THE STATISTIC CHARACTER OF THE SHORT-CIRCUIT CURRENTS STRESSES

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Abstract. Knowing the thermal and electro-dynamic stresses is crucial to a safe design of equipment and power system components, manufacturing and other key industries but the subject generally does not receive the proper attention in engineering probabilistic design. The magnitude of these stresses depends directly on the short-circuit currents and the fault time and indirectly on the structural system characteristic and state just prior to the fault, the type of fault, etc. These components affecting the magnitude of the thermal and electro-dynamic stresses may be assumed as random variables, so, in order to take in account these parameters in stress analysis, the probabilistic approach will be a new way to explore the engineering design.

Key words: Thermal and electro-dynamic stresses, probability density function.

1. INTRODUCTION

Electrical equipment failures can occur due to local degradation of the components as a consequence of the effect of the thermal or electro-dynamic stresses. Considering that the main cause which goes to the appearance of the thermal and electro-dynamic stresses in the electrical equipment is given by the short-circuit current in the electrical system, in the following, we will analyze the influence of the short-circuit current statistic character on the thermal and electro-dynamic stresses.

The short-circuit currents and the thermal and electro-dynamic stresses represent important parameters that must be considered in the design of the system buses, breakers, the substation apparatus, etc. A fault may be appears anywhere in the system while the loads and the configuration of the network continuously changing, so the magnitude of the short-circuit currents has a statistic character, modeled as a random variable. Based on the analytic expressions of the thermal and electro-dynamic stress, depending on the amplitude and the distribution of the short-circuit current, the authors propose in the paper an original method to determine the analytic expressions of the thermal and electro-dynamic stress probability distribution functions.

2. THE STATISTIC CHARACTER OF THE SHORT-CIRCUIT CURRENTS

Based on the determinist analysis of the three phase short–circuit currents and considering the fault's place as a random variable uniformly distributed, we presented in the other paper [1] the way of changing of a random variable fault's place, in a random variable of the amplitude of the short–circuit current.

Generally, the probabilistic analysis of the short-circuit current, in the given point, is a function of the fault's place on the network line. This function is used together with the probability distribution function of the distance till the point of the fault on the line. Considering the impedance between the source and the fault location, as a function of the type of fault *(TF)* and the condition of the network *(C)*, the probability distribution function of the current using the theory of the total probability applied to the probability distribution functions is given by:

$$f_I(i) = \sum f_{I \mid C,TF}(i \mid C,TF) P_C P_{TF} \tag{1}$$

where $f_{I \mid C,TF}(i \mid C,TF) = f_I(i)$ is the probability distribution function of the short-circuit current, conditioned by the type of particular fault and the system state.

For a network with a foregone configuration and with a certain type of fault, the size of the fault current is depending on the distance x from the source, this means $I=J(x)$. If the source – fault distance probability distribution function is $f_X(x)$, than the probability distribution function of the current may be calculated with the:

$$f_I(i) = \frac{dF_I(i)}{di} = \frac{d}{di}\left[F_X(J^{-1}(i))\right] = \frac{d}{di}\left[\int_{-\infty}^{J^{-1}(x)} f_X(x)dx\right] \tag{2}$$

Derived from this change, in the mentioned papers, we developed the main expressions of the probability distribution functions of the short-circuit current, for different networks configurations. The results of this analysis lead to the conclusion that, although the default place distribution is uniformly, the default has the same probability to appear for the whole line and the probability is as smaller as its length is bigger. The probability of appearance of the short-circuit current are very different, the probability distribution function of the short-circuit current have a different shape, directly influenced by the network configurations. For most of the analyzed configurations, we demonstrated that the small values of the short-circuit current have bigger probability than the current with big values. In other words, the frequency of the small current appearance is bigger than the frequency of big currents, the values of the frequencies depending on the configuration, dimension and system parameters. This reality can be explained by the fact that the growth of the line length on which the fault appears, lead to the decrease of the probability of the fault appearance in one point and the domain of definition of the variable short-circuit currents amplitude, increases. From the study of the analyzed network configurations, we can assume that the growth of the number of parallel lines or loops connected to the same bus system, lead to the acquiring of some probability distribution functions of short-circuit currents, centered to the small values.

3. THE RANDOM CHARACTER OF THE THERMAL AND ELECTRO-DYNAMIC STRESSES

To evaluate the probability distribution function of the thermal and electro-dynamic stresses, we will consider the deterministic analysis of the stress induced by peak short-circuit current I_p, the subtransient short-circuit current I_k'', the steady state short-circuit current $I_{k\infty}$ and the disconnecting short-circuit time t_k. The analytic expressions of the thermal and electro-dynamic stresses, depending on the short-circuit current are:

$$ST(t_k) = \int_0^{t_k} i_k^2(t)dt = \int_0^{t_k} i_{kp}^2 dt + \int_0^{t_k} i_{ka}^2 dt \approx I_{k\infty}^2 \cdot t_f \quad \text{and} \quad I_p = \sqrt{2} \cdot k_p \cdot I_k'' \tag{3}$$

Considering also the distributions of the short-circuit current, we propose, in the following, an original method to determine the analytic expressions of the distribution functions of the thermal $ST(t_k)$ and electro-dynamic I_p stresses [2].

$$f_{ST}(ST(t_k)) = f_I\left(\sqrt{\frac{ST(t_k)}{t_k}}\right) \cdot \left|\frac{1}{2\sqrt{ST(t_k) \cdot t_k}}\right| \quad \text{and} \quad f_{i_p}(i_p) = f_I\left(\frac{i_p}{\sqrt{2} \cdot k_p}\right) \cdot \left|\frac{1}{\sqrt{2} \cdot k_p}\right| \tag{4}$$

Firstly, we consider the case of single line connected to a source, alike in figure 1.
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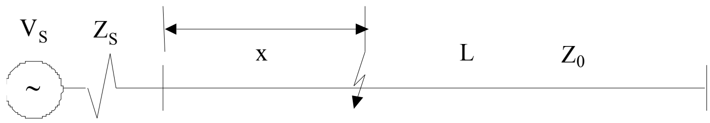

Fig. 1 The system with a single line to a source

In the case of a fault located at the distance *x* from the source, the probability distribution function of the short-circuit current is given by:

$$f_I(i) = \frac{V_S}{LZ_0 i^2} \qquad for \quad \frac{V_S}{LZ_0 + Z_S} \le i \le \frac{V_S}{Z_S} \tag{5}$$

where V_S is phase-to-neutral system voltage, Z_S is the impedance equivalent of the source and Z_0 is the specific impedance of the line.
The probability distribution functions of the thermal and the electro-dynamic stresses are given by:

$$f_{ST}(ST(t_k)) = \frac{V_S\sqrt{t_k}}{2LZ_0 ST\sqrt{ST}} \text{ for } \left(\frac{V_S}{LZ_0 + Z_S}\right)^2 t_k \le ST(t_k) \le \left(\frac{V_S}{Z_S}\right)^2 t_k \tag{6}$$

$$f_{i_p}(i_p) = \sqrt{2}k_p \cdot \frac{V_S}{LZ_0 i_p^2} \text{ for } \sqrt{2}k_p \frac{V_S}{LZ_0 + Z_S} \le i_p \le \sqrt{2}k_p \frac{V_S}{Z_S} \tag{7}$$

For the studied configuration, beside the analytic expressions of the distribution functions, the way to obtain them by practice, using the transformations of variables or the Monte Carlo simulation is presented. All these practical applications have the role to validate the acquired analytic models.

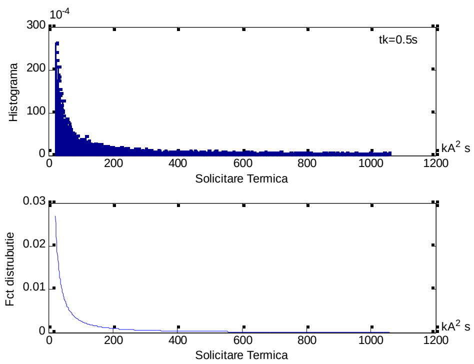

Fig. 2 The thermal stress pdf
(simulation and analytical)

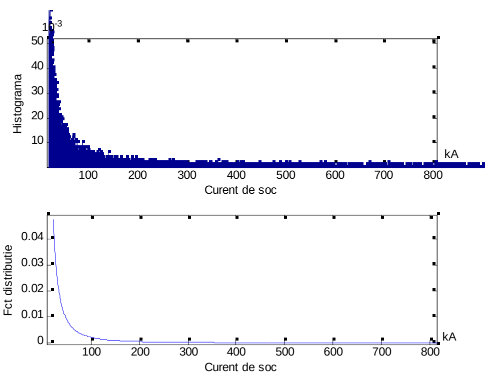

Fig. 3 The electro-dynamic stress pdf
(simulation and analytical)

Taking into account the real network configuration the result is the idea to model the probability distribution functions of thermal and electro-dynamic stresses, in case of complex configurations.

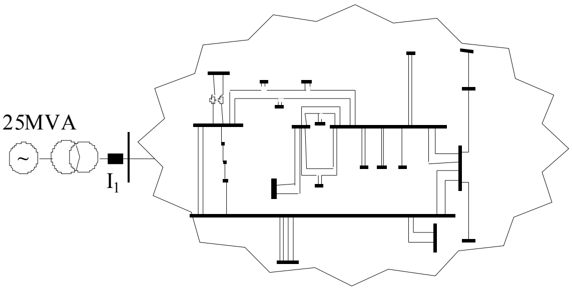

Fig. 4 A real complex system network - 110 kV Iasi

Therefore, in the following, the analysis of the distribution functions of thermal and electro-dynamic stresses was extended as well as for the case of a real complex system (network of 110 kV Iasi county), for which the authors established the distribution functions of short-circuit current using the analytic method and Monte Carlo simulation.

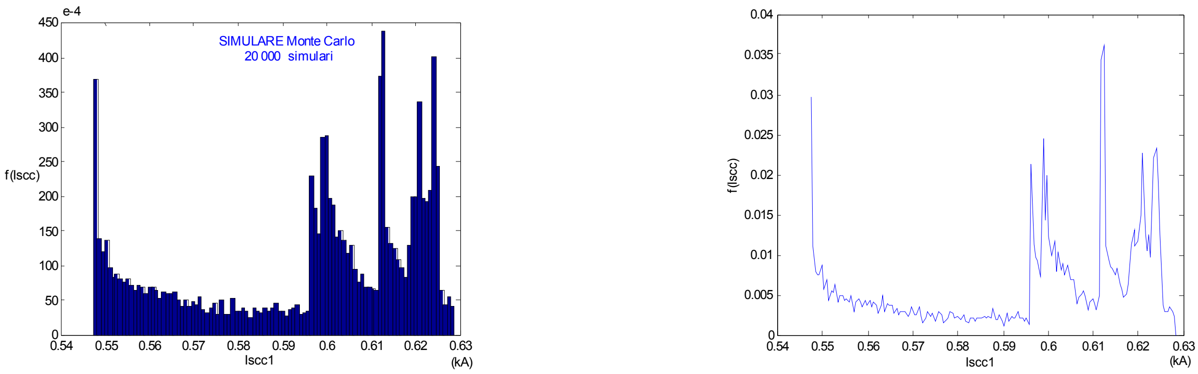

Fig. 5 Probability distribution function for the short-circuit currents I_1 (simulation and analytical)

The intention was to obtain the distribution functions of the thermal and electro-dynamic stresses, in the case of the complex system 110 kV Iasi county. The expressions of the thermal and electrodynamics stresses probability distribution functions from the case of simple configurations were obtained, using a mathematical analysis and also using Monte Carlo simulation. For the considered system it was settled the distribution functions of the two stresses, in the case of two switches.

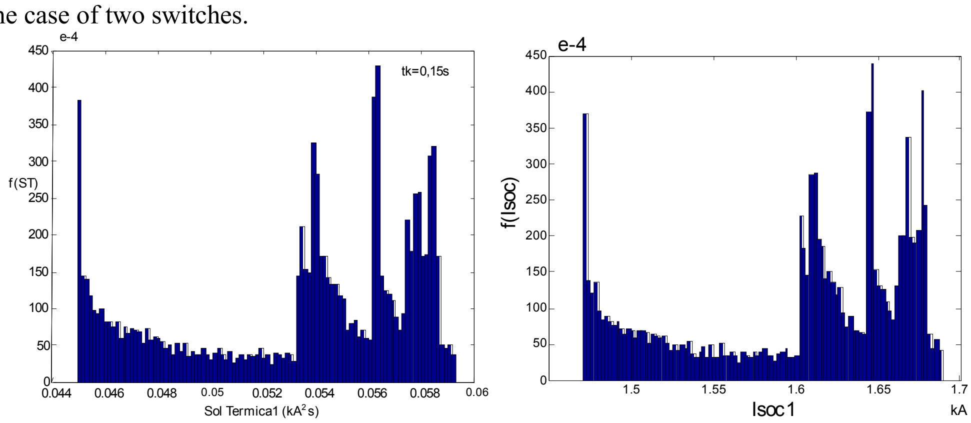

Fig. 6 Probability distribution functions for the therma and electro-dynamic stresses in the switch I_1

4. CONCLUSIONS

When analyzing the thermal and electro-dynamic stresses, the conditions of the system are prior and these values are calculated depending on the short-circuit currents for the different combinations, on the local power involved, the systems configurations and on the time of fault. Usually we consider the most unfavorable situations, in order to limit the number of the case studies. The stresses caused by the three-phase faults located to the system buses are usually considered. The equipment is chosen from thermal and electro-dynamic stresses restrictions, calculated in those points. If the amplitude of these stresses is considered as random variables so, the probabilistic methods become very attractive solutions to analyze the stress magnitudes caused by short-circuit currents. The probabilistic concepts concerning the values of the thermal and electro-dynamic stresses can be used for the power system design, by calculating a security coefficient taking into account that the maximal values of the thermal or electro-dynamic stress, that appear with a smaller probability that their minimal values.

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