Brittle Fracture Failures at Israel Electric: Study & Analysis

BACKGROUND

Between June 1997 and March 1998 four composite insulators failed by brittle fractures on 161 kV lines belonging to Israel Electric. At the time, about 4000 such insulators were already in service on the company's HV lines (beginning from 1989).

Not long before those failures occurred, management at the utility had decided to switch from the use of ceramic long rod insulators to silicone rubber composite insulators for all new 161 and 400 kV lines. In this context, the above successive failures of HV composite insulators in Israel - made many think that the above decision had perhaps been too hasty.

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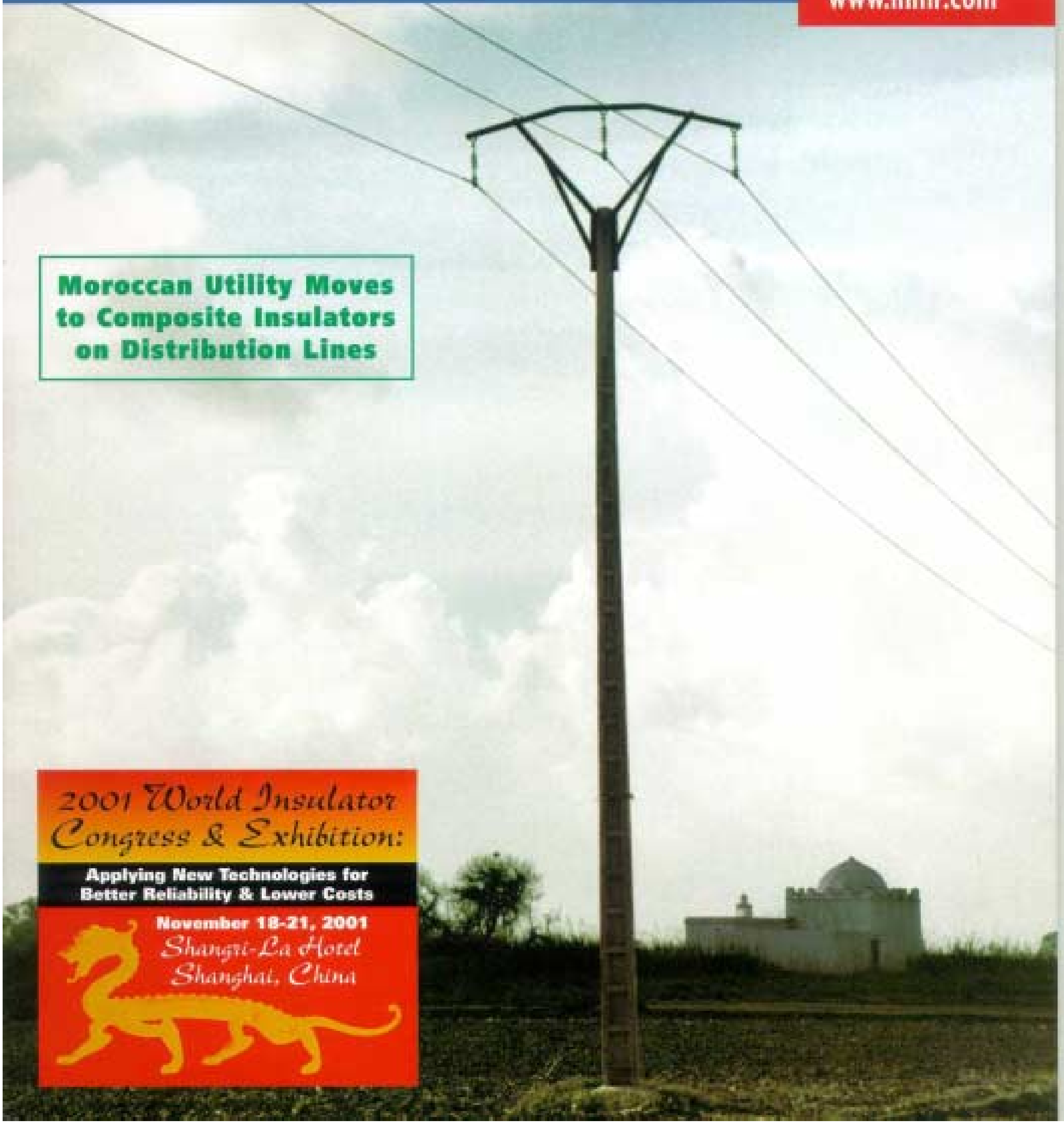

Moroccan Utility Moves to Composite Insulators on Distribution Lines

Brittle Fracture Failures at Israel Electric: Study & Analysis

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1. Background

Between June 1997 and March 1998 four composite insulators failed by brittle fracture on 161 kV lines belonging to Israel Electric. At the time, about 4000 such insulators were already in-service on the company's HV lines (beginning from 1989).

Not long before those failures occurred, management at the utility had decided to switch from the use of ceramic long rod insulators to silicone rubber composite insulators for all new 161 and 400 kV lines. In this context, the above successive failures - the first recorded failures of HV composite insulators in Israel - made many think that the above decision had perhaps been too hasty.

Given these circumstances, the Insulator Section of the Electrical R&D Laboratory was asked to perform an in-depth investigation of the failures. The purpose of the investigation was twofold: to document the status of installed composite insulators of the same type and age; and to gather and evaluate data which might explain the reason for these failures in order to find ways to avoid them in the future.

The investigation comprised the following activities:

a. Field trips to lines equipped with the same type of insulators as those which had failed in order to examine their behaviour under operating conditions (e.g. checking for corona sources and partial discharges on their surfaces).

b. Calculating the electric fields on the surfaces of these insulators.

c. Examining the failed insulators, including visual inspection to identify and characterize the damage as well as chemical testing of the fracture surface and its examination under a microscope.

The selection of tests to be performed was based on published data about possible causes of failures of composite insulators as well as relying on consultations with international experts and the insulator manufacturer. All chemical tests and microscope examinations were conducted at the IEC Materials Laboratory.

2. Findings

Shortly after the investigation began, it was found that one of the insulators failed as a direct result of the application during installation of a bending stress which was above the permissible limit. Therefore, the investigation continued only for the remaining three failed insulators.

2.1 Findings from insulator inspection under operational conditions

Two field trips were made along 161 kV lines equipped with the same type of insulators which had failed. These were undertaken at night during the months of August and September (1997) in conditions of high relative humidity (exceeding 75%). Partial discharges and corona sources were identified in most of the insulators inspected, but with differing intensities.

Figure 1

Figure 2

Figures 1 and 2 illustrate instances where high intensity discharges were recorded. As these figures show, the end fittings differ from one composite insulator to the other. The insulators observed on these lines had already been in service for 1.5 up to 7 years. The figures also show that most of the discharges were concentrated in the area between the end fitting near the conductor and the first shed of the insulator. Constant corona discharges were also registered on the ends of the arcing horns.

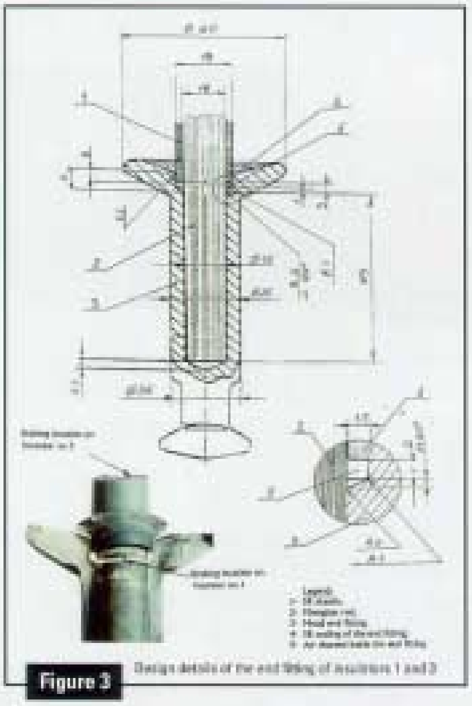

Figure 3 Design details of the end fitting of insulators 1 and 3

2.2 Findings from electric field calculations on the insulator surface

A computer model of the insulator under study was set-up in order to calculate the electric field strength in the area near the conductor. The "Coulomb" software program was used for this purpose. This model took into account the precise geometric details of the insulator (see Figure 3) but neglected the influence of neighbouring phases. The dielectric constant (e) of the materials (glass fibers, silicone rubber, air) was however taken into account.

The electric field strength inside the end fitting (under a voltage of 100 kV) was zero, rising to a maximum value at the opening to the fitting. The maximum value obtained along the fiber glass rod axis was 12.9 kV/cm and on the rod surface 13.8 kV/cm. These values were obtained at a distance of 15 mm outside the opening of the end fitting.

Electric field strength was calculated in the area of the fitting containing the ring of air. The maximum value obtained was 2.2 kV/cm, which is much lower than the electric field strength needed to cause ionization of the air.

The area under maximum electrical stress was located near the silicone rubber sealing layer at the arc control lip. (These results are presented in Figure 4). The maximum value calculated for this area was 36 kV/cm.

Based on the findings from two of the failures, two more calculations were made of the electric field which develops in the presence of a defective insulator, e.g.:

1. An air bubble in the silicone rubber housing, near the end fitting.
2. A contaminated crack (or groove) on the surface of the silicone rubber housing, near the end fitting.

For a crack 1 mm wide on the silicone rubber housing, covered with thin, very wet, conductive contamination and located close to the end fitting, the maximum electric field was some tens of a kV/cm. For an air bubble with a 0.6 mm diameter, the maximum electric field was 8 kV/cm (see Figure 5). The discharge locations on the surface of those insulators observed during the field trips under operational conditions matched the maximum electric field distribution calculated in the computer model.

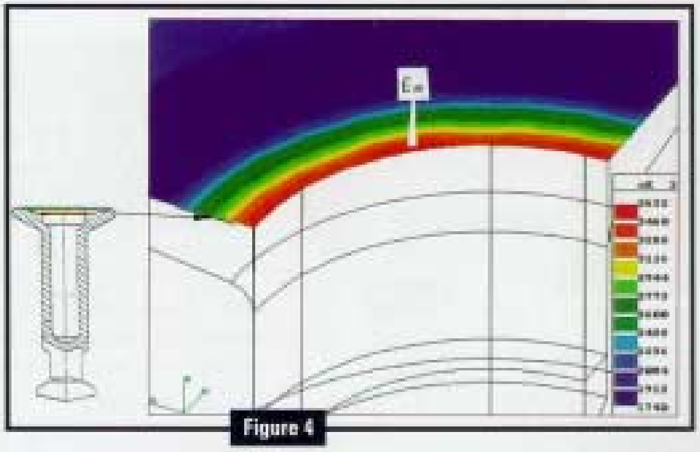

Figure 4

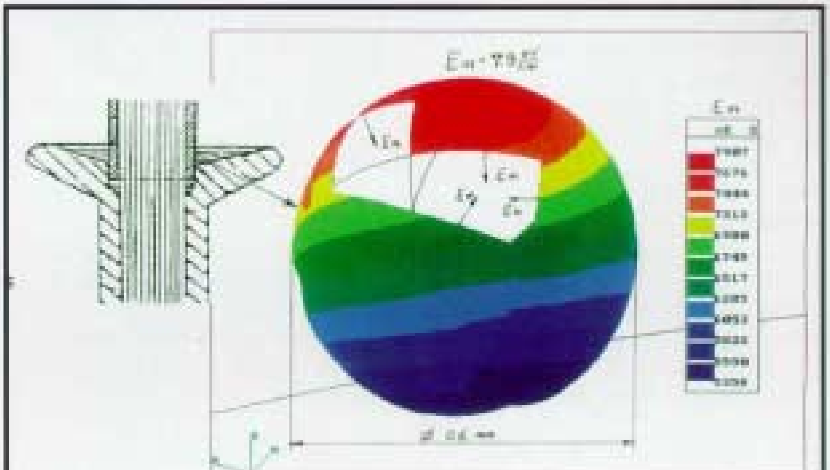

Fig.5. Electric field distribution on the internal surface of the air bubble located in the SR-housing on the end of the fitting (on the output level)

Figure 5

2.3 Findings from the investigation of the failed insulators

The three insulators which had failed were taken to the laboratory for investigation (two of these are shown in Figures 6 & 7). These insulators were 6-7 years old and had been used on the line for between 1.5 and 6 years.


Photos courtesy of Israel Electric

Figure 6

Figure 7

After several tests, the first insulator was given to the manufacturer for examination and to submit their opinion about the failure. In order to receive further opinions concerning the causes of the failures, other experts in the field of composite insulators were also contacted.

2.3.1 Findings from visual inspection

- For all three insulators, the silicone rubber housing was found to be 1.5 mm thick.
- All three insulators were identical in structure.
- In all three cases, the brittle fracture failure occurred in the area between the end fitting close to the conductor and the first shed of the insulator.
- In the vicinity of the failure, accelerated wear of the insulator housing was recorded, apparently caused by electrical activity (discharges).
- Signs of mechanically-induced damage were recorded in this area (insulators 1 and 3).
- The silicone rubber material which seals the opening to the end fitting was found to be burnt and partially peeled by electrical activity including discharges and the appearance of corona (see Figure 8).
- Two distinct areas were visible on the fracture surface: one perpendicular to the insulator axis, and the other (about 15% of the rod fracture surface area) having the appearance of a standard fracture which results from tensile stress.

2.3.2 Findings from examination of the fracture area under a microscope

Fracture areas and the regions around them were examined using an electronic microscope. Magnification of 1000x and 2000x enabled identification of individual glass fibers (the diameter of a single glass fiber is about 10 microns) as well as the condition of the fracture area.

On each of the three failed insulators, on some areas the cross-section of glass fibers is clearly visible and their surface is smooth as typical of a brittle fracture.

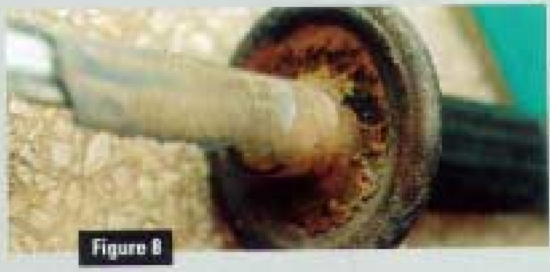
Photo courtesy of Israel Electric

Figure 8

The examination also investigated the content of the key chemical elements (Si, Al, Ca) of the glass fibers in the various regions around the fracture. The results obtained did not show a significant and consistent variation of these values for different regions of the fracture.

3. Summary of Findings from the Failure Analysis

After thorough investigation of the three failures, the following findings were found to be especially relevant:

a. From examination of similar insulators under operational conditions, a constant high level of electrical activity was evident in the area where the failures occurred.

b. Electric field calculations on the insulator surface determined that there would be a permanent maximum concentration of the electric field in the failure area.

c. Laboratory examination of the insulator found numerous signs of advance corona corrosion in the failure area.

d. The insulator's silicone rubber housing was only 1.5 mm thick and apparently could easily be destroyed by a mechanical blow or steady corona discharges.

e. The insulator was not equipped with a corona ring. Generally, such rings radically reduce or prevent corona formation in the area of the end fitting.

f. The silicone rubber layer sealing the end fitting lost its sealing ability with time.

g. The glass fiber used for the rod of the failed insulators was not brittle fracture resistant.

h. Signs of mechanical blows were found on the first shed, near the failure area.

i. Microscope examination of the fracture area revealed glass fibers with different fracture shapes. Some matched the properties of an ordinary mechanical fracture, while others matched the properties of a brittle fracture.

4. Stages of the Failure Process

Based on the above findings and the knowledge gathered during the investigation, the failure process seems to have passed through the following stages:

1. A mechanically induced damage to the silicone rubber housing in the failure area during insulator storage or installation with/without exposing the fiber glass rod;

2. Corona activity in the failure area while the insulator is in service under voltage exacerbating the harm done to the housing;

3. Nitric acid ($HN0_3$), which forms on the insulator surface from drops of rain water exposed to corona discharges, penetrating the rod and starting to erode the glass fibers;

4 When the residual mechanical strength of the rod is equal to the weight of the conductor and the dynamic stresses on it under operating conditions, the rod breaking by brittle fracture.

5. Conclusions

The initial stages of the failure process (see points 1. and 2. of section 4) were made possible by a combination of both design and operational factors.

a. Design Factors

1) The thickness of the silicone rubber housing was only 1.5 mm.

2) A constant high intensity electric field developed in the failure area, which led to strong and permanent discharges at that location. This was likely to erode the rod housing with time (corona corrosion).

3) The insulators were not equipped with grading rings and the manufacturer did not subject them to corona tests.

4) The insulator rod was not resistant to brittle fracture.

b. Operational Factors

1) The insulators rubber housing was damaged (at least in the case of two failed insulators) near the energized end fitting *prior* to service on the grid.

2) The condition of the insulators was *not* examined *before* commissioning. More than that, one of the failed insulators was re-used without first being checked for physical integrity between the two different installations.

As a result of this investigation, the continuing purchase and use of composite insulators on the HV network of Israel Electric was made subject to implementation of the following key guidelines:

- The width of sheath required in specifications for composite insulators is now defined as "at least 3 mm"
- Composite insulators for 161 kV are specified to be supplied with grading rings on the line end and must pass a corona test.
- Storage and line personnel receive special instructions for proper handling of composite insulators.