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Statistical analysis of conductor clashing particles in low-voltage distribution network

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Abstract—**Conductor clashing phenomena and sparks production have been analyzed for last decades. Those sparks can cause fire on the ground and enormous financial damages. A few simulations of conductor clashing have been done in a low-voltage distribution network. Particles created by these clashing of ACSR conductors were recorded with high speed camera and statistically analyzed. The particles with great diameter have greater probability to cause fire on the ground. The target was to find out the probability density function (PDF) of particles diameter in dependence on both short circuit currents and short circuit durations. The statistical analysis of conductor clashing particles in a low-voltage distribution network is presented in this paper.**

Keywords-conductor clashing; sparks; fire; statistical analyses;

I. INTRODUCTION

Fires around the world have an increasing impact on the ecology and economy of the states. In many cases, fires are caused by people. Very often conductor clashing of overhead lines is considered as fire cause [1]. Fires due to conductor clashing can create very ugly scenes as human death or forest combustion with great financial damage. Many witnesses claimed that they saw conductor clashing and then fire on the ground. Those are very serious charges because damages due to fire can cost millions. Croatia is a Mediterranean country with high wildfire risk. For example in 2003 only in Split and Dalmatia County there were 130 wildfires, the total burned area was 9.700 ha [2]. Considering only Croatia, it can be seen that there were many fires that allegedly were started by conductor clashing. Regarding the fire in Makarska that fire burned down 800 hectare of forest, land, vineyards and olive. According to witnesses, the fire started after arcing of overhead lines. There is no research work reported in the public literature relating to the ignition of bushfires from electric arcs. It is apparent from the literature that there has been very little research activity on the prospects of electrical arcs and the associated plasma jet causing fires in grasses and forest material [3]. Conductor clashing is known to cause service disruptions and can lead to ground fires, personal injury and property damage. They can also lead to conductor failure, which can result in electric shock and property damage. The conductors clashing phenomena is very complex. It depends on bay configuration and line length, conductor type, conductor tension, asset defects and external interference [4]. Finding PDF of particles diameter by conductor clashing in an electrical distribution network is a contribution of this paper. This PDF can help to calculate the probability of fire starting by conductor clashing in dependences on both short circuit currents and time settings of protection devices.

II. CONDUCTOR CLASHING PHENOMENA

By conductor clashing part of metal from conductor melts and part vaporize ([5], [6]-[7]). Ratio of melted/vaporized metal is not straight set. It varies from 1% to 50% ([6]-[7]). Part of the available literature attributes the creation of particles to the electric arc (arcing between two conductors) [6], [8]-[12], while the rest attribute the creation of sparks to either electric contact or the electric arc [3], [5], [13]-[14]. In the low voltage distribution network, electric arc is not possible [15] whereas it is possible in the high voltage network. The arc motion between two conductors in high voltage networks, which increases at higher currents, can lead to decreasing the emission of sparks because of the lack of concentrated heating at any particular electrode spots [5]. Electric arc "walks" over surfaces of two conductors. Since electric contact is solid connection between two conductors in low voltage network without electric arcs and it's surely worse case than conductor clashing followed by electric arc in high-voltage network. So, it can be concluded that the most dangerous conductor clashing is in low voltage network and surely it's also the most usually. Reference [6] describes forming of electrical sparks very good. It says that the pressure underneath the arc can be as high as 300 kPa, and hence the metal surface can attain a temperature in excess of the normal boiling point (2730 K). The local high pressure causes ejection of molten alumina as small droplets (sparks). These droplets can have initial temperatures ranging between the surface temperature and the melting point of alumina, the latter temperature being 930 K. Some of these droplets will ignite and burn, while others will simply fall to the ground, cooling off on the way. The ignition temperature for an alumina droplet is about 2300 K, which corresponds to the melting point of alumina oxide. Below this temperature the accumulation of solid oxide on the droplet surface inhibits the contacting of oxygen and alumina and the oxidation process is relatively slow. However, if the oxide is molten, aerodynamic forces can sweep the oxide away to expose bare metal. Reference [15] explains clearly that during arcing, a bright flash, sparks and a puff of white smoke appear. The arc-produced alumina sparks will either ignite and burn or simply fall to the ground, cooling off on the way. Reference [5] says that the actual mechanism of particulate loss due to conductor clashing at the relatively slow rates of contact separation encountered is similar to that of normal contact erosion. Power will be developed in the current flow constriction at the point of contact. When the contacts are separated the contact resistance increases. Thus the temperature of the contact increases until it reaches the melting point of the conductor material. At this point, a molten bridge forms between the separating contacts to carry the current. When true separation occurs as the bridge is broken, the temperature at the contact points is high enough for vaporization of metal and electron emission to initiate an arc discharge. Metal sparks are naturally cooled by convection and radiation. When sparks falls to the ground it can potentially cause fire if it has enough temperature and amount of heat. According [6] and [16] sparks are spherical geometrical bodies. Spark temperature (at the ejection time), spark diameter and wind velocity are variable of primary importance [16]. Size of particles that were created by conductor clashing simulations and fell to the ground without vaporizing is described in [5] and [17]. According to [17], the laboratory simulations were done with conductor clashing simulating at 240 V and 415 V. Particles diameters were independent on current tough some connection existed at 240 V where higher current meant larger diameters of sparks. Also, spark diameters are independent on speed of clashing of conductors. In [5] the simulations were done with conductor clashing at voltage 240 V and increasing current. The number and the size of produced particles were increased in accordance with the increased magnitude of current. Some others literature assumed sparks diameter, but those assumptions are based on speculations. In [15] authors took the particle diameter of 0.5 mm as the reference diameter. In [16] authors assumed that the diameter of particles is from 0.5 mm to 5.5 mm. In [6] authors believe that the greatest particle produced by conductor clashing is 1.5 mm. In [11] the diameter of particles was assumed between 0.5 mm to 2 mm. By assumption, the electric arc can create particles with the diameter of 1 mm [14]. According to [7] the electric arc can produce particles with diameter of 1-3 mm. Particles with diameter less than of 1.5 mm can start fire. This is an assumption too. Only in [17] and [5] simulations in laboratory which represented conductor clashing have been done. In all those tests represented particles which reached the ground have got diameter between 0.5 and 2.5 mm. In accordance with [16] important note is that mass and diameter of particles are invariant with time. In [18] were done some tests that show how particles created by conductor clashing cannot be fire cause. Particles in that test were with diameter up to 1 mm.

III. CONDUCTOR CLASHING SIMULATION

Conductors clashing in a live 400 V overhead distribution network were simulated. Conductors were ACSR of 25/4 mm^2. Clashing has been done by an isolated crane. This was practically the simulation of line-to-line short circuit (Fig. 1). Created particles (sparks) were recorded with high speed camera (50 fps) and statistically analyzed. Knowing network data and environmental parameters, critical conditions (critical particle diameter) for fire starting by conductor clashing can be calculated. Knowing both the probability density function (PDF) of particles diameter and the critical particle diameter, probability of fire starting by conductor clashing can be found.

Figure 1. Sparks produced by conductor clashing (short circuit) experiment

Experiments were done on three locations in an electrical network. These locations were selected based on the amount of short-circuit current. In these cases short circuit currents were: 1700 A, 900 A and 650 A. Different short circuit currents were obtained by simulating short circuits on different places in electrical network as it’s shown in Fig. 2. If the short-circuit place is further from low-voltage infeed bus than short circuit current is less and short circuit duration is longer. For each simulated case several fuse rated currents were used. Wind speed was 1 m/s during these simulations. PDF of particles diameter were found for different short circuit time durations and for different short circuit currents. This approach can be applied anywhere in any distribution network.

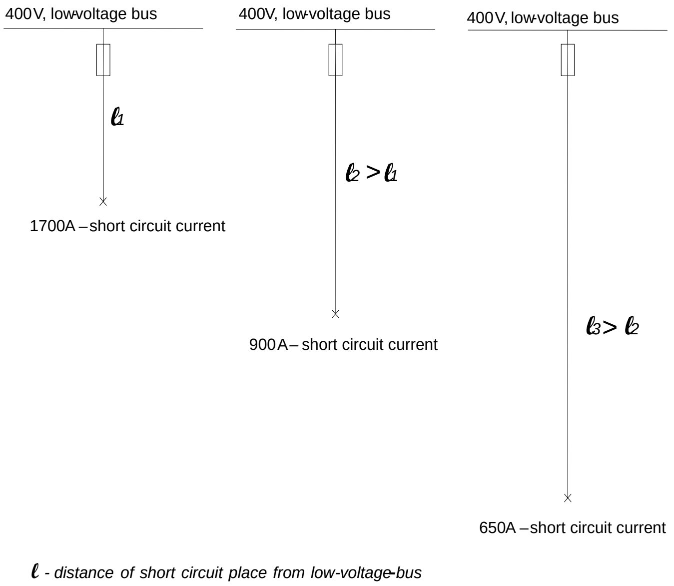

Figure 2. Short circuit currents for which conductor clashing was recorded

IV. STATISTICAL ANALYSES OF PARTICLES PRODUCED BY CONDUCTOR CLASHING

Simulation of conductor clashing was done in a live low-voltage network as line-to-line short circuit. Conductors were ACSR. Statistical analysis of particles created for each short circuit current case and for every short circuit time duration was made and particles diameter PDF was found. We quantitatively described the main features of the sets of observed data with descriptive statistics (mean, variance, standard deviation, coefficient of variation, coefficient of skewness etc.).

The number of particles, means of diameter of particles in mm, standard deviations in mm, and coefficients of skewness obtained in experiments in a real low-voltage network are shown inTables I, II and III. Experiments were carried out for three cases according to short circuit currents (1700 A, 900 A and 650 A). In each case two short circuit time durations were tested (in accordance with changed rated current of fuses). The coefficient of skewness is positive in all cases.

TABLE I. DESCRIPTIVE STATISTICS OF LINE-TO-LINE SHORT CIRCUIT CURRENT OF 1700 A

Short circuit duration (ms)	15	40	100
number of particles	215	608	1154
mean (mm)	0,577	0,696	0,838
std. deviation (mm)	0,248	0,27	0,359
skewness	1,88	1,23	0,695

TABLE II. DESCRIPTIVE STATISTICS OF LINE-TO-LINE SHORT CIRCUIT CURRENT OF 900 A

Short circuit duration (ms)	100	200
number of particles	243	504
mean (mm)	0,739	0,821
std. deviation (mm)	0,328	0,344
skewness	1,08	0,985

TABLE III. DESCRIPTIVE STATISTICS OF LINE-TO-LINE SHORT CIRCUIT CURRENT OF 650 A

Short circuit duration (ms)	100	200	300	500
number of particles	47	115	200	258
mean (mm)	0,62	0,738	0,857	0,909
std. deviation (mm)	0,276	0,322	0,393	0,408
skewness	0,852	0,973	1,2	1,03

For all experiments, in first step, we made histogram of particle diameters. Then we tried to fit several statistical theoretical distributions. The frequencies of particles were very good approximated by some of them. Testing the compatibility of empirical data with the theoretical probability distribution function was performed with the Kolmogorov-Smirnov test. Three-parameter PDFs were better fitted to the empirical data than two-parameter PDFs. Testing all cases, in most of them Dagum PDF and Log-Pearson 3 PDF were best fitted to the empirical data. Empirical data frequencies and fitting PDF are presented in Fig. 3., Fig. 4., Fig. 5., Fig. 6., Fig. 7., Fig. 8., Fig. 9., Fig. 10. and Fig. 11. Results are similar as in [19]. If short circuit (conductor clashing) has got longer duration (less sensitive over current protection) greater number of particles were appeared and their mean value was greater. Greater mean value is associated with greater probability of fire starting due to conductor clashing.

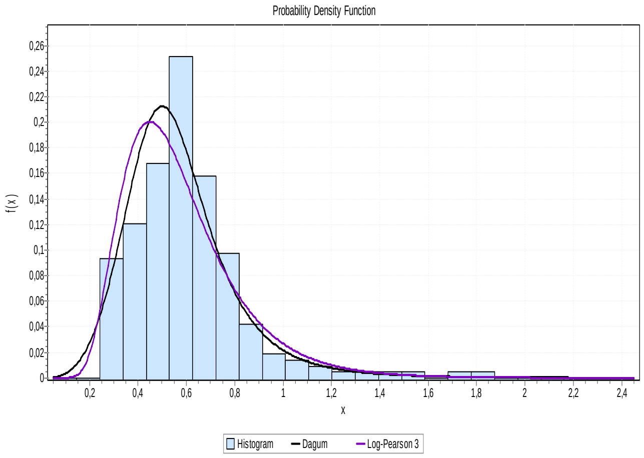

Figure 3. Fitting probability density functions in case of short circuit current of 1700 A and time duration of 15 ms

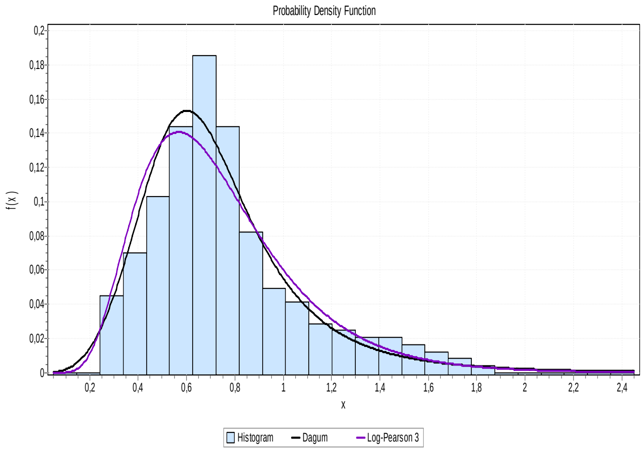

Figure 6. Fitting probability density functions in case of short circuit current of 900 A and time duration of 100 ms

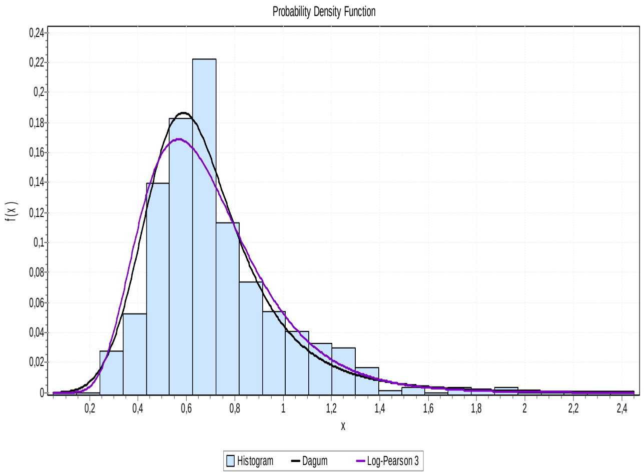

Figure 4. Fitting probability density functions in case of short circuit current of 1700 A and time duration of 40 ms

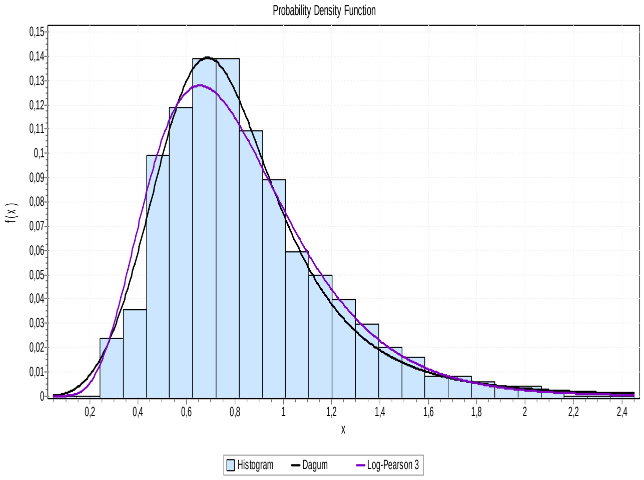

Figure 7. Fitting probability density functions in case of short circuit current of 900 A and time duration of 200 ms

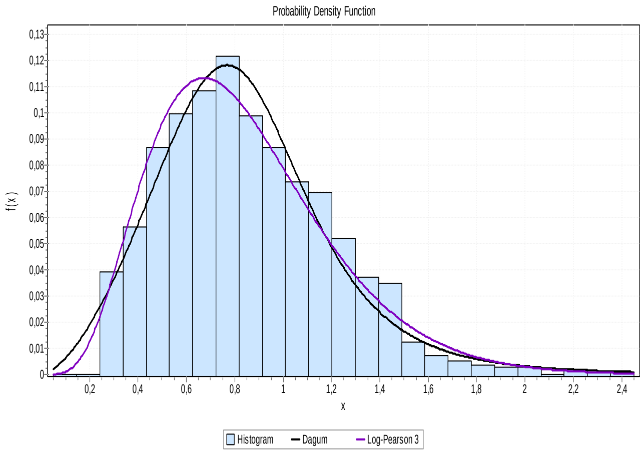

Figure 5. Fitting probability density functions in case of short circuit current of 1700 A and time duration of 100 ms

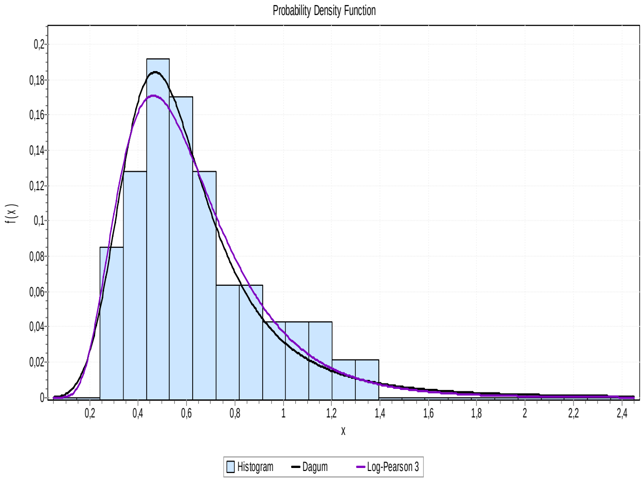

Figure 8. Fitting probability density functions in case of short circuit current of 650 A and time duration of 100 ms

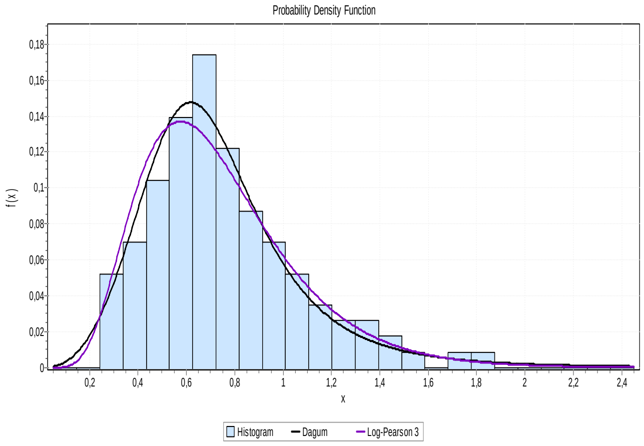

Figure 9. Fitting probability density functions in case of short circuit current of 650 A and time duration of 200 ms

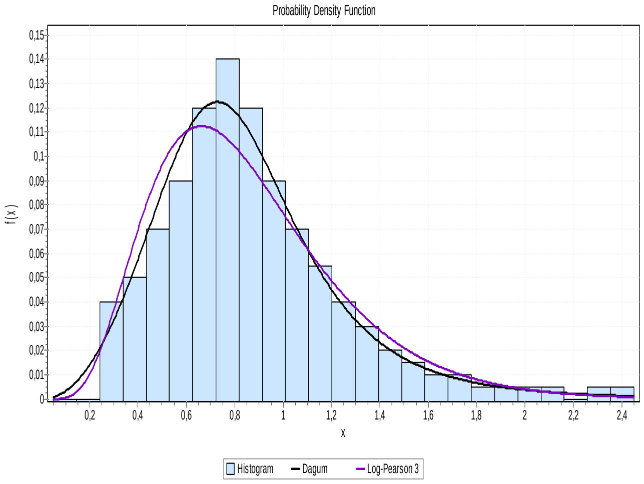

Figure 10. Fitting probability density functions in case of short circuit current of 650 A and time duration of 300 ms

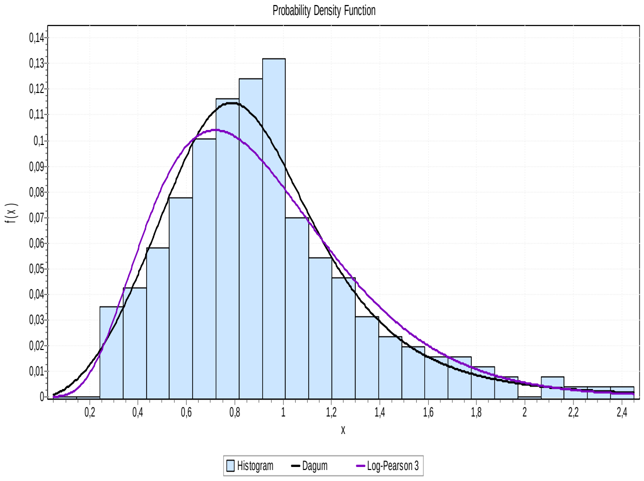

Figure 11. Fitting probability density functions in case of short circuit current of 650 A and time duration of 500 ms

CONCLUSION

Using PDF is a scientific way of dealing with uncertainty as particle diameter distribution. Analyzing PDF for different cases of conductor clashing presented in this paper (different places of short circuits and different rated current of fuses in an energized low-voltage distribution network) can be concluded that Dagum and Log-Pearson 3, as three-parameter distributions, very good fitted frequency of particles diameter. These distributions can be applied to diameter distribution of particles created by conductor clashing on any place in low-voltage network (any short circuit current) and for different time settings of protection devices. Contribution of this paper is in finding unique PDF of created particles diameter by conductor clashing in an electrical network. Also, in this paper is proven fact that longer short circuit time duration and increased short circuit current cause greater mean value of produced particles diameter, what means greater probability of fire starting due to conductor clashing.

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