Short-circuit currents and their calculation

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***Abstract* — There are a number of reasons why it is important to analyze short-circuit conditions in electrical networks. One of the most important aspect is the safety and reliability of operation. The Most interesting are the minimum and maximum values of short circuit currents. Many of software tools are used to calculate these values. This article deals with basic description of short-circuit currents, reasons leading to their calculation, comparing and verifying the results of short-circuit currents calculation in the various software tools.**

***Keywords* — Short-circuit current, short-circuit calculation, deviation.**

I. Introduction

The short circuit is one of the major incidents affecting electrical systems. The consequences are often serious, if not dramatic. It is necessary to know the short-circuit conditions in operated power system. It is important for a safe and reliable control and operation of the power system. Short-circuit currents at individual points of the power grid must be known because of several reasons, such as:

- design of electrical equipment from point of view of thermal and dynamic effects of short-circuit currents,
- control of circuit breakers switching capability,
- design of grounding systems and the associated determination of allowable touch-voltage, step-voltage and transferred voltage (for example in low-voltage grid during earth-fault in high-voltage grid),
- design and operation of protection devices,
- stability control of parallel operated synchronous machines in power grid,
- control of voltage ratios during short-circuit and during the start-up of large asynchronous motors,
- calculation of induced voltage in telecommunication lines caused by high-voltage or extra high-voltage networks,
- control of propagation and impact of upper harmonics in power system,
- assessment of overvoltage occurrence during line-to-ground faults.

II. Description of the Short-Circuit Current

The short-circuit is defined as accidental or intentional conductive path between two or more conductive parts (e.g. three-phase short circuit) forcing the electric potential differences between these conductive parts to be equal or close to zero [1].

Course of short-circuit current is considerably complicated and depends on many circumstances such as R/X ratio of circuit, moment of short-circuit occurrence, angle between voltage and current before short-circuit and so on.

Possible course of short-circuit current is shown on Fig.1 and consists of two parts:

- symmetrical short-circuit currents (its amplitude is during the short-circuit constant – blue course),
- dc component of short-circuit currents (its amplitude is exponentially decreasing in time during short-circuit currents – red course).

Sum of both parts results in asymmetrical short-circuit current flowing in point of fault (yellow course).

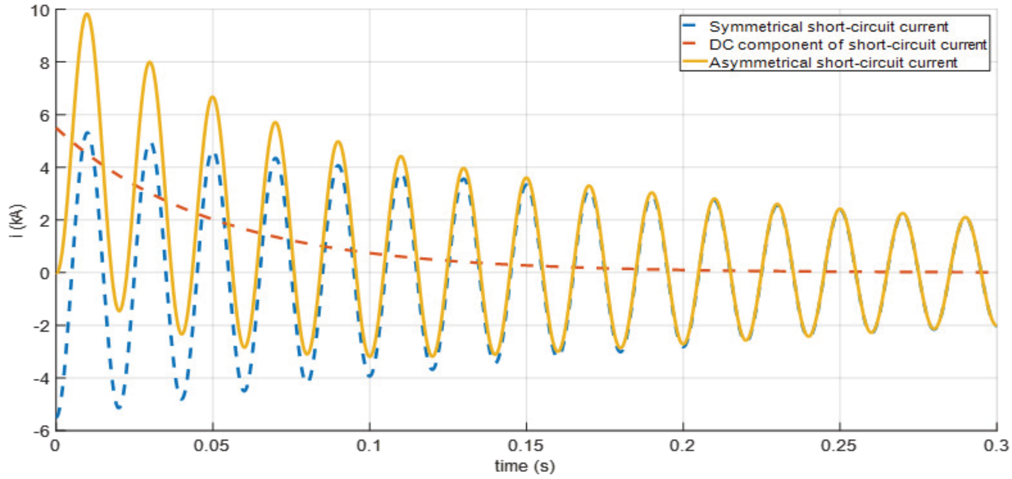

Fig. 1 Short-circuit current flowing in fault point (F)

From the course of short-circuit currents were derived characteristic values of short-circuit currents which serve as basic criteria for short-circuit current assessment. These are:

- initial symmetrical short-circuit current (I_k''): it is RMS value he alternating current (AC) symmetrical component of a prospective (available) short-circuit current applicable at the instant of short circuit if the impedance remains at zero-time value (see Fig.2),
- peak short-circuit current (i_p): is maximum possible instantaneous value of the prospective short-circuit current (see Fig.2)).
- equivalent thermal short-circuit current (I_{th}): the RMS value of a current having the same thermal effects as the actual short-circuit current (see Fig.3)

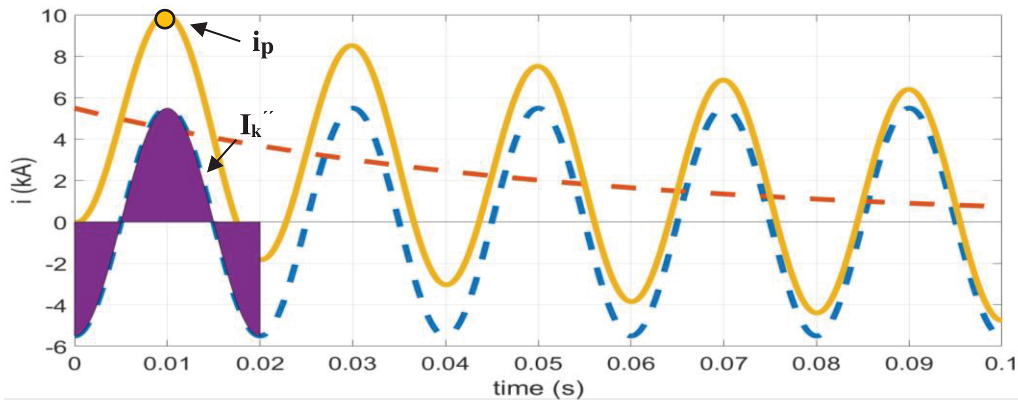

Fig. 2 Characteristic values of short-circuit current

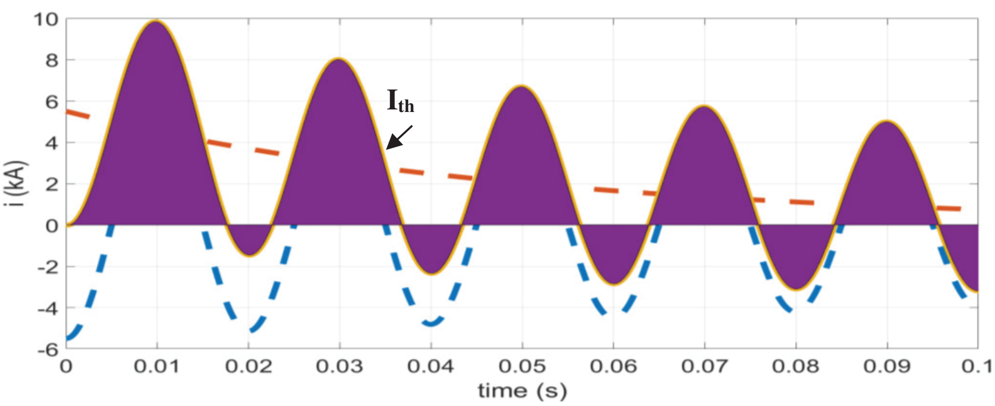

Fig. 3 Equivalent thermal short circuit current

III. Calculation of Short-Circuit Currents

In the past, various numerical and numerical-graphic procedures were used to calculate short-circuit currents. From the group of numerical-graphic methods is possible to mention: calculation according to short-circuit curves and using nomograms. Short-circuit curves can be used if the task of finding short-circuit conditions is limited to finding the short-circuit current at the short-circuit location. This method has gained popularity with its simplicity and relative accuracy. The method consisted in the application of special curves which give the value of the alternating component of the short-circuit current as a function of the so-called computational reactance of the diagram for any moment of the short-circuit event. Short-circuit curves were processed in ČSN 38 04 11 standard. The nomogram method is a simple graphical method that consists of subtracting the necessary parameters of the electrical system elements (impedances) from the graphs that were pre-printed on the sheets, separately for each voltage level. The disadvantage of nomograms is their limited use only for beam networks and the fact that accuracy is directly dependent on the accuracy of reading from the graphs drawn.

From the numerical methods it is possible to distinguish: the method of superposition and the method using the equivalent voltage source at the short-circuit point. The superposition method gives a short-circuit current only in relation to one assumed network load condition. Therefore, it does not necessarily lead to the maximum short-circuit current. To overcome this problem and to find the case with the worst load conditions that lead to the maximum short-circuit current at the short-circuit point, a method for changing operating conditions - an equivalent voltage source method - has been developed. The principle of this method is to introduce an equivalent voltage source at the short-circuit point. This short-circuit voltage source is the only active system voltage [2].

Brief characteristics of the methods used:

- ohm method, the disadvantage of this method is its cumbersome if the system under investigation contains several voltage levels [1],
- per united method, is no better in terms of manual calculations than the previous method, since it involves a number of relationships and bonds associated with reference values, which can often cause calculation errors [1],
- the superposition method, this method is very often used but requires knowledge of steady state ratios before the short circuit occurs, which reduces the slag's applicability for general and rapid calculations [3],
- Extended Active Two-Port Method [4].
- The MVA method: this method is quite simple, fast, accurate and the procedure is easy to remember [5].

The solved power system (transmission and distribution system) is usually very robust and complex system so the manual calculation would be very time-consuming and computationally intensive. Therefore, for this reason a lot of software tools were developed.

It is necessary to say that fault calculation is not simple for a number of reasons:

- there are many different types of fault in three phase systems,
- the impedance characteristics of all electrical items in the system must be known,
- the fault impedance itself may be non-zero and difficult to estimate,
- there may be substantial fault current contribution from rotating machines etc.,
- the initial cycles of fault current may be asymmetric with substantial DC offset,
- the earth impedance in earth faults can be difficult to estimate accurately,
- DC system faults also include inductance effects in fault current growth.

Each of software tool has its own calculation accuracy given by calculation method, modeling of power system elements and so on. European short-circuit calculation standard IEC 60909 allows only a permissible deviation of the results (maximum ±5%).

The aim of this paper is to compare the results of calculating short-circuit current across the selected programs used in practice and their comparison with the manual calculation of a simple network from literature [2]. There were selected following tools for short-circuit calculation:

- **GLF** (Graphical Load Flow): is simple and overview program. GLF uses Fortescue method of symmetrical components to short-circuit calculation. It is intended to solution mainly high voltage, very high voltage, ultra-high voltage networks. It can be used for steady state calculation, analysis of voltage conditions, analysis of short-circuit conditions checking the reliability of network operations by the criterion (n-1).
- **Pas Daisy**: is package of programs used in preparation of operations, planning for further development, design, evaluation and operation of networks. It is characterized

by enhanced supply of calculation method.

- **PSLF** (Positive Sequence Load Flow): is a suite of programs for the analysis of (mainly) transmission system. It allows the calculation of the steady state, as well as transitional phenomena (short circuit, earth-faults or dynamic stability).
- **NEPLAN**: is user-friendly program, serving on the planning and calculation of electric, gas or water supply networks.
- **MODES**: is very complex network simulator with very precisely developed calculation methods and extensive library of dynamic models of power system elements. It can be used for wide range of tasks across power system (load flow, stability of power system, motor-start up, operational planning, protection system settings and so on). MODES contains module ZKRATY, which serve for short-circuit currents calculation.
- **DigSilent PowerFactory**: is a power system analysis software application for use in analyzing generation, transmission, distribution and industrial power systems.

A. Example of manual calculation

Considering the following case – see Fig 4 (taken from [2]). Power plant supplies the power system and 3-phase fault occurs in point F. The parameters of the system are following:
Generator: S_rG = 400 MVA, U_rG = 21 kV, cosφ = 0.8, x''_d = 0,25, p_G = 0,05
Transformer: S_rT = 400 MVA, U_{THV} /U_{TLV} = 230 / 21 kV, u_k=15%
System: U_{qmin}=230 kV, U_{nq}=220 kV, c= 1,1

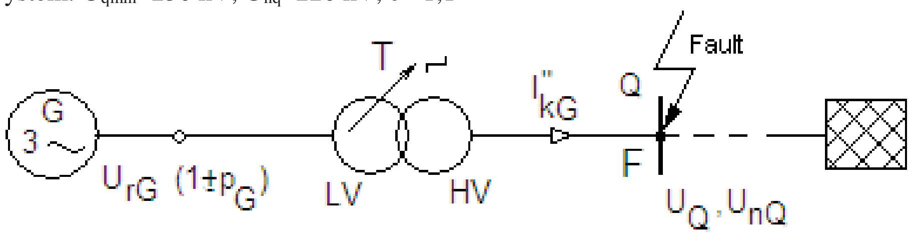

Fig. 4 Short-circuit contribution from power plant to point of fault (F).

The corrective factors according to STN IEC 60909 are considered in calculation [1].
For the short-circuit impedance calculation in electrical power plant block with tap-changer the following relationship is used:

$$\mathbf{Z_S} = K_S\left(t^2 \cdot \mathbf{Z_G} + \mathbf{Z_{THV}}\right) \tag{1}$$

Where Ks is corrective factor:

$$K_S = \frac{U_{nQ}^2}{U_{rG}^2} \cdot \frac{U_{TLV}^2}{U_{THV}^2} \cdot \frac{c_{\max}}{1 + (x_d'' - x_T)\sin\varphi_{rG}} \tag{2}$$

$$K_S = \frac{220.230}{21^2} \cdot \frac{21^2}{230} \cdot \frac{1,1}{1 + (0,25 - 0,15)\sin 36,87^\circ}$$

Short-circuit impedance of generator:

$$\mathbf{Z}_G = x_d'' \frac{U_{rG}^2}{S_{rG}} = 0,25\frac{21^2}{400} = 0,276\Omega \tag{3}$$

Short-circuit impedance of transformer:

$$\mathbf{Z}_{THV} = u_k \frac{U_{THV}^2}{S_{rT}} = 0,15\frac{230^2}{400} = 19,836\Omega \tag{4}$$

Short-circuit impedance of considered power system (in point F) is:

$$\mathbf{Z}_S = K_S(t^2.Z_G + Z_{THV}) =$$
$$= 0,9926\left(\left(\frac{230}{21}\right)^2 .0,276 + 19,836\right) = 52,552\Omega$$

The maximum initial symmetrical three-phase short-circuit current:

$$I''_{kG} = \frac{c.U_n}{\sqrt{3}.Z_s} = \frac{1,1.220}{\sqrt{3}.52,552} = 2,659kA \quad (5)$$

B. Comparison of the results

Following example was modeled in selected software tools and results of short-circuit calculation are listed in Table 1. As the reference value the short-circuit current value calculated manually was chosen.
Deviation for each case was calculated by the formula below:

$$D = \frac{I_{kB} - I_{kA}}{I_{kA}}.100\left(\%\right) \quad (6)$$

Table 1
Comparison of results of short-circuit calculations in various software tools

	I''_{k3} [kA]	Deviation[%]
Manual calculation	2,66	-
GLF	2,65	-0,33
Pass Daisy	2,79	4,9
PSLF	2,71	2,03
NEPLAN	2,72	2,4
MODES	2,69	1,1
DigSilent Powerfactory	2.68	0.8

IV. Conclusion

Calculation and comparison of the results was focused on maximum three phase bold short-circuit current value because in most cases that value takes into account for dimensioning equipment. A deviation with value to (+/-) 2% can be neglected. The maximum possible deviation allowed by standard is (+/-) 5%. Deviation are mainly due to the following facts, that not all of the software packages consider corrective factors, which were considered in manual calculations (according to STN IEC 60909). STN IEC 60909 standard is conservative, which means that it sets strict conditions for calculating short-circuit current through the correction factors. With these corrective factors is achieved better dimensioning and also setting up of protection relays. That is very important for safety and reliable operation of power system.

Acknowledgment

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References

[1] STN IEC 60909-0: Short-circuit currents in three-phase a.c. systems. Part 0: Calculation of currents. November 2016

[2] MEŠTER, M., – Výpočet skratových prúdov v trojfázových striedavých sústavách. ABB-elektro, s.r.o., 2005. ISBN 80-89057-10-1

[3] KAKILLI, A.: System Analysis with the MVA Method for Symmetrical Three-Phase Faults. TEM Journal, vol2 no1, 2013.

[4] MÁSLO, K. a kol.: Řízení a stabilita elektrizační soustavy. ČEPS a Asociace energetických manažerů. Praha 2013. ISBN 978-80-260-4461-1

[5] JAFFARI, H.: Fault Current Calculation. Power System Review: Module 6. Northeast Public Power Association, 2013.

[6] KRIŠTOF, V, – Výpočet skratových pomerov podľa STN IEC 60909. Diplomová práca. Košice: Technická univerzita v Košiciach, Fakulta elektrotechniky a informatiky, 2009.

[7] MITOLO, Massimo: SHORT-CIRCUIT CALCULATION METHODS, 10/2004 Dostupné na internete: <http://ecmweb.com/mag/electric_shortcircuit_calculation_methods/>.