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Impulse Voltage Distribution

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ABSTRACT

Things that are going to be discussed in this paper include- the distribution of impulse voltage in transformer windings, various methods of increasing the process of impulse voltage distribution and comparison of impulse distribution in various types of transformer windings like inter shield, interleaved and continuous windings.Here we are also going to add certain ideas on improving the performance of these windings. Impulse voltages are those which happen in the windings of transformer during certain abnormal transient conditions such as lightning. It is a well known fact that improving the series capacitance of the windings will increase the voltage distribution by reducing the impulse voltage distribution constant α. So let us also talk something about the controlling techniques of α.

Keywords:***series capacitance, intershield winding, impedance mismatching, mutual inductance, impulse voltage distribution, lightning***.

INTRODUCTION:

Whenever there is a sudden lightning stroke strikes the transformer there will be a flow of enormous amount of voltage called impulse voltage in the windings of the transformer. If the voltage distribution is not equal then it will cause a huge damage to the transformer and the load connected to it. So it is necessary to make the voltage as distributed equally over the windings. This is called impulse voltage distribution. In the analysis of impulse voltage distribution, an important factor to notify is the impulse distribution factor α. It is given by the expression

$E=A_1e^{\alpha}+A_2e^{\alpha}$ .... (1)

Where,

$\alpha=\sqrt{Cg/Cs}$............................(2)

Cg is the winding to ground capacitance,

Cs is the series capacitance.

α is the voltage distribution constant- which represents the amount of stress on the windings especially on the upper layers of the winding.

There are numerous ways of increasing the series capacitance in order to decreaseα, as mentioned earlier. One way is designing of the transformer windings. There are a few types of windings designed for this purpose, they are

1. layer winding
2. continuous winding
3. interleaved winding
4. intershield winding

Let us briefly discuss on the above mentioned designs and comparison of those windings.

LAYER WINDING:

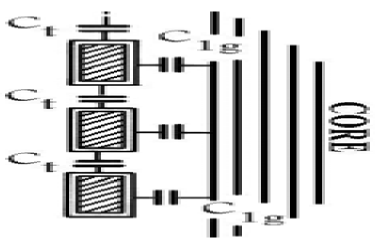


Figure.1

In layer type of winding, each conductor is placed successively to one another with a capacitance in between them(series capacitance Cs) and in each turn(turn to turn capacitance Ct) as shown in *figure1*. Here the series capacitance can be determined through the equation

$C_s= C_t/ (n-1)$ ………………………… (3)

Where, n is the number of turns. Similarly the parallel capacitance can be found by

$C_p = nC_{lg}$ .... (4)

Where, C_{lg} is the capacitance between each layer and ground.

Here one thing should be considered that as the number of series conductors decreases, the series capacitance increases.

CONTINUOUS DISK WINDING:

This type of winding shown in *figure 2* has conductors placed successively without leaving any space. So the capacitance of this winding can be calculate as..

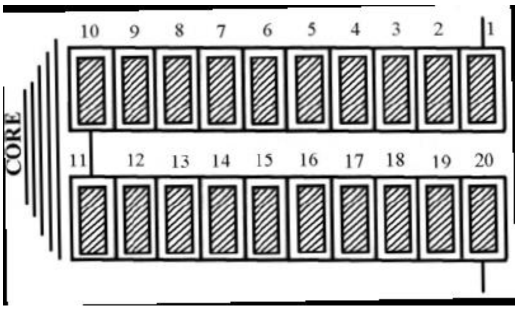


Figure.2

equivalent capacitance between the turns is

$C_{tr} = \frac{Ct}{2n^2}(2n-1)$ .... (5)

Similarly equivalent capacitance between two disks is

$C_{dr} = n\ C_d/6$ .... (6)

Therefore the series capacitance is $C_s = C_{tr} + C_{dr}$ .... (7)

Hence

$C_s = n\ C_d/6 + \frac{Ct}{2n^2}(2n-1)$ .... (8)

Thus this type of winding has an increased range of series capacitance.

INTERLEAVED DISK WINDING:

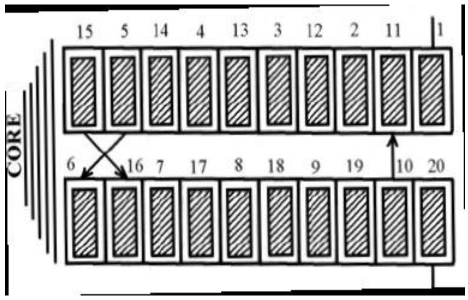


figure 3

In this type of winding, the conductors are placed one after the other with a conductor of next slot in between as shown in *figure 3*. In this type, the series capacitance can be found from the relation,

$C_s = \frac{ECt}{4}(n-1)$ .... (9)

Where, E is the number of disks considered for interleaving the winding. There are a few types of interleaved winding such as helical, interleaved with two parallel conductors etc…

The major advantage of this type of winding is that the series capacitance increases leading to linearization of the voltage distribution curve. But increase in the potential difference between the turns during steady state distribution confirms the necessity that insulation should be capable of withstanding such difference. Also the complexity in the production & labour of these windings leads to leaving certain portions of them as continuous disks. This causes impedance mismatching leading to formation of amplitude transient voltages and consequently insulation deterioration. This reduces the usage of these windings.

INTERSHIELD DISK WINDING:

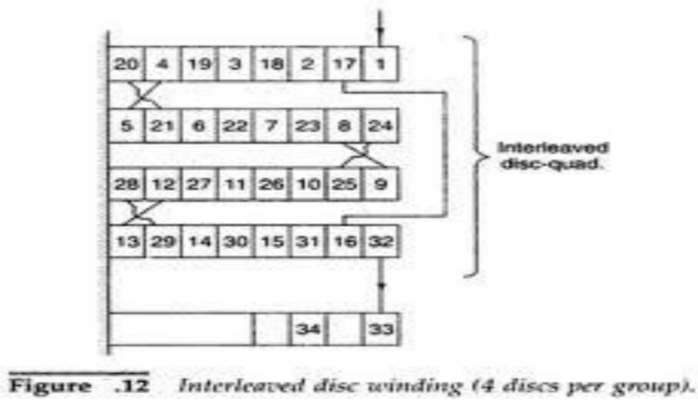


Figure 4

The last type of winding is the intershield type. Here the windings are arranged in successive positions with a space between them filled by electrostatic shields made of copper and aluminium.

Every uppershield is connected to every lower shield as in *figure 4.* Thus as regular the capacitance of the winding can be calculated from

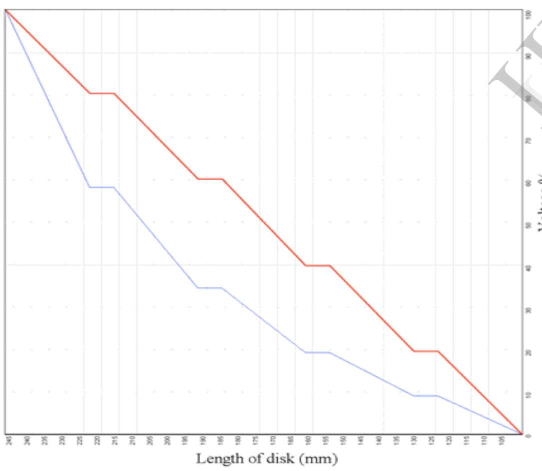
$C_s = \frac{n}{6}C_d + \frac{n^2-n-2}{n^2}C_t$ ……………………. (9)

Eventhough the capacitance value gets increased, the series capacitance of interleaved winding is greater than that of the intershield with only one shield. So several numbers of shields are used in the intershield windings to increase the capacitance and the total capacitance

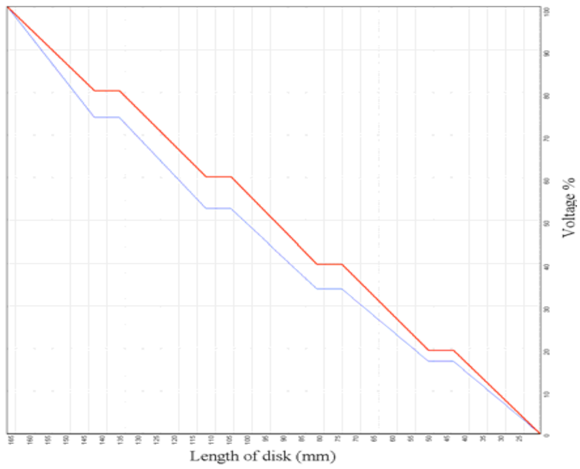
$C_s = \frac{n}{6}C_d + \frac{2(n-s-1)}{4n^2}C_t + \frac{s}{4n^2}C_t \left[\frac{V-Vcross}{\Delta V} + \left(\frac{V-Vcross}{\Delta V} - 1\right)^2 + \left(\frac{V-Vcross}{\Delta V} - 2n\right)^2 + \left(\frac{V-Vcross}{\Delta V} - 2n+1\right)^2\right]$ …………(10)Where, s is the number of shields in the same disk.

The series capacitance gains the highest value via shielding till the last turn of the disk. Also s is directly proportional to Cs.Thus owing to simplicity in the construction and increment in the series capacitance intershield winding gains a major place in the impulse voltage distribution.

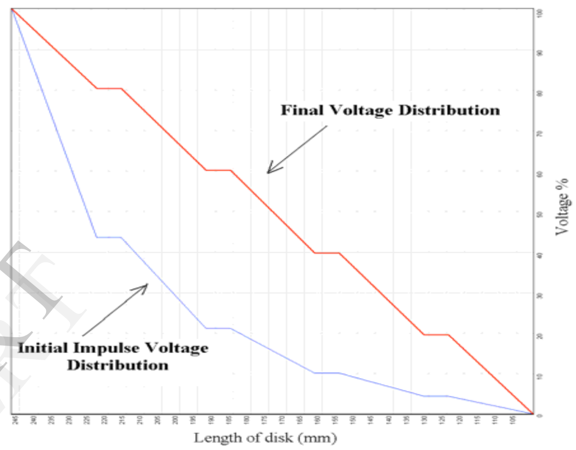
Here are the graphs comparing IVD in various type of windings below with n=8:



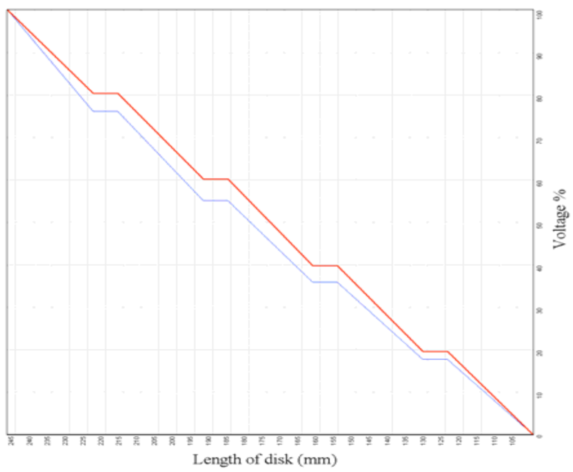
IVD in continuous winding



IVD in interleaved winding



IVD in intershield winding s=1



IVD in intershield winding s=6

OTHER RELATED FACTORS OF CONSIDERATION:

There are certain other factors apart from this series capacitance to improve the voltage distribution. They are:

1. mutual inductance between sections

2. electrostatic fringing effects between the sections

MUTUAL INDUCTANCE BETWEEN SECTIONS:

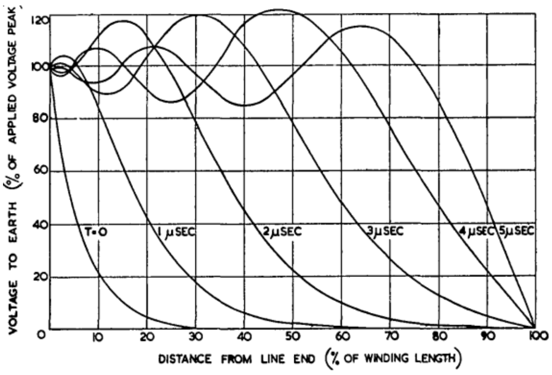


Figure a

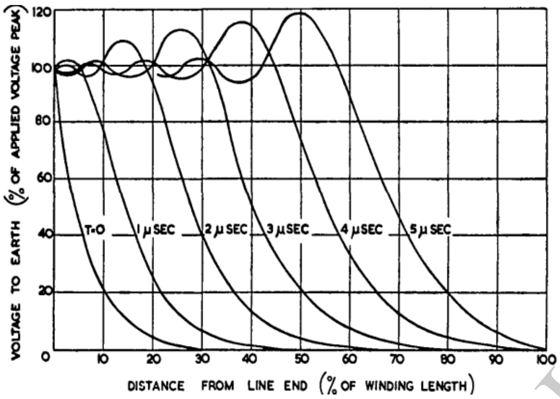


Figure b

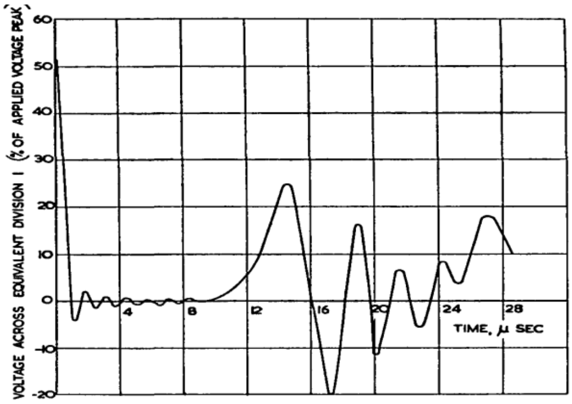


Figure c

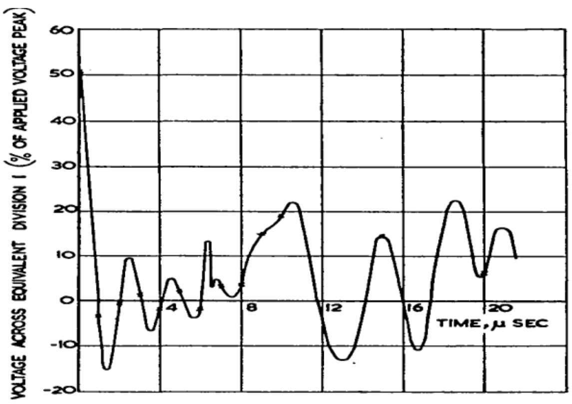


Figure d

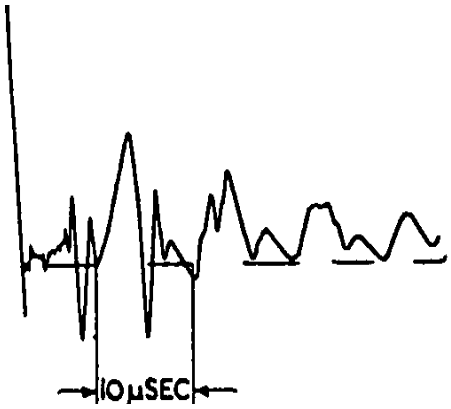


Figure e

Figure a. Calculateddistribution of voltage to earth throughout winding (mutual inductances neglected).

Figure b. Calculateddistribution of voltage to earth throughout winding(mutual inductances included).

Figure c. Calculated voltage across first three winding sections(mutual inductances neglected).

Figure d. Calculated voltage across first three winding sections (mutualinductances included).

Figure e. Measured voltage across first three winding sections.

By analysing these four graphs it has been found that inclusion of mutual inductance has a significant effect on travelling wave's form as well as its velocity.In comparing *Figure c*& *Figured*with *Figure e.*, it should be notedthat, whereas the calculated results assume a unit-functionapplied wave, the nearest approximation to this which could beobtained on the recurrent-surge oscillograph was a 0.1/150wave. But it has a little effect on the windings when compared to the capacitance.

The effect of electrostatic phenomenon on windings will be discussed later.

MODERN TECHNIQUES OF ANALYSIS:

As there has been a remarkable improvement in the field of electronics ,the impulse voltage distribution can be analysed through computer with the help of EMTDC/PSCAD simulation by applying Fast Fourier Transform, RungeKutta method etc…. There are still more techniques needing some improvements are there. No special explanation is made on the recent techniques as they are under deep research and not that much practical.

ADDITIONAL TECHNIQUES FOR IMPROVING IVD:

In my analysis, it may be better to design intershield windings with

1.Increased space between the two successive conductors'

2.More compact shields

Since, series capacitance increases with these two phenomena.

CONCLUSION:

Hence it is concluded that the analysis of impulse voltage distribution and various techniques for improving IVD note the fact that these abnormal voltages can be made less harmful and equally distributed over windings by improving the series capacitance of the windings. It should be taken into account that, decreasing capacitance makes a complex construction and on the same hand, insulation should also be looked after.

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