HISTORICAL PERSPECTIVE OF MINIMUM PHASE TO PHASE CLEARANCES SPECIFIED BY TABLE 13 OF C57.12.00

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Prior to 1993, C57.12.00 did not specify minimum phase-phase clearances. The 1993 revision introduced Table 11, "Minimum External Clearances between Transformer Live Parts of Different Phases." This table is essentially the same as appears in the current revision, although the number of tables has increased in the following revisions of C57.12.00, so that its contents now appear in Table 13.

Phase-phase switching voltages levels were originally specified for EHV transformers in IEEE Std. 262B-1977, "Trial-Use Standard Dielectric Test Requirements for Power Transformers for Operation on Effectively Grounded System 345 kV and Above." These values were 1050, 1550 and 2300 kV for 362, 550 and 800 kV maximum system voltages, respectively.

Prior to 1993, phase-phase clearances were specified by Table TR 1-0.06 of NEMA Standard TR-1. It was recognized in 1982 that TR1 only covered system voltages of up to 230 kV and that EHV transformers were not covered by any ANSI or IEEE standard. Furthermore, there was considerable confusion emanating from the fact that NEMA had recently changed the table in a rather haphazard manner. As a result, the entire meaning and usage of the table changed, and different manufacturers applied the table differently. The chair of the Dielectric Test Subcommittee requested that NEMA address these problems, but to no avail.

Table 11, now Table 13, is a result of approximately five years of work done within the Dielectric Test Subcommittee. The following description is how it happened:

At the urging of several utility representatives (actually, several negative comments on a previous ballot), a task force was established in Spring 1983 comprised of two representatives from manufacturers and two from utilities. At the time, I was a young eager beaver looking for committee assignments, so I volunteered to be one of those original utility representatives on the task force. All three of the remaining original members of the task force have since retired from the Transformers Committee, so I have the opportunity to present my version of how the values and equation were put into the table.

The original scope of the task force was to consider and accomplish the following:

- Establish minimum phase-phase clearances definitely for EHV voltages and preferably down to 115 kV
- Determine the typical polarity split between tested and untested terminals
- Determine the expected ratio between phase-phase and phase-ground voltage levels
- Possibly explain our findings in a technical paper.

The initial charge of the task force was to review available technical literature. Several pieces of applicable literature were found, and these references are listed in Appendix 1. The following gives general conclusions of this review and the action taken by the task force:

- Table 1 summarizes the per unit phase-phase voltages, based on peak line-neutral voltage.

- The split between phases ranged from 81/19 % on the surged/unsurged phase to 58/42 %. For higher values of phase-phase voltage, the split becomes closer to a 50/50 %.

Table 1
Summary of Per Unit Phase-Phase Voltages Found in Literature

Configuration	Simulated Studies (TNA)			Measured		
	No CB Resistors	With CB Resistors	Controlled Closing	No CB Resistors	With CB Resistors	Controlled Closing
Energizing Transformer and Line		3.75			2.3	
Energizing Transformer	3.0					
Energizing Line	3.0					
Energizing Capacitor Bank	4.2			3.45		

- It was decided that energization of a capacitor bank is a special situation and that 3.8 p.u. was the appropriate withstand level. On this basis, the switching impulse voltages were 1123, 1706 and 2482 kV for 362, 550 and 800 kV maximum system voltages, respectively. It is interesting to note that these values are 7 to 10 % higher than the values specified by IEEE 262B-1977.

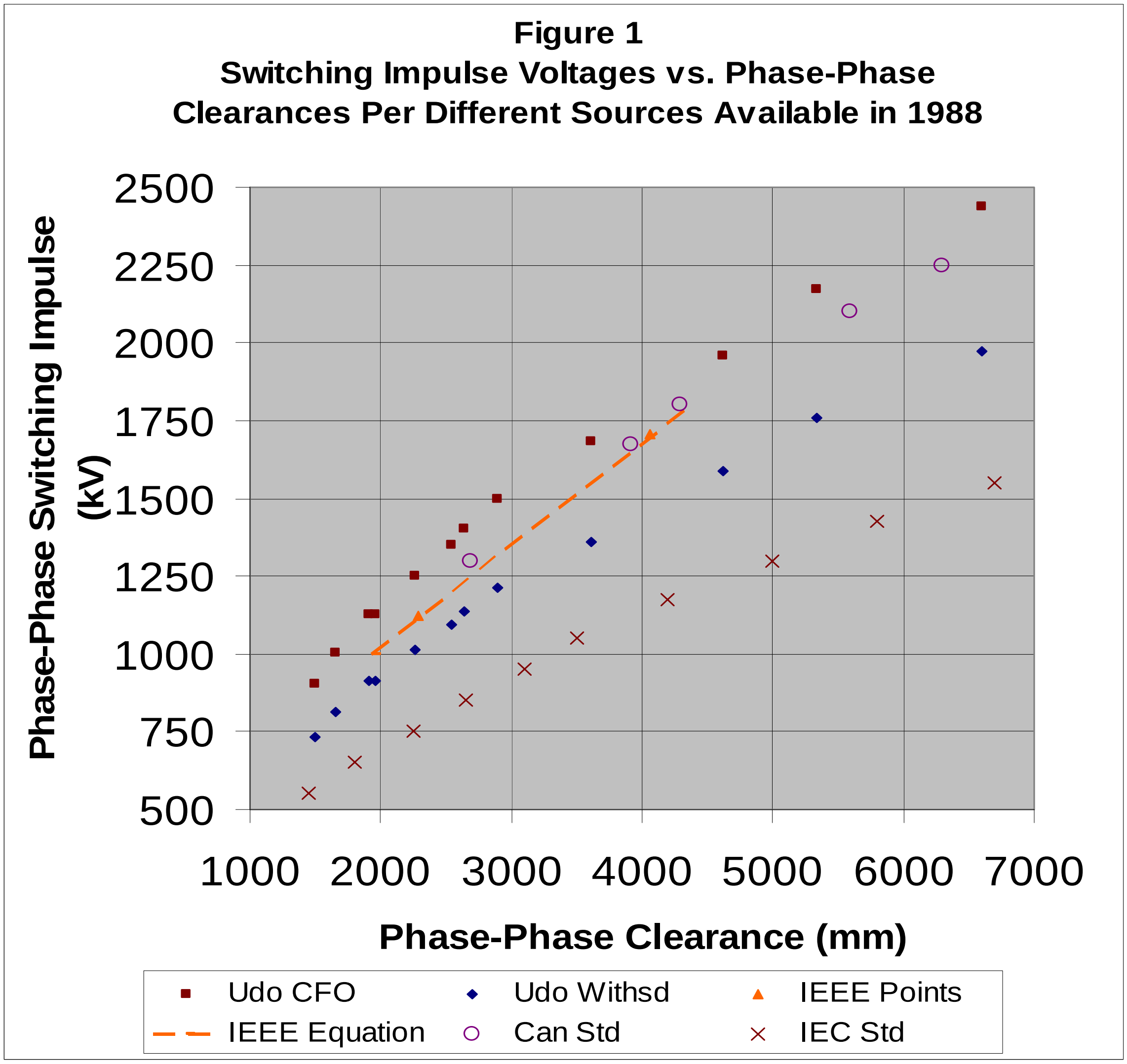
- In the same time frame, IEC was considering minimum phase-phase and phase-ground clearances, based on either lightning or switching impulse voltage, for inclusion in IEC Publication 76-3 [5]. At that time, IEC was experimenting with two methods, the first based on BIL and the second on BSL. In the meantime, IEC has adopted the basis of BSL only, and those levels are shown in Table 2. Comparison of the past clearance values shows that present values are to identical to the switching impulses listed back in 1983. The only change since that time is that three additional switching levels and associated clearances have been added.

Table 2
Past and Present Phase-Phase Clearances per IEC

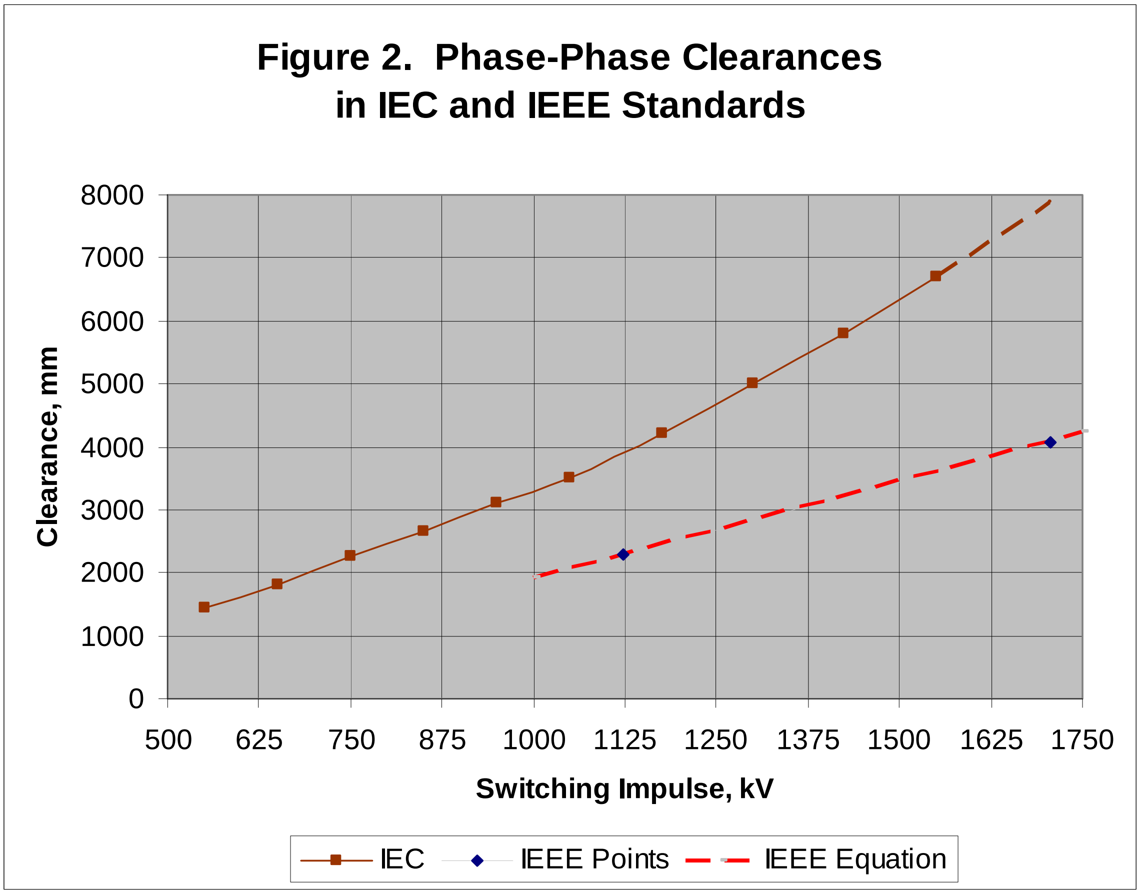
Rated BSL, kV	Minimum Phase-Phase Clearance, mm	
	1982 Proposal	Latest Revision
550		1450
650		1800
750	2250	2250
850	2650	2650
950	3100	3100
1050	3500	3500
1175	4200	4200
1300		5000
1425	5800	5800
1550	6700	6700

- Based primarily upon Udo [13], the task force proposed metal-metal clearances of 90 and 160 inches for 345 and 500 kV systems, respectively. Although the task force established a “no flashover” guideline, there was some discussion within the group about the margin provided by these values. I was a skeptic on this matter and argued that the Udo paper called for 100 and 201 inches clearance for 1123 and 1706 kV switching surge voltages, respectively. The task force chair, a manufacturing representative, presented information to me that the lower clearances were being used on transformers, one of them on my company’s system, and a check of our field people indicated that these had not experienced any flashover problems. Based on this service data, I reluctantly withdrew my objection to the 90 and 160 inch clearances.

- Figure 1 shows these data, plus data from the Canadian standard [16]. Note that all of the data show that the switching impulse strength saturates slightly with phase-phase clearance.



- A plot of the IEC values (present and past) and the IEEE values are shown in Figure 2. It is interesting to note that 154 and 311 inches of phase-phase clearance are necessary for 1123 and 1706 kV switching impulse, respectively. Note that the position of the axes has been reversed in this figure.



- It was apparent from Figures 1 and 2 that the phenomenon described was almost but not perfectly linear. The following linear equation was therefore included in the IEEE proposal, with the proviso that it only applied in the range of 1000 to 1800 kV:

  Min. Distance between Live Parts of Different Phases (inches)

  = 0.121 (Peak switching voltage between phases) – 45

  Or, as it appears in the present revision, converted to mm

  = 3.0734 (Peak switching voltage between phases) – 1143

  I was the lone critic of the use of the linear equation in the standard and proposed that either discrete data points be given, a second order equation be used or a curve be given. I was overruled by the remainder of the task force, and the result was that the two data points were listed in the table, and the linear equation remained in Note b.

In Figure 2 above, note that the IEC data can be described by two distinct linear equations, one from 550 kV to 1050 kV and the other from 1150 kV to 1550 kV switching impulse.

- Note c, stating "Power transformers, at nominal system voltages of 765 kV and 1100 kV, are usually single phase so that clearances between live parts of different phases is not an issue," was added to give justification for not including in Table 13 clearances for transformers used for 800 and 1100 kV systems. It was discussed, however, that there were at the time three-phase 735 kV transformers on the Hydro-Quebec system.

In retrospect, after almost 20 years of industry experience with this table, I have following observations:

- The last element of the original charter, i.e., documentation of our findings, was not completed by the task force, and this has contributed significantly to the present lack of knowledge about the background of this table. The reason for this omission is not clear, but I think it stemmed from the fact that the task force was in existence for so long and members were just glad to have it over with. In addition, the original chair of the task force resigned from the Transformers Committee about half way through the project, and Robert Veitch took over as chair. He was probably not aware of the planned documentation, and this task fell through a crack.

- To my knowledge, the clearance values given in Table 13 have worked well in service. However, a recent test witnessing experience shows that some guidance needs to be given about shielding permitted on the test floor so that adjacent bushings do not flash over during the switching impulse testing.

- As many of you know, the topic of phase to ground clearances has come up recently. The Dielectric Test Subcommittee struggled with this topic at several meetings, but no conclusions were reached. It is my hope that this memo will help to push this topic along, and we shall discuss it at our Spring 2007 meeting.

Appendix 1

Technical References for ANSI/IEEE C57.12.00-1993 Phase-Phase Clearances
for the Task Force Studies

A. Dealing with Phase-Phase Voltages Generated during Switching Surges

1. Hileman, Schmid & Bennon, Phase-to-Phase Strike Distances for EHV Transformers, IEEE Transactions, Vol.
2. IEEE Committee Report, Coordination of External Insulation for EHV Transformers, IEEE Transactions, Vol. PAS-90, Sept/Oct., 1971, pp. 2321-2329.
3. IEEE Committee Report, Dielectric Tests and Test Procedures for EHV Transformers Protected by Modern Surge Arrestors and Operated on Effectively Grounded System 345 kV Through 765 kV, IEEE Transactions, Vol. PAS-92, Sept/Oct., 1973, pp. 1752-1762.
4. Schneider (Chair of Cigre Study Comm. No. 33), Phase-to-Phase Insulation Coordination, Electra No. 64, May, 1979, pp. 137-236.
5. Wilson, Phase-to-Phase and Phase-to-Neutral Switching Surges on 500 kV Open Ended Lines, IEEE Transactions, Vol. PAS-88, May, 1969, pp.660-665.
6. Wilson, Phase-to-Phase Switching Surges on 500 kV Transformer Terminated Lines – Part II – Switching from the Low Voltage Terminals, IEEE Transactions, Vol. PAS-89, May/June, 1970, pp.691-697.
7. Transformer Supplier's Internal Report on Three-Phase Transformer that Failed due to Higher than Anticipated Phase-to-Phase Switching Surge Voltages.
8. IEEE Committee Report, Switching Surges: Part IV – In Control and Reduction on AC Transmission Lines, IEEE Transactions, Vol. 101, August, 1982, pp. 2694-2702.
9. Gert, Jirku, Lokhanian & Rashkes, Phase-to-Phase Switching Overvoltages in EHV Systems, 1978 CIGRE Paper No. 33-03.
10. Garrity, Haahn, Knudsen & Raezer, Experience with AEP 765 kV System, Part V – Switching Surges and Staged Fault Tests, Analysis, IEEE Transactions, Vol. PAS-92, May/June, 1973, pp. 1074-1084.

B. Dealing with Minimum External Clearances Required to Withstand Phase-Phase Switching Voltages

11. AIEE Committee Report, A Guide for Minimum Electrical Clearances for Standard Basic Insulation Levels, Transactions AIEE, Vol. 73, Part A, June, 1954, pp. 636-641.
12. IEEE Paper 31 TP 65-39, Second Interim Report – Minimum Electrical Clearances for Substations Based on Switching Surge Requirements, May, 1965.
13. Udo, Minimum Phase-to-Phase Electrical Clearances for Substations Based on Switching Surges and Lightning Surges, IEEE Transactions, Vol. PAS-85, August, 1966, pp. 838-845.
14. Correspondence of IEC TC14 WG14 – Clearances, 1981 thru 1985.
15. NEMA Std. TR1-1980, Part 0, Page 5, Par. TR1-0.06, External Clearances between Bushing Live Parts, 1980.
16. CSA Standard CAN/CSA-C88-M90, Power Transformers and Reactors, Art. 11.4 and Table 6, External Clearances in Air.