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Design and Development of Combined Instrument Transformer

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Abstract - *Combined current and voltage transformer for high voltages, consists of a current transformer of inverse construction placed in the head portion and an inductive voltage transformer at the bottom. Combined solution integrates the current and voltage transformers in one casing; this means significant cost reduction and compact size. The main insulation of the transformer is two separate condenser bushings placed in the same insulator body. The crucial part of this equipment is to design the two bushing which are in opposite polarity and challenging task is to achieve uniform voltage and stress distribution along the surfaces of porcelain structure. In the present work, the methodology has been developed to achieve the uniform voltage distribution and reduced the electric stress within allowable limits by using 3D Finite Element Analysis (FEA). The capacitive grading was done carefully by selection of shields and its location, in order to control the tangential stress along the surfaces of porcelain housing. The electrical strength of insulation system is improved and optimized during the design process using an iterative approach. The prototype has been all the dielectric test as per IEC 61869 [1]*

The Combined current & voltage transformer offer the designer the skill of being able to house the CT & VT in one unit. This allows best possible use of substation space and also getting the cost savings by exclusion of one set of mounting pads and support structures. In addition, erection time is significantly reduced.

Combined Instrument Transformers are commonly used where the space for substation is less or limited. This products are available either in oil or SF6 dielectric systems

Key Words: oil impregnated paper bushing; Finite element analysis; electric field; High voltage techniques; combined instrument transformer

1. INTRODUCTION

Combined Instrument Transformers (CITs) are used to transform high system voltages (kV) and currents (kA) into low measurable values. Fig. 1 shows the basic construction of combined instrument transformer. A CIT accommodates current transformer (CT) and voltage transformer in a single unit/ housing. The constructional feature of CIT is the active part of voltage transformer (IVT) situated at bottom and current transformer situated at top of the porcelain housing. Otherwise, the design and manufacturing process of CT and IVT active parts are as same as regular practices. The HV terminals of both the transformers are at the top and the LV terminals are at the bottom. The centre pipe of CT bushing carrying secondary terminal (low potential) connected to the cable box and IVT bushing carrying high voltage cables connected to the high voltage transmission line.

The insulation system of the ceramic insulator of the combined instrument transformer(CIT) is more complicated than that of a voltage or current transformer. An especial case of voltage grading is seen on bushings of CIT containing two central conductors, one at high voltage (voltage part) and one a ground potential (current part). When a capacitive system is used to control the electric field in the surface of the bushing insulator, each of the conductors has its own capacitive grading foils. Usually the last electric shield in the current part is at the high voltage while the last electric shield in the voltage part is grounded. The rest of the foils acquire a floating potential that depends on their dimensions and position, which is considered as a fundamental drawback of this solution, because the voltage is distributed along the height of individual bushings of the opposite sign, so that the places of the same potential should be adjusted in space.

Fig.1 - Combine Instrument transformers (CITs)

Bushings are used in high voltage apparatus to convey the HV conductors to ground throughout the structure. The surface discharge occur near the ground area is dominant hence to avoid this electric field near to ground portion need to be graded. One of the more used field control techniques is the capacitive grading. Capacitive graded bushings can be formed with lesser diameters without high electric stress attention on the outside surface of the insulating housing close to to the grounded metal flange. In

OIP bushing the capacitive grading is achieved by separating the conductive aluminum foil by paper layers. In this design the bushing manufacturing process must be done under a strict quality control process to avoid field enhancements due to an incorrect installation of the shields.

2. ELECTROSTATIC FIELD ANALYSIS

The design process concerns the design of electrostatic control shields for two bushings and computing the electric field distribution in the insulation system of CIT. The electric field in an insulation system is described by Laplace's equation after introducing the scalar potential with proper boundary condition

$$\nabla^2 V = 0 \qquad (1)$$

The geometry of CIT bushings causes its voltage and electric stress distribution to be non-uniform. It is very complicated to calculate electric fields by two dimensional or analytical formulae. Applying the finite element method in 3D systems makes it possible to solve for the stress distribution for this product.

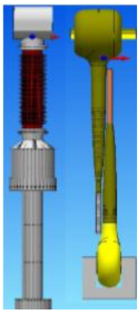

Fig -2: 3-D Model of CIT

2.1 Three Dimensional Modelling

The biggest problem of modelling the physical device is the reproduction of real shape of device. It is much complicated to maintain accurate neck radius of CT and IVT bushing as mentioned in the introduction section, both CT and IVT active parts are used same as existing product. Bushing portion is modified including porcelain in the present work. 3 D scanner is used to measure the actual dimension of CT and IVT active parts and converted into 3D CAD models [2]. This helps to achieve accurate calculation of electric field at various locations. The 3D CAD model of CIT shown in figure 2.

2.2 Electric Field Control By 3D FEA

The capacitive grading method is used to achieve the uniform electric field with the help of 3D electrostatic analysis. An electric field distribution of the product is shown in figure3. The bushing design could not be done by using regular design calculation, because the mutual capacitance effect of both the bushings and 'n' number of capacitive foils [3].

The bushing design is optimized by varying the number of foils, dimensions and location. The criteria for choosing the parameters of shields are not exceeding the permissible electric field stress and uniform electric field in all the direction. Each modification causes changes in the voltage distribution. Using iterative process optimum foils parameters are achieved.

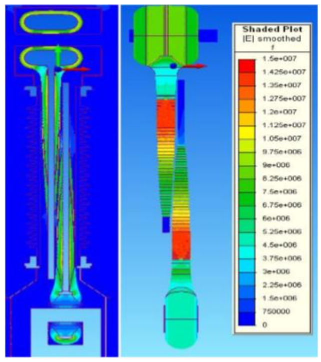

Fig -3: Distribution of the electric field

The outer diameter of the CT and IVT bushings are different and hence to accommodate both active parts inside the porcelain is difficult by maintaining manufacturing clearance. This also achieved through iterative process. The voltage distribution in the porcelain inner surface at CT side and IVT side are controlled equally as shown in chart 4.The small deviation at top and bottom portion is due to vicinity of high potential [4]. The electric field distribution at normal and tangential direction at particular angle has shown in chart 5 and 6 respectively. By maintaining homogeneity of field distribution throughout the product, possibility of insulation breakdowns and partial discharges in any internal part of product is eliminated.

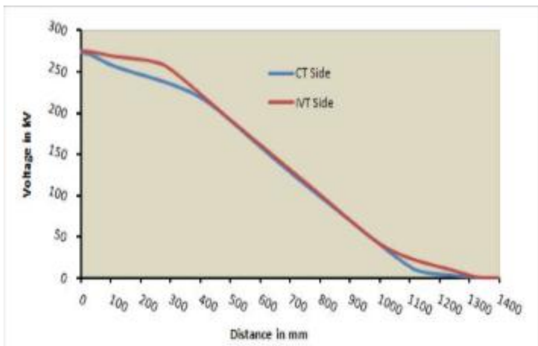

Chart -1: Voltage distribution along the porcelain insulator

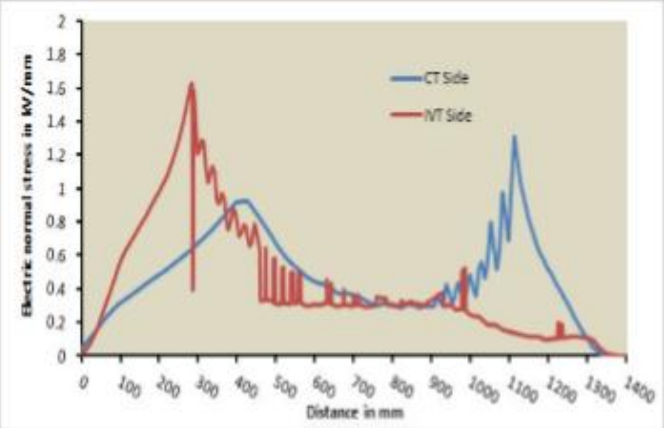

Chart -2 : Normal Electric field distribution along the height of porcelain

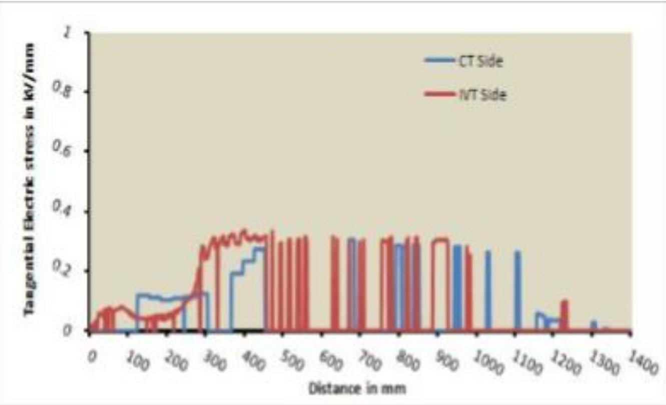

Chart -3 : Tangential electric field distribution on the Porcelain internal surface

3. PROTOTYPE AND TESTING

The CT and IVT bushings shown in figure 4 are manufactured by following the design guidelines achieved through electrostatic analysis. The bushing manufacturing process was done under a strict quality control process and maintained the tolerance within the limit to avoid field enhancements due to incorrect installation of the shields.

Fig -4: CT and IVT bushing

In oil impregnated paper (OIP) technology, paper being hygroscopic it soaks up the water molecules approximately 7% by its weight. The assembled product is subjected to autoclave process of various cycles to remove moisture. Drying process verified with water quantity collected at condensation tank, then oil flooding starts with preset litre per hours (LPH) rate on flow meter. Oil flow rate decided based on paper capillary action. In bushing region paper is wound with stress by machine, hence oil flow rate is larger compared to other parts.

After processing the combine unit in autoclave it needs to provide the standing time and pressurization to ensure the complete impregnation of paper, after this routine testing carried out to confirm the effectiveness of autoclave cycle and design validation. After drying process, the product was subjected to all destructive and non-destructive test and type test as per IEC 61869. It has been successfully cleared the entire test.

4. CONCLUSIONS

This paper has shown the use of numerical methods and analytical methods in one design process of an insulation system. computation are carried out based on the finite-element numerical method so as to make it possible to find the locations of high electric field strength values. The electric strength of an insulation system during the design process was achieved using an iterative approach. This designing procedure were persistent until the allowable electric field strength had not been crossed in any part of the insulation system and the homogeneity of the electric field was maintained.

Thus from this paper we can say that combined instrument transformer having many advantages

i. Reduced transport costs with one unit instead of two

ii. smaller substation material costs due to a compact quantity of supports and primary connections

iii. Lower Installation effort as only one unit has to be installed instead of two

iv. Less space needed with just one with one footprint

v. Lower the manufacturing & handling cost

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