadašnjim planovima trebao biti završen do 2014. godine, kada će 1440 metara operativne obale s mogućnošću prihvata triju velikih brodova za kružna putovanja biti u funkciji [20]. Stoga bi maksimalno tri priključna mjesta za napajanje s kopna trebala biti dovoljna da pokriju potrebe za vrijeme vrhunca sezone kružnih putovanja.

Potrošnja električne energije putničkog broda za kružna krstarenja tijekom boravka u luci ovisno o vrsti i veličini broda, kreće se od 2 do 12 MW (Slika 2.) [15].

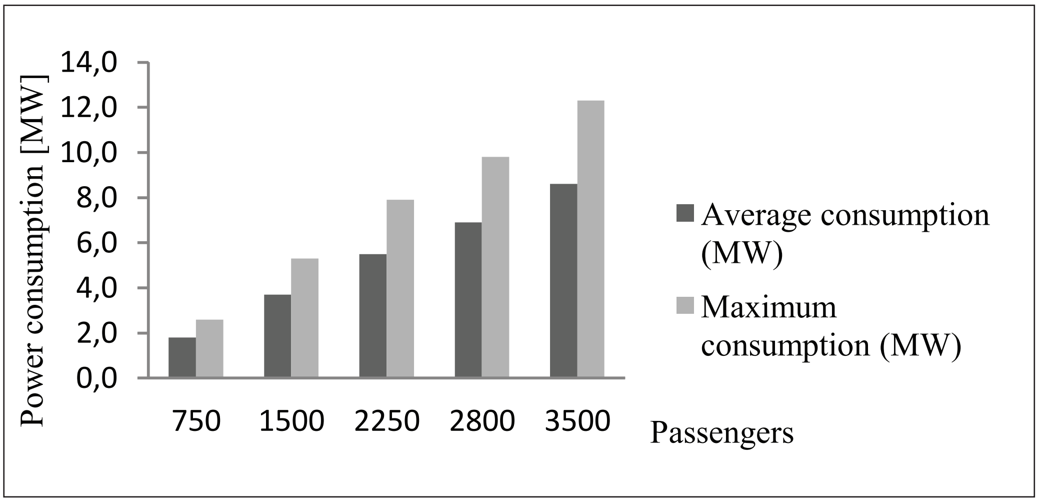
Kao primjer može poslužiti snimljeni dijagram potrošnje električne energije broda od 3100 putnika za vrijeme boravka u luci (Slika 3.). Iz slika 2. i 3. može se zaključiti da bi u luci Dubrovnik trebalo omogućiti 12 – 15 MVA

of cruise ship calls is present, both at the Gruž terminal and at anchorage. In order to meet the increased demands for docking capacity and passenger accommodation, it is necessary to build an adequate port infrastructure. The on-going project on the reconstruction and building of the operational quay is in the final stage and according to current plans it should be finalized by 2014, when 1440 meters of the operational quay capable for the accommodation of three large cruise ships will be in function [20]. Thus, a maximum of three shore supply connection points should be enough to cover the needs during the cruising season peek.

The consumption of cruise ships while in port can vary between 2-12 MW, depending on the ship's size and type (figure 2) [15].

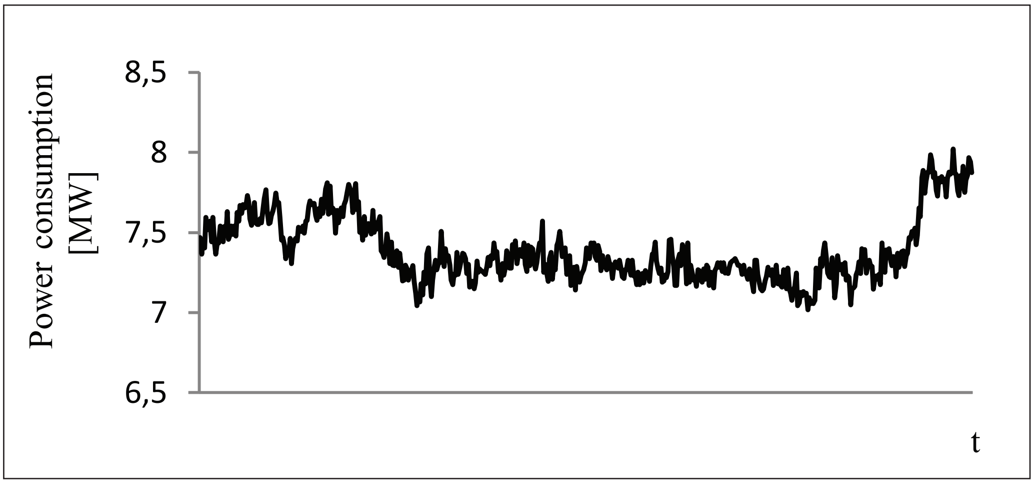
As an example, the recorded power trend of the 3100 passenger cruise ship during the stay in the port is shown on figure 3. From figures 2 and 3, it can be seen that the HVSC system in the port of Dubrovnik should be able to provide at least 12-15 MVA of continuous power per berth in order to satisfy the power requirements of the largest cruise ships visiting the port.

Rijeka, as the Croatian largest cargo port, has a great potential for increasing its cargo throughput, particularly in the container sector. The increase in the container handling capacity in Rijeka will be done in two phases as a part of the Rijeka Gateway project. By the end of 2012,



Slika 2. Potrošnja električne energije kruzera na vezu s obzirom na njihovu veličinu
Figure 2 *Consumption of cruise ships while in port, depending on the ship's size*

Izvor / ***Source:*** Autori prema [15] / *Authors according to* [15]



Slika 3. Dijagram snage kruzera kapaciteta 3100 putnika za vrijeme boravka u luci
Figure 3 *Power trend of the 3100 passenger cruise ship during port stay*

Izvor / ***Source:*** Autori / *Authors*

trajne snage po priključku, kako bi se zadovoljile energetske potrebe najvećih brodova (preko 3000 putnika).

S druge strane, Rijeka kao najveća hrvatska teretna luka ima veliki potencijal za povećanje ukupnog prometa, posebno u kontejnerskom sektoru. Povećanje kapaciteta prekrcaja kontejnera u riječkoj luci provest će se u dvije faze kao dio Rijeka Gateway projekta. U prvoj fazi će postojeći terminal Brajdica dobiti novih 300 metara operativne obale, dok se u drugoj fazi planira izgraditi novi kontejnerski terminal sa 680 metara operativne obale na zapadnoj strani riječkog bazena. Jednom završeni, svaki će terminal moći istovremeno primiti po dva velika kontejnerska broda [21] [22].

Uvođenje visokonaponskih priključaka zahtijevalo bi, dakle, na svakom terminalu po dva priključna mjesta kontinuirane snage od 6 do 7,5 MVA pri naponu od 6,6 kV, što su tipične vrijednosti VN priključaka na kontejnerskim terminalima u svijetu.

Gledano u svjetskim razmjerima, zbog frekvencije kopnene mreže od 50 Hz, hrvatske se luke može općenito klasificirati kao luke s visokim troškovima instalacije VN kopnenih priključaka. Kako se na velikoj većini brodova koristi frekvencija od 60 Hz, moraju se instalirati snažni i stoga vrlo skupi pretvarači frekvencije. Iz iskustva luka koje su već uvele VN kopnene priključke, cijena pretvarača frekvencije i transformatora predstavlja 50 – 65% ukupnih troškova implementacije. Pretvarači frekvencije

the existing container terminal Brajdica will get a new 300 meters wharf. The further increase in the capacity will be achieved by a new container terminal with a 680 meters wharf, located at the western part of the already existing port basin. Once completed, each terminal will be able to accommodate and serve two large container ships at the same time [21][22].

The implementation of the HVSC system in the port of Rijeka would require two connection points per wharf on both terminals. Each connection should provide between 6 and 7.5 MVA of continuous power at 6.6 kV, which is s typical power rating of the existing high voltage connections at container terminals around the world.

In general, Croatian ports can be classified as high cost ports in term of the HVSC installation. One of the main reasons for that is the operating frequency of the Croatian electrical grid, which is 50 Hz. Since the majority of onboard electrical systems are designed for 60 Hz, it dictates the use of expensive power frequency converters. Based on the experience from the ports where the HVSC is already implemented, the costs of frequency converters and transformers present 50-65% of the total implementation costs. Frequency converters should have a fast dynamic response and a minimal impact on the local electric grid, meaning a low harmonic distortion on the network side and a high power factor across the whole power range. In addition to, the quality of the electrical energy supplied to the ships at berth must be within trebali bi imati brz dinamički odziv te mali utjecaj na kvalitetu električne energije lokalne mreže, tj. mala harmonička izobličenja na strani mreže i visoki faktor snage na cijelom rasponu opterećenja. Pored toga, kvaliteta električne energije kojom se napaja brodski sustav mora zadovoljavati uvjete koje postavljaju klasifikacijska društva. Uzimajući u obzir spomenute činjenice, širinsko-impulsno modulirani (ŠIM) pretvarači s više naponskih razina predstavljaju najprimjerenije, ali ujedno i najskuplje rješenje.

Drugi, također vrlo važan faktor koji će sigurno imati utjecaja kod eventualnog uvođenja VN priključaka u hrvatskim lukama je mali prijenosni kapacitet postojećih napojnih vodova. Povećanje njihovog kapaciteta zahtijevat će znatne investicije u potrebnu infrastrukturu, a poglavito u nove vodove i lučke podstanice.

Kako bi se odredili vanjski troškovi zbog utjecaja brodskih emisija u hrvatskim lukama, neophodno je odrediti udio tih emisija u odnosu na ostale izvore (industriju i kopneni promet). Za to je posebno prikladna metoda *odozdo prema gore* (bottom-up method) koja se temelji na stvarnim operativnim podacima i omogućuje izračun emisija upotrebom specifičnih faktora emisija pridruženih pojedinom brodu ili tipu broda. Upotreba upravo te metode preporučuje se u tehničkim naputcima Europske okolišne agencije (European Environment Agency – EEA) kao temelj za pripremu nacionalnih inventara emisija [23]. To pak zahtijeva precizne baze podataka s tipovima i snagama brodskih motora i faktorima emisija za sve brodove koji posjećuju pojedinu luku. Mogu se, također, rabiti i druge metode, kao što su upotreba automatskog sustava za identifikaciju ili snimanje brodskih ispušnih plinova pomoću sustava baziranih na LIDAR tehnologiji [24] [25].

5. ZAKLJUČAK

Koristi od primjene VN kopnenih priključaka s gledišta ekonomije i zaštite okoliša, zajedno s pozitivnim povratnim informacijama koje dolaze od luka u kojim su već u upotrebi, doveli su do povećanog interesa za tu relativno novu tehnologiju. Luke koje nude mogućnost napajanja s kopna privlačnije su brodarima, pogotovo ako se radi o brodovima za kružna putovanja i velikim kontejnerskim brodovima koji posjećuju luke unutar EU i ECA područja, te predstavljaju dobro alternativu korištenju skupog

the limits set by the classification society rules. Considering the above-mentioned, multilevel pulse width modulated (PWM) converters with active front end present the best, but also the most expensive, solution for HVSC applications.

Other very important factor, that will certainly have a considerable impact on the HVSC implementation costs, common for Croatian ports, is a small capacity of the already existing harbour power supply lines. The increase in the supply capacity will require a considerable investment into the required infrastructure, particularly into new power lines and harbour substations.

For the estimation of external costs caused by ship emissions from Croatian ports, it is necessary to determine the share of the ships emissions within the total emissions coming from the transportation sector and industrial sources. The bottom-up method which is based on actual operational data and allows the calculation of emissions by using the ship's specific emission factors for each operating mode is particularly applicable for that purpose. The use of that method is recommended by the European Environmental Agency (EEA) technical guidelines for preparing national emissions inventories [23]. It requires a precise data base with the engine type and load, and emission factors for each ship visiting a particular port. Other methods, such as the use of the Automatic Identification System (AIS) data and the LIDAR monitoring of the ship exhaust gases can be used as well[24][25].

5 CONCLUSION

Economic and environmental benefits, together with a positive feedback coming from ports that already use the HVSC, lead to an increased interest in this rather new technology. Ports with the HVSC are more attractive to the ship-owners, especially for cruise ships and large container ships visiting the European Community ports and ports within the ECAs, offering good alternative for burning expensive 0.1% of sulphur fuel required by the 2005/33/EC directive.

With Croatia's forthcoming entry into the EU in 2013, the HVSC implementation is becoming an option worth of consideration for some of its major ports, particularly Dubrovnik and Rijeka. One reason for that are the already goriva s udjelom sumpora manjim od 0,1 % što zahtijeva Direktiva 2005/33/EC.

Uzimajući u obzir skori ulazak Republike Hrvatske u EU (1. srpnja 2013.), uvođenje VN kopnenih priključaka postaje opcija vrijedna razmatranja, poglavito za luke Dubrovnik i Rijeka. Jedan od razloga za to je prilagodba postojećem regulatornom okviru o zaštiti okoliša unutar EU i zahtjevima MARPOL konvencije, a drugi još i važniji, prevencija zagađenja zraka u gradskim područjima uslijed naglog rasta broja posjeta velikih putničkih i kontejnerskih brodova. Mogućnost uvođenja VN kopnenih priključaka za te dvije luke analizirana je na bazi dostupnih javno objavljenih statističkih podataka i postojećih razvojnih planova.

Hrvatske luke mogu se klasificirati kao luke s visokim troškovima implementacije VN kopnenih priključaka zbog potrebe ugradnje skupih pretvarača frekvencije i nedovoljnih prijenosnih kapaciteta postojećih napojnih vodova u lukama. S obzirom na iskustva luka koje već koriste VN kopnene priključke i tipične zahtjeve za električnom energijom brodova koji posjećuju razmatrane luke, procijenjeno je da potreban snaga po priključku može iznositi do 15 MVA za luku Dubrovnik i 7,5 MVA za luku Rijeka.

Direktni troškovi uvođenja mogu se relativno lako odrediti nakon štio se definira potrebna infrastruktura. Kako bi se ocijenila stvarna ekonomska opravdanost uvođenja VN kopnenih priključaka moraju se izračunati i troškovi uzrokovani negativnim utjecajem brodskih emisija na lokalnu populaciju i ekosustave. Da bi se oni odredili za lokalne zajednice koje se nalaze u blizini glavnih hrvatskih luka potrebno je napraviti registar brodskih emisija po preporukama EEA, što bi trebao biti predmet zasebne studije.

existing EU and IMO environmental regulations, and the other one, even more important, is the prevention of the local air pollution due to the rapid growth of cruise and cargo ship calls. The possibility of the HVSC implementation in those two ports has been analysed by using available data from port statistics and the existing development studies.

Croatian ports can be classified as high cost ports in term of the HVSC implementation. This is mainly due to the requirement for expensive frequency converters and insufficient capacity of the existing power supply lines in harbours. Based on the experience from ports that are already using the HVSC and on typical power requirements of ships visiting ports of interest, it is estimated that the required power per berth can go as high as 15 MVA in Dubrovnik and 7.5 MVA in Rijeka.

Direct implementation costs can be easily found, once the required infrastructure is defined. In order to determine the justifiability of the HVSC installation, the external costs which present a monetary equivalent of the harm done to the society by the ship emissions have to be calculated as well. To calculate the external costs for communities near the major Croatian ports, it is necessary to form a ship emission register and to determine the share of the ship emissions in the national emission inventory, according to the EEA recommendations. This, however, has to be the subject of a new study.

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