ANALYSIS OF SURFACE FLASH OVER OF 33 kV INSULATOR DUE TO SALINE POLLUTION

A Dissertation submitted to the
Department of Electrical Engineering, University of Moratuwa
in partial fulfillment of the requirements for the
Degree of Master of Science

by
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2010

Abstract

Ceylon Electricity Board (CEB) has the responsibility of Transmission, most of the Generation and Distribution of electric power in Sri Lanka. Contamination-driven insulator failure is a problem that incessantly plagues distribution systems. It erodes power quality and diminishes system reliability. Contamination levels can continue to grow unless abated by natural cleaning or if not taken measures to wash insulators at the distribution level in a preventative maintenance mode. When contamination is combined with moisture, a pollution layer forms and provides a path for leakage current to flow. Increases in contamination severity result in heightened levels of leakage current activity.

As a result of rapid development and growth of populated areas, several high voltage power transmission systems operating at various voltages up to 132 kV have been put into service and flashover difficulties with insulators of these systems caused by pollution of different types have been experienced. Not only the transmission network but also the distribution network of 33kV, running in coastal belt, has experienced frequent insulator flashover making a burden to the maintenance Engineers.

In order to assess the pollution behavior of insulators in the distribution network, 33kV pin type insulator was selected as a sample insulator and been subjected to natural pollution at three selected localities for considerable period. The naturally polluted , insulators have been subjected for conductivity test and by which the equivalent salt deposit density (ESDD) which points out the pollution severity is calculated. Subsequently, artificially contaminated insulators of different pollution severities were tested for power frequency and impulse test in the High Voltage Laboratory of University of Moratuwa.

To better understand the progression of insulators from a healthy state to failure, the flashover voltage (FOV) of insulator must be studied. This study was focused on the following key areas.

- Experiment of 33kV Pin Insulator contamination severity based on Zone categorization (Zone-I, 2 and 3)
- Prediction of surface flashover voltage of Insulators over ESDD and tabulate the figures for reasonable ESDD values.
- Streamline the process of Insulators treatment under preventive maintenance.
- Review the levels of insulator's specific creepage distances placed at different pollution severity in Sri Lanka co-relating with IEC regulation.

Experimented results state that insulator contamination level improves over the duration in ad hoc basis and could be utilized to build up a trend curve to predict a relationship against the insulator exposure duration. It is recommended that insulators in Zone 1 have to be treated after 8 months from the date of last treatment and those in Zone 2 & 3 to be treated after 18 months under preventive maintenance to get away from flashover.

It is also recommended to review the required specific creepage distance of insulator installed in non-polluted areas due to the fact that the current practice of insulators placement in all over is with specific creepage distance of 25mm/kV which is recommended for high polluted zones as per IEC regulation.

DECLARATION

The work submitted in this dissertation is the result of my own investigation, except where otherwise stated.

It has not already been accepted for any degree, and is also not being concurrently submitted for any other degree.

UOM Verified Signature

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ACKNOWLEDGEMENT

This work has been carried out at the Department of Electrical Engineering, University of Moratuwa.

Thanks are due first to my supervisor, Prof. J.R Lucas, Senior Professor, University of Moratuwa for the continuous support extended throughout the research programme, for his valuable comments and immense knowledge. His guidance helped me in all the time of research and writing of this dissertation.

I take this opportunity to extend my earnest thanks to Eng. Rienzie Fernando, Managing Director, Amithi Power Consultants (Pvt) Ltd, who enlightened me the first glance of research and motivated me, whenever I discussed technical issues, encouraging me to try out this research successfully.

I also thank to Eng. S Bogahawatte, Project Director, Lighting Sri Lanka Hambantota Project, Ceylon Electricity Board for his encouragement throughout the research programme and it helped me a lot to carry out the project works successfully.

My sincere thanks to also go to Dr.Thilak Siyambalapitiya, Consultant, RMA Pvt Ltd, Mr. K.G.S Perera, Deputy General Manager (Asset Management) of Ceylon Electricity Borad and Mr.Chandan Banerjee, Sales Engineer/Aditya Birla Insulators, India for facilitation me with the necessary data and information.

Lastly, I should thank my loving wife Dr. G.B.S Ranganee, my son N.H Amiru Pasandul, my parents, my wife's parents, many individuals, friends and colleagues who have not been mentioned here personally in making this educational process a success. May be I could not have made it without your support.

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Chapter 1

Introduction

1.1 Background

In recent years, the demand of electric power has been enlarged considerably. To satisfy this demand, electrical utilities have had to improve the efficiency of their power lines and provide a better quality of service to the consumers.

The efficiency of the system is based mainly on the continuity of the service, avoiding faults that suppose economical losses for utilities and users. To maintain this continuity, one of the main problems that have been found is the effect produced by pollution in the insulators of electric lines. This pollution is one of the main causes of flashover in the insulators. The insulator begins to fail when the pollutants that exist in the air settle on the surface of the insulator and combine with the humidity of the fog, rain, or dew. The mixture of pollutants, plus the humidity form a layer that can become a conductor and allow passing currents that will facilitate the conditions of short circuit. This is due to a decrease of the resistance of the insulator surface. Unless there is a natural cleaning or an adequate maintenance, the electrical activity will be affected by a possible flashover in the insulator.

The flashover of polluted high voltage insulators constitutes one of the most important high voltage energy transmission problems. Due to rapid rise of voltages and growth of pollution, this problem has drawn more attention in recent years.

The level and the type of pollution of a region are associated with the sources of pollution, as well as with weather factors of the place. Independently of the existing pollution type, the normal phases in which a flashover can appear in the insulator by pollution are:

- The pollution is placed on the surface of the insulator and a contaminant layer appears. The pollution can be caused by a great variety of sources, (sea salt, industries, ashes...). The wind is the main bearer of the particles, having a secondary role the gravity and the electric field.

- By the action of rain, fog, etc. the layer on the surface is dampened and enlarges the conductivity.
- The contaminant layer dries. Thus, there is an increase of conductivity and leakage current.
- Dry bands are formed as a consequence of the warming-up of the layer on the insulator surface.
- Partial arches appear through the dry bands.
- Partial discharges are produced, these discharges produce audible noise.
- Finally, the total discharge is produced.

So that the flashover can be produced these phases have not to happen consecutively but that several phases can occur at the same time.

The level and the type of pollution of a region are associated with the sources of pollution, as well as with weather factors of the place. Pollutants and the sources that produce them are described in Table 1.1.

Contaminant	Source of pollution
Salt	Coastal areas,· Salt Industries,· Highways with deposit of snow where salt is used to melt the snow
Cement	Cement Plant, Construction sites, Rock quarries
Earth	Plow fields, Earth moving on construction projects
Fertilizers	Fertilizer plants, Frequent use of fertilizers in cultivated fields
Metallic	Mining handling processes, Mineral handling processes
Coal	Coal mining, Coal handling plants/thermal plants, Coal burning/brick kilns areas
Volcanic ash	Volcanic activity areas
Chemical	Wide variety of chemical/process industries, oil refineries...
Smog	Automobile emissions at highway crossings, Diesel engine emissions at railway crossings / yards
Smoke	Wild fire, Industrial burning, Agriculture burning

Table 1.1 Contaminants and their sources

Although many factors can define the insulators pollution. three types of pollution can be distinguished: the industrial. saline and desert.

A. Industrial Pollution

People in their daily work generate smoke. dust or particles that are in suspension in the air. These particles are mainly by the action of the wind spread over zones where electric lines exist.

The industrial pollution of the insulators appears with the development of industries and by the contaminants generated and expelled to the atmosphere. being possible of diverse types: metallurgical. chemical substances. dust. smoke. cement...

These substances will settle by the action of the wind. weight. electric fields.... on the insulators creating a contaminant layer. This layer settled on the insulators is formed slowly during a period that can last months or years. During this period will alternate dry epochs with humid epochs.

Among the contaminants sources that characterize this type of pollution. we have to keep in mind the characteristic sources of industrial pollution as well as other sources that enlarge the problem:

- The typical contaminant sources are: the smoke of industries. the one produced by vehicles. buildings ...
- Industries that consume fossil fuels. diesel. coal... the heavy particles of the fuel remain in suspension in the environment.
- Heavy industries such as fertilizing plants. oil refineries. businesses cement works ... these can have severe emissions of contaminant particles.
- If the electric line is near the coast. we have to keep in mind the action of the waves. breezes or winds coming from the sea. the fogbanks and the particles of salt that are in suspension in the outskirts of the zone where the insulators are located.
- Agricultural areas. the farming of the lands. occasional fires. the harvest of fertilizers. etc....

B. Saline Pollution

The insulators exposed to coastal or saline environments, can become to be conductors due to the formation of a conductive layer on its surface. This layer will be formed on account of the salted dew in the mornings in these zones close to the coastal areas. When dried with the heat produced in the same insulator or with the environment temperature, is going to deposit in the insulator the evaporated salt that had been absorbed before. The particles placed in the insulators are not dangerous in dry weather but, the problem arises when the environmental weather is humid, when it rains or when there is dew, fog...etc then the layer can become a conductor. The conductivity of this layer will depend on the kind of salt that forms it. The weather conditions vary considerably from the coastal areas to the interior areas and they play a very important role in the contaminants deposition rate and in the operation of the insulator. The problem of pollution depends mainly on the environment.

The danger of the pollution will depend on the type of material and on the form of the surface. Also the sources of pollution must be investigated and the way of deposition of the pollution. The wind is the main bearer of the pollution and the others being the gravity and the electric fields. The pollution will depend also on the direction of the wind for a greater or smaller pollution of the insulators.

The severity of the pollution in a location is quantified in terms of Equivalent Salt Deposit Density (ESDD) measure in units of NaCl mg/cm^2, in which are taking into account, the following five weather factors: Temperature, humidity, pressure, rain and velocity of the wind. This value of ESDD provides a base to do a classification of the severity of the pollution of the zone and will serve for knowing the value from which we have to do the maintenance of the insulator, that is to say to develop a politics of correct conservation. The saline pollution is located not only in the surrounding area of the coast, but also to considerable distances by the action of the wind.

C. Desert Pollution

In Middle East countries, the insulators of the electric lines are often subject to the deposition of contaminant substances of the deserts. This can cause a serious reduction in the efficacy of the insulator, having as a result the flashover and the electricity supply lack.

The insulator flashover due to saline or rather industrial pollution has gained special importance in Sri Lanka in recent years, so several distribution systems have been put into operation in polluted areas. This problem in coastal area will maintain its importance and even may become more severe because of:

a. The construction of more open transmission/distribution lines in coastal areas due to the growing demand.
b. The increase in transmission voltage.
c. The quick spread of industrial areas.
d. Irregular rainfall pattern throughout the year.

1.2 Motivation

Contamination-driven insulator failure due to saline pollution in particular is a problem that incessantly plagues distribution systems. It erodes power quality and diminishes the system reliability. This phenomenon is not yet analyzed by Ceylon Electricity Board (CEB) being the main utility of electricity in Sri Lanka. The outcome of this study will streamline the preventive maintenance procedure, which would be benefitted by the Maintenance Engineers to treat the polluted insulators periodically. A relationship between FOV and the ESDD is to be built up so as to predict the flash over voltages over ESDD in areas in which insulators get contaminated due to saline pollution. As an Engineer, the author was motivated to select this topic for this study due to above facts.

1.3 Objective

Effect of porcelain insulators due to saline pollution and analysis of flashover voltages in saline polluted areas have not been investigated by the CEB yet. Therefore, the objectives is to,

- Predict flash over voltage of 33kV insulators due to saline pollution and streamline preventive maintenance procedure to treat the polluted insulators.

- Review the IEC regulation for insulator's specific creepage distance based on polluted zones and co-relates the same in actual scenarios.

1.4 Scope of work

1 Data Collection

- Survey on insulator flash over the last six months.
- Sample solutions after insulators washing having exposed to the environment for six months period.
- Rainfall and Thunder Day data in Hambantota over last three year period.

2. Streamline preventive maintenance procedure

- For all 3 Zones selected based on specified distances from ashore. streamline the preventive maintenance procedure for treating the polluted insulators.

3. Prediction of flash over voltages over ESDD.
4. Analyze the results and co-relate the IEC regulations to make concluding remarks on proper utilization of specific creepage distance of insulators.

Chapter 2

Problem Statement

A survey has been carried out in Hambantota and Tissamaharama areas where they are very much closer to the coastal belt and to check the status of system breakdowns due to 33kV insulator flashover. Key findings of the survey have been tabulated over the year 2009. Detail data is available in Annex-1and 2.

Month		April	May	June	July	August	September
flashover occurrences	Hambantota	9	4	3	1	1	-
	Tissamaharama	2	1	-	11	2	8

Table 2.1 Insulator flashover records in 2009(April-Sep.)

It is obvious that this situation is more general and well known to Area Engineers and Maintenance Engineers having involved with attending frequent breakdowns due to insulator flashover in coastal regions over the years. This phenomenon is more aggravated in areas where less rainfall pattern, high windy and lightning conditions prevail.

There are so many research being done and published with respect to the topic but have been unable to come up with an acceptable solution so as to accommodate all territories due to the fact of aforementioned climatic differences. When it comes to Arab, desert pollution, coastal pollution and industrial pollution emerge. A country like Sri Lanka is generally having coastal pollution and industrial pollution. This also differs geographically as the industries are not spread over the country equally. For instance, Galle, Negombo etc are highly indutrialised cities which are located in coastal belt whereas Hambantota, Batticoloa etc are having very less industrial base in the coastal belt.

Having considered the above requirement, Hambantota area was considered as the sample area for this study. In this particular sample area, insulator contamination is purely due to saline pollution. 33kV distribution network in this area goes parallel to the coastal belt and there are so many occasions where the insulators get flashover due to lightning, switching or earth fault resulting considerable amount of insulators being damaged. This is more general in Boondala, Kirinda, Mirijjawila and Hambantota town area. In order to get away from this burden, CEB has recently converted the 33kV distribution line to 11kV in Waligatta area in Hambantota District by installing a primary substation. Though it is somewhat a costly method to maintain a primary substation additionally, Maintenance Engineers are interested in this concept as the numbers of insulator flashovers are minimized as a result of it. Even though, this could not be followed as a practice to all 33kV network since it may affect the voltage drop being increased in the system and thereby the reliability of the system get disturbed. Therefore, it is one of the key outlines of this study to propose preventive maintenance procedure for CEB to adopt and develop appropriate mechanism for insulator treatment periodically.

In addition, 33kV Pin insulators used in CEB are everywhere same irrespective of the pollution condition of the environment. Presently CEB purchases 33kV pin type insulators of 25mm/kV specific creepage distance which is recommended for high pollution areas as per the IEC 815 regulations. This study would review the requirement of having 25mm/kV specific creepage distance insulators for Sri Lanka's perspective.

Chapter 3

Theoretical Development

3.1 High Voltage Insulators

High voltage insulators have been developed rapidly since early this century, beginning with simple porcelain insulators. A classification of the main types of insulators is shown schematically in Figure 3.1.

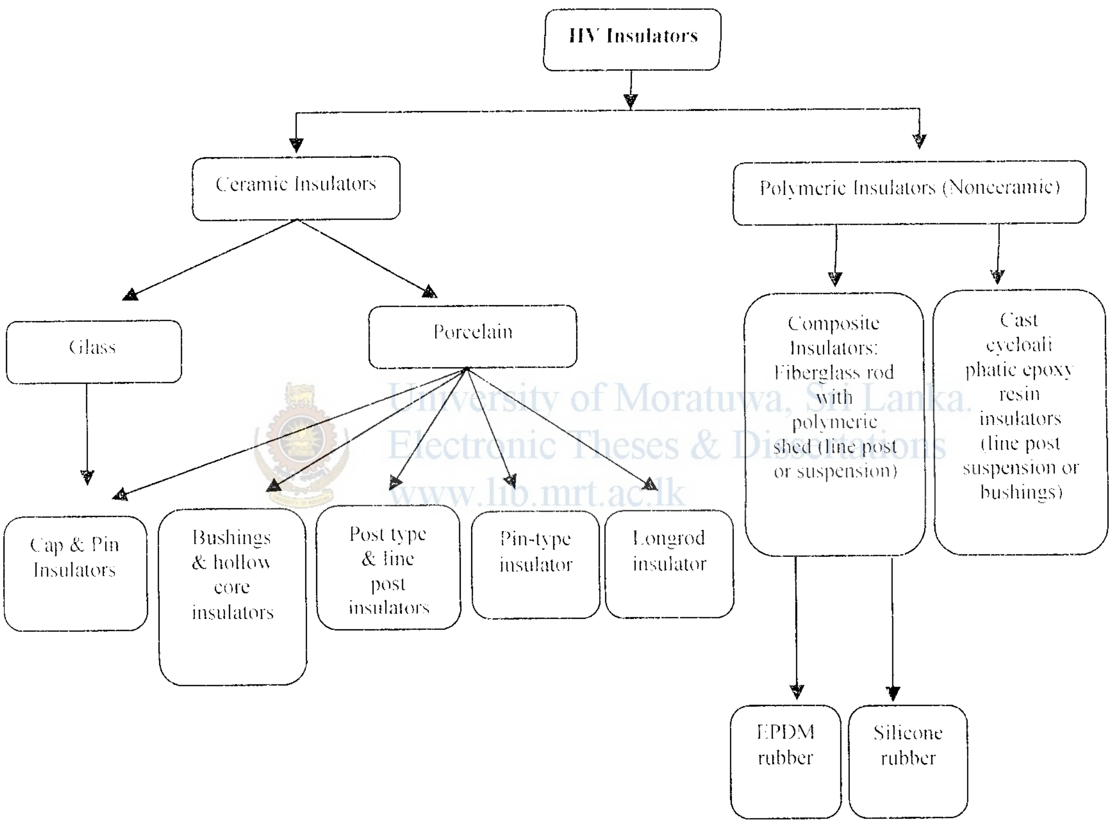

Figure 3.1 the classification of power line Insulators

Figure 3.1 classify the HV insulators in various categories. Generally, ceramic insulators are very common in distribution network and of which some famous insulators used in Sri Lankan context are highlighted in figure 3.2.

Figure 3.2 Ceramic insulator types

Ceramic insulators are further categorized as porcelain and glass insulators and the usage of porcelain is too high due to its popularity due to following reasons.

1. More information has surfaced about the porcelain insulator business and a number of dedicated individuals have written books, articles, and reprinted catalogs that have significantly increased collector knowledge and interest in the porcelain side of the hobby.
2. Glass prices have been on the increase in recent years, making porcelain an attractive and affordable alternative. Porcelain insulators are now much more available at insulator shows.
3. Collectors have realized that the amount of colour available in porcelain is very significant and has increased as more distribution lines are dismantled.
4. The increase of information available on the internet as well as the variety of porcelain insulators available gives a larger population exposure to porcelain insulator collecting.
5. More historical interest has been generated in the early development of power generation and distribution which has been primarily dependent on porcelain insulators. Current linemen are much more familiar with porcelain, as very little glass remains in use today.

Some of the key porcelain insulators are described below.

3.1.1 Porcelain Pin type Insulator

Figure 3.3 Pin Type Insulators

Pin type insulators are being adapted in medium voltage CEB distribution network all over the country for years.

3.1.2 Cap and Pin Insulator

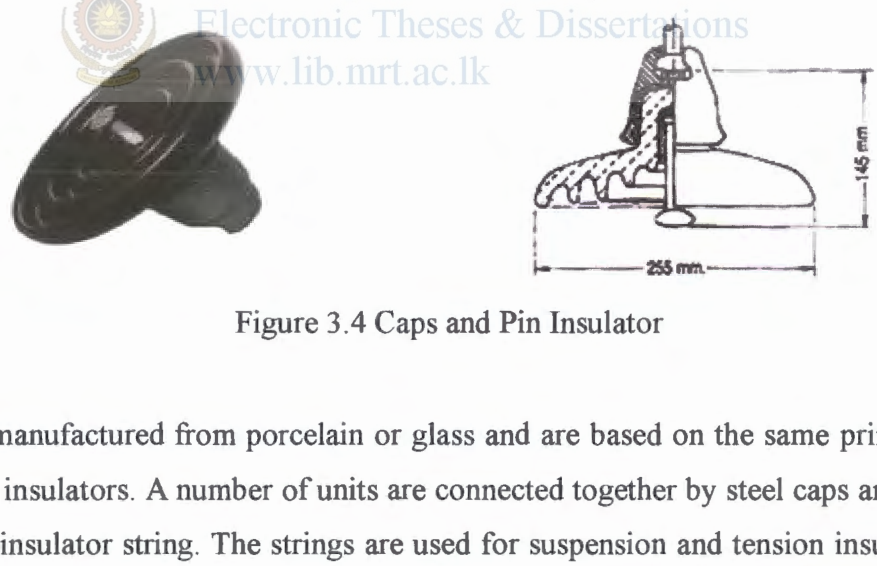

Figure 3.4 Caps and Pin Insulator

These are manufactured from porcelain or glass and are based on the same principles as pin-type insulators. A number of units are connected together by steel caps and pins to form an insulator string. The strings are used for suspension and tension insulators. The caps and pins are fixed to the glass or the glass or porcelain disc with cement. The conical shapes of the fittings ensure high mechanical strength under tensile stress. A typical cap and pin disc is shown in figure 3.4. Pin type and cap and pin insulators are classified as Class B insulators. The porcelain or glass can be punctured by severe electrical stress. The manufacturing process of glass insulators includes thermal cooling that ensures that the glass sheds shatters in the event of a puncture. A faulty disc is therefore visible.

3.1.3 Glass Insulators

Figure 3.5 Glass Insulators

Porcelain and toughened glass are the two types of insulators that are being used for high tension transmission lines and equipment throughout the world. The world market comprises of the power projects being set up mainly in the under developed and developing countries using porcelain and toughened glass insulators. In Sri Lanka also toughened glass insulators are being used in transmission and distribution lines. Some characteristics of porcelain and toughened glass insulators are given in Table 3.1. However, it may be noted that this comparison is not exhaustive, as complete data on properties and performance of glass insulators is not available due to its limited use so far. Toughened glass insulator technology acquisition and adaptation has not received sufficient attention so far in the country. Generally glass tends to deteriorate in outdoor applications as it is not crystalline. Also surface damage in glass insulators leads to shattering, while porcelain insulators can withstand reasonable degree of surface damage. Performance of glass is yet to be proved in tropical countries.

3.2 Comparison between Porcelain and Glass Insulators

The standards and regulations indicate that the insulators utilized in the overhead electrical lines can be made of porcelain, glass or another material of adequate characteristics to their function. The most used insulators in power distribution lines until today are manufactured with porcelain or glass. Table 3.1 gives a comparison between glass and porcelain insulators.

Item	Characteristics	Porcelain Insulator	Glass Insulator
1	Dielectric Rigidity at 25°C and 50Hz	Low (Approximately 160 kV/cm)	High (Approximately 250 kV/cm)
2	Tensile Strength	4 daN/Sq.mm	12 daN/Sq.mm
3	Effect of cyclic temperature changes	Insulators mechanical strength reduces.	Insulators strength is appreciably affected
4	Electrical Puncturing strength	Low	High
5	Electromechanical failure	Gradual which could be due to electromechanical fatigue	Sudden scattering caused by impacts exceeding the explosive stresses in the skin of insulators.
6	Weights of 90 kN disc insulator	6.2 kg	4.0 kg
7	Flaw detection	Not easy. Damaged piece may remain in service over long periods increasing losses.	Disc shatters and can be sighted easily from a distance.
8	Fire Hazard	No stresses in the body of the Insulator.	Likely to focus sunrays. Fire may be caused if concentrated on dry Grass.
9	Stresses in the Insulator body	No stresses in the body of the Insulator.	There is dynamic equilibrium of stress.
10	Product Range	Covers the complete range for transmission and apparatus application.	Covers only transmission and substation insulators due to mass production technique used and consequent limitations in producing small quantities.

Table 3.1 Comparison between Glass and Porcelain Insulators

The above comparison implies that both glass and porcelain insulators are having some advantageous and disadvantageous over each other but availability of glass insulators are limited due to mass production technique needed and consequent limitations in producing small quantities.

3.3 Pollution Severity

The performance of outdoor high-voltage insulators is adversely affected by environmental pollution in coastal and industrial regions. In some instances, solid pollution particles settle on the insulator surface and become a conductive electrolyte when the insulator surface is wetted by rain or fog. This allows leakage currents to flow over the insulator surface and lowers the electrical withstand voltage of the insulator, leading to possible flashover. IEC 815[2] describes on four levels of pollution such as Light, Medium, High and Very High. For each level of pollution, the corresponding minimum specific creepage distance for ceramic insulators as per IEC 815 is given in Table 3.2.

Pollution Level	Minimum specific creepage distance (mm/kV)
I-Light	16
II-Medium	20
III-Heavy	25
IV-Very heavy	31

Table 3.2 IEC Recommended specific creepage distance over polluted severity

Different methods are generally used to evaluate pollution severity. They are:

1. Volume conductivity for the pollutant collected by means of directional gauges
2. Equivalent Salt Deposit Density on the insulator surface (ESDD method)
3. Total number of flashovers of insulators strings of various lengths
4. Surface conductance of sample insulators
5. Leakage current of insulators subjected to serve voltage

3.4 Measurement of Contamination Severity

Contamination severity on the surface of insulators can be given in terms of ESDD as explained earlier. The measurement of ESDD in case of porcelain and glass has been standardized in the International Electro technical Commission (IEC) document 60507. ESDD is measured by dissolving the contaminants on the surface of the insulators, in pure water and then measuring the conductivity of the water.

The solution conductivity is calculated using the following formula [1].

$$\sigma_{20} = \sigma_{\theta}[1 - b(\theta - 20)] \tag{3.1}$$

Where, σ_{20} is the volume conductivity at a temperature of $20\,^{0}C$ (S/m)

σ_{θ} is the volume conductivity at a temperature of $\theta\,^{0}C$ (S/m)

θ is the solution temperature (^{0}C)

b is the factor depending on temperature θ

The salinity S (kg/m^3) of the solution is determined, when σ_{20} is within the range of 0.004-0.4 S/m by the use of following formula [1].

$$S_a = (5.7\sigma_{20})^{1.03} \tag{3.2}$$

The Equivalent salt deposit density ESDD (mg/cm2) is then obtained by the formula [1].

$$ESDD = \frac{S_a.V}{A} \tag{3.3}$$

Where, S_a is the salinity (kg/m^3)

V is the volume of the solution (cm^3)

A is the area of the surface of Insulator (cm^2)

3.5 Flashover Mechanism – General Theory

During wet atmospheric conditions like light rain or fog the contamination layer on the surface of the insulator gets wet and promotes leakage current flow along the surface.

The heat dissipated due to the flow of leakage current evaporates the moisture on the surface of the insulator. This evaporation leads to the formation of areas termed as "dry bands." Dry bands tend to form near the surface of the insulator parts where the diameter is the smallest, because of the high current density in those parts. A concentration of voltage stress is formed around the dry bands as the surface resistance of the dry bands is much higher than the conductive contaminated surface film. Subsequently the dry band will break down causing an initial partial arc over the surface. After the formation of a partial arc it will propagate if the voltage gradient ahead of the arc, which is the voltage gradient of the pollution layer, is greater than that of arc gradient. This is due to the fact that ionization of the path ahead of the arc by the increasing current at every instant enables the arc to proceed. When the arc propagation across the contaminated layer bridges the whole insulator a flashover will occur. The flashover triggers a power arc that results in the interruption of power supply and may damage the insulator temporarily or permanently, depending on the severity of flashover.

Though the study of the process of contamination flashover has been done for many decades at different labs and at outdoor locations across the world, the understanding of the physical process is not completed even now. This can be attributed to the intense complexity involved in the flashover process. Also, the numerous parameters involved in the process of flashover make it even more difficult to understand the process completely. As an example it has been observed in service that FOV depends upon various factors but is not limited to such as, the polarity of voltage, particle size, non-uniform wetting, the size and nature of the pollutant surface conductivity, wind, washing, length, orientation, diameter and profile of the insulator.

3.6 HV Testing

The high voltage tests include power frequency tests and impulse tests by applying voltages across the insulator unit arranged properly.

3.6.1 Power Frequency Test

In porcelain insulators, breakdown or flashover occurs in most cases as a result of high frequency disturbances in the power line, these being due to either switching operations or external causes. Sudden interruptions in the line would give rise to resonant effects in the line which would give rise to voltage waves in the line of high frequency. These might cause flashover of the insulators. It is also found that high frequency oscillations cause failure of insulation at a comparatively low voltage due to high dielectric loss and heating. High voltage tests at high frequency are made at the manufacturing works so as to obtain a design of insulator which will satisfactorily withstand all conditions of service.

Dry and Wet flashover Test

In dry flashover test, a power frequency voltage is applied across the insulator, the voltage being increased at a uniform rate of about 3kV/s. The voltage is continuously increased till a flashover occurs across the surface of the insulator.

In wet flashover test, the same procedure is adopted, except that the insulator is subjected to an artificial "rainy" condition. The test unit is subjected to a spray of water of specified conductivity with the help of nozzles which are so arranged that the water drops fall approximately at an inclination of 45° with the vertical. The spray of water on the insulator should begin at least a minute before the application of the voltage and should continue all throughout the test.

3.6.2 Lightning Impulse Test

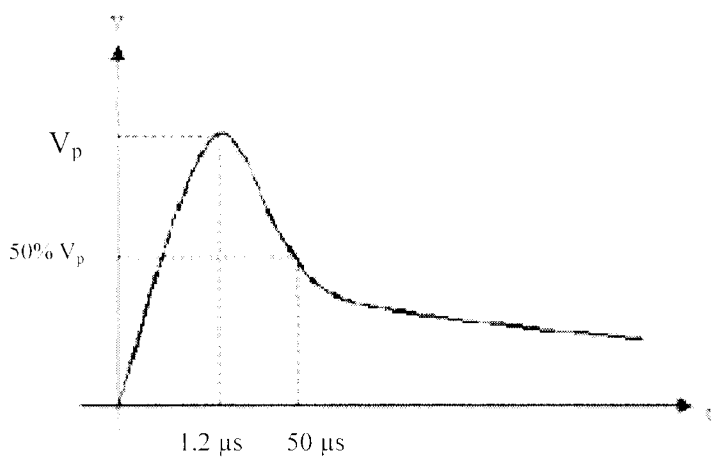

Figure 3.6 Impulse Wave 1.2/50µs

Lightning impulse test is made using a standard 1.2/50μs wave shape as shown in Figure 3.4 with a tolerance of +-30% in the front time and +-20% on half value time on the wave-tail. Impulse generator is adjusted to deliver a positive standard impulse wave. The voltage is then increased to the specified value. Twenty such applications are made and approximately half of the impulses applied should cause flashover.

3.6.3 Flash-over Tests

Porcelain insulators are designed so that spark over occurs at a lower voltage than puncture. thus safeguarding the insulator. in service against destruction in the case of line disturbances. Flash-over tests are very important in this case.

(i) 50 percent dry impulse flash-over test. using an impulse generator delivering a positive 1/50 _s impulse wave.
The voltage shall be increased to the 50 percent impulse flash-over voltage (the voltage at which approximately half of the impulses applied cause flash-over of the insulator)

(ii) Dry flash-over and dry one-minute test.
In this the test voltage (given in the B.S.S.) is applied. The voltage is raised to this value in approximately 10 seconds and shall be maintained for one minute. The voltage shall then be increased gradually until flash- over occurs.

(iii) Wet flash-over and one minute rain test
In this case. the insulator is sprayed throughout the test with artificial rain drawn from source of supply at a temperature within 10 degrees of centigrade of the ambient temperature in the neighborhood of the insulator. The resistivity of the water is to be between 9.000 and 11.000 ohm cm.

In the case of the testing of insulating materials. it is not the voltage which produces spark-over breakdown which is important. but rather the voltage for puncture of a given thickness (i.e. dielectric strength) .
It is found that the dielectric strength of a given material depends. apart from chemical and physical properties of the material itself. upon many factors including.

(a) Thickness of the sample tested

(b) Shape of the sample

(c) Previous electrical and thermal treatment of the sample

(d) Shape, size, material and arrangement of the electrodes

(e) Nature of the contact which the electrodes make with the sample

(f) Waveform and frequency of the applied voltage (if alternating)

(g) Rate of application of the testing voltage and the time during which it is maintained at a constant value.

(h) Temperature and humidity when the test is carried out

(i) Moisture content of the sample.

Chapter 4

Methodology

4.1 Assumptions

1. Three zones have been assumed as Zone 1 (0-300m), Zone 2 (300m-1000m) and Zone 3 (1000m-3000m) based on pollution severity.
2. Porcelain Pin type insulator was selected as a sample. When respective sample insulators are placed in the power line, effect of vegetation which covers the sea breeze hitting on the insulator is considered to be same for all cases.
3. Saline pollution is considered on the insulator and free of industrial pollution.
4. Sample insulators are pin type insulators and having similar surface finish.
5. Conductivity of the tap water to be negligible.

4.2 Selection of Test Sites

Hambantota was selected as a sample area and which was recording no regular rainfall pattern throughout the year like other parts of the country and also having high frequency of insulator flashover. For simplicity, three zones have been assumed as Zone 1, Zone 2 and Zone 3 as per the following distances from the coastal boundary and sample insulators were placed in respective zones.

Zone No.	Zone Type	Distance from coastal boundary (m)
1	Coastal	0-300
2	Semi-coastal	300-1000
3	Inland	1000-3000

Table 4.1 Pollution zones with distance from coastal boundary

4.3 Procedures and Data Acquisition

Sample pin type insulators each with same condition and fresh quality were placed in 33kV distribution network in Hambantota town area within the distance limit and arrangement shown in Table 4.1 so as to represent all three zones.

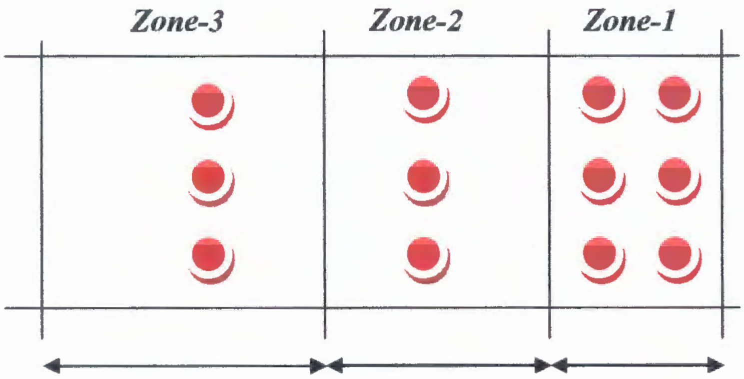

Figure 4.1 Sample insulator arrangements in three zones

Following procedures were adopted to test the conductivity of the above insulators:

1. One insulator from each zone was removed safely from the power line after one month from the installation. The particular insulator was washed with tap water of 1L.
2. Item 1 was repeated after 2nd and 3rd months from the installation of insulators.
3. Item 1 was repeated for ***Zone-1*** for 4th, 5th and 6th month from the date of installation.
4. 500ml sample solutions were obtained from each solution of 1L for conductivity test.

4.4 Measurement of Conductivity

Sample solutions collected having washed the contaminated insulators is subjected for conductivity test. Specification of the conductivity meter is attached in Annex-3.

Figure 4.2 Conductivity Test Meter

Conductivity of the sample solution was obtained using a digital conductivity meter as shown in Figure 4.2. Specification of the conductivity meter is attached in Annex-3.

Conductivity of each solution for Zone-1 is tabulated as follows:

Zone No.	Exposure duration (months)	Conductivity (µs/cm)
1	1	669
	2	699
	3	1180
	4	2500
	5	2030
	6	2190

Table 4.2 Conductivity data for Zone-1

Conductivity of each solution for Zone-2 is tabulated as follows:

Zone No.	Exposure duration (months)	Conductivity (µs/cm)
2	1	547
	2	598
	3	900

Table 4.3 Conductivity data for Zone-1

Conductivity of each solution for Zone-3 is tabulated as follows:

Zone No.	Exposure duration (months)	Conductivity (µs/cm)
3	1	526
	2	586
	3	830

Table 4.4 Conductivity data for Zone-1

4.5 Artificial Contamination of Insulators

An examination of insulators that were in the field for a long time and exposed to various contaminants indicates that the contamination is dispersed fairly uniformly. Based on this it is important to make sure that a uniform layer of contamination is applied on the insulators for the experiments. The contamination slurry to be applied on the insulator is obtained by mixing salt in one liter of water and spraying on top on the insulator. For this experiment, salt in five different weights were mixed with 1L of water samples and sprayed on top of the each insulator expecting wider range of contamination levels which is represented by the ESDD.

Sample Insulator	Salt (g)
1	20
2	50
3	100
4	150
5	250

Table 4.5 artificial contamination on sample insulator

There was several hours elapsed from the time the surface was dry to the time at which they were tested. Five insulators were washed using tap water of 1L and obtained 500ml sample solutions out of them for conductivity test after undergone for power frequency and impulse test.

Sample Insulator	Salt (g)	Conductivity (µs/cm)
1	20	619
2	50	662
3	100	1096
4	150	1541
5	250	1763

Table 4.6 conductivity of artificially polluted insulators

4.6 Power Frequency Test & Impulse Test

Figure 4.3 Sample Insulators before Testing

Five sample insulators as shown in Figure 4.3 applied with different salt levels to represent the contamination were undergone for power frequency test and thereafter the impulse tests as shown in Figure 4.4. This process was repeated for 3 attempts at each test and data were recorded each time to calculate the average value. In each attempt insulators were damped with water spray and thereby created artificial wet condition in the laboratory.

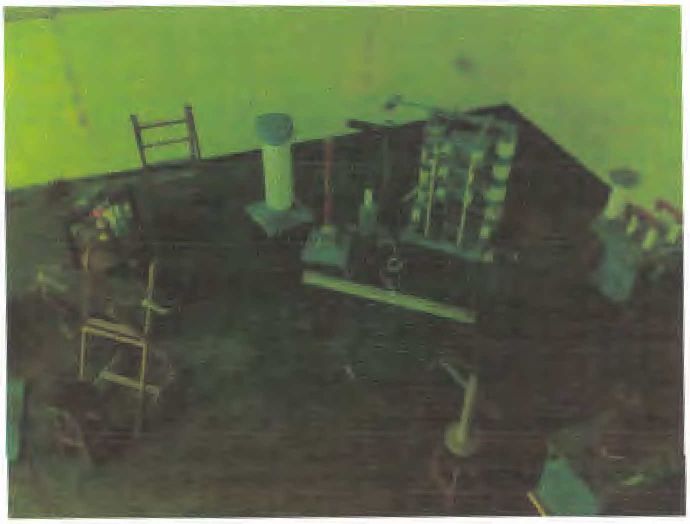

Figure 4.4 Power Frequency and Impulse Test in Laboratory condition

Chapter 5

Result and Analysis

5.1 Calculation of ESDD

By applying data on table No.4, 5 and 6 for equation 3.1, 3.2 and 3.3, ESDD values for respective zones have been calculated and results are tabulated below:

Insulator Exposure period (months)	ESDD (mg/cm^2)		
	Zone-1	Zone-2	Zone-3
1	0.116	0.094	0.090
2	0.121	0.103	0.101
3	0.207	0.157	0.144
4	0.449	N/A	N/A
5	0.362	N/A	N/A
6	0.392	N/A	N/A

Table 5.1 ESDD over Insulator Exposure Period (months)

Above data are plotted in Figure 5.1 for all three zones.

ESDD Level Vs Exposure period

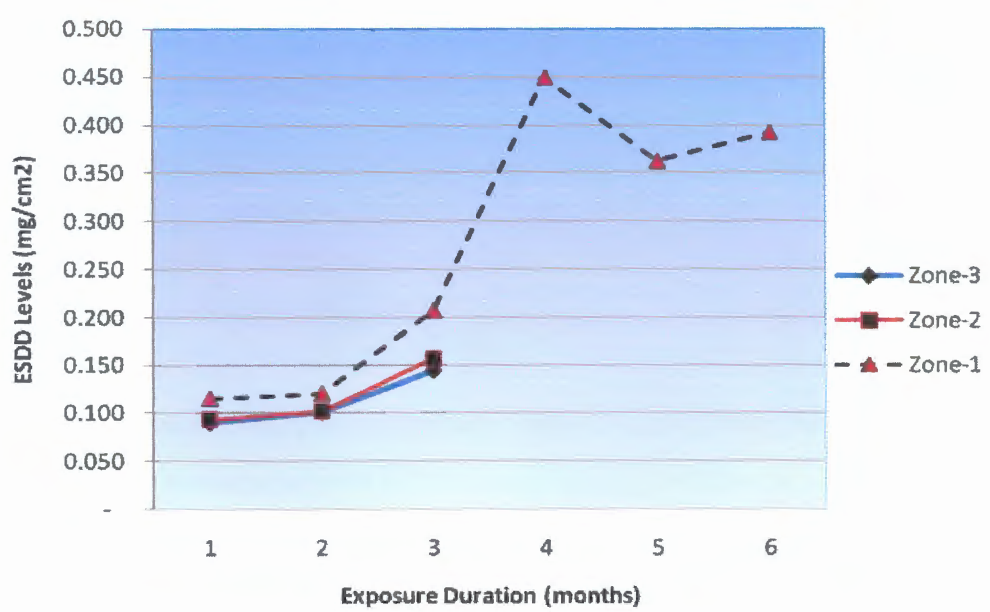

Figure 5.1 ESDD pattern variations

ESDD levels in all zones are varying in having ad-hoc pattern and affected by the rainfall, wind etc. of the area. Insulator exposure test was initiated in May and continued up to September. Rainfall level in Hambantota area is limited as represented by the Figure 5.6. Zone-1 shows higher ESDD level whereas Zone-2 and 3 having almost similar pattern of ESDD variation which is less compared to Zone-1.

5.2 Power Frequency Test Results

ESDD values with respect to artificially contaminated insulators are calculated based on conductivities measured in Table 4.6. All insulators have been undergone the test for 3 attempts and thereby calculated the average values for each cases.

Insulator	ESDD (mg/cm^2)	Flash over voltage (kV)			
		1st Attempt	2nd Attempt	3rd Attempt	Average
1	0.107	95	90	85	90
2	0.114	100	95	90	95
3	0.192	65	70	60	65
4	0.273	65	60	55	60
5	0.313	50	45	40	45

Table 5.2 Flashover Voltage under different pollutant levels

Tabulated data in above Table 5.2 are plotted in Figure 5.2. Trend curve for the experimented results is exponential. The curve has been extrapolated for more values of ESDD based on the tabulated results.

The operating voltage V_{PE} (phase to Earth Voltage) in 33kV system is 19kV. Then, the insulator to be flashover under operating voltage of 19kV, ESDD value should reach to 0.6 mg/cm^2 value as shown in Figure 5.2.

Further, a non contaminated insulator was subjected for power frequency test and observed flash over voltage of 100kV.

Flashover voltages Vs ESDD (Power frequency Test)

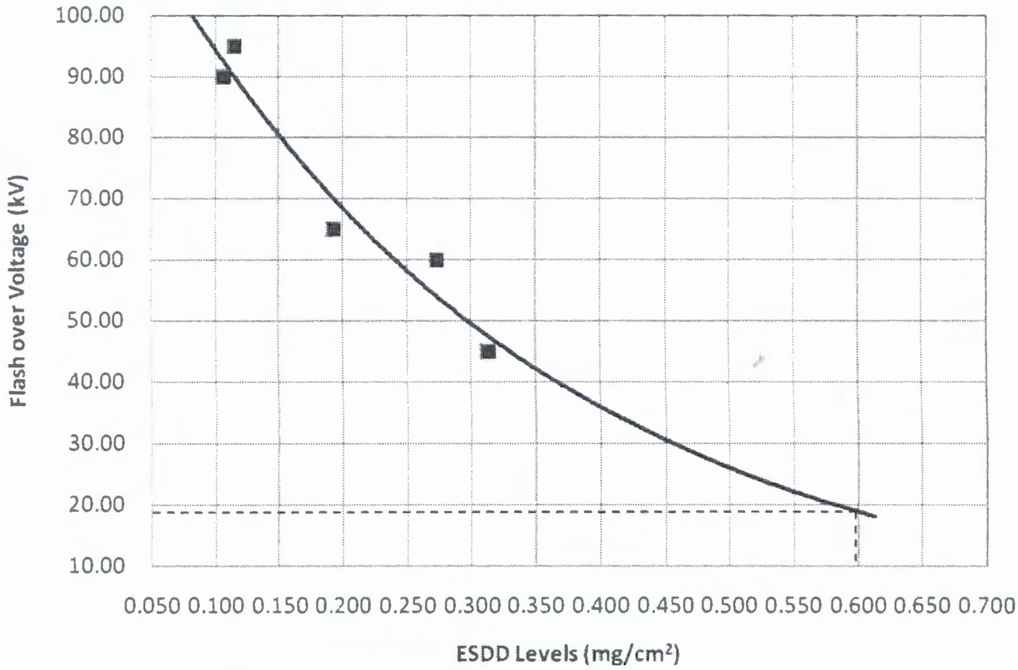

Figure 5.2 Flashover Voltage variations under power frequency test

5.3 Impulse Test Results

All insulators have been undergone the test for 3 attempts and thereby calculated the average values for each cases.

Insulator	ESDD (mg/cm^2)	Flash over voltage (kV)			
		1st Attempt	2nd Attempt	3rd Attempt	Average
1	0.107	95	90	85	228
2	0.114	100	95	90	232
3	0.192	65	70	60	210
4	0.273	65	60	55	204
5	0.313	50	45	40	192

Table 5.3 Flashover voltages Vs ESDD (Impulse Test)

Tabulated data in above Table 5.3 are plotted in Figure 5.3. Trend curve for the experimented results is exponential.

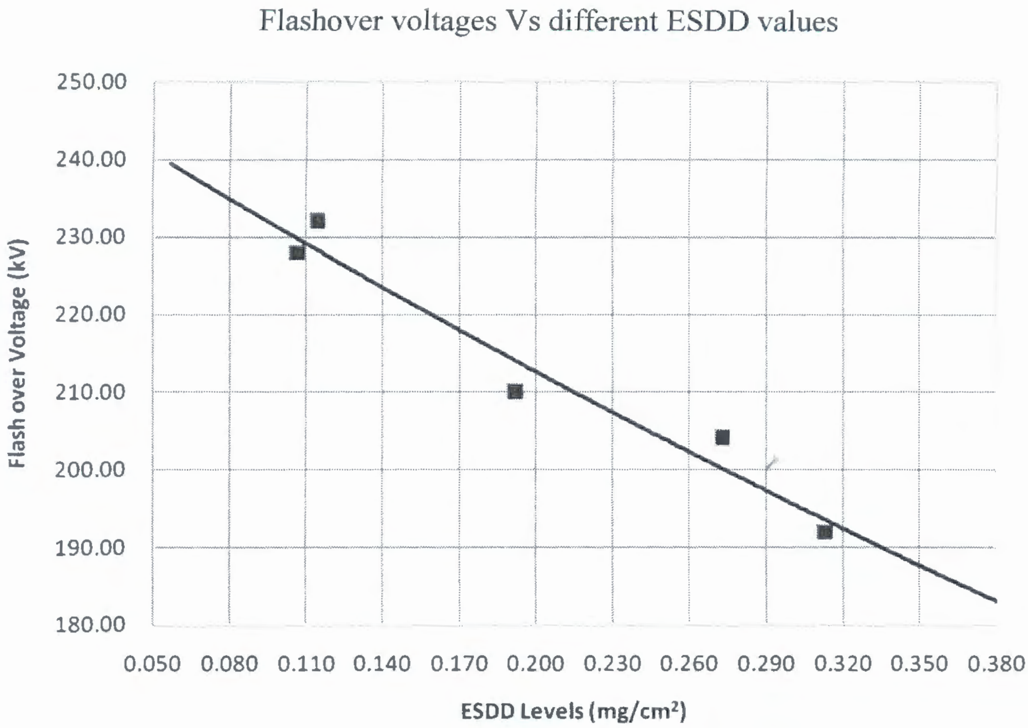

Figure 5.3 Flashover voltages under different ESDD values

Further, a non contaminated insulator was subjected for impulse test and observed flash over voltage of 240kV.

5.4 Prediction of Flashover Voltages under Power Frequency and Impulse Test

Based on figure 5.2 and 5.3, flashover voltages under two tests are predicted by the trend curve and tabulated below for some ESDD values.

ESDD (mg/cm^2)	Flashover Voltage (kV)	
	Power Frequency Test	Impulse Test
0.1	94.36	231.01
0.2	68.38	212.61
0.3	49.55	195.67
0.4	35.91	180.09
0.5	26.03	165.75
0.6	18.86	152.54

Table 5.4 Predicted flashover voltages Vs ESDD

5.5 Preventive Maintenance

In zones where there is pollution, besides a good selection of the insulator, it is advisable to have a maintenance plan to treat the insulators. This is more important in areas with severe environments of pollution or low rain probability, being necessary the elimination of the pollutant layer placed on the insulator. This maintenance can be carried out with the system energized, washed in hot, or de-energized.

Figure 5.1 shows the variation pattern of ESDD against insulator exposure duration based on the results obtained through insulator exposure under field condition. Further, Figure 5.1 is elaborated zone wise separately to forecast on preventive maintenance procedure.

Figure 5.4 shows ESSD variation pattern over exposure duration for Zone-1.

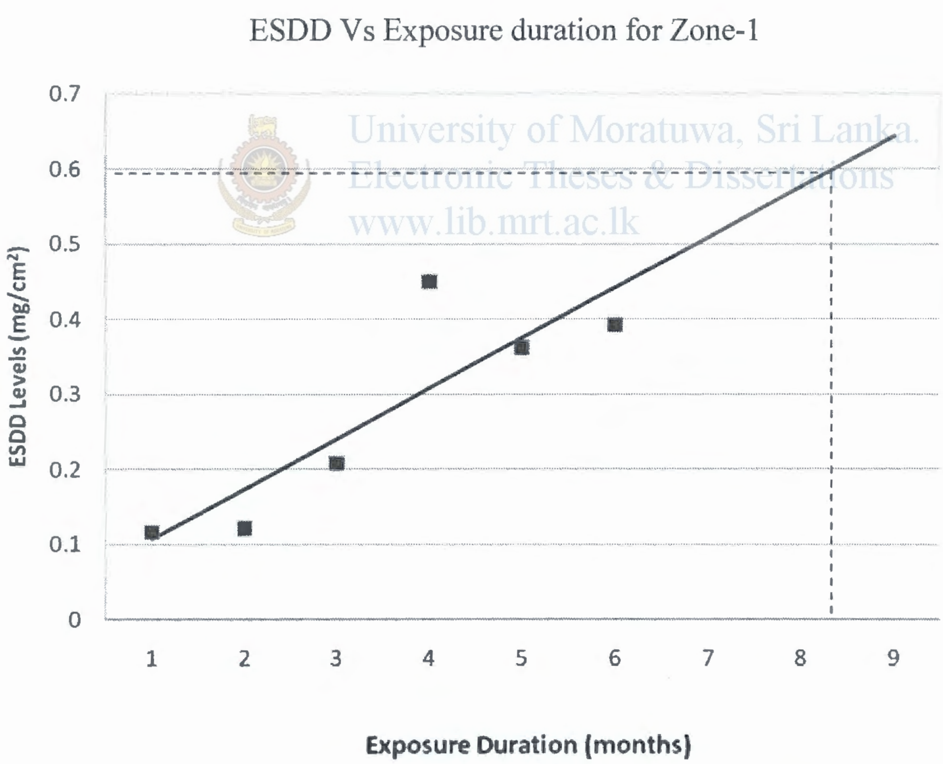

Figure 5.4 ESDD variations under exposure duration for Zone-1

ESDD values for Zone -1 are plotted against insulator exposure duration of 6 months period. The actual trend for data points would probably be not linear if the study is carried out over longer period. Having assumed a linear trend line, the curve is drawn and it cuts the 0.6 mg/cm^2 ESDD value (relates the operating voltage of 19kV) at 8th month. This implies that insulators have to be cleaned artificially or naturally after 8 months from the date of fist cleaning.

Similar analysis carried out for Zone-1, is applied for Zone-2 and Zone-3 as well. Since the exposure duration for both Zone-2 and Zone-3 is only 3 months and to reach more accuracy, linear trend curve is correlated with extrapolation as shown in Figure 5.5 and Figure 5.6 respectively (Exponential curve was not considered as the experimented data shows an incremental nature and may not represent practical scenario due to environmental changes like rain, wind etc. time to time.).

Figure 5.5 and Figure 5.6 show the variation pattern of ESDD over exposure period of 3 moths and data have been extrapolated for certain period.

ESDD Vs Exposure Period for Zone 2

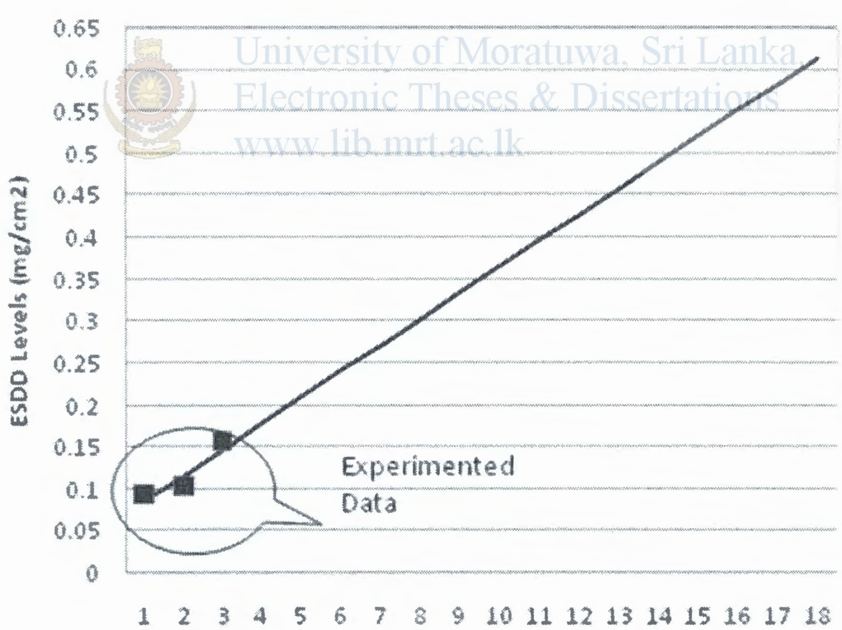

Figure 5.5 ESDD variations under exposure Period for Zone-2

ESDD Vs Exposure Period for Zone-3

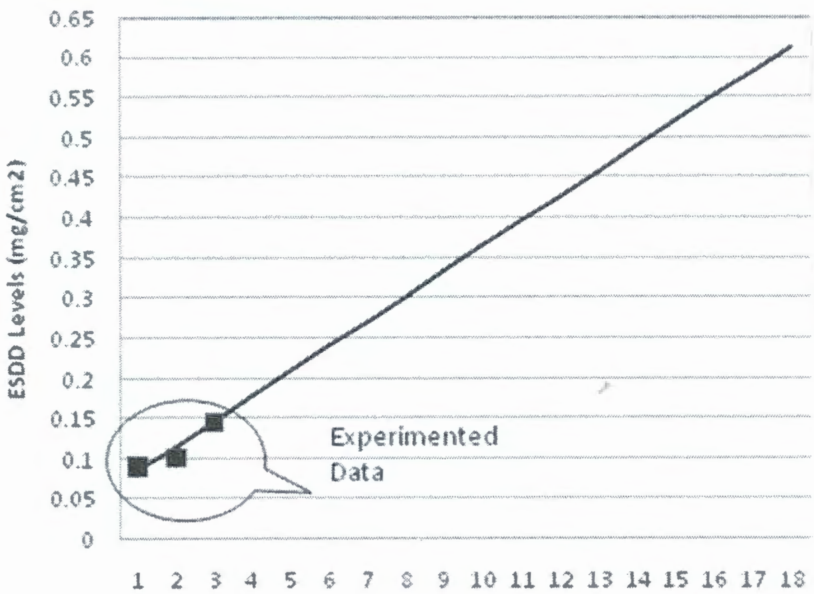

Figure 5.6 ESDD variations under exposure Period for Zone-3

When trend curves for Figure 5.5 and Figure 5.6 are drawn, the curve cut the 0.6 mg/cm^2 ESDD value (relates the operating voltage of 19kV) at 18^{th} month for both zones. This implies that insulators have to be cleaned artificially or naturally at 18 month from the date of fist cleaning for both Zone-1 and Zone-2. Above results for all three zones are summarized below:

Zone No.	*Zone Type*	*Coverage from coastal boundary (m)*	*Recommended insulator cleaning period (months)*
Zone-1	Coastal	0-300	8
Zone-2	Semi-coastal	300-1000	18
Zone-3	Inland	1000-3000	18

Table 5.5 Zone wise recommended Preventive Maintenance

There are certain remedial actions which could be practiced to treat the insulators under preventive maintenance mode.

Washing

Insulators can be washed when de-energized or when energized. Under de-energized manpower is utilized and considerable maintenance cost is incurred for this purpose. Automatic washing is done under energized condition.

Greasing

A thin layer of silicon grease, when applied to ceramic insulators increases the hydrophobicity of the surface. Pollution particles that are deposited on the insulator surface are also encapsulated by the grease and protected from moisture. Nevertheless, this is costly and requires a periodic maintenance to remove and reapply the layer.

Coating

Silicone rubber coatings are available to be used on ceramic insulators. But research is still in progress to evaluate their aging processes.

5.6 Rainfall and Thunder Day Analysis

Rainfall and thunder day analysis for Hambantota district is carried out below based on data obtained from Metrological department of Sri Lanka.

5.6.1 Rainfall Data Analysis

Rainfall pattern in Hambantota for the past three years has been analyzed as rain could play a major roll as far as insulator natural cleaning is concerned.

Month	*Year 2007*	*Year 2008*	*Year 2009*
January	230.2	23.2	31.1
February	15.2	18.5	9.3
March	20.3	237.4	30.4
April	198.8	66.4	25.8
May	2.5	11.4	55.6
June	59.8	28.5	47.4
July	27.6	62.2	25.3

Table 5.6 Rainfall data analysis

Tabulated data in Table 5.6 are plotted in Figure 5.7.

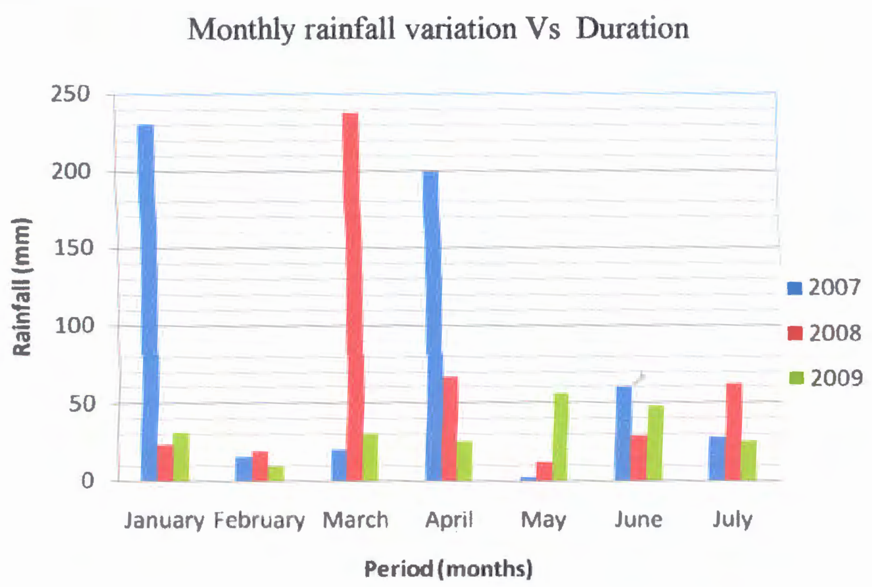

Figure 5.7 Monthly rainfall variation for year 2007,2008 and 2009

Furthermore, rainfall data is catogarized into certain modes as shown in Table 5.7 based on the amount of rainfall recorded in a particular area.

Rain Type	*Rainfall range (mm)*
Light	Below 12.5
Light to moderate	12.5-25
Moderate	25-50
Fairly high/Heavy	Above 50

Table 5.7 Rainfall categorization

In year 2007, heavy rainfall has been recorded in January and April as 230.2mm and 198.8mm respectively. Other than that 59.8mm rainfall is recoded in June and all other months' rainfall is below 30mm. In year 2008, heavy rainfall has been recorded in March as 237.4mm whereas 66.4mm and 62.2mm rainfall have been recorded in April and July respectively. Rainfall is well below 30mm in all other months. In year 2009, from January to July rainfall is placed in moderate level which is below 50mm.

With all above facts, it is obvious that rain pattern in Hambantota in not regular but having less rainfall pattern far as a year is concerned. So the natural cleaning of insulator is unpredictable and need more concern on a preventive maintenance procedure.

5.6.2 Thunder Day Analysis

Thunder days in Hambantota for the last three years have been tabulated based on the data obtained from metrological department of Sri Lanka.

Month	***Year 2007***	***Year 2008***	***Year 2009***
January	2	1	1
February	2	1	0
March	1	14	10
April	15	2	4
May	0	0	5
June	3	2	0
July	2	2	0

Table 5.8 Thunder day Analysis for year 2007, 2008 and 2009

Tabulated data in Table 5.8 are plotted below in Figure 5.8.

Thunder day analysis Vs Duration

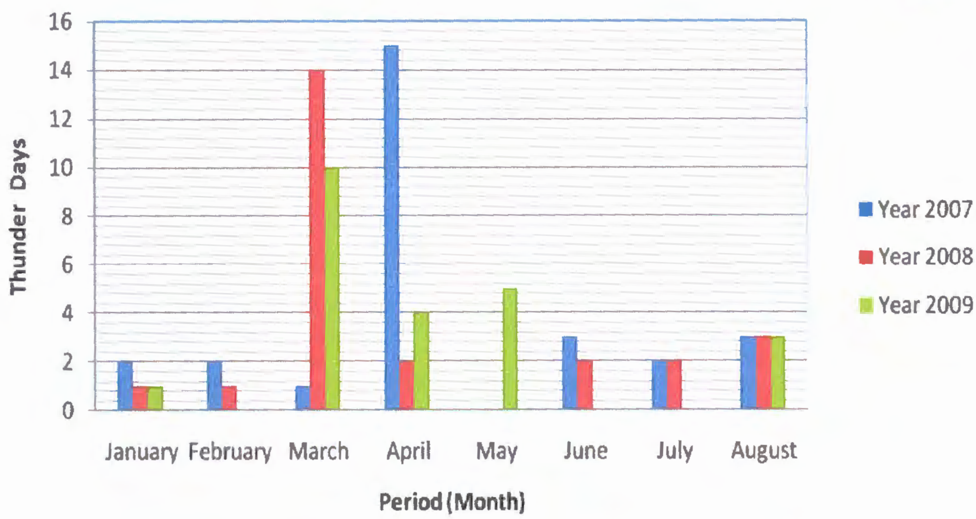

Figure No.5.8 Thunder day analysis

No. of thunder days have been reported to be higher in March or April in each year.

5.7 Calculation of Specific Creepage Distance

Specific Creepage Distance (SCD) = Creepage Distance/V_{L-L}

Creepage distance for 33kV pin insulator -900mm

V_{L-L} -36kV

Specific creepage distance for 33kV pin insulator (900/36) = 25 mm/kV

IEC 815 regulation [2] describes relationship between pollution levels and artificial pollution test as follows.

Pollution Level	Specific Creepage Distance (mm/kV)	SDD (mg/cm^2)
I-Light	16	0.03-0.06
II-Medium	20	0.1-0.2
III-Heavy	25	0.3-0.6
IV-Very heavy	31	-

Table 5.9 Relationship between pollution levels and artificial pollution test

The analysis has been done using pin type insulators of 25mm/kV specific creepage distance and recommended pollution severity could be 0.3-0.6mg/cm^2 as per IEC 815. Figure 5.2 states that cut-off limit of pollution severity under operating voltage (33/sqrt(3)=19kV) is considered as 0.6mg/cm^2 whereas Figure 5.4, 5.5 and 5.6 state that insulators have to be treated before reaching this pollution severity.

It is obvious from above analysis that no requirement emerge to increase the specific creepage distance from 25mm/kV to the next upper level provided the insulators treatment are done according to proposed procedure under preventive maintenance explained in Table 5.5. Table 5.9 describes one important fact that the possibility of using lower specific creepage distances such as 16 and 20 for inland sites where lowers ESDD levels is assumed.

Chapter 6

Conclusion and Recommendations

6.1 Conclusion

CEB has not yet adopted any streamlined process for treating contaminated insulators under preventive maintenance. Under this study, an effort has been taken to introduce a certain mechanism as to which period insulators could be treated and the types of remedial actions to be taken and the optimal solution.

Severest pollution is experienced in the coastal area which is 0-300m range in the coastal boundary. However, at semi-coastal and inland sites ESDD is almost an order of magnitude lower than that experienced in the coastal belt. Figure 5.1 show that both Zone-2 and Zone-3 are almost overlapping each other. Study implies that insulators in the Zone-1 has to be treated after 8 months from the date of last washing under preventive maintenance and same has to be done in after 18 months for Zone-2 and Zone-3.

Site conditions have been represented in laboratory conditions by applying artificial pollution on five sample insulators which were subjected for power frequency and impulse tests to analyze the flashover voltages.

The decrease of pollution will depend on the type of insulator, the maintenance, the increase of the creepage distance, a better design of the insulators etc. They are subjected to conditions that depend on the place in which they are installed. These conditions can vary extensively from a place to another, depending on the characteristics of the region considered. These characteristics make possible that the level of insulation required can vary in the same line, due to the conditions of the pollution are different for all the line. The weather factors influence in a very important way on the growth of the pollution levels in a region.

6.2 Future Recommendations

Insulator coating on top of the insulator could be recommended to treat the insulators under preventive maintenance, but which has to be proven with a comprehensive study. Greasing is not recommended as it requires regular maintenance for removing grease and recoating and is expensive.

An Insulator Pollution Monitoring Relay (IPMR) has been developed to monitor the severity of pollution on insulators by measuring the surface conductivity. The IPMR measurements can then be utilized to indicate whether the surrounding insulator should be cleaned [10].

Table 5.5 states recommended preventive maintenance period under this study. However exposing insulators for at least 2 years is necessary to tune up the results. In that regard, 33kV pole line of 2km distance which runs in the coastal zone exposing to the sea breeze is suggested to be selected as a sample area. Each pole line consists of 3 insulators for three phases and poles are generally located in 60m span. For 2km length, there would be around 96 insulators. At the end of each month, 4 insulators to be washed at four different places of the same power line and then subjected for conductivity test. Thereby 93rd, 94th, 95th and 96th insulators would be washed at the end of 2nd year. In such a manner, an average ESDD value would be calculated in each month based on the four conductivity readings. The average ESDD values are plotted over the exposure period of 2 year to obtain a clear picture with respect to saline variation pattern in the area.

In clause 5.7, specific creepage distance of the 33kV pin type insulator is derived as 25mm/kV. If insulators are treated as per the recommended schedule (Before reaching 0.6 mg/cm^2 ESDD level), need of increasing creepage distance is not emerged to get away from insulator flash over. CEB is installing 25mm/KV insulators in distribution network in inland sites irrespective of pollution severity. Hence, requirement of higher specific creepage distance like 25mm/kV for inland sites where pollution severity is minimum, has to be reviewed through a comprehensive analysis which could be exercised exposing insulators with different specific creepage distances (16, 20 and 25 mm/kV) at real site condition for well over 2 years. If required level of specific creepage distance for inland sites could be reduced to 16 or 20. with which considerable savings can be achieved on insulators.

It is indeed essential to study the antipollution performances of glass insulators over porcelain insulators with the same profile and for this a comprehensive study is needed to find the optimum solution having exposed both types of insulators under same field condition for a reasonable period.

References:

[1] IEC Publication 60507, "Artificial Pollution Tests on HV Insulators to be used on AC Systems", Second Edition, 1991.

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[3] F. Zedan, M. Akbar, A. Farag and H. Zarzoura, "Insulator Contamination Research in Saudi Arabia", March 1989.

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[8] IEC Publication 71-2, "Application Guide", Part 2, Third Edition, 1996.

[9] S. Ray, An Introduction to High Voltage Engineering, Pantnagar, India, 2004.

[10] W.H. Schwardt, J.P. Holtzhausen, W.L. Vosloo, "A comparison between measured Leakage Current and Surface Conductivity during Salt Fog Tests", Stellenbosch, South Africa.

33 KV Pin type Insulator flashover – Hambantota in year 2009

Month	Date	Observed Time	Location	Nos of Insulator flashover
April	08 09 10	- - -	Hambantota Habour Bank of Ceylon/Hambantota Mahanagapura	03 05 01
May	02 05 20	- - -	Hambantota Habour Mirijjawila Mirijjawila	02 01 01
June	08	-	Hambantota Hospital	01
July	25	-	Hambantota Town	01

33 KV Pin type Insulator Flashover -Tissamaharamaya in year 2009

Month	Date	Observed Time	Location	Nos of Insulator flashover
April	25 28	3.30 p.m 3.50 p.m	Kirinda Kirinda	1 1
May	12	5.15 p.m	Konwalana	1
July	15 16 19 20 21 30	7.30 a.m. 8.00 a.m. 4.00 p.m. 7.30 p.m. 10.00 a.m. 7.30 a.m. 10.30 a.m. 8.30 p.m. 9.50 p.m.	Yala Yala Waladora Modarapelessa Yala Waladora Waladora Yala Kasingama	01 01 03 01 01 01 01 02 01
August	08 21	4.30 p.m. 7.30 a.m.	Kasingama Yala	01 01
September	09 10 13 14 16	7.30 a.m. 9.15 a.m. 4.30 p.m. 9.10 p.m. 7.00 a.m.	Dodana Waladora Yala Kasingama Waladora	01 01 01 01 04

SPECIFICATIONS	CON510
Conductivity Range	0 to 20.00, 200.0, 2000μS/cm; 0 to 20.00, 200.0 mS/cm
TDS Range	0 to 10.00, 100.0, 1000 ppm; 0 to 10.00, 100.0, 100 ppt (max. 200 ppt depending on factor setting)
Resolution	0.05% Full Scale
Accuracy	+-1% Full Scale
Temperature Range	0.0 to 100.0 ^{0}C: 32.0 to 212^{o}F
Temperature Resolution/ Accuracy	0.1 /0.5^{o}C or 0.9^{0}F
Cell Constant	0.1, 1.0, 10.0 (Selectable)
Temperature Compensation	Automatic/ Manual (from 0 to 100^0 C)
Temperature Coefficient	0.0 to 10.0%/^{o}C
Normalization Temperature	15.0 to 30.0 ^{o}C (adjustable)
Conductivity to TDS Conversion factor	0.40 to 1.00
Number of calibration points (Automatic)	4; Maximum 1 per range
Number of calibration points (Manual)	1; Maximum 1 per range
Auto-ranging	Yes
Hold Function	Yes
Memory	50 data sets
Averaging/Stability (READY)/Auto-hold	Selectable
Input	6-pin round connector
Display	Custom Dual LCD
Power Requirements	110/220VAC mains, 50/60 Hz
Dimension	230 x180 x63 mm (meter only); 395x 260x 90 mm (boxed)
Weight	750 gm (unit); 1250 gm (boxed)

Rainfall Data - Hambantota

Month	2007	2008	2009
January	230.2	23.2	31.1
February	15.2	18.5	9.3
March	20.3	237.4	30.4
April	198.8	66.4	25.8
May	2.5	11.4	55.6
June	59.8	28.5	47.4
July	27.6	62.2	25.3
August	230.2	23.2	31.1
September	15.2	18.5	9.3
October	20.3	237.4	30.4
November	198.8	66.4	25.8
December	2.5	11.4	55.6

Climate Division,
Department Of Meteorology,
Colombo.
29.09.2009

No. of Thunder days - Hambantota

Month	2007	2008	2009
January	02	01	01
February	02	01	00
March	01	14	10
April	15	02	04
May	00	00	05
June	03	02	00
July	02	02	00
August	03	03	03
September	04	00	
October	05	05	
November	11	08	
December	03	04	

Climate Division.
Department Of Meteorology.
Colombo.
29.09.2009