Short-circuit - analysis and calculation

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Abstract: - This paper discusses about analysis and calculation of short – circuit by the program created to solve a short – circuit ratios in the power system according to Standard IEC 60909. One of the main subject is describing short-circuit current in system with currents without attenuation alternating component and short-circuit current in system with currents with attenuation alternating component. A short circuit is a part of the circuit that for some reasons has become "shorter" than it should be.[4] The current in an electrical circuit flows the easiest way and if two points in a circuit with different potentials are connected with low electrical impedance the current is taking a shortcut between the two points. The consequences of short circuit can be everything from just a minor malfunction to a disaster. The consequences are dependent of the system´s capacity for driving current in short circuit situation and how long time the short circuit current is allowed to flow. In almost every electric circuit there has to be some kind of protection against short circuit currents.[5]

Key-Words: -short-circuit impedance matrix, power system, short-circuit current, three-phase short-circuit power, positive sequence short-circuit impedance matrix, negative sequence short-circuit impedance matrix, zero sequence short-circuit impedance matrix

1 Introduction

Constantly evolving society increases its demands on Power System. It is associated with an increasing the amount of the consumed energy and also with the quality and price of electricity. In consequence, there is also increasing demand on security and reliability of the power system.[6]
During operation of the power system there may occur transient effects that appear while the system transits from one steady-state into another with new parameters.
One of the reasons of occurrence of these transient events could be short-circuit. Impedance of short-circuit is multiply decreasing which leads to increase of current and decrease of voltage. Duration of short-circuit is short but due to the size it causes the mechanical and dynamic effects on various machines.[11]
Among the most important tasks, when planning and operating power systems are the short – circuit calculations. Short – circuits can be minimized in the system through planning, design and well – performed maintenance and operation of the system, but cannot be totally avoided. Electrical equipments must be designed that when exposed to short – circuit currents that may occur in that locations not incurred a damage or deformation of electrical, mechanical or thermal character. It is therefore necessary, due to the dangerous effects of short – circuit currents on electrical equipment, to know the short – circuit ratios at the entire length of the electrical circuit.[10]
Short – circuits can cause mechanical oscillations in generators which can lead to oscillations in the power system, causing problems of stability in the power transfer. In the worst case this can lead to a blackout of the system.[6][7] Due to the dangerous effects of short – circuit currents on electricity equipments belongs the knowledge of the short – circuit ratios in the entire length of the electrical circuit to the most important background for projecting some electrical components. Setting the switches and the circuit breakers, respectively the protections is determined by the tripping circuit current, the mechanical and the thermal effects by the other constituents of short – circuit current.[7]

2 Standard IEC 60909

The IEC 60909 International Standard is intended to give the methodology for the fault currents calculation in three-phase a.c. systems at a nominal frequency of 50 Hz.[1]It describes universal practical process ensuring sufficiently accurate result with respect to degree of security.The short-circuit currents is considered as the sum of an a.c. symmetrical component and of an aperiodic component. The standard distinguishes between near to generation and far from generation short circuits. The methodology includes of a.c. motors contribution, too. In the present are used two numerical methods for short – circuit calculations.It is superposition method and equivalent voltage source method. Superposition method gives the short-circuit current only in relation to one assumed amount of the load.[2][3] Hence, it need not lead to maximum short-circuit current in the system. For removing this lack, it was developed the equivalent voltage source method.

2.1 Maximum short – circuit current

The main criterion which relates with creating the design for the rating of equipment is the maximum short – circuit current. It will limit the equipment as to how much thermal and mechanical effects it can resist without breaking. Calculation a maximum short – circuit currents with IEC 60909-0:

- A voltage factor c_{max} will be applied for the maximum calculation,
- There should be used the configuration, that gives the maximum contributions from the power plant and feeders, which leads to the highest short – circuit current,
- The motors are included in the calculations.
- Lines are introduced at a temperature of 20°C.[9]

2.2 Minimum short – circuit current

It is needed when designing the protections and relay settings to ensure accurate and coordinated relay operation. When planning the safety margins of the protection of the system, it is important that none of the breakers trip for the highest operating current in the circuit as well as they have to be switched off for any short – circuit event. [7][8]
Calculation a minimum short – circuit currents with IEC 60909-0:

- A voltage factor c_{min} is applied for the minimum calculation,
- The system configuration that leads to the minimum short – circuit current at the location of the fault has to be chosen,
- All motors can be neglected,
- Lines are introduced at a higher temperature.[9]

3 Symmetrical three – phase fault

The symmetrical fault occurs when all the three different phases are connected or shorted to ground. The duration of a fault can be divided into three areas:

- The sub – transient period which occurs directly at the fault location. It lasts only for a couple of cycles,
- The transient period which occurs for tens of cycles,
- The steady – state period this will last a longer time.

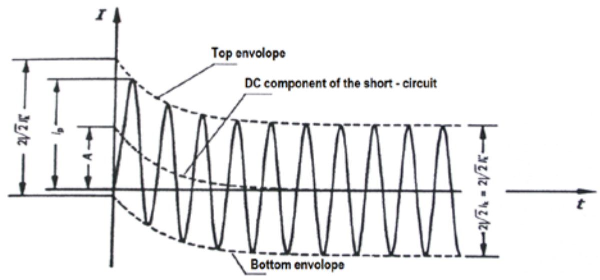

Fig. 1 Short – circuit currents [9]

3.1 Initial short – circuit current I_k''

The highest initial short – circuit current will for this type of system occur when there is a three – phase fault. This current is the root mean square value of the initial AC component of the short – circuit current. It is used for maximum short – circuit current calculations. For the three – phase short – circuit the initial short – circuit current is calculated according to equation:

$$I_k'' = \frac{c_{max}.U_n}{\sqrt{3}.Z_k} = \frac{c_{max}.U_n}{\sqrt{3}.\sqrt{R_k^2+X_k^2}} \quad (1)$$

$c_{max}.U_n/\sqrt{3}$ is the equivalent voltage source at the fault location and Z_k is the short – circuit impedance. To get the total current at a fault location I_k'' is calculated as the phasor sum of the individual partial short – circuit currents at the location.

3.2 Steady state short – circuit current I_k

When the steady state current is calculated the result will be less accurate than for the initial short – circuit current. [9] For the calculation of the maximum steady state short – circuit current it is assumed that synchronous machines are set at the maximum excitation.
For the minimum steady state current, the value of the steady state short – circuit current for the

synchronous machines is used to calculate the corresponding equivalent impedance. All asynchronous motors are neglected for these types of calculations.[9]

3.3 Peak short – circuit current I_p

The peak current is the largest momentary value of the short – circuit current. It is only calculated for the maximum short – circuit current. For a three – phase balanced fault the contribution of the peak short – circuit current from one branch can be calculated according to equation:

$$I_p = \kappa.\sqrt{2}.I_k'' \quad (2)$$

κ is a function of the R/X ratio and can be calculate with equation:

$$\kappa = 1{,}02 + 0.98.e^{\frac{3.R}{X}} \quad (3)$$

4 Method of short-circuit impedance matrix

When circuits are analyzed mathematically, short circuit is usually described by zero impedance between two nodes in the circuit. In reality it is impossible that the impedance should be zero and therefore the calculations will not give the "real" value but in most cases the highest possible value. To get right results of a calculation it is also important to know all parameters of the circuit. Especially in short circuit situations the behaviour of the circuits are "strange" and there is no linearity between the voltage of the system and the current flowing.

For computing is necessary to make line admittance matrix, that is diagonal. Members of matrix are admittances of system elements.[12]

$$\underline{Y}_V = \begin{bmatrix} Y_{V11} & 0 & \dots 0 & \dots 0 & \dots 0 \\ 0 & Y_{V22} & \dots 0 & \dots 0 & \dots 0 \\ . & . & . & . & . \\ . & . & Y_{Vii} & . & . \\ . & . & . & . & . \\ 0 & 0 & \dots 0 & Y_{V(n-1)(n-1)} & \dots 0 \\ 0 & 0 & 0 & \dots 0 & \dots Y_{Vnn} \end{bmatrix}$$

Fig. 2 Example of admittance matrix

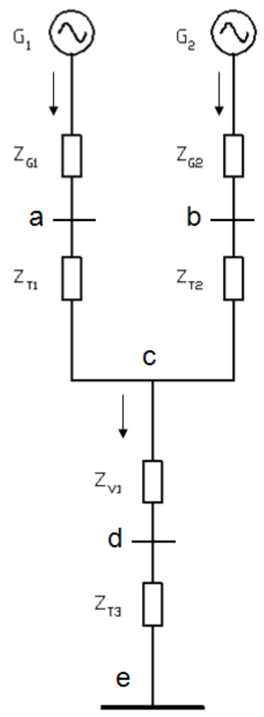

Fig.3Example of calculating power system

The example showed the method of making matrixes $\underline{k_V}$ and $\underline{Y_V}$.

For the power system on figure 3can be matrix $\underline{Y_V}$in this form:

$$\underline{Y}_V = \begin{bmatrix} Y_{G1} & 0 & 0 & 0 & 0 & 0 \\ 0 & Y_{G2} & 0 & 0 & 0 & 0 \\ 0 & 0 & Y_{T1} & 0 & 0 & 0 \\ 0 & 0 & 0 & Y_{T2} & 0 & 0 \\ 0 & 0 & 0 & 0 & Y_{V1} & 0 \\ 0 & 0 & 0 & 0 & 0 & Y_{T3} \end{bmatrix}$$

Fig. 4 The admittance matrix

Sequence of elements is free but is necessary make the same sequence for making matrix$\underline{k_V}$.

List of common used elements is in a chapter 5. Admittances can be calculated like inverse value of impedance of elements.

Then for making matrix$\underline{k_V}$is necessary the system topology. Component k_{ij}determine selected direction of current for element Y_{Vii} to node$j$

$k_{ij} = 1$if current flows fromY_{Vii} to node$j$,

$k_{ij} = -1$if current flows from $Y_{Vii}$to node$i$.

Matrix $\underline{k_V}$ has dimension$n\ x\ m$, where $m$is number of nodes of system.[14]

Short-circuit admittance matrix is then calculated:

$$\underline{Y} = \underline{k_V^T}.\underline{Y_V}.\underline{k_V} \quad (4)$$

For example showed on the figure 3 can matrix $\underline{Y}$ have this form:

$$Y_K = \quad k_V^T \quad . \quad Y_V \quad . \quad k_V$$

$$Y_K = \begin{array}{c} \begin{array}{ccccc} a & b & c & d & e \end{array} \\ \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ -1 & 0 & 1 & 0 & 0 \\ 0 & -1 & 1 & 0 & 0 \\ 0 & 0 & -1 & 1 & 0 \\ 0 & 0 & 0 & -1 & 1 \end{bmatrix}^{-T} \end{array} . \begin{bmatrix} Y_{G1} & 0 & 0 & 0 & 0 & 0 \\ 0 & Y_{G2} & 0 & 0 & 0 & 0 \\ 0 & 0 & Y_{T1} & 0 & 0 & 0 \\ 0 & 0 & 0 & Y_{T2} & 0 & 0 \\ 0 & 0 & 0 & 0 & Y_{V1} & 0 \\ 0 & 0 & 0 & 0 & 0 & Y_{T3} \end{bmatrix} . \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ -1 & 0 & 1 & 0 & 0 \\ 0 & -1 & 1 & 0 & 0 \\ 0 & 0 & -1 & 1 & 0 \\ 0 & 0 & 0 & -1 & 1 \end{bmatrix}$$

Fig.5Example of matrix form

On example is showed method of making matrixesand short-circuit matrix is computed:

$$\underline{Z} = \underline{Y^{-1}} \quad (5)$$

Diagonal elements of short-circuit matrix $\underline{Z}$ determines short-circuit impedance of system elements. Element Z_{jj} determines short-circuit impedance in node j.
In next step is calculated short-circuit current for node j using this formula:

$$I_k'' = \frac{c_{max}.U_n}{\sqrt{3}.Z_k} \quad (6)$$

This state is described in next formula:

$$\begin{bmatrix} 0 \\ 0 \\ . \\ I_k \\ . \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & \dots & Y_{1j} & \dots & Y_{1m} \\ Y_{21} & Y_{22} & \dots & Y_{2j} & \dots & Y_{2m} \\ . & . & \dots & . & \dots & . \\ Y_{j1} & Y_{j2} & \dots & Y_{jj} & \dots & Y_{jm} \\ . & . & \dots & . & \dots & . \\ Y_{(m-1)1} & Y_{(m-1)2} & \dots & Y_{(m-1)j} & \dots & Y_{(m-1)m} \\ Y_{m1} & Y_{m2} & \dots & Y_{mj} & \dots & Y_{mm} \end{bmatrix} . \begin{bmatrix} U_1 \\ U_2 \\ . \\ U_j \\ . \\ U_{m-1} \\ U_m \end{bmatrix}$$

Fig 6 The equation in matrix form

$$\underline{I} = \underline{Y}.\underline{U} \quad (7)$$

Modification of formula (7):

$$\underline{U} = \underline{Y^{-1}}.\underline{I} \quad (8)$$

$\underline{U}$ is a matrix of voltages during short-circuit. Multiplication gives us matrix $\Delta\underline{U}$:

$$\underline{\Delta U} = \underline{k_V}.\underline{U} \quad (9)$$

For computation of line currents between nodes is used next formula:

$$\underline{I_V} = \underline{Y_V}.\underline{\Delta U} \quad (10)$$

Matrix form of formula (10):

$$\begin{bmatrix} I_{V1} \\ I_{V21} \\ . \\ I_{Vj} \\ . \\ I_{Vn-1} \\ I_{Vn1} \end{bmatrix} = \begin{bmatrix} Y_{V11} & 0 & \dots 0 & \dots 0 & \dots 0 \\ 0 & Y_{V22} & \dots 0 & \dots 0 & \dots 0 \\ . & . & . & . & . \\ . & . & Y_{Vii} & . & . \\ . & . & . & . & . \\ 0 & 0 & \dots 0 & Y_{V(n-1)(n-1)} & \dots 0 \\ 0 & 0 & 0 & \dots 0 & \dots Y_{Vnn} \end{bmatrix} . \begin{bmatrix} \Delta U_1 \\ \Delta U_2 \\ . \\ \Delta U_j \\ . \\ \Delta U_{m-1} \\ \Delta U_m \end{bmatrix}$$

Fig. 7 The equation in matrix form

Calculations of short-circuit currents in asymmetric short-circuit is similar to computation of three - phases short-circuit. For asymmetric short-circuit is necessary to calculate short-circuit matrix individually for positive sequence, negative sequence and zero sequence of impedance. We must keep the same marking of nodes and lines in all three parts.[13]

5 Program for calculation of the behaviour of power system during the short-circuit

Program for calculation of the behaviour of power system during the short-circuit respects the Standard IEC 60909. In the calculation is used correction coefficient for generator and power plant block.
Input data are inserted by using main menu (Elements).You can choose from:

- Power network (Q)
- Motor (M)
- Transformer (T*2 – double winding, T*3 – triple winding)
- Line (V)
- Generator (G)

or by inserting dates to main table. When dates are inserted it is necessary to use the key (View ->Sort). The key (Q, M, T*2, T*3, V or G) is written to the first cell. This key determines which component is used.

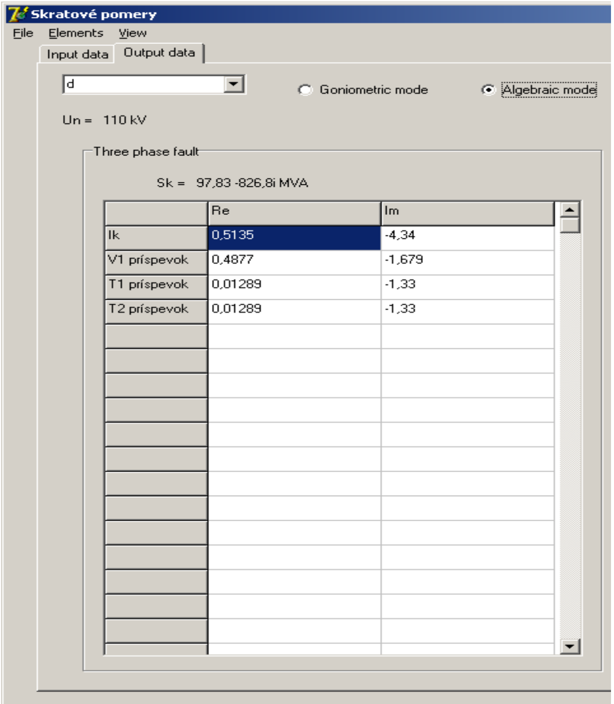

Fig.8Page of output data

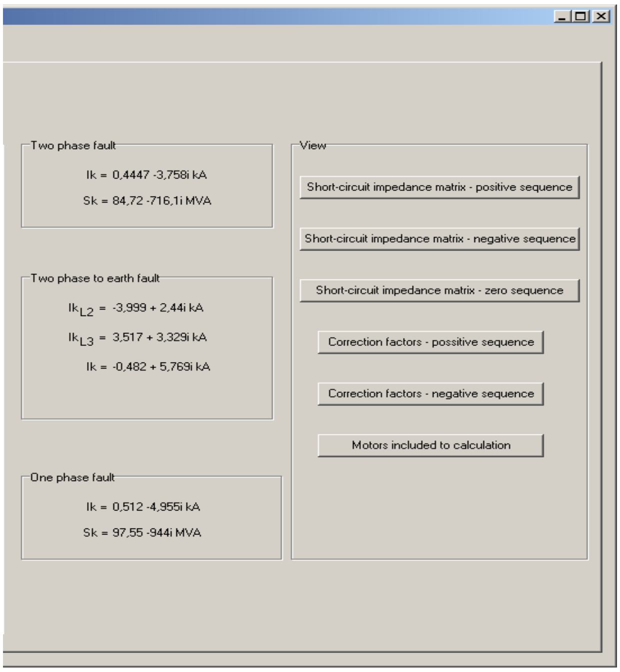

Fig.9Page of output data

Calculated values are possible to watch in page (Output data). There is possibility to choose short-circuit node, format of calculated values (goniometric form, algebraic form) and motors which contribution will be considered in calculation. Program does not solve the case of connection ofone phase with ungrounded node. In this case the result is zero, because short circuit impedance is zero. Calculated values are:

- 3-phase short-circuit current
- Part of 3-phase short-circuit current
- Power of 3-phase short-circuit current
- 2-phase short-circuit current
- Power of 2-phase short-circuit current
- 1-phase short-circuit current
- Power of 1-phase short-circuits current

Advanced values:

- Positive sequence short-circuit impedance matrix
- Negative sequence short-circuit impedance matrix
- Zero sequence short-circuit impedance matrix
- Correction coefficient for positive sequence impedance
- Correction coefficient for negative sequence impedance

6 Calculations of short – circuit

In this chapter is calculated an example,that it shown a calculation according to Standard IEC 60909 and the results are compared with the program outputs.The calculation is done in relative values. The example is shown the calculation of near to generation and far from generation short – circuit. In case of calculation near to generation short – circuit are used a correction factors according to Standard IEC 60909. This example is also calculated by the program.

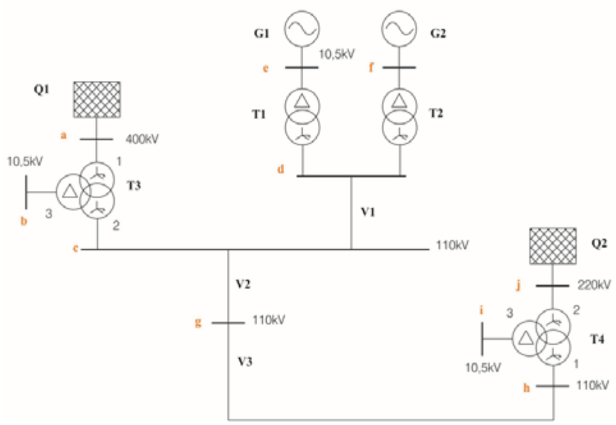

Fig. 10 Scheme of power system

Parameters of power system elements:

Q1:

$I_k^{''(3)} = 30\ kA$ (Three – phase initial short – circuit current)

$I_k^{''(1)} = 30\ kA$ (Phase initial short – circuit current)

Q2:

$I_k^{''(3)} = 30\ kA$ (Three – phase initial short – circuit current)

$I_k^{''(1)} = 15\ kA$ (Phase initial short – circuit current)

G1, G2:

$U = 10{,}5\ kV$ (Nominal voltage of generator)

$S_n = 80\ MVA$ (Generator MVA rating)

$x_d^{''} = 17\ \%$ (Relative reactance)

$x_2 = 17\ \%$ (Negative – sequence reactance)

$x_0 = 10\ \%$ (Zero – sequence reactance)

V1, V2, V3:

$X_1 = 0{,}4\ \Omega.km^{-1}$ (Line reactance)

$R_1 = 0{,}15\ \Omega.km^{-1}$ (Line resistance)

$X_0 = 1{,}2\ \Omega.km^{-1}$ (Zero – sequence reactance)

$R_0 = 0{,}45\ \Omega.km^{-1}$ (Zero – sequence resistance)

$L_{V1} = 65\ km, L_{V2} = 55\ km, L_{V3} = 40\ km$

T1, T2:

$u_k = 15\ \%$ (Short – circuit voltage in %)

$S_n = 80\ MVA$ (Transformer MVA rating)

$t_r = (10{,}5/110)\ kV$ (Transformer ratio)

$\Delta P_k = 248\ kW$ (Losses)

$Z_0 = 1.Z_1$ (Zero – sequence impedance)

T3:

$u_{k12} = 13{,}2\ \%$ (Short – circuit voltage in %)

$u_{k13} = 15{,}16\ \%$ (Short – circuit voltage in %)

$u_{k23} = 9{,}16\ \%$ (Short – circuit voltage in %)

$S_{n1} = 250\ MVA, S_{n2} = 250\ MVA, S_{n3} = 100\ MVA$

$U_{1n} = 400\ kV, U_{2n} = 121\ kV, U_{3n} = 10{,}5\ kV$

$\Delta P_{k12} = 639\ kW$ (Losses)

$\Delta P_{k13} = 268\ kW$ (Losses)

$\Delta P_{k23} = 257\ kW$ (Losses)

$Z_0 = 1.Z_1$ (Zero – sequence impedance)

T4:

$u_{k12} = 10{,}6\ \%$ (Short – circuit voltage in %)

$u_{k13} = 32{,}8\ \%$ (Short – circuit voltage in %)

$u_{k23} = 20\ \%$ (Short – circuit voltage in %)

$S_{n1} = 200\ MVA, S_{n2} = 200\ MVA, S_{n3} = 100\ MVA$

$U_{1n} = 230\ kV, U_{2n} = 121\ kV, U_{3n} = 10{,}5\ kV$

$\Delta P_{k12} = 432\ kW$ (Losses)

$\Delta P_{k13} = 399\ kW$ (Losses)

$\Delta P_{k23} = 356\ kW$ (Losses)

$Z_0 = 1.Z_1$ (Zero – sequence impedance)

Impedances are calculated in the relative values with the reference value $S_{VZ} = 100\ MVA$.

Tab. 1 Impedances of equipments

	Equipment	Positive – sequence impedance↙Ω↘	Negative – sequence impedance↙Ω↘	Zero – sequence impedance ↙Ω↘
1	Q1	0,00529j	0,00529j	0,00529j
2	Q2	0,01443j	0,01443j	0,02886j
3	G1	0,2125j	0,2125j	0,125j
4	G2	0,2125j	0,2125j	0,125j
5	T1	0,00387 + 0,1875j	0,00387 + 0,1875j	0,00387 + 0,1875j
6	T2	0,00387 + 0,1875j	0,00387 + 0,1875j	0,00387 + 0,1875j
7 I	T3(1)	0,0032 + 0,0779j	0,0032 + 0,0779j	0,0032 + 0,0779j
7 II	T3(2)	0,00319 + 0,054j	0,00319 + 0,054j	0,00319 + 0,054j
7 III	T3(3)	-0,002775 - 0,0173j	-0,002775 - 0,0173j	-0,002775 - 0,0173j
8 I	T4(1)	0,001 - 0,0055j	0,001 - 0,00055j	0,001 - 0,00055j
8 II	T4(2)	0,0009 +	0,0009 +	0,0009 +

		0,0585j	0,0585j	0,0585j
8 III	T4(3)	-0,0000125 + 0,1055j	-0,0000125 + 0,1055j	-0,0000125 + 0,1055j
9	V1	0,0806 + 0,2149j	0,0806 + 0,2149j	0,2417 + 0,6446j
10	V2	0,0682 + 0,182j	0,0682 + 0,182j	0,2045 + 0,5454j
11	V3	0,0496 + 0,132j	0,0496 + 0,132j	0,1488 + 0,3967j

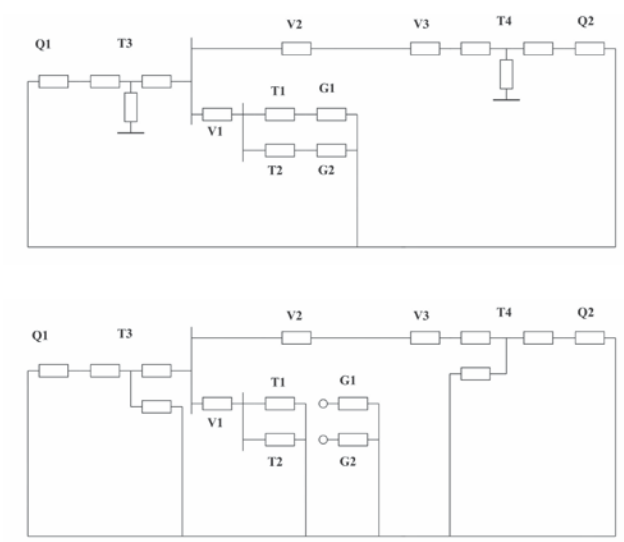

Fig. 11 Schemes of positive – sequence, negative – sequence and zero – sequence impedance

For the chosen short – circuit place applies:

Tab. 2 Comparison of calculation and program results

Type of short - circuit	Place of short - circuit	Short – circuit currentIk[kA]	
		Calculation	Output ofthe program
Three – phase short - circuit (overall)	d	0,5126 - 4,334j	0,5135 - 4,34j
Three – phase short - circuit(accession from V1)	d	0,487 - 1,676j	0,4877 - 1,679j
Three – phase short - circuit(accession from T1)	d	0,0128 - 1,327j	0,01289 - 1,33j
Three – phase short - circuit(accession from T2)	d	0,0128 - 1,327j	0,01289 - 1,33j
Double – phase short – circuit	d	0,444 - 3,754j	0,4447 - 3,758j
Double – phase to ground short - circuit	d	-0,483 + 5,76j	-0,482 + 5,769j
Double – phase to ground short - circuit(L2)	d	-3,98 + 2,43j	-3,999 + 2,44j
Double – phase to ground short - circuit(L3)	d	3,52 + 3,32j	3,517 + 3,329j
Phase short - circuit	d	0,513 - 4,956j	0,512 - 4,955j
Three – phase short - circuit (overall)	g	1,205 - 4,596j	1,208 - 4,598j
Three – phase short - circuit (accession from V2)	g	0,505 - 1,881j	0,508 - 1,887j
Three – phase short - circuit (accession from V3)	g	0,700 - 2,714j	0,7005 - 2,711j
Double – phase short – circuit	g	1,046 – 3,98j	1,047 - 3,982j
Double – phase to ground short - circuit	g	-0,913 + 2,622j	-0,9123 + 2,618j
Double – phase to ground short - circuit(L2)	g	-4,438 + 0,263j	-4,438 + 0,2626j
Double – phase to ground short - circuit(L3)	g	3,53 + 2,36j	3,526 + 2,356j
Phase short - circuit	g	1,055 - 3,344j	1,057 - 3,342j

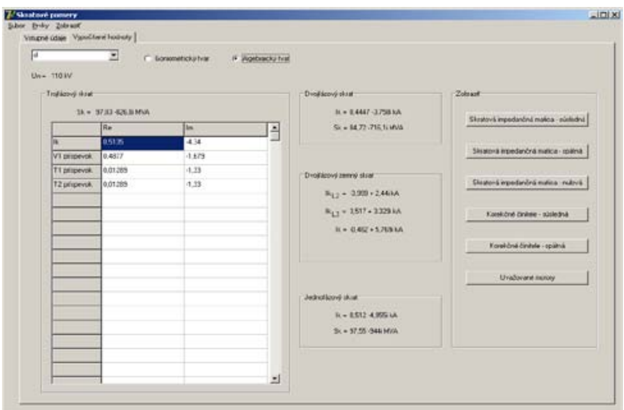

Fig. 12Page of output data

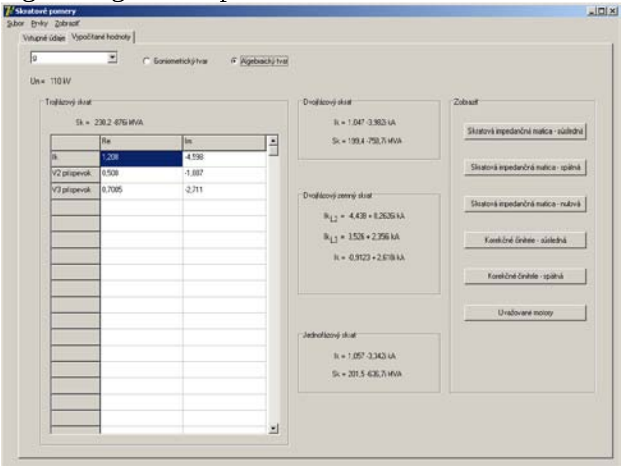

Fig. 13Page of output data

7 Conclusion

Calculation of the behaviour of power system has great application sphere in building new segments of power system and reconstruction of old segments too. In theoretical section is shown method for calculation of short-circuit currents in power system with difficult topology. It is necessary to identify short-circuit in system with attenuation alternating component and system without attenuation alternating component. In the system with attenuation alternating component is needed to use correction coefficient. Program for calculations of the behaviour of power system during short-circuit respects Standard IEC 60909. It is described in fifth chapter.

Acknowledgement

This work was done during implementation of the project Effective control of production and consumption of energy from renewable resources, ITMS code 26240220028, supported by the Research and Development Operational Program funded by the ERDF.

References:

[1] Reváková, D., Eleschová, Ž., Beláň, A. (2008).Prechodnéjavy v elektrizačnýchsústavách. *Slovak University of Technology in Bratislava*. ISBN: 978-80-227-2868-3.

[2] Standard IEC 60865-1:2011, Short – circuit currents – Calculation of effects – Part 1: Definitions and calculation methods.

[3] Standard IEC/TS 60865-2:2011, Short – circuit currents – Calculation of effects – Part 2: Examples of calculation.

[4] Neeser, D.R. (2013). "Short-circuit current ratings of equipment," *Industrial & Commercial Power Systems Technical Conf (I&CPS), 2013 IEEE/IAS 49th* , vol., no., pp.1,4, April 30 2013-May 3 2013.

[5] Ramos, M. J S; Bernardon, D.P.; Comassetto, L.; Resener, M.; Daza, E.B. (2012). "Analysis of short-circuit asymmetrical currents in power distribution systems," *Universities Power Engineering Conference (UPEC), 2012 47th International* , vol., no., pp.1,6, 4-7 Sept. 2012

[6] Nedic, Dusko, Bathurst, Graeme & Heath, John (2007). *A Comparison of Short Circuit Calculation Methods and Guidelines for Distribution Networks*, CIRED2007 session3, paper No. 0562. 19th International Conference on Electricity Distribution; 21-24 May 2007; Vienna.

[7] Schlabbach, J. (2005). *Short-Circuit Currents*. London, United Kingdom: *Institution of Engineering and Technology (IET)*.ISBN: 0-86341-514-8 & 978-0-86341-514-2.

[8] Tleis, Nasser D. (2008). *Power Systems Modelling and Fault Analysis : Theory and Practice*. Oxford: Elsevier Ltd. ISBN-13: 9780750680745.

[9] International Electrotechnical Commission, IEC (2001). *International Standard - IEC 60909-0:2001*.

[10] Cintula, B., Eleschová, Ž., Beláň, A. (2012).3-phase Short Circuit Impact in Various Length of Power Line on Transient Stability of Synchronous generator. Proceedings of the 3rd International Conference on Development, Energy,Environment, Economics (DEEE´12); 2-4 December 2012; Paris. ISBN: 978-1-61804-139-5.

[11] Muhammad M.A.S. Mahmoud (2012). Electrical Short Circuit Finding in MV Network Using Fuzzy Clustering Techniques. Proceedings of the 12th WSEAS International Conference on Electric Power Systems, High Voltages, Electric Machines (POWER´12); 24-26 September 2012; Prague. ISBN: 978-1-61804-128-9.

[12] Amer, R.A., Morsy, G.A., Yassin, H.A. (2011). Stability Enhancement for a

Superconducting Generator in Multimachine Power System Using STATCOM. WSEAS Transactions on Systems and Control; Issue 8, Volume 6, August 2011. ISSN: 1991-8763.
[13] Toljan, I., Banovac, E., Tešnjak, S. (2009). Static and Dynamic Analysis of Reconnection of Former Two UCTE Synchronous Zones. WSEAS Transactions on Power Systems; Issue 1, Volume 4, January 2009. ISSN: 1790-5060.
[14] Pancu, C., Baraboi, A., Adam, M. (2009). New Approach Regarding the Electroerosion Estimation of the Circuit Breakers Contacts. WSEAS Transactions on Circuits and Systems; Issue 1, Volume 8, January 2009. ISSN: 1109-2734.