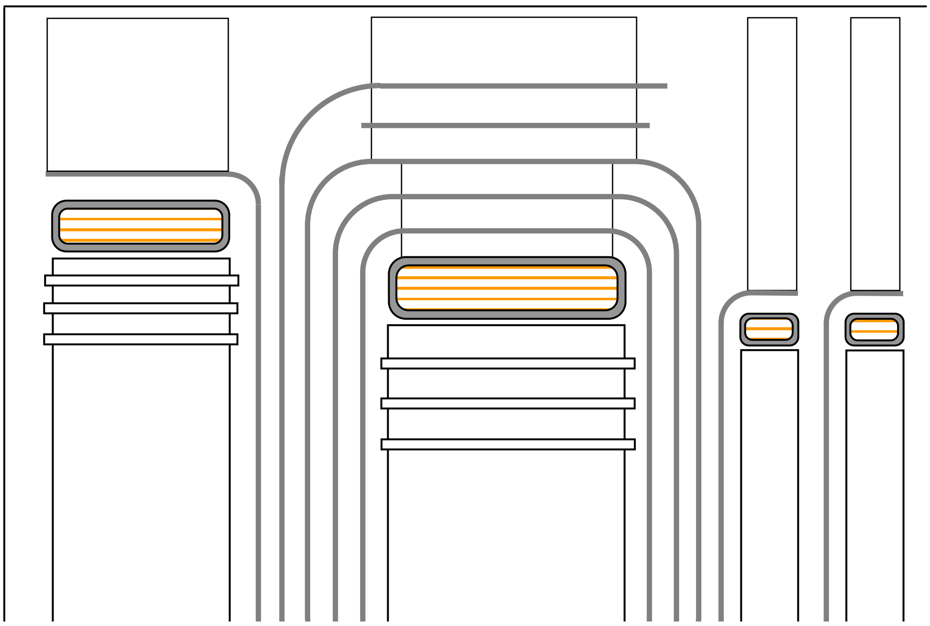
P D C-Evaluation

Polarisation and Depolarisation Current Evaluation Program

Version 3.0 – June 2000



User's Guide

(for the Input of Geometry Parameters in the Advanced Evaluation Tools)

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1 Introduction

To perform quantitative assessment of the moisture content in the pressboard and the oil conductivity in the homogeneous and multi-layer oil-paper insulation systems information concerning the dimensions and the composition of the insulation is needed.

2 Homogeneous insulation systems

Typical components with homogeneous oil-paper insulation systems are cables, bushings or instrument transformers, where the investigated insulation with PDC-Analyser consists only in impregnated paper without any kind of oil ducts. The geometry of such insulation systems can be described with only one parameter. This geometry parameter is the vacuum capacitance "Co" *or* the capacitance measured at 50 Hz "C50Hz" at a temperature "T'".

The advanced tool of PDC-Evaluation program permits the alternative input of these two quantities.

In case of input of vacuum capacitance "Co", the 50 Hz capacitance "C50Hz" is calculated for a chosen temperature "T'" in function of the moisture content in paper.

In case of input of values of the 50 Hz capacitance "C50Hz" at temperature "T'", the vacuum capacitance is calculated in function of the moisture content.

The advanced tool permits the differentiation between the temperature "T'", at which the 50Hz capacitance has been measured and the temperature "Tm", at which the relaxation currents have been measured.

3 Multi-layer insulation systems

The advanced tool for evaluation of the moisture content and oil conductivity in multi-layer insulation systems is conceived specially for the investigation of power transformers.

The geometry of the main insulation investigated of a power transformer can be described with the following input parameters (see section 4):

- hwin *or* C50Hz:	The average height of windings surrounding the main insulation in [mm] *or* the capacitance of the transformer measured at 50 Hz at a temperature "T'" in [F].
- nph:	The number of phases of the transformer investigated.
- nsec:	The number of sectors in the main insulation.
- X1:	The thickness of lumped barrier in a sector in [mm].
- X2:	The thickness of lumped oil duct in a sector in [mm].
- Y1:	The width of a spacer in a sector in [mm].
- Y2:	The width of multi-layer insulation in a sector in [mm].

Using the above parameters, the advanced tool permits the determination of following quantities at temperature "T'" in function of moisture content in the pressboard.

- C50Hz *or* hwin:	The resulting 50 Hz capacitance of the transformer in [F] *or* the average height of windings surrounding the main insulation in [mm].
- C barr.:	The resulting 50 Hz capacitance of all pressboard barriers in [F].
- C gap:	The resulting 50 Hz capacitance of all oil gaps in [F].
- C spac.:	The resulting 50 Hz capacitance of all pressboard spacers in [F].

If the height values of the windings surrounding the main insulation are not available, the parameters "hwin" can be replaced by the parameter "C50Hz" measured at temperature "T'". In this case the evaluation program calculates the value of "hwin" in function of the moisture content in the pressboard.

In general, the advanced evaluation tool for multi-layer arrangement differentiates 3 alternative possibilities for the input of geometric parameters, depending if the "hwin" or "C50Hz" or "C50Hz total" (see section 3.2) are known.

The advanced tool permits also the differentiation between the temperature "T'", at which the 50Hz capacitance has been measured and the temperature "Tm", at which the relaxation currents have been measured.

3.1 Description of the main insulation with a reduced number of parameters

The geometry arrangement of the main insulation of a power transformer can also be described with a reduced number of parameters (see section 4.1). These parameters are:

- C50Hz:	The 50 Hz capacitance of the investigated transformer in [F].
- X:	The relative amount of the barriers in the main insulation.
- Y:	The relative spacer coverage in the main duct.

In this case the geometry input parameters of evaluation tool must be set as following:

- C50Hz: The 50 Hz capacitance of the investigated transformer in [F].
- nph = 1
- nsec = 1
- X1 = X
- X2 = 1 - X
- Y1 = Y
- Y2 = 1 – Y

By the input of the reduced parameters, the values of "nph" and "nsec" can be set to 1.

Of course in this case the resulting value of "hwin" will not correspond to the real average height of windings surrounding the main insulation.

3.2 The geometry description of the multiple insulation systems

The advance tool permits the evaluation of the relaxation currents generated from up to 10 main insulation contemporaneously by calculating and representing the resulting "total" currents.

This possibility permits e.g. the evaluation of currents generated from transformers with three voltage levels, where the middle voltage "mv" winding is surrounded from the high voltage "hv" and the low voltage "lv" windings. In such transformers it is possible to investigate two main insulation jointly by applying contemporaneously the dc excitation voltage to hv and lv windings and by sensing the generated currents from the central "mv" winding.

The "multiple" input possibility permits also the evaluation of the main insulation with a more complex structure as presented in section 4.2.

The advanced tool calculates also the value "C50Hz total", which is equal to sum of all individual "C50Hz" capacitance of the jointly parameterised main insulation systems. If the individual values of "hwin" *or* "C50Hz" of jointly investigated main insulation systems are not available, the value of measured total capacitance "C50Hz total" can be used as an input parameter. In this case it is assumed that the average heights "hwin" of all jointly investigated main insulation systems are equal.

4 The geometry description of the main insulation of a power transformer

To analyse the relaxation currents measured on a power transformer by advanced tool of PDC-Evaluation program, adequate information about the geometrical design of the main insulation is needed.

Taking in consideration one phase of a power transformer, its main insulation can be described with the average height "hwin" *or* the measured capacitance at 50 Hz "C50Hz", the number of the sectors "nsec", which correspond in general to the number of the spacers distributed in the circumference of the main duct and the parameters "X1", "X2", "Y1" and "Y2", which described the composition of the main insulation.

In general, the average height "hwin" of the main insulation can be calculated as following:

$$\mathbf{hwin = (h_{LW} + h_{HW}) / 2,} \qquad (1)$$

where "h_{LW}" and "h_{HW}" are respectively the height of the low voltage winding and the height of the high voltage winding with the height of static rings included (see figure 1).

The parameters "X1", "X2", "Y1" and "Y2", are defined as following (see figures 2 and 3):

$$\mathbf{X1 = \sum b_i \,, \qquad for\ i = 1 \ldots n,} \qquad (2)$$

where "b_i" is the thickness of the barrier "i".

$$\mathbf{X2 = d - X1,} \qquad (3)$$

where

$$\mathbf{d = r_2 - r_1.} \qquad (4)$$

The "r_1", "r_2" and "d" are respectively the inner radius, the outer radius and the width of the main duct.

$$\mathbf{Y1 = s,} \qquad (5)$$

where "s" is the width of a spacer.

$$\mathbf{Y2 = (c / nsec) - Y1,} \qquad (6)$$

where "nsec" is the number of sectors in the main insulation. In general, the "nsec" corresponds to the number of spacers distributed in the circumference of the main duct. The "c" is the average circumference of the main duct defined as following:

$$\mathbf{c = 2\pi[(r_1 + r_2) / 2].} \qquad (7)$$

If the height values of the windings surrounding the main insulation are not available, the parameters "hwin" can be replaced by the parameter "C50Hz", which is the value of 50 Hz capacitance measured at temperature "T"".

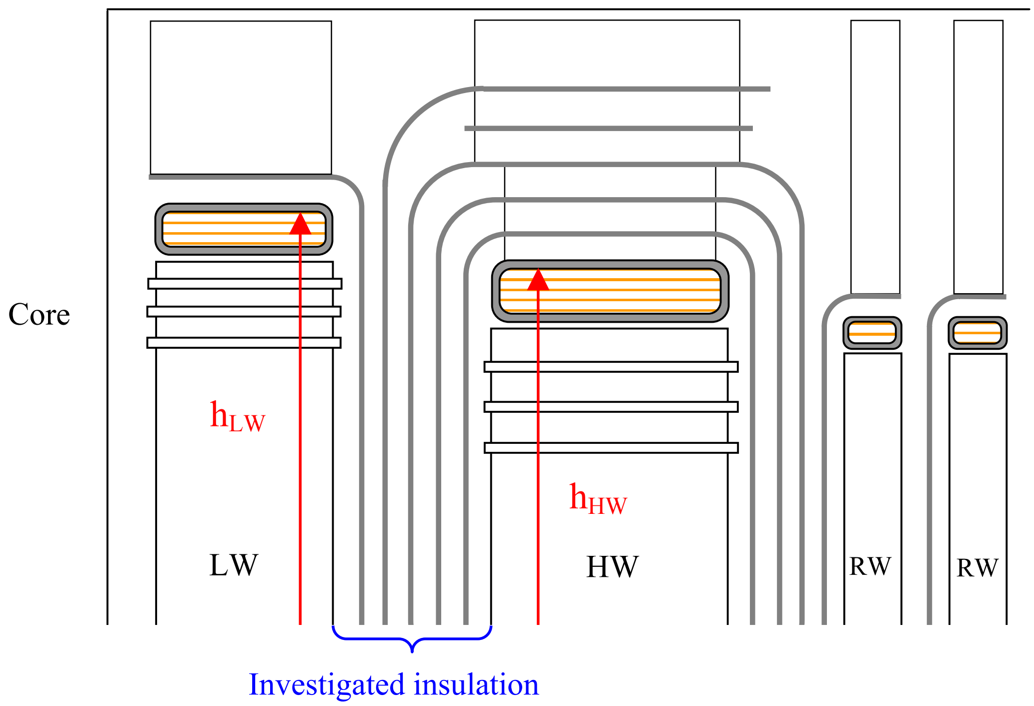

Figure 1: A typical arrangement of windings in one phase of a power transformer.

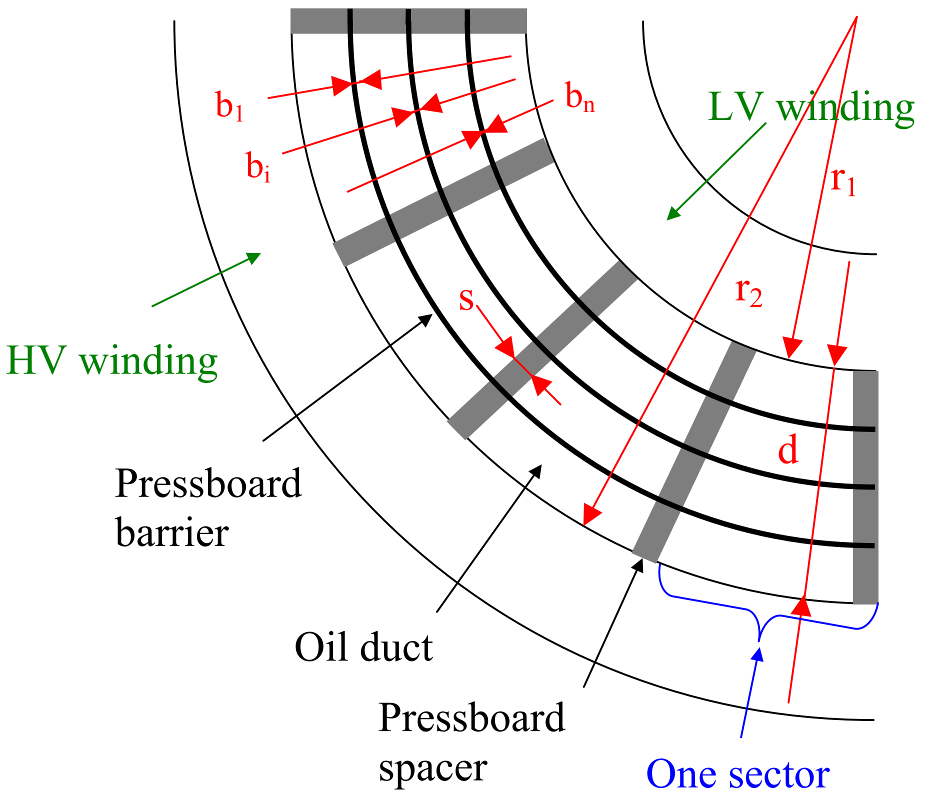

Figure 2: The cross-section of the main insulation between low and high voltage windings of a power transformer.

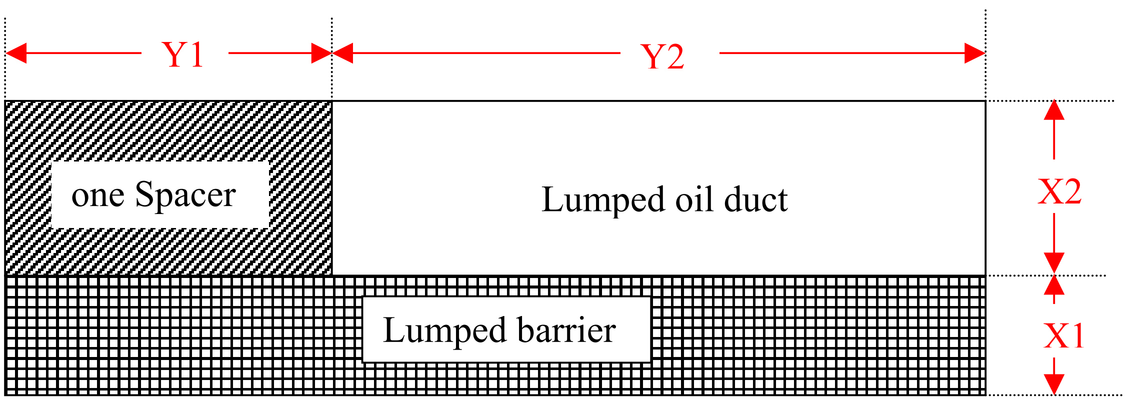

Figure 3: Lumped insulation system in a single sector.

4.1 Description of the main insulation with a reduced number of parameters

The geometry arrangement of the main insulation of a power transformer can also be described with a reduced number of parameters. These parameters are:

- C50Hz: The 50 Hz capacitance of the investigated transformer in [F].
- X: The relative amount of barriers in the main insulation.
- Y: The relative spacer coverage in the main duct.

According to the figure 1, the "X" and "Y" are defined as following (see figure 4):

$$\mathbf{X = B_{Total} / d} \qquad (8)$$

with

$$\mathbf{B_{Total} = \sum b_i ,} \qquad \mathbf{for\ i = 1 \ldots n} \qquad (9)$$

and

$$\mathbf{d = r_2 - r_1,} \qquad (10)$$

where b_i is the thickness of the barrier i and "r_1", "r_2" and "d" are respectively the inner radius, the outer radius and the width of the main duct.

$$\mathbf{Y = S_{Total} / c} \qquad (11)$$

with

$$\mathbf{S_{Total} = m \times s,} \qquad (12)$$

and

$$\mathbf{c = 2\pi[(r_1 + r_2) / 2],} \qquad (13)$$

where "m" is the number of spacers distributed in the circumference of the main insulation and "s" is the width of a spacer. The "c" is the average circumference of the main duct.

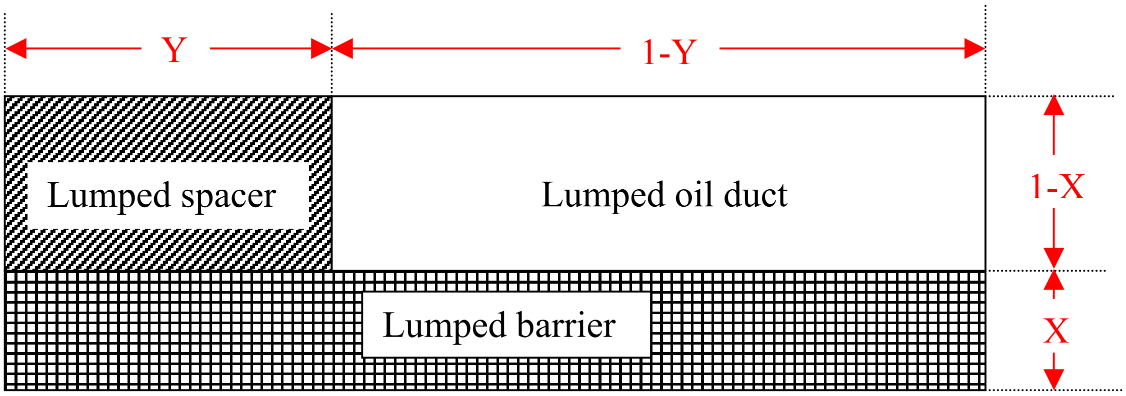

Figure 4: Lumped insulation system.

4.2 Description of the main insulation with a more complex composition

In case of the main insulation with a more complex insulation arrangement e.g. insulation with the spacers of different widths (see figure 5) or insulation with the different number of spacer in the different oil ducts (see figure 7), the insulation system must be described with more than one set of parameters "X1", "X2", "Y1" and "Y2" (see figures 6 and 8).

The two set of parameters "X1'", "X2'", "Y1'", "Y2'" and "X1''", "X2''", "Y1''", "Y2''" presented in the figure 6, are defined as following (see figures 5 and 6):

$$\mathbf{X1' = \sum b_i\,, \qquad for\ i = 1\ ...\ n,} \tag{14}$$

where "b_i" is the thickness of the barrier "i".

$$\mathbf{X2' = d - X1',} \tag{15}$$

where
$$\mathbf{d = r_2 - r_1.} \tag{16}$$

The "r_1", "r_2" and "d" are respectively the inner radius, the outer radius and the width of the main duct.

With the assumption that the width "s_1" of the spacers positioned in the outer oil duct of the main insulation is larger than the width "s_2" of the spacers positioned in the rest oil ducts ($s_1 > s_2$), following equations can be written:

$$\mathbf{Y1' = s_2,} \tag{17}$$

$$\mathbf{Y2' = (c\ /\ nsec) - s_1,} \tag{18}$$

where "nsec" is the number of sectors in the main insulation. The "c" is the average circumference of the main duct as defined in equation 7.

$$\mathbf{X1'' = X1' + d_1\,,} \tag{19}$$

where "d_1" is the thickness of spacers positioned in the outer oil duct.

$$\mathbf{X2'' = d - X1'',} \tag{20}$$

where "d" is the width of the main duct (see equation 16).

$$\mathbf{Y1'' = 0.} \tag{21}$$

$$\mathbf{Y2'' = s_1 - s_2.} \tag{22}$$

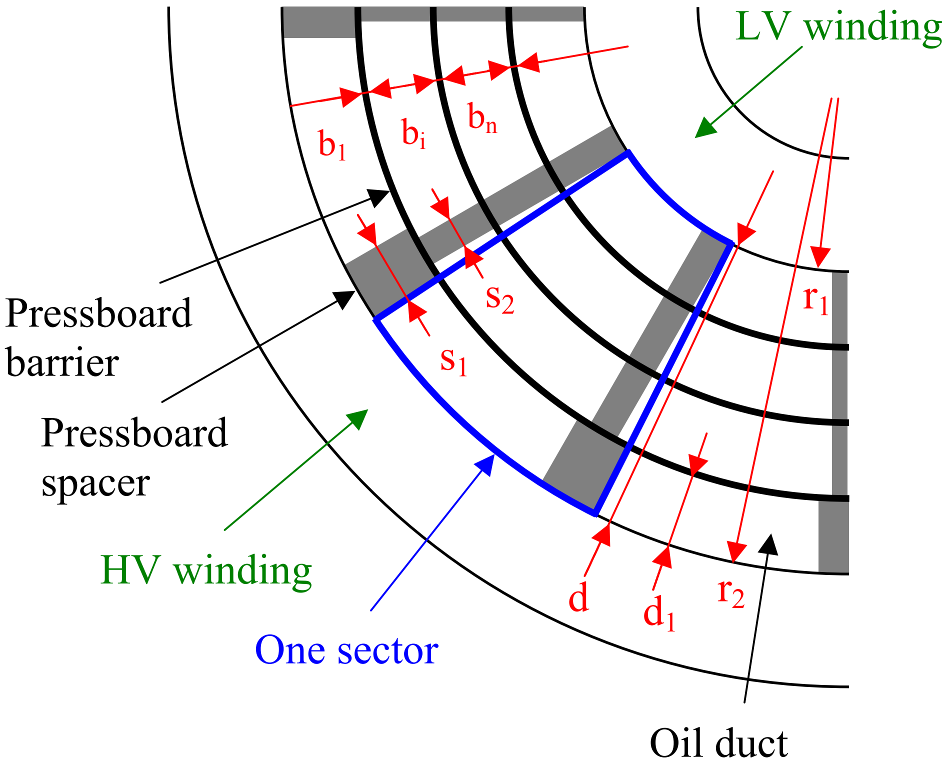

Figure 5: The cross-section of the main insulation between low and high voltage windings of a power transformer with different widths of spacers.

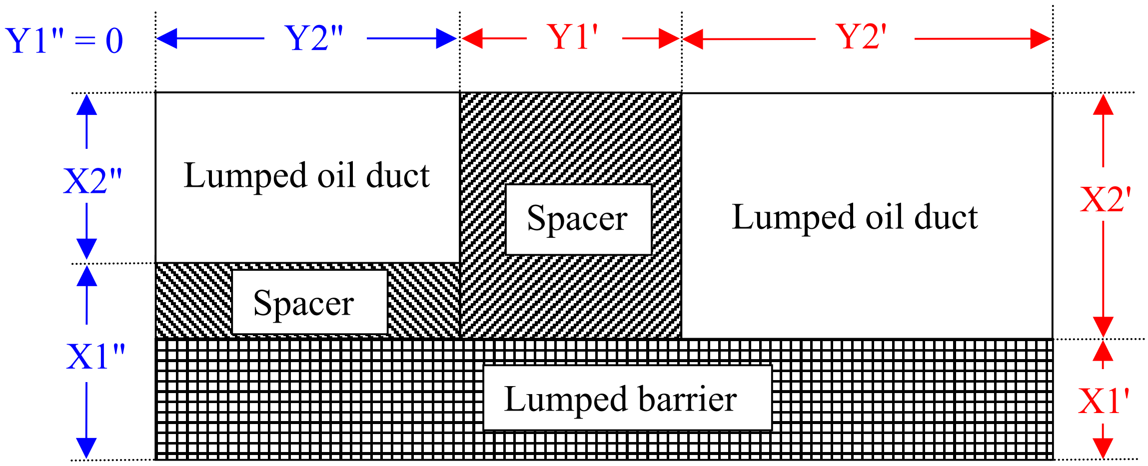

Figure 6: Lumped insulation system of a single sector of the main insulation presented in the figure 5.

The two set of parameters "X1'", "X2'", "Y1'", "Y2'" and "X1"", "X2"", "Y1"", "Y2"" presented in figure 8, are defined as following (see figures 7 and 8):

$$\mathbf{X1' = \sum b_i\ ,\qquad for\ i = 1\ ...\ n,} \tag{23}$$

where "b_i" is the thickness of the barrier "i".

$$\mathbf{X2' = d - X1',} \tag{24}$$

where

$$\mathbf{d = r_2 - r_1.} \tag{25}$$

The "r_1", "r_2" and "d" are respectively the inner radius, the outer radius and the width of the main duct.

$$\mathbf{Y1' = s_2,} \tag{26}$$

where "s_2" is the width of the spacers positioned radial in all oil ducts.

$$\mathbf{Y2' = (c\ /\ nsec) - (s_1 + s_2),} \tag{27}$$

where "nsec" is the number of sectors in the main insulation, which correspond in this case to the number of spacers with the width "s_2" distributed in the circumference of the main duct. The "c" is the average circumference of the main duct as defined in equation 7. The "s_1" is the width of the extra spacers positioned in the outer oil duct of the main insulation.

$$\mathbf{X1'' = X1' + d_1,} \tag{28}$$

where "d_1" is the thickness of extra spacers in the outer oil duct of the main insulation.

$$\mathbf{X2'' = d - X1'',} \tag{29}$$

where "d" is the width of the main duct (see equation 25).

$$\mathbf{Y1'' = 0.} \tag{30}$$

$$\mathbf{Y2'' = s_1,} \tag{31}$$

where "s_1" is the width of extra spacers in the outer oil duct of the main insulation.

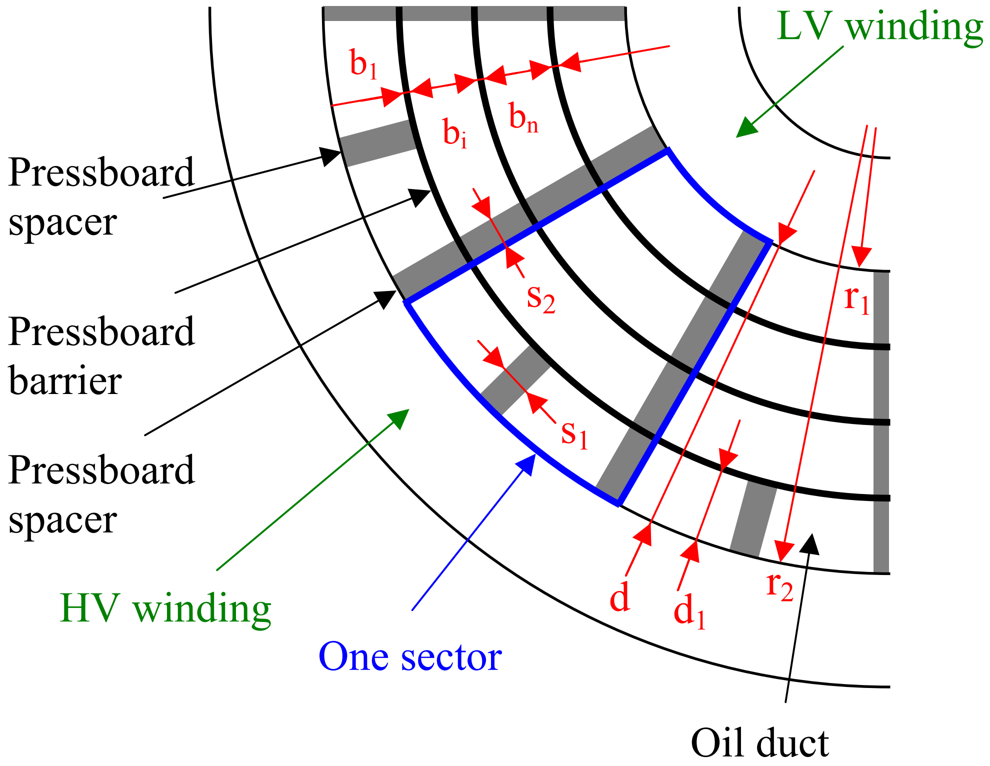

Figure 7: The cross-section of the main insulation between low and high voltage windings of a power transformer with different number of spacers in the different oil ducts.

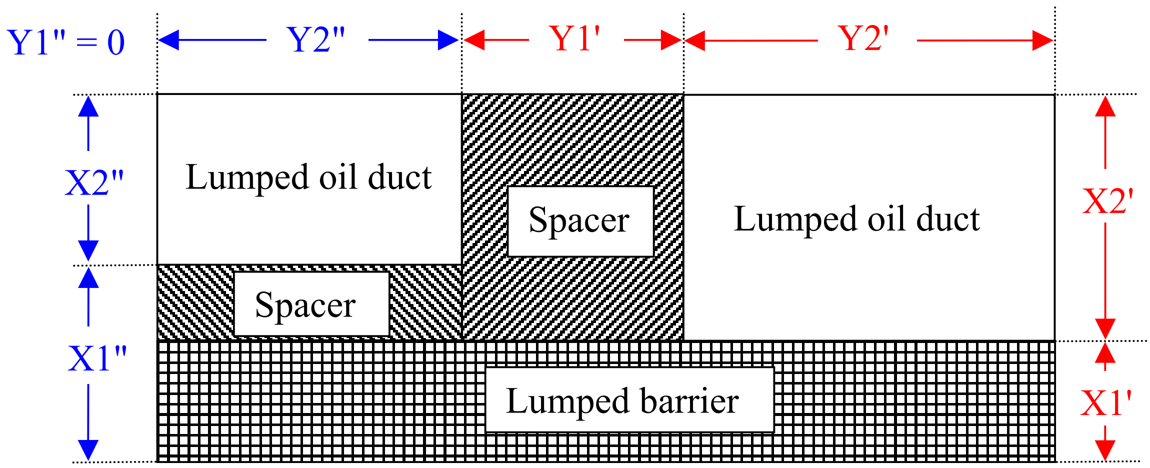

Figure 8: Lumped insulation system of a single sector of the main insulation presented in the figure 7.