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SELECTED ISSUES CONCERNING THE ATYPICAL TT/TN-S NETWORKS USAGE IN MARINE ELECTRICITY SYSTEMS

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Abstract: This article deals with to the selected issues of design and characteristics of the operation atypical of electricity networks used on ships. The presented analysis and an attempt of re- design is based on the case study.

Keywords: IT, TNS power grid, corrosion.

1. INTRODUCTION

The definition of a specific type of power grid enables the use of an international symbolic code. This code is based on the letter marking of different connections between the active conductors, conductive parts and the earth. The international marking system and technical use features five types of network systems: TN-C, TN-S, TN-C-S, TT, IT. And so, the first letter specifies the connection method of the network system, the so-called operational earthing: T (terre) – direct connection to the earth (most often the neutral point), I (isolation) – no connection to the earth or surge protection impedance connection. The second letter specifies the connection of the accessible conductive parts with earthed conductors: N (neutre) – directly to the earthed neutral point, T – directly to the earth (body). The following letters determine the connection between the neutral conductor and the protective conductor: C (combine) – a single common protective-neutral PEN conductor, S (separe) – two separate conductors, N – neutral, PE – protective, C-S – PEN – N hybrid, PE [Kostyszyn and Nowak 2016].

The standard solution for the power grids used in ship systems are those based on IT grids, or sometimes TT grids. These systems dominate in maritime solutions. In particular, it is applicable to the IT system, which is most often used for its features and in particular due to the benefits of the continuity and safety of the power supply to the ship's equipment [Mindykowski 2001]. The international ship associations associated with IACS, including the Polish Register of Shipping, allow the use of an alternative solution (part VIII, chapter 4; for example 3-phase, 3-wire with an earthed neutral point, for voltages up to 500 V AC, 3-phase, 4-wire with an earthed neutral point, but without using the ship's hull as the return conductor). The regulations still use the obsolete notion of the neutral point and conductor, while not mentioning the application of 5-wire TNS systems. These systems are subject to the following provision in the regulation "The application of other systems is subject to separate review by PRS" [Nowak 2018]. The application of the TN-S network system in the is very rare, but still encountered. The article presents the basic problems encountered during the short operation of the TN-S network systems on the ships built in Poland under PRS supervision.

Section 2 discusses the basic properties of the IT and TT power grids. Section 3 is dedicated to the TN power grid used on ships. Section 4 is focussed on the operational problems resulting from the selection of an atypical network type. This section presents the analysed case studies, defines the difficulties and proposes precautions. In section 5, the final conclusions are formulated.

2. BASIC PROPERTIES OF IT AND TT GRID SYSTEMS IN SHIP SOLUTIONS

The IT grid in the basic configuration is presented in Figure 1.

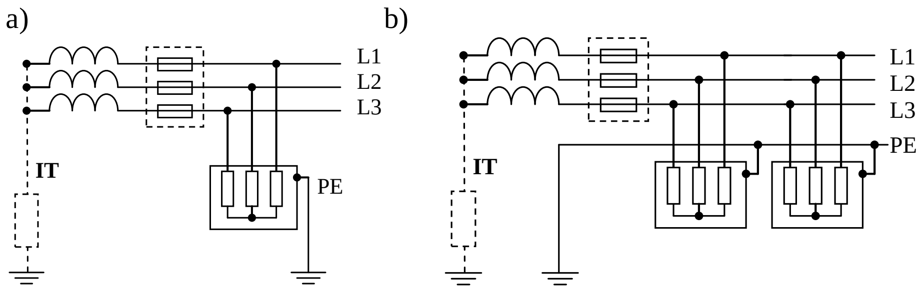

Fig. 1. Structure of the IT grid system with earthing: a) individual, b) group

Source: T. Nowak, Wybrane zagadnienia dotyczące sieci IT, TT w świetle użytkowania w okrętowych systemach elektroenergetycznych, Zeszyty Naukowe Akademii Morskiej w Gdyni, 2018, no. 103, p. 6.

It is characterised by the minimum earth fault current value I_d, regardless of the short-circuit location. This current is closed by the earth leakage and the capacity of the non-damaged phases relative to the earth or PE conductor, when used in the area of the galvanic-connected grid with loads [Kostyszyn and Nowak 2016].

The basic reason for the application of the IT grid in the installation of a specific receiving network is the increased reliability of power supply continuity by eliminating the necessity to deactivate the dominant single-point earth fault and reducing the explosion or fire hazard. This solution determines the necessity of equipping this grid with an earth leakage indicator that continuously monitors the condition of the insulation resistance for the earth potential of all active components. This necessitates continuous supervision by properly qualified technical personnel. In the case of limited, autonomous ship systems, this condition is easy to meet, in contrast to the public, land-based distribution grids. A single piece of damage must be quickly located and repaired to prevent the failure from escalating to a level causing automatic power supply interruption [Białek and Budziłowicz 2019].

When using a TT power grid in the power system, a direct earthing neutral point of the power source is formed by resistance R_B as shown in Figure 2.

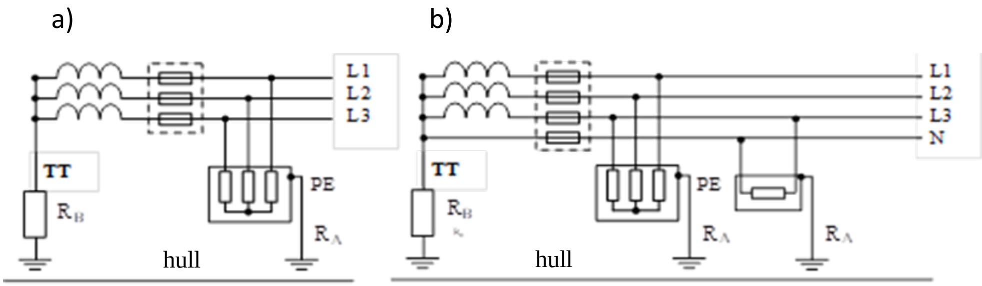

Fig. 2. The TT grid: a) without neutral conductor, b) with neutral conductor

Source: T. Nowak, Wybrane zagadnienia dotyczące sieci IT, TT w świetle użytkowania w okrętowych systemach elektroenergetycznych, Zeszyty Naukowe Akademii Morskiej w Gdyni, 2018, no. 103, p. 9.

In the case of damage to the basic insulation in the powered circuit, the earth fault loop is closed by the hull (earth) (Fig. 3).

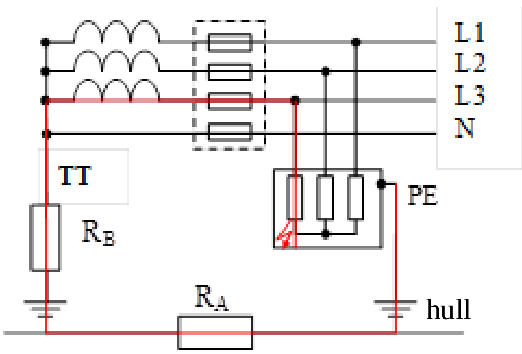

Fig. 3. Current flow in case of damage to the basic insulation in the TT system

Source: T. Nowak, Wybrane zagadnienia dotyczące sieci IT, TT w świetle użytkowania w okrętowych systemach elektroenergetycznych, Zeszyty Naukowe Akademii Morskiej w Gdyni, 2018, no. 103, p. 10.

The current finds its way to the earth through the earthing or earthing assembly of the protective conductor, and returns through functional earthing to the neutral point of the grid (neutral point of the generator). The short-circuit loop includes the earthing and hull resistance, which is difficult to determine and variable during system operation due to the material heterogeneity. This resistance is certainly higher than the loop resistance if a neutral conductor is used. This complicates the process of selecting the proper overcurrent protection, both relative to the type and parameter setting values. A solution to this problem is the application of residual current devices (RCD) for automatic power supply interruption in these systems. However, in ship systems, RCDs are usually not used and these connectors are characterised by high failure rate [https://budujemydom.pl...].

RCD switches or relays in IT grids can be efficiently and reasonably used to divide the grid into sections. In such a case, it is not necessary to check the efficiency of double earth fault interruption. When a short-circuit occurs multiple times in the IT system with group earthing (common galvanic connection with PE conductor to the common earthing point), the situation will be similar to the TN system on the first failure and the interruption should be completed by overcurrent protection devices. The impedance of the short-circuit loop in such a circuit should be:

– without N conductor

$$Z_S \le \frac{U}{2I_a} \tag{1}$$

– with N conductor

$$Z'_S \le \frac{U_0}{2I_a} \tag{2}$$

where:

- U − rated voltage of the system [V],
- U_0 − voltage between the active conductor and the neutral conductor [V],
- Z_s − impedance of the short-circuit loop L-PE-L [Ω],
- Z'_S − impedance of the short-circuit loop L-PE-N [Ω],
- I_a − breaking current [A].

In accordance with the standard [PN-HD 60364-1:2010], in IT grids in which the first earth fault is interrupted, it is necessary to check the efficiency of the double earth fault interruption. The evaluation in accordance with the standard − in contrast to the TN grid − ensures safety only when the result is positive for all outgoing feeders of the considered grid. Therefore, in some cases − for example loads protected with high-rated current fuses − the residual current switch or relay ensures efficient interruption of double earth faults − the first in the considered outgoing feeder and the second at any other point of the grid.

3. BASIC PROPERTIES OF THE TN GRID, CUSTOM SOLUTION USED IN THE SHIP'S SYSTEM

When the TN grid system is in use, in the case of a breakdown of the basic insulation, the short-circuit current in the L-PE or L-PEN loop reaches high values (impedance of the short-circuit loop $Z_s < 2\ \Omega$), because the loop is completely made of energy conductors (Fig. 4). This is the most distinctive feature of the TN system that differentiates it from other systems (TT and IT) [Musiał 2012].

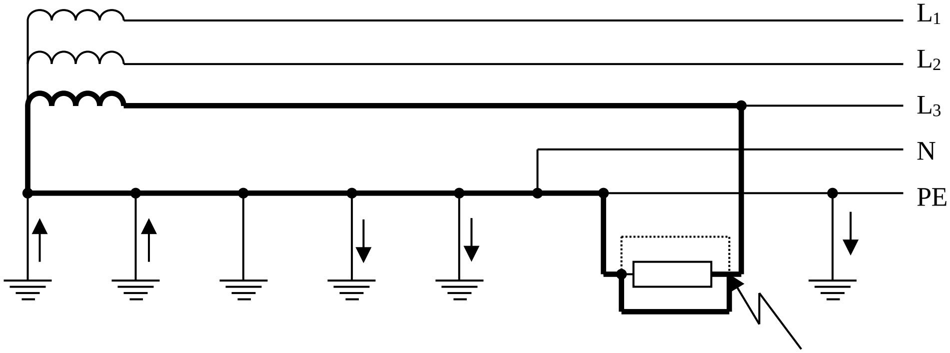

Fig. 4. L-PE short-circuit loop in the TN system, completely made of conductors

Source: E. Musiał, Ochrona od porażeń w instalacjach niskiego napięcia w świetle aktualnych przepisów i norm. Współdziałanie dwóch różnych układów, w tym TT i TN, http://www.edwardmusial.info/pliki/ochrona_it_tt_tn.pdf. [26–27.11.2012], p. 30.

In the TN system, for the automatic power supply shutdown, residual current devices are enough: overcurrent switches, fuses. The prerequisite for efficient automatic power supply shutdown is sufficiently low impedance Z_s of the short-circuit loop. In a circuit with the voltage to earth U_o, the impedance of the short-circuit loop Z_s should meet the following condition:

$$Z_S \leq \frac{U_0}{I_a} \tag{3}$$

where I_a is the protection shutdown current that causes the automatic power supply shutdown in the required time.

The abovementioned advantages of the TN system are shadowed by the hazard in case of breakage of the protective-neutral conductor in the TN-C system (Fig. 5, occurrence of dangerous voltage on the device housing). For this reason, this system was excluded from moving solutions.

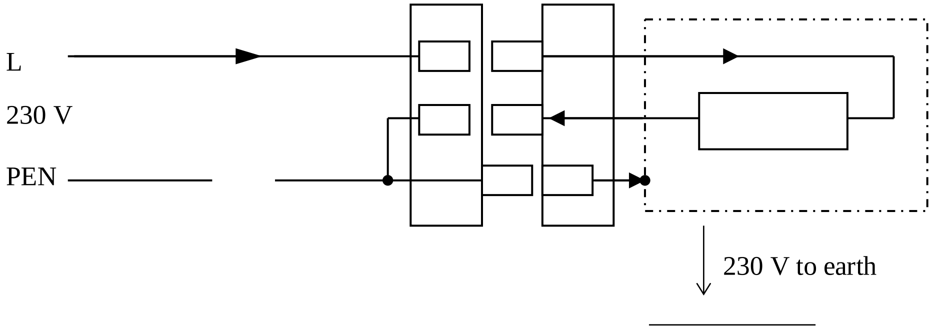

Fig. 5. Consequences of breakage of the protective-neutral PEN conductor in the TN-C system

Source: E. Musiał, Ochrona od porażeń w instalacjach niskiego napięcia w świetle aktualnych przepisów i norm. Współdziałanie dwóch różnych układów, w tym TT i TN, http://www.edwardmusial.info/pliki/ochrona_it_tt_tn.pdf. [26–27.11.2012], p. 32.

4. THE CONSIDERED SHIP SYSTEM

The atypical ship system solution presented in Figure 6 was used in the ship of the Maritime Office for harbour-roadstead inspection purposes.

In the ship, an earthed TNS system was used to power the individual pieces of electrical equipment.

In the case of power supply of the ship from land, a separation transformer with a triangle-star winding connection was used. In this case, an energy land-ship TN-C/incomplete TT/TN-C/TN-S connection with partial use of the hull as the PE conductor and group earthing was formed.

In Figures 6, 7, 8 key parts of the analysed TT/TN-S ship system are shown.

This atypical connection of the grid systems follows the specifics of use of the ship. Occasional work and relatively long stoppages in port favour the use of an uncomplicated system for connection to the land grid.

Presumably, these premises determined the equipment of the ship with this atypical electric power supply solution.

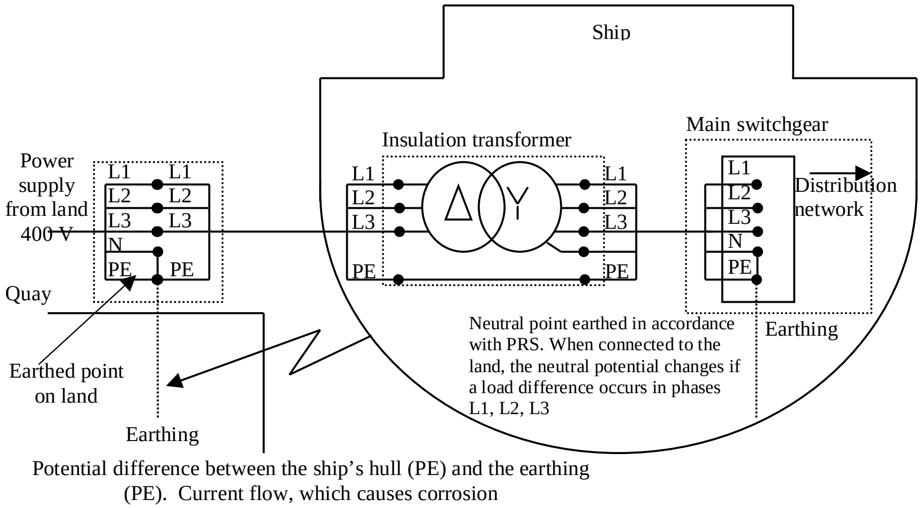

Fig. 6. Connection diagram of the considered ship system with the land grid

Source: own study based on the documentation made available.

The 3 x 400 VAC main switchgear system (Fig. 7) was equipped with a 63 A main switch, 100 / 5A current switches, an electronic analyser of the MIC-2 grid, a 0.3; 63 A residual current device, and branch circuits of the ship's systems. The main switchgear was adjusted for the power supply from the land grid or generator (- 1 × Caterpillar C 2.2, 24.5 kW). The selection of the power supply is connected with a brief system shutdown. The generator circuit was protected with a 60 A generator switch. The characteristic feature of the system is the use of operating earthing, both in the generator part and in the land-based power supply part. The distribution grid was equipped with group earthing.

An analysis of the power system used in the considered ship shows that it is characterised by state-of-the-art technical solutions (grid analyser, voltage relays, LED visualisation systems, current transformers, etc.), care for safety (separation transformer), and complete lack of experience in the operation of such system in other ships. This experience becomes a key problem in the context of the emerging, but unpredicted effects of operation of the concerned power system.

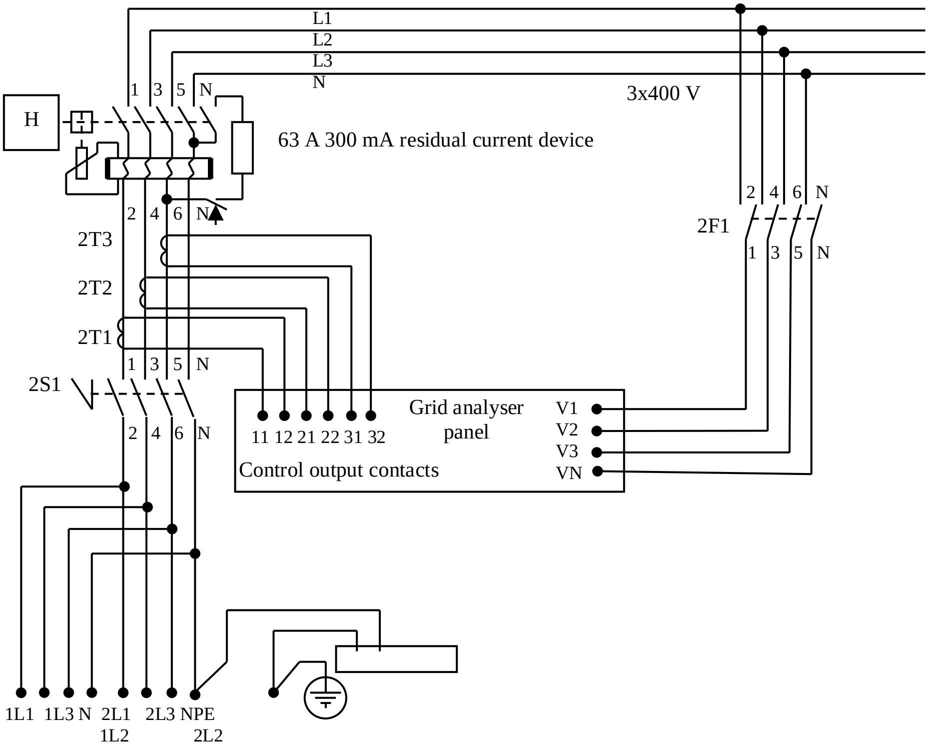

Fig. 7. Connection diagram of the main busbar of the main switchgear with the land or generator power supply system

Source: own study based on the documentation made available.

As a result of the load imbalance in ship systems, the measured asymmetrical current flowing between the ship hull and the port quay earthing in the land connection is up to 63 A (close to the rated current value).

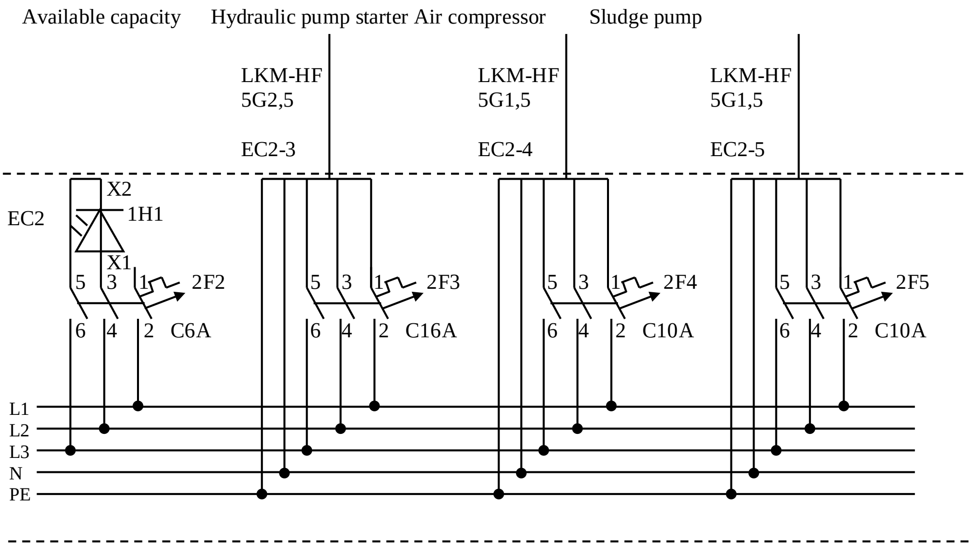

Fig. 8. Part of the EC2 receiving field of the main switchgear

Source: own study based on the documentation made available.

5. OPERATIONAL PROBLEMS OF THE CONSIDERED TN-S GRID AND RESOLUTION ATTEMPT

The basic problem noted during the operation of the above power system is the increased electrochemical corrosion.

Corrosion is material destruction under the chemical or electrochemical impact of the environment. The phenomenon of corrosion is applicable to different materials, not only metallic. The mechanism of corrosion of different materials depends on the type of electrical conductivity at the material-environment interface and the type of environment. In high conductivity materials (a ship's hull), corrosion is mainly electrochemical. The mechanism of potential generation on moist or water-submerged metal surfaces is analogous to galvanic cells [http://www.bc.pollub.pl...]. This mechanism leads to accelerated material deterioration, directly proportional to the maintained potentials, which depend on the selected configuration of the used grid system.

During a half-year operation of the ship, corrosion caused the hydraulic systems to need to be overhauled early. The inability to control the electrochemical corrosion phenomenon forced the shipowner to act to redesign and reconstruct the grid power system of the considered ship and other ordered units.

After consultations with specialists (including the author of this study) and inspectors of the PRS classification association, a halfway solution was adopted, with minimum intervention in the existing TN-S system. An earthed IT system with a neutral conductor was chosen. This solution does not require additional transformers, however it does not enable clear determination of whether a single or multiple earth fault occurred, and leads to uncertain activation or lack of activation of the protections. This is illustrated by Figure 9 and described in the standard [PN-E-05009-41:1992]. The overload current protection does not support using the neutral conductor in the IT grid. The purpose of the provisions of the standard is to prevent a situation in which, in the case of multiple short-circuits (two-point), a dangerous interphase voltage occurs in an unsuitable load [Nowak 2018].

In this situation, it was necessary to quickly reconstruct the power system without deep interference with the ship's structure, which forced the adoption of a solution that was not recommended, but not prohibited. In accordance with PRS and standard recommendations, if it is necessary to use a neutral conductor in the IT system, it may be used provided that overcurrent detection is implemented in the neutral circuit, with circuit interruption in the case of a short-circuit interference. In special cases, it is required that the insulation monitoring device be a safety component for shutting down the power supply on the first failure.

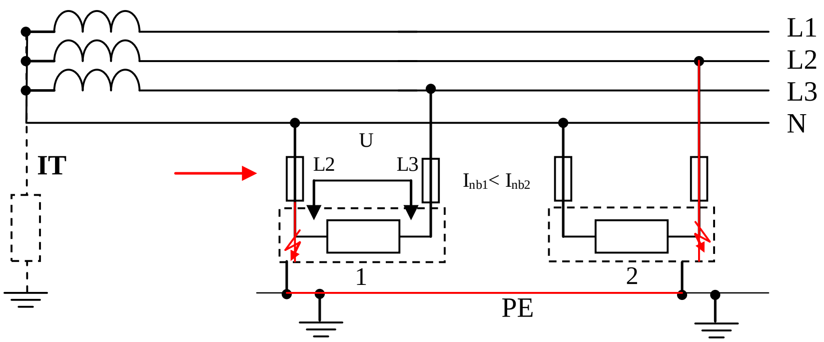

Fig. 9. Two-point short-circuit interruption in the IT system with distributed neutral conductor

Source: T. Nowak, Wybrane zagadnienia dotyczące sieci IT, TT w świetle użytkowania w okrętowych systemach elektroenergetycznych, Zeszyty Naukowe Akademii Morskiej w Gdyni, no. 103, Gdynia 2018, p. 10.

In the considered case, a solution was adopted based on detailed provisions which allowed the structure of the IT grid of the ship to be used with a neutral conductor, subject to the application of overcurrent protections including active conductors and reinforcement of the response severity to the alarm sent by the device monitoring the current insulation resistance of the insulated grid. This condition requires preparing suitable, non-standard rules of operation and service of the power system of the ship. The essence of the redesigned system being part of the system shown in Figure 7 is presented in Figure 10.

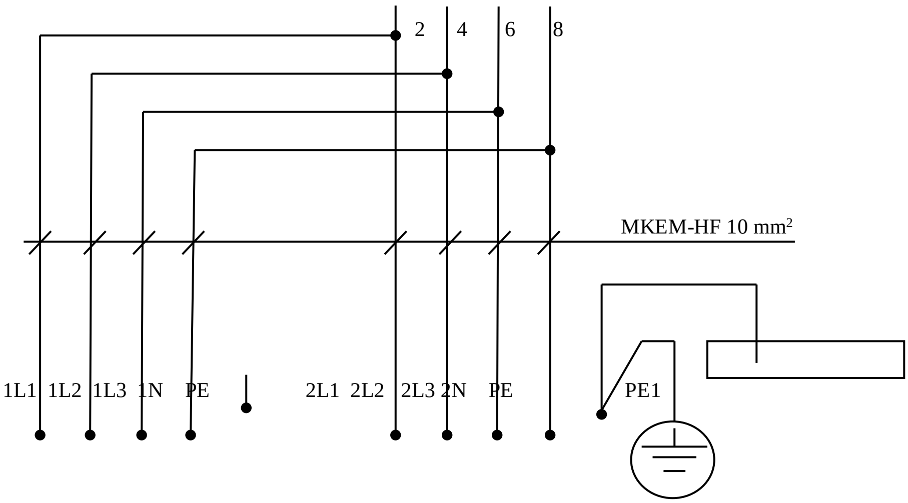

Fig. 10. Part of the main busbar of the redesigned power system of the ship

Source: own study based on the documentation made available.

6. CONCLUSIONS

In ship power systems, there is a problem of network coordination (adjusting parameter values) in the case of supplying a ship in a port from a shore connection. This means that a particularly large variety of features and parameters of various installations must be met. The point is to determine whether and under what conditions two or even three systems can cooperate, selected from the following: IT, TT, TN-C, TN-S. If a connection with galvanic separation is used, no system limitations are applicable. This situation is represented by the unit shown above. It appears, unfortunately, that these solutions cause problems, not only electrical, but also in other operational areas of the ship (material corrosion).

The common use of the IT grid system in ships results from the properties of this solution, as briefly presented in section 2. In addition, the popularity of using the insulated system is dictated by the experience of users, shipowners, and the so-called good maritime practice. The application of other solutions is permitted by Classification Societies, but not recommended for different reasons.

An undoubted advantage of the grid system with an insulated neutral point is the possibility of continuous monitoring of the insulation condition in the system. Degradation of the insulation triggers an alarm. Proper early detection and interruption of an earth fault in the electrical system prevents electric shock, and fire hazard. There are also situations resulting from the magnitude of the load or transported load specifics, in which the use of the earthed grid is most advantageous (high voltage, passenger ships). In this situation, the reasonable solution is to use the TT grid. Every earth fault causes significant currents, and only the condition of the protective system and the reliability of the protection effectively protect against electric shock. As shown by both cases, the condition of the protection systems is important to prevent the generation of a dangerous potential on the housing, as well as the condition of the protections to interrupt the short-circuit in a sufficiently short time. The advantage of the IT system protected by an earthing system consists in early warning and the fact that a short-circuit of one phase to earthed components should not cause excessive potential that is dangerous to humans. This is important for a steel ship.

The application of the TNC-S system in a small area, in which the operating condition of “stoppage in port” is the assumed operating condition with port power supply, seems to be the logical solution. However, the application of galvanic separation through the transformer caused an unexpected technical problem in the form of increased corrosion caused by the unbalanced current of the 3-phase system flowing to the quay (presence of pulse and constant components).

It seems that the better solution is to use the galvanic connection to the land system. Then, the TT island can be used in the TN grid. This may be implemented pursuant to PE-HD-60364. Sheet 41 reads as follows: “If the residual current device is used for automatic shutdown of the circuit outside the zone covered by the main equipotential bonding, the available conductive parts cannot be connected to the protective conductors of the TN system, provided that they are connected to the earthing with resistance suitable for the trip current of the residual current device.” A circuit protected in this manner would be included in the TT system.

In the presented situation, the applied solution forced the completion of an unplanned overhaul of the unit in use, and a redesign and conversion of the TNC-S system to the IT system with a neutral conductor. This solution is not perfect, but offers minimum intervention in the existing system. The operation of this system requires that special protections (including the neutral conductor) and special devices are used to monitor the resistance of the insulation (for shutting down the circuits in the case of a second earth fault). The application of these devices forces the application of a special system operation procedure. These conditions were accepted by PRS inspectors.

The analysis of the presented problem confirms the known good maritime practice rules on the necessity to use above all known and proven solutions in the shipbuilding industry. The ship power system is exposed not only to electrical phenomena, but also to phenomena related to the impact of the maritime environment. Therefore, land solutions are not always efficient in the operation of ship equipment and systems. This should be remembered and considered in the design of new ship power systems.

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