IJIREEICE

ISSN (Online) 2321-2004
ISSN (Print) 2321-5526

International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering

Vol. 7, Issue 1, January 2019

# Analysis of Brittle Fracture of Composite Insulators by using Finite Element Technique

**Nagaraj.H.P[1], K N Ravi[2], N.Vasudev[3]**

Research Scholar, VTU-RRC, Head Sapthagiri College of Engineering, Bangalore[1]

Professor & Head, EEE Department, Sapthagiri College of Engineering, Bangalore[2]

Addnl Director & Group, CPRI, Bangalore[3]

**Abstract:** The Brittle fracture process causes cracks on the FRP rod of the Composite (Composite) insulator that leads to premature failure of Composite insulators. Major types of stress affecting the service life of an insulator are electrical, mechanical and environmental stress whereas the major physical threat is vandalism. For various transmission and sub-transmission voltages, the insulators are required withstand the maximum tensile strength of the conductor. Therefore, understanding the mechanical stress withstanding capability of Composite insulator is important. Proper designing of the strength of FRP (Fibre Reinforced Plastic) rod is most important. FEA (Finite Element Analysis) analysis of voltage distribution along the length of the Composite insulator is also necessary for the understanding of electric field stress required for surface deterioration of Composite insulator. The mechanical stress analysis for various cross sections of FRP rods for a given mechanical load has to be carried out in order to optimize the diameter of the FRP rod for better reliability. FRP rods of different diameter were considered, it is observed that when diameter is increased the maximum stress is reduced and hence, by increasing the diameter of FRP road better results can be obtained. It is also observed that displacement is more in FRP rod of lower diameter.

**Keywords:** FEA, FRP Rod, Composite, Brittle Fracture, Maximum Tensile Strength, Electric Field Stress

## I. INTRODUCTION

Compared to Ceramic Insulators, Composite insulators are having special features such as hydrophobicity and greater mechanical strength to its weight ratio. Even though there are many advantages in using Composite insulators, when they are exposed to ambient conditions for long duration, the influence of environmental conditions, pollution conditions, electrical stress and mechanical stress will cause damage to the insulators. Deterioration of weather sheds and FRP rod occurs because of UV, environmental conditions, salt, rain, moisture etc. The maximum tensile strength of FRP rod reduces and failure may occur. Hence, it is required to study mechanical stress the insulators.

The Brittle fracture is a failure of FRP rod in Composite insulator, the decrease in mechanical tensile strength of FRP rod due to tracking and erosion occurs when solutions like nitric acid generated in the field due to electrical activities like corona with moisture and electric stress. Cracks are formed in the Composite insulator rods before the brittle fracture failure of Composite insulators. Though there are several factors that lead to failure of Composite insulators, the in-field failure analysis carried out in various countries across the world suggest that Ageing and Brittle Fracture are the two major failures of a Composite insulators.

## II. TRACKING & EROSION ON FRP ROD SAMPLE

### A.Experimental Set-Up to study erosion and tracking of FRP rod

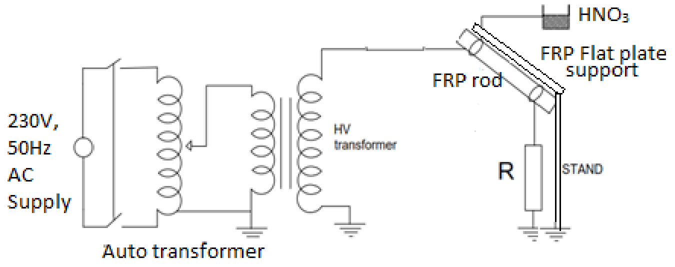

Figure 1: Schematic Diagram of the experimental Set up for erosion and tracking test of FRP rod

The Schematic of the experimental test set-up to study erosion and tracking of FRP rod is as shown in figure 1. Experimental setup for conducting these tests in the laboratory is as shown in figure 2. Severity used for the brittle fracture experiment is of 0.1N and 0.5N of $HNO_3$ solutions. Periodic observations were made and samples were assessed. Samples of FRP rod used in Composite insulators were considered and the tests were carried out on the sections of FRP rods, without polymer shed.

### B. Procedure: Erosion and tracking of FRP rod

Two samples (A and B) of FRP rods of 15 mm diameter and 150 mm length were subjected for Erosion, tracking and brittle fracture tests. They were placed in stand used for inclined plane tests and copper foils were used as electrodes with 4cm distance between electrodes. A nozzle was fixed over the rod for proper drip of nitric acid solution. Drops were directed to drip at line end of electrode along the FRP rods. Variable voltage is applied to the specimens from an AC source 230V/5kV transformer. The voltage was applied to one of the electrodes and the other was earthed. The duration of the test was about 60 minutes. The drip rate of the solution was also varied from 10 drops/minute to 30drops/ minute. Scintillations were observed between the electrodes connected to FRP rod, which is as shown in Figure 3.

Figure 2: Experimental setup for FRP Rod test

Figure 3: Scintillations on FRP Rod

### C. Results and discussions of experimental study of Brittle fracture of FRP rod samples

Experiments were carried out in order to understand brittle fracture of FRP rod. Sample of FRP rod before placing it for test is as shown in Figure 4.

Figure 4: Sample of FRP rod

DOI 10.17148/IJIREEICE.2019.7103

When copper foils were used as electrodes, it was found during an experiment, that copper was forming cupric sulphate on the FRP rod surface. This formation was leading to increase in surface conduction on the FRP rod. Hence, it was thought that by using stainless steel foils this can be avoided. Few experiments were repeated using stainless steel foils, in which there was no formation of conductive paths on the surface. Further tests were conducted using stainless steel foils as electrodes and there was no conductive path between the electrodes.

Sample – A
Test results of Sample A: Though the tracking and erosion was observed in sample A, they were of lesser severity compared to Sample B. Tracking and erosion of samples A and B are as shown in figures 5 and 6 respectively.

Figure 5: Sample A of FRP rod - after test

Sample B
Test results of Sample B: It is observed that tracking and erosion was high in sample B.

Figure 6: Sample B of FRP rod - after the test

**D.Application of Mechanical Load (Tensile) on both samples of A & B**
After tracking and erosion on samples A & B, mechanical load was applied on the samples in order to obtain brittle fracture in the laboratory. FRP rods were subjected to tensile strength test. The FRP rod of Sample-A got fractured at peak load of 68kN. The photograph of brittle fracture is as shown in Figure 7. Sample B was also subjected to Mechanical load test, and it fractured at about 60 kN as shown in Figure 8 showing that the sample B is inferior to Sample A. It can be seen from the results that the sample A, is of good quality. The Fractured sample (Sample B) shows similar pattern of the failure in the field.
After the experimental studies of water droplets on surface and tracking & erosion of FRP flat plate samples & rods, it is very much necessary to analyze theoretically both the failures.

Figure 7: Brittle fracture of FRP rod Sample A

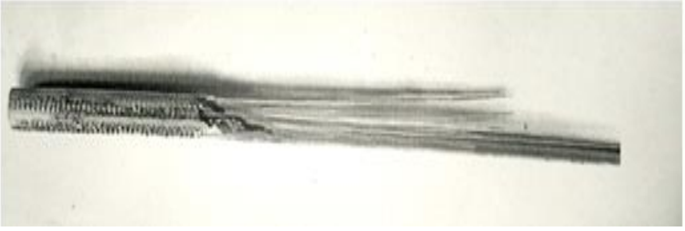

Figure 8: Brittle fracture of FRP rod Sample B

One of the main causes of the failures is the voltage distribution across the length of Composite insulator. It is also necessary to understand the mechanical stress distribution along the cross section of the FRP rod. Therefore simulation studies were carried out using FEA technique for both electrical stress analysis and mechanical stress analysis. The details of the simulation studies are given in the chapter to follow.

## III. THEORETICAL STUDY OF VOLTAGE DISTRIBUTION AND BRITTLE FRACTURE

It was intended to study the structural integrity with mechanical and electrical analysis of 220 kV System. Mechanical stress analysis is required for different radii of FRP rod which will help in finding out the failure stress on FRP rod and withstand level of FRP rod. Normally the diameter for 220kV is 24 mm and mechanical load is 140kN. If we consider a reduction in the area of FRP by about 25% the diameter may reduce to 18mm (due to erosion). In case if it fails at this diameter safety has to be considered and hence 25% higher diameter i.e., 30mm is also considered in the present study.
FRP of different radii considered for Mechanical stress analysis, which helps in finding out the stress on FRP rod and voltage distribution is as shown in Table I.

Table I: FRP rods of different diameters considered for analysis

| Sl. No | CASE | FRP ROAD DIMENSION |
|---|---|---|
| 1 | 1 | Original diameter = 24 mm |
| 2 | 2 | 25% increase in diameter = 30 mm |
| 3 | 3 | 25% decrease in diameter = 18 mm |

### A.Electrical analysis of Composite insulator

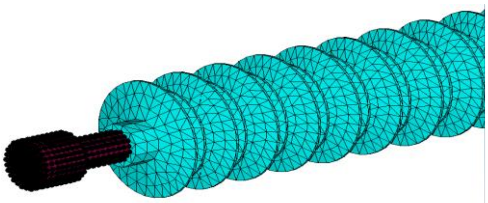

Figure 9: Voltage at ground end ( 0 Volts)

The details of voltage applied are shown in figures 9 and 10. Voltage applied at ground end is shown in figure 9, which is the reference voltage (0 Volts) and 198 kV applied at line end which is shown in figure 10.
Voltage applied at ground end of the insulator: 0
Voltage applied at line end of the insulator: 198 kV

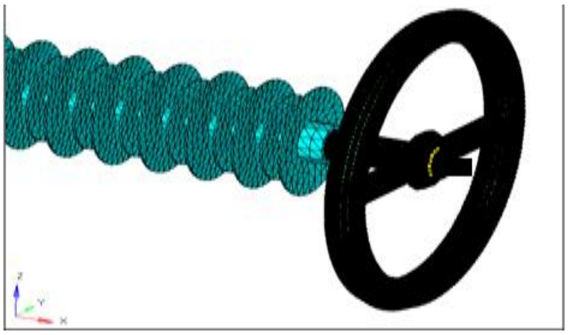

Figure 10: Voltage at line end – 198kV

DOI 10.17148/IJIREEICE.2019.7103

### B. Results and Discussions of FEA studies

Electrical stress analysis and mechanical stress analysis were simulated using FEA technique and the results for different radii of FRP model were analyzed in the sections to follow.

### C. Electrical Analysis Results and discussions of CASE 1

a) CASE 1- FRP Rod diameter of 24 mm

The voltage distribution pattern is as shown in Figure 11 and it is observed that maximum voltage is at the line end with 198 kV and keeps decreasing from line end towards ground end.

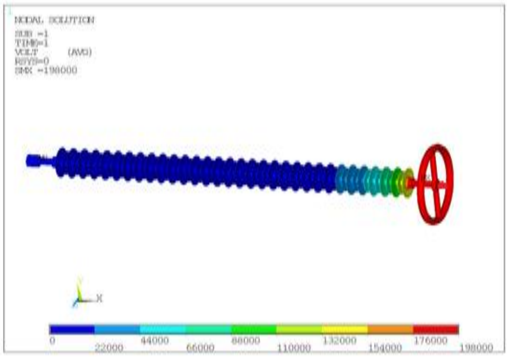

Figure 11: Voltage distribution along the insulator

The voltage distribution and maximum is observed at the line end with 198000 V. Corresponding electrical potential distribution lines are shown in figure 12.

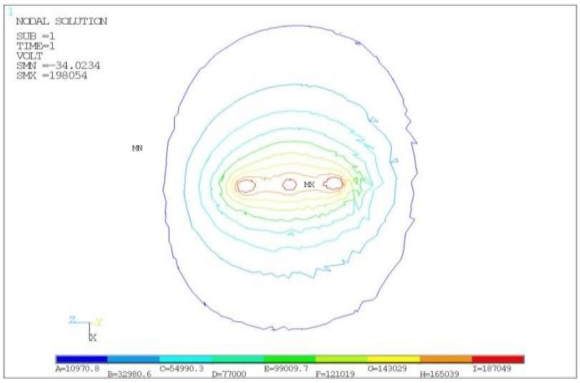

Figure 12: Electrical potential distribution lines

The voltage values at different distance from line end to ground end is shown in table 3.1 and plot of graph of variation of voltage with respective to distance is as shown in figure 13.

From the graph, it is observed that most of the voltage drops across the length of the insulator from 170mm to 400mm from the line end, i.e. the drop in the voltage is about 150kV. The average stress in this region is 150kV/23cm = 6.52kV/cm. The intensity of the stress is high at the line end and decreases sharply to 1/4th of the insulator length.

Table II: Distance V/s Voltage

| Distance (mm) | Voltage distribution (Volts) |
|---|---|
| 33 | 1.98E+05 |
| 36 | 1.98E+05 |
| 98 | 1.98E+05 |
| 140 | 1.98E+05 |
| 166.9 | 1.85E+05 |
| 199.2 | 1.28E+05 |
| 226.905 | 1.17E+05 |
| 286.9 | 95935 |
| 346.9 | 70307 |
| 406.9 | 38843 |

DOI 10.17148/IJIREEICE.2019.7103

| | |
|---|---|
| 442.15 | 38843 |
| 502.14 | 33734 |
| 526 | 25409 |
| 649 | 19215 |
| 709 | 12642 |
| 742 | 9620.6 |
| 802 | 8439.6 |
| 922 | 6431.6 |
| 1042 | 3742.2 |
| 1188 | 2181.7 |
| 1309 | 1109.8 |
| 1429 | 645.94 |
| 1522 | 376.9 |

### D.Mechanical (Structural) Analysis Results and discussions of CASE 1

Mechanical stress analysis is required for different radii of FRP rod which will help in finding out the failure stress on FRP rod and withstand level of FRP rod. Normally the diameter for 220kV is 24mm and mechanical load is 140kN. If we consider a reduction in the area of FRP by about 25% the diameter may reduce to 18mm (assuming due to erosion). In case if it fails at this diameter safety has to be considered and hence 25% higher diameter i.e. 30mm is also considered. Due to these considerations, a detailed analysis is required using FEA technique for Composite insulator of 220kV system.

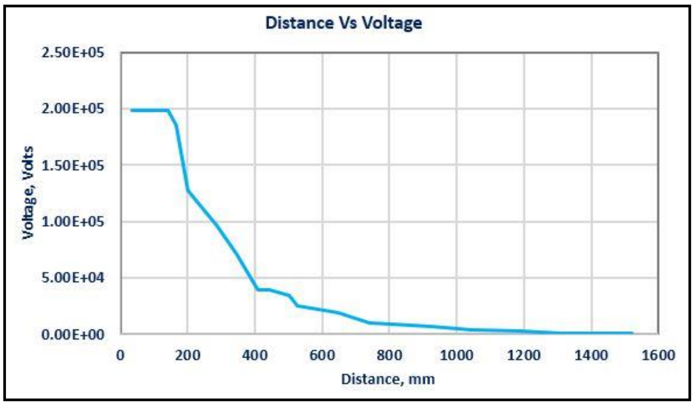

Figure 13: Distance V/s Voltage distribution – Case 1

The displacement plot on application of load is as shown in figure 14 clearly shows that the maximum displacement of 0.41 mm is on the line end where the
load is applied which gradually decreases at the ground end.

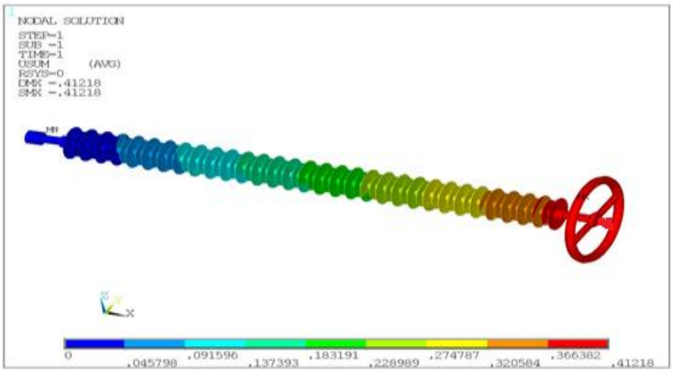

Figure 14: Displacement contour- case 1

The summery of electrical and structural analysis of all the 3 case studies are given in Table III. FRP rods of different radii are considered and their displacement and electrical stress values gives the comparison of all the 3 cases.

DOI 10.17148/IJIREEICE.2019.7103

Table III : Summery of FEA analysis

| Sl No. | Case FRP ROD of diameter | Electrical stress value at 1/4th of length (V/cm) | Displacement in mm | Stress in MPa |
|---|---|---|---|---|
| 1 | 24 mm | 6.52 | 0.41 | 32.02 |
| 2 | 30 mm | 6.66 | 0.24 | 24.27 |
| 3 | 18 mm | 6.07 | 0.49 | 30.52 |

## CONCLUSIONS

Based on the experimental works carried out on FRP rods and based on simulation studies of FRP rods the following conclusions can be drawn.

The gradual deterioration of the fiber glass rod were closely studied and recorded. The effect of the solutions of severity 0.1N and 0.5N of HNO3 concentrations were also studied. The samples on which the erosion was observed were subjected to mechanical load & it was found that the fracture has occurred on both the samples resembling the brittle fracture.

Both the rods were subjected to tensile load & they failed at 68kN (Sample A) & 60 kN (Sample B) respectively. On the observation of failures in both samples of A & B, it can be seen that, the brittle fracture occurred at the eroded zones. After the tensile load it can be seen that sample A is better than Sample B, because of the reason that there are no fibres at the fractured areas.

From all the 3 FRP rods of different diameter varying 18mm, 24mm and 30 mm, it is observed that when diameter is increased to 30mm the maximum stress is reduced to 24.27 MPa and hence, by increasing the diameter of FRP road better results can be obtained. It is also observed that displacement is more in FRP rod of lower diameter of 18mm.

## ACKNOWLEDGMENT

The authors thank the Management and Principal of Sapthagiri College of Engineering, Bangalore for permitting them to publish this paper. Authors also thank authorities of CPRI for publishing this paper

## REFERENCES

[1]. Lucas S. Kumosa, Maciej S. Kumosa, and Daniel L. Armentrout, “Resistance to Brittle Fracture of Glass Reinforced Polymer Composites Used in Composite (Non-ceramic) Insulators”, IEEE Transactions On Power Delivery, Vol. 20, No. 4, October 2005
[2]. Frank Schmuck and C. de Tourreil, “Brittle Fractures of Composite Insulators an Investigation of their Occurrence and Failure Mechanisms and a Risk Assessment”, CIGRE WG 22-03
[3]. STRI – Guide 5, 2003 – Guide for visual identification of deterioration & Damages on Suspension Composite Insulators
[4]. R. S. Gorur and J. W. Chang, 0. G. Amburgey, “Surface Hydrophobicity of Polymers Used For Outdoor Insulation”, IEEE Transactions on Power Delivery, Vol. 5, No. 4, November 1990
[5]. Muhammad Amin and Muhammad Salman, “Ageing of Polymeric Insulators (An Overview)”, November 2006
[6]. Subba Reddy B, Shakti Prasad and M Rajalingam, “Studies on Corona Degradation of Polymeric Insulators”, ©2014 IEEE
[7]. L. S. Nasrat, A. A. Ibrahim, C. G. Melad, “Tracking and Erosion Resistance of Rubber Blends for High Voltage Insulators”, International Journal of Technical Research and Applications Volume 4, Issue 1 - January-February, 2016
[8]. F. Aouabed, A. Bayadi, R. Boudissa, “Flashover voltage of silicone insulating surface covered by water droplets under AC voltage”, Electric Power Systems Research 143 (2017)
[9]. S.H. Carpenter and M. Kumosa, “An Investigation of Brittle Fracture of Composite Insulator Rods in an Acid Environment with Either Static or Cyclic Loading”, Journal of Materials Science, Vol. 35, No. 17 (2000)
[10]. Maciej Kumosa, Lucas Kumosa, and Daniel Armentrout, “Failure Analyses of Nonceramic Insulators: Part II—The Brittle Fracture Model and Failure Prevention”, July/August 2005
[11]. Jiafu Wang, Xidong Liang and Yanfeng Gao, “Failure Analysis of Decay-like Fracture of Composite Insulator”, December 2014
[12]. Subba Reddy B, Shakti Prasad and M Rajalingam, “Studies on Corona Degradation of Polymeric Insulators”, ©2014 IEEE
[13]. Subba Reddy B, Shakti Prasad and M Rajalingam, “Studies on Corona Degradation of Polymeric Insulators”, ©2014 IEEE