Statistical evaluation of oil/transformerboard surface creepage tests for the development of barrier boards for use in power transformers

I. Robinson
Whiteley Ltd.
United Kingdom

F. Derler K. Schultz
H. Weidmann Ltd.
Switzerland

This paper investigates the dielectric properties of barrier boards made of transformerboard. Such insulation components are used in oil-immersed power transformers and experimental data is required for their design. The electrical withstand strength of a terminal configuration used in these barrier boards was examined using AC, lightning and switching impulse, and as a large number of individual tests were made, it was possible to evaluate the results statistically by the use of Weibull distributions.

INTRODUCTION

Power transformers are amongst the most important pieces of equipment in electric power systems. Considering the high investment costs and the outage costs in case of a failure or unforeseen repair, a reliable design becomes essential. The long time reliability of a power transformer should be evaluated very early in the design process. A well-considered design not only ensures a low failure probability, but also reduces the necessity for maintenance and makes a short repair time possible. Keeping these requirements in mind a new barrier board was developed for use in power transformers.

In many transformers the tapchanger and selector are located in the main tank together with HV- and LV-windings. However, in order to reduce the time spent on assembly and maintenance, the tapchanger may be separated from the oil in the main tank and be mounted in a separate oil compartment. With the tapchanger arranged separately maintenance and repair work can be carried out without draining the oil from the main tank and there is no risk of contaminating the main tank with impurities caused by ingress of moisture and particles. Such separation with a mechanical barrier reduces the risk of propagation of failures from the tapchanger to the vital parts in the main tank and also dissolved gas analysis can be performed separately. The barrier board (fig. 1) forms a mechanically rigid and dripproof barrier between the two oil compartments, with bushings through the barrier board consisting of plug and socket type terminals integrated into the transformerboard plate. The sealing of the terminals is accomplished by means of a special transformerboard moulding technique. With large numbers of these connection terminals passing through the board, all operating at different voltage levels across the tapping range of the transformer, it is essential that the most efficient arrangement of these terminals is utilised to give the best distribution of voltage stress. The insulation structure of a barrier board is subjected to a combination of surface creepage stress and long oil gap stress in a moderate non uniform field configuration. Theoretical considerations have been published [Moser (1), Nelson (2), Derler et al (3)] which give general indications on how to tackle this problem. Experimental data provide a reliable tool for barrier board design and can be applied to many similar arrangements in oil-filled transformers.

TEST ARRANGEMENT

In order to establish a statistically supported and experimentally confirmed reliable basis for the proper design of barrier boards, suitable test arrangements were made which permitted a sufficiently high number of flashovers in a short period of time and at reasonable expense. They consisted of turntables on which 24 terminal studs are mounted in a circle (fig. 2). By turning these disks stepwise after each flashover, one stud after another was energized with rising voltage until a breakdown occured to the grounded flange (fig. 4). The whole set-up was immersed in an approximately 12 m^3 tank filled with transformer oil and energized through an oil/air bushing. In order to reduce the contamination of the oil due to the flashovers it was continuously circulated through a filter. The disks were dried and impregnated and the oil was processed prior to the tests. It was possible to take oil samples during the tests.

TEST PROCEDURE

The individual tests at ambient temperature were performed according to the following program :

Table 1. Test program

Type of test	Polarity	Number of individual flashovers	Voltage rise step [kVrms]
AC 50 Hz/1 min.		48, 24 covered 1) 24 uncovered	25
Lightning impulse 1,2/50 µs	+ -	24 covered 1) 24 covered 1)	30 2) 30 2)
Switching impulse 250/2500 µs	+ -	24 covered 1) 24 covered 1)	25 2) 25 2)

1) terminal stud with transformerboard sealing sleeve
2) one impulse performed at each voltage level

The condition of the oil was evaluated before and after each test series checking the following parameters: breakdown voltage, gas and water content, number of particles. After the tests the disks were examined, and the carbonised trackings recorded, categorized and correlated with the flashover voltage.

DISCUSSION

We assumed that the flashover voltage was distributed according to the 2-parameter Weibull distribution. The scale and shape parameters (table 2) were calculated using the maximum likelihood method. The test results indicate the well known pattern for tests in oil with a large range of the data (min. to max. values). The ratio between the highest and lowest flashover voltage equals about 2.7 for AC. The Weibull plots for AC, lightning and switching impulse are shown in fig. 3. Although the two AC distributions for covered and uncovered terminals have the same scale parameter (same breakdown voltage at 63,3% probability) the scatter of the covered terminals is much smaller resulting in higher shape parameter.

Table 2. Statistical parameters for the Weibull distributions

		AC 1)		(1,2/50µs)		(250/2500µs)	
				(+)	(-)	(+)	(-)
		uncovered	covered	covered	covered	covered	covered
min. / max. value	(kV)	120 / 320	120 / 320	383 / 767	413 / 883	325 / 775	300 / 700
Shape parameter α		4,43	6,29	6,47	5,40	5,97	4,72
Scale parameter β 2)	(kV)	247	247	613	728	613	533
50 % fractile	(kV)	227	233	580	680	563	494
1 % fractile	(kV)	87	119	301	311	284	201

1) kV_{rms}
2) 63,3% (fractile) probability breakdown voltage

The electric strength for covered terminals is distinctly higher (119 kV versus 87 kV) at 1% breakdown probability although the lowest flashover voltage measured was 120 kV for both variants. The 90% range of confidence shown for AC in fig. 3 indicates that for a technically relevant low breakdown probability the electric strength of covered terminals will be higher with statistical significance. At switching impulse the lowest flashover voltages were measured with negative polarity, in contrast to lightning impulse. The number of flashovers on the surface of the board at negative switching impulse was about 50% higher than at positive polarity. The pattern of the traces showed that flashovers at negative switching impulse were initiated in the gap between the ground electrode and the surface of the board (fig. 4). This finding relates well to the general observation that the shaping of ground electrodes is substantial for the breakdown phenomenon at negative switching impulse.

Analysis of the oil samples taken during the tests confirmed that no oil degradation took place. The contents of moisture and gas in the oil stayed almost constant and did not exceed 2,2 ppm and 1,0% resp. during the tests, neither were lower breakdown voltages measured at the end of each test series using the IEC standard electrodes for breakdown tests in oil.

The field plot (fig. 4) can be applied [3] to calculate the AC pd inception voltage on the surface and in the oil gap at the shortest distance between the energized electrode and ground flange. This is done with a new software program which automatically calculates the pd inception voltage for a given path between the high voltage and ground electrode. The method is described in detail in [2, 3]. Fig. 5 shows the calculation (breakdown voltage = 128 kV) for a covered terminal in degassed oil. This value can be compared to the experimental AC breakdown voltage (about 1% breakdown probability) for covered terminals in fig. 3. In the oil gap the calculated breakdown strength is about 20% higher than on the board surface. Analysing the traces of the AC flashovers confirmed the lower strength on the board surface. About 90% of all flashovers with AC were identified on the board surface.

CONCLUSION

For insulation systems immersed in oil it is essential to consider the statistical nature of their breakdown strength. The individual results of test series, particularly with a limited number of tests do not allow design rules to be set up by simple calculation of "mean values" or finding of "minimum values", unless they are evaluated in a statistical way. The application of the 2-parameter Weibull distribution gives the choice to the design engineer at which level of low probability (1% or less) the designed insulation structure will break down. Using the "critical path" method (fig. 5) it is possible to calculate the 1% breakdown strength for a given electrode configuration. In order to optimize and automate such calculations the method was implemented as a postprocessor linked with the FEM field calculation program on a personal computer. Such calculations are essential for optimizing the design of insulation and they can now be carried out very effectively. One of the conclusions of the experimental part of this work was that the breakdown strength of barrier board is improved, if the terminals are sealed and insulated with moulded transformerboard. In particular the scatter of the low probability breakdown voltage is reduced which is most relevant in the design of transformer insulation. The results showed furthermore that, if appropriately used, the "design oil-curves" for uniform field stress can be applied with success to study the electric strength of moderately non uniform field configurations.

REFERENCES

[1] H.P. Moser, "Transformerboard", Scientia Electrica, 1979.

[2] J. K. Nelson, "An assessment of the physical basis for the application of design criteria for dielectric structures", IEEE Trans. on Electrical Insulation, Vol. 25, No. 5, 1989.

[3] F. Derler, H.J. Kirch, Ch. Krause and E. Schneider, "Development of a design method for insulating structures exposed to electric stress in oil gaps and along oil/transformerboard interfaces", 7th ISH, Dresden, Paper 21.16, Vol. 2, 1991.

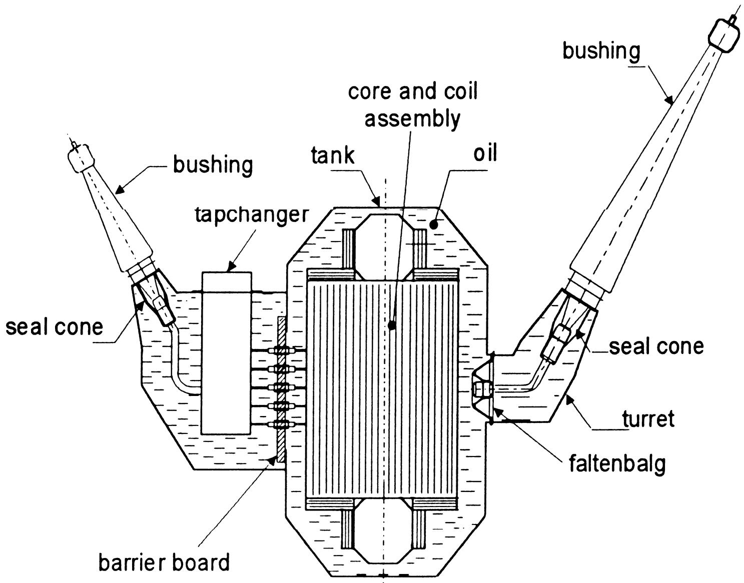

Fig. 1. Auto-Transformer with barrier board

Fig. 2. Disk prepared for test

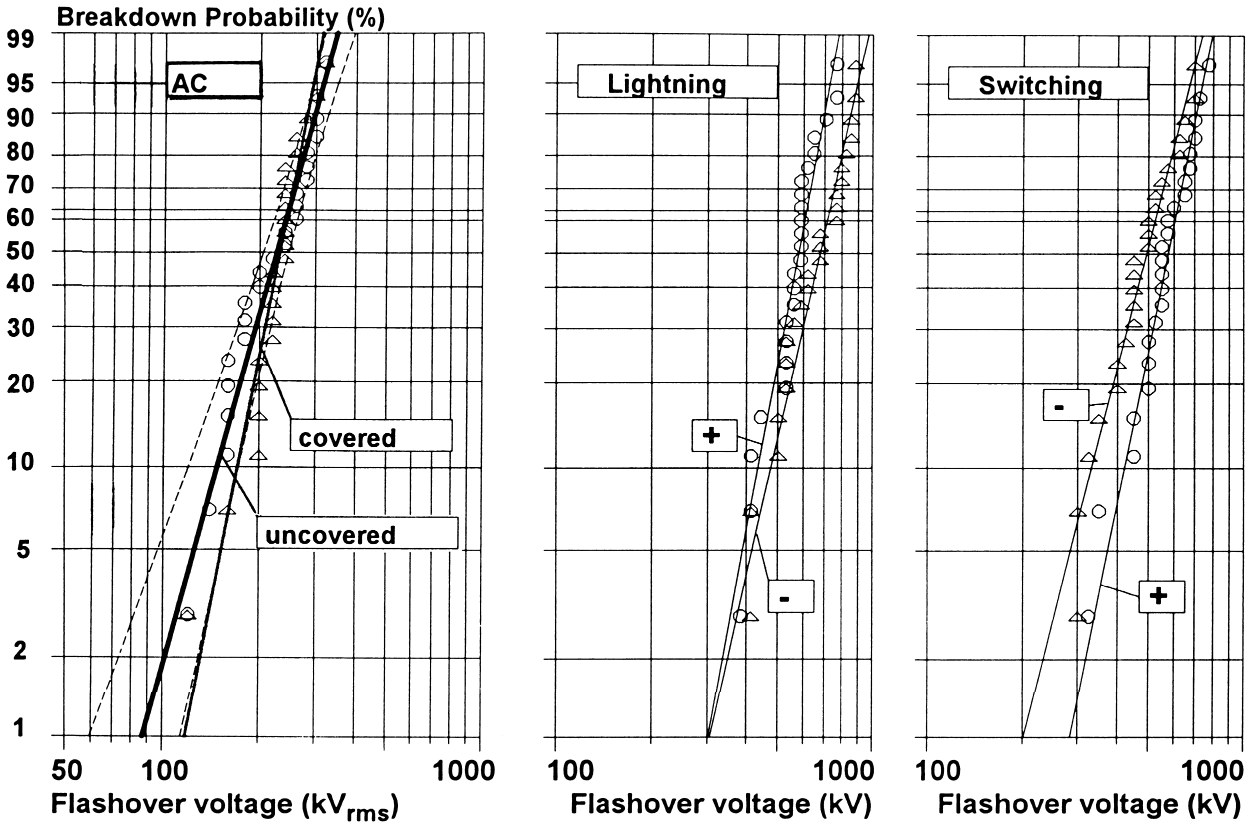

Fig. 3. Weibull plots for AC, lightning and switching impulse

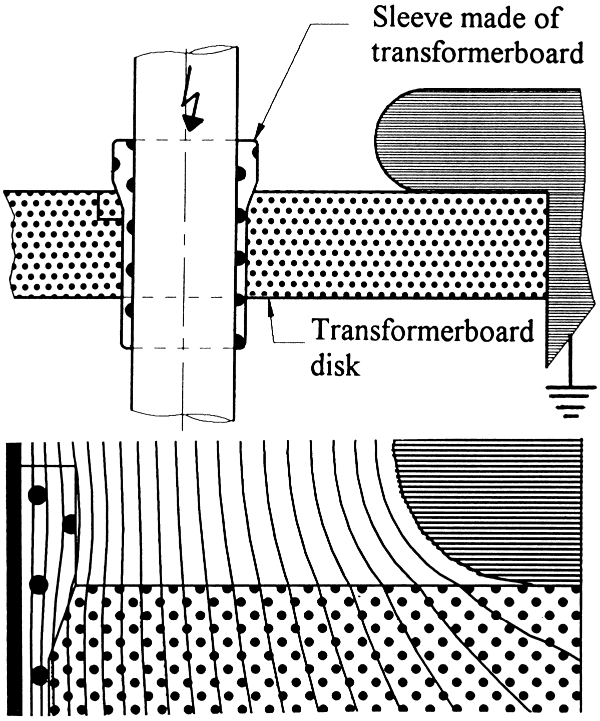

Fig. 4. Electrode configuration with field plot

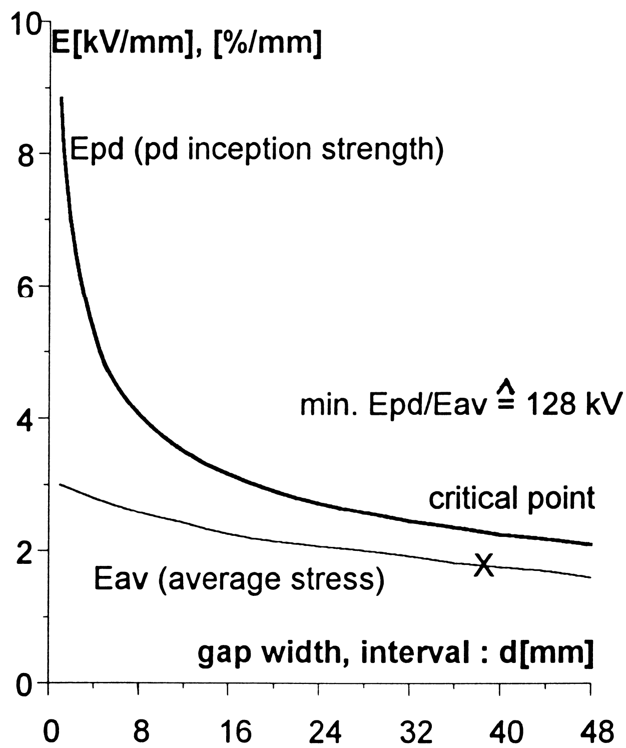

Fig. 5. Calculation of AC pd inception voltage for covered terminal