Important considerations in marine electrical installations

Why High Voltage on Board of Ships

Vibrations

Limited and or Confined Space

Equipment
floating ground (Isolated neutral or high impedance earthing)

- We have to take into consideration the vibrations on a ship
- Technical spaces can be very small
- The temperature is most of the time high but can also be very cold
- We can have a humidity of near to 100 percent

A ship is constructed out of steel which is an excellent conductor for electricity and heat

- An electrical network in ship application is an island network
- If failure occurs in the island network only consumers connected to that network suffer the consequences
- The exception is the shore to ship connection
- Shore to ship arrangements will increase in the future due to stricter port emission rules
Why High Voltage on Board of Ships

A high voltage distribution system has lower current levels
- Lower current reduces the size of the cables
- Lower current lowers the cost of the network
- Lower current levels also lower the losses in the distribution system

<table>
<thead>
<tr>
<th>Voltage (KV)</th>
<th>CB Max.Rating (KA)</th>
<th>Source or Load (MW)</th>
<th>% Increase Vs. 480 V</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.480</td>
<td>4</td>
<td>2.7</td>
<td>-</td>
</tr>
<tr>
<td>4.16</td>
<td>3</td>
<td>17.3</td>
<td>6.5 times</td>
</tr>
<tr>
<td>6.6</td>
<td>3</td>
<td>27.4</td>
<td>10.3 times</td>
</tr>
<tr>
<td>13.8</td>
<td>3</td>
<td>57.4</td>
<td>21.6 times</td>
</tr>
</tbody>
</table>

*Table: source ABB*
Possible Alternatives for Systems Voltage Levels

Using IEC voltage levels, following alternatives can be selected.

- **11 KV**: medium voltage generation and distribution. When total installed generator capacity exceeds 20 MW. For motors from 400 KW and above.
- **6.6 KV**: medium voltage generation and distribution. Total installed generator capacity is between 4-20 MW. For motors from 300 KW and above.
- **680 V**: low voltage generation and distribution. Total installed generator capacity is below 4 MW. For motors below 400 KW.
- For utility distribution a lower voltage is used, e.g. 400/230 V.

Why High Voltage on Board of Ships

Figure: Low voltage cable tray
Engine vibrations can create problems:
- in consequence of mechanical resonance things can extremely move and even break apart.
Vibrations

Engine vibrations can create problems:

- loose connections can cause damage
- a loose connection has a resistance and accordingly produces heat
- in the extreme the heat can be so high that it can cause fire
- a loose connection can completely interrupt a circuit and produce dangerous transients
- In order to identify potential overheating problems and or loose connections the use of thermal imaging equipment for preventive maintenance can be advised
### Vibrations

![Figure: View of a Low voltage fuse with a loose connection](image)

### Confined Space

Working in a confined space asks for a special permit to work (gas test)

A space is classified as confined if:

- a person can enter and work in it and
- if the space has restricted means for entry or exit and
- if the space is not designed for continuous employee occupancy
- One can consider any normal space on bord as confined if an entrance and or exit is completely or even only partially blocked
Working in very small and even confined spaces. Always take into account:

- the proximity of hot and even live parts
- it can be necessary to put additional physical barriers, locks and screens to keep out bystanders
- but also to prevent ourselves from accidently touching hot or live parts
Electric Cabling

The main accepted types are:

- low smoke
- low toxic
- fire resistant
- Disadvantages versus PVC-insulated types:
  - strenght against mechanical stress while being pulled
  - possibility of damage while installing
Important considerations in marine electrical installations

Why High Voltage on Board of Ships

Vibrations

Limited and or Confined Space

Equipment

Normal three-core power cable

Fire resistant screened power cable
Fire resistant power cable

Willem Maes  High Voltage Safety

Fire resistant control cable

Willem Maes  High Voltage Safety
Double screened (EMC) power cable

Overall screened cable
Cables for Marine use

Cables for marine use differ from those used for on-shore installations:

- Core is not solid but consist of stranded conductor of 7 or more wires to cope with the vibrating environment.
- Cables in a marine environment must be fixed to the cable supports.
- Flexible cables for cranes or telescopic supported wheelhouses are fixed to movable cable trays.

Flexible Cables

Flexible cables shall consist of flexible conductors, stranded with 19 or more wires and special flexible insulating materials. The cables must stay flexible at lower temperatures (below 0)
Cables with solid conductors up to $2.5mm^2$ can be used in ship’s accommodations.

Single conductor AC cables in systems rated more than 20A arrangements are to be made to account for the harmful effect of electromagnetic induction:

- the cable is to be supported on non-fragile insulators
- The cable armoring or any metallic protection must be non-magnetic and earthed on mid-span or supply end only
- When single core cables pass a bulkhead the sum of the currents through this penetration must be 0
Fire resistant cables

Must remain functional under fire conditions. Have a similar construction as other cables, but are provided with an additional layer of mineral insulation around the conductors, in this case mica.

Application of fire resistant cables

When the circuit have to remain in service under fire conditions.

- emergency lighting
- fire detection
- communication circuits
- fire pump
- fire safety shut down circuits
When the circuit have to remain in service under fire conditions. But also to ensure continuity of service in spaces adjacent to the space which could be damaged by fire.

### Cable selection tables

<table>
<thead>
<tr>
<th>Nominal cross section mm² (#AWG)</th>
<th>THERMOPLASTIC, PVC, PE</th>
<th>EP RUBBER and CROSSLINKED PE</th>
<th>SILICON RUBBER or MINERAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Single Core</td>
<td>2-core</td>
<td>3- or 4-core</td>
</tr>
<tr>
<td>0,75</td>
<td>6</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>1 (#/16)</td>
<td>8</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>1.25 (#/16)</td>
<td>10</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>1.5</td>
<td>12</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>2 (#/14)</td>
<td>13</td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td>2.5</td>
<td>17</td>
<td>14</td>
<td>12</td>
</tr>
<tr>
<td>3.5 (#/12)</td>
<td>21</td>
<td>18</td>
<td>14</td>
</tr>
<tr>
<td>5.5 (#/10)</td>
<td>22</td>
<td>19</td>
<td>15</td>
</tr>
<tr>
<td>6</td>
<td>29</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>9 (#/6)</td>
<td>35</td>
<td>30</td>
<td>24</td>
</tr>
<tr>
<td>10</td>
<td>40</td>
<td>34</td>
<td>26</td>
</tr>
<tr>
<td>14 (#/6)</td>
<td>47</td>
<td>42</td>
<td>34</td>
</tr>
<tr>
<td>16</td>
<td>54</td>
<td>46</td>
<td>38</td>
</tr>
<tr>
<td>22 (#/4)</td>
<td>66</td>
<td>56</td>
<td>46</td>
</tr>
<tr>
<td>25</td>
<td>71</td>
<td>60</td>
<td>50</td>
</tr>
<tr>
<td>30 (#/2)</td>
<td>80</td>
<td>68</td>
<td>56</td>
</tr>
<tr>
<td>35</td>
<td>87</td>
<td>71</td>
<td>61</td>
</tr>
<tr>
<td>38</td>
<td>97</td>
<td>76</td>
<td>65</td>
</tr>
</tbody>
</table>

Willem Maes
High Voltage Safety


<table>
<thead>
<tr>
<th>Insulation material</th>
<th>Correction factor for ambient air temperature of °C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>35</td>
</tr>
<tr>
<td>PVC, Polyethylene</td>
<td>1.29</td>
</tr>
<tr>
<td>EPR, XLPE</td>
<td>1.12</td>
</tr>
<tr>
<td>Mineral. Silicon rubber</td>
<td>1.10</td>
</tr>
</tbody>
</table>

Correction factor for ambient air temp of 45 C

Correction factors for bunching of cables or when the numbers of conductors in a cable exceeds 4 may also be applied and class rules must be consulted for the corresponding values. ABS pg654
Important considerations in marine electrical installations

Cable selection tables

Cables are printed on the outside, according to the production standard.

Cable trays and cable fixing

fixed cable trays.
Important considerations in marine electrical installations

**Cable trays and cable fixing**

flexible cable trays.

**Pipe and cable tunnel**
An average figure of 6 times the overall diameter is a reasonable rule of thumb. Above 1000V the figure lies between 15 times the overall diameter for multi-core and 20 for single-core cables.
High voltage cables

High voltage cables must be segregated from low voltage cables.
Control cables must be segregated from all power cables.
Cables are normally fixed with Ty-wraps.

- These ty-wraps must be UV resistant.
- When cables are mounted on vertical or overhead cable-trays steel cable band are used.
- When single-core or high voltage cables are involved non magnetic materials should be used (stainless-steel).
Paint on cables

Where paint or any other coating is systematically and intentionally applied on the electric cables, it is to be established...... ABS 4-8-4 21.1.6
Above 3KV cables have a radial field construction with an earthing screen between the cores and the outside insulation. These cables have to be terminated with a special 3-pole sleeve.

Flexible cables

Telescopic supported wheelhouse.
Cable penetrations

Multiple glands with rubber sealing blocks

Standard cable penetrations are A-60 fire resistant and are watertight up to a pressure of 50 metres water column.
Important considerations in marine electrical installations

Why High Voltage on Board of Ships

Vibrations

Limited and or Confined Space

Equipment

Watertight cable penetration

Additional fire protection
Important considerations in marine electrical installations

Why High Voltage on Board of Ships

Vibrations

Limited and or Confined Space

Equipment

design assessment

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High Voltage Safety

CERTIFICATE OF Design Assessment

This is to Certify that a representative of this Bureau did, at the request of UNIKA UNIVERSAL KABLO SAN. VE TIC A.S., assess design plans and data for the below listed product. This assessment is a representation by the Bureau as to the degree of compliance the design exhibits with applicable sections of the Rules. This assessment does not waive unit certification or classification procedures required by ABS Rules for products to be installed in ABS classed vessels or facilities. This certificate, by itself, does not reflect that the product is Type Approved. The scope and limitations of this assessment are detailed on the pages attached to this certificate. It will remain valid as noted below or until the Rules or specifications used in the assessment are revised (whichever occurs first).

PRODUCT: Electric Cables

MODEL: U-HF m, U-HFA m, U-HFA m EMC, U-HFFR m, U-HFFRA m, U-HFAT m, U-HFAT m (I), U-HFAT m (C), U-HFAT m (I+C), U-HFFRAT m, U-HFFRAT m (I), U-HFFRAT m (C), U-HFFRAT m (I+C).
Cable connections

- Cables are to be installed as far as practicable, in continuous lengths between termination points.
- Where necessary the use of junction boxes will be permitted.
- Cable splices will be permitted during construction for joining cables between modules, or when extending or truncating the lengths of cables during repair or alteration.
Important considerations in marine electrical installations

Why High Voltage on Board of Ships
Vibrations
Limited and or Confined Space
Equipment

cable terminations

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High Voltage Safety

Electric Propulsion

Figure: Dual motor electric propulsion unit
Benefits of Electrical Propulsion

- **Building Cost**
  - Better utilisation of space, more efficient ship design
- **Operational**
  - fuel efficient
- **Increased Safety**
  - safety, redundancy and availability is increased
- **Environmental**
  - Minimizing NOx
  - Clean combustion, reduced particle emission and reduced maintenance.

Components of Electrical Propulsion System

- **Combustion engines**, often diesel engines or gas motors, function as the primary sources of power.
- These run the **generators**. Depending on the required power, engines can be turned off and generators detached from the network.
- The generators are connected to the electrical system’s main bus bar, which is the main **switchboard**.
Components of Electrical Propulsion System

- With busbar **breakers** in the main switchboard, generators, motors, transformers or damaged sections can be detached from the network.
- The main switchboard is divided into two or more sections to make the system redundant.
- We have a **frequency converter** between the main switchboard and the **propulsion motor**.
- and a **transformer** between the main switchboard and the frequency converter.

**Main Switchboard**

*Figure: High Voltage Marine Switchboard*
Main Switchboard

- The function of a ship's electrical distribution system is to safely convey electrical power to every item of equipment connected to it.
- The most obvious element in the system is the main switchboard.
- The main switchboard is divided into two or more sections to make the system redundant.
- The main board supplies bulk power to motor starter groups (often part of the main board), section boards and distribution boards.

Transformers interconnect the HV and LV distribution sections of the system.

Circuit breakers and fuses strategically placed throughout the system automatically disconnects a faulty circuit within the network.

The main switchboard is placed in the engine controlroom and from there engineroom staff monitor and control the generation and distribution of electrical power.

It is very important that every engineer has a profound knowledge of the electrical distribution of the ship's power.

The only way to acquire this knowledge is to study the ship's power diagrams.
Important considerations in marine electrical installations

Why High Voltage on Board of Ships

Vibrations

Limited and or Confined Space

Equipment

Main Switchboard

- Usually a ship's electrical distribution scheme follows shore practice.
- Normal industrial equipment can be used after being adapted and certified, so it can withstand the conditions on board of a ship as there are:
  - vibration, freezing and tropical temperatures, humidity, the salty atmosphere, etc.

Figure: generators
Today’s High Voltage generators are used to produce all of the electrical energy on a ship. In general on a ship there are for to six large machines that function as generators, usually driven by diesel engines.
Generators

- Marine generators also called alternators are almost always synchronous generators.
- Marine generators are almost always connected in star and of the brushless type.
- Synchronous machines are exited by DC current.
- An AVR or automatic voltage regulator controls the exiting current.
- The AVR keeps the generators voltage between the limits demanded by class, regardless of variations in active load, reactive load, temperature and frequency.

AVR Automatic Voltage Regulator

Figure: Automatic Voltage Regulator
AVR Automatic Voltage Regulator

- Is a device that continuously monitors the voltage at the voltage regulating point of the system and maintains the terminal voltage of the generator.
- The AVR also controls that the synchronous generator operates within pre-set limits.
- An auxiliary winding supplies the excitation power under the control of the AVR.

- A voltage feedback is supplied by the voltage transformer and a current feedback is provided by the current transformer.
- The transformers are installed in the generator.
- Operational limits, such as over and under excitation, machine voltage and Volts/Hz, are implemented in the AVR.
- Static reactive power compensation in parallel operation and several other software functions are also available.
Marine generators have an adapted AVR to generate a sustained short-circuit current of 350% of the nominal current.

This short circuit is required to allow the circuit breakers to trip in a selective way.

The ability of ships generators to generate a short circuit current high enough for selectivity or discrimination is essential and above industrial (shore) standards.

Transformers are used for changing voltage levels.

Other functions are galvanic isolation, establishing phase shift and performing measurements.

Transformers that bring about a phase shift can be used to feed a frequency converter in order to remove the largest harmonic currents.
### Transformers

- There are two types of transformers: liquid filled and dry transformers.
- Dry transformer windings are cooled by air.
- Liquid cooled transformers are cooled with special oil.
Transformers

Figure: High Voltage current transformer

Safety measures when working on transformers

Work on a transformer is only permitted in voltage-free and earthed condition.

- Transformer windings can be normally insulated on the outer surface by means of an epoxy resin layer. This insulation does not make them shockproof in terms of the valid standards.
Safety measures when working on transformers

- Every transformer radiates a magnetic field when in operation.
- The magnetic field is not significantly reduced by a housing.
- Any person with a cardiac pacemaker or metal implants should avoid the area within a radius of 3 metres.
- Housing or housing parts must not be disassembled during operation.

- Verify that any conductor is de-energized before testing for continuity or resistance.
- Uncontrolled release of energy may result if the inductors current is suddenly interrupted.
- Electromagnets may produce large external forces which may affect the proper operation of the protective instruments and controls.
Safety measures when working on transformers

- By suddenly de-energizing a magnet large eddy currents can be produced in adjacent conductive materials that may cause excessive heating and hazardous voltages.
- A magnetic field can attract nearby magnetic material, including tools, which could cause injury or damage on impact.

- Transformers supplied as only IP00 must be locked away under use so that when energized they can never be touched. The transformer cast resin surface is not an approved isolator and therefore is not safe to touch. Accidental touch protection could be provided through the installation of safety barriers, gates or similar.
Earth connections

- The total resistance of the protective earthing must be dimensioned in such a way that protective systems are in operation all the time and can act upon an earthfault.

- The cross section of the earthing connections must comply with the regulations and on-site conditions and must be maintained at all times also during repair and maintenance operations.
Safety measures when working on transformers

Electrical and mechanical connections

- The minimum distance (according to the rules) between live parts and between live parts and earth must never be diminished. This relates to the distances between cables and high voltage windings in particular.

- All retaining elements of the screw connections are to be checked and replaced if necessary before reconnecting.

- All connections must fit tightly and be mechanically secure. The bolts for the electrical connections are to be tightened using a torque wrench.
Modern frequency converters can control the rotational speed and the torque of AC motors very precisely.

Drive has become a general name for a power appliance, made up of one or several converters.

Function depends on the converter type. Drives often use energy storage elements as there are inductor and capacitor banks.
Important considerations in marine electrical installations

Why High Voltage on Board of Ships

Vibrations

Limited and or Confined Space

Equipment

Motor Drives

Figure: Small frequency drive for asynchronous motors

Safety measures when working on drives

Installation and maintenance work

- Only qualified electricians are allowed to install and maintain the drive.
- The main switch on the cabinet door does not remove the voltage from the input busbars of the drive. Before working on the drive, isolate the whole drive from the supply.
Safety measures when working on drives

Installation and maintenance work

- Never work on the drive, the motor cable or the motor when main power is applied.
- After switching off the input power, always wait for 5 min to let the intermediate circuit capacitors discharge before you start working on the drive, the motor or the motor cable.
- Measure the voltage between intermediate DC voltage terminals with a multimeter to ensure that the drive is discharged before beginning work.
- Apply temporary grounding before working on the unit.

- Do not work on the control cables when power is applied to the drive or to the external control circuits.
- Externally supplied control circuits may cause dangerous voltages to exist inside the drive even when the main power of the drive is switched off.
- Do not make any insulation or voltage withstand tests on the drive or drive modules.
- When reconnecting the motor cable, always check that the phase order is correct.
Important considerations in marine electrical installations

Why High Voltage on Board of Ships

Vibrations

Limited and or Confined Space

Equipment

Safety measures when working on drives

Installation and maintenance work

- When joining shipping splits (if any), check the cable connections at the joints before switching on the supply voltage.

- Live parts on the inside of the doors are protected against direct contact. Special attention shall be paid when handling metallic shrouds.

- After maintaining or modifying a drive safety circuit or changing circuit boards inside the module, retest the functioning of the safety circuit according to the start-up instructions.

- Do not change the electrical installations of the drive except for the essential control and power connections. Changes may affect the safety performance or operation of the drive unexpectedly. All customer-made changes are on the customer’s responsibility.
The motor cable terminals on the drive are at a dangerously high voltage when the input power is on, regardless of whether the motor is running or not.
Circuit Breakers and Contactors

- A circuit breaker is designed to detect and switch a short-circuit current and overload current when applicable.
- A contactor is an automated switch.
- A contactor has far better electrical properties than a circuit breaker, related to the nominal current.
- A circuit breaker can switch a short circuit current of 400 times the nominal current, however this can be done only a few times.

16 Ampere circuit breaker (width 3 cm)

Can interrupt a short-circuit current of 6000A
Important considerations in marine electrical installations

**Why High Voltage on Board of Ships**
- Vibrations
- Limited and or Confined Space
- Equipment

**12A contactor (width 8cm)**

A 12A contactor (width 8cm) can switch on the starting current of 120A of a 12A nominal motor thousands of times.

**Current versus time characteristic**

![Graph showing current versus time characteristic](image-url)
Important considerations in marine electrical installations

Why High Voltage on Board of Ships
Vibrations
Limited and or Confined Space
Equipment

5000A circuit breaker (1m width)

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1000A circuit breaker (0.5m width)
Important considerations in marine electrical installations

Why High Voltage on Board of Ships

Vibrations

Limited and or Confined Space

Equipment

Diagram of 16A circuit breaker

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The closing mechanism of a contactor is operated by a coil pulling an iron core and thus closing the contacts. Opening is by de-energizing of the coil, small springs will open the contacts.
Important considerations in marine electrical installations

Why High Voltage on Board of Ships
Vibrations
Limited and or Confined Space
Equipment

small contactor

1000A contactor
Selectivity

The aim of selectivity, or discrimination is to make sure that only the circuit-breaker upstream of the fault trips and that other parts of the installation are not affected.

For Further Reading

The Rules

*Lloyds register of shipping.*

The Rules

*ABS.*