DEVELOPMENT OF CAST RESIN MULTISECONDARY 1600kVA TRANSFORMER FOR REGULATED HIGH VOLTAGE POWER SUPPLY- A PROTOTYPE

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ABSTRACT

Regulated High Voltage Power Supplies (RHVPS) are commonly used in high-energy particle accelerators. RHVPS is a modular power supply in which kV level modules (40 or 80#) are cascaded to generate desired level of voltage/power [1]. One of the most challenging tasks involved is to provide input power to number of rectifier modules with required isolation (inter-winding and winding to ground). This is accomplished by deploying multi-secondary (large numbers, say 40 secondaries) transformers. This RHVPS concept was realized for the first time in the country with development of oil filled multi-secondary transformer. A pair of 3.3MVA, 11kV/(940Vx40) has been successfully demonstrated, isolation of 6kVDC (inter-winding) and 160kVDC (all secondary to ground) tested.

The next generation power supplies are unitized with indoor installations. This has created the demand for dry type multi-secondary transformers in compliance with safety regulations. This paper presents manufacturing issues and testing of the prototype resin cast coil. On the manufactured prototype, inter-winding isolation is tested up to 6kVDC and 125kVDC with respect to ground.

1. INTRODUCTION

High-energy particle accelerators are modulated by high voltages/power. Certain uses like Neutral beam heating of Plasma in TOKAMAK require high power. A typical Neutral beam has few tens of megawatt power. Typical example is a 5 MW neutral beam injector at the Institute for Plasma Research (IPR). Ion source provides H\(^+\) ions, which are accelerated at 55kV. The new age particle accelerators may require millions of volts for atomic particle acceleration. To meet the demand, modular power supplies are best suited based upon the facts that they are easy to maintain, well-controlled, regulated, can have sharp rise and fall time and have better serviceability.

The chosen topology for such applications has introduced multi-secondary transformers (figure1a & 1b). The design of these transformers accommodates the need to feed modules individually in isolation mode. Earlier, the capability has been demonstrated in oil-cooled transformers successfully and an attempt has been made in Resin Cast [2], [3]. Dry type multi-secondary transformer is proposed under an MoU between IPR and BARC for development of a 100kV, 25A RHVPS. Unlike oil filled transformers, dry type transformers are manufactured up to 33kV voltage class only. This has posed the limitation on the achievable kVDC isolation and resin system to support the same. Also to assure the manufacturing feasibility, a prototype resin cast coil, section of LV cast with four coils having radial dimensions same as with actual transformers (1600kVA, 11kV/1.1x40), was proposed.
2. PROTOTYPE

Prototype was motivated due to the fact that this is a first ever attempt by industry to go for such non-standard cast resin transformer (CRT) with multisecondary design and high voltage requirements. Based on available data and FEM analysis, dimensions, size and clearances were chosen. A one-tenth section (4 LV coils) of LV of actual transformer (1600kVA, 11kV/1.1kVx40) design was preferred to cast as prototype. The HV coil (11kV class) is standard practice for industry and has not been considered as part of the prototyping.

3. MODELING

A model has been developed to analyze the electrical stresses in and out of the resin medium. A cylindrical electrostatic shield to reduce corona in intercoil region is provided between LV and HV coils. Simulation has been done for different thicknesses of resin at radial/top/bottom regions. Each winding of the coil is subjected to DC level by virtue of power supply topology. The last coil in the series is subjected to the highest voltage. In order to reduce the thickness of resin at top and bottom, dummy coils of larger diameter are used to shield top and bottom coils electro-statically. The schematic is shown in the figure 2.
Figure 2 Schematic shows the internal arrangement of coils.

Due to the symmetry of coil distribution, only the end conductor of the winding, shielding conductor and electrostatic shield/screen were chosen for modeling. The FEM results figure 3 show that stress levels have decreased from 6.2kV/mm to 4.5kV/mm with dummy coils at 100kV. Based upon these results, the dimensions are chosen as inputs for the design.
4. MANUFACTURING

Industry procedure was followed for the manufacturing of prototype. The coils were assembled in moulds and put into the vacuum chamber. Huntsman make resin (CY 205/HY 905), McLube make releaser (MA2021), 300-mesh size of silica and Binani make copper strands were used in the cast. The manufacturer, based upon his experience, chose the hardener (DY061), plasticiser (DY040) and their mixing ratio. The resin mixture was poured into the mould in fluid form. Curing & post curing followed as per the recommended procedures. The finished product was examined mechanically as well as electrically.

5. EXPERIENCES WITH THE CAST

This cast was first of its kind to be manufactured. The cast did not show a good insulation resistance (IR) value on megger test. Skewing of screen was found in the cast. Also, development of cracks along the periphery was observed during the post-curing phase (figure 3a). These issues were not expected, as the manufacturer never observed them before. One of the reasons envisaged was the mass involved in the cast. The OD 770mm and ID 460 mm of the coil cast gave resin thickness of 155 mm, which is bulky. As stated earlier in FEM analysis that 60 mm thickness of resin is required at the top and bottom and inside periphery of the coil. In order to deal with such issues, following arrangements were made during next assembly.
1. Introduction of FRP isolators at ID side of copper coils and at the ID of the coil cast.
2. Placing of screen over FRP isolator.
3. Use of fibreglass matt in bulk resin region.

After these incorporations in assembly, the second cast was produced. The megger value increased to the desired level and no skewing was observed. The whole cast was found intact. A few lines of cracks were observed (figure 3c). The cast was subjected to electrical testing and excellent results were obtained.
Figure 3: (a) Picture after casting of first coil. Skewing of screen and crack lines are seen along the inner periphery. (b) Assembly before casting (c) The final cast with dimensions.

6. TESTING AND MEASUREMENTS

**High voltage withstand test**

**Setup**

![Diagram of high voltage withstand test setup](image)

Figure 4: Testing arrangement for the cast.
Testing terminals
All coil terminations are shorted and HV is applied between screen and shorted terminations.

Megger test:
Before HV application, all the adjacent winding terminations withstood megger test for 1 min.
IR value > 2000 MOhms @ 5 kVDC

| S. No | Applied voltage (kV) | Duration of application | Remarks             |
|-------|----------------------|-------------------------|---------------------|
| 1.    | 45                   | 60 sec                  | No Corona           |
| 2.    | 64                   | 60 sec                  | No Corona           |
| 3.    | 75                   | 60 sec                  | Initiation of audible Corona |
| 4.    | 86                   | 60 sec                  | -do-                |
| 5.    | 93                   | 60 sec                  | -do-                |
| 6.    | 97                   | 60 sec                  | -do-                |
| 7.    | 99                   | 60 sec                  | -do-                |
| 8.    | 100                  | 60 sec                  | -do-                |
| 9.    | 102                  | 60 sec                  | -do-                |
| 10.   | 105                  | 60 sec                  | -do-                |
| 11.   | 110                  | 60 sec                  | -do-                |

HVDC (in-house test)

| S. No | Applied voltage (kV) | Leakage current* (micro Amp) | Remarks            |
|-------|----------------------|------------------------------|--------------------|
| 1.    | 60                   | not readable                 | No corona          |
| 2.    | 80                   | Not readable                 | Initiation of audible corona |
| 3.    | 90                   | 100                          | -do-               |
| 4.    | 100                  | < 200                        | -do-               |
| 5.    | 110                  | < 200                        | -do-               |
| 6.    | 120                  | < 200                        | -do-               |
| 7.    | 125                  | < 200                        | -do-               |

Duration of application at each voltage step was 60 sec
*The measurement scale does not show below 100 microamps and the scale is in steps of 100 microamps.
All the readings were between 100 and 200 microamps.

Megger test:
After HV application, all the adjacent winding terminations withstood megger test for 1 min.
IR value > 2000 MOhms @ 5 kVDC

7. DISCUSSION

CRT for high voltage application ~ 100 kV or beyond with multisecondary features call for investigation in the area of bulk resin castings, thermal management and advance approach in the dielectrics to make the overall equipment compact and cost effective. The prototype development has demonstrated the capability of manufacturing but with limitations in database and experience. The lack of database in
areas like FRP interaction with resin, Cross linking phenomena in bulk resin, curing, mixing ratio & composition of resin for bulky/compact design, in view of HV applications, open up investigations for future endeavours.

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