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To cite this article: O O Rubanenko *et al* 2024 *IOP Conf. Ser.: Earth Environ. Sci.* **1415** 012118

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Study of double short circuits on earth in 10 kV power grids with isolated neutral and with high level penetration RES

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Abstract. Proposed study described positive influence of high level penetration of renewable energy sources in distributed electrical networks for power system in total in war conditions. Faults in transmission power lines are analysed and shown depend on level voltage. The paper presents the results of studies of double earth faults in 10 kV networks with an isolated neutral in the MATLAB program package.

1. Introduction

Reliability indicators of power supply systems as a whole are largely determined by the level of reliability of distribution electrical networks voltage of 6-35 kV. In previous work was indicated problem of 0.4 kV power grids [1]. According to various literary sources, the emergency in networks voltage of 6-35 kV, operating in the mode with an isolated or resonance-grounded neutral, is largely connected with the shorting of the phases of the lines between themselves and to the ground [2].

The analysis of damage and experience of operation of 6-35 kV networks [3–5] allow us to made the following conclusions:

- finding and eliminating places with weakened insulation is a complex process, as it requires multiple disconnections of the same network elements;
- a significant share of damage in networks is damage to support and through insulators and switching devices [6, 7];
- specific damage of switching devices from internal overvoltages is quite high and only 3 times lower than from lightning overvoltages [8].

In three-phase electrical networks with an input switch and lines fed from 10 kV substation busbars, during different single-phase short-circuits on two lines, there are cases of non-selective operation of the input switch protection, in the event that the current of the input switch exceeds the tripping set point of the current protection that acts on this switch. At the same time, such an excess occurs before the conditions for tripping of current protections are met, which act to

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disconnect the circuit breakers connected to the buses and the input circuit breaker. Therefore, the serviceable line will be turned off by the input switch.

2. Importance of distributed sources of generation in times of war

RES were implemented in distributed power grids last few years. Also, the green energy market is developing rapidly because more and more people understand and want to pass on our world to their descendants in at least as good a condition as we received from our parents and distributed power plant can be more safety, then nuclear power plants or condensing heating plants. Other reasons, that see from global surveys that equipment used in green energy is becoming cheaper and more affordable every year. More windmills and solar panels appearing on our streets and in our homes, because energy communities is developing. But it is imported to note that at the current level of development, green generation alone will not be able to meet the full demand for electricity. A lot of RES and distributed power grids were damaged under war attacks also (figure 1 and figure 2).



Figure 1. Damaged photo-voltaic power station.

In blog materials of Yurii Kasich for Energy Club was noted, that small sources of energy are able to provide electricity to settlements close to them, the enemy will of course be able to damage them, but in most cases thermal power plants, hydroelectric power plants, distribution substations are under attack. The lower the voltage class of power lines or substations, the greater their number and the less known to the aggressor. It is there, in those networks, that the distributed small generation of Ukraine (solar power plants, wind power plants, bio-fuel

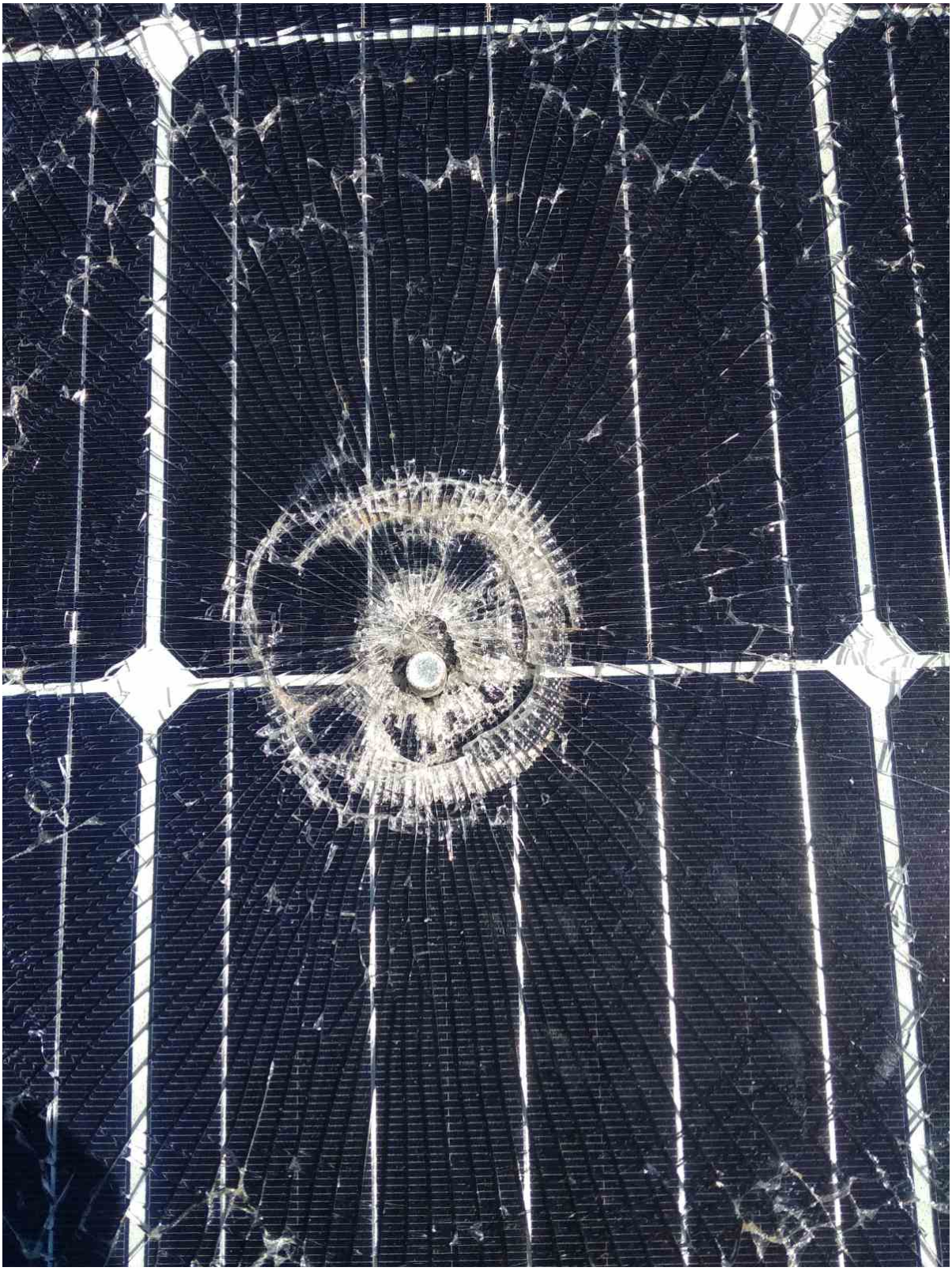


Figure 2. Damaged solar module.

installations, small hydroelectric power plants) is located, which should not be forgotten in today's conditions. These sources, in most cases, do not require the use of fossil fuels and the entire infrastructure associated with fuel supply. RES can work in off-grid mode. Dispersion of distributed energy sources of electrical energy is a valuable indicator – it is impossible to damage them at the same time, and in practice it is impractical (the costs far exceed the cost and benefits). Each individual distributed source of electrical energy does not represent "systemic, or national" value, but the whole point is that all of them (small sources) together are valuable as a general source of energy in Ukraine. Such sources are able to provide electricity to nearby settlements with all infrastructure (hospitals, communications, etc.) for an almost unlimited time [9]. High penetration of RES in distributed power grid forces up to development of effective means of researching reasons of over-voltages in these networks and find approach to decrease over-voltages.

3. Analysis of 10 kV network damage data

The main causes of damage to 10 kV transmission lines are

- in overhead networks: damage to line poles, overlapping and damage to insulation on poles, damage to cable couplings during the transition of overhead lines to cable lines;
- in cable networks: damage to insulation at substations, damage to terminal and connecting couplings, damage during excavation works in the vicinity of the cable route, damage to cables.

The most vulnerable element of the power grid to internal overvoltages are cables, in particular, the places where they are connected to each other and to other elements of the grid. Therefore, a significant proportion of damage is associated with overvoltages during single-phase earth faults in cable networks (according to data, 77 percents of the number of damages [8]).

The analysis shows that the causes of damage to cable lines in most cases are: mechanical damage, factory defects, defects in the installation of couplings, violations of the technology of laying cable lines, and extreme operating conditions. Single-phase short circuits occur, as a rule, in places of defects in the insulation of cable lines and substation equipment due to aging of the insulation, failure to comply with the technology of manufacturing insulating structures at factories, standards and instructions for the installation and operation of equipment, as well as mechanical damage, which at the time of their occurrence leads to only a partial reduction in electrical strength.

Internal overvoltages often occur during transients from an intermittent arc and are dangerous for the insulation of electrical installations due to their duration and the breadth of coverage of the network associated with the damage site.

The process of insulation aging is greatly influenced by technological and operational factors. Technological factors include hidden defects in manufacturing and installation; the use of materials that do not meet the requirements for them; changes in the modes of thermal vacuum treatment of insulation after manufacturing; and crimping defects. Operational factors, if we exclude accidents caused by human error, include, first of all, overloads: short-circuit currents, switching and lightning surges. Overloads lead to the emergence of various kinds of defects, which then develop in the operating mode. The complex organic insulation of cables, connecting and termination cable couplings tends to accumulate defects. The effect of over-voltage on such insulation is accompanied by a decrease in electrical strength, which is not restored to its original state after the over-voltage ceases. After the over-voltage action, the cumulative development of weaknesses (defects) occurs, and a breakdown may occur with further accidental over voltages. An inter-phase short circuit occurs, as a rule, after multiple accidental actions. In a complex set of locations with weakened insulation, a network disturbance occurs when at least one location with the most weakened insulation (with the largest defect) finally loses its electrical strength.

To ensure sufficiently high operational reliability, measures must be taken to strengthen the insulation and limit over-voltages. The second way, as less costly, is more profitable.

The most frequent type of internal over-voltage in 6-35 kV networks is over-voltage associated with single-phase earth faults, accounting for up to 80 percents of all types of accidents (figure 3). In recent years, the average specific rate of damage to grids due to electrical causes has increased by about an order of magnitude and, according to operational experience, taking into account the equipment of power grids that was broken during tests, is more than 100 damages for every 100 km of the grid per year. In the overwhelming majority of cases (up to 90 percents of the number of disruptions to the normal operation of the network), the damage begins with an insulation breakdown to the ground, and then more than half of them (up to 70 percents under the circumstances) develop into inter-phase short circuits or multi-location insulation breakdowns with group failure of electrical equipment.

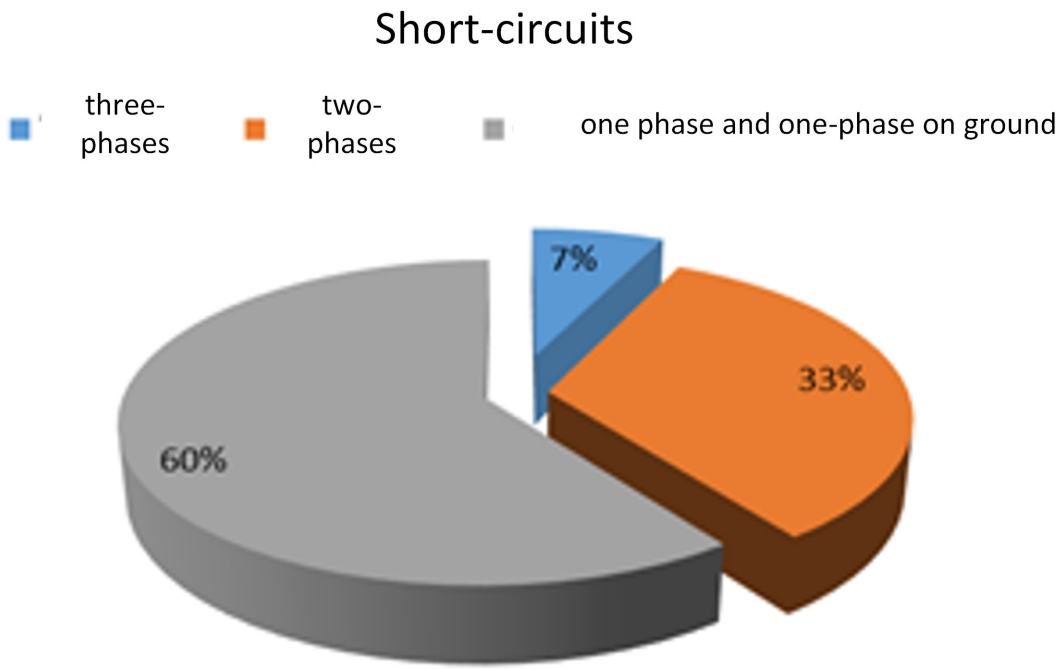


Figure 3. Diagram of damage to power lines with a voltage of 6-10 kV.

The biggest danger is posed by arc over-voltages that occur in the network when the arc burns in an intermittent manner at the point of breakdown of phase insulation to earth, as the arc can damage the insulation and cause a two- or three-phase short circuit. According to some reports, about 60 percents of earth faults in these electrical networks are of this nature. The extinguishing and ignition of an intermittent arc causes complex transients, the intensity of which, as operating experience shows, depends on such factors as arc characteristics, capacity, inductance, circuit resistance, etc. In networks with a predominance of cable lines, outages due to the transition of a single-phase fault to an inter-phase fault reach 70 percents of the number of outages. An increase in earth fault current leads to an increase in the probability of single-phase fault to inter-phase fault directly at the point of arc burning.

From the experience of operating 6-10 kV cable networks, there are repeated cases of multi-location insulation breakdowns under operating voltage. There are cases of simultaneous breakdowns in 4-5 points of the lines. First, the presence of insulation breakdowns under operating voltage indicates an insufficiently high level of insulation. Secondly, the presence of multiple breakdowns indicates the existence of over-voltages. Thus, despite significant insulation

reserves, the accident rate of 6-35 kV networks due to internal over-voltages is quite high. Therefore, the development of effective means of studying over-voltages in these networks and means of reducing them is currently relevant [10].

The goal of the research is to investigate the causes of false activations of relay protection of 10 kV power transmission lines during double earth faults using MATLAB. Therefore, the purpose of research is relevant.

Data on the features of operation, damage and damage protection of 10 kV lines are given in [8]. Features of the protection of equipment of electric power systems are considered in [11]. The processes of changing currents and voltages in lines with an isolated neutral and protection against their damage during earth faults are discussed in [7, 12].

Relay protection in 6–10 kV power grids s with an isolated neutral (including a neutral grounded through an arc extinguishing reactor) must be provided with relay protection devices against multi-phase circuits and single-phase circuits to the ground). Protection against multi-phase short-circuits should be provided in a two-phase version and connected to the same phases throughout the network of a given voltage to ensure that in most cases of double earth-faults, only one point of damage is turned off. Protection should be performed with one, two or three relays depending on the requirements of sensitivity and reliability. As a rule, two-stage current protection should be installed on single lines with single-sided power supply from multi-phase circuits, the first stage of which is made in the form of current cut-off, and the second – in the form of maximum current protection with an independent or dependent time delay characteristic.

On non-reactor cable lines with one-way power, departing from the busbars of power plants, current cut-offs must be performed without time delay and the area of their effect must be determined from the condition of short-circuit shutdown, accompanied by residual voltage on the busbars of the specified power plants below 0.5–0, 6 nominal. To fulfill the specified condition, it is allowed to perform non-selective protection in combination with Automatic Transfer Switch (ATS) or automatic circuit reclosers (ACRs) devices, which fully or partially correct the non-selective effect of protection. It is allowed to install the specified cut-offs also on the lines departing from the busbars of substations and feeding large synchronous electric motors. Current cut-offs are not allowed on lines whose switches are not designed to turn off the short-circuit to the reactor. On double-fed single lines with or without bypass connections, as well as on lines forming part of a ring network with a single point of supply, it is recommended to use the same protections as on single-sided fed lines, performing them directional if necessary. In order to simplify protections and ensure their selective action, it is allowed to use automatic division of the network into radial sections at the time of damage with subsequent automatic restoration.

4. Simulation of the mode of a three-phase 110/10 kV network in MATLAB

A model of a three-phase 110/10 kV network was built using Matlab. Three lines are connected to the 10 kV bus, on which switches Q1, Q2, Q3 are installed. The input switch is marked QBB. The load of the lines is 600, 500, 400 kW, according to lines 1-3. The model simulates single-phase short circuits on lines with the first (line 1) and second breaker (line 2). During the simulation of a short-circuit at a given time, a transient process occurs, the model allows analyzing the parameters of this process, considering the processes in a certain period of time. With the help of models of measuring devices and the “Scope” element, we can study the graph of current and voltage at the desired moment in time in the examined node of the circuit. For example, by installing, after the input switch, a three-phase measuring device connected to the “Scope” element, the model allows you to obtain a current oscillogram (figure 4). The network diagram is shown inlabelThe diagram of the studied network Consider figure 4, “Scope” built an oscillogram of three-phase current: yellow line – phase A, blue – phase B, orange – phase C.

In the study was simulated the short circuit of phase A of the first line and the short circuit of phase B of the second line at a time of 0.2 s. The maximum value in phase A, the first line,

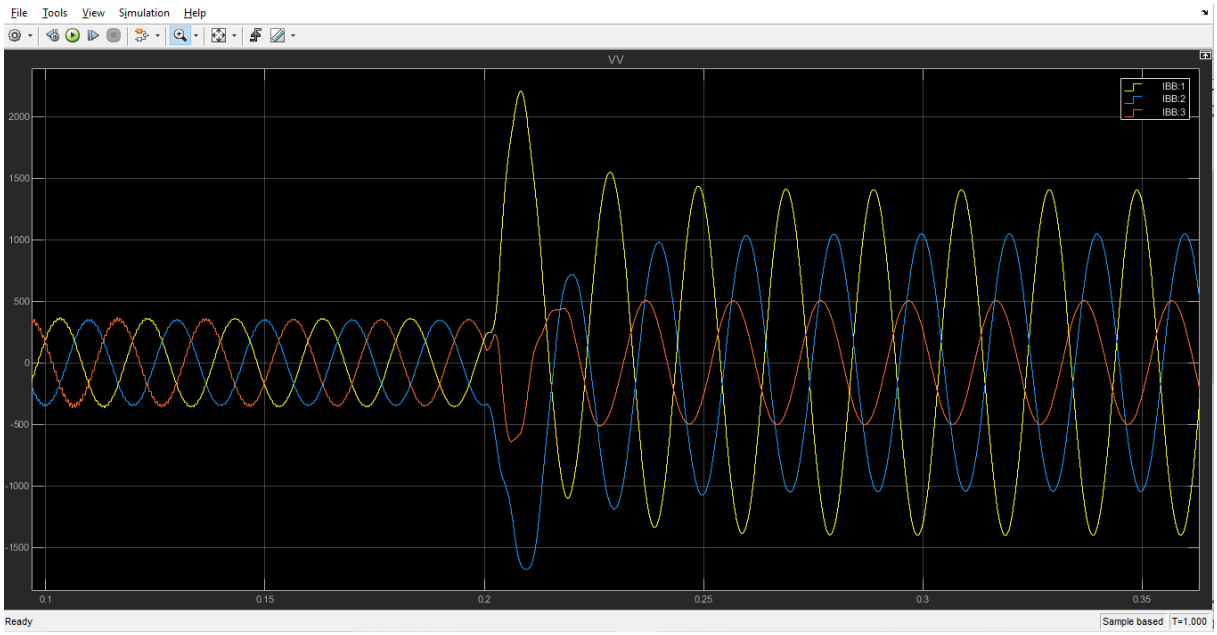


Figure 4. Current oscillogram obtained using "Scope".

is 2300 A, and in phase B, the second line, 1905 A. On the input switch, the same values were equal to 2206 A and 1680 A, respectively. Values in short-circuit mode have increased by 30 – 40 times.

The calculated values of the maximum current protection settings for phase A of the first line, phase B of the second line and for the input switch are shown in table 1.

Table 1. The calculated values of the maximum current protection settings for phase A of the first line, phase B of the second line and for the input switch.

Name	**The calculated values of the maximum current protection**
A	300.3
B	264.5
Input	1322.75

For clarity, a graph of the K coefficients is plotted (figure 6), showing how many times the short-circuit current is greater than the short-circuit current.

The graph shows that the excess of the current in the damaged overhead line over the over-current protection set-point of this overhead line, during double faults, can occur earlier, by 0.004 s, than the increase in the current in the input switch for certain values of the overhead line and short-circuit parameters. Therefore, it is necessary to set a delay in the operation of the input circuit breaker so that it does not trip the undamaged lines. The graph shows what value of the delay time in the operation of the recloser should be set (taking into account the time of the selectivity degree, to ensure error-free operation of the protection. The time selectivity degree of the recloser takes into account the operating time of the circuit breakers and the errors of the time relay. According to the graph, the delay time is 0.05 s, as the transient process ends and the steady-state short-circuit mode begins.

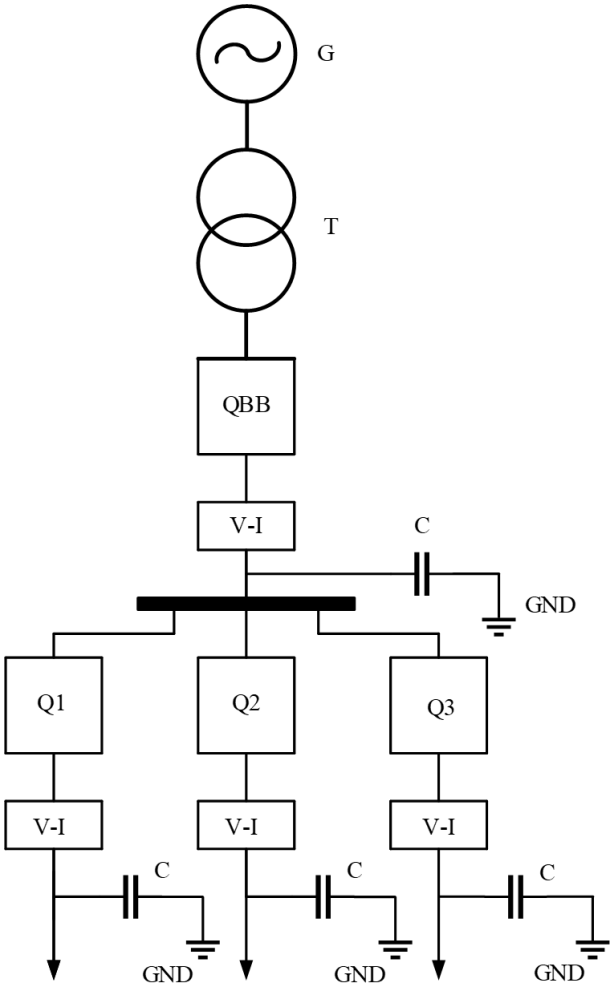


Figure 5. The diagram of the studied network.

5. Conclusions

According to the results of the analysis of double short circuits in the power line, the current in the damaged power line exceeds the set point of the relay protection system of this power line, during double short circuits, may occur earlier, by 0.004 s. Than the current increases in the input circuit breaker for certain values of the power line and short-circuit parameters. Based on the results of calculations of the parameters of the 10 kV power transmission line considered in the work, it was determined that the tripping current is equal to 300 A, and the power supply acting on the input switch of the substation to which the 10 kV power line is connected is equal to 1323 A. For the considered examples of operation of the power transmission line in the first case will happen selectively, and in the second case, the protection will not work correctly. First, the input switch will turn off, and then the feeder switch. Turning off the input switch de-energizes not only damaged lines, but also healthy lines. Therefore, the conditions for ensuring the selective operation of the power transmission system for the investigated variant of the power transmission line are not always provided. In order to reduce false disconnections of 10 kV power lines, it is necessary to increase the operating time of the relay protection acting on the input circuit breaker at the substations on the 10 kV side so that the 10 kV input circuit breaker operates later than any of the feeder circuit breakers of the investigated substation.

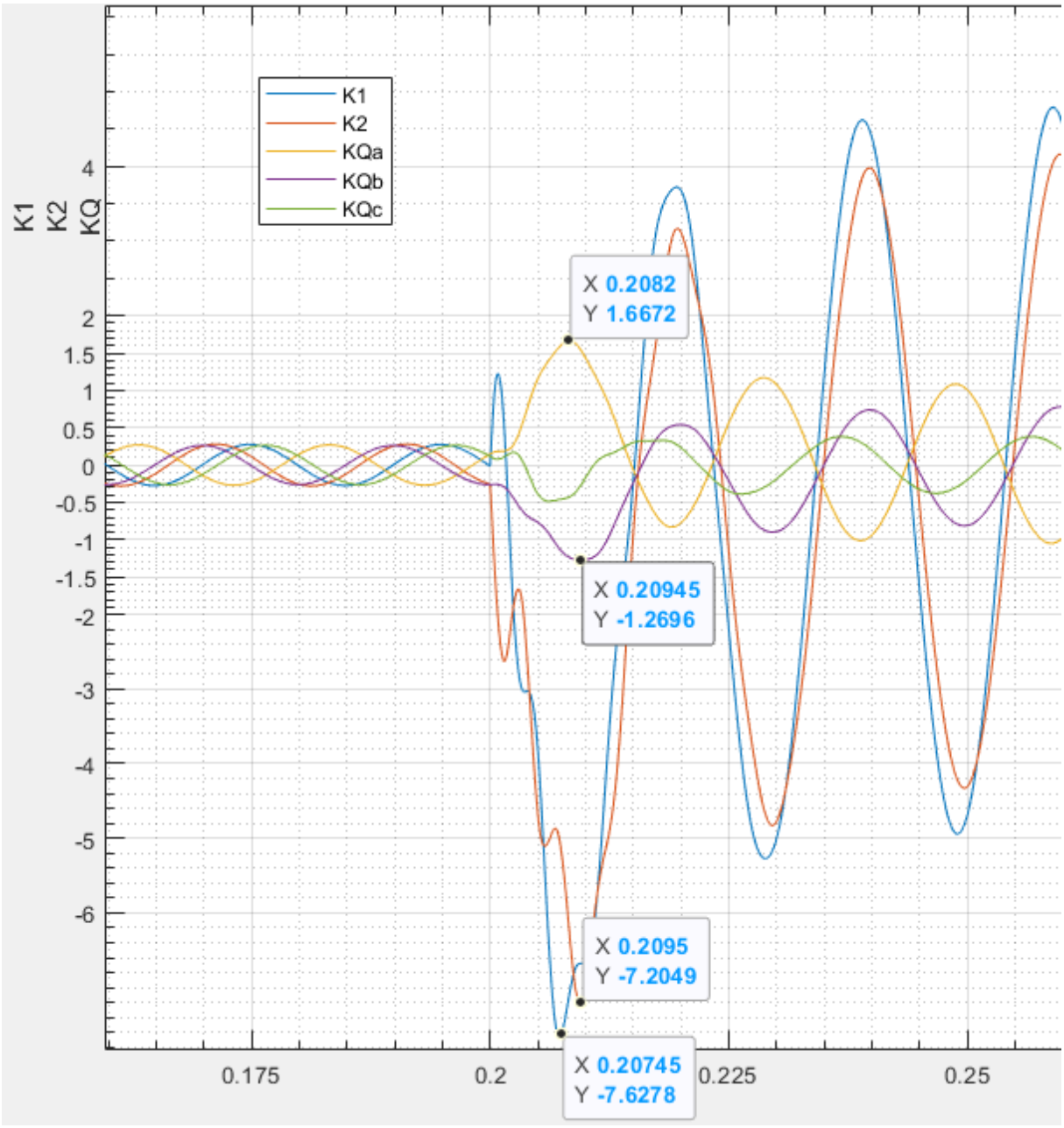


Figure 6. Graph of the coefficients K1, K2, KQ(a, b, c) as a function of time.

Acknowledgments
This study was supported by project MSCA4Ukraine ID number 1233365, 24-PKVV-UM-006, 24-PKVV-UM-007.

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