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RIGA TECHNICAL UNIVERSITY
1862

Transport and Aerospace Engineering

ISSN 2255-9876 (online)
ISSN 2255-968X (print)
August 2017, vol. 4, pp. 96–105
doi: 10.1515/tae-2017-0012
https://www.degruyter.com/view/j/tae

Ship Power System Analysis Based on Safety Aspects

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Abstract **– This article analyses the reasons for the reduction of insulating resistance, processes influencing them and isolation diagnostic methods. It provides a short description of electrical safety situation on ships with isolated neutral electrical power systems. It also covers the methods of protecting personnel from electric shock or preventing ignition or arching damage at the fault location with the help of fault current compensation. Principal fault current compensation circuit diagrams are analysed by using the minimum value and time of transient fault current as criteria.**

Keywords **– Compensation methods, electrical power system, insulating resistance.**

I. INTRODUCTION

Safety and security of electrical power systems during the period of technical maintenance occupy an important place in transport operation. Annually, an increasing number of consumers of electricity indicate the need for special equipment to be developed for vessels with the aim to ensure electrical safety.

Security of electrical power directly depends on the reliability of equipment and electricity supply chain from the generator to the consumer. Insulation resistance is an indicator of equipment reliability. This paper analyses the reasons for insulation resistance reduction, processes that affect such a reduction, insulation diagnostic methods, as well as possible directions of increasing the reliability of power systems. This field of research on maritime transport was launched in the late seventies of the last century. However, to date, there is no single system of protection that would cover all electrical equipment of the vessel.

II. REASONS FOR INSULATION RESISTANCE DECREASE

Maritime transport involves the use of almost all types of electrical equipment which is generally used in industrial facilities: generators and electric motors, switching and distribution equipment, protective devices, semiconductor converters, voltage transformers and power converters, electrochemical converters – batteries, electrical protection, automatic control and diagnostics, reactive power filters and device power restrictions, drivers, couplings, bushings, various distribution boxes, lighting and heater installations, etc.

External and internal factors have a significant impact on the reliability of power systems. Maritime climate can be characterized by a consistently high relative humidity. The absolute humidity varies depending on the geographical location of a vessel. Unlike the continental areas located in the same latitudes, absolute and relative humidity varies greatly and depends on the amount of evaporated water. Vibration, mechanical shocks, radial and axial shift, different types of vaporizations, exposure to electromagnetic fields can also be the reason of electrical power safety reduction. The most important and most common reason of electrical equipment damage, among the factors that affect the quality of electrical insulation, is high humidity (especially in tropical climate). Rapid temperature variations cause the electrical condensation effect. The concentrations of salt and pollution may cause the deterioration of material electrical properties. At operating temperatures, chemical reactions take place causing gradual changes in isolating material structural characteristics, which leads to the constructive change of the material. As the temperature increases, these processes accelerate reducing the equipment life. Insulation resistance is one of the most important measurements of ship electrical systems and the best indicator of overall equipment condition. The international regulations stipulate various requirements to the insulation resistance [1], [2].

To evaluate insulation (dielectric) performance and possible applications, it is necessary to explore physical phenomena occurring in materials when they are exposed to electromagnetic fields, and to set basic electrical, mechanical, thermal, humidity and physicochemical properties, particularly:

- dielectric electrical properties;
- dielectric polarization;
- dielectric electrical conductivity;
- dielectric losses;
- spark-over;
- dielectric mechanical properties;
- dielectric thermal properties;
- dielectric humidity properties;
- water absorption;
- dielectric physicochemical properties [3], [4].

III. INSULATION DIAGNOSTICS

Traditional methods, such as insulation resistance, absorption or polarization coefficient, measurements of the dielectric loss angle tgδ, have become classical non-destructive diagnostic methods [5], [6]. The measurement of insulation resistance is based on measuring resistance by temporarily using voltage for up to one minute. The measurement voltage is usually up to 5000 V.

The polarization index of the absorption coefficient c_{abs} or polarization coefficient is defined as a ratio between isolation resistance values obtained in 15 seconds (1 minute) and 60 seconds (10 minutes) after connecting voltage to isolation. Some studies point to the parabolic dependence of this coefficient on the aging of insulation, hence the misinterpretation of results takes place [7].

The dielectric losses angle, also the dielectric losses factor, is an angle between active and capacitive current components that flow through the insulation. The higher the active current component in relation to the capacitive one, the higher the angle of current, and the insulation dielectric properties are considered to be poor. This method should be analysed in detail as one of the possible methods which can be used for maritime transport.

Knowing the capacity of the single elements of the power system of a ship, which is obtained through calculations or direct measurements on board, the value of the total electrical energy systems of vessels can be obtained as a simple sum of these elements. Such a summation is useful for each operating mode of a ship's power plant. This approach was initially offered for an operating mode where the sum of capacities in different modes was calculated for a series of power systems of ships with a voltage of up to 1000 V. The results of these calculations are also used in operating modes [8]. This diagnostic test presents a known way of assessing the cable condition [5]. To minimize the possibility of incorrect measurements during the installation, it is necessary to pay attention to the measuring instruments. The measurement data analysis provides information on the condition of the cable.

Partial discharge isolation is characterized by the degradation of insulating material under the influence of an electric field. The partial discharge characteristic-excitation and damping voltages, as well as the size of the discharge in the coils, are determined by measuring the partial discharge [9].

Measurements of dielectric conductivity (spectroscopy) at various frequencies allow to obtain a permeability spectrum. This spectrum characterizes the dielectric properties of a material in a given frequency spectrum and allows to determine the tgδ [10].

IV. MAIN DISADVANTAGES OF DIAGNOSTIC METHODS

Classical methods and tests with high voltage or alternating voltage are the most commonly used diagnostic methods. This is mainly due to relatively simple data analysis and evaluation of the result. However, these methods have significant disadvantages [11], [12].

With the deterioration of insulation, the absorption coefficient decreases and approaches 1 reaching its minimum. However, as the aging process continues, the absorption coefficient starts to increase. The obtained result may be inaccurate from the diagnostic point of view.

On the other hand, high-tensile testing activates aging processes in the insulation, even if these processes have not yet begun in the insulation [13]. Therefore, this method is considered negative as a diagnostic technique.

The dielectric spectroscopy method provides a more complete description of the dielectric properties of insulation compared to resistance measurements and high voltage tests. The disadvantages of this method are analogous to those of the method of dielectric loss angle: measurement results are affected by the defects of compounds and possible contamination, as well as the effect of corona [14]–[16].

Also, the measurement of partial discharge requires an environment with very small external influences. The analysis of partial discharge is relatively complicated, although its popularity is great [17]–[19]. One of the disadvantages of the methodology is a philosophical aspect – finding damage by searching partial discharge. The search usually takes too much effort. Therefore, the method can replace the above-mentioned destructive high-voltage test and inherit the disadvantages of destructive methods.

Chemical analyses are usually performed if the results of classical methods indicate significant degradation processes in the insulation thus helping to draw the final conclusion. However, this conclusion is given only after the analyses are performed, which reduces the attractiveness of this method. The influence of external factors on samples should be mentioned as another drawback of chemical analyses, as well as the cases when samples are taken only from the lower part of the device, which does not show the condition of isolation in the entire piece of equipment. In some cases, a chemical analysis requires an isolation sample. When taking such a sample it is possible to damage the insulation monolith.

V. ANALYSIS OF ELECTRICAL POWER SAFETY ON A SHIP

In the case of ship's low voltage power supply, electric networks with isolated neutrals are mainly used. From the above-discussed diagnostic methods, classic methods and tests with high voltage are used onboard. In these systems, the insulation resistance of the system in relation to the ship hull is controlled. This is done by insulating resistance control equipment, and this process is continuous. Insulation control devices when signalling about the insulation damage do not provide the system restoration safety, reduction or elimination of possible or resultant adverse effects. However, electrical safety is strongly affected by a cable leakage capacitance currents [20]–[24]. These currents depend on the total length of the cabling system and on the insulation material and technical condition. The equivalent scheme of the ship's electrical supply systems with an isolated neutral electrical safety analysis is shown in Fig.1.

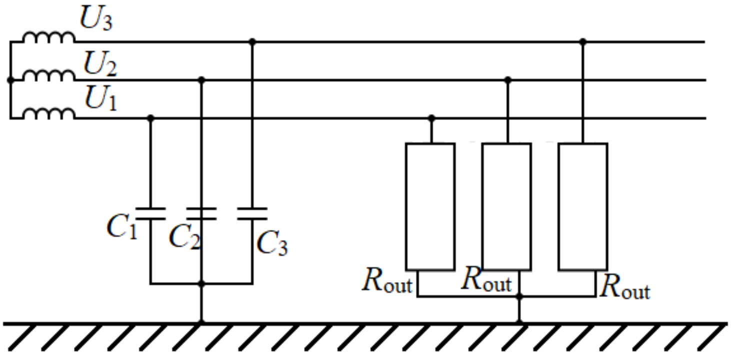

Fig. 1. Equivalent scheme of the ship's electrical supply systems with an isolated neutral electrical safety analysis.

Inspections of the ships' electrical grid [20], [21] show that the total electrical power versus the ship's hull in phase 1 of the network varies from several μF to 15–20 μF for different types of vessels. Also, depending on the time of year, the ambient temperature and relative humidity of the ship's power supply system capacity is characterized by drift up to ±(10 to 15) % [21]. Greater network capacities sum up. The effect of these factors can have a significant effect on the automatic and manual modes of the automatic faultless operation of the ship's electrical equipment. A reduction in fire safety is another potential negatively effecting factor.

Assessing the potential negative consequences, another important aspect should be considered – the possibility of crew members to get under the influence of electric current.

The following techniques can be used to protect personnel against the effects of electrical shock by touching metallic conductive parts that may come under voltage due to the isolation fault [21]:

- protection grounding;
- potential equalization;
- unlocking protection;
- isolation of conductive parts;
- electric separation of networks;
- use of small voltages;
- ground-current power compensation;
- individual protection methods, etc.

VI. ANALYSING THE METHODS OF COMPENSATING THE GROUND FAULT CURRENT OF A SHIP'S ELECTRICAL SYSTEM

The possibilities of compensating the ground fault currents in a ship's electrical network have been known for a long time. They started to be studied more closely in the 70s in the former USSR. Here, it is necessary to mention a number of authors, for example, G. Kitajenko, G. Manilov, N. Nikiforovsky, J. Tyachenko, J. Brunavs and others [20]–[22], [25]. The further research of this problem continued in this century [26], which became the basis and the starting point for further development and progress of this issue.

The methods of ground fault compensation are characterized by the idea of compensating the ground current with another opposite direction current. In the three-phase system, this opens the phase separation of the system (120°), which, in combination with inductive, resistive and capacitive circuit elements, allows the circuit to receive the compensation needed. These options can be better described by a vector diagram (the hull's closure has occurred in phase B), Fig. 2.

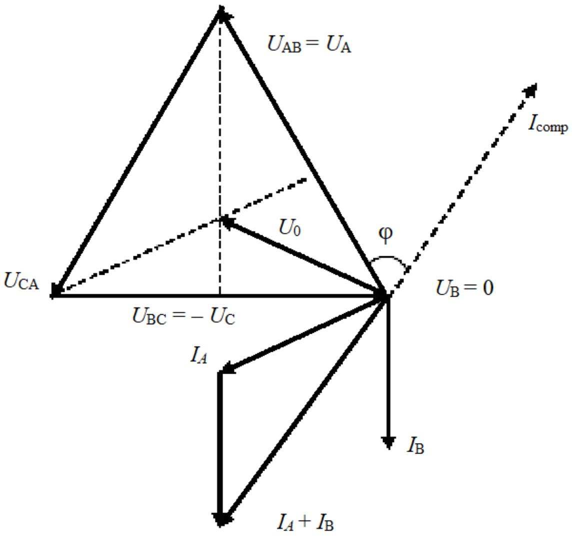

Fig. 2. An explanatory vector diagram of ground fault compensation.

The vector diagram (Fig. 2) shows full short circuit current compensation. It shows both the compensated current and its value. In the case of $I_A = I_B$, $I_{comp} = \sqrt{3}I_A$, but φ = 60° [26].

After evaluating the vector diagram, several possible directions for compensating methods were marked out using the passive elements *R*, *L* and *C* of the scheme.

1. Inserting a throttle with a low equivalent active resistance between the generator neutral and the ship’s hull (Fig. 3, Fig. 4).
2. Simultaneous activation of two throttles with low equivalent active resistance in both the lagging and the leading phases (Fig. 5, Fig. 6).
3. Turning the throttle on the leading phase and the resistor on the lagging phase (Fig. 7, Fig. 8).
4. Inserting the low-grade throttle into the leading phase (Fig. 9) [26].

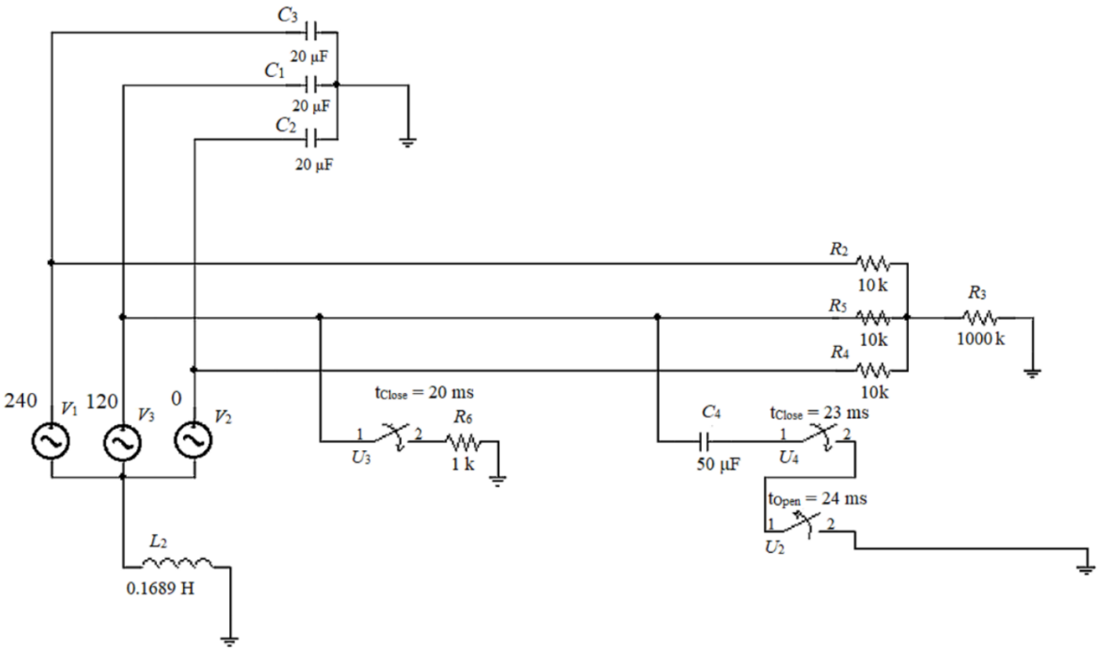

Fig. 3. Equivalent active resistance between the generator neutral and the ship’s hull and simulating.

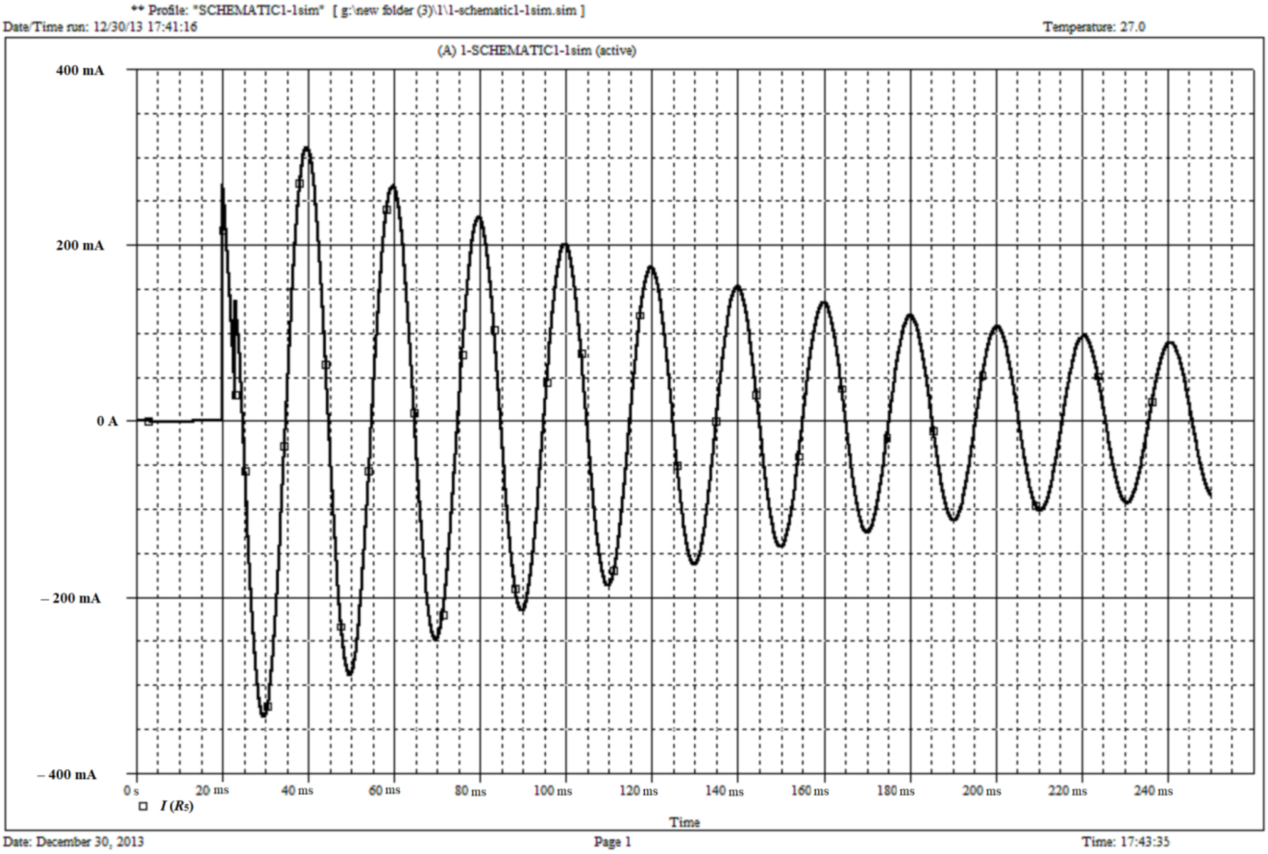

Fig. 4. Simulating of the equivalent active resistance between the generator neutral and the ship's hull.

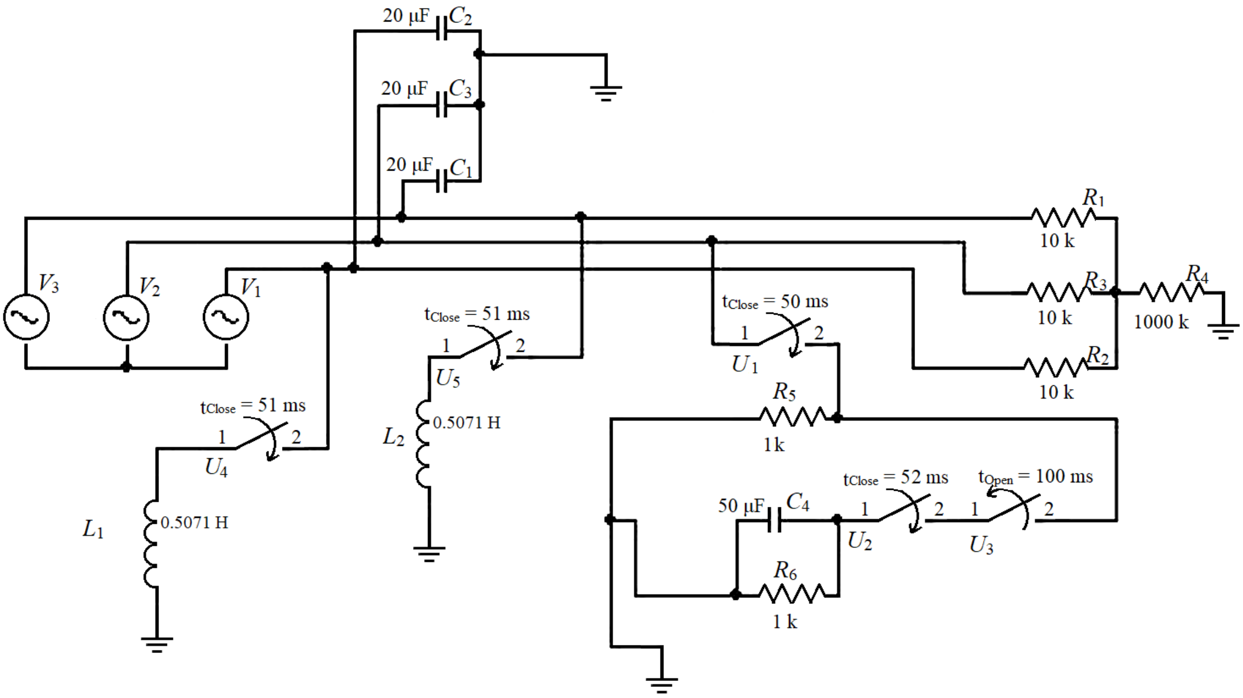

Fig. 5. Ground fault active compensation system using two throttles with low equivalent active resistance in both the lagging and the leading phases.

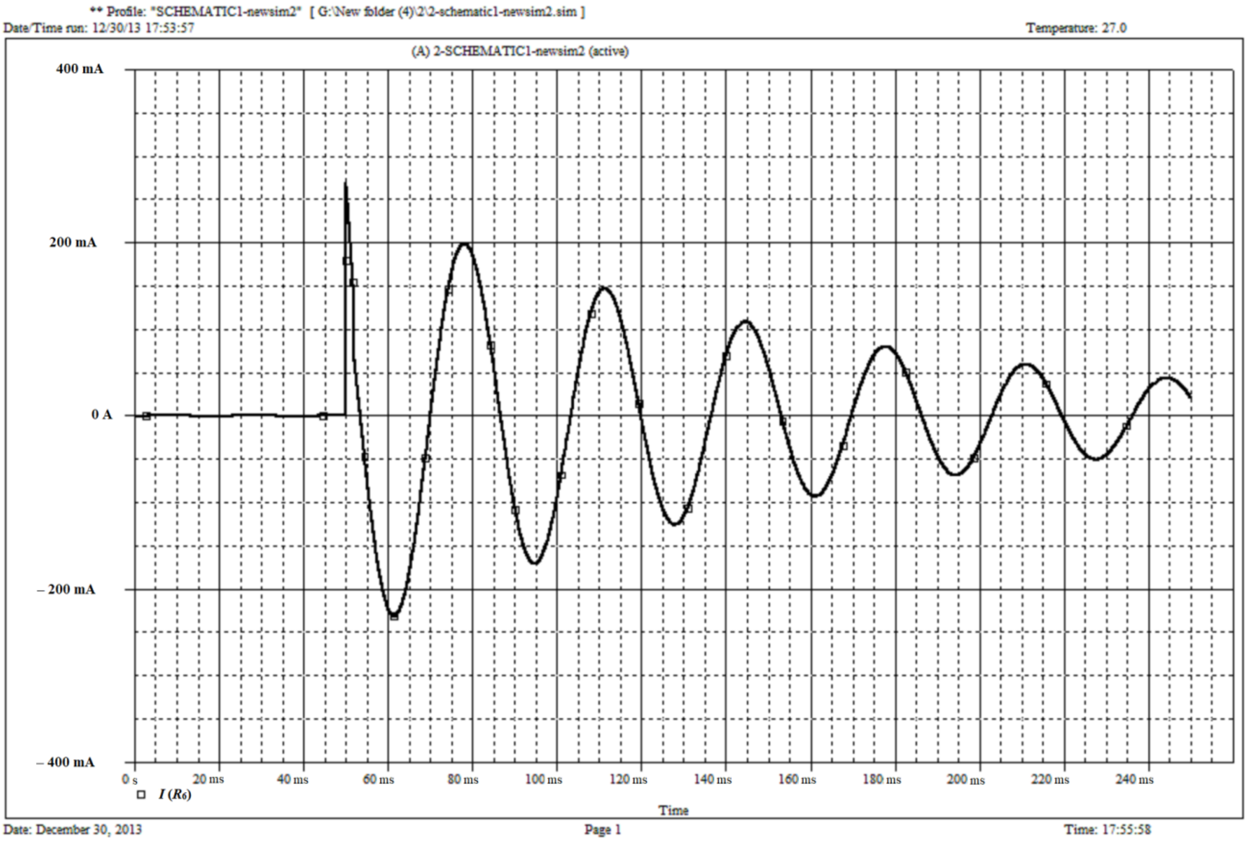

Fig. 6. Simulating of the ground fault active compensation system using two throttles with low equivalent active resistance in both the lagging and the leading phases.

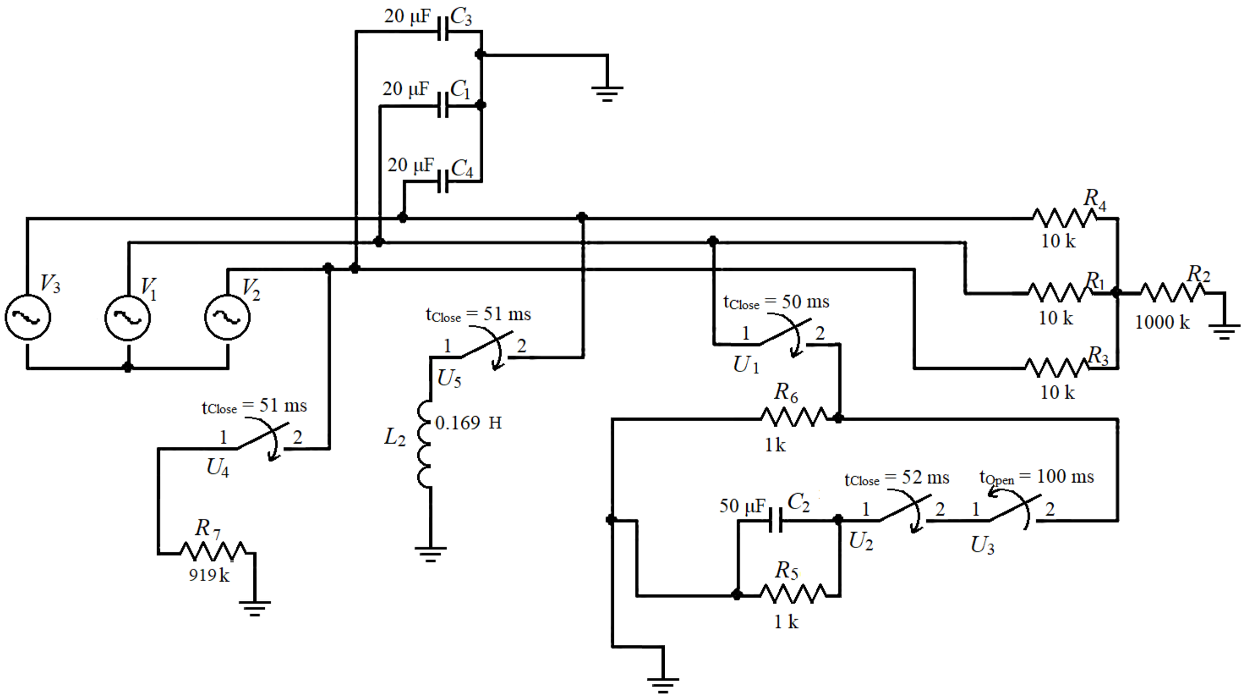

Fig. 7. Ground fault active compensation system using throttle on the leading phase and the resistor on the lagging phase.

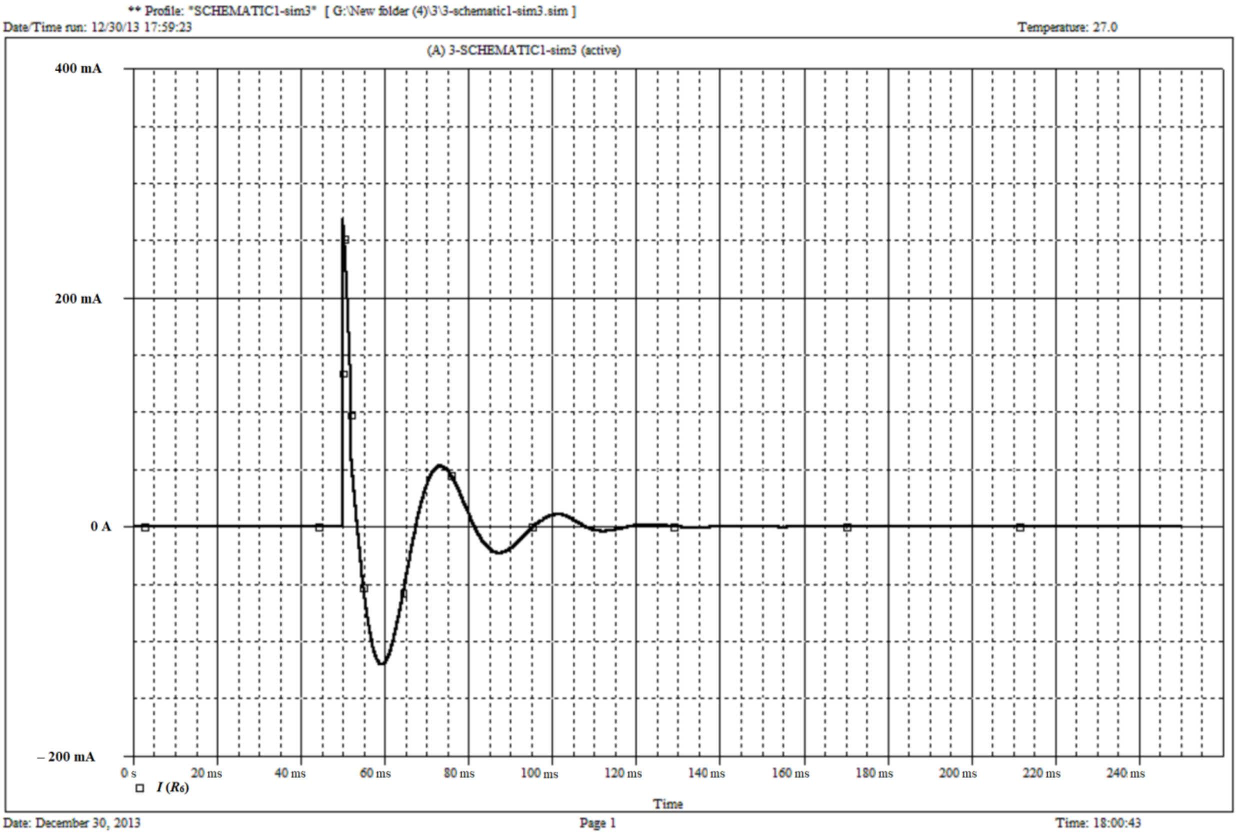

Fig. 8. Simulating of the ground fault active compensation system using throttle on the leading phase and the resistor on the lagging phase.

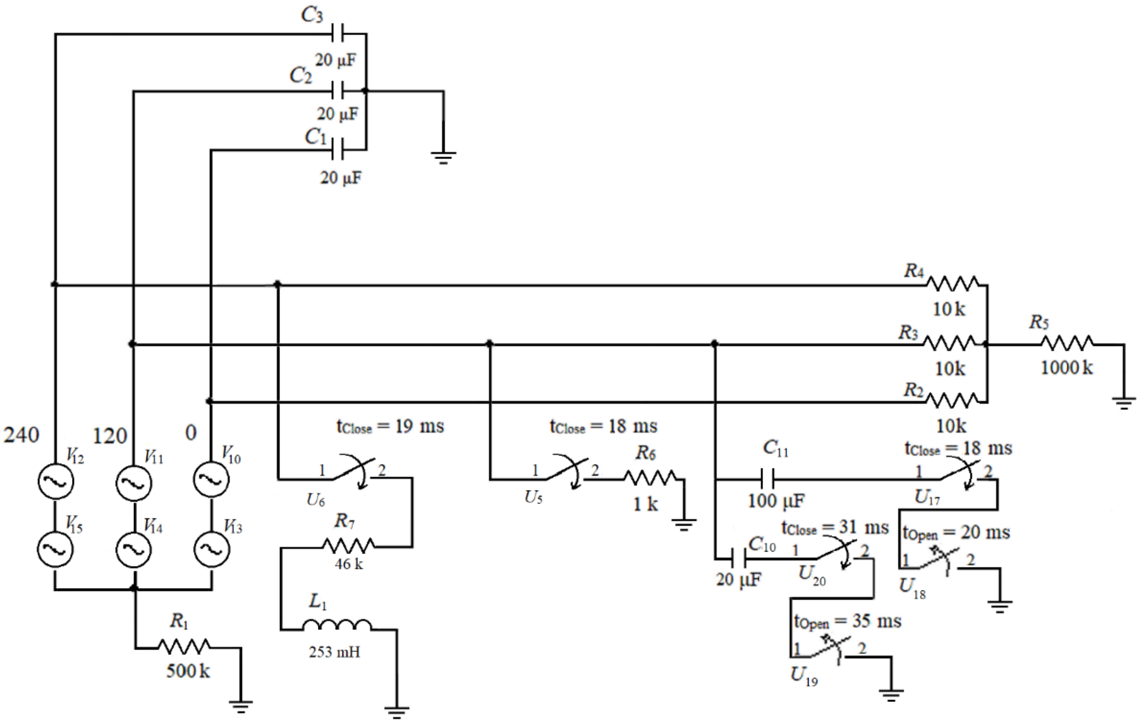

Fig. 9. Ground fault active compensation system.

The results of the computer modelling [26] give an opportunity to choose the optimal power protection scheme, as well as to optimize the parameters of the selected circuit elements.

VII. CONCLUSION

Based on the obtained results, the simplest compensation option corresponds to the generator's neutral and hull connection. However, using such a scheme it is not possible to compensate for the complete connection of the hull due to the active loss of the real throttle, which necessitates the improvement of the scheme. On these simple examples, simulating processes using the PSpice platform, the posed question seems solvable. Further investigation of this issue is connected with the determination of the exact operation time of the whole system, the change in the scheme to compensate for active losses, and the possibility of the entire system as a whole. This necessity is justified by the fact that for the system to work without violating the integrity of the initial state it is necessary to fulfil the following conditions:

- creation of artificial neutral;
- devices that detect leakage current;
- schemes of the compensation system.

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