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Underground cable time to next fault assessment using Crow-AMSAA method

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***Abstract*—This paper will present time to next fault assessment of underground cables using Crow/AMSAA method. For this example, two groups of cables are analyzed, 10 kV cables from one 35/10 kV substation and 35 kV cables from one 110/35 kV substation.**

Aim of the paper is to propose easy solution for time to next fault calculation in order to help company to make plans for future period based on precise data. With new data, company could plan necessary work force, material and costs.

Keywords—cable; Crow/AMSAA; fault; intensity; time to next fault;

I. Introduction

Underground cables represent important part of one power system. For that reason, knowing and understanding their condition and life cycle is of great importance to system operator. By understanding cable fault intensity, system operator can plan new investments, preventive actions and necessary resources.

Underground cables analyzed in this paper are part of Power system of Serbia. Right now, this company is facing challenges, in the manner that is trying to reduce its business and labor costs. Understanding condition of its underground cable network can help company to make right decision towards offices, which are responsible for cables fault location and their repair.

Faults history is important asset, which can help creating of mathematical model of cables remaining useful life and time to next failure [1]. In this paper, time to next fault will be determined for underground cables of two substations. Data consists of 10-year long fault history.

Underground cables during their normal operation suffer multiple stresses such as ionization, electrical, thermal and mechanical stress [1]. For that reason, cables ageing is complex process that consists of combination of all mentioned stresses but also from outside factors [2].

Fault on underground cable is harder to repair. First, it has to be precisely located and then repaired after access to fault spot gets available. Such process demands cooperation of few teams from different offices. Because of mentioned problems, time without voltage supply may last longer [3]. For example, comparing to overhead lines, cost of underground cable installation is 10-15 higher; on the other hand, repair of fault on cable takes 3-5 more time [4].

In analyzed power system, preventive maintenance of underground cables is not part of company's policy. Unlike some other equipment in power system, it is not easy to maintain cable in order to reduce its fault intensity. On the other hand, cable replacement is a major financial undertake. Power industry of Serbia have never carried out early and preventive cable weak spot detection. Such process would require investment in new equipment and work force and that is hard to expect from company at this moment. For that reason, Power industry of Serbia uses run-to-failure work method, which means, cables are in use until next failure.

In this paper, Crow/AMSAA (Army Material System Analysis Activity) calculates time to next fault using Excel software [5]. Idea is to present easy solution for company such as Power industry of Serbia, which in this moment may not be able to invest in such areas. Last few years [6, 7] Crow/AMSAA is widely used for reliability monitoring and fault prediction for repairable equipment in power systems. In [6] authors use Crow-AMSAA method, (also known as non-homogenous Poison process) for next fault equipment prediction in repairable systems. Medium voltage underground cables are also repairable, since after each fault, they are repaired by installing joints and system continues to work in manner as-bad-as-old [7].

In [8] Crow-AMSAA does historical data analysis, and Weibull distribution determines time to next cable fault. For Weibull distribution data need to consist of time to first fault [9], which is hard to expect in system such is Power industry of Serbia where precise data does not exist.

Like any other equipment in power system, life cycle of cables follows so called „bathtub curve“. In “bathtub curve” greatest number of faults are happening after devices installment (due to manufacturing and install mistakes) and at the end of devices life due to aged material. In [6] estimates that cables first period covers first 5 years after its installation, useful life period 5-25 years and wear-out period starts after 25 years.

II. Collected Data Analysis

A. *Number of monthly faults on analyzed cables*

Gathered data consist of cable faults history from the period of 10 years (2012 - 2022). Paper analyses two groups of cables. First group consists of 35 kV cables (29 in total) from one 110/35 kV/kV substation and second group are 10 kV cables (74 in total) from one 35/10 kV/kV substation. Source of data used in this paper is the office, which maintains all faults in city cable network.

Fig. 1 shows number of recorded faults in period of 10 years. Fig.1 also presents number of faults per month of occurrence. For 35 kV cables during summer period (May and July) is most likely that fault will occur. On the other hand, number of faults on 10 kV cables are more or less constant throughout the year.

B. Number of faults per year

Fig. 2 and fig.3 are showing number of faults for each year. From fig.2 and 3, it is obvious that fault trend line is increasing with time. Increasing number of faults is important information for company, because for future period, it may be useful to plan increasing number of personal in offices, which are responsible for faults location and cables repair.

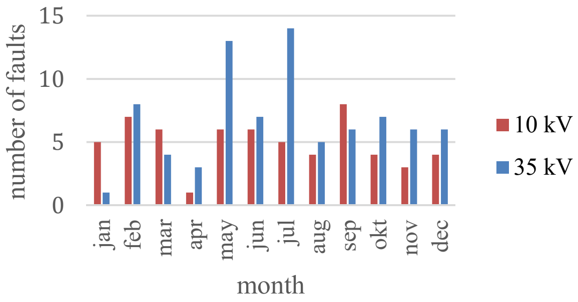

Fig. 1. *Recorded number of faults during analyzed period*

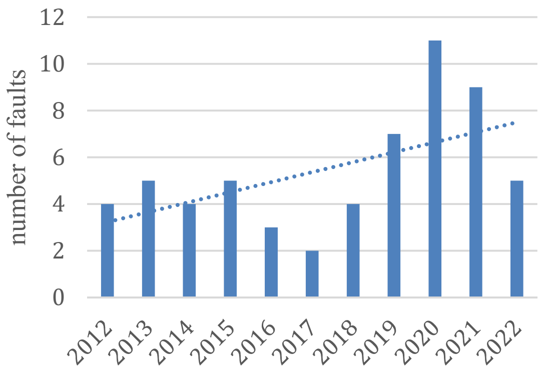

Fig.2 *10 kV faults for each year*

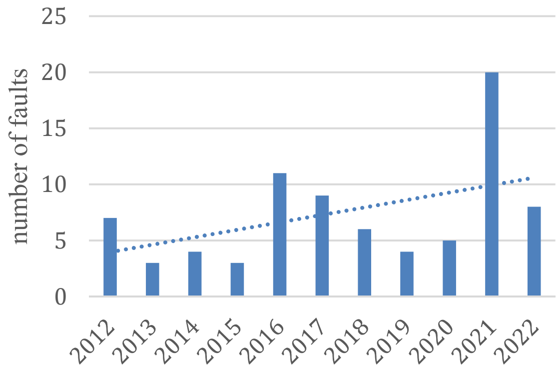

Fig.3 *35 kV faults for each year*

C. Number of faults per feeder level

Fig. 4 and fig.5 are showing number of faults on each feeder level. From presented figures, we can easily notice that first level of feeders are suffering the greatest number of faults. Unfortunately, it was not possible to obtain feeder load at the moment of fault occurrence, but logically first level is carrying the entire load and therefore it is easy to understand that load plays great role in cable faults intensity.

At 35 kV feeders (which consist of three levels), first feeder has incomparable greater number of faults comparing to second and third feeder. On the other hand, observing 10 kV feeders, second and third feeder are also suffering large number of faults comparing to following feeders, especially last four.

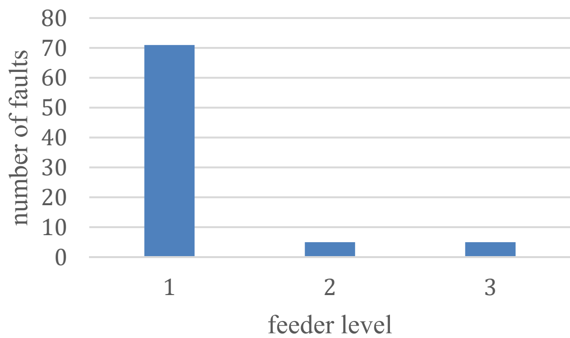

Fig.4 *35 kV faults on each feeder level*

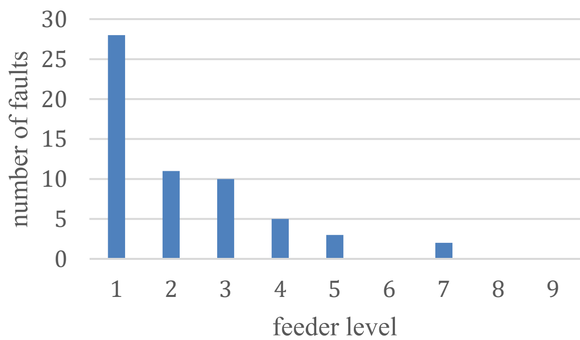

Fig.5 *10 kV faults on each feeder level*

D. Influence of temperature on cable faults

Fig. 6 and fig.7 are showing chronologically recorded faults relative to maximal daily temperature. In both cases (10 kV and 35 kV), it can be noticed that faults starting to occur during higher daily temperatures then before. One of the reasons is higher energy consumption during summer for air-conditioning because of the higher temperatures. In analyzed power system, it was typical that during winter power consumption gets higher, but throughout last few years summer months had more power consumption then winter. In addition, on fig. 6 and fig.7, distinct clusters of faults happening during similar temperatures are marked.

III. RESULTS AND DISCUSSION

Expected number of failures in a specified interval is [6]:

$$N(t_2) - N(t_1) = \int_{t_1}^{t_2} \lambda(t)dt \quad (1)$$

Values for β and λ are given by equations (2) and (3) respectively, while fault intensity is presented in equation (4):

$$\beta = \frac{n}{n \ln T - \sum_{i=1}^{n} \ln T_i} \quad (2)$$

$$\lambda = \frac{n}{T^\beta} \quad (3)$$

$$\lambda_i(T) = \lambda \cdot \beta \cdot T^{\beta - 1} \quad (4)$$

Mean time between faults:

$$MTBF = \frac{1}{\lambda_i} \quad (5)$$

Time to next fault:

$$T_{n+1} = \left(\frac{n+1}{\lambda}\right)^{1/\beta} - T_{n\ cum} \quad (6)$$

In given equations λ is a scale parameter that has no physical meaning [7] and β is a measure of the failure rate.

Value of β shows equipment life period. If its greater than 1, the failure rate is increasing which means equipment is getting old and its end of life is getting near. β less than 1, represents infant mortality period when equipment fails because of manufacturing or installation errors. Failure rate is decreasing until it is equal to one, which means that equipment is in normal working condition and failure occurs randomly [7]. Fig. 8 presents life cycle of equipment considering β parameter.

For that reason, Crow/AMSAA method is useful, because just by observing β parameter workers can draw very important conclusions about analyzed equipment's state. Further calculations can determine the time to next failure, which can show do the failures occur more frequently or not.

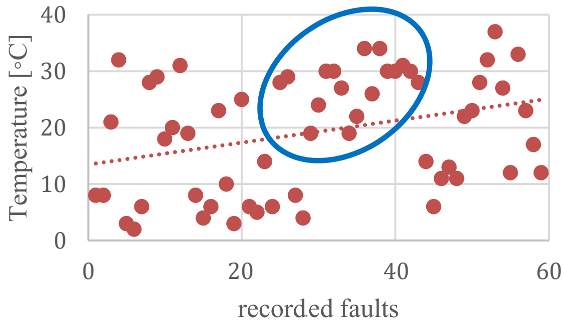

Fig.6 *10 kV faults vs max. daily temperature*

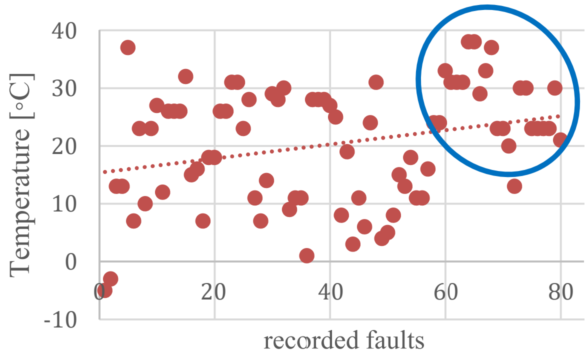

Fig.7 *35 kV faults vs max. daily temperature*

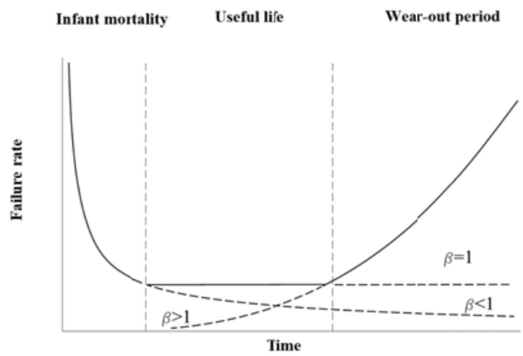

Fig.8 *Life period and beta parameter*

Table I shows Crow/AMSAA parameters for both voltage level cables. Beta parameter shows that 10 kV cables are in period of their useful life, where faults occur only randomly. On the other hand, 35 kV cables are slowly getting beyond useful life period, and system operator can expect increased fault intensity in the future. Time to next fault confirms conclusion that 35 kV feeders suffer more faults, and for that voltage level, time to next fault is almost two times shorter then at 10 kV cables.

Table II shows Crow/AMSAA parameters for feeders with greatest number of recorded faults (5 or more faults). Number of data may not be sufficient to make calculation on prticular single cable, since data sugest that cables are in first period of their life cycle which is actually not true. Fot that reason it is recomended to includ longer period during time to next fault for single cables.

Fig. 9 and 10 preset Crow/AMSAA log-log plot of cumulative number of faults vs. cumulative time.

Alternatively, log-log plots could be used to obtain Crow/AMSAA parameters.

TABLE I. CROW/AMSAA PARAMETERS FOR ALL CABLES OF EACH VOLTAGE LEVEL

	35 kV	***10 kV***
λ	0.001503	0.008024
β	1.313708	1.074954
Time to next fault	37	62

TABLE II. CROW/AMSAA PARAMETERS FOR FEW FIRST LEVEL FEEDERS

	35 kV					***10 kV***
Feeder number	***10***	***12***	***17***	***18***	***24***	***22***
λ	0.0396	0.0377	0.0189	0.0557	0.0606	0.1029
β	0.6521	0.6341	0.7246	0.5810	0.5444	0.5883
Time to next fault	632	814	705	844	1316	300

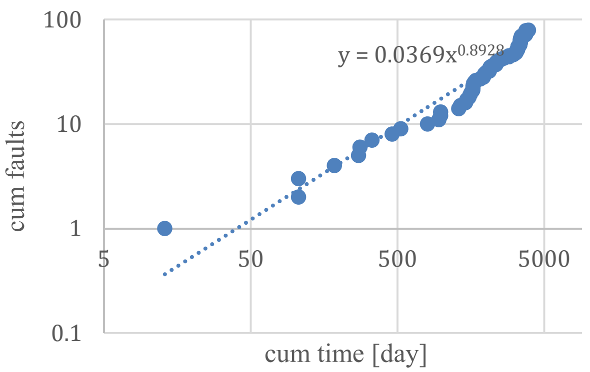

Fig.9 *35 kV log-log faults vs. cum.time*

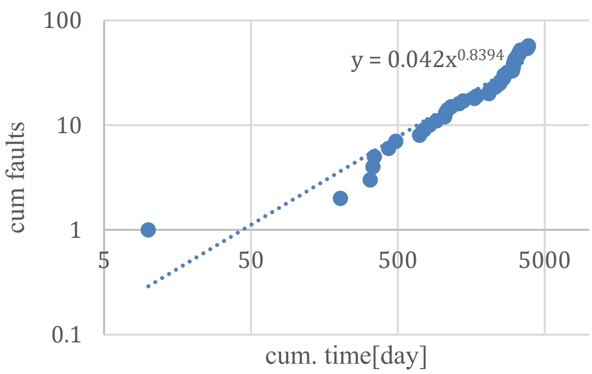

Fig.10 *10 kV log-log faults vs. cum.time*

Time to next failure can significantly help in the job planning process, when responsible persons knows the expected moment of underground cables failure. Company, which is in the process of cutting costs and reducing the workforce, such data, can help in making important decisions for its future work. In order not to make a mistake that would affect the increase in the time of detecting failures and longer time without voltage consumption, it's recommended to evaluate all underground cables condition.

By observing the β parameter at the substation level, 35 kV cables are having a higher intensity of failures compared to 10 kV cables. Although both β values are greater than 1, it still cannot be concluded that the cables are in an advanced stage of life when the intensity of failure is more frequent. One of the recommendations is to use more date for next analysis (longer time period and more middle voltage cables).

IV. CONCLUSION

Given that so far no analysis of mean time to failure based on recorded failures has been carried out in Power industry of Serbia, this work presents good starting point in that direction.

Based on the obtained calculations, it can be concluded that with this simple method it is possible to monitor the expected time until the next failure. Moreover, obtained results, as well as the regular monitoring of the intensity of failures, can contribute to a better organization of work in terms of easier planning of resources for the future period.

Conclusions and recommendations after the analysis:

- The cable fault intensity (10 kV and 35 kV) increases with time,
- Breakdowns starting to occur at higher temperatures compared to the earlier period,
- Stored information of individual sections of the cables where faults are occurring often may help in decision making for possible replacement of section.
- Possibility of considering maintaining a database of the types of installed cables, updating the database when replacing part of the section with a new type of cable, accurate records of failures and their causes (third party, short circuit, earth fault...), as well as records of the year of installation of the cable.

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