

## **Annexure 18: Supporting related to Transmission Line Surge Arrestor**

Project No: JB00986

Form no.10

**REPORT**  
**On**  
**Condition Assessment**  
**Of**  
**400 kV, 120 kN Silicone Rubber Insulator**



**SUBMITTED TO:**

**JSW-JPTL**

**Chiplun**

**By**  
**Root Cause Analysis Group**  
**Electrical Research and Development Association**  
**Vadodara**

DECLARATION

JSW-JPTL, Chiplun, entrusted ERDA with the task of Root Cause Analysis of Failed Silicone Rubber Insulator.

The Failure Analysis group of ERDA, Vadodara, carried out this work.

The contents of the report are based on the observations/results of work carried out by ERDA team and the inputs/data provided by the client.

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## EXECUTIVE SUMMARY

Two silicone rubber suspension insulators failed on a 400 kV transmission line, both the failure took place on tower number 151 of Jaigarh to Karad transmission line. The failed composite insulators had approximate service life of 4 years before failure.

To understand the root cause of the failure, the two failed composite insulator along with four working insulator removed from same tower were analyzed. One failed insulator showed damaged silicone rubber housing on the entire length of insulator indicating final failure with flashunder. The corona rings on both ends of insulator also showed arcing related overheating and damage. The second insulator showed punctures in silicone rubber housing and most of the silicone housing was damaged. The two insulator were installed on opposite end of tower, one connecting the tower no. 152 on Karad end and second connecting tower no. 150 on Jaigarh end, respectively. Both the insulators showed different failure mechanism.

Among the 4 working service insulators analyzed, one insulator on Karad end did not show any damage or ageing related degradation. Remaining three service insulators were punctured on line end, the punctures observed up to 80-90 cm from line end tri-junction. Two punctured insulators were located on Jaigarh end of tower 151 and the remaining one insulator was located on the Karad end of the same tower. All the insulator received for analysis, failed and service insulators, were covered with algae deposits which may reduce hydrophobic properties of silicone rubber insulators.

One failed and two service insulators on Jaigarh end of the tower 151 showed punctures indicating enhanced electrical stresses. On the Jaigarh end the angle between porcelain tension insulator and suspension composite insulator appeared small compared to Karad end of tower. This results in closer proximity of line end of porcelain insulator to the composite insulator leading to enhanced electrical field. Such enhancement of the e-field was also confirmed by FEM analysis. The high e-field punctured the silicone rubber housing leading to water ingress inside the composite insulator resulting in progressive degradation and failure of the insulator.

The failed insulator on Karad end showed arcing related damage to the insulator and metallic end fitting. This insulator failed during monsoon because of lightning strike. The algae deposits

on the insulator housing material deduces the hydrophobicity of the silicone rubber leading to reduced arcing distance resulting in failure. Testing of the service insulator did not indicate quality issues. The unique location of the tower 151, maximum height, local climate and ground conditions all played roles in failure of the two insulators.

It is recommended to increase the angle between porcelain and composite insulator on Jaigarh end. The algae deposits on the insulators, corona rings and arcing horns should be cleaned periodically. Periodic monitoring with IR and UV camera shall be carried out to detect hot spots or corona activity. It is recommended to install surge arrester on the transmission tower to minimize damage due to lightning strikes.

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## 1. INTRODUCTION

JSW-JPTL, Chiplun entrusted Electrical Research and Development Association (ERDA), a job of Root Cause Analysis of 120 kN, 400 kV composite insulator.

ERDA has studied the failed silicone rubber insulator with respect to following aspects:

1. To determine the root cause of failed silicone rubber insulator
2. To suggest remedial measures to avoid similar failure

The cause of failure was investigated in the framework of:

- i) Analysis of failed and working samples of silicone rubber insulator
- ii) Inference drawn from visual observations and testing data
- iii) FEM analysis for electrical field evaluation

### 1.1 Sample Received

JSW-JPTL has submitted following 120 kN 400 kV rated insulators for RCA:

1. Failed Insulator - two samples
2. Working insulator - five samples

### 1.2 Failure Details

Details of failed component

Name of component	120 kN Polymer Insulator (Pilot) string
Location of installation	Loc no 151 (R Ph-Ckt-II) Bottom phase
Date of Installation	02.04.2017
Function of component	Providing electrical insulation & mechanical support to control swing of jumper conductor
Design drawing & specification of the component	<a href="#">Dalion drawings.pdf</a>
Operating parameters as per design	
Environmental conditions, as per design	
Expected life of component	20-25 years

Details of earlier similar failures, if any	On dated 18.09.21, similar nature of fault occurred on same tower & circuit. ie Tower no 151 (ckt-II), Middle (Y-Phase) resulting to failure of Pilot string of same lot (Dalion make insulator) which was installed on 28.04.2016. (running hours: 47248 Hrs)
Major repair work carried-out, if any	The failed string was replaced by new Polymer string (Deccan Make, batch of 2020-21 supply) on 19.09.2021

#### Details of failure incidence

Date of failure	22.08.2022 to 24.08.2022
How failure was noticed	Fault witnessed during line charging during 4 <sup>th</sup> trial, as no abnormality observed in first three instance in dense foggy weather condition.
Major abnormality noticed just before failure	1 <sup>st</sup> tripping instance reported on 22.08.22 while charging hand tripped line on 07:22 Hrs, fault current: 6.9 kA, 2 <sup>nd</sup> tripping: SOTF, AR lock out on 22.08.22 at 14:07 hrs , Fault current: 5.022 kA, 3 <sup>rd</sup> tripping: SOTF, AR lock out on 23.08.22 at 16:39 hrs, fault current: 7.182kA, 4 <sup>th</sup> tripping: SOTF, AR lock out on 24.08.22 at 17:23 hrs, fault current: 7.07 kA.
Results of any diagnostic test done before or after failure	NA
Operating parameters at the time failure	SOTF (Line hand tripped due to over voltage at Karad end substation.
Service life (running hours) before failure, including number of on & off / trippings	(Running hours = 47256 Hrs) 16 no of tripping occurred in the region on both ckt-I & II.

## 2.0 VISUAL OBSERVATIONS

### 2.1 Silicone Rubber/Composite Insulator

Visual examination carried out by physical observations of silicone rubber insulator samples received and site visit. For better understanding of technical components described in this report, drawing of silicone rubber insulator is shown in Figure 2.1 indicating different components of SRI.

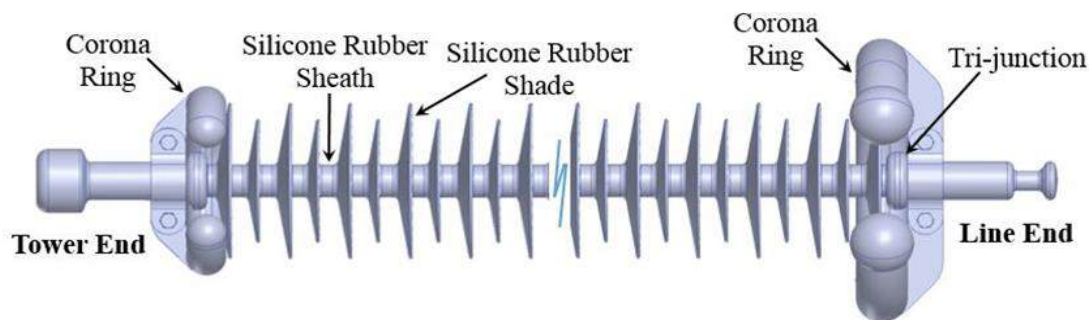


Figure 2.1: Drawing of silicone rubber insulator with component name

Three insulators were received for RCA, details of the insulators are given in Table 2.1.

Table 2.1: Details of insulator received for analysis

Insulator Name	Insulator details
SRI-1	Failed insulator - A (Karad end bottom phase)
SRI-2	Failed insulator removed from same tower - 5 (Jaigarh end middle phase)
SRI-3	Working insulator removed from same tower - B (Karad end middle phase)
SRI-4	Working insulator removed from same tower - 2 (Jaigarh end bottom phase)
SRI-5	Working insulator removed from same tower - 3 (Jaigarh end top phase)
SRI-6	Working insulator removed from same tower - 4 (Karad end top phase)
SRI-7	Working insulator removed from same tower - 1 (Jaigarh end middle phase)

Among the above insulators, SRI-1 to SRI-6 are from the same manufactures and having approximately similar life (approximately 4 years).

SRI-7 was from different manufacturer and having different service history. Since SRI-7 is of different make and different service history, this insulator was not analyzed for this RCA work.

## 2.2 Visual Observations of Failed Insulator - SRI-1

As received failed insulator is shown in Figure 2.2. The silicone rubber housing was found broken and separated from the composite rod on the entire length of insulator. Figure 2.3 shows both ends of insulator, it is tri-junction where composite rod, silicone rubber and metallic end fitting are joined together. Silicone rubber seal at both the tri-junction was found broken and composite rod showed tracking marks. Metallic end fitting at the tower end shows indications of arcing related overheating.

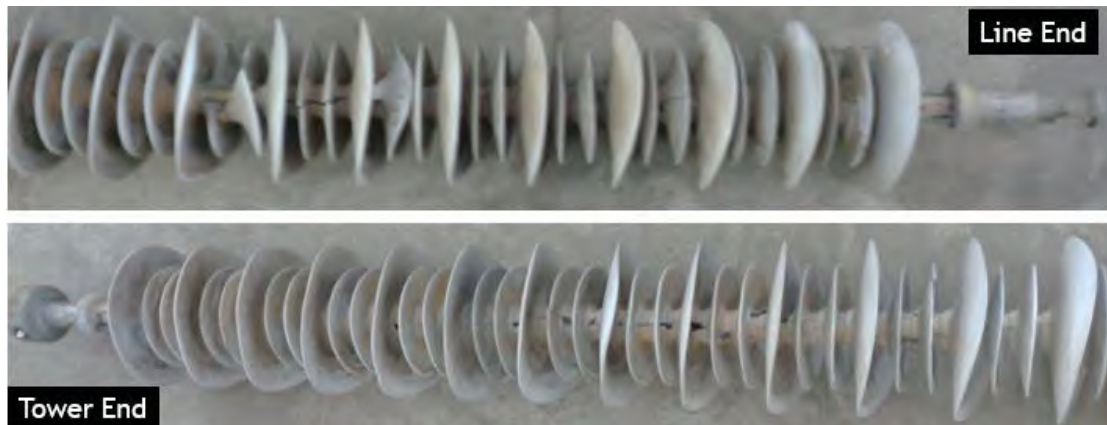


Figure 2.2: As received failed insulator (SRI-1) at the line end and tower end



Figure 2.3: As received failed insulator (SRI-1) at the line end and tower end. Yellow arrow indicate arcing damage to the tower end metallic end fitting

Figure 2.4 shows the central part of the failed insulator (SRI-1), the silicone rubber is broken as several places. The silicone rubber shades are covered with algae. The silicone rubber

housing was removed from the SRI-1 as shown in Figure 2.5. The silicone housing was easily removed from the insulator indicating weak bonding between the composite rod and silicone rubber sheath.

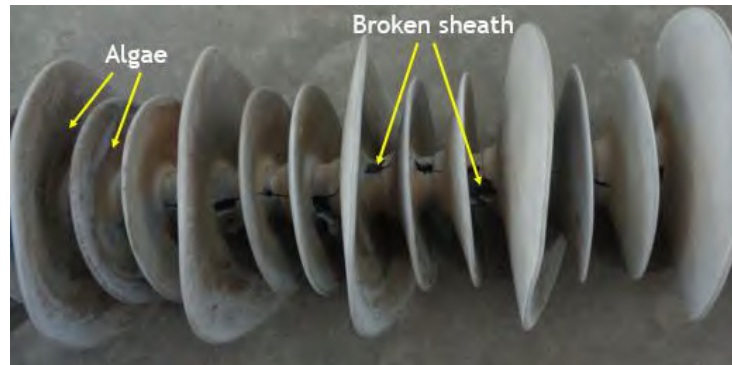


Figure 2.4: Central part of the insulator showing broken silicone rubber housing. The silicone rubber shades are covered with algae



Figure 2.5: Failed insulator silicone housing separated from the composite rod

Figure 2.6 shows bare composite rod sections after removal of silicone rubber housing. Electrical tracking marks (black lines) are clearly visible on the composite rod surface. The tracking also penetrated deep in the composite rod resulting in wide crack in the composite rod. Figure 2.7 shows the silicone rubber shades, the smooth interface with composite rod is visible in the photograph indicating very weak bonding with the composite rod. The silicone rubber shade was also covered with large amount of algae and dust particles.

Figure 2.8 and 2.9 shows the corona rings at on tower end and line end, respectively. The tower end corona ring shows number of arcing marks and the coupling area attached to insulator is highly damaged. It indicated high temperature damage due to arcing. The corona ring at the line end showed relatively few arcing marks compared to the tower end corona ring.

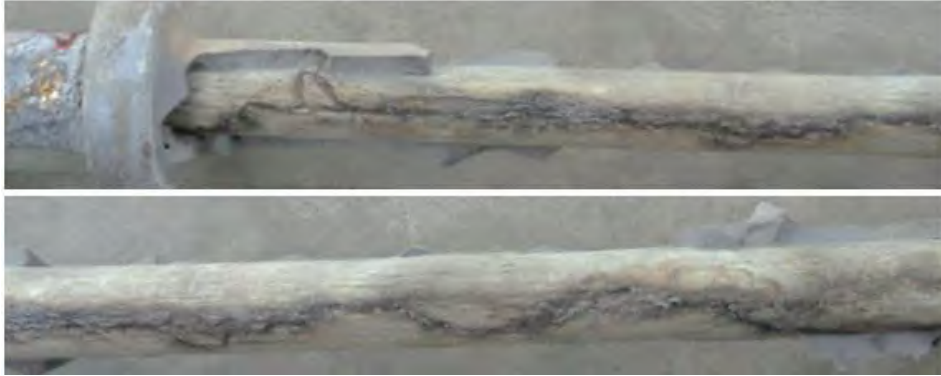


Figure 2.6: Failed insulator silicone housing separated from the composite rod

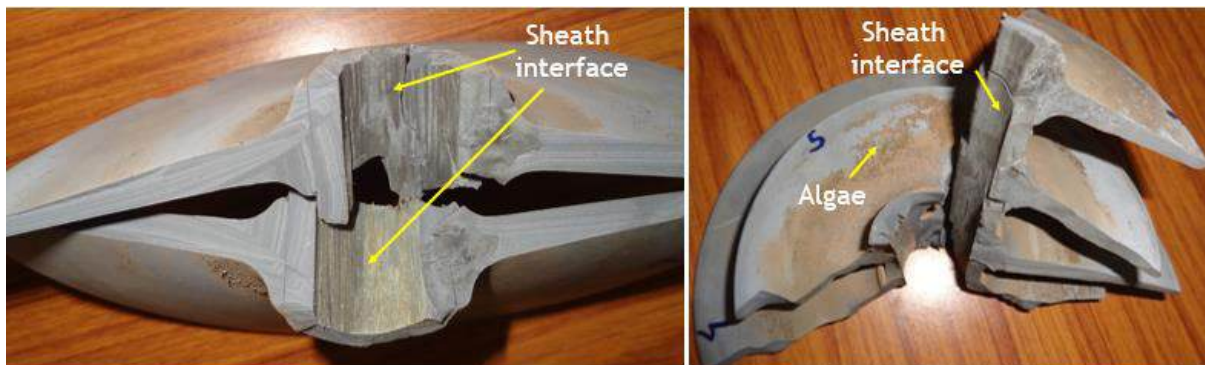


Figure 2.7: Failed insulator (SRI-1) silicone rubber housing removed from the insulator. The interface with composite rod is smooth

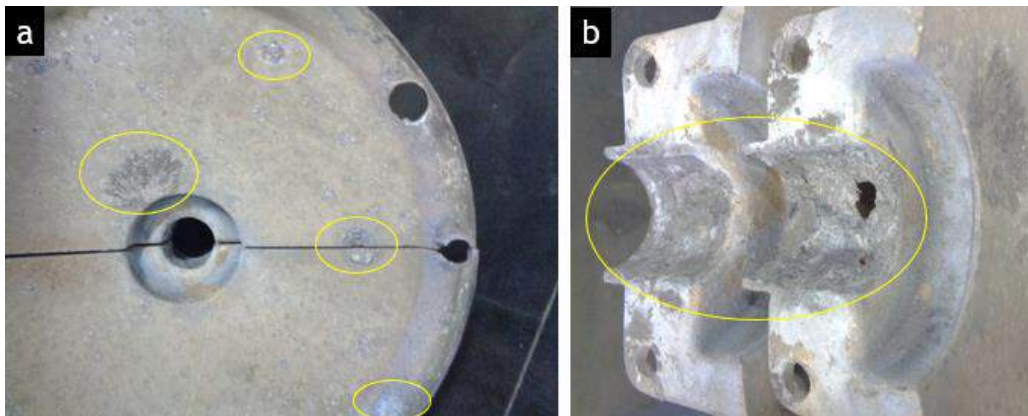


Figure 2.8: Corona ring on tower end showing arcing marks (metal is damaged) - a) corona ring surface and b) joint area with insulator is damaged due to arcing related melting (arcing marks are indicated in yellow)

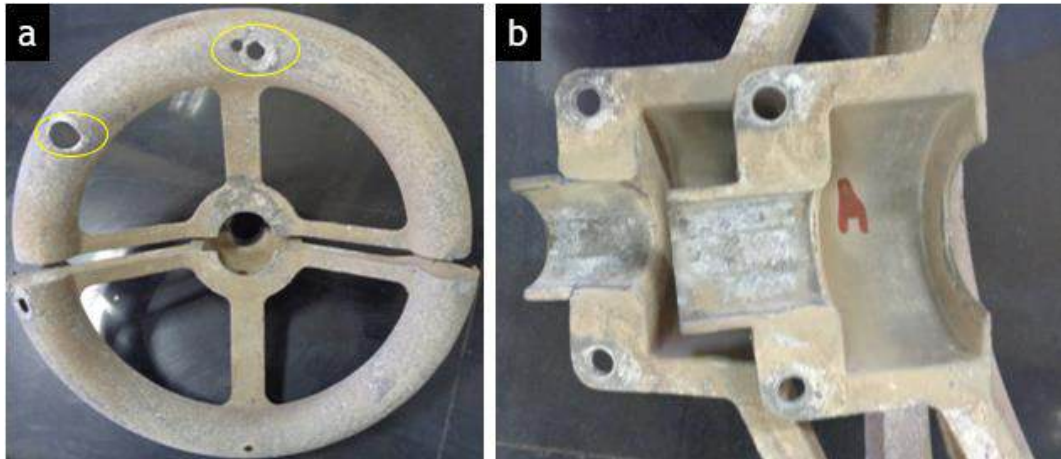


Figure 2.9: Corona ring on line end showing arcing marks (metal is damaged) - a) corona ring surface and b) joint area with insulator is damaged due to arcing related melting (arcing marks are indicated in yellow)

#### Summary of visual observations of failed insulator - SRI-1:

- Silicone rubber housing was cracked on entire length of insulator
- The silicone housing was easily removed from the composite rod indicating weak interface with composite rod
- Silicone rubber seal at the tri-junction on both ends was open
- Silicone rubber shades were covered with algae and dust
- Entire composite rod showed electrical tracking marks
- Corona rings at both ends on insulator showed indications of arcing damage
- Tower end fitting also showed arcing damage

#### 2.3 Visual Observations of Failed Insulator - SRI-2 (Sample 5)

As received failed insulator is shown in Figure 2.10. Similar to SRI-1 for entire length of insulator the silicone rubber housing showed cracks and showed weak interface with composite rod. Tower end corona ring of insulator was not received and line end corona ring was broken. The broken corona ring did not show arcing damage. Figure 2.11 shows both ends of failed SRI-2, at the line end the silicone rubber sheath is broken. On tower end the silicone sheath was undamaged. Arcing related damage was not visible on both ends.



Figure 2.10: As received failed insulator (SRI-1) at the line end and tower end



Figure 2.11: Both end of insulator the silicone shades are broken, silicone rubber seal at both ends are not directly affected

Figure 2.12 shows the silicone rubber housing, punctures were visible on the silicone rubber sheath. The silicone rubber shades and sheath was covered with algae in dust. Figure 2.13 shows punctures in different sections of insulator. Several punctures were found on line end as well as tower end of insulator. The punctures on tower end indicate enhanced electric field on both ends of insulator.

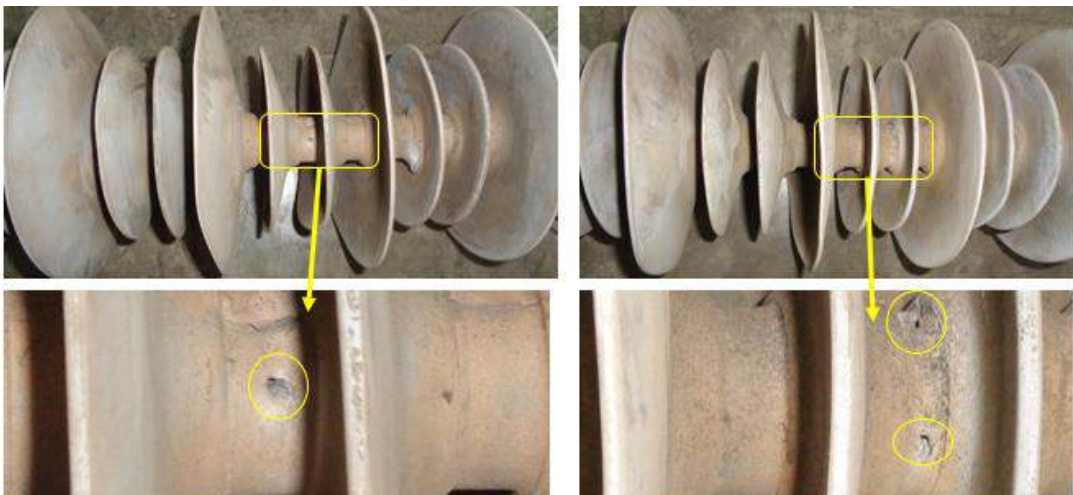


Figure 2.12: Silicone rubber housing of SRI-1 showed several punctures, bottom picture are enlarged section of highlighted area of top pictures



Figure 2.13: Punctures observed in different sections of SRI-2 insulator

Figure 2.14 shows silicone rubber housing removed from the composite rod. The housing was easily separated from the composite rod indicating weak interface with the composite rod. The composite rod under the housing showed tracking marks on entire length of insulator.



Figure 2.14: Silicone rubber housing removed from failed SRI-2



Figure 2.15: Tracking marks were found on entire length of composite rod from SRI-2

#### Summary of visual observations of failed insulator - SRI-2:

- Silicone rubber housing showed cracks and punctures on entire length of insulator
- The silicone housing was easily removed from the composite rod indicating weak interface with composite rod
- Silicone rubber shades and sheath was covered with algae and dust

- Entire composite rod showed tracking marks
- Arcing related damage on insulator end fittings was not observed

#### 2.4 Visual Observations of Failed Insulator - SRI-3 (Sample B)

As received working insulator removed from same tower is shown in Figure 2.16. The working insulator did not show any damage. Figure 2.17 shows close view of silicone rubber housing, the housing is covered with algae. Figure 2.18 shows the enlarged view of silicone rubber sheath from different sections of SRI-3. Apart from algae and dust covering the sheath no visible damage or degradation is visible.



Figure 2.16: As received working insulator (SRI-3) received for analysis



Figure 2.17: Most of the silicone rubber housing was covered with algae



Figure 2.18: Silicone rubber sheath mostly covered with dust and algae but no punctures

Figure 2.19 shows the silicone rubber seal at the tri-junction on both ends. No damage or degradation visible in the silicone rubber seal. To evaluate the interface between silicone rubber and composite rod, stripe test was conducted. Silicone rubber in axial and circumferential direction was cut and pulled out. Figure 2.20 shows the rough surface remaining after the pull out that the interface indicating good interfacial bonding between silicone rubber and composite rod.

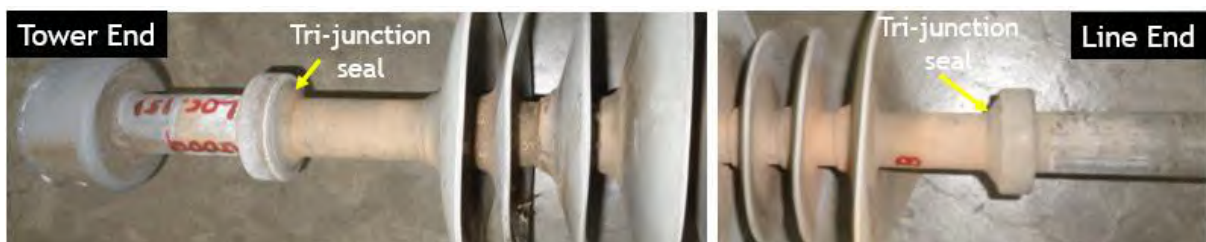


Figure 2.19: End fitting with tri-junction seal of SRI-3



Figure 2.20: Stripe test on SRI-3, the interface was found good

Figure 2.21 shows the corona ring from SRI-3. The tower end corona ring surface is covered with algae. Line end corona ring is relatively clean on the outer surface. The corona ring covered with dirt/algae (insulating material) may not function properly to reduce the electric field on the insulator.

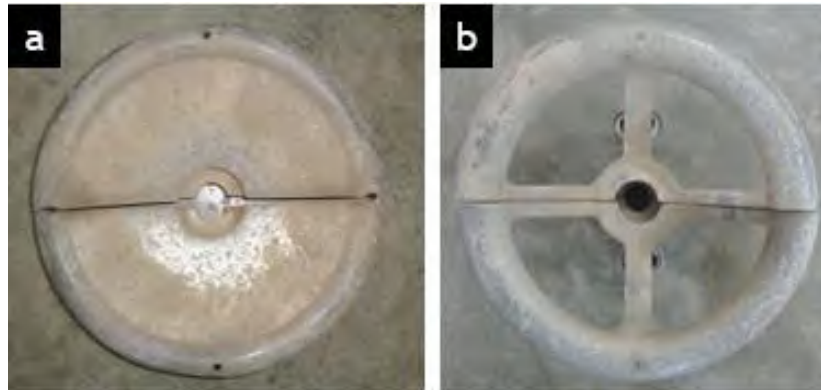


Figure 2.21: Corona rings: a) tower end and b) line end

#### Summary of visual observations of working insulator - SRI-3:

- Working insulator did not show any indication of damage or degradation
- The insulator silicone rubber housing was covered with algae and dust on most of the insulator
- No visible cracks or puncture observed in the silicone rubber sheath
- Silicone rubber seal at the tri-junction was found intact
- interface between composite rod and silicone rubber found good
- Corona ring surface on the was covered with algae, it may not reduce electrical stresses as per design due to the algae layer

#### 2.5 Visual Observations of Working Insulator - SRI-4 (Sample 2)

As received working insulator removed from same tower is shown in Figure 2.22. The working insulator received with one corona ring attached to it. Figure 2.23 shows close view of silicone rubber housing, the housing is covered with algae and dust. Figure 2.24 shows the insulator section near metallic end fittings at both ends. On the line end side the silicone rubber sheath near tri-junction shows a large crack.



Figure 2.22: As received working insulator (SRI-4) received for analysis



Figure 2.23: As received working insulator (SRI-4) received for analysis

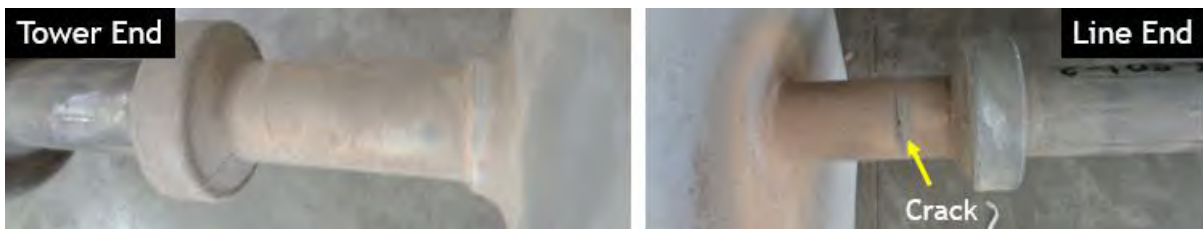


Figure 2.24: Silicone rubber seal at tri-junction with metallic end fittings

Close observations of silicone rubber sheath of SRI-4 showed several punctures as shown in Figure 2.25. The punctures were observed up to 90 cm from the line end of insulator. The tower end section did not show any punctures. To closely observe the punctures, the silicone rubber shades from the insulator section was removed. The puncture in different sections of the insulator is shown in Figure 2.26.

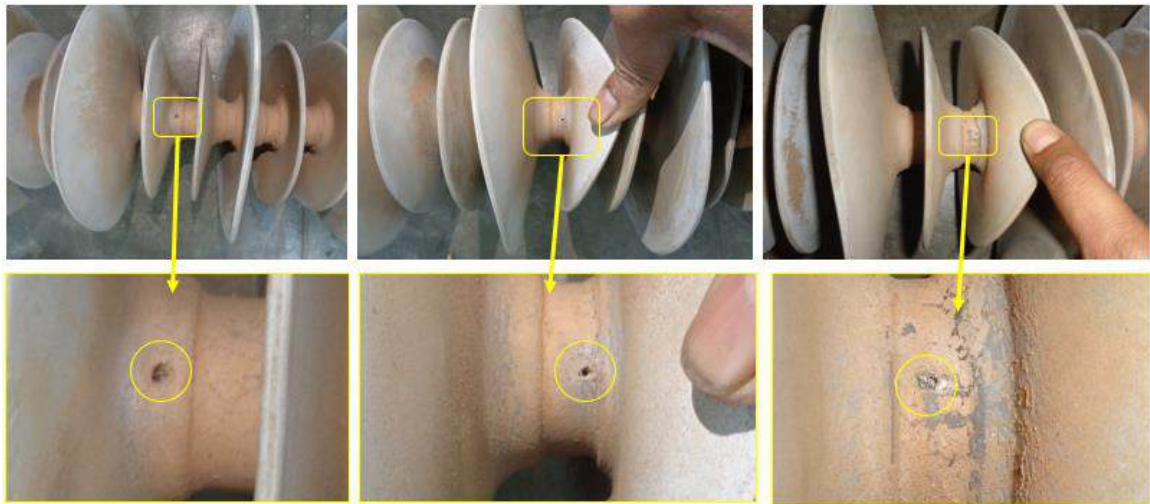


Figure 2.25: Silicone rubber seal at tri-junction with metallic end fittings

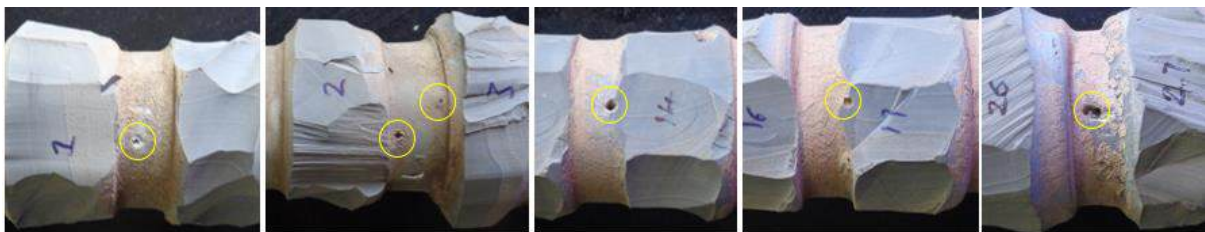


Figure 2.26: Silicone rubber seal at tri-junction with metallic end fittings

To analyse the effect of cracks and punctures in silicone rubber sheath the sheath was cut and removed. Figure 2.27 shows the crack and underneath the degraded composite rod is visible in Figure 2.27 b & c. At the exact back side the composite rod was intact, indicating imitation of composite rod degradation due to penetration of water through the crack.

Silicone rubber from seal at the tri-junction was removed for visual analysis as shown in Figure 2.28. The area under the seal did not show any indication of water/moisture entry.



Figure 2.27: a) Crack near the tri-junction, b) cut in silicone rubber, c) degraded composite rod visible and d) back side of same section the composite rod was intact

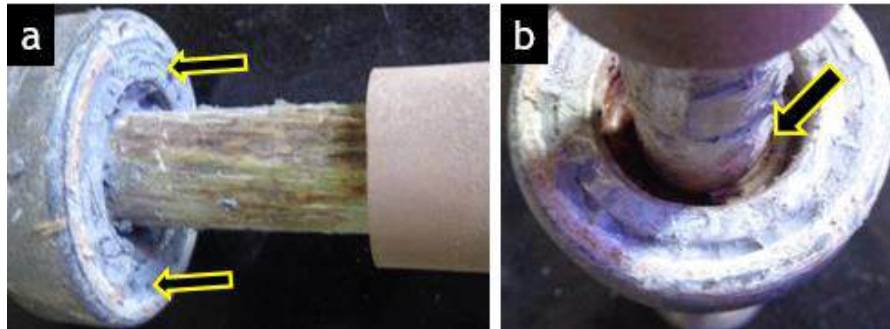


Figure 2.28: a) Area under the seal at tri-junction and b) area inside the tri-junction

Silicone rubber sheath above the puncture was removed, refer Figure 2.29. The silicone rubber or the composite rod under the puncture did not show major degradation. Another puncture area, shown in Figure 2.30 showed degraded composite rod underneath. The last puncture was approximately 90 cm away from the tri-junction, near shade number 26 as shown in Figure 2.31. Composite rod under the puncture was degraded and exact back side of the composite rod was intact with good adhesion. Whenever there was degradation of composite rod, the area silicone rubber sheath was easily removed showing weak interface. Otherwise the interface was found strong.

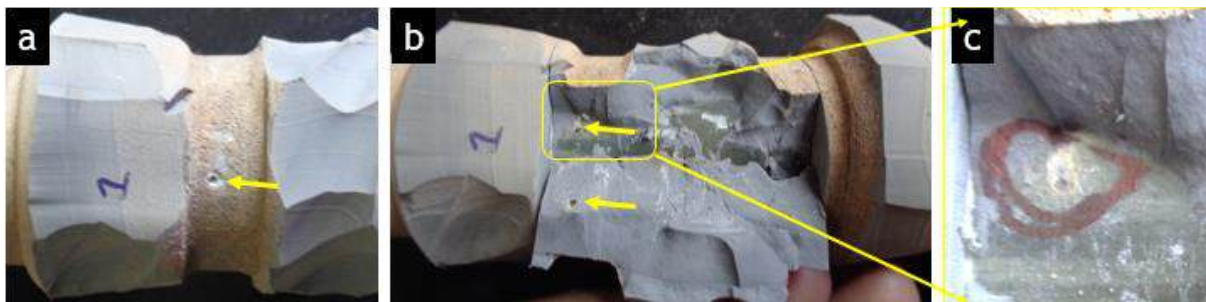


Figure 2.29: a) puncture near shade-1, b) interface area under the puncture and c) enlarged area under the puncture, just beginning of degradation of composite rod

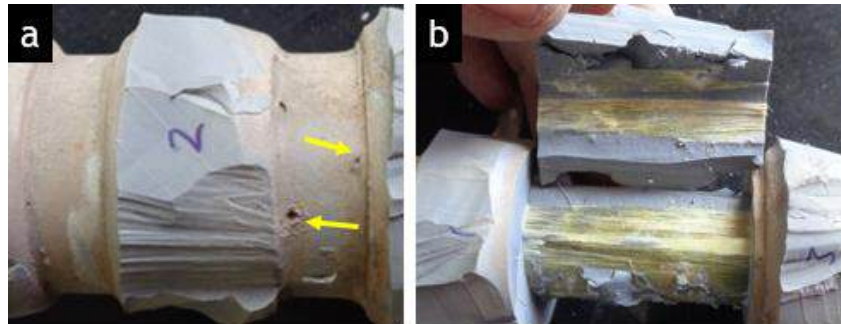


Figure 2.30: a) Two puncture visible near shade number 2 and b) interfacial area under the puncture is degraded

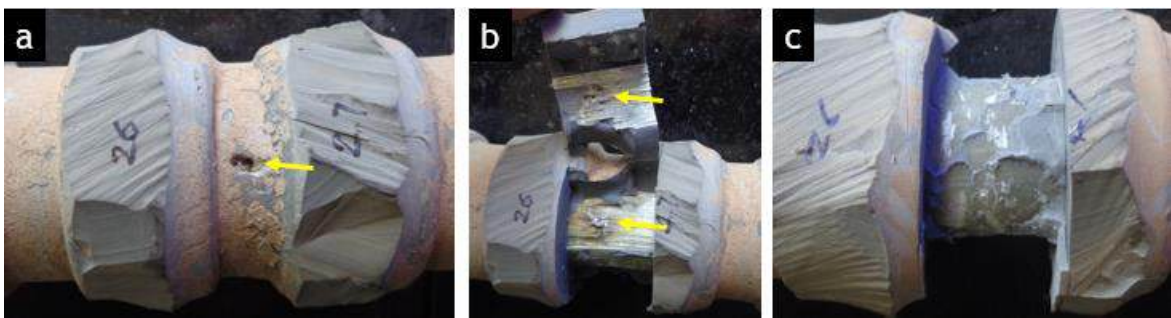


Figure 2.31: a) A puncture visible near shade number 26, b) interfacial area under the puncture is degraded and c) back side of the rod was found intact

#### Summary of visual observations of working insulator - SRI-4:

- Silicone rubber housing of insulator was covered with algae and dust on most of the insulator length
- Several puncture in the silicone rubber sheath were observed up to a length of 90 cm measured from tri-junction at line end
- Silicone rubber seal at the tri-junction was found intact and no indication of water/moisture entry was found
- Silicone rubber sheath near the tri-junction at line end showed cracks
- Area under a punctures showed degradation of composite rod, it was localised degradation as the degradation was in the immediate vicinity and not spread to the circumferential area
- The tower end section did not show any puncture

### 2.6 Visual Observations of Working Insulator - SRI-5 (Sample 3)

As received working insulator, SRI-5, removed from same tower is shown in Figure 2.32. The working insulator received with both corona rings attached to it. Figure 2.33 shows close view of silicone rubber housing, the housing is covered with algae and dust.



Figure 2.32: As received working insulator (SRI-5) received for analysis

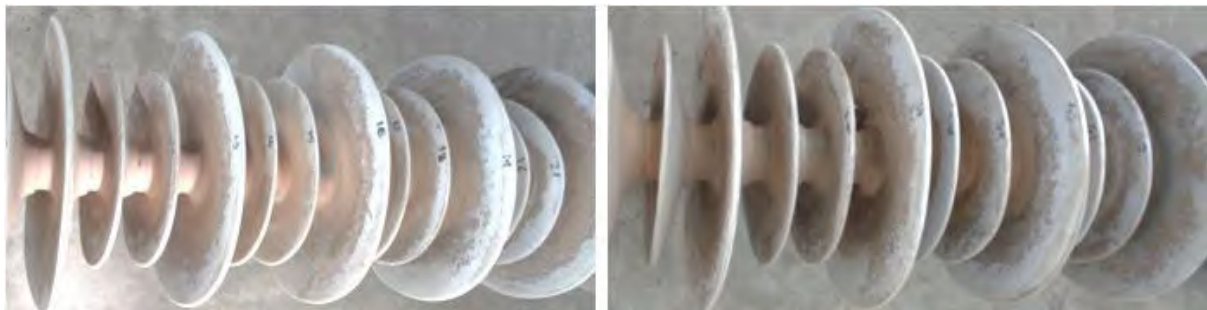


Figure 2.33: As received working insulator (SRI-5) received for analysis

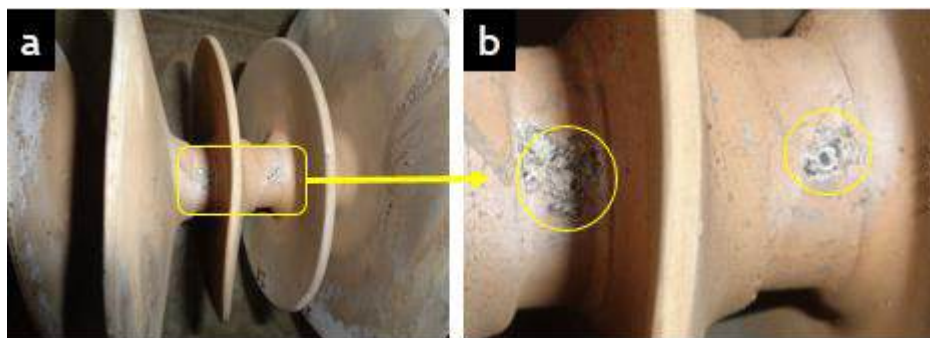


Figure 2.33: Silicone rubber sheath was puncture between the shade numbers 25 to 27

Figure 2.34 shows the insulator section near metallic end fittings at both ends. At both ends no visible damage or crack observed in silicone rubber sheath. However, the sheath is covered with large amount of dust. To evaluate the silicone rubber sealing at line end on insulator, the

silicone rubber from the area was removed as shown in Figure 2.35. No indication of degradation and water penetration observed at the tri-junction.

Two punctures were observed in silicone rubber sheath between shade numbers 25 to 27. The sheath from punctured area was removed to evaluate the state of composite rod. The degradation was found localized near the punctured area as shown in Figure 2.36. Adhesion between silicone rubber and composite rod in surround area of puncture found good.



Figure 2.34: Silicone rubber seal at tri-junction with metallic end fittings

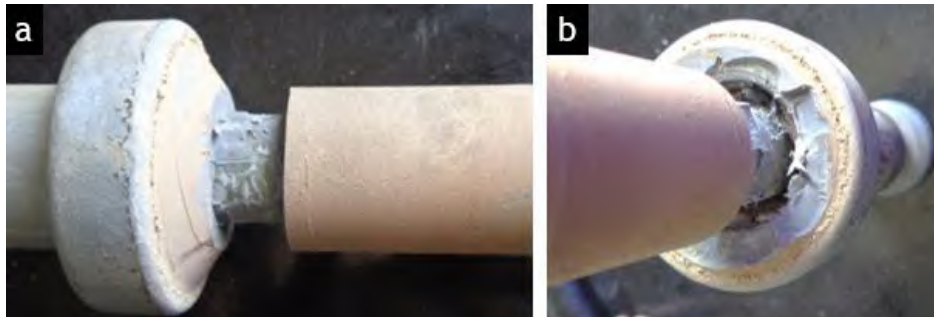


Figure 2.35: Silicone rubber seal at the tri-junction on line end



Figure 2.36: a) Punctured sheath, b) composite rod under first puncture and c) composite rod under the second puncture

Corona rings from SRI-5 are shown in Figure 2.37 from both end of insulator. The tower end corona ring is covered with algae and dust particles.

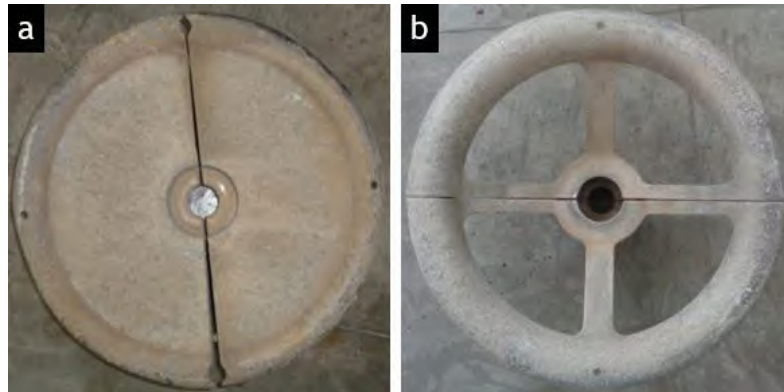


Figure 2.37: Corona rings from SRI-5: a) tower end and b) line end

#### Summary of visual observations of working insulator - SRI-5:

- Silicone rubber housing of SRI-5 was covered with algae and dust on most of the insulator length
- Two punctures were observed in the silicone rubber sheath approximately 85 cm from tri-junction at line end
- Silicone rubber seal at the tri-junction was found intact and no indication of water/moisture entry was found
- Area under a punctures showed localised degradation of composite rod
- The tower end section did not show any puncture

#### 2.7 Visual Observations of Working Insulator - SRI-6 (Sample 4)

As received working insulator, SRI-6, removed from same tower is shown in Figure 2.38. The working insulator received with both corona rings attached to it. Figure 2.33 shows close view of silicone rubber housing, the housing is covered with algae and dust.



Figure 2.38: As received working insulator (SRI-6) received for analysis



Figure 2.39: As received working insulator (SRI-5) received for analysis

The silicone rubber sheath showed number of punctures up to 90 cm distance from the tri-junction at line end. Some of the punctures in the silicone sheath is shown in Figure 2.40. To analyze punctured sheath, shades from the insulator section was removed as shown in Figure 2.41. The punctures in various section of insulator are visible.

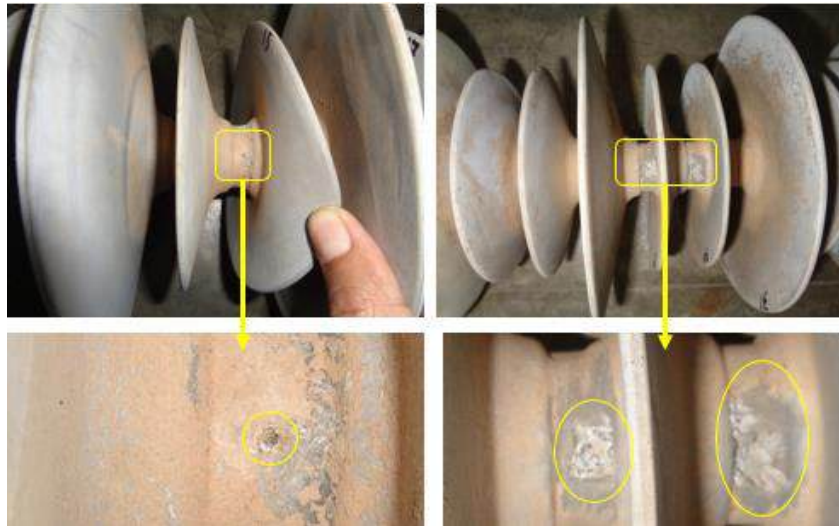


Figure 2.40: Silicone rubber sheath showed punctures, magnified view in the bottom photographs

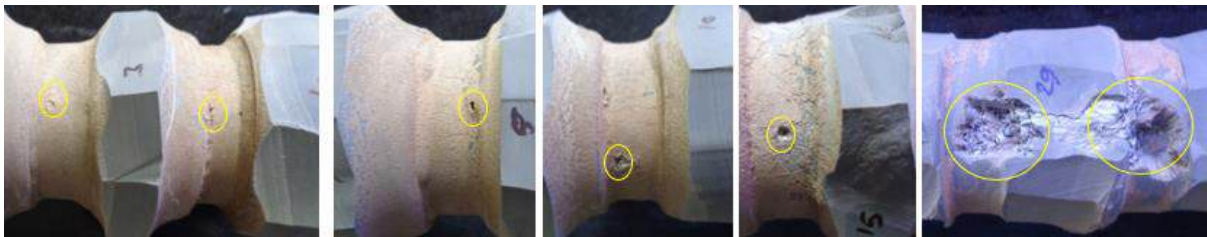


Figure 2.41: Punctures visible in silicone rubber sheath after removal of shades from SRI-6

Figure 2.42 a shows the insulator section near metallic end fitting showing a crack. To evaluate the composite rod under the sheath, the silicone rubber was removed from the section. Near the cracked sheath the composite rod was found degraded, refer Figure 2.42 b. Only small area of the composite rod near the tri-junction was degraded, rest of the composite rod was in good condition, refer Figure 2.42 c. It appears that the composite rod is only degraded covering 20% of circumference and spread in axial direction as confirmed by stripe test, refer Figure 2.43. Two punctures found at approximately 90 cm from tri-junction from line end are shown in Figure 2.44 a. Degradation underneath the puncture was very much localized indicating recent initiation of degradation. Interface in strength by stripe test in surround area was found good.

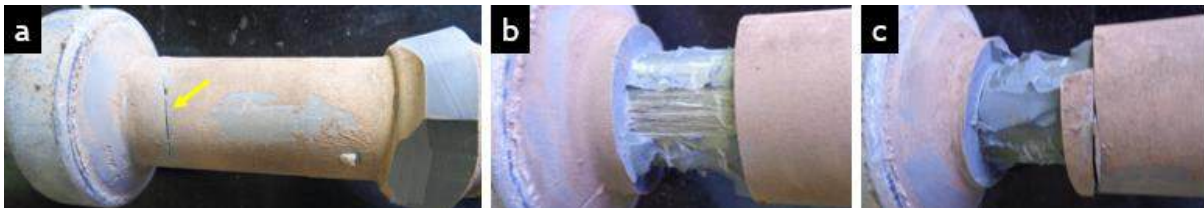


Figure 2.42: a) crack visible near the tri-junction at line end, b) sheath removed, composite rod is degraded and c) rest of the composite rod is intact near the tri-junction

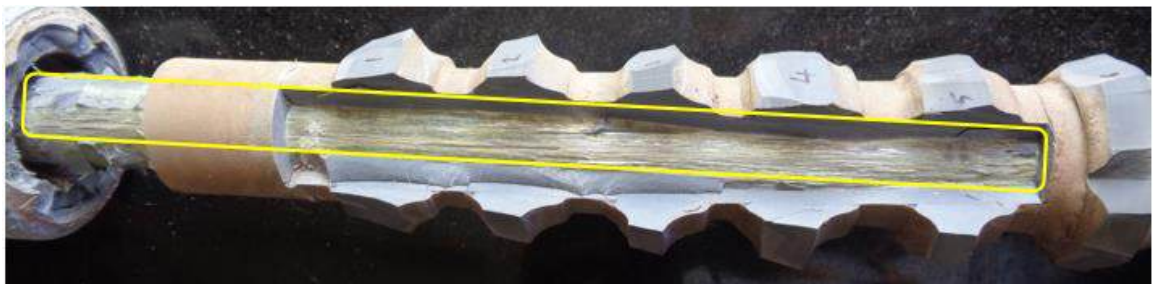


Figure 2.43: Stripe test on puncture sheath in axial direction, composite rod is degraded on one axial direction



Figure 2.44: a) Punctured sheath, b) degraded silicone rubber and c) composite rod degradation found localised (highlighted in yellow border)

**Summary of visual observations of working insulator - SRI-6:**

- Silicone rubber housing of SRI-6 was covered with algae and dust on most of the insulator length
- Several punctures were observed in the silicone rubber sheath up to approximately 90 cm from tri-junction at line end
- Silicone rubber sheath near tri-junction at line end was cracked and composite rod degraded, the degradation was spread in axial direction. Circumferential area was less affected.
- The tower end section did not show any puncture or composite rod degradation

**2.8 Common Observations for Insulators on Tower 151**

For working insulators, removed from service, punctures were found only on the line end of insulators with last puncture at 90 cm from tri-junction. All the three working insulators showed punctures at distance 85 cm to 90 cm (between shade numbers 25 to 30). Punctures observed at this location are larger in size than the other punctures observed on the insulators, refer Figure 2.45. This indicated that enhanced electrical stresses up to 90 cm from tri-junction at line end.

Also, the failed insulator (SRI-2) also showed damage at around 90 cm from line end in the photo shared from site. All this indicated enhanced localized electrical stresses at line end of insulators.

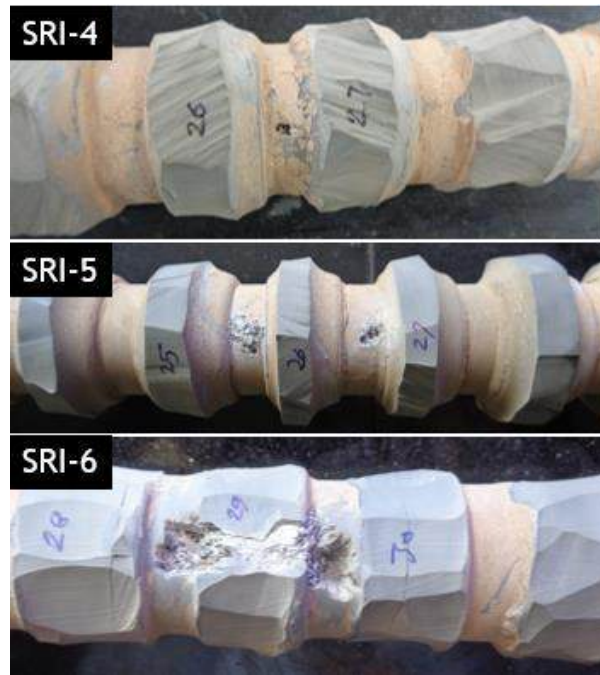


Figure 2.45: Punctures found in three working insulators removed from the tower

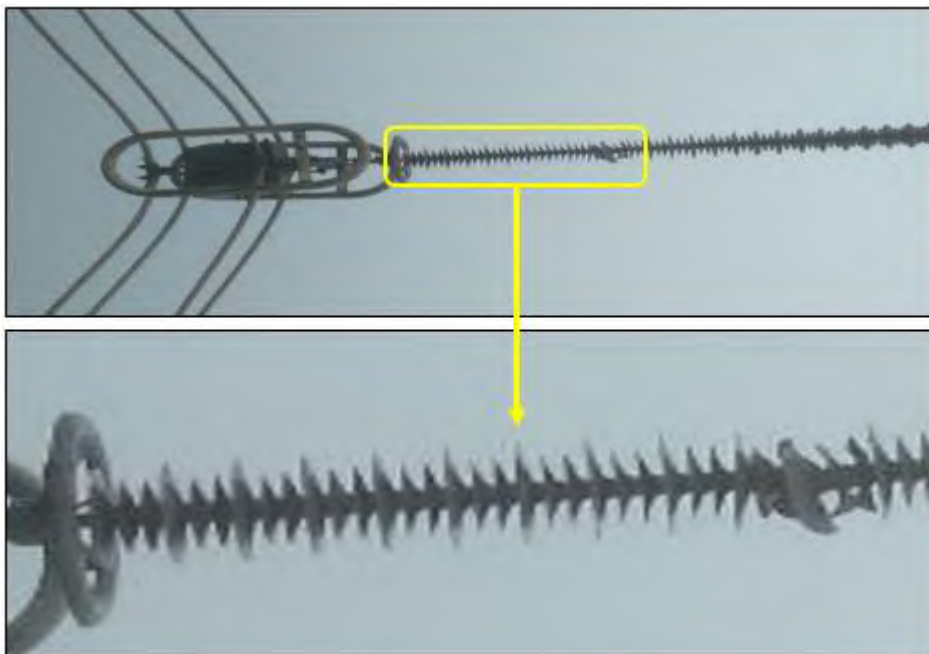


Figure 2.46: Failed insulator photo from site, the major damage appears near shade number 30

### Summary of Common Observations of Insulators from Tower 151:

- Three working insulators removed from tower showed punctures in silicone rubber up to 90 cm from the tri-junction of line end
- One failed insulator and three working insulator showed larger puncture area between 85 cm to 90 cm from tri-junction at line end

### 2.8 Site Visit Observations

The two failed insulators were located on tower 151, the failure took place on the same tower twice. No other tower was affected by the insulator failure. Figure 2.45 shows the tower along with the porcelain suspension and silicone rubber composite tension insulators are visible. The electrical stress control accessories like corona rings at both end and arcing horns were correctly placed on the insulators. Damaged or broken stress control accessories were not found on the tower.

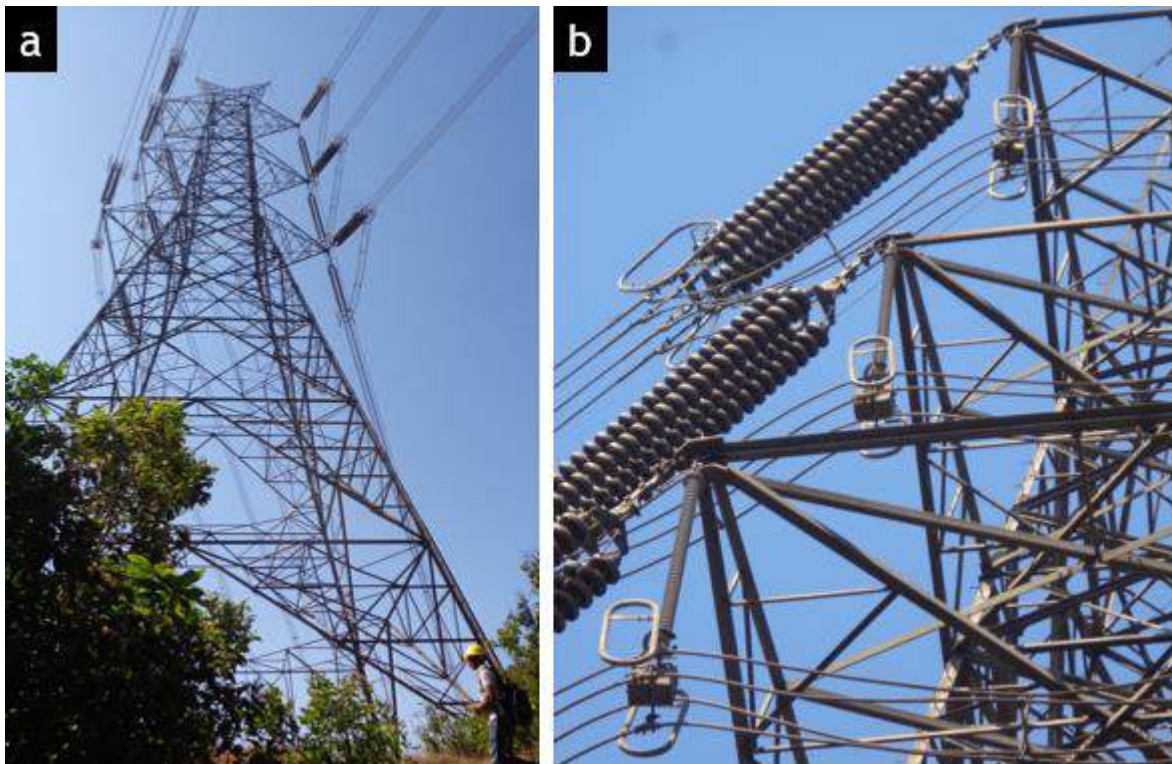


Figure 2.47: a) Tower no. 151 with the insulators and b) The suspension insulator and tension insulator located on the tower

The tower no. 151 is located in a forest area on hill with height approximately 2500 feet and suspension insulators were located at height of 250 feet on the tower. Therefore, the failed insulators were located approximately 2750 feet above sea level. The failed insulator were located at the highest elevation in the transmission line. Corona inception voltage is lower as the tower height increases, resulting in increased probability of corona discharges. The hilly terrain where the towers are located are under monsoon rain continuously for four months. Therefore, all the tower components including the insulators are normally covered with algae.

Tower 151 has four string porcelain tension insulators connecting the conductors on both sides. The conductors are further supported by one composite suspension insulator each for the three phases. Tower 151 is located on a hill and is connected with incoming conductor from Jaigarh end (Tower No. 150) which is located in a valley at much lower height than Tower 151. On the other side, the outgoing conductors toward Karad is connected with tower 152 which is located on similar elevation as that of tower 151. This results in closer proximity of porcelain insulators with the composite insulators on the tower 150 side (Jaigarh end) compared to wider angle on the Karad end of Tower -152. The angle between metallic end fittings of porcelain insulators appears to be lower on Jaigarh end (tower 152 side), as indicated in figure 2.48 and 2.49. This asymmetry may lead to higher electrical stresses on composite insulators located at Jaigarh end of tower 151. The smaller angle between porcelain and composite insulator combined with the tower elevation and algae covered insulators, all leads to increased localized electrical stresses on the insulators. This increases the possibility of degradation and puncture of silicone rubber sheath.

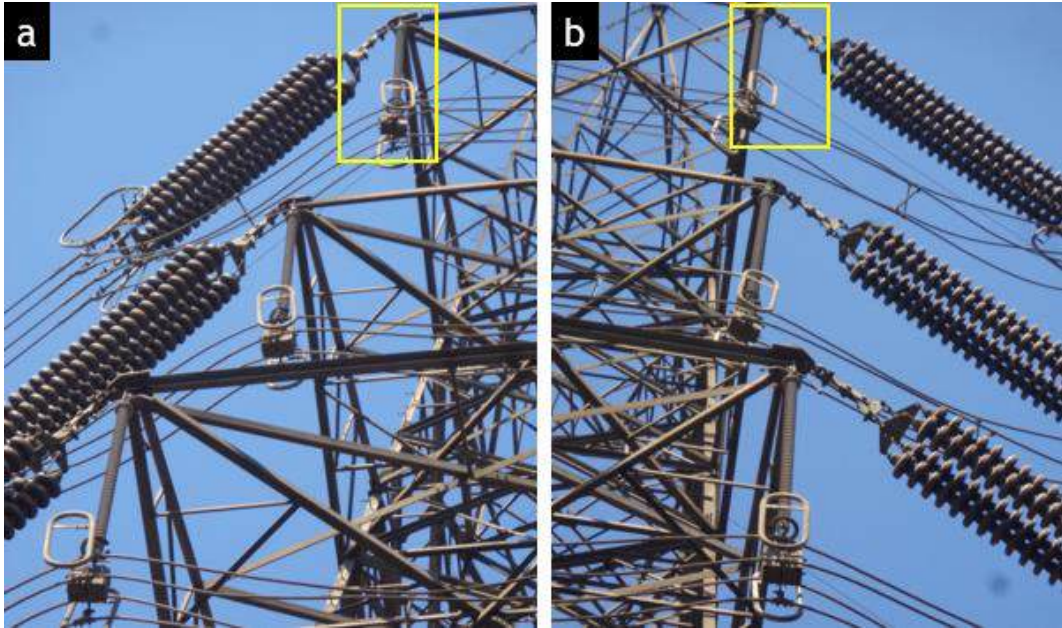


Figure 2.48: Two side of tower 151 showing porcelain insulators connected with conductors on a) tower 150 and b) tower 152 side. The angle between porcelain and composite insulator is different on both sides (highlighted in yellow rectangle)

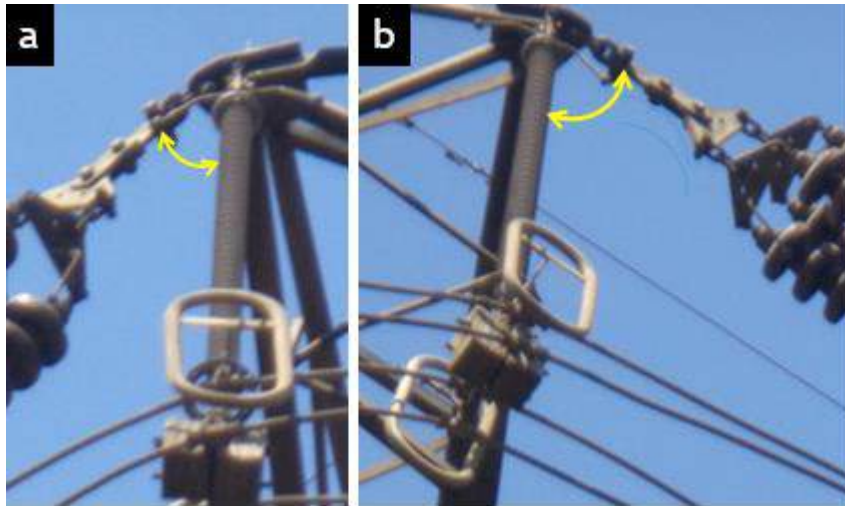


Figure 2.49: Photographs showing angles (indicated by yellow) between porcelain insulator with composite insulator at tower end on a) tower 150 side and b) tower 152 side.

**Summary of visual observations from site:**

- Currently installed insulator found to be correctly installed with proper positioning of corona rings and arcing horns
- The failed insulator was located at highest height on the entire transmission line
- Algae is critical issue and some of the tower structures were found covered with algae
- Due to geometry of the tower, porcelain insulators on one side are in closer proximity than the other side to the composite insulators

**Remarks on Visual Analysis of Insulators**

- Failed insulator-1 (SRI-1) most likely failed because of arcing related damage, arcing evidence found on the tower end corona ring (insulator located on Karad end)
- Failed insulator (SRI-2) was initially punctured and gradually the insulator interface degraded resulting in final failure (insulator located on Jaigarh end)
- All the failed insulators and working insulators were covered with algae and dust layer. The extra layer on the insulators reduces the hydrophobicity thereby increasing probability of leakage current and arcing
- One failed insulator (SRI-2) and three working insulators showed punctured sheath, Punctures in the silicone rubber sheath takes place because of following reasons:
  - Poor interface between silicone rubber sheath and composite rod
  - Excess electrical stresses on the insulator surface
- Three working insulators showed punctures at distance 85 cm to 90 cm (between shade numbers 25 to 30). Punctures observed at this location are larger in size than the other punctures observed
- Failed insulator photo shared from site also showed initial damage at shade number 30

### 3.0 OPTICAL MICROSCOPIC OBSERVATIONS

Samples of the composite insulator were observed under stereo optical microscope to analyse composite rod surfaces. For stereo microscopic observations, the insulator composite rod was cut by precision saw using diamond cutting blade. The circular samples with approximately 10 mm height was observed under the microscope.

Figure 3.1 shows stereo microscopic images with different magnification for composite rod for failed insulator. The images does not show micro-crack in the composite rod indicating good quality of the rod. The interfacial area of the composite rod where tracking was observed in shown in Figure 3.2. Interfacial degradation and tracking marks are visible on the composite rod surface.

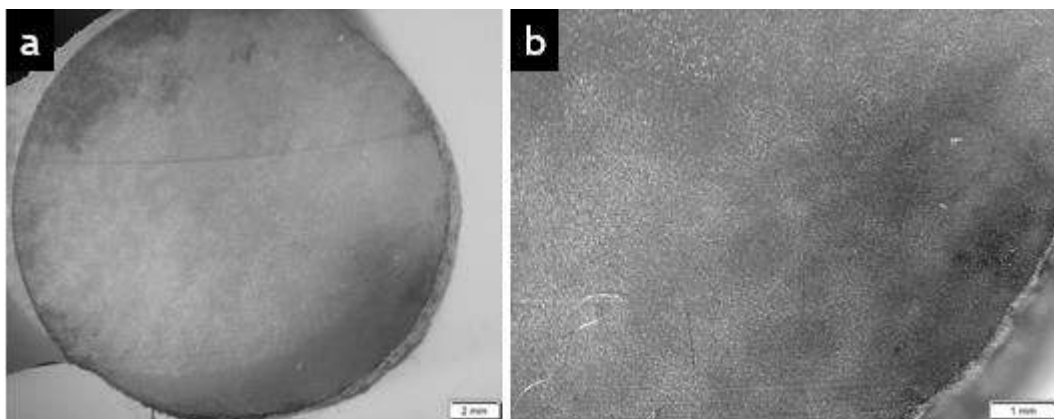


Figure 3.1: Stereo microscope images of composite rod section of failed insulator (SRI-1) with different magnification

Figure 3.3 shows the stereo microscope images from working insulator (SRI-3), few micro-cracks in centre of composite rod was observed. The micro-cracks are not near the interfacial surface where it can cause puncture due to PD. Figure 3.4 shows microscopic images of SRI-4, for a section cut near the puncture. No microscopic crack is observed in the composite rod indicating that composite rod has not played a role in puncture of the sheath.

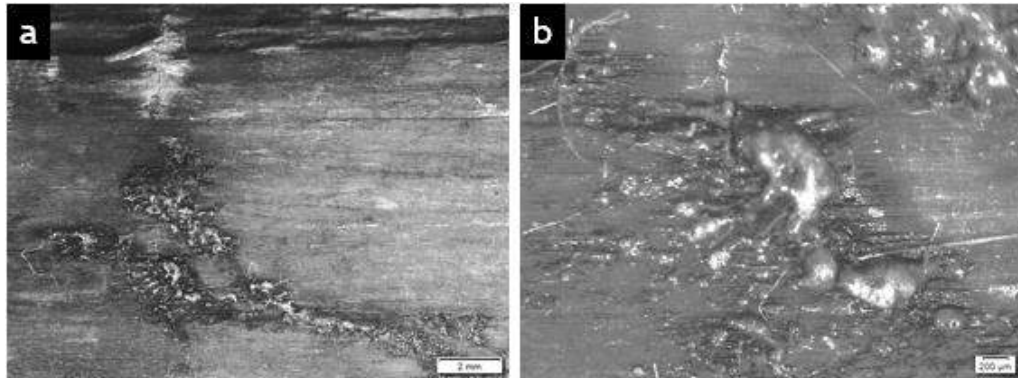


Figure 3.2: Stereo microscope images of interfacial area of composite rod from failed insulator (SRI-1) with different magnification

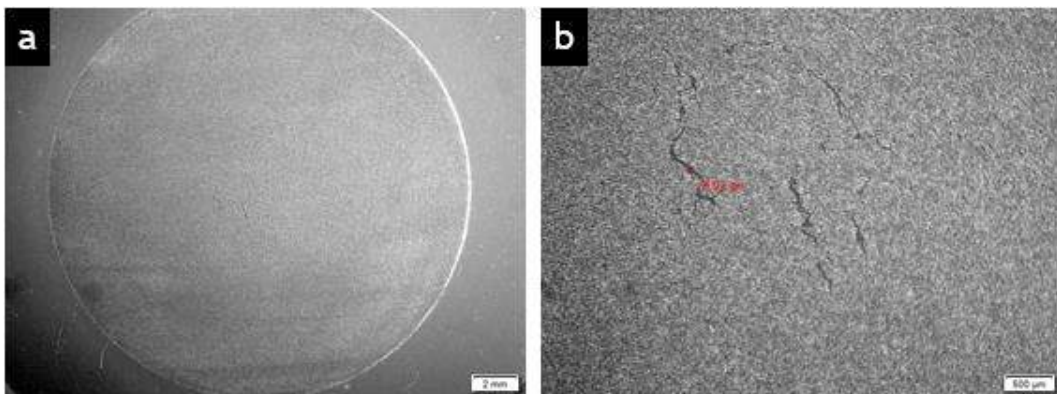


Figure 3.3: Stereo microscope images of composite rod section of working insulator (SRI-3) with different magnification

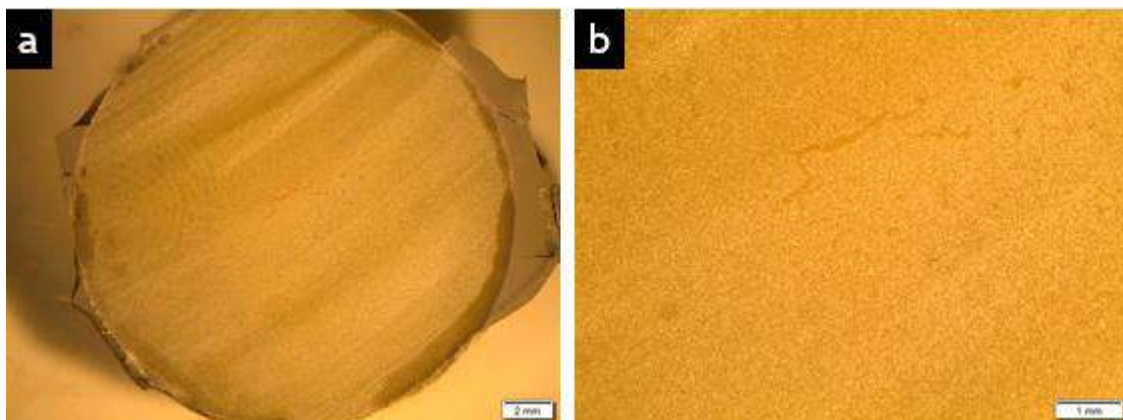


Figure 3.4: Stereo microscope images of composite rod section removed where a puncture on silicone rubber sheath was found for working insulator (SRI-4). Images with different magnifications

**Summary of Optical Microscopy Observations:**

- Composite rod sections from failed as well as working insulator showed few microscopic cracks
- Composite rod section from punctured area also did not show cracks in composite rod indicating the composite rod quality has not played a role in insulator failure

**Remarks on Visual Microscopic Analysis**

- Composite rod of insulator found in good condition, no indication of micro-cracks found where the PD discharge can initiate the degradation process.

## 4.0 PHYSICAL AND CHEMICAL TEST RESULTS

### 4.1 Energy Dispersive Spectroscopy (EDS)

EDS is a chemical characterization technique and gives elemental composition of a material under investigation. EDS was used to analyze type of dust/pollutant particles present on the silicone rubber shades. Figure 4.1a shows a photograph of working insulator covered with dirt layer, the yellow highlighted section was used for EDS analysis. Figure 4.1b shows SEM image of area from which EDS spectra in Figure 4.1c was obtained.

Table 4.1 shows the SEM-EDS result of the silicone shade sample. Among the compounds found Carbon (C), Silicone (Si), Oxygen (O) and Aluminium (Al) are expected to found as they are all part of the silicone rubber compound. Other elements found in minor quantities such as Ca, K, and Mg can be part of fillers used in silicone compound. Carbon compound indicate that the layer on the silicone rubber is made up of organic material, which can be algae.

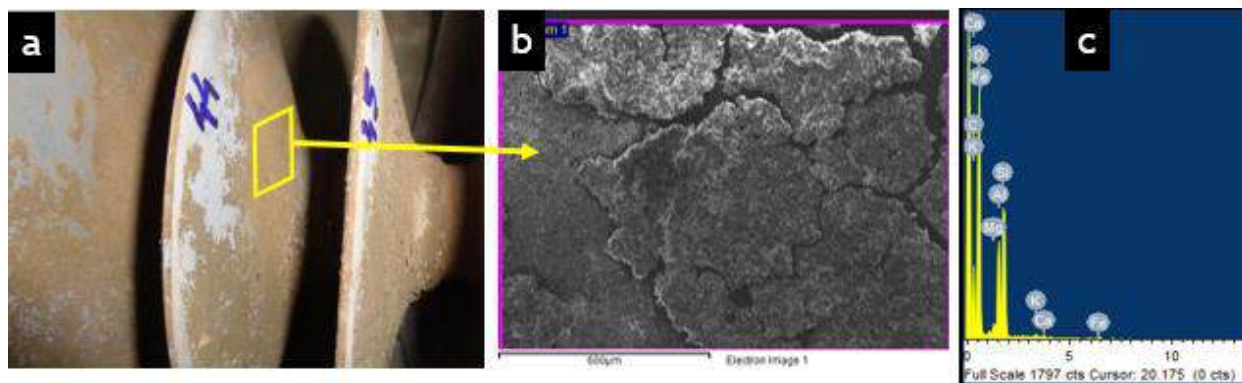


Figure 4.1 a) Photograph showing working insulator shade covered with dirt (Yellow Square) used for EDS analysis, b) high magnification SEM image of sample and c) EDS spectra

Figure 4.2a shows the silicone rubber shade without the dirt layer. SEM image and EDS spectra for the grey colored area is shown in Figure 4.2b and 4.2c, respectively. SEM-EDS result from the grey area of silicone rubber shade is shown in Table 4.2. Similar result as in Table 4.1 is observed but with reduced carbon amount. This indicate that the extra carbon percentage in dirt layer is from organic matter.

No other pollutant material found on the insulator silicone rubber shades.

Table 4.1: SEM-EDS result table showing elements present on the silicone rubber shade covered with dirt layer as indicated in Figure 4.1a

Element	Weight%	Atomic%	Compd%	Formula
C K	22.60	29.02	82.82	CO <sub>2</sub>
Mg K	0.53	0.34	0.88	MgO
Al K	3.03	1.73	5.73	Al <sub>2</sub> O <sub>3</sub>
Si K	4.64	2.55	9.92	SiO <sub>2</sub>
K K	0.11	0.04	0.13	K <sub>2</sub> O
Ca K	0.13	0.05	0.18	CaO
Fe K	0.26	0.07	0.34	FeO
O	68.70	66.20		
Total	100.00			

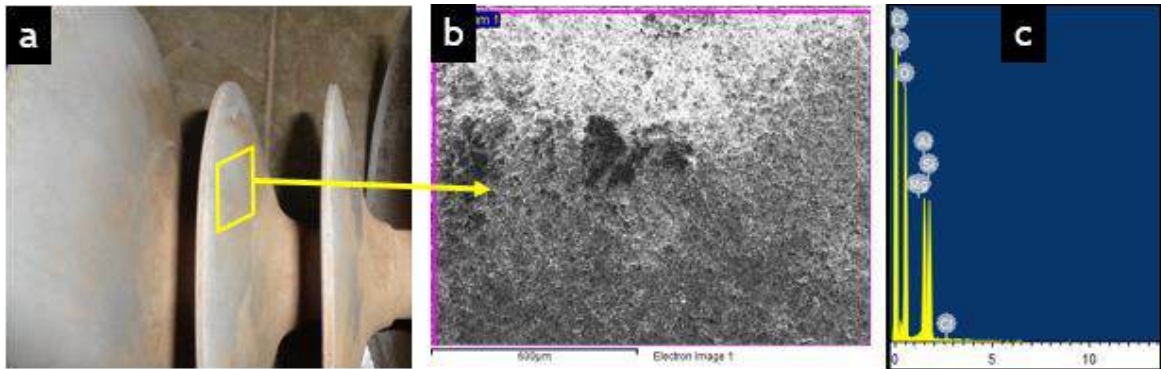


Figure 4.2 a) Photograph showing failed insulator with location of silicone rubber piece taken out for EDS analysis, b) high magnification SEM image of sample and c) EDS spectra

Table 4.2: SEM-EDS result table showing elements present on the silicone rubber shade without the dirt layer as indicated in Figure 4.2a

Element	Weight%	Atomic%	Compd%	Formula
C K	15.78	21.80	57.81	CO <sub>2</sub>
Mg K	0.35	0.24	0.58	MgO
Al K	9.79	6.02	18.49	Al <sub>2</sub> O <sub>3</sub>
Si K	10.70	6.32	22.89	SiO <sub>2</sub>
Cl K	0.23	0.11	0.00	
O	63.16	65.51		
Total	100.00			

## Summary of EDS Results

- The dirt layer found on the silicone rubber shades was found as organic matter and most likely algae
- External pollutants not found on the insulator surface

## 4.2 Thermogravimetric Analysis (TGA)

TGA is thermal analysis method in which a material is heated to high temperature with uniform heating rate while continuously monitoring the weight of material. Any change in mass of material is related to degradation or thermal stability of the material. In case of silicone rubber, TGA was used for estimation of silicone, filler and volatile matter content in the silicone rubber housing of insulator. Figure 4.3 shows TGA curve for sample from silicone rubber sample from failed insulator.

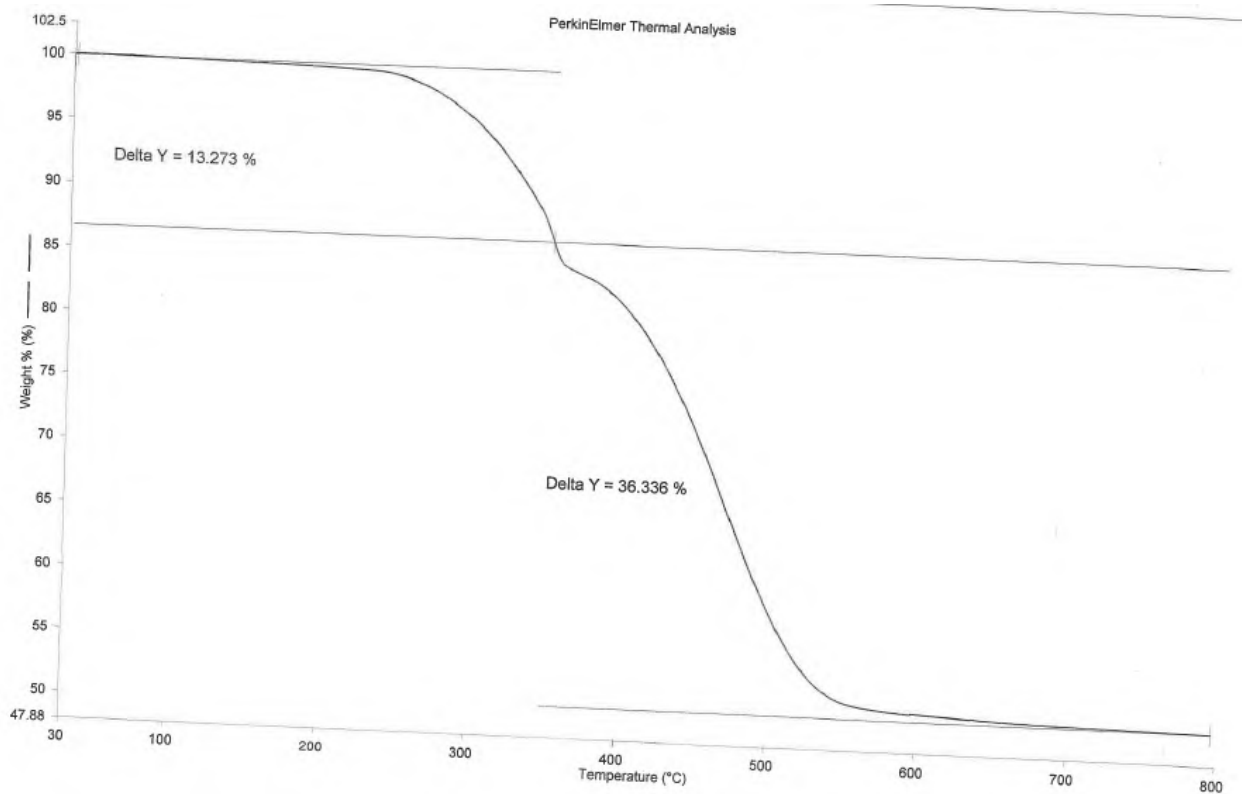


Figure 4.3: TGA graph of silicone rubber sample from failed insulator line end

The TGA curves shows three distinct zones:

- Zone-1: room temperature to 360 °C - it shows plastisizers/softners content in silicone rubber
- Zone-2: 360 °C to 550 °C - it shows silicone content
- Zone-3: above 550 °C - represents filler content in sample

Table 4.3 shows the TGA result for silicone content. Minimum silicone content of 30% is recommended in silicone rubber compounds for insulators. Below values of silicone contents conforms to the industry standard for silicone content.

Table-4.3: Composition of silicone rubber analyzed by TGA

Sr. No.	Material	Silicone shade from failed insulator
1	Plastisizers/softners	13.2 %
2	Silicone	36.3 %
3	Filler	50.5 %

#### Summary of TGA Result:

- TGA showed that the silicone content of 36.3% found in the silicone rubber form the failed insulator

#### 4.3 Fourier Transform Infrared Spectroscopy (FTIR)

FTIR was utilized to identify the type of molecular units present in material. FTIR spectra of undamaged silicone from failed insulator is shown in Figure 4.4. FTIR identified the material as Poly(dimethyl siloxane) which is a standard silicone base used in silicone rubber compounds for insulators.

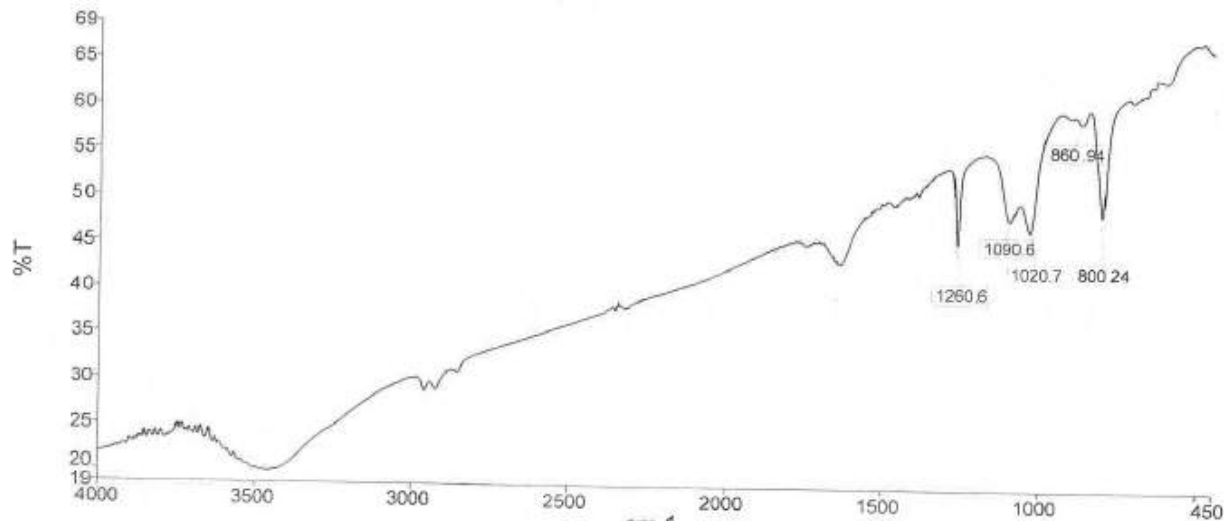


Figure 4.4: FTIR spectra of silicone rubber from failed insulator

**Comment on FTIR Results:**

- FTIR showed presence of poly(dimethyl siloxane) in silicone rubber compound from failed insulator. No abnormality found in silicone rubber compound.

**4.4 Arc Resistance Test**

Arc resistance of silicone rubber was measured as per ASTM D495:14, it tests the ability of insulating material to resist the arc. Arc resistance is measured in seconds, increased duration in arc resistance test shows better ability of material to withstand the arc. Results of arc resistance are shown in Table 4.5. For silicone compound arc resistance value should be more than 200 second. Silicone sample (black) from the failed insulator (SRI-1) shows arc resistance for 259 seconds.

Table 4.5: Arc resistance test results of silicone rubber

	Black Shade (Line end)	
	Cent.	Min.
<b>Arc resistance in seconds</b>	259	251

**Comment for arc resistance test:**

- Arc resistance of silicone rubber samples from failed insulator was found to be more than the required 200 seconds

**4.5 Comparative Tracking Index**

CTI was measured as per IEC 60112: 2003+A1:2009 for measuring the tracking properties of insulators. Test was performed on silicone rubber samples from line end (black) and tower end (Grey). Both samples showed CTI value more than 600 volts.

**Comment for CTI:**

- CTI was found more than 600 volts for silicone rubber samples of failed insulator which conforms to the requirement

**4.6 Shore Hardness A**

Shore hardness A was measured as per ASTM D-2240:2015. Shore hardness A of silicone rubber was checked if silicone from failed insulator is showing any hardening. Table 4.7 shows the Shore-A hardness of silicone compound from failed insulator. The shore hardness is not much increased.

Table 4.7: Shore-A Hardness of silicone rubber shade

Sample	Failed insulator (SRI-1)
Shore Hardness	78

**Comment for Shore-A Hardness**

- Shore-A hardness does not show any abnormality in silicone rubber compound from failed insulator.

**4.7 Water Diffusion Test**

Water diffusion test was carried out as per IEC 62217: 2012. In water diffusion test, 12 kV voltage is applied to sample of 3 cm height and leakage current is measured. Before applying the voltage the samples are boiled in 0.1% NaCl solution for 100 hours. Leakage current greater

than 1 mA indicates that the sample is failed. For water diffusion test sample from failed and working insulator was tested. Specimen prepared for water diffusion is shown in Figure 4.5. Water diffusion results are shown in Table 4.8. As expected the samples for failed insulator failed the test as the composite rod was already degraded due to internal tracking. The working insulator passed the test with low leakage current value indicating good interface with silicone rubber.

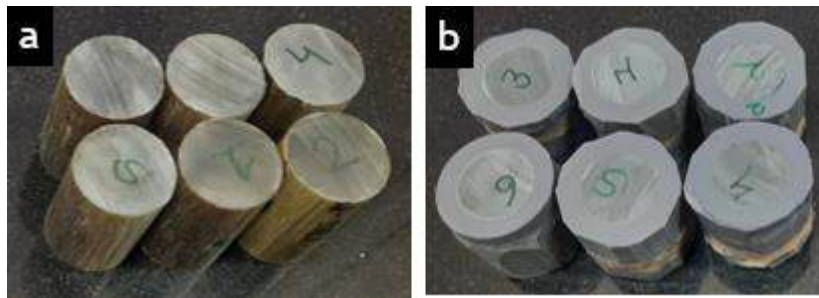


Figure 4.5: Water diffusion samples: a) failed insulator (SRI-1) and b) working insulator (SRI-3)

Table 4.8: Shore-A Hardness of silicone rubber shade

Sample	Failed insulator (SRI-1)	Working insulator (SRI-3)
Leakage Current (mA)	> 1 mA at 1 to 5 kV	0.06 at 12 kV

**Comment for Water Diffusion Test of Composite Rod:**

- Composite rod from failed insulator failed the water diffusion test
- Composite rod removed from the working insulator SRI-3 conform to the water diffusion test with very low leakage current

**Remarks on Physical and Chemical Tests:**

- No abnormality found in insulator composite rod and silicone rubber
- Water diffusion test indicate good adhesion between silicone rubber and composite rod for working insulator

## 5.0 FEM ANALYSIS

Electric field (E-field) distribution on insulator was studied by FEM analysis. Electrostatic modeling of Insulators helps in understanding the electric field present in and around the insulator for a given excitation of voltage. Depending on the material properties and geometry of insulator, electric fields tend to concentrate at certain locations leading to problems like corona discharges, insulator degradation and ultimately to insulator failure.

### 5.1 E-Field on Composite Insulator

FEM analysis for 400 kV-120 kN insulator with corona ring was carried out using the MAXWELL 3D software. It was excited with  $400/\sqrt{3}$  kV of phase to earth R.M.S. voltage. The material properties and boundary conditions used for simulation are as shown in Table-5.1 and 5.2 respectively.

Table-5.1: Standard values of material properties taken from software database

Sr. no.	Component	Relative Permittivity	Conductivity (Siemens/m)
1	Ball fitting end, hardware fittings (steel)	1	$2.0 \times 10^6$
2	Socket fitting end, hardware fittings (steel)	1	$2.0 \times 10^6$
3	Silicon Rubber Insulator	3.7	0
4	Fiber Rod (FRP)	5.03	0
5	Corona rings (Aluminum)	1	$3.8 \times 10^6$

Table-5.2: Boundary Condition

Boundary Type	Behavior
Default Boundary Condition (Neumann, Natural boundaries)	Neumann boundaries- Electric Field Strength, E is tangential to boundary. Flux cannot cross a Neumann boundary.  Natural boundaries- The Normal component of Electric Flux Density, D changes with the amount of surface charge density. No special condition is imposed.

Figure 5.1 and 5.2 shows electric field distribution on bare composite rod and silicone rubber housing material. Both the figure show that the electrical stress between the tri-junction and first shade varies between 0.1 kV/mm to 0.36 kV/mm. Figure 5.3 and Figure 5.4 shows the enlarged view of insulator near line end and tower end, respectively. Maximum electrical stress found on the silicone rubber housing is 0.4 kV/mm which is below the recommended electric stress value 0.45 kV/mm (Ref. A.J. Phillip et al. IEEE Transaction on Power Delivery, vol. 23, no. 2, April 2008).

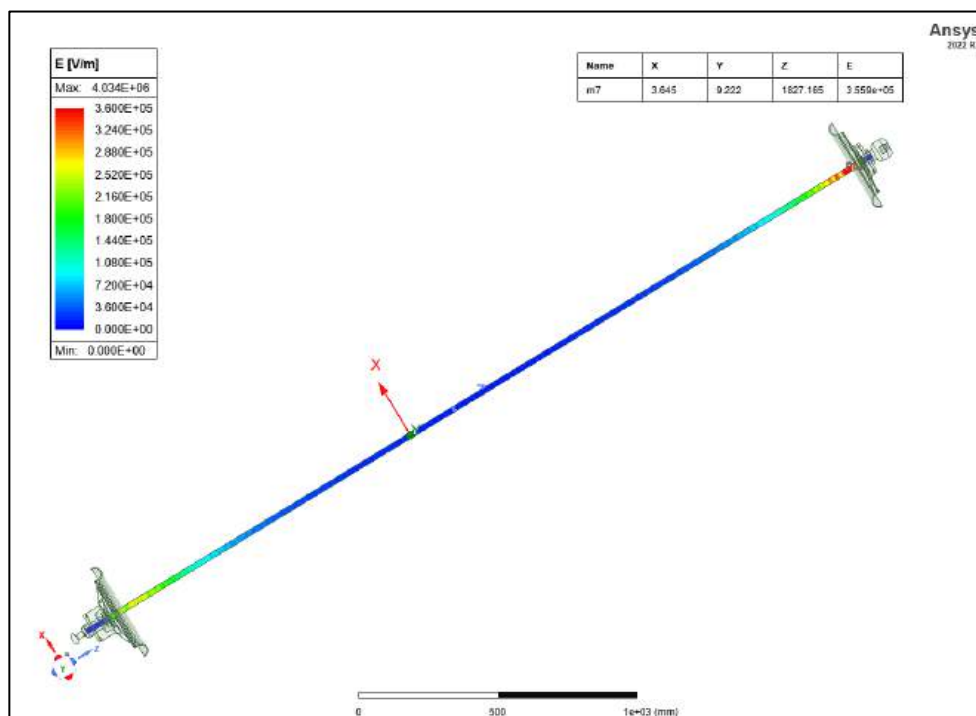


Figure 5.1: E-field distribution on composite rod surface

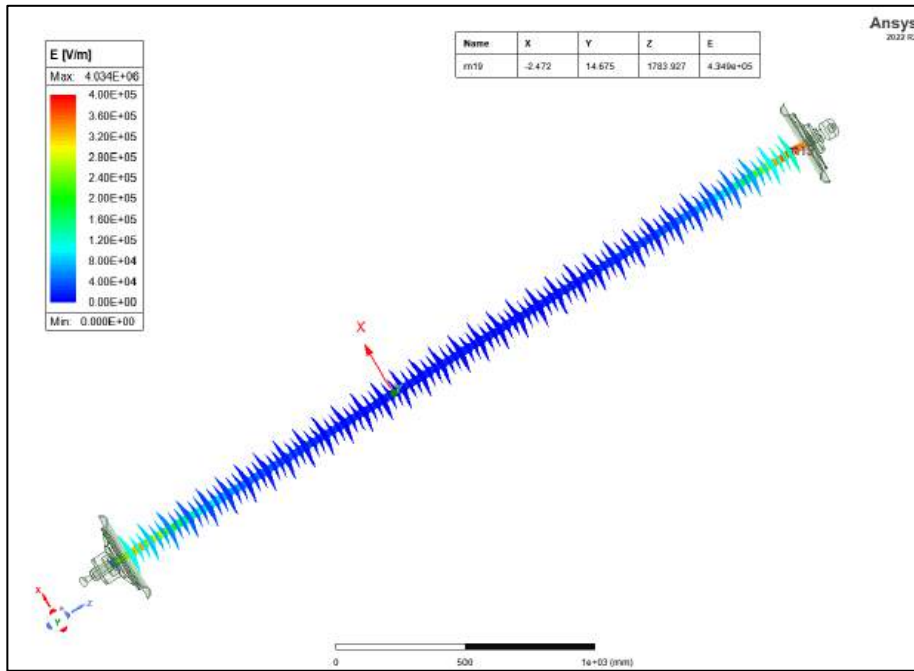


Figure 5.2: E-field distribution on overall surface of silicon rubber housing of insulator

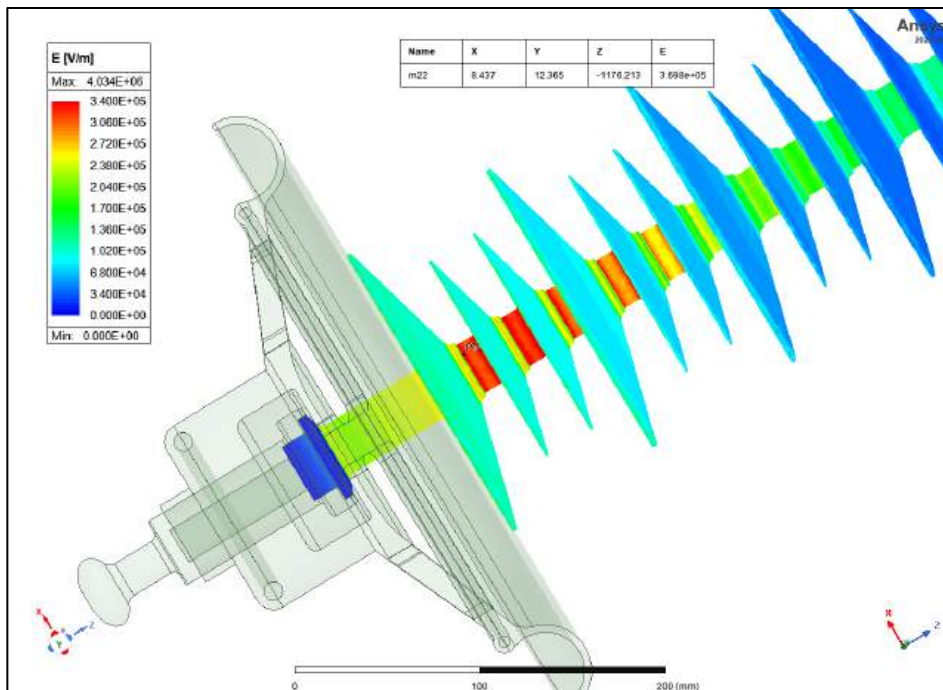


Figure 5.3: E-field distribution on silicon rubber near the line end of insulator

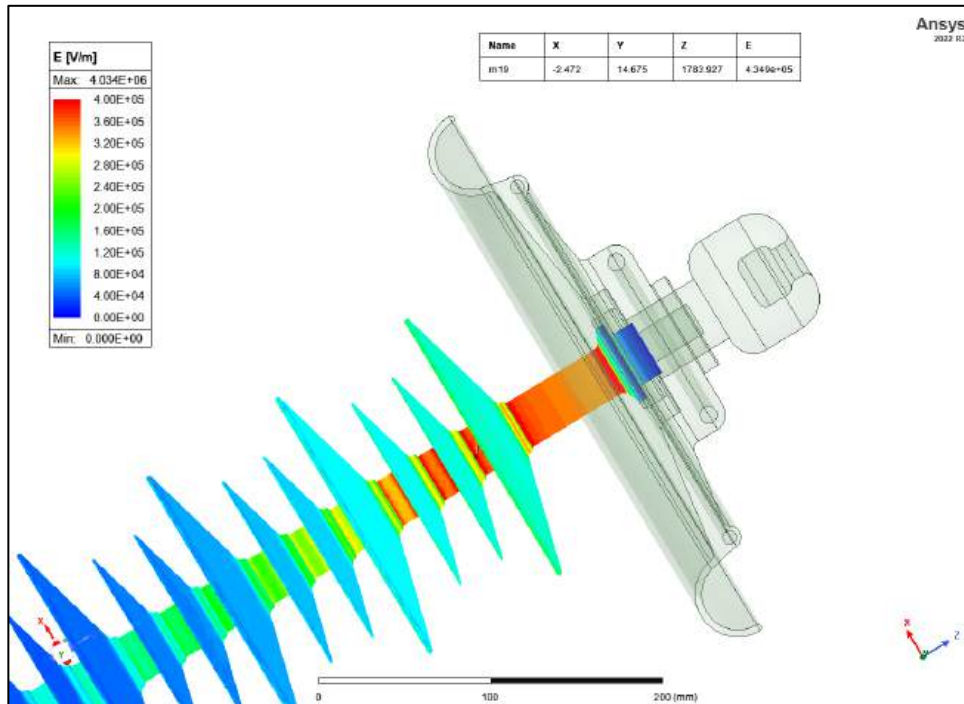


Figure 5.4: E-field distribution on silicon rubber near the line end of insulator

## 5.2 E-Field on Insulator due to Proximity to Porcelain Insulators

As discussed in section 2.8, the composite insulator on one side of tower 151 is in close proximity with porcelain insulator assembly. This may result in additional E-field on the composite insulator. Based on the available information and porcelain insulator drawings, 3D model of composite insulator and porcelain insulator assembly was prepared in the FEM software as shown in Figure 5.5. Due to limitations of available information, the 3D insulator assembly is not an exact replica of insulator configuration present on the tower 151. However, the 3D assembly gives a rough estimation of electrical stress on composite insulator due to its surroundings.

Figure 5.6 shows the E-field distribution on the porcelain - composite insulator assemble simulated for  $40^\circ$  angle between porcelain and composite insulator. It shows that the, the E-field on composite insulator surface near the tri-junction is between 0.42 kV/mm to 1 kV/mm. This E-field is above the recommended value of 0.45 kV/mm. The E-field on composite insulator can further increase due to following reasons:

1. Angle between composite insulator and porcelain insulator reduces
2. deposition of algae on insulator surface and on corona rings

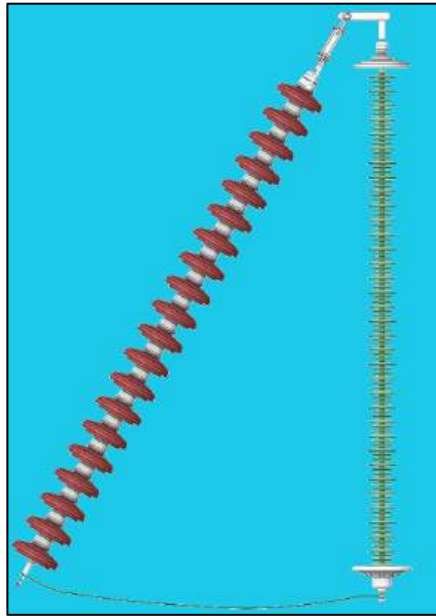


Figure 5.5: 3D model prepared for evaluating E-field on composite insulators due to proximity to the porcelain insulators

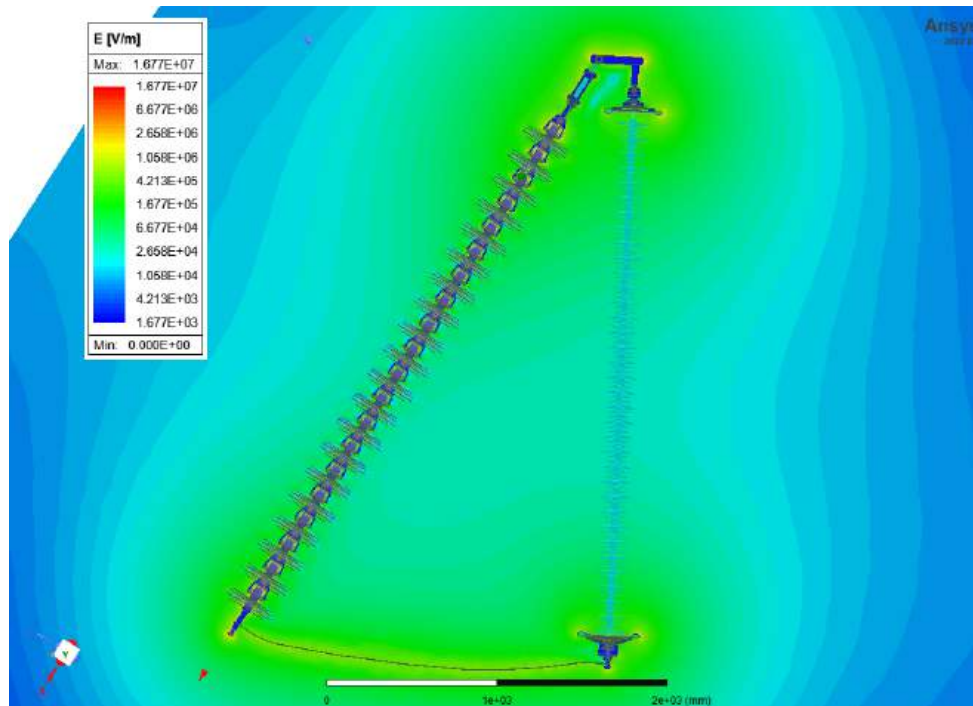


Figure 5.6: E-field distribution on assembly of porcelain and composite insulator.

**Comment on FEM Analysis:**

- Composite insulator design found to E-field values are lower than the recommended critical stress
- Due to proximity with the porcelain insulators the E-field on composite insulator increases above the recommended critical E-field

**Remark on FEM Analysis:**

- The composite insulator design is validated and E-field on the insulator surface found within recommended limits
- Due to close proximity with porcelain insulators, the E-field may increase above the recommended limit

## 6.0 SUMMARY OF RESULTS

### I. VISUAL OBSERVATIONS

#### Summary of visual observations of failed insulator - SRI-1:

- Silicone rubber housing was cracked on entire length of insulator
- The silicone housing was easily removed from the composite rod indicating weak interface with composite rod
- Silicone rubber seal at the tri-junction on both ends was open
- Silicone rubber shades were covered with algae and dust
- Entire composite rod showed electrical tracking marks
- Corona rings at both ends on insulator showed indications of arcing damage
- Tower end fitting also showed arcing damage

#### Summary of visual observations of failed insulator - SRI-2:

- Silicone rubber housing showed cracks and punctures on entire length of insulator
- The silicone housing was easily removed from the composite rod indicating weak interface with composite rod
- Silicone rubber shades and sheath was covered with algae and dust
- Entire composite rod showed tracking marks
- Arcing related damage on insulator end fittings was not observed

#### Summary of visual observations of working insulator - SRI-3:

- Working insulator did not show any indication of damage or degradation
- The insulator silicone rubber housing was covered with algae and dust on most of the insulator
- No visible cracks or puncture observed in the silicone rubber sheath
- Silicone rubber seal at the tri-junction was found intact
- interface between composite rod and silicone rubber found good
- Corona ring surface was covered with algae

**Summary of visual observations of working insulator - SRI-4:**

- Silicone rubber housing of insulator was covered with algae and dust on most of the insulator length
- Several puncture in the silicone rubber sheath were observed up to a length of 90 cm measured from tri-junction at line end
- Silicone rubber seal at the tri-junction was found intact and no indication of water/moisture entry was found
- Silicone rubber sheath near the tri-junction at line end showed cracks
- Area under a punctures showed degradation of composite rod, it was localised degradation as the degradation was in the immediate vicinity and not spread to the circumferential area
- The tower end section did not show any puncture

**Summary of visual observations of working insulator - SRI-5:**

- Silicone rubber housing of SRI-5 was covered with algae and dust on most of the insulator length
- Two punctures were observed in the silicone rubber sheath approximately 85 cm from tri-junction at line end
- Silicone rubber seal at the tri-junction was found intact and no indication of water/moisture entry was found
- Area under a punctures showed localised degradation of composite rod
- The tower end section did not show any puncture

**Summary of visual observations of working insulator - SRI-6:**

- Silicone rubber housing of SRI-6 was covered with algae and dust on most of the insulator length
- Several punctures were observed in the silicone rubber sheath up to approximately 90 cm from tri-junction at line end

- Silicone rubber sheath near tri-junction at line end was cracked and composite rod degraded, the degradation was spread in axial direction. Circumferential area was less affected.
- The tower end section did not show any puncture or composite rod degradation

#### **Summary of Common Observations of Insulators from Tower 151:**

- Three working insulators removed from tower showed punctures in silicone rubber up to 90 cm from the tri-junction of line end
- One failed insulator and three working insulator showed larger puncture area between 85 cm to 90 cm from tri-junction at line end

#### **Summary of visual observations from site:**

- Currently installed insulator found to be correctly installed with proper positioning of corona rings and arcing horns
- The failed insulator was located at highest height on the entire transmission line
- Algae is critical issue and some of the tower structures were found covered with algae
- Due to geometry of the tower, porcelain insulators on one side are in closer proximity than the other side to the composite insulators

#### **Remarks on Visual Analysis of Insulators**

- Failed insulator-1 (SRI-1 on Karad end) most likely failed because of arcing related damage, arcing evidence found on the tower end corona ring
- Failed insulator (SRI-2 on Jaigarh end) was initially punctured and gradually the insulator interface degraded resulting in final failure
- All the failed insulators and working insulators were covered with algae and dust layer. The extra layer on the insulators reduces the hydrophobicity thereby increasing probability of leakage current and arcing
- One failed insulator (SRI-2) and three working insulators showed punctured sheath, Punctures in the silicone rubber sheath takes place because of following reasons:
  - Poor interface between silicone rubber sheath and composite rod
  - Excess electrical stresses on the insulator surface

- Three working insulators showed punctures at distance 85 cm to 90 cm (between shade numbers 25 to 30). Punctures observed at this location are larger in size than the other punctures observed
- Failed insulator photo shared from site also showed initial damage at shade number 30

## II. MICROSCOPIC OBSERVATIONS

### Summary of Optical Microscopy Observations:

- Composite rod sections from failed as well as working insulator showed few microscopic cracks
- Composite rod section from punctured area also did not show cracks in composite rod indicating the composite rod quality has not played a role in insulator failure

## III. PHYSICAL AND CHEMICAL TEST RESULTS

### Summary of Results

- The dirt layer found on the silicone rubber shades was found as organic matter and most likely algae
- External pollutants not found on the insulator surface
- TGA showed that the silicone content of 36.3% found in the silicone rubber form the failed insulator
- FTIR showed presence of poly(dimethyl siloxane) in silicone rubber compound from failed insulator. No abnormality found in silicone rubber compound.
- Arc resistance of silicone rubber samples from failed insulator was found to be more than the required 200 seconds
- CTI was found more than 600 volts for silicone rubber samples of failed insulator which conforms to the requirement
- Shore-A hardness does not show any abnormality in silicone rubber compound from failed insulator.
- Composite rod from failed insulator failed the water diffusion test
- Composite rod removed from the working insulator SRI-3 conform to the water diffusion test with very low leakage current

**Remarks on Physical and Chemical Tests:**

- No abnormality found in insulator composite rod and silicone rubber
- Water diffusion test indicate good adhesion between silicone rubber and composite rod for the working insulator

**IV. FEM ANALYSIS****Comment on FEM Analysis:**

- Composite insulator design found to E-field values are lower than the recommended critical stress
- Due to proximity with the porcelain insulators the E-field on composite insulator increases above the recommended critical E-field

**Remark on FEM Analysis:**

- The composite insulator design is validated and E-field on the insulator surface found within recommended limits
- Due to close proximity with porcelain insulators, the E-field may increase above the recommended limit

## 7.0 CONCLUSION

Two failed insulators and four working insulators analyzed for the root cause analysis. One of the failed insulator showed arcing related damage to corona rings and metallic end fittings, indicating failure due to arcing. The other failed insulator showed several punctures in the silicone rubber housing, indicating failure initiation due to punctures and subsequent water ingress resulting in failure. Three working insulators also showed punctured silicone rubber sheath. All the punctures were located up to 90 cm from tri-junction of line end. Tower end section of insulator had no puncture. The puncture in the silicone rubber is typically related to electrical stresses on the insulator surface. FEM analysis of the insulator did not indicate excessive electrical stresses on the silicone rubber housing when both corona rings are properly installed.

Both the failed insulators were located on tower no. 151, one on Jaigarh end and the other on Karad end. Insulators located on other towers on the same transmission line did not fail after installation. The transmission line pass through a hilly terrain with continuous rain in monsoon leading to algae growth on tower components for all the tower located in the region. All the insulators and corona rings removed from the tower showed algae deposits. Tower no. 151 is located at highest elevation at 2500 feet with additional tower height of 250 feet, the failed and working insulators analyzed were located at the maximum height compared to other insulators in the transmission line.

Assembly of four porcelain tension insulators support each incoming and outgoing conductors on both side of tower. Tower 151 is connected on one side by incoming conductor Jaigarh side of tower 150 which is located in a valley (low elevation). The outgoing conductor towards Karad is connected with tower 152, which is located at similar elevation as that of tower 151. The vast difference in height on two side leads to close proximity of porcelain insulators with composite insulator on tower 150 side. This leads to additional electric field on composite insulators on tower 150 side. FEM simulations indicate that this asymmetry can enhance the e-field on composite insulator higher than the recommended value. The E-field is further enhanced due to algae covering on the insulator and corona rings. This excessive E-field can

lead to punctures in the silicone rubber housing resulting in water ingress and accelerating the degradation process and failure of the insulator.

The other failed insulator on Karad end of tower showed indications of arcing damage to the insulator and metallic end fitting. It appeared to have failed due to repeated lightning strikes. The insulator failed during monsoon when lightning strikes were observed. The location, height and ground condition of the tower makes it more susceptible for lightning strikes. The algae on the insulator surface can help in reducing the arcing distance resulting in failure of the insulator.

Testing of the composite insulator located on the tower 151 did not indicate quality issues. The unique location, height and geometry of the tower 151 played a role in failure of the composite insulators.

## 8.0 RECOMMENDATIONS

- The angle between porcelain insulator assembly and composite insulator should be increased to reduce the E-field on composite insulator
- Most of the insulators were covered with algae and dust. Clean surface of silicone rubber housing is important for proper functioning of insulator. Yearly cleaning activity of the insulator surface should be carried out
- The corona ring surface was also covered with algae, during periodic maintenance the corona rings and arcing horns should be cleaned
- The polymer insulator must be transported in a box during manual transport to the tower site to avoid any excessive bending stress on the insulator during transport. This will reduce possibility of microscopic damage to the composite core rod.
- Periodic inspections with IR and UV camera for hot spot and corona detection shall be carried out
- Considering the location of the tower with increased possibility of lightning, the tower can be fitted with surge arresters to reduce the lightning damage to the composite insulators.

\*\*\*\*\* End of Project Report \*\*\*\*\*