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Analysis of earth faults in the MV grid using the EMTP-ATP program

***Streszczenie**: W pracy przedstawiono model symulacyjny zwarcia łukowego w programie EMTP-ATP. Przeprowadzono symulacje zwarć doziemnych w sieci SN. Dokonano porównania zwarć łukowych w zależności od sposobu pracy punktu neutralnego sieci. Zbadano również występowanie wyższych harmonicznych podczas zwarcia łukowego. Przedstawiono oraz przeanalizowano otrzymane wyniki, uzyskane drogą symulacji komputerowej. (**Analiza zwarć doziemnych w sieci SN za pomocą programu EMTP-ATP**)*

***Abstract**: The paper presents a simulation model of short circuit arc in the EMTP-ATP program. Earth fault simulation in medium voltage grid was performed. A comparison of arc faults has been made, depending on neutral point operating mode of the network. The occurrence of higher harmonics during arcing has also been investigated. Obtained results by computer simulation were presented and analyzed.*

Słowa kluczowe: zwarcia doziemne, modelowanie, łuk elektryczny, harmoniczne.
Keywords: earth faults, modeling, electric arc, harmonics.

Introduction

Short-circuits are one of the most common disturbances in the power system. In the MV grid, most of them are ground faults, which constitute about 75% of all short circuits [1]. The most interesting type of short-circuit from the point of view of the analysis is the arc fault. These faults can be divided into permanent or interrupted ones. The type of short circuit in the grid depends on the grid parameters, fault location and weather conditions. Arc faults, in addition to damage caused by a burning arc at the fault location, significantly affect the operation of the grid. They induce surges reaching the amplitude of the phase voltage several times, they damage the construction of poles, insulators and switchgear, they generate higher harmonics and disrupt the operation of protection automation [2].

Until recently, the only reliable source of information on the behavior and effects of the burning arc was expensive research in the real grid [1]. Currently, in the era of ubiquitous computer simulations, specialized computer programs are increasingly being used, which allow to carry out research quickly and comparatively cheaply.

The article presents a mathematical model and simulations of arcing faults in the MV grid. A specialized EMTP-ATP program was used, which is a great tool for modeling transient states in the power system.

Mathematical model of a fault arc

The mathematical model of the fault arc describes the course of its conductance as a function of arc current (or voltage) and environmental conditions [3, 4]. There are many known relationships describing the behavior of a burning arc. In [5] is presented the mathematical description of the electric arc, burning in the air, which was obtained on the basis of experimental research. This description can be represented by the following first order differential equation:

$$\frac{dg(t)}{dt} = \frac{G(t) - g(t)}{\tau} \tag{1}$$

where: $g(t)$ - dynamic conductance of the arc; $G(t)$ - static conductivity of the arc; τ - time constant.

The static conductivity $G(t)$ can be physically interpreted as the arc conductivity value when the arc current is maintained for a sufficiently long time under constant external conditions [6]. That is described by the following relationship:

$$G(t) = \frac{|i(t)|}{|U(t)|} = \frac{|i(t)|}{U_0 + R_1 \cdot |i(t)|} \tag{2}$$

where: U_0 - threshold voltage of the arc characteristic; R_1 - resistance defining the slope of the arc characteristic; $i(t)$ - temporary current [3].

The threshold voltage U_0 and the resistance R_1 are functions of the arc length and can be determined from the following relationships:

$$U_0 = u_0 \cdot l + U_{0\min} \cong 900 \cdot l + 400 \tag{3}$$

$$R_1 = r_1 \cdot l + R_{1\min} \cong 0{,}040 \cdot l + 0{,}008 \tag{4}$$

where: u_0 - voltage drop per unit of arc length [V/m], l - arc column length [m], U_{0min} - minimum arc voltage [V], r_1 - resistance per unit of arc length [Ω/m], R_{1min} - minimum arc resistance [Ω] [3].

The proposed arc model may also include elongation of the arc column. In addition to the changes U_0 and R_1 described by the relations (3) and (4), the extension of the arc column also influences the value of the time constant τ. This variability can be described by the following relationship:

$$\tau = \tau_0 \cdot \left(\frac{l}{l_0} \right)^{\alpha} \tag{5}$$

where: $\alpha \cong -0{,}4$; τ_0 - time constant at the beginning of the short circuit.

Simulation model of the fault arc

Equation (1) is a nonlinear equation that can only be solved numerically. To solve them, his operator form was used as a function of the Laplace operator:

$$g(s) = \frac{G}{\tau \cdot s + 1} \tag{6}$$

To create the model, in the EMTP-ATP program, all the dependencies given above were used. MODEL and TACS elements were used in the model's construction (fig. 1). A program calculating the dynamic resistance of the arc has been implemented in the MODEL element type. The program was written in the FORTRAN language (fig. 2) [7]. The algorithm, taking into account the phenomena described above and signals coming from the circuit, generates a corresponding control signal. The TACS element is controlled by a signal coming from the MODEL element of the resistor.

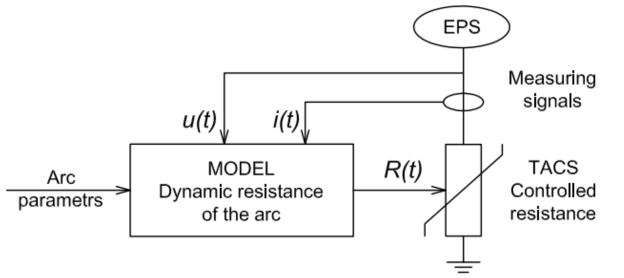


Fig. 1. Block diagram presenting the arc model in the EMTP-ATP program

```
MODEL arc
INPUT U, Iarc
OUTPUT Rarc, gdyn, Gstat
DATA TAU0 {DFLT:0.25e-3}, Larc {DFLT:0.15},
      L0 {DFLT:0.15}, alfa {DFLT:-0.4}
VAR gdyn, Gstat, Rarc, U0, R1, TAU
HISTORY gdyn {DFLT:1}
Gstat {DFLT:1}
Rarc {DFLT:1E-8}
INIT
Rarc:=1E-8
ENDINIT
EXEC
TAU:=TAU0*((Larc/L0)**alfa)
U0:=(900*Larc)+400
R1:=(0.040*Larc)+0.008
Gstat:=abs(Iarc)/(U0+(R1*abs(Iarc)))
LAPLACE(gdyn/Gstat):=1.0|/(1.0|+TAU|S)
Rarc:=recip(gdyn)
ENDEXEC
ENDMODEL
```

Fig. 2. The program calculating the dynamic resistance of the arc [8]

A very important activity associated with the modeling of the arc is the selection of its appropriate parameters. Table 1 presents a combination of arc parameters used during simulation.

Tab. 1. List of arc parameters

Parameter	Value
τ_0	0,25 [ms]
l_0	0,15 [m]

Simulation results

During the tests, a typical SN grid was used (fig. 3) consisting of four overhead lines with a total length of fifty kilometers. The neutral point of the grid was obtained by using the TPW's own needs transformer. Detailed grid parameters are presented in [9]. During the tests, simulations of single-phase faults in the MV grid were carried out depending on the way the neutral point of the grid works, both arc fault and through the resistance of the transition, eg. when the line wire falls to the ground. It was assumed that the fault starts at t = 0.02 s.

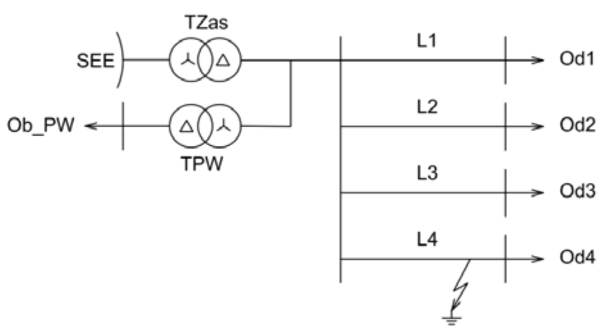
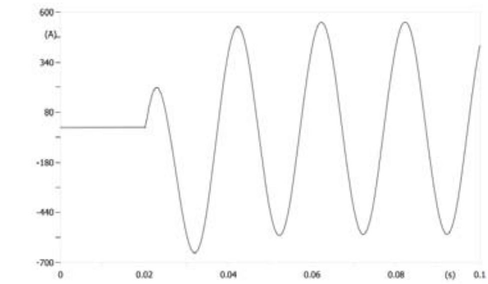


Fig. 3. The scheme of the considered test grid

Analyzing the results of the simulation (fig. 4 and fig. 5), it can be noticed that the value of short-circuit current depends both on the way the neutral point of the grid works and on the nature of the short-circuit. The currents for a short circuit at a network with a directly grounded neutral point are several hundred amperes, while in the second case they do not exceed several amperes. This is because the circuit for the zero sequence component is not closed, because the impedance Z (0) = ∞ [10]. However, taking into account the capacitance of the transmission lines, a connection is created that allows the flow of a small short-circuit current. It was also noticed that the course of short-circuit current during arc fault in the network with an isolated neutral point is continuous and indicates a continuous circular arc fault.

a)



b)

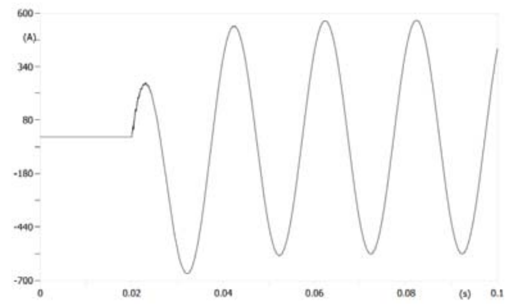
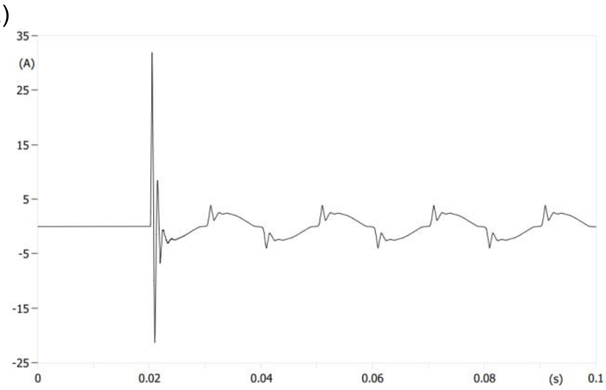


Fig. 4. Arc current in the grid with a directly earthed neutral point; a) arc fault; b) short-circuit via the transition resistance R_f = 0.01 Ω

a)



b)

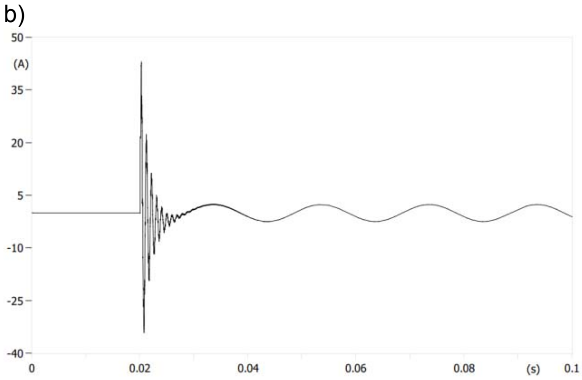


Fig. 5. Arc current in the grid with insulated neutral point; a) arc fault; b) short circuit via the transition resistance R_f = 0.01 Ω

Figure 6 shows the spectrum of higher harmonics current for arc fault in a grid with isolated neutral point. It can be seen that there are only odd harmonics in the spectrum. The THD value for this run is 30.7%.

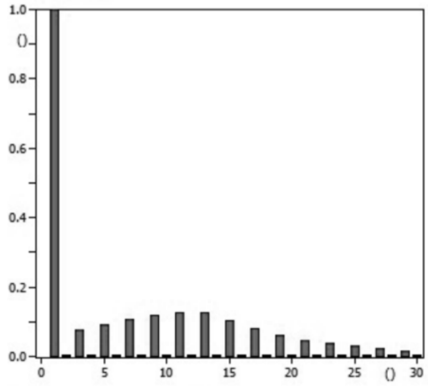
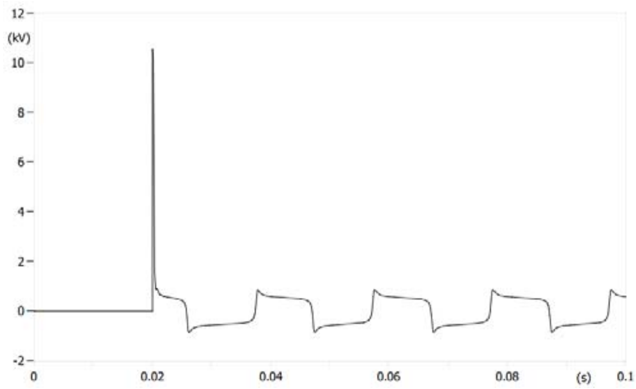


Fig. 6. Spectrum of higher harmonics of current for arc fault in a grid with isolated neutral point

Analyzing figure 7, it can be noticed that the arc waveform at the network with an isolated neutral point contains more high frequency oscillations compared to the arc waveform at the network with a directly earthed neutral point.

a)



b)

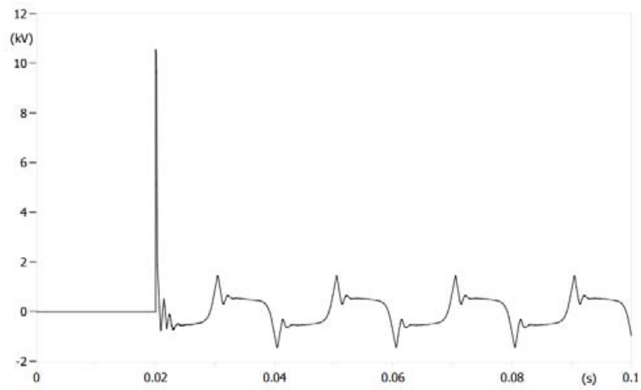
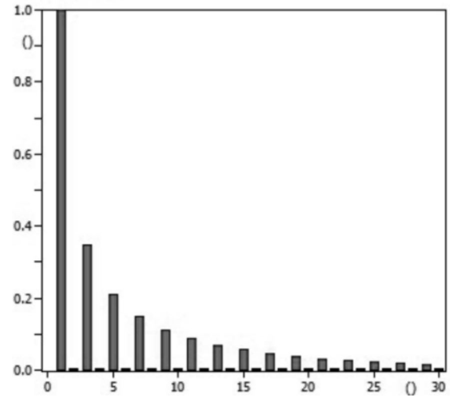


Fig. 7. Arc voltage: a) a grid with a directly grounded neutral point; b) grid with isolated neutral point

Figure 8 shows the spectrum of higher voltage harmonics for grid operation with a directly grounded neutral point and an isolated neutral point. It can be seen that, as in the case of arc current, the voltage spectrum consists exclusively of odd harmonics. It should be noted that for harmonics of a lower order, the harmonics for the operation of the grid with an isolated neutral point are more important. On the other hand, for higher order harmonics, a larger share occurs for grid with a directly grounded neutral point. The THD value for these runs is 46.4% for grid with directly grounded neutral point and 59.5% for grid with an isolated neutral point.

a)



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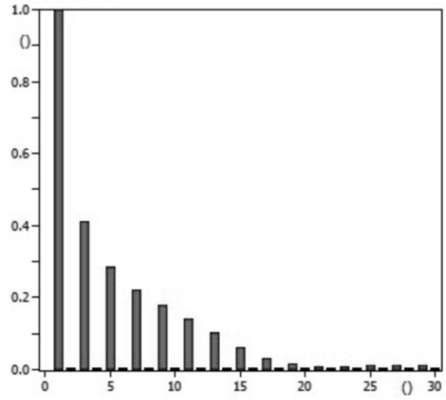
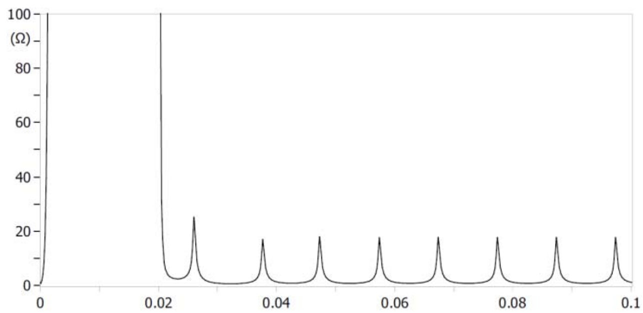


Fig. 8. Spectrum of higher voltage harmonics; a) a grid with a directly grounded neutral point; b) grid with isolated neutral point.

a)



b)

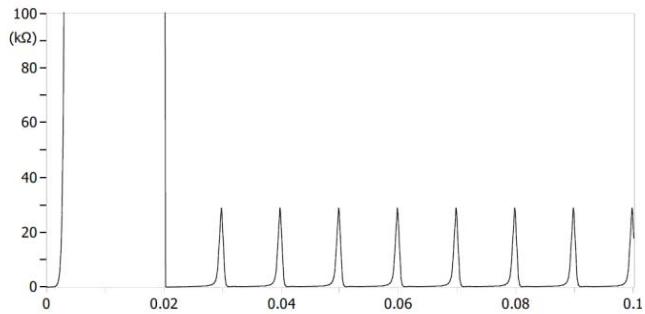


Fig. 9. Arc resistances; a) a grid with a directly grounded neutral point; b) grid with isolated neutral point.

A characteristic feature of arc faults is the resistance of the arcing column that changes over time (fig. 9). This resistance assumes maximum values when the current passes through zero. This is because, when the current passes through zero, the insulating properties of the arch column are partially rebuilt. For a short-circuit in the grid with a directly grounded neutral point, the rebuilding of the insulating properties of the arc column is small due to the significant short-circuit current. This causes the short circuit to be permanent. In the second case, the resistance of the arc when the current passes through zero reaches the value of several tens of thousands of ohms. This results in interruptions in the conductivity of the current and makes the arc fade when the current passes through zero.

Conclusions

Simulations of ground faults in the medium voltage grid were performed. Two variants of grid operation were considered, i.e. with a directly grounded neutral point and an isolated neutral point. As can be seen in the attached figures, the arc waveform at the network with an isolated neutral point contains more high frequency oscillations compared to the arc waveform in the network with a directly earthed neutral point. The resistance of the arc column reaches very low values even when the current passes through zero, below 20 Ω. In the arc current, no noticeable interruptions in the conductivity were noted.

Analyzing the short circuit in the grid with the isolated neutral point, it was noticed that the current shape deviates significantly from the sinusoidal waveform, and the voltage from the rectangular shape. The resistance of the arc column at the moment of passing the current through zero reaches values of the order of kΩ, therefore the arc ignites cyclically, once every half-period. The reason for this is the relatively small current flowing through the arc, which causes the instantaneous resistance of the arc column to become much larger compared to the capacitance of the line.

The occurrence of higher harmonics during an arc fault was also analyzed. Arcing faults generate significant harmonics regardless of the operation of the neutral point of the network. The most unfavorable situation occurs for the operation of the network with isolated neutral point. Significant harmonics are generated for both currents and voltages. What can potentially affect the work of receivers connected to this network.

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