Comparative Analysis of Cold Ironing Rules
Komparativna analiza pravila za hladno peglanje

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Summary

The current paper pretends to offer a global vision about the actual situation of the regulations and requirements applied to High Voltage Shore Connection (HVSC) systems, also known as cold ironing. To develop the entire study, the following Classification Societies rules have been consulted: ABS - High Voltage Shore Connections; BV- High-Voltage Shore Connection System; DNV-Electrical Shore Connections; DNV-GL- Rules for classification of ships; LLOYD'S REGISTER-Rules and regulations for the classification of ships and RINA-Rules for the classification of ships. In the way to accomplish the proposed objective, the mentioned rules have been compared including all the specific aspects and regulations related with "the shore side" of the entire installation. These requirements are also compared with the international standard ISO/IEC/IEEE 80005-1 High Voltage Shore Connection Systems and show the grade of accuracy provided by each Classification Society against that standard. Finally, the results of the comparison show that many of the studied rules focus their rules just on the ship side of the installation or just provide some general recommendations for the shore side. According to that, the shore side is considered such as not part of the ship and consequently is not considered in their rules.

KEY WORDS
High Voltage Shore Connection
Power demand
Cold ironing
cruise ships
air pollution

Sažetak

U radu se pokušalo dati globalnu sliku o aktualnoj situaciji propisa i pravila koji se primjenjuju na HVSC sustave, poznate kao hladno peglanje. Da bi se moglo provesti istraživanje, konzultirana su sljedeća klasifikacijska društva: ABS – HVSC; BS – HVSC; DNV – električni spojevi s kopnom; DNV – Pravila za klasifikaciju brodova; Lloyd's Register – Pravila za klasifikaciju brodova i RINA – Pravila za klasifikaciju brodova. U svrhu ostvarivanja postavljenoga cilja, spomenuta pravila uspoređena su uključujući sve specifičnosti i pravila koja se odnose na kopnenu stranu instalacije. Ovi zahtjevi uspoređeni su s međunarodnim standardom ISO/IEC/IEEE 80005-1 HVSC sustava, te su prikazani postotci usklađenosti svakoga pojedinačnog klasifikacijskog društva sa standardom. Rezultati usporedbe pokazuju da se mnoga pravila orijentiraju samo na brodsku stranu instalacije ili daju samo neke opće preporuke za kopnenu stranu. U skladu s time, kopnena strana smatra se nečim što nije dio broda i zato se na nju pravila ne odnose.

KLJUČNE RIJEČI
HVSC
potražnja za energijom
hladno peglanje
brodovi za kružna putovanja
zagađenje zraka

1. INTRODUCTION / *Uvod*

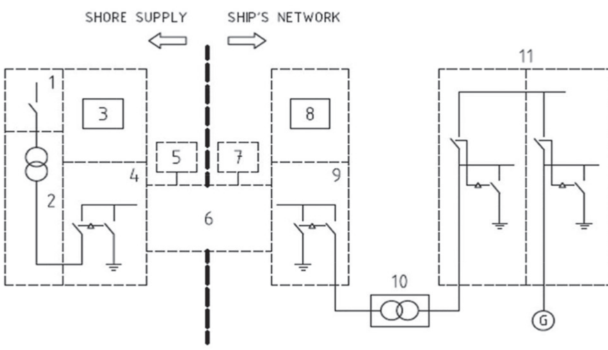
The combustion of fuel in the ship's engine creates exhaust gases that contain harmful compounds such as nitrogen oxides, carbon dioxide and monoxide, and sulphur oxides and soot [6]. Nowadays, many important ports are developing new technologies aiming to reduce emissions from ships. One of these technologies consist on the possibility of connecting ships at port, and substitute their main power source, generators, for a power source provided from the shore by a shore to ship connection, also known as HVSC or cold ironing [8]. The maritime sector, particularly ship's safety, design and construction, is always over the control of Classification Societies' rules. When these rules become outdated they refresh with new regulations or modifications based on their experience. But, when new technologies start to take importance within the sector it is necessary to refresh them as soon as they can, trying to rise their accuracy on its design. The main objective of this paper is to provide a clear idea of the current situation of the rules of Classification Societies related on HVSC. Following Classification Societies will be analysed and compared: American Bureau of Shipping (ABS) [1]; Bureau Veritas (BV) [2]; Det Norske Veritas (DNV)* [3]; Det Norske Veritas & Germanischer Lloyd (DNV-GL) [4]; Lloyd's Register (LR) [7] and RINA Services (RINA) [9]. In addition, the International Standard (STND) ISO/IEC/IEEE 80005-1[5] is going to be studied and contrasted with the mentioned rules provided by Classification Societies. To increase the value of this contribution, DNV-GL rules have been considered. After the analysis, it has been noticed that this rule does not provide specific requirements. Because of that, DNV rules, published before DNV-GL merger have been considered too such as informative data.

2. METHOD / *Metoda*

Aiming to organize this contribution clear and understandable, all the components or parts of the complete installation are going to be isolated in order to study additional requirements and specific rules.

2.1. Installation's main composition requirements / *Zahtjevi za glavne dijelove instalacije*

From a simplified point of view and according to the STND, any system shall be designed in accordance with a generic architecture showed in figure 1:



Source: ISO/IEC/IEEE 80005-1

Figure 1 Main composition of the installation (1. HV- Shore supply system, 2. Shore side transformer, 3. Shore side protection relaying, 4. Shore side circuit breaker and earth switch, 5. Control, 6. Shore-to-ship connection and interface equipment. 7. Control, 8. Ship protection relaying, 9. Shore connection switchboard, 10. On-board transformer (where applicable) and 11. On-board receiving switchboard)

Slika 1. Glavni dijelovi instalacije

The STND and BV are the unique that provide layouts and some useful diagrams for designing shore connection installations. Particularly, BV provides more than the typical legend and includes some notes about the versatility of each element against a good compatibility with the major part of world's fleet. The rest of the checked rules do not include any visual source for general installation's composition. In addition, complementary requirements for HVSC systems are provided in the annexes of the STND for some type of ships that are going to use the shore connection. These sources provide a generic idea about the composition and prevent design mistakes.

2.2. General requirements / *Opći zahtjevi*

The STND establishes that, in order to standardize this type of installations and link nominal voltages in different ports, high voltage shore connections shall be provided with a nominal voltage of 6,6 kV A.C and/or 11 kV A.C. Otherwise, if some ships have regular routes (same ports and berths), other IEC voltage nominal values may be considered. BV agrees with the STND regarding to that each ship is to be provided with a dedicated high voltage shore supply installation which is galvanically isolated from other connected ships and the shore power.

Moreover, according to the standard, at the connection point looking to the socket/connector face, the phase sequence shall be L1-L2-L3 or A-B-C or R-S-T and the system shall be balanced. Phase sequence rotation diagram shall be fixed at its location and phasors must rotate counter clockwise in reference to fixed observer.

Considering general requirements, only the STND and BV provide requirements or recommendations. BV adds that additional requirements and/or restrictions may be imposed by the National Administration or Authorities within whose jurisdiction the ship is intended to operate and/or by the Owners or Authorities responsible for a shore supply or distribution system. Moreover, it includes that the connection must not adversely affect the availability of ship's own power sources in order to allow them to restore power.

As regard to power supply's capacity, BV provides that the rating of the supply system is to be adequate for the normal continuous electrical load of the vessel at quay. In particular, the external supplies are to be sufficiently rated to supply the following services: Essential services normally required in port; Services required to ensure ready availability of non-operating main and auxiliary machinery; and Services required to prevent damage to cargo of stores. In case that propulsion machinery is intended to be used to maintain the vessel at quay because of heavy weather, the whole shore supply system is to be sized accordingly.

2.3. Power's quality / *Kvaliteta energije*

The energy supplied from shore to ships shall be able to maintain certain quality parameters, such as voltage, frequency and harmonic distortion. After analysing the rules, only the STND, BV and LR cover power's quality by their own requirements. DNV-GL provides some requirements included in its general rules for electrical installations. According to their specific rules for HVSC, BV is the most complete because provides many tolerances for each situation and parameter. LR is, as well as BV, very complete, but data for power's quality has to be consulted in its general part for electrical engineering. LR provides an equation to calculate the total harmonic distortion (THD) depending on the frequency, fact which is very interesting. All these requirements are provided in table 1:

Table 1 Power's quality requirements comparison. Continuous tolerances, Transient tolerances and Harmonic distortion and global tolerances

Tablica 1. Usporedba zahtjeva za kvalitetu energije. Stalne tolerancije, prelazne tolerancije i harmonično iskrivljenje globalne tolerancije

Continuous tolerances	STND	BV	DNV-GL	LR
Voltage tolerance at the terminals of the shore connection switchboard according to IEC 600092-301 (1980)	X	±2,5%	±2,5%	6%/-10%
Voltage unbalanced tolerance including phase voltage unbalance as a result of load according to IEC 600092-201	X	7%	X	X
Phase to phase voltage unbalance	X	3%	X	X
Voltage cyclic variation deviation	X	2%	X	5%
Voltage tolerance at the point of the shore supply connection (% of nominal voltage), for no-load conditions	6%	X	6%	+6%
Voltage tolerance at the point of the shore supply connection (% of nominal voltage), for rated load conditions	-3,5%	X	X	6%/-10%
Frequency tolerance (continuous) between no load and nominal rating; according to IEC 600092-301 (1980)	±5%	±5%	+5%	±5%
Frequency cyclic variation tolerance (continuous)	X	0,5%	X	X
Transient tolerances	**STND**	**BV**	**DNV-GL**	**LR**
Voltage (V)	+20%/-15%	+20%	+20%/-15%	+20%
Voltage transient recovery time	X	Max.1,5s	Max.1,5s	Max.1,5s
Frequency (F)	+10%	+10%	+10%	+10%
Frequency transient recovery time	X	Max.5s	X	Max.5s
The response of the V and F at the shore connection when subjected to an appropriate range of step changes in load shall be defined and documented for each HV shore supply installation;	√	√	X	X
The maximum step change in load expected when connected to a HV shore supply shall be defined and documented for each ship.	√	X	√	X
Harmonic distortion and global tolerances	**STND.**	**BV**	**DNV-GL**	**LR**
Voltage individual harmonic distortion tolerances, for no-loads conditions	3%	3%	5%	3%
Voltage total harmonic distortion tolerances, for no-loads conditions	5%	5%	X	5%
Voltage total variation tolerances (continuous + transient variations)	X	20%	X	X
Frequency total variation tolerances (continuous + transient variations)	X	12.5%	X	X

2.4. Comparable assessment before connection / *Procjena za usporedbu prije spajanja*

Before connecting any ship to shore High Voltage (HV) supply, a compatibility checking shall be performed to verify the possibility of connection between both parts. This assessment is not covered by all rules. Only STND, RINA, BV and LR include the compatibility checking procedure. In addition, according to LR, the owner is the main responsible of doing the compatibility assessment before arriving to an enabled shore connection port. In Table 2, a comparison between the different checking aspects has been developed.

As a result of that comparison, a compatibility assessment has been developed trying to include all the important aspects. This complete assessment shall include, as minimum, the following requirements of Table 2: 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 (included equipotential bond monitoring), 13, 14, 15, 16, 17, 18, 19, 20 and 24.

2.5. Conversion equipment / *Oprema za pretvaranje (konverziju)*

For transformer's and equipment's design, the requirements are more complete. For semiconductors converters, requirements have not been developed further than construction in order to be in compliance with the respective IEC rule. The comparison between the implicated rules is showed in table 3.

Equipment requirements that shall be considered at the design statement are basically divided in four types: Constructive requirements based on IEC international standards; Main requirements of the transformer (Type and configuration); Transformer equipment and Protections and Safety requirements. In addition, alarm and data communication system shall be considered. It is only completely covered by the STND which requires a data communication system between the ship and the shore. Alarms from onshore protection equipment shall be transmitted to the ship and transformers, shore transformer high-temperature alarm shall be transmitted. In the ABS rules, onboard transformers are well covered, but not onshore transformers because the rule does not cover onshore systems furthermore than interface equipment.

2.6. Galvanic Isolation / *Galvanska izolacija*

A galvanic isolation is a good measure to increase the safety. In particular, only the STND, BV, DNV* and RINA mention in their rules some regulations for it. The comparative analysis is showed in table 4:

Table 2 Compatibility assessment, requirements comparison

Tablica 2 Procjena kompatibilnosti, usporedba zahtjeva

Compatibility requirements	STND	LR	RINA
1.- Compliance with the requirements of the IEC/ISO/IEEE standard and any deviations from the recommendations; 2.- Minimum prospective short-circuit current; 5.- Any de-rating for cable coiling or other factors; 8.- System study and calculations; 16.- Total harmonic distortion (THD); 18.- Consideration of electrochemical corrosion due to equipotential bonding;	√	X	X
3.- Maximum prospective short-circuit current; 4.- Nominal ratings of the shore supply, ship to shore connection and ship connection; 10.- Compatibility of shore and ship side control voltages, where applicable; 11.- Compatibility of communication link; 12.- Distribution system compatibility assessment (shore power transformer neutral earthing); 13.- Functioning of ship earth fault protection, monitoring and alarms when connected to a HVSC supply; 15.- Compatibility of safety circuits, in accordance with the rule;	√	√	√
6.- Acceptable voltage variations at ship switchboards between no-load and nominal rating; 7.- Steady state and transient ship load demands when connected to a HV shore supply, HV shore supply response to step changes in load; 9.- Verification of ship equipment impulse withstand voltage; 14.- Sufficient cable length; 17.- Consideration of hazardous areas, where applicable; 19.- Utility interconnection requirements for load transfer parallel connection; and equipotential bond monitoring;	√	X	√
20.- Emergency Shut-Down requirements; 21.- Rated current or apparent power; 22.- Quality of power supply; 23.- Minimum supply apparent power or current Capacity; 24.- Isolation;	X	√	X

Table 3 Conversion equipment, requirements comparison

Tablica 3. Oprema za pretvaranje, usporedba zahtjeva

Conversion equipment requirements	STND	BV	DNV*	RINA
Transformers shall be of the separate winding type for primary and secondary side. The secondary side shall be star-configuration with neutral bushings (Dyn) & Short circuit protection for each supply transformer shall be provided by circuit-breakers or fuses in the primary circuit and by a circuit breaker in the secondary & Overload protection shall be provided for the primary and secondary circuit. In the event of overload, an alarm signal shall be activated to warn relevant duty personnel & A cooling system shall be installed for transformers on shore. Whether by air or with liquid, an alarm shall be initiated when the cooling medium exceeds a predetermined temperature and/or flow limits.	√	X	X	X
The temperature of supply-transformer windings shall be monitored. In the event of over temperature, an alarm signal shall be transmitted to the ship using the data-communication link.	√	X	X	√
Where provided, converting equipment for connecting HV shore supplies to a ship electrical distribution system shall be constructed in accordance with IEC 60076 for transformers and IEC 60146-1 series for semiconductor convertors. & The protection for electrical equipment shall be in accordance with IEC 61936-1, as applicable.	√	√	X	X
The transformer shall include overvoltage protection,	X	X	√	X
If necessary, means are to be provided to reduce transformer current in-rush and/or to prevent the starting of large motors, or the connection of other large loads, when an HV supply system is connected.	X	X	X	√
The effect of harmonic distortion and power factor is to be considered in the assignment of a required power rating.	X	√	X	X

Table 4 Galvanic isolation, requirements comparison

Tablica 4. Galvanska izolacija, usporedba zahtjeva

Regulations and requirements	STND.	BV	DNV*	RINA
Galvanic separation is to be provided between the on-shore and on-board systems.	√	√	√	√
Each ship shall be provided with a dedicated HV shore supply installation which is galvanically isolated from other connected ships and consumers. This may not be required where a HV shore supply is dedicated to supply only ships which have galvanic isolation on board.	√	√	√	X
When the isolation is performed by a transformer, this shall have separate windings for the primary and the secondary side. & It is recommended that If a power transformer is installed on shore, the transformer shall include overvoltage protection, protecting the vessel against lightning impulse over voltages.	X	X	√	X

2.7. Neutral earthing resistor and Equipotential bonding / *Otpornik za neutralno uzemljenje i ekvipotencijalno spajanje*

The earthing resistor is one of the most important safety systems within the installation. The unique rules that include some requirements are STND, BV and DNV* (see Table 5).

The main requirement is that the neutral point of the Shore power feeding transformer shall be earthed through a neutral earthing resistor. According to BV, the neutral point treatment on the shore supply must be able to adapt to various grounding philosophies. So, the system will be able to supply a wider range of ships. In case frequency conversion of the shore supply would be required, it can be earthed though the same system or using an earthing transformer with resistor on the primary side that provides an equivalent earth fault impedance to the system.

One very important requirement provided by the STND and DNV*, is that the neutral earthing resistor shall be continuously monitored to verify of the equipotential bonding between shore earthing electrode and ship's hull.

Table 5 Neutral earthing resistor, requirements comparison

Tablica 5. Otpornik za neutralno uzemljenje, usporedba zahtjeva

Requirement or regulation	STND	BV	DNV*
The neutral point of the HVSC system transformer feeding the shore-to-ship power receptacles shall be earthed: a) through a neutral earthing resistor; or b) where frequency conversion of the shore supply is required, either through a neutral earthing resistor or through an earthing transformer with resistor on the primary side that provides an equivalent earth fault impedance.	√	√	X
If the system is earthed through a neutral earthing resistor, its rating in amperes shall not be less 1.25 times the preliminary system charging current. The rating shall be minimum 25 A continuous. & Where equivalent earth fault impedance is chosen when frequency conversion of the shore supply is required, studies should be conducted to verify effectiveness.	√	X	X
The continuity of the neutral earthing resistor shall be continuously monitored. In the event of loss of that continuity the shore side circuit breaker shall be tripped.	√	X	√
An earth fault shall not create a step or touch voltage exceeding 30V at any location in the shore to ship power system.	√	X	X
The vessel is not to be permitted to establish shore power connection with an earth fault present in the high voltage system on both sides.	X	√	X

Table 6 Equipotential bonding, requirements comparison

Tablica 6. Ekvipotencijalno spajanje, usporedba zahtjeva

Regulations and requirements	STND	ABS	RINA	BV
An equipotential bonding between the ship's hull and shore earthing electrode shall be established.	√	√	√	√
An interlock is provided such that the HV shore connection cannot be established until the equipotential bonding has been established. An interlock arrangement is to be provided such that the loss of equipotential bonding is to result in the disconnection of the HV shore power. & Arrangements are to be provided so that when the shore connection is established, the resulting system grounding onboard is to be compatible with the vessel's original electrical system grounding philosophy. Integrity of the equipotential bonding is to be continuously checked as a part of the ship shore safety system.	X	√	√	X
The voltage rating of electrical equipment insulation materials is to be appropriate to the system grounding method, taking into consideration the fact that the insulation material will be subjected to 3 times higher voltage under single phase ground fault condition.	X	√	X	X

All requirements constitute a guide to be taken into account for neutral earthing and equipotential bonding.

2.8. Short circuit protection onshore / *Zaštita od kratkog spoja na kopnu*

Interlocking some protection measures is basically to guarantee personal's safety in all port's environment. Including short circuit protections such circuit breakers is basic in design statement (see table 7).

We can conclude that each rule tries to cover short circuit protection in a basic way. Only the STND covers in an accurate way providing concrete values for short-circuit current, among others.

2.9. Circuit breakers and safety interlocks / *Osigurači i sigurnosni prekidači*

The main protection devices, circuit breakers and switches, shall be designed with accuracy and with a guarantee that they would work and would be activated in the exact situation. From table 8, we can conclude that rules can be very complete such as the STND or RINA, or, in the other hand, very incomplete.

Table 7 Short circuit protection, requirements comparison
Tablica 7. Zaštita od kratkog spoja, usporedba zahtjeva

Regulations or requirements	STND	DNV*	ABS	BV	RINA
The prospective short-circuit contribution level from the HV shore distribution system shall be limited by the shore side system to 16 KA rms; (for general ships) & Electrical system/equipment shall be rated for minimum of 16 kA rms for 1 s, and 40 kA peak.	√	X	X	X	X
The rated short-circuit making capacity of the circuit breaker is not to be less than the prospective peak value of the short-circuit current. The rated short-circuit breaking capacity of the circuit breaker is not to be less than the maximum prospective symmetrical short-circuit current.	X	X	√	√	X
All circuit breakers and cables used for the electrical shore connection shall be rated for the prospective short circuit currents that may appear at their location in the installation. & Interlocks shall be provided in switchboards against simultaneously feeding from the ship's own generators and the electrical shore connection when the parallel connected short circuit power exceeds the switchboards' short circuit strength. & A short time parallel feeding as a "make before break" arrangement is accepted when arranged with automatic disconnection of one of the parallel feeders within 30 s.	X	√	X	X	X
Shore connection HV circuit breaker is to be equipped with low voltage protection (LVP).	X	X	X	X	X
In calculating the maximum prospective short-circuit current, the source of current is to include the maximum number of generators which can be simultaneously connected the shore supply contribution and the maximum number of motors which are normally simultaneously connected in the system.	X	X	X	X	√
Protection against short-circuit currents is to be provided by circuit- breakers or fuses.	X	X	X	√	X
The calculations may take into account any arrangements that: prevent permanent parallel connection of high voltage shore supply with ship sources of electrical power and/or; restrict the number of ship generators operating during parallel connection to transfer load; restrict load to be connected.	X	X	X	X	√

Table 8 Circuit breakers and safety interlocks, requirements comparison
Tablica 8. Osigurači I sigurnosni prekidači, usporedba zahtjeva

Requirements		STND	ABS	BV	DNV*	LR	RINA
In order to have the installation isolated before it is earthed, the circuit-breaker, disconnector and earthing switch shall be interlocked in accordance with the requirements of IEC 62271-200.		√	√	√	√	√	√
HV shore connection circuit breaker is to be remotely operated.		√	√	X	X	X	√
The rated making capacity of the circuit breaker and the earthing switch shall not be less than the prospective peak value of the short-circuit current (IP) calculated in accordance with IEC 61363-1. & The rated short-circuit breaking capacity of the circuit-breaker shall not be less than the maximum prospective symmetrical short-circuit current IAC(0,5T) calculated in accordance with IEC 61363-1.		√	√	X	√	X	X
Short circuit protection for each supply transformer shall be provided by circuit-breakers or fuses in the primary circuit and by a circuit breaker in the secondary.		√	X	X	X	X	X
The continuity of the neutral earthing resistor shall be continuously monitored. In the event of loss of the continuity the shore side circuit breaker shall be tripped.		√	X	X	√	X	X
The HV circuit-breaker on the secondary side of the transformer shall open all insulated poles in the event of the following conditions:							
a	overcurrent including short-circuit,	√	√	√	√	√	√
b & c	over-voltage/ under-voltage & reverse power	√	X	√	X	√	√
d	over frequency	√	X	X	X	X	√
In order to satisfy the last requirement, at least the following protective devices, or equivalent protective measures, shall be provided:							
d	synchrocheck (25) or voltage sensing device (84) (for dead bus verification)	√	X	X	X	X	√
e & f & h	undervoltage (27) & reverse power (32) & instantaneous overcurrent (50)	√	X	√	√	X	√
g	load unbalance, negative phase sequence overcurrent (46)	√	X	X	√	X	X
i	phase time overcurrent (51)	√	X	X	√	X	√
j	earth fault overcurrent (51G)	√	X	√	√	X	√
k	overvoltage (59)	√	X	√	X	X	√
l	directional phase overcurrent (67)	√	X	X	√	X	√
m	Phase sequence voltage (47)	X	X	X	X	X	√
n	Overload (49)	X	X	√	X	X	√
o	Frequency (under and over) (81)	X	X	X	X	X	√
(Standard device designation numbers are shown in brackets above, as per IEEE Std C37.2™)							
The protection systems shall be provided with battery back-up adequate for at least 30 min. Upon failure of the battery charging or activation of the back-up system, an alarm shall be communicated to the ship.		√	X	X	X	X	X
Arrangements shall be provided so that the circuit-breakers cannot be closed when any of the following conditions exist:							
a	one of the earthing switches is closed (shore-side/ship-side);	√	X	X	√	X	√

b	the pilot contact circuit is not established;	√	√	X	√	X	√
c	emergency stop facilities are activated;	√	√	X	√	X	√
d & e	ship or shore control, alarm or safety system self-monitoring diagnostics detect an error that would affect safe connection; & the communication link between shore and ship is not operational, where applicable;	√	X	X	√	X	√
f & h	the permission from the ship is not activated; & equipotential bonding is not established (via equipotential bond monitoring relays)	√	√	X	X	X	X
g	the HV supply is not present;	√	√	X	X	X	√
i	An error within the HV connection system that could pose an unacceptable risk to the safe supply of shoreside power to the vessel;	X	√	X	X	X	√
j	An earth fault;	X	X	X	X	X	√

2.10. Interface equipment / *Interface oprema*

2.10.1. Sockets and plugs / *Utičnice i utikači*

The interface equipment is very important within onshore power installations. The huge amount of power that is going to be supplied to a ship is very dangerous because of its high voltage. In that way, the requirements for connection and interface equipment are generally covered in different levels of accuracy to guarantee high safety levels during the power supply and during the procedures of connection and disconnection. After the analysis (see table 9), STND, BV and RINA have a very good coverage and similar criteria. Moreover, BV provides an extended and very detailed section about type tests on power connection plug and socket-outlets.

2.10.2. Cable / *Kabel*

Requirements for cables are very diverse (see table 10). Once again, the STND is the most complete rule for covering cables in an onshore power installation. RINA and BV are the most complete and show similar criteria.

Table 9 Sockets and plugs, requirements comparison

Tablica 9. Utičnice I utikači, usporedba zahtjeva

Requirements	STND	ABS	BV	DNV*	LR	RINA
Plugs and sockets are to be protected from dust, moisture and condensation while not in use.	√	√	X	X	X	X
The minimum protection rating of plugs and sockets is to be IP66.	X	√	X	X	X	X
The plug and socket system shall be of a type tested design, suitable for marine use.	X	X	X	√	X	X
Plugs and socket-outlets shall be in accordance to IEC 62613-1 and IEC 62613-2 or a relevant National Standard. (IEC 62613: Plugs, socket-outlets and ship couplers for high-voltage shore connection systems (HVSC Systems): Part 1: General requirements; Part 2: Dimensional compatibility and interchangeability requirements for accessories to be used by various types of ship.) Plugs and socket-outlet connection shall be in areas where personnel will be protected in the event of an arc flash as a result of an internal fault in the plug and/or socket-outlet by barrier and access control measures.	√	X	√	X	√	X
Each plug shall be fitted with pilot contacts for continuity verification of the safety circuit.	√	X	√	X	X	√
The plug and socket-outlet arrangement is to be fitted with a mechanical securing device that locks the connection in engaged position. In addition, they are to be designed so that an incorrect connection cannot be made.	√	X	√	X	X	√
The shore-side of the connection cable is to be fitted by plug(s). The plug body is to protect all contacts. Cable connections may be permanently connected on shore to suitable terminations.	X	X	X	X	X	√
The shipside of the connection cable is to be fitted with connector(s).Cable connections may be permanently connected on board to suitable terminations. & Cable extensions are not permitted.	X	X	X	X	X	√
The earthing contacts are to make contact before the live contact pins do when inserting a plug.	X	X	√	X	X	√
Plugs are to be designed so that no strain is transmitted to the terminals and contacts. The contacts are only to be subjected to the mechanical load which is necessary to ensure satisfactory contact pressure, also when connecting and disconnecting.	√	X	√	X	X	√
Each plug and socket-outlet is to have a permanent, durable and readable nameplate with the following information: Manufacturer's name and trademark; Type designation; and Applicable rated values.	X	X	X	X	X	√

Table 10 Cable requirements comparison

Tablica 10. Usporedba zahtjeva za kabel

Requirements	STND	ABS	BV	DNV*	LR	RINA
Non-fixed HV cables are to be constructed and tested to recognized standard acceptable to ABS.	X	√	X	X	X	X
A flexible shore connection cable can be arranged either on board the vessel or situated at key. & The flexible cable shall be terminated close to the ship's side, and not be used as a part of the fixed cable installation in the vessel. & All cables installed on board shall be DNV type approved.	X	X	X	√	X	X
High voltage cables are to be readily identifiable by suitable marking.	√	√	X	√	X	X
Cables shall be at least of a flame-retardant type in accordance with the requirements given in IEC 60332-1-2. & The outer sheath shall be oil-resistant and resistant to sea air, seawater, solar radiation (UV) and shall be non-hygroscopic.	√	X	√	X	X	√
The temperature class shall be at least 90 °C, insulation, in accordance with Annex A. The maximum operating temperature shall not exceed 95 °C, taking into account any heating effects (e.g. as a result of cable coiling). & Correction factor for ambient air temperatures above 45 °C shall be taken into account (see IEC 60092-201:1994, Table 7). & Size, quantity and rating of cables shall be sufficient to meet the maximum power rating and voltage that the terminal can supply to the ship.	√	X	X	X	X	X
The insulation temperature class is to be at least 85°C.	X	X	X	X	X	√
Control and monitoring cables shall be at least of a flame retardant type in accordance with the requirements of IEC 60332-1-2. The environmental requirements for the sheath shall be the same as described for the ship to shore connection cable.	√	X	√	X	X	X
Connection Equipment power cables are to be Type Approved in accordance with LR's Type Approval System Test Specification Number 3 or, alternatively, surveyed by the Surveyors during manufacture and testing to assess compliance with the particular section of the rules, and application of an acceptable quality management system.	X	X	X	X	√	X
Power, control and monitoring may be based on a single cable or cables in bunch.	X	X	√	X	X	X

2.10.3. Cable handling / *Rukovanje kablovima*

The flexible cable that shall be used for the connection cannot be managed such a rope. It is very important to handle the cable during the connection to avoid extra strains over it and develop a correct use (see table 11). In addition, the effectiveness of that system will help on maintenance, making it easier and cheaper.

2.10.4. Management / *Upravljanje*

Cables, plugs and sockets shall have a management system to assist the connection procedure. That system includes safety procedures, management equipment and protection systems such as switches and interlocks. The regulations aiming to guarantee the safety of operations are compared in table 12.

2.10.5. Location and construction / *Lokacija i konstrukcija*

Due to increase of safety in onshore installations, the major part of the rules mention some requirements related on the location and installation. These requirements are compared in table 13:

Table 11 Cable handling, requirements comparison
Tablica 11. Rukovanje kablovima, usporedba zahtjeva

Requirements	STND	ABS	BV	DNV*	LR	RINA
A cable handling system must be arranged. & The cable management system shall give alarm at high cable tension to a manned position. At high voltage, the shore connection shall be automatically disconnected. Automatic release of the plug and socket connection is not required.	X	X	√	√	X	X
The cable management system is to allow extending cable and retracting cable without causing undue stress to the cable.	√	√	√	X	X	X
There shall be installed equipment enabling efficient cable handling and connection.	X	X	X	√	X	X
Handling of plug and socket outlets shall be possible only when the associated earthing switch is closed.	√	X	X	X	X	X
Connection Equipment cable reels, cranes and/or gantries used to manage, handle or adjust connection cables, plugs and/or socket-outlets, are to be designed and manufactured in accordance with applicable LR Rules or a marine standard acceptable to LR.	X	X	X	X	√	X
The ship to shore connection cable installation and operation are to be arranged to provide adequate movement compensation, cable guidance, anchoring and positioning of the cable during normal planned ship to shore connection conditions.	X	X	√	X	X	√
Connection Equipment support and management arrangements, including those for control engineering arrangements, are to be arranged not to apply damaging forces or tension to correctly applied equipment. Support arrangements are to ensure that the weight of connected cable is not borne by cable end terminations or connections.	X	X	√	X	√	X
Cable management system, cables are to be physical protected against heavy seas and mechanical damages	X	X	√	X	X	X

Table 12 Interface management, requirements comparison
Tablica 12. Upravljanje interfaceom, usporedba zahtjeva

Requirements	STND	ABS	BV	DNV*	LR	RINA
Socket-outlets and inlets shall be interlocked with the earth switch so that plugs or connectors cannot be inserted or withdrawn without the earthing switch in the closed position. 6 The current-carrying capacity of the earth contact shall be at least equal to the rated current of the other main contacts.	√	X	X	X	X	√
The power plugs as well as the neutral plug shall be fitted with fail-safe limit switches that are activated only when the plug and socket-outlet are properly mated. These fail safe limit switches shall be part of, and activate the emergency shutdown, if the plug is moved from the mated position while live. & Connection between the neutral and ship's hull shall be robust and durable for proper bonding.	√	X	X	X	X	X
Interlock between the plug and the shore connection circuit breaker is to be provided such that the plug can be disengaged only after the shore connection circuit breaker has been opened.	√	√	X	√	X	X
Connections with external electrical power supply arrangements are to be designed to prevent damage to the ship structure or Connection Equipment cable reels, cranes and/or gantries as a result of the connections separating in the event of the ship leaving a berth inadvertently or as a result of high cable tension for other reasons.	X	X	X	X	√	X
Interlocking with earthing switches is to be arranged to ensure that the HV power contacts remain earthed until: all connections are made; the communication link is operational; self-monitoring properties of ship or shore alarm, control and safety systems detect that no failure would affect safe connections, and the permission from ship and shore is activated.	X	X	X	X	X	√
Each plug shall be fitted with pilot contacts for continuity verification of the safety circuit.	√	√	X	X	X	√
An interlock, which prevents plugging and unplugging of the HV plug and socket outlet arrangements while they are energized, is to be provided.	√	√	√	X	X	X
Opening, or release, of the plug and socket may be a manual operation.	X	X	X	√	√	X

Table 13 Location and construction, requirements comparison

Tablica 13. Lokacija i konstrukcija, usporedba zahtjeva

Requirements	STND	ABS	BV	LR	DNV*	RINA
HVSC equipment shall be installed in access controlled spaces.	√	√	√	X	X	√
When determining the location of the HVSC system, the full range of cargo, bunkering and other utility operations shall be considered, including: 1. The cargo handling and mooring equipment in use on the ship and shore, and the areas that must be clear for their operation; 2. Traffic management considerations;	√	X	√	√	X	√
3. Personnel safety measures, such as physical barriers to prevent unauthorized personnel access to HVSC equipment or the cable management equipment;	√	√	√	√	X	√
4. Presence of hazardous areas	√	X	√	X	X	√
If some of the equipment cannot be located in a non-hazardous area, then it is to be certified of a safe type. & Ship equipment is to comply with the applicable requirements of IEC 60092-101 and IEC 60092-503.	X	X	√	X	X	X
The shore connection switchboard is to be located in a compartment that is sheltered from the weather. HV shore cables are to enter this compartment through a temporary opening with weather tight arrangements & Appropriate arrangements are to be provided for storage of removable HVSC equipment when not in use.	X	√	√	X	X	X
Higher voltage equipment is not to be combined with low voltage equipment in the same enclosure, unless safety measures are taken. & High voltage cables are to be installed on cable trays or equivalent when they are provided with a continuous metallic sheath or arm or which is effectively bonded to earth; otherwise, they are to be installed for their entire length in metallic casings effectively bonded to earth.	X	√	X	X	X	X
At all locations from where the electrical shore connection or cable management system may be controlled, the following alarms and controls shall be available: high tension of the flexible cable, loss of shore power, emergency disconnection & activation of protective functions as earth fault, overcurrent and short circuit	X	X	X	X	√	X

Table 14 General comparison between classification rules

Tablica 14. Opća usporedba klasifikacijskih pravila

RULE			APPLICATION		ISO/IEC/IEEE 80005 CONSIDERATION
Ranking	Rule	Class Notation	Ship side	Shore Side	
1	RINA	HVSC	√	√	√
2	BUREAU VERITAS	HVSC	√	X	X
3	ABS	HVSC	√	X	√
4	LLOYD'S REGISTER	OPS	√	X	√
5	DNV*	SHORE POWER	√	√	√
6	DNV-GL	X	X	X	X

3. RESULTS AND CONCLUSIONS / *Rezultati i zaključci*

According to the developed comparative analysis, the most complete requirements provided by Classification Societies, are provided by RINA. Lloyd's Register and Bureau Veritas rules are very complete, but just according to ship side and interface equipment. A general comparison considering all rules is resumed in table 14. In addition, class notation for their additional class is provided.

The main conclusion about the situation of HVSC is the focalization of the Classification Societies on the ship side installation, which is completely comprehensive because of their specific function, classify and regulate ship's design and construction. But, from an engineer's point of view, it is better to have a global vision and regulation of the whole system aiming to apply a reliable and safety design criteria pursuing the highest effectiveness degree. The result of the mentioned focalization is the less effectiveness of these rules against the international standard ISO/IEC/IEEE 80005-1 because it considers shore and ship such as an entirely system.

STND is the most complete, but there are some important requirements provided from other rules that should be added to the standard. Likewise, it would be a good idea for Classification Societies to consider the international standard such as another way to get the class notation. Particularly, Bureau Veritas is widely based on the standard for ship side system but do not recognise its consideration for ships classified under it.

Nowadays, because of the rising importance of environment's pollution control, many sustainable technologies have been developed to contribute on their regulation and their reduction. The HVSC is one of these technologies and it is gaining consideration by many ports in many countries. Classification Societies are in constant evolution refreshing their rules and improving them aiming to increase their effectiveness and their safety degree. According to the current paper, there are still many fields and requirements that can be included or developed for future rules, contributing in that way to improve the maritime sector.

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