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A NEW ACTIVE METHOD OF PROTECTION AGAINST ELECTRICAL SHOCK IN LOW VOLTAGE SHIP NETWORKS: EXPERIMENTAL RESULTS

Key words

Protection against shock current, parametric compensation, active compensation, four-leg inverter.

Summary

The commonly applied electrical networks with an insulated neutral point in ships are not able to protect against electric shock, due to the presence of capacitance between phase wires and the hull, which increases the values of shock current. A new approach to solve this problem is presented.

The new idea is based on active compensation of shock current using current sources inserted between the phase wires and the metallic hull. A four-leg transistor inverter controlled by a signal processor (DSP) and a logic programmable array (FPGA) was used as a set of current sources.

The arrangement of the test stand obtained for the experimental checking of the concept compensation of shock current is presented together with the experimental results.

Introduction

Sea-going ships, from point of view of crew protection against electric shock, are completely different from typical on-shore objects. The metallic environment of workers and specific external conditions (humidity, temperature) as well as psychical strain and physical load increase the risk of shock. The electric network of the ship is so designed to minimise the frequency of an unpredicted cutting-off of the supply voltage, which has an influence on the conditions of protection. The majority of low-voltage installations are completely insulated from the hull, forming the so-called IT network, contrary to on-shore applied networks, also called TN networks, where the neutral point is connected with ground.

In TN –type networks, almost all of the damage of the insulation of phase wire leads to the switching-off of the supply voltage; whereas, in an IT-type network, such an event is only indicated without switching-off in order to ensure the continuity of supply voltage (due to conventions e.g. SOLAS, IMO regulations, etc).

The electric network can be analysed as two separated networks, i.e., the working network and the transversal network, as is shown in Fig. 1.

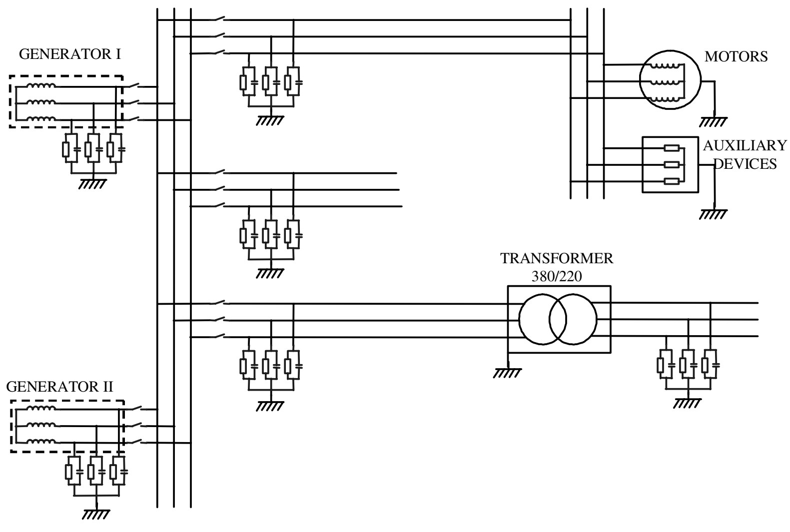

Fig. 1. Typical electric network applied on sea-going ships

Assuming that insulation resistance is greater than 3 MΩ, the reason for electric shock can be the capacitance between phase wires and the hull (transversal capacitance), being the sum of partial capacitance of wires and appliances, e.g. generators, motors and suppressing filters. Measuring results [1] have shown, that the capacity values are within range 0.5 to 6 μF, in extreme cases, even to 20 μF. Such values correspond to the values of the reactance of only a few hundred ohms.

Shock current has two components, forced by phase-to-phase voltages, which is presented in Fig. 2. Human body resistance and the transversal impedance of undamaged phases have closed two circuits of the shock-current.

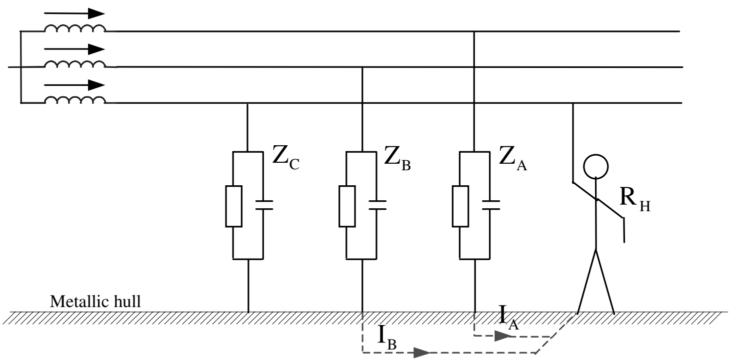

Fig. 2. Flow of shock current components in an IT-type network ($Z_{A, B, C}$ – grounding impedance in each phase, R_H – human body resistance, $I_{A, B}$ – shock currents)

An efficient method (excluding continuous monitoring of insulation) should be used to minimise the shock-current value by using a capacity current compensation system.

Applying this method can solve this problem in two ways;

- parametric (passive) compensation,
- active compensation.

1. Parametric (passive) compensation

The concept of passive compensation is realised by connecting the inductive coil between phase wires and the metallic hull. This method is based on tuning the inductance to resonance between the coil and the transversal capacities, which neutralises the presence of transversal capacities. The scheme for the passive compensation system is shown in Fig. 3.

As result of the research, performed in the eighties in Maritime Academy of Szczecin, realised the passive system of the UKKP type determined to provide compensation of the capacity currents. The system was patented and installed onboard about fifteen ships owned by PZM (Polish Steamship Company) and PLO (Polish Ocean Lines).

Despite sufficient results, this method of passive compensation also has some imperfections as follows:

- The method can not be automated and the components of the compensator have to be tuned after every variation of the transversal capacities, which is unacceptable for contemporary ships of the A24 class;
- The method has a limited speed of reaction (the time constant of the compensated circuit has relatively large values);
- The UKPP system has relatively large dimensions.

Taking into consideration all of the above mentioned aspects, the active compensation system can be more active.

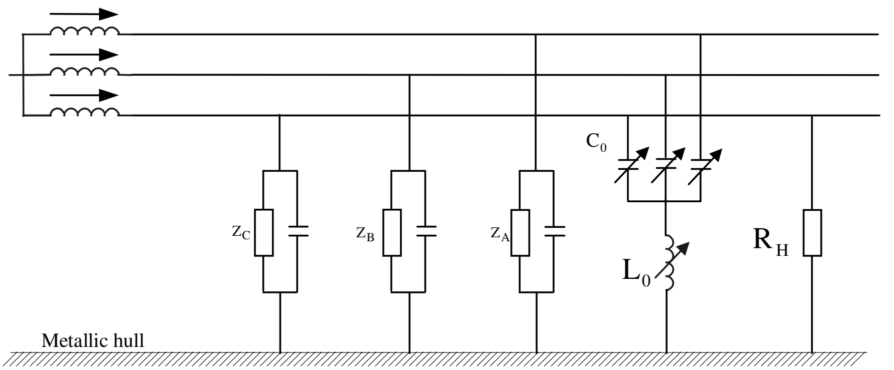

Fig. 3. Circuit diagram of the passive compensation system ($Z_{A,\ B,\ C}$ – grounding impedance in each phase, R_H – human body resistance, C_0 – additional symmetrizing capacity, L_0 – compensating coil)

2. Active compensation

The rule of active compensation is based on inserting three controlled current sources between the phase wires and the hull. By adequately tuning the sources' parameters (amplitude, phase angle), the shock voltage can be reduced to zero, because such sources can vary the distribution of voltages between the phase wires and the hull.

In fact, capacity currents can not be measured in a direct way. Knowledge of transversal capacity values and the identification of the damaged phase wire are necessary to obtain the proper compensation. The other basic problem is a high accuracy in the generation of demanded currents, which is required due to safety reasons.

In described solution, the current source was applied to the four-leg source inverter, as shown in Fig. 4.

Simulated laboratory tests [3] of three-phase, 6- and 8-valve, four-leg inverters as well as one, 12-valve, four-leg inverter, consisting of three one-phase inverters used as active current source compensator of capacity current in IT-type network lead to the conclusions as follows:

- The voltage inverter in a closed control system (hysteresis control) can work as a source for three independent and asymmetric currents;
- Although three-phase, 8-valve four-leg inverter can be applied in an active compensation system, it has some inconvenient properties;
- Using the three-phase, four-leg inverter, consisting of three one-phase inverters as a current source in an active compensation system is the best solution.

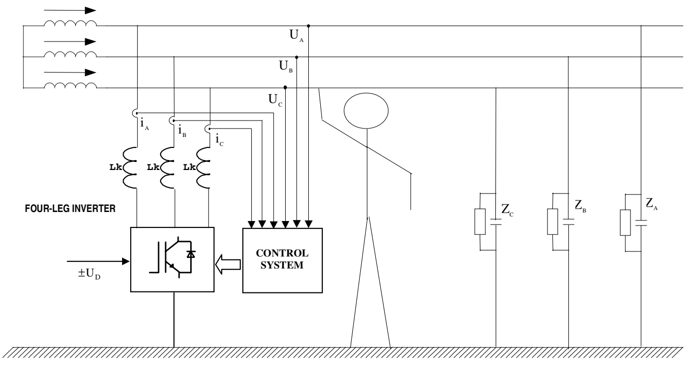

Fig. 4. Circuit diagram of active compensation system in IT-type network using four-leg Inverter ($U_{A,\ B,\ C}$ – voltages between phase wires and hull, $I_{A,\ B,\ C}$ – inverter output currents, $\pm U_D$ – inverter DC supply voltage $Z_{A,\ B,\ C}$ – grounding impedance)

3. Laboratory tests

The concept of using the three-phase, four-leg inverter as a shock current compensator has been examined during laboratory test. The inverter was connected to a model of an IT-type network, fed with a voltage of 3x110 V.

An arrangement of the test stand is presented in Fig. 5. The test stand consists of the following:

- an active compensation system containing:
  - A set of measuring devices of LEM type (CV3-1000 and CT1-T),
  - FPGA and DSP modules as well as set of inverters of the FAL-S1 type,
  - and FPGA and DSP programmers,
- a monitoring system containing a PC with a PLC-1800 card,
- a network simulator of the SSO type, and
- a shock current measuring system of the UPPRC type.

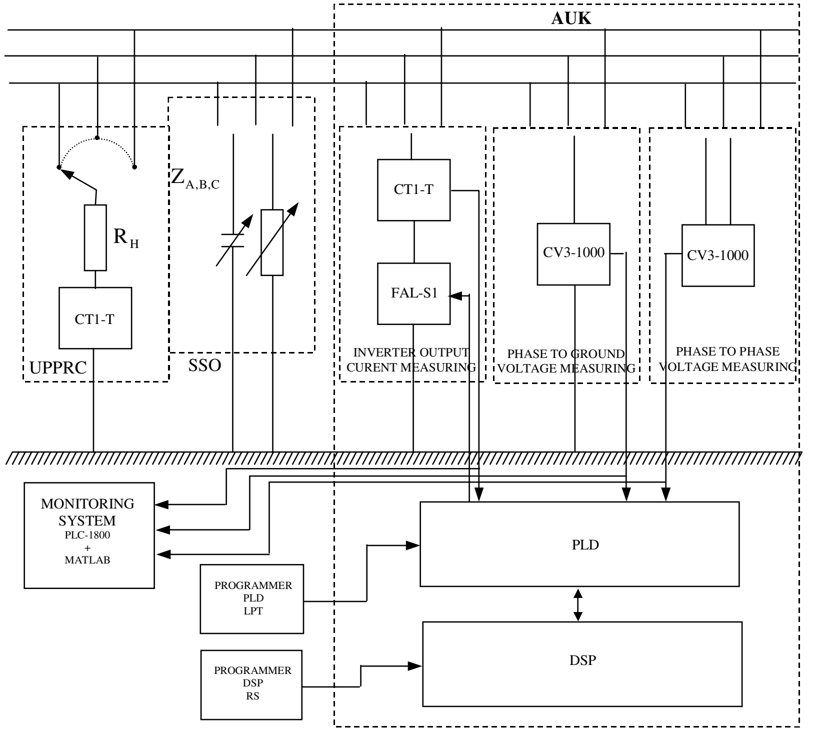

Fig. 5. An arrangement of the research stand

The control system was built using a programmable FPGA structure, type FLEX6000 produced by Altera, and a superior control unit based on a floating-point signal processor, type ADSP-21065L produced by Analog Device. Algorithm of hysteresis control and A/D converters handling was implemented in the FLEX6000 structure, whereas the algorithm of the determination of the demanded values of the current and synchronisation with the network was implemented in DSP.

The route of the instantaneous values of inverter output currents during compensation, obtained with a sampling frequency up to 1 MHz, are shown in Fig. 6. The routes, apart from the basic frequency of the 50 Hz component, also contain a high frequency component dependant on the switching frequency of inverter valves. The routes of the shock current, with and without compensating 12-valve inverter, are presented in Fig. 7.

The obtained results confirmed the possibility of the application of the 12-valve, four-leg inverter in a shock current compensation system. The maximum value of the shock current after compensation is less than the boundary value of self-releasing, equal to 10 mA.

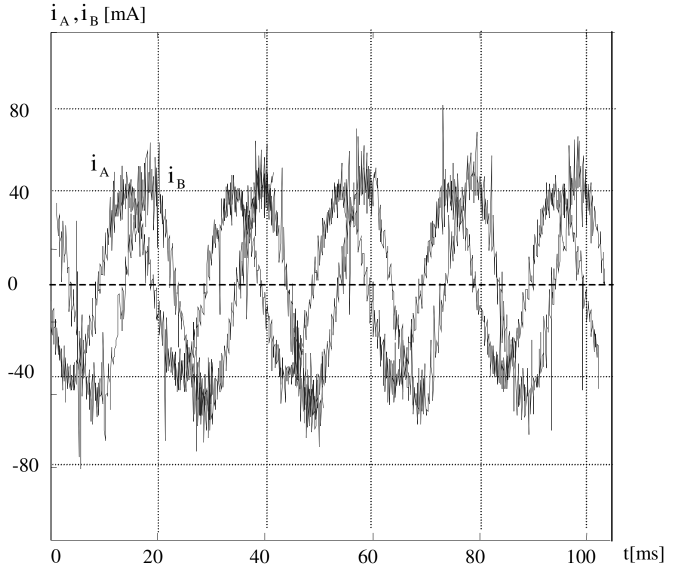

Fig. 6. The routes of the instantaneous values of inverter output currents during compensation (Laboratory test results)

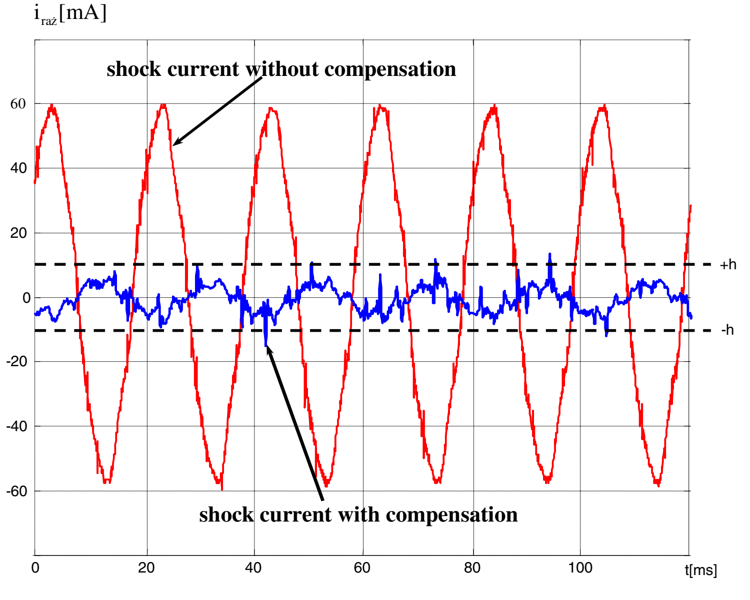

Fig. 7. The routes of the instantaneous values of the shock current with and without compensating

Conclusions

Using a 12-valve, four-leg inverter in an automatic shock current compensation system allows the enhancement of the safety conditions on ships connected with the risk of electric shock or fire caused by the leakage currents of capacitive nature.

Considering the obtained laboratory test results and the continuation of research, the industrial production of an automatic shock current compensation system is recommended.

References

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Reviewer:
Janusz MINDYKOWSKI

Nowa aktywna metoda ochrony przeciwporażeniowej w sieciach okrętowych niskiego napięcia: badania eksperymentalne

Słowa kluczowe

Ochrona przeciwporażeniowa, kompensacja parametryczna, kompensacja aktywna, falownik czteroprzewodowy.

Streszczenie

Powszechnie stosowane w okrętownictwie sieci elektryczne z izolowanym punktem zerowym z powodu występowania pojemności doziemnych (powodujących wzrost prądu rażenia) nie zapewniają ochrony przeciwporażeniowej. Autor prezentuje nowe podejście do rozwiązania tego problemu.

Nowa idea aktywnej kompensacji prądu rażenia człowieka polega na włączaniu pomiędzy przewody fazowe a kadłub statku aktywnych źródeł prądu. W proponowanym rozwiązaniu jako źródła prądowe został wykorzystany falownik w układzie czteroprzewodowym.

W referacie przedstawiono układ stanowiska badawczego, przeznaczonego do eksperymentalnego sprawdzenia koncepcji aktywnej kompensacji prądu rażenia w sieciach okrętowych niskiego napięcia, oraz wyniki badań.