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Question 9: What are the experiences regarding the application of semi-probabilistic insulation coordination methods in either HVAC or HVDC systems? How do the results compare to the deterministic and statistical methods defined in the international standards?

Before 1965's the insulation coordination of power systems was only approached by the conventional deterministic method. This method specifies a sufficient margin by which the maximum overvoltage should be less than the minimum strength of the insulation. In the 70's power systems engineers realized that insulation coordination was suited for statistical analysis. The probabilistic method consists of selecting the insulation strength or clearances based on a specific reliability criterion. Consequently, insulation coordination is defined as the selection of the insulation strength consistent with the expected overvoltages to obtain an acceptable risk of failure [1 – 2]. The goal is not only to select the insulation strength, or minimum clearance since minimum strength can be equated to minimum cost.

Statistical methods have been indeed employed for the purpose of devising an economical transmission system operating at an acceptable rate of failure. The increment of transmission voltage in the 60's and 70's passing from a 345kV systems towards 500kV lines and then 735kV in 1965 challenged the power system from economic and ecological point of view requiring the use of common power line corridors. The use of common corridors gave moment to the need of implementation of a statistical insulation coordination, requiring the lowest cost consistent with the required reliability and acceptable levels of audible and radio noise [3]. This means that statistical insulation coordination methods have been applied for circa 60 years ago in HVAC applications.

The selected reliability criterion is primary a function of the consequences of the failure and the lifetime of the equipment. For example, the reliability criterion for a station may be more stringent than that for a line because a flashover in a station is of larger consequence. IEC standard from 1973 introduced the statistical method in the insulation coordination standards IEC 60071-1 where the probability of flashover or failure was defined as 10%. The probabilistic study can be applied to three fields of insulation coordination design: formulation of overvoltage magnitudes and waveshapes, the characterization of the dielectric strength of the insulation and finally the coordination of the insulation components. It is important to highlight that the statistical method in the standard could be considered as semi-probabilistic, as not all variables are considered statistical, for example the waveshapes of the overvoltages are considered following the standard overvoltage waveforms like switching impulse 250/2500 μs, lightning impulse 1.2/50 μs.

The implementation of semi-statistical methods in HVAC were expanded in a way that in IEC guideline 60071-4 [4] was introduced to guide users on how to set-up electrical modeling of components and how to apply statistical and semi-statistical calculation of overvoltages by means of numerical programs. Therefore, successful experience in application of statistical methods (semi- probabilistic and fully probabilistic) is extensive within HVAC power systems.

In the case of HVDC, since the beginning of HVDC installations in 1950's the probabilistic part of insulation coordination was considered in the characterization of the dielectric strength of the air insulation. IEC standards for HVDC applications IEC 60071-5 [5] from its first edition guides the reader to follow the AC insulation coordination standards for the design of air clearances. Based on installation practices worldwide, in the edition of 2014, the probability of flashover failure was defined as 2%. Consequently, it is possible to conclude that semi-probabilistic methods for insulation coordination for clearance distance design have been used in HVDC applications for more than 70 years of operational experience.

Nevertheless, it is important to highlight that overvoltage levels have been calculated following a deterministic calculation, i.e., a maximum voltage with a large margin is used as input for overvoltage in the air clearance design. Paper [6] presents a semi-probabilistic method considering the statistical nature of the overvoltage magnitudes and the probabilistic nature of the dielectric strength of air represented usually as a cumulative Gaussian distribution. A comparison between conventional HVDC clearance design considering deterministic overvoltage levels and the probabilistic nature of the dielectric strength of air is presented. Results indicate that by using the conventional method, the design does not take a significant risk, i.e., the risk of failure of air clearance it is almost negligible.

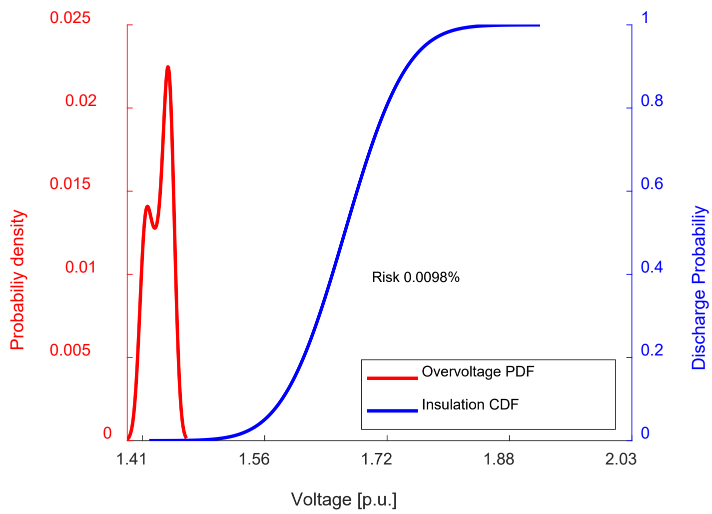

Figure 1. Combined stress and strength distribution on DC side of the converter valve an HVDC station. Blue color represents the strength and red color the stress. Taken from [6]

Table 1 Maximum overvoltage and cumulative probability for critical fault and all fault location

Node	SIPL [p.u]	SIWL [p.u]	LIPL [p.u]	LIWL [p.u]	LIWL risk %	LIWL risk all faults %	SIWL risk critical fault %	SIWL risk all faults %
AC bus (Node 1)	1.42	1.6	2.14	2.5	~0	~0	7.69E-08	5.30E-08
DC bus (Node 3)	1.78	2.1	2.26	2.6	~0	~0	9.83E-03	3.90E-05

In conclusion, nowadays, we are facing challenges to reduce our carbon footprint, find green energy solutions, and been able to cover the demands on energy consumption worldwide. Challenges that are very similar to those that motivated HVAC power systems in 1970's to increase operational voltages and try to minimize the impact of power lines by using common corridors and introduce probabilistic methods for system design.

Based on the successful 70 years of operational experience of HVDC, designed by using a conventional method, taking into account the increment on the computational capability of system calculation software and the vast knowledge on HVDC systems, it is necessary to consider to start introducing the use of probabilistic overvoltages for the insulation coordination process and risk evaluation.

References

[1] IEEE Standard 1313.1. IEEE standard for insulation coordination – definitions, principles and rules.
[2] IEC 60071-1. Insulation coordination. Part 1 : Definitions, principles and rules.
[3] Transmission line reference book 345kV and above. EPRI 1975
[4] IEC 60071-4. Insulation coordination. Part 4 : Computational guide to insulation coordination and modelling of electrical networks.
[5] IEC 60071-5. Insulation coordination. Part 5 : Procedures for high voltage direct current (HVDC) converter station
[6] Semi-probabilistic insulation coordination for HVDC converter stations. CIGRE 2022 Paris. L. Arevalo, A. Bilock, S. Sathish, A. Hermansson.