# "STUDY OF INSULATION LEVEL OF THE TRANSMISSION SYSTEM IN BANGLADESH & POSSIBLE CAUSES OF INSULATION FAILURE"

A
THESIS
SUBMITTED
TO THE DEPARTMENT
OF ELECTRICAL ENGINEERING
BANGLADESH UNIVERSITY OF ENGINEERING
AND TECHNOLOGY, DACCA, IN PARTIAL FULFILMENT
OF THE REQUIREMENTS FOR THE DEGREE OF MASTER
OF SCIENCE IN ENGINEERING (ELECTRICAL)



BY

MD. SHARIFUL ISLAM

DEPARTMENT OF ELECTRICAL ENGINEERING
BANGLADESH UNIVERSITY OF ENGINEERING
AND TECHNOLOGY, DACCA

1975

ACCEPTED AS SATISFACTORY FOR PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF M.SC.ENGINEERING IN ELECTRICAL ENGINEERING.

EXAMINERS:

(i) ____________________

(ii) ____________________

(iii) ____________________

(iv) AHM Abdur Rahim

# CERTIFICATE

THIS IS TO CERTIFY THAT THIS WORK WAS DONE BY ME AND IT HAS NOT BEEN SUBMITTED ELSEWHERE FOR THE AWARD OF ANY DEGREE OR DIPLOMA OR FOR PUBLICATION.

Countersigned

Supervisor.

Signature of the Candidate.

ACKNOWLEDGEMENTS

THE AUTHOR WISHES TO ACKNOWLEDGE HIS INDEBTNESS TO PROFESSOR DR. A. M. ZAHOORUL HUQ FOR SUGGESTING THE PROBLEM, FOR GUIDANCE AND FOR CONSTANT ENCOURAGEMENT IN THE COURSE OF THE WORK.

THE AUTHOR ALSO WISHES TO GRATEFULLY ACKNOWLEDGE THE ASSISTANCE FROM THE DEPARTMENT OF ELECTRICAL ENGINEERING, BANGLADESH UNIVERSITY OF ENGINEERING & TECHNOLOGY FOR PROVIDING SUCH FACILITIES AS WERE REQUIRED FOR THE RESEARCH WORK.

THE AUTHOR WISHES TO EXPRESS HIS DEEP SENCE OF APPRECIATION TO THE AUTHORITIES OF BANGLADESH POWER DEVELOPMENT BOARD FOR GIVING PERMISSION TO PERFORM THIS WORK.

THE AUTHOR ALSO GRATEFULLY ACKNOWLEDGE THE ENCOURAGEMENT FROM DR. M.A. RAHMAN ASSOCIATE PROFESSOR ELECTRICAL ENGINEERING IN THIS WORK.

THE ASSISTANCE FROM MR. MD. ABU BAKER, STENO-TYPIST OF GRID MAINTENANCE DIVISION-1, & MR. MD. RAFIQUL ISLAM, STENO-TYPIST, LOAD DESPATCH DIVISION, BANGLADESH POWER DEVELOPMENT BOARD IN PRINTING & TYPING OF THE THESIS IS THANKFULLY ACKNOWLEDGED.

## ABSTRACT


Insulation strength ofthe transmission lines and trip-pouts of the same depend on the tower footing resistance and isokeraunic level of the country. Specific resistivity of soil has been measured experimentally. Tower footing resistance calculated analytically and measured experimentally. Span length, mid span clearance, protective angle and coupling factor of the transmission line has been measured from the actual construction of the transmission line.

Annual isokeraunic level of the country has been determined after collecting number of thunder storm days of the recording stations of meteorological department throughout the country. Average annual isokeraunic level comes out to be 50.

Value of lightning currents have been taken from the international curves. Insulation strength of the transmission lines for calculated footing resistance and coupling factor comes to be 1630 KV. Outage probability of the transmission lines have been calculated analytically and the results have been compared with the actual outage of the transmission lines.

Incidents of insulation failures have been studied to find out reasons of such failures.

TABLE OF CONTENTS

## LIST OF FIGURES

# CHAPTER - 1

## 1.1. INTRODUCTION:

Determined by the availability of natural resources, the designers have to build big Power Stations away from the load centres. For transmission of bulk power from the generating stations to different load centres, it is needed to build long high voltage transmission lines. Insulation strength of transmission system should be such that outage of the transmission lines due to insulation failure should be minimum and the cost involved for insulation strength provided to the transmission lines should be economically justified. It is aimed to keep damage to equipments due to insulation failures to minimum. Outage of the transmission line should be minimum for stability of the system and reliability of power supply to consumers.

Insulation of the transmission line is subjected to stresses due to over voltage developed on the system. Neglecting normal frequency voltage, overvoltages are developed in the system due to switching, system faults and lightning strike on the transmission line. Outage of the line occur when the line insulation is subjected to voltages, higher than the designed insulation strength. Line outages, other than those due to lightning, are more less under control but lightning remains as one element which are not under complete control. The over voltage developed on the transmission line due to lightning is dependant on nature of lightning surges, tower footing resistance, tower inductance, tower height, span length, protective angle and coupling factor.

The Isokeraunic level and the tower footing resistance play an important role on the number of outage of the transmission lines. The higher is the isokeraunic level, more is the number of outage of the transmission lines, Tower footing resistance depend on specific resistivity of the soil and the number of outage of the transmission is higher when the tower footing resistance is greater.

The annual isokeraunic level of the Bangladesh has been determined and tower footing resistance measured to find out the insulation strength of the transmission line and the number of outage of the same. Outage of the transmission line due to lightning flash-over can be minimized by increased insulation strength of the transmission line and decreeasing the tower footing resistance. Ground wires with sufficient mechanical strength must be located to shield the line conductors adequately from direct strokes. Adequate clearance from the line conductor to the tower or ground must be maintained so that full effectiveness of the insulating structure can be obtained. Adequate drainage facilities and adequate insulator strengths are to be provided so that lightning discharge can drain to the ground without affecting conductors and without interference with flow of normal frequency current.

A thorough study has been conducted to enumerate the insulation strength provided to the transmission line in the light of natural conditions such as annual isokeraunic level and tower footing resistance. The number of outage of the transmission line calculated have been compared with actual outage of the same.

Incidents of insulation failures have been studied. Tripouts due to lightning have been compared with total failures of the system.

## 1.2. THE PROBLEM.

In Bangladesh major generating stations have been set up in the Eastern and north Eastern part of the country: Hydro electric station at Kaptai and other four big thermal power stations at Shahjibazar, Ashuganj, Ghorasal and Siddhirganj. Thermal Generating Stations have been installed in those places due to obvious reasons of availability of natural gas and the hydro stations on the Karnafully river. Long transmission lines have been built for interconnecting these generating stations and transmitting the bulk power to different load centres.

The country is divided into two parts Eastern and Western by Brahmaputra river. In western part there have been no such facility for establishing generating plants depending on the own resources of the country as of the Eastern part.

At present the 132 K.V. Grid system is divided into two parts: Eastern Grid and Western Grid. An interconnection between the two grids, for transmitting bulk power generated at low cost in the Eastern Grid, is yet to be completed.

In the Eastern Grid there are two long transmission lines:

1. Siddhirganj-Kaptai 132 K.V. transmission line is a double circuit one and 170 miles long. This transmission line transmits power from Kaptai Hydro Power Station to load centres at Chittagong, Comilla and Dacca. Part of the transmission line passes through the hilly area of Chittagong. Meghna & Sitalakhya river have been crossed by 132 K.V. oil filled submarine cables.

2. The 155 mile long Siddhirganj-Sylhet 132 K.V. transmission is a double circuit one and connects all the gas fired power stations mentioned earlier. This line transmits power to load

centres at Dacca and Sylhet areas. The height of Meghna river crossing towers are 275' ft. and span length between the river crossing tower is 2756' ft. some portion of transmission line passes through hilly areas of Sylhet district. In the Western Grid: Ishurdi-Goalpara 132 K.V. line is 110 mile long. This transmission line transmit power from Goalpara power Station to load centres at Ishurdi and other places.

Besides these existing transmission lines other transmission lines are being added in both Eastern and Western Grids. Although these lines are designed and constructed on the basis of protection against direct stroke of lightning, trip outs of the lines are very frequent, specially during monsoon period. As a result of these outages the consumers incur huge loss of production and Bangladesh Power Development Board incurs loss of revenue and reputation.

Our aim is to study the problem of such outage; whether this is due to inadequacy of insulation strength of the transmission system. The local conditions such as soil resistivity, tower footing resistance and the number of thunder storm days may have certain effects on the design of insulation strength of the transmission line and to find a remedial measures for

for over coming the problem.

## 1.3. LITERATURE SURVEY:

At the beginning, a power system consisted usually of a small generators supplying power to localized areas. The size of power systems began to increase with passage of time and industrial revolution throughout the world. High voltage and extra high voltage transmission lines came into being for transmitting bulk power. With the increase of transmission line voltage, increased insulation strength of the equipments of the system have been provided. Increased insulation strength will add more cost to the transmission line.

Prior to the direct stroke theory the designers did not attempt to protect lines from direct stroke and it was thaught to be impossible to cope the direct strokes and lines were designed on the basis of induced strokes. With increassed knowledge about lightning strokes, the transmission lines and equipments connected with it have been insulated to with stand over voltage produced by direct strokes of lightning. The insulation strength of transmission line have been designed for a desired performance. Methods of combating direct strokes started as early as 1929. Some of the works in the field are mentioned below:

"Grounding Electric circuits Effectively" by J. R Eaton (1). This work has furnished methods of measuring soil resistivity and ground resistance. The effect of tower footing resistance on the number of outage of the transmission lines have been shown. But it has not dealt the insulation strength of transmission line and effect of isokeraunic level on the outage probability of the transmission line.

"Electrical Resistivites Tests On Barrie-Scarborough 110 kv Transmission Line" report ofthe Hydro-Electric Power Commission of Ontanio, Canada (2). This work has furnished variation of tower footing resistance, shown relation between soil resistivity and tower footing resistance but effect of those on the insulation strength of transmission line has not been discussed.

"The Transmission Line Tower Grounding in Rugged Country" a report of the Hydro - Electric Power Commission of Ontario, Canada (3). This report furnished methods of improvement of tower footing resistance in rugged country by using long grounding roads, counterpoise and crow feet. It did not state the effect of local soil properties on the insulation strength of transmission line.

"Electrical Transmission and Distribution Reference Book" by Westing house Electric Corporation U S A [4]. This book has shown works carried out earlier in this connection. In 1930 Dr. C. L. Fortesque published an article "Direct Strokes Not Induced Surges Chief Cause of High Voltage Line Flash Over". The theory is now completely accepted for high voltage lines and the induced strokes is of no significance. Performance of lines based on direct strokes have been discussed. Waldorf's curves for probabilities of outage have been furnished and the methods of determining insulation strength of transmission lines based on the tower footing resistance and midspan clearance have been formulated. Nothing have been said about the effect of lightning current due direct strokes.

"The Selection of Insulation levels and Tests for High Voltage Transformers -- by G. B. Harpar, Proc. Inst. Elect. Engr. Paper 28045 Publication January, 1959 p 10[5]. This work deal with insulation strength of high voltage transformers only.

"Tropicproofing Electrical Equipment" by Miroslav Rychtera and Benorda Bartakova [6]. This book has shown the change of property and performance of electrical equipments depending on the climatic zones of the world. But no specific cause and type of failures have been discussed about any particular place such as Bangladesh.

"Geoelectric resistivity survey in Bangladesh, 1968, by Dr. K. Depporman and Dr. J. Theile [7]. In this work specific resistivity of the soil of Bangladesh have been measured.

"Vistas in Electric Power " by Philip Sporn [8]. Field investigation of lightning incidents on 132 kv line of American Gas and Electric Co. have been carried out and the effect of footing resistance on the outage of the transmission line have been discussed. But there is no evaluation insulation strength of the transmission line depending on the lower footing resistance and high annual isokeraunic level.

"Design Transmittals East-West Interconnector Projetts" by Bangladesh Power Development Board 1970 [9]. It has stated that the insulation level of the proposed 132/230 kv transmission has been set at 1395 kv. The details of local factors for calculating the insulation strength have not been mentioned.

"Lightning Invistigation on 220 kv Steel tower Transmission Line". by A.Cewe of Gdansk Technical University, High Voltage institute [10]. This dealt with measurement of lightning current but the effect of the same on the transmission line insulators have not been considered.

"Electro Dynamic Consideration of Lightning Problems" by Stanislow Szpor, Gdansk, Poland [11], furnish information about formation of charges inside the thunder cloud and theoretical calculations of field components.

"A Proposal of a Method of Lightning Protection Calcu - lations for Transmission Lines" by Stanislaw Szpor, Gdansk, Poland [12]. This work furnished some formulas for calculations of induced over voltage on transmission towers and their effect on insulator strings.

"International curves of lightning currents and their application for protection calcules" By Stanislow Szpor,Gdansk, Poland [13]. This work furnished percentage curves of lightning current erest values on the basis of revision of records obtained in many countries in the world. This curves can be used for calculations of insulation strength of transmission lines and their outage probability.

From the available literature and reference, it is apparent that no work has been done an a systematic study on the insulation strength, trip outs of the transmission line due to high isokeraunic level and failure of insulation in the light of the existing natural phenomanon in Bangladesh. Our work, therefore, is the first of its kind in Bangladesh. An attempt has been made to determine the soil resistivity and tower footing resistance analytically and experimentally and collecting information on annual thunder storm days and relative humedity of the country and calculating insulation strength of the transmission line and insulation failures. Lack of facilities have compelled us to remain satisfied with lightning current erest values of the international curves.

## 1.4. SCOPE OF THE THESIS:

Neglecting normal frequency voltage the insulation strength of the transmission line depends on the following factors : (a) The stroke current magnitude and wave shape of the lightning stroke (b) Tower footing resistance (c) Span length and (d) Coupling factor.

The outage probability of a transmission line depend on the annual isokeraunic level. To ascertain the causes of insulation failures a detail history of the equipments are necessary.

The scope of the work is :

a) Calculation of insulation strength of the transmission line.

b) Calculation of voltage developed across insulation string.

c) Collection of records of thunder storm days for 10 years of all the recording centeres of Bangladesh Meteorological department. Preparation of average Annual isokeraunic map of Bangladesh.

d) Calculation of outage probability of transmission line depending on the annual thunder storm days.

e) Comparison of calculated outage of the transmission line with actual outage, so far as records permitted.

f) Measurement of ground resistivity, tower footing resistance experimentally and calculation of the same theoritically and comparing both the results.

g) Determination of relation between the outage probability and the tower footing resistance of the transmission line.

h) Collection of history of insulation failures of equipments and finding out the reasons of such failures.

i) Calculation of coupling factor from the parameters of the transmission line.

j) Determination of protective angle of the transmission lines.

k) Average span length of the lines obtained form design transmittals of the transmission lines.

# CHAPTER - II

## 2.1. VOLTAGES SURGES ON TRANSMISSION LINE.

Causes of over voltage: An electrical system may experience over voltages which may be internal and/or external.

Internal over voltage : Internal over voltages originate in the system itself and may be transient, dynamic or stationery.

The transient over voltages have frequency unrelated to the normal system frequency and will persist for a few cycles only. These can be caused by the operation of circuit breakers of the line.

Dynamic over voltages can occur at normal system frequency and persist for a few cycles only. They may be caused, for example by disconnection of a generator which over speeds or when a large part of the load is suddenly removed.

A stationery over voltage may also occur at system frequency in case of single phase to ground fault when the neutral is earthed through an are suppression coil. Such fault may persist for some time.

These over voltages rarely exceed three to five times the normal phase to neutral peak voltage of the system and generally harmless to the apparatus having adequate insulation level.

External over voltage : These over voltages are produced by atmospheric discharges such as static charges or lightning strokes and are therefore not related to the system voltage. They are often of such magnitude as to cause considerable stress on the insulation and in case of lightning may be of various intensity depending on how the line is struck.

Ground wires, serve to diminish the induced over voltages. Subsequently it has been found that ground wires may be a direct stroke protection. They may receive the lightning flashes and lead the lightning currents through the tower members to earth without causing flash over to insulators.

The inductive voltage drop has been shown to play an important role specially in very high lines. This voltage is connected with the magnetic field around the tower.

Besides, voltage induced in the conductors below the ground wire have been considered. There are two induced components: a voltage induced by ground wires formulated mathematically be coupling factor, a voltage induced by lightning channel which contain two components: electrical component produced by electrical field and magnetic component produced by magnetic field.

The black flash over is connected with the lightning stroke to the mast or the ground wire near the mast. When a lightning strike the ground wire at the mid span, a black flash over from ground wire to the phase conductor may result. The calculation of this is relatively simple but very often not important because the clearance between the ground wire and the conductor is in general very great for other reasons.

Induced voltage surges may be calculated by using the following formula : (12)

a) Variation of grounding resistance:

It has been seen that the grounding resistance deminishes as the surge current increases. Unfortunately the experimental results exist only to about 10 KA. For greater current variation ground resistance can be determined by using the formula

$$R_g = \sqrt{\frac{2}{\pi} \rho K_o \frac{1}{i}} \qquad (1)$$

Where,

$R_g$ = ground resistance in ohms,

$i$ = crest value of the lightning current in KA,

$\rho$ = ground resistivity in ohm-cm,

$K_o$ = voltage gradient in the soil in Kv/cm,

b) <u>Inductive voltage drop in the tower:</u>

The inductive voltage drop along a relatively short tower is given by the relation:[12]

$$u_L = L_t \quad l_t \quad \frac{di_t}{dt} \qquad (2)$$

For a relatively long tower it may be written:

$$u_L = z_t \quad i_t \qquad (3)$$

Where $L_t$ is the average inductance of the transmission line tower, $l_t$ is the length of tower and $\frac{di_t}{dt}$ is the maximum rate of rise the current in the tower,

The inductivity Lt can be calculated by the approximate formula.

$$L_t = \frac{1}{\frac{n_1}{L_{t1}} + \frac{n_2}{L_{t2}}}$$

Where $n_1$ = Number of vertical parallel branches

$n_2$ = Number of oblique paralled branches

$L_{t1}$ = Inductivity for a vertical branches

$L_{t2}$ = Inductivity for an oblique branches

If $L_{t1}$ = 2$\mu$H/m and $L_{t2}$ = 2.85$\mu$H/m, then

$$L_{t2} = \frac{2}{n_1 + 0.7\, n_2} \quad \mu H/m$$

$z_t$ may be calculated by using the formula

$$Z_t = V\ Lt$$

Where $V = 300$ m/μs, velocity of wave in the air.

c) Combination of the ground voltage and the inductive tower voltage:

If the maximum values i and $\frac{di_t}{dt}$ occur in the same lightning stroke, in the first stroke of a multiple lightning flash, then the ground voltage and the inductive tower voltage may be combined for a cosinosoidal front of the tower current by using the formula,

$$u_{tt} = \frac{1}{2} R_g i_t + \sqrt{\frac{1}{4} R_g^2 i_t^2 + L_t^2 i_t^2 \frac{di_t^2}{dt}} \quad (4)$$

For very high towers the component $u_L$ will be taken probably as the tower top voltage and the component $R_g i_t$ will be neglected.

For very low towers the component $R_g i_t$ will be taken as the tower top component and component $u_L$ will be omitted. This formula will be used for some medium height towers.

d) Coupling factor.

When over voltage waves $u_{tt}$ enter the ground wire at both sides of the towers struck by lightning, then induced waves $u_{tt}$ appear on the phase conductors. They are determined by the coupling factor K. (12)

$$u'_{tt} = K\, u_{tt}$$

and the insulators obtain the difference:

$$u_{tt} - u'_{tt} = (1 - k)\, u_{tt} \qquad (5)$$

Coupling factor K is, after Bewley's multiplo - velocity theory of waves a geometric mean of electrostatic and magnetic coupling factors:

$$K = \sqrt{\frac{C_{AA}}{C_{AB}} \times \frac{L_{AB}}{L_{AA}}}$$

Where $C_{AA}$, $L_{AA}$ are self capacity and self inductivity of ground wire.and

$C_{AB}$, $L_{AB}$ are mutual capacity and mutual inductivity of phase conductors and ground wires. Corona is known to increase materially the capacity $C_{AA}$ and the coupling factor. Neglecting effect of Corona, the electrostatic and magnetic coupling will be equal. The coupling factor for one ground wire may be determined by the formula

$$K = \frac{\log \frac{b}{a}}{\log \frac{2h}{r}} \qquad (6)$$

Where, a = distance from conductor to ground wire

b = distance from the conductor to the image of the ground wire,

$h$ = height of the ground wire above the ground

$r$ = radius of the ground wire.

e) Protective angle

The probability $\Psi_{PR}$ of lateral stroke to a phase conductor under the ground wire is greater with greater protective angle $\alpha$. Kostiemko proposed in 1949 the formula:

$$\log \Psi_{PR} = \frac{\alpha}{20} - 4 \qquad (7)$$

f) Frequency of lightning flashes:

In Poland and Russia the number of lightning flashes N per year can be calculated by the formula:

$$N = 1.8\, h_a \frac{D}{20} \frac{l}{100} \qquad (8)$$

Where, $h_a$ = average height of the line in meters

$l$ = length of the line in km

$D$ = number of thunder storm days per year

## 2.2. TOWER FOOTING RESISTANCE.

Tower footing resistance can be calculated by using the formula:(1)

$$R = \frac{\rho}{2\pi L}(\log \frac{4L}{a} - 1) \qquad (9)$$

Where, $\rho$ = resistivity of the soil in ohm-meter.

L = Length of the ground rod in meter.

a = Radius of the ground rod in meter.

The tower legs of the Siddhirganj-Kaptai transmission line have been connected with a 10' long 3/4" copper rods. Tower legs having concrete foundation of the Siddhirganj-Sylhet 132 K.V. Transmission line have been earthed in the same way.

## 2.3. INSULATION STRENGTH OF TRANSMISSION LINE.

Considerable work has been done on establishing methods for pre-determining the design requirements of lines to provide a desired immunity against lightning tripouts. Curves have been calculated on the basis that the stroke is intercepted by a shield wire. The lightning current is then expected to take the path along the shield wire, down the tower or towers and through the tower footing resistance to ground. As the current follows this path to ground a transient voltage appears across the line insulation. Neglecting normal frequency voltage, the magnitude of this voltage depends chiefly on the stroke current magnitude and wage shape, tower footing resistance, tower inductance, span length and coupling factor.

Using these solutions and taking coupling into account the insulation strength can be determined from the following relation[4].

Insulation strength = stroke current x tower-top voltage per ampere of stroke current x ( 1 - coupling factor) ( 10 )

2.4.1. EXPERIMENTATION.

In order to determine the value of tower footing resistance and ground resistivity, an earth test megger has been used.

The calculated result of the tower footing has been compared with the result obtained experimentally. The ground resistivity has been measured experimentally and the same has been compared with results of ground resistivity measured by WAPDA in 1968 [7].

2.4.2. PROCEDURE FOR GROUND RESISTIVITY MEASUREMENT.

1) An Evershed megger earth tester has been used.

2) Correctness of the megger was tested in laboratory by connecting known value of resistance as shown in the connection diagram No.1 page 23.

   A known value of resistance was connected between $C_1P_1$ & $P_2$ and another known value was used between $P_2$ and $C_2$. When the reading shown by the megger was equal to the value of the resistance connected

# METHOD OF USING MEGGER EARTH TESTER FOR MEASURING AVERAGE RESISTIVITY OF SOIL.

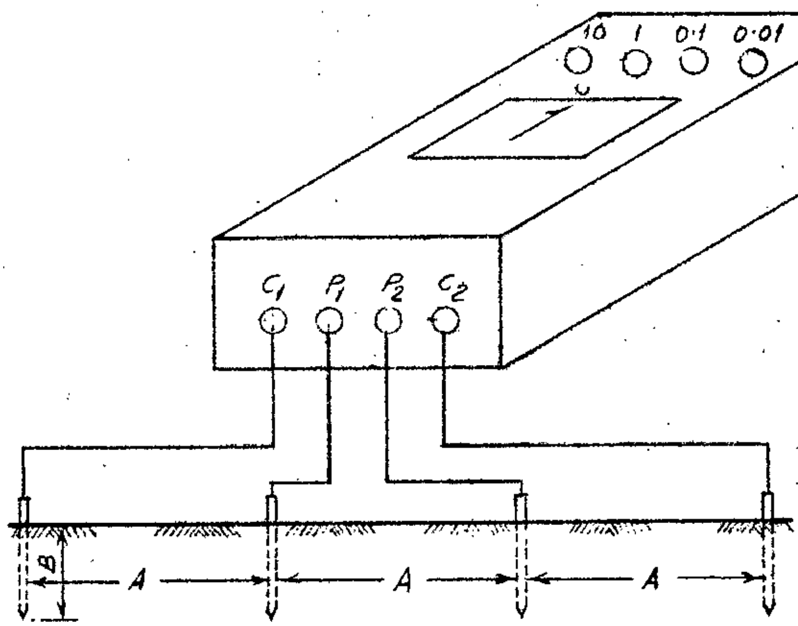



FIG. 1

between $C_1 + P_1$ & $P_2$ null point of the megger was obtained.

3) For measurement of average ground resistivity, the terminal of the megger was connected shown in Fig 1. The depth of the spike inserted inside the ground was 0.5 meter and the distance A between the electrodes was 10 meters.

The ground resistivity $\rho$ can be calculated by the following formula(6).

$$\rho = 2\pi AR \qquad (11)$$

Where A = distance in meters between electrodes,

R = Reading in the meter.

2.4.3. PROCEDURE FOR MEASUREMENT OF TOWER FOOTING RESISTANCE.

$C_1$ $P_1$ shorted and connected to the tower legs and the two auxiliary grounds were connected to $C_2$ & $P_2$ as shown in drawing of Fig.2 page 25.

For measurement of tower footing resistance three sets of readings were taken in each experiment keeping the following distance:

No. 1 $C_1 P_1 - P_2$ = 40 ft.

$C_1 P_1 - C_2$ = 90 ft.

# METHODS OF GROUND RESISTANCE MEASUREMENT

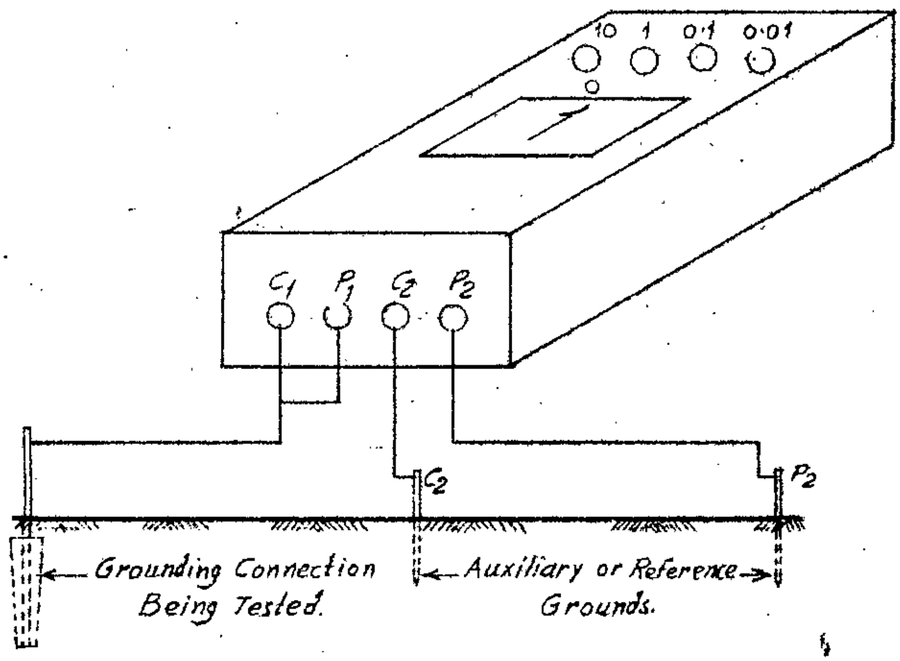



FIG. 2

No. 2 $C_1 P_1 - P_2 = 50$ ft.

$C_1 P_1 - C_2 = 100$ ft.

No. 3 $C_1 P_1 - P_2 = 60$ ft.

$C_1 P_1 - C_2 = 110$ ft.

Average of the three readings were taken as the tower footing resistance.

## 2.5. THE STROKE CURRENT MAGNITUDE AND WAVE SHAPE.

To protect the transmission line from lightning stroke a knowledge of the magnitude, duration and wave shapeof the voltage and current surges appearing on the transmission lines are necessary. The characteristics of the strokes itself determines the resulting surges occuring on the electrical system. Since the value of stroke current, may vary from a few amperes to thousands of amperes, it is very difficult to measure the lightning stroke current. As there is no such facility and as there have been no such attempt to measure the lightning stroke current on the transmission lines in Bangladesh, the results obtained in the field studies of different countries are adopted for the purpose of calculation.

The international percentage curve Fig. 3 (a) for current crest value i has been proposed by S. Szpor[13].It has been stated that between 20 KA & 200 KA of current crest values there is no doubt. Below 15 KA the Polish percentage curve have been adopted. Above 200 KA the position of the curve is doubtful.

In Fig. 3 (b) percentage curves of rates of rise of lightning currents i' has been proposed. There is no doubt of values between 35 KA/μs and 80 KA/μs. Below 35 KA/μs and above 80 KA/μs values of the curve has obtained by extrapalation.

Different values of i and i' should be chosen from Fig.3 (a) and 3 (b) respectively for lightning protection calculus of different importance. For instance;

6 - 8% strokes have values of 100 KA and 80 KA/μs. These values are used for protection calculations of less important objects.

1 - 1.5% strokes have values of 200 KA and 150 KA/μs. These values are used for protection calculations of objects medium importance.

0.1 to 0.2% strokes have values 400 - 500 KA and 250 KA/μs. These values are considered for protection calculation for objects of greatest importance.

## 2.6. INSULATION CO-ORDINATION.

Insulation co-ordination may be defined as the process of setting standards of insulation strength and assigning them

## INTERNATIONAL CURVES OF LIGHTNING CURRENTS

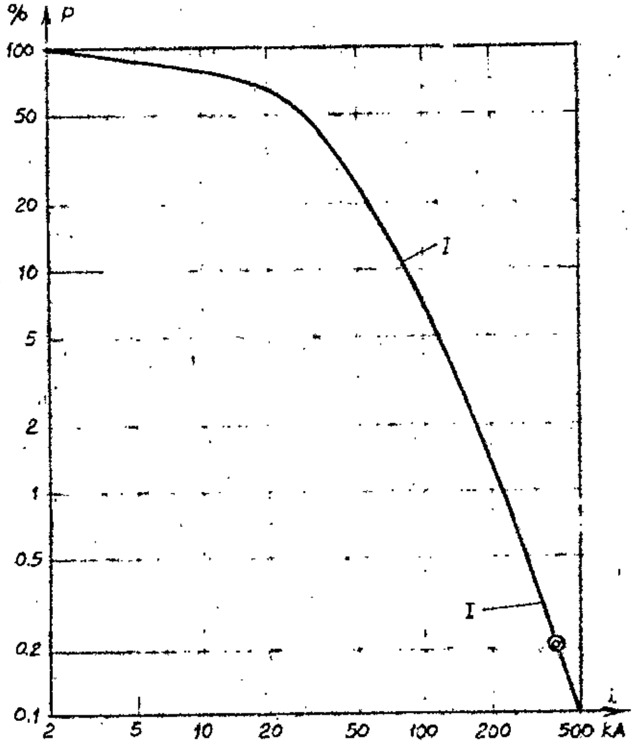



FIG. 3 (a)

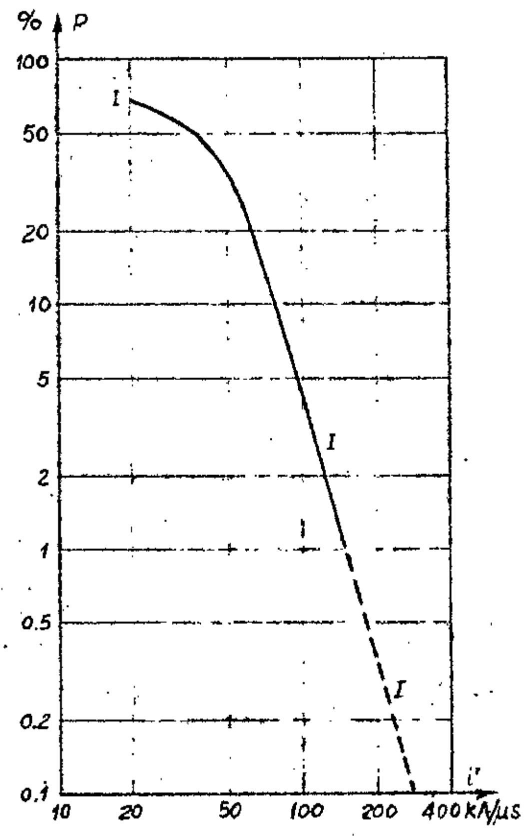



FIG. 3 (b)

to all the items of equipment in the various classes in such a manner as to produce, from an economic and operating point of view, both a maximum of protection and a minimum of damage to the system.

The present definition of "Basic impulse insulation are reference levels expressed in impulse crest voltage with a standard wave not longer than 1.5 X 40  sec wave. Apparatus insulation as demonstrated by suitable tests shall be equal to or greater than the basic insulation level".

Alarming situation may arise due to variation in insulator strength of different manufacturers. The variations in insulator flash over of 25 to 33% are not all unusual. Yet not all is seen on the surface. Some of the value listed are sphere gap determinations and still some others are given as test values and not as flash over values at all.

There has been no scientific yardstic employed in the determination of ratings of bushings by various manufacturers, or else there would not be such discrepancy and variation. In general the present system of ratings of insulators is confusing in fact very often dangerous.

The situation among the apparatus manufacturers may not be quite so bad, but certainly cannot be called either good or orderly. At present time there are group of more or less standard voltages on which the design class are based; but the various groupings there are undoubtadly manufacturing classes which may and probably do, differ from the usage voltage standards. Often various parts of specific design are not corrected and under the many existing conditions, cannot be.

For example, many switch & transformer manufacturers do not make their bushings, obviously a confusion is bound to crepp into the equipments as long as the bushing manufacturer is held to no standard. This of course, is not meant to employ that such situation can not occur and has not occurred where all the various parts of a piece of apparatus have been made by a single manufacturer.

The operating power authority and the designers and constructors for them, at least would have seen the necessity for bringing some orders in this situation, but such does not happen to be the case. The more one talks with the manufacturers, the more one realises the predicament in which they find themselves, in attempting to carry out the different ideas of the various organisations with regard to the relative values of insulations of component parts of apparatus. On examination of different practices, it may be found that one system particularly bent on over insulating its lines, another system over insulating its transformers and having bushings of normal strength and still another following riverse practises. Not only will this conditions be found to exist in the moderate voltages, but in the higher voltages they are in some times even worse.

The effect of this condition leave one with a general impression that the whole matters is confused that it would be hopeless to try to change it so as to bring order into it.

In a single installation under Power Development Board, it is seen that equipments from various countries and various manufacturer have been installed. This practice made the problem of insulation co-ordination more difficult.

## 2.7. DEFINATIONS.

1. Protective angle: The protective angle is the angle formed by a line through the ground wire and the outer phase wire and the vertical.

2. Coupling factor: It is the ratio of the induced voltage on the conductor to the ground wire voltage.

3. Corona: There is a critical electric gradient for air that cannot be exceeded, without profuse ionization of the air.

4. Surge Impedance: When a voltage surge moves along the

the line, the current wave will have exactly the same wave form as the voltage and at any instant proportional to the voltage. The constant of proportionality is known as surge impedance and is usually designated by the symbal $Z = \sqrt{\frac{L}{C}}$

5. Voltage surges: It is a sudden deviation of voltage from normal conditions and may be caused by lightning, switching operation and/or faults.

6. Systems: Transmission and or distribution network of lines, transformers and generators.

# CHAPTER - III.

## RESULTS

### 3.1. Tower Footing Resistance & Ground Resistivity:

a) The specific resistivity of ground has been measured in the northern part of the country by WAPDA[7] in 1968 and found that the resistivity vary from 5 ohm - m to 50 ohm - m depending on the soil condition.

Experimentally resistivity has also been calculated using the formula $\rho = 2\pi AR$. The results of three such experiment are shown in the table 1 below:

**Table - 1.**

| Experiment No. | Resistivity in ohm meter. |
|---|---|
| No. 1 | 5.7 |
| No. 2 | 7.01 |
| No. 3 | 6.10 |

b) Tower footing resistance R is calculated by using formula (10).

$$R = \frac{\rho}{2\pi L} \left(\log_e \frac{4L}{a} - 1\right)$$

$$L = 10 \text{ ft.} = 3.05 \text{ m.}$$

$$a = \frac{3}{8} \text{ inch,}$$

$$\rho = 5.70 \text{ ohm - m,}$$

$$R = \frac{5.70}{2X3.14X3.05} \left(\log_e \frac{\frac{4 X 10}{3}}{4X2X12} - 1\right)$$

$$= 0.295 \, (2.303 \, Log_{10} \, 1280 - 1)$$

$$= 0.295 \, (2.303 \, X \, 3.1072 - 1)$$

$$= 0.295 \, X \, 6.15$$

$$= 1.81 \text{ ohm.}$$

For $\rho$ = 7.01 ohm - m

R = 2.26 ohm

For $\rho$ = 6.10 ohm - m

R = 1.97 ohm.

Tower footing resistance are shown in the Table 2.

Table - 2.

| Resistivity in ohm - m | Tower footing-resistance in ohm. |
|---|---|
| 5.7 | 1.81 |
| 7.01 | 2.26 |
| 6.10 | 1.97 |

c) Measured values of Tower footing resistance. Tower footing resistance have been measured by using earth test megger as per Fig. 2 page 25. Towerwise resistance are shown in Table 3 below:

Table - 3.

| Name of the transmission lines. | Tower specification. | | Location of Tower | Result in ohms. |
|---|---|---|---|---|
| | Tower No. | Type of foundation | | |
| Siddhirganj - Sylhet. | 44 | No foundation. | Near Siddhirganj | 1.2 |
| -do- | 100 | -do- | Narsingdi | 1.1 |
| -do- | 444 | Concrete foundation | Sreemongal,Sylhet | 0.92 |
| -do- | 450 | No foundation | -do- | 1.03 |
| -do- | 452 | Concrete foundation. | -do- | 1.2 |
| -do- | 455 | No foundation. | -do- | 0.74 |
| -do- | 456 | Concrete foundation | -do- | 0.87 |
| -do- | 457 | -do- | -do- | 0.17 |
| Siddhirganj-Kaptai | 1 | With foundation. | Siddhirganj | 1.12 |
| -do- | 2 | No foundation. | -do- | 0.74 |
| Siddhirganj-Ullon. | 1 | With foundation. | -do- | 0.24 |

3.2 COUPLING FACTOR.

Coupling factor K is determined by using the formula.

$$K = \frac{\log \frac{b}{a}}{\log \frac{2h}{r}}$$

b = 178 ft.

a = 21.4 ft.

h = 97 ft.

$$r = \frac{5}{32} \text{ inch}$$

$$K = \frac{\log \frac{178}{21.4}}{\log \frac{2 \times 97}{\frac{5}{32 \times 12}}}$$

$$= \frac{\log 8.35}{\log 14900}$$

$$= \frac{0.9217}{4.1732}$$

$$= 0.224$$

## 3.3. INSULATION STRENGTH OF THE TRANSMISSION LINE.

Insulation Strength of the transmission can be calculated by the equetion :

Insulation Strength = Stroke current X Tower Top Voltage Per Amp of Stroke current X (1-coupling factor)

Wouldorf's curve for tower flash over which is reproduced in Fig. 4. page 37. From the curve, permissible Stroke current for 1.2 ohm tower footing resistance and ten (10) of dise insulators is 15 X $10^4$ Amp.

# TOWER FLASHOVERS

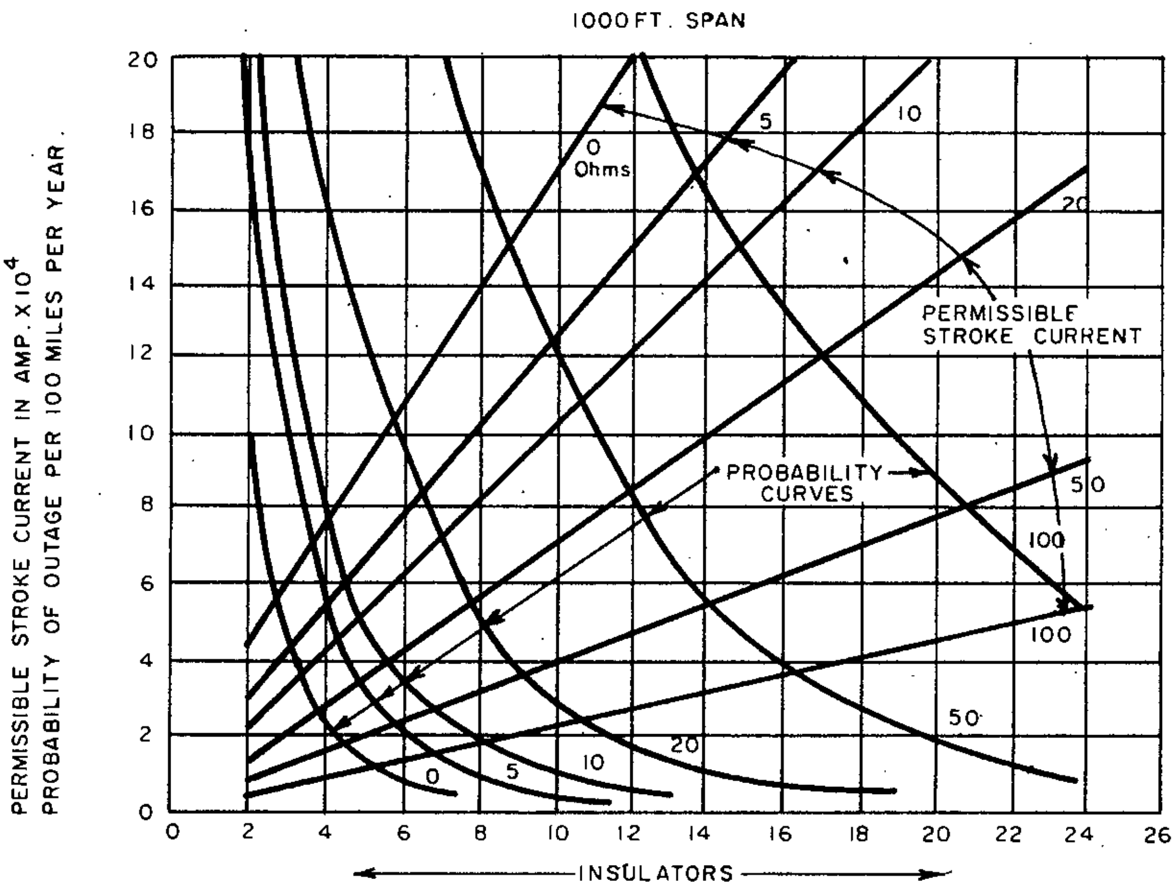



FIG. 4

## STROKE CURRENT PROBABILITY CURVE

# MIDSPAN FLASHOVERS

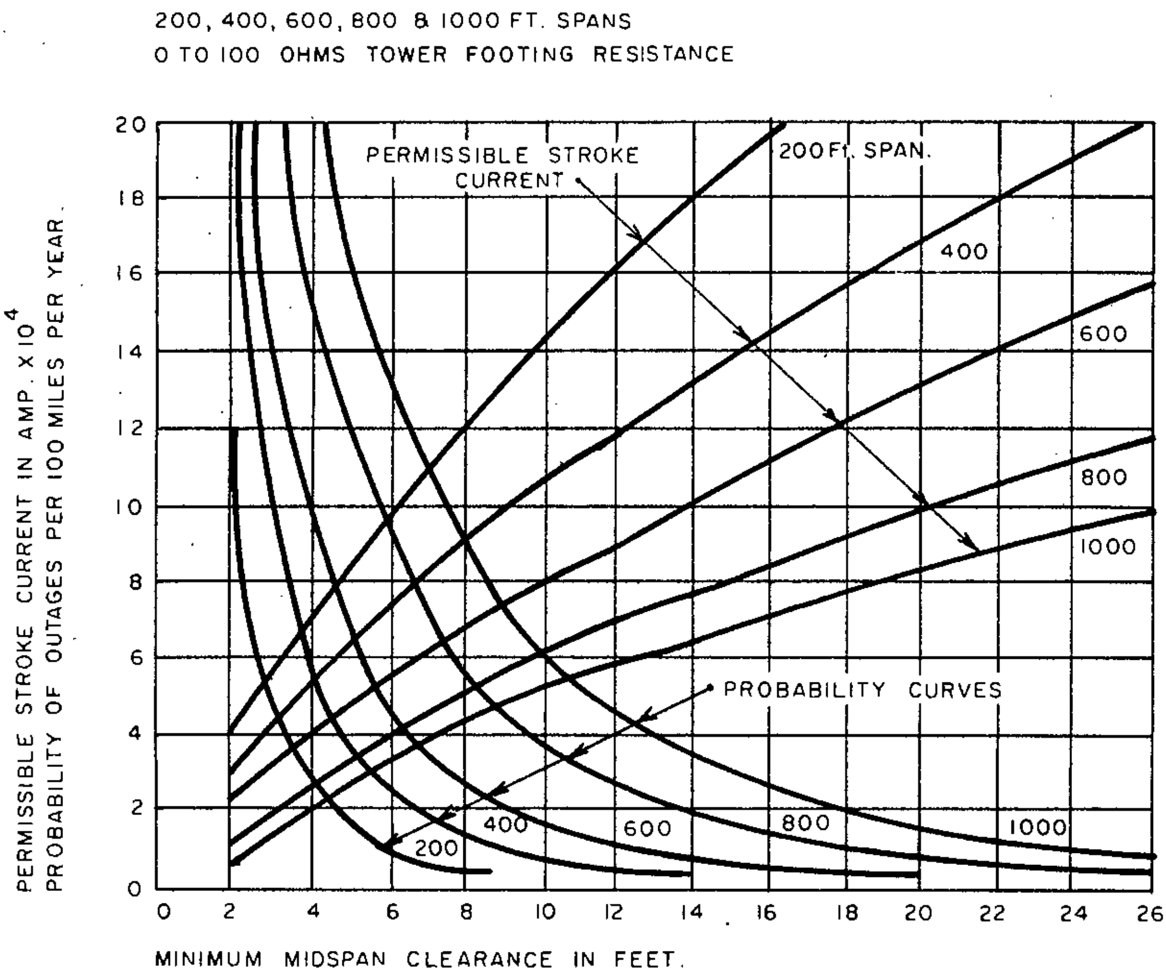



FIG. 5

Tower top voltage per ampere of Stroke current can be obtained from results of anacom study. Appendix 1. For 1000ft. span length and 5 ohm tower footing resistance, tower top voltage per ampere of stroke current is 14 Volts.

Therefore Insulation Strength

$$= 15 \times 10^4 \times 14\ (1-0.224)$$

$$= 15 \times 10^4 \times 14 \times 0.776$$

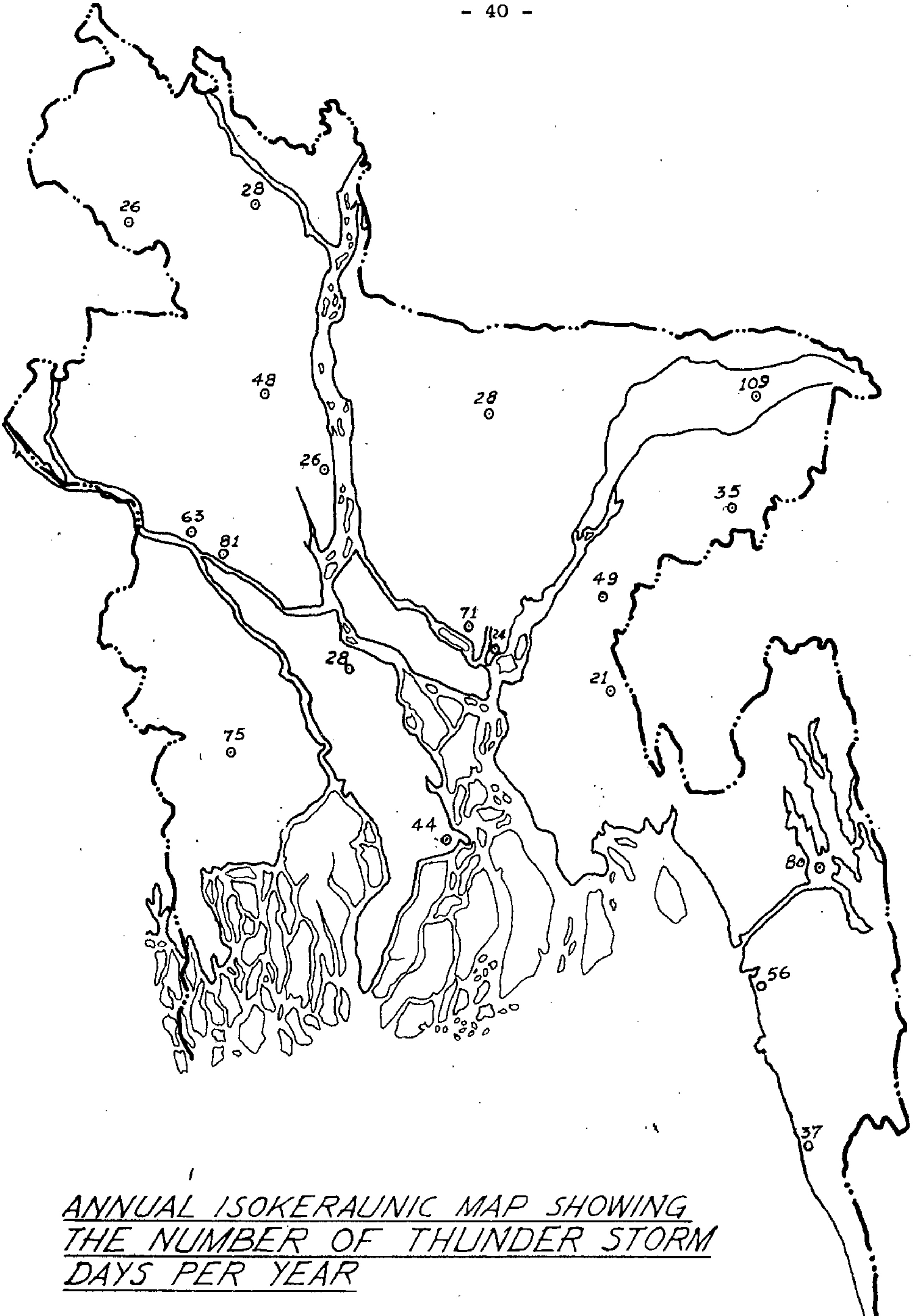
$$= 1630 \times 10^6 \text{ volts}$$

$$= 1630 \text{ kv.}$$

Tower Top Voltage Per amp of Stroke current for footing resistance of less than 5 ohm has not been provided in the anacom study. So, we had to take tower top voltage for footing resistance of 5 ohms.

## 3.4. FREQUENCY OF THUNDER STORMS.

The total number of Storm days of 23 recording centers throughout Bangladesh have been collected for 10 years from 1961 to 1970 and shown in table 4 and Examination of the table 4 reveals that the annual average number of Thunder Storm days of Bangladesh is about 50. The average thunder storm days of all the centres throughout Bangladesh are shown in the map of Bangladesh fig 6 page 40 . The hilly areas of Chittagong and




ANNUAL ISOKERAUNIC MAP SHOWING THE NUMBER OF THUNDER STORM DAYS PER YEAR

FIG. 6

Sylhet show more number of thunder storm with a maximum of 109 at Sylhet.

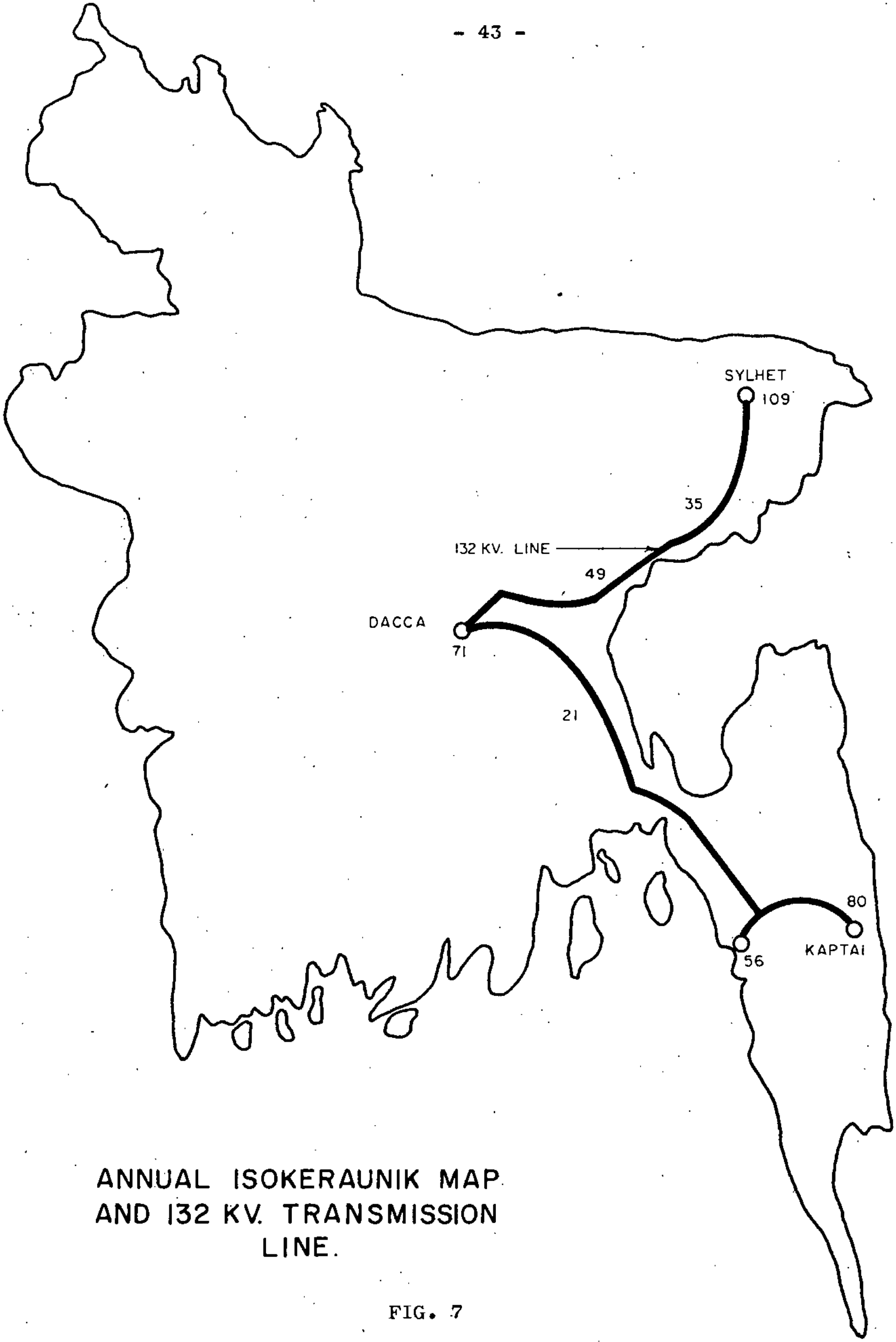
The average number of storm days recorded each month over a period 10 days are shown in table 5. December is the month of least storm days and in the month of November, January and February it remains very low. For the succeeding months the storm incidents increases throughout the country and reaching the peak in the month of May.

The storm incidents from May to September remains very high and from October again it began to fall down reaching near to zero in December. The highest record of 20 storm days have been obtained at Sylhet in the month of May. The Chart do not give an indication of intensity duration, extent or number of storm occuring. Disturbance of power system due to lightning has been shown in table 6. The relative number of power system disturbance due to lightning recorded varies in the same manner as the number of storm days per month. However, the number of such disturbances varies widely from year to year and different places although the number of storm days of the places are nearly same. There are several reasons for this. The number of lightning reaching arrestors transformers etc. should depend to a great extent upon their density of installation and on the degree and effectiveness of shielding of the lines.

Local topographical and meteorological conditions appear to cause large localized variation in storm densities. The nature of thunder storms such as cold front also depend an local topographical and meteorological conditions.

## 3.5. AVERAGE ANNUAL THUNDER STORM DAYS OF THE TRANSMISSION LINE.

Siddhirganj - Sylhet line passes through the places having average annual thunder storm days: Dacca - 71, Brahmanbaria - 49, Srimongal - 41 and Sylhet - 109. And Siddhirganj - Kaptai line passes through the places having average annual thunder storm days : Dacca - 71, Comilla - 21, Chittagong-56 and Rangamati - 81. Fig.7 page 43. The average annual thunder storm days of the two transmission lines are tabulated in Table 7.




ANNUAL ISOKERAUNIK MAP AND 132 KV. TRANSMISSION LINE.

FIG. 7

Table - 4

Annual Thunder Storm Days for Various Years

| Name of the Centres | Years | | | | | |
|---|---|---|---|---|---|---|
| | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 |
| Bogra | 45 | 40 | 51 | 72 | 43 | 41 |
| Sylhet | 67 | X | 69 | 150 | 110 | 95 |
| Pabna | 104 | 72 | 95 | X | X | X |
| Rangamati | 82 | 89 | X | 83 | 68 | 82 |
| Jessore | X | 59 | 70 | X | 70 | 59 |
| Dacca | 74 | 68 | 79 | 95 | 51 | 61 |
| Ishurdi | X | 9 | 82 | 58 | 56 | 55 |
| Brahmanbaria | 32 | 59 | 55 | 72 | 49 | 22 |
| Chittagong | 50 | 45 | 48 | 67 | 61 | 46 |
| Cox's Bazar | 29 | 29 | 28 | 34 | 46 | 36 |
| Srimongal | X | 14 | 62 | 26 | X | 24 |
| Barisal | 16 | 10 | 6 | 40 | 42 | 31 |
| Comilla | X | 30 | X | 15 | 19 | X |
| Faridpur | 28 | 39 | 33 | X | 25 | 21 |
| Rangpur | 38 | 12 | 21 | 22 | 24 | 20 |
| Dinajpur | 27 | 22 | 42 | 30 | 18 | X |
| Mymensingh | 42 | 55 | 33 | 34 | 28 | 23 |
| Serajganj | 36 | 15 | 23 | 20 | 17 | 23 |
| Satkhira | 6 | 21 | 10 | X | 17 | X |
| Narayanganj | 43 | 42 | 25 | 21 | 16 | X |
| Rajshahi | X | X | X | X | X | X |
| Lalmanirhat | X | X | X | X | X | X |
| Sandip | X | X | X | X | X | X |

X Indicate no record available.

Table - 4 (Continued)

Annual Thunder Storm Days for Various Years

| Name of the Centres. | Years | | | | | |
|---|---|---|---|---|---|---|
| | 1967 | 1968 | 1969 | 1970 | Total | Average |
| Bogra | 58 | 48 | 54 | 33 | 485 | 49 |
| Sylhet | 132 | 116 | 115 | 128 | 982 | 109 |
| Pabna | X | 62 | 80 | 76 | 489 | 82 |
| Rangamati | 83 | 94 | 82 | 83 | 726 | 81 |
| Jessore | 82 | 94 | 88 | 77 | 599 | 75 |
| Dacca | 67 | 67 | 64 | 81 | 715 | 72 |
| Ishurdi | 62 | 81 | 88 | 77 | 564 | 63 |
| Brahmanbaria | 52 | 55 | 50 | 47 | 493 | 49 |
| Chittagong | 52 | 55 | 69 | 68 | 361 | 56 |
| Cox's Bazar | 50 | 54 | 37 | 31 | 374 | 37 |
| Srimongal | X | 79 | 40 | X | 245 | 41 |
| Barisal | 47 | 59 | 63 | 61 | 435 | 44 |
| Comilla | X | X | X | X | 64 | 21 |
| Faridpur | 22 | X | 24 | 31 | 223 | 28 |
| Rangpur | 32 | 28 | 46 | 39 | 282 | 28 |
| Dinajpur | 18 | 31 | 23 | 22 | 233 | 26 |
| Mymensingh | 27 | 20 | 9 | 21 | 282 | 28 |
| Serajgonj | 37 | X | X | 36 | 207 | 26 |
| Satkhira | X | X | X | 5 | 59 | 12 |
| Narayanganj | 11 | X | 12 | X | 170 | 24 |
| Rajshahi | X | 48 | 59 | 32 | 139 | 46 |
| Lalmanirhat | X | X | X | 31 | 31 | 31 |
| Sandip | X | X | X | 20 | 20 | 20 |

X Indicate no record available

Table - 5.

Average Monthly Thunder Storm Days

| Name of place | Jan. | Feb. | Mar. | Apl. | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sylhet | 0 | 2 | 7 | 17 | 20 | 19 | 12 | 11 | 15 | 4 | 1 | 0 |
| Ranga-mati | 0 | 1 | 4 | 8 | 10 | 15 | 10 | 11 | 14 | 8 | 2 | 0 |
| Pabna | 1 | 1 | 4 | 11 | 13 | 9 | 9 | 12 | 12 | 4 | 1 | 0 |
| Jessore | 0 | 2 | 4 | 8 | 9 | 10 | 8 | 7 | 11 | 4 | 1 | 0 |
| Dacca | 1 | 0 | 6 | 11 | 13 | 10 | 7 | 8 | 10 | 5 | 1 | 1 |
| Ishurdi | 0 | 1 | 3 | 7 | 10 | 9 | 7 | 8 | 7 | 4 | 1 | 0 |
| Ctg. | 0 | 1 | 3 | 6 | 9 | 9 | 5 | 5 | 8 | 6 | 1 | 1 |
| Brahman Baria | 0 | 0 | 5 | 10 | 9 | 8 | 4 | 4 | 7 | 3 | 1 | 0 |
| Bogra | 0 | 1 | 2 | 6 | 13 | 7 | 5 | 6 | 6 | 3 | 0 | 0 |
| Barisal | 0 | 1 | 4 | 6 | 6 | 6 | 4 | 4 | 4 | 2 | 0 | 0 |
| Cox's Bazar | 0 | 1 | 2 | 5 | 7 | 7 | 2 | 2 | 5 | 4 | 1 | 0 |
| Sri-mongal | 0 | 0 | 2 | 5 | 9 | 7 | 7 | 7 | 3 | 1 | 0 | 0 |
| Faridpur | 0 | 0 | 2 | 4 | 9 | 4 | 1 | 2 | 3 | 1 | 0 | 0 |
| Rangpur | 0 | 0 | 2 | 4 | 9 | 4 | 2 | 3 | 4 | 1 | 0 | 0 |
| Dinajpur | 0 | 0 | 1 | 3 | 5 | 3 | 2 | 3 | 4 | 1 | 0 | 0 |
| Seraj-ganj | 0 | 1 | 1 | 4 | 5 | 4 | 2 | 3 | 4 | 2 | 0 | 0 |
| Rajshahi | 1 | 0 | 2 | 5 | 10 | 8 | 6 | 5 | 6 | 4 | 1 | 0 |
| N.ganj. | 0 | 2 | 3 | 8 | 7 | 8 | 5 | 1 | 6 | 3 | 1 | 0 |
| Comilla | 0 | 0 | 1 | 6 | 3 | 2 | 2 | 0 | 4 | 2 | 1 | 0 |
| Lalmanir Hat | 1 | 4 | 2 | 6 | 4 | 10 | 8 | 8 | 2 | 0 | 1 | 0 |
| Sandip | 1 | 1 | 3 | 4 | 5 | 0 | 3 | 3 | 0 | 0 | 0 | 0 |

Table - 6.

Trip outs of the transmission line due to lightning transient over voltage.

| Name of the transmission line and year. | Name of the months | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan. | Feb. | Mar | Apl | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. |
| Siddhirganj Kaptai line 1967 | - | - | 2 | 1 | - | - | - | 1 | - | 1 | - | - |
| Siddhirganj Kaptai line 1968 | - | - | - | - | 1 | 4 | - | - | 1 | - | - | - |
| Siddhirganj Kaptai line 1969 | - | - | - | - | - | 2 | - | - | - | - | - | - |
| Siddhirganj Kaptai line 1970 | - | - | - | - | - | 3 | - | - | - | - | - | - |
| Siddhirganj Sylhet line 1973 | - | - | - | 1 | 2 | - | 3 | - | - | - | - | - |
| Siddhirganj Sylhet line 1974 | - | - | - | 1 | - | - | - | - | - | - | - | - |

Table - 7.

Average annual thunder storm days of transmission line.

| Name of the line | Length of the line | Average annual thunder storm days. |
|---|---|---|
| Siddhirganj-Kaptai | 170 | 57 |
| Siddhirganj-Sylhet | 155 | 68 |

## 3.6. OUTAGE PROBABILITY OF THE TRANSMISSION LINES BASED ON THE ISOKERAUNIC LEVEL OF BANGLADESH.

From Waldorf's curve Fig. 4 (Tower Flashovers) page 37, there is no outage probability for tower footing resistance of 1.2 ohms and 10 disc insulators. The outage probability from Waldorf's curve Fig. 5 page 38 for midspan flshovers is 0.9 per year per 100 miles of line for 25 feet midspan clearance.

The above curves of outage probability is based on annual isokeraunic level of 30[4]. The probability of outage is assumed to very directly with number of storm days. The outage probability of Siddhirganj-Kaptai and Siddhirganj-Sylhet transmission lines based an thunder storm days of Table 7 have been calculated and found to be 2.90 per year and 3.16 per year respectively. It is shown in the table 8.

Table - 8.

| Name of the line | Length of the line | Outage probability of the line. |
|---|---|---|
| Siddhirganj-Kaptai | 170 | 2.90 |
| Siddhirganj-Sylhet | 155 | 3.16 |

Total Trip outs of the transmission lines and those due to lightning Stroke are shown in the table 9 and 10. Trip Outs of the lines at the occassion when there had been raining with thunder storms and the nature of faults shown by the relay are considered due to lightning strike.

Table - 9.

Tripouts of Siddhirganj-Kaptai line.

| Year | Tripout due to other reasons. | Tripouts due to lightning | Total tripouts |
|---|---|---|---|
| 1967 | 31 | 5 | 36 |
| 1968 | 35 | 5 | 40 |
| 1969 | 19 | 1 | 20 |

Table - 10.

Trip outs of Siddhirganj-Sylhet line.

| Year | Tripout due to other reasons. | Tripouts due to lightning | Total tripouts |
|---|---|---|---|
| 1972 | 15 | Not known | 15 |
| 1973 | 21 | 3 | 25 |
| 1974 | 37 | Not known | 17 |

3.7. FREQUENCY OF LIGHTNING FLASHES N ARE CALCULATED BY THE FORMULA. (8)

$$N = 1.8\ h_a \frac{D}{20} X \frac{1}{100}$$

$h_a$ = 100 ft. = 30.6 meter

l = 272 Km

D = 57

$$N = 1.8 X 30.6 X \frac{57}{20} X \frac{272}{100} = 440$$

Similarly the number of lightning flashes N of Siddhirganj-Sylhet line is 370. The results shown in the table 11.

Table - 11.

Lightning flashes N of transmission lines.

| Name of the line | Number of thunder storm days | Length of line in Km | Height of line in meters | Frequency of lightning flashes, N |
|---|---|---|---|---|
| Siddhirganj-Kaptai. | 57 | 272 | 30.5 | 440 |
| Siddhirganj-Sylhet. | 68 | 249.5 | 30.5 | 370 |

3.8. OUTAGE PROBABILITY BASED AN INTERNATIONAL CURVES OF LIGHTNING CURRENTS.

From Table 11, the lightning flashes for Siddhirganj-Kaptai line is 440 and Siddhirganj-Sylhet line is 370. From Waldorf's curve the insulation strength of the transmission line is 1630 KV and the permissible stroke current is 150 KA.

From the international curves Fig. 3 (a), the probability of lightning strokes having 150 KA value of current is 2.5 % of the total strokes. Hence the probability of occurrence of outages having above stroke current value is:

for Siddhirganj-Kaptai line = 2.5 X 4.4 = 11

for Siddhirganj-Sylhet line = 2.5 X 3.7 = 9.25

Calculated results are shown table 12 below:

Table - 12.

Outage probability of the transmission lines due to lightning strokes based on international curves.

| Name of the line | Outage probability calculated from international curve. |
|---|---|
| Siddhirganj-Kaptai | 11 |
| Siddhirganj-Sylhet | 9.25 |

The maximum actual outage due to lightning strike for Siddhirganj-Kaptai line is 5 and that of Siddhirganj-Sylhet line is 3.

The outage probability calculated from Waldrof's curve for Siddhirganj-Kaptai line is 2.90 and that of Siddhirganj-Sylhet line is 3.16.

The outage probability calculated from international values of stroke current probability for Siddhirganj-Kaptai line is 11 and that of Siddhirganj-Sylhet line is 9.25.

Thus it is seen that the outage of the lines is between the outage calculated by Waldorf's curve and that calculated from international stroke current probability curve.

As per international stroke current values, the transmission lines fall between the category of less and medium importance.

## 3.9. VARIATION OF GROUNDING RESISTANCE $R_g$

From equation (1) and adopting, $k_o$ = 3 KV/cm and

$$= 5 \times 10^2 \text{ ohm - cm}$$

$$R_g = \sqrt{\frac{2}{\pi} \rho \, k_o} \times \frac{1}{\sqrt{i}}$$

$$= \sqrt{\frac{2}{3.14} \times 5 \times 10^2 \times 3} \times \frac{1}{\sqrt{i}}$$

$$= \frac{31}{\sqrt{i}} \text{ ohm}$$

For $\rho = 5 \times 10^3$ ohm - cm & $k_o$ = 3 KV/cm.

$$R_g = \sqrt{\frac{2}{3.14} \times 5 \times 10^3 \times 3} \times \frac{1}{\sqrt{i}}$$

$$= \frac{97.5}{\sqrt{i}} \text{ ohm}$$

Ground resistance $R_g$ for different soil resistivity and current crest value are tabulated below:

| ohm - cm | $5 \times 10^2$ | $5 \times 10^3$ |
|---|---|---|
| i KA | $R_g$ ohm | $R_g$ ohm |
| 100 | 3.1 | 9.75 |
| 150 | 2.73 | 7.95 |
| 400 | 1.55 | 4.87 |

## 3.10. INDUCTIVE VOLTAGE DROP IN TOWERS.

Inductive voltage drop along a relatively short tower is calculated by the formula, (2).

$$u_L = L_t \; l_t \; \frac{di_t}{dt}$$

Where $l_t = 30.6$ m

$$\frac{di_t}{dt} = 80 \text{ KA}/\mu s$$

And $L_t$ is calculated by the formula

$$L_t = \frac{1}{\frac{n_1}{L_{t1}} + \frac{n_2}{L_{t2}}}$$

$n_1 = 4$ & $n_2 = 130$

$L_{t1} = 2 \mu H/m$ & $L_{t2} = 2.85 \mu H/m$

$$L_t = \frac{1}{\frac{4}{2 \mu H/m} + \frac{130}{2.85 \mu H/m}}$$

$$= 0.0214 \mu H/m$$

Therefore $u_L = 0.0214 \times 30.6 \times 80$ KV

$= 52.38$ KV

Inductive voltage drop along a relatively long tower is calculated by formula, (3).

$$u_L = z_t \; i_t$$

Where $z_t = V \; L_t$

$v = 300\ m/\mu s$

$L_t = 0.0214\ \mu H/m$

$i_t = 150\ KA$

Therefore $u_L = 300 \times 0.0214 \times 150\ KV$

$= 963\ KV$

Therefore inductive voltage drop along a tower will be 53.38 KV which is smaller of the two results calculated above.

3.11. COMBINING THE GROUND VOLTAGE AND INDUCTIVE TOWER VOLTAGE.

The ground voltage and inductive tower voltage can be combined together by the formula,(4).

$$u_{tt} = \frac{1}{2} R_g\ i_t + \sqrt{\frac{1}{4}\ R_g^2\ i_t^2 + L_t^2\ l_t^2 \frac{di_t}{dt}^2}$$

For $i_t$ = 150 KA, the permissible stroke current,

$\frac{di_t}{dt} = 100\ KA/\mu s$

$R_g = 2.73$

So $u_{tt} = \frac{1}{2} \times 2.73 \times 150 + \sqrt{\frac{1}{4} \times 2.73^2 \times 150^2 + 0.0214^2 \times 30.6^2 \times 100^2}$

$= 410\ KV$

For higher values of $i_t$ and $\frac{di_t}{dt}$ the value of $u_{tt}$ will be greater although $R_g$ will be smaller.

3.12. PROTECTIVE ANGLE:

The protective angle of 132 KV. double circuit line can be measured from Fig. 8 page 55.

The protective angle for upper conductor, middle and bottom conductors are $28\frac{1}{2}^{o}$, $18^{o}$ & $13\frac{1}{2}^{o}$ respectively.

3.13. SPAN LENGTH:

Average span length of 132 K.V. transmission line is 1000 ft. On the basis of this span length permissible stroke current has been calculated.

3.14. VARIATION OF OUTAGE WITH TOWER FOOTING RESISTANCE:

American experimental[10] result for variation of tower footing resistance and outage of the line has been shown in the Fig. 9 page 57.

# EFFECT OF TOWER FOOTING RESISTANCE ON LINE OUTAGE

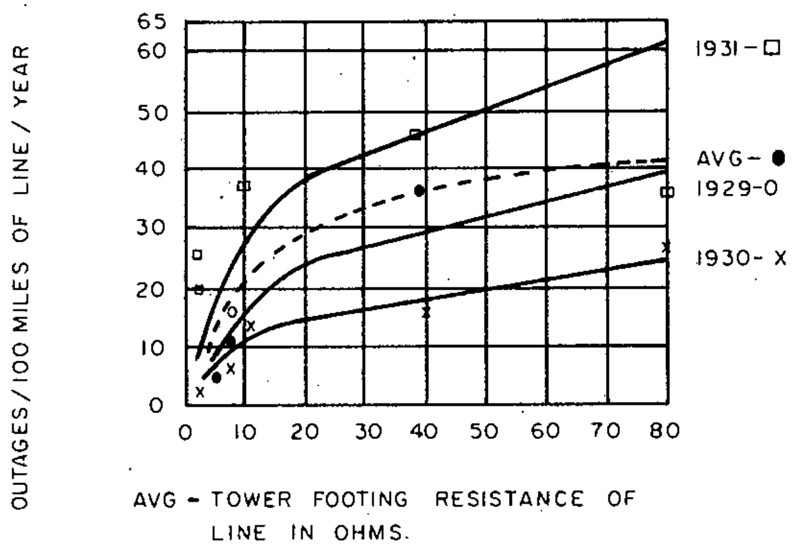



FIG. 9

## CHAPTER - IV.

### ANALYSIS OF RESULT.

The insulation strength of the transmission line has been calculated to be 1630 KV for tower footing resistance of less than 2 ohm. The average thunder storm days are very high for the transmission lines under study but on the other hand the tower footing resistance is less than 2 ohm due to low soil resistivity.

The number of lightning flashes N is very high as the isokeraunic level is very high.

The outage probability calculated are shown in Table (8) and actual outage due to lightning in Table 9 & 10. These number are nearly in close agreement. The outage of the transmission line due to other reasons are much more higher than the outage of the due to lightning strokes as can be seen from the Table 9 & 10.

From Fig. 9 page 57 it is seen that lower the tower footing resistance lower is the outage of line[8]. From Fig. (9) it has been seen that there have been a drop from 30 outages per year to 8 as the average footing resistance fell from 80 ohms to 5 ohms. The magnitude of tower footing resistance to make a line lightning proof has been much discussed.American Study shew that tower footing resistance in the Order of 5 or 10 ohms have little prospect of rendering conventional 132 KV lines lightning proof but undoubtedly make them more lightning resistant. As such attempt for further improvement of performance of 132 K.V. lines by lowering the footing resistance will not produce much benefit.

# CHAPTER - V.

## 5.1. INCIDENCE OF INSULATION FAILURES.

Power Supply trip out due to failure of equipments of the 132 K.V. transmission system are listed below:

| Date | Weather condition | Type of equipment failed |
|---|---|---|
| 14.4.67 | Fair | Lightning arrester at Comilla Sub-Station of 132 K.V. Siddhirganj-Kaptai line. |
| 26.4.67 | Fair | Lightning arrester at Comilla Station circuit No.1 of Siddhirganj Kaptai 132 K.V. line. |
| 6.9.67 | Rainy | Burning of solenoid coil of Kaptai Unit No.1. |
| 25.3.68 | Good | Failure of lightning arrestor at Madanhat. |
| 26.3.68 | Good | Failure of lightning arrestor at Madanhat. |
| 26.3.68 | Good | Failure of lightning arrestor at Chittagong. |
| 14.6.68 | Rainy | Loop Joint Severed at Madanhat-Kaptai Section of circuit No.2 of Siddhirganj-Kaptai 132 transmission line. |
| 10.5.69 | Good | Insulator of 11 K.V. cables of pot head at Siddhirganj Sub-station. |
| 18.5.69 | Good | Insulation failure of 11 K.V. cables of 132/11 K.V. transformer at Siddhirganj Sub-station. |
| 5.9.68 | Raining | One number of lightning arrestor damaged at Shahjibazar Sub-station. |
| 23.10.70 | - | One number of lightning arrestor at Ashuganj caught fire and damaged. |
| 12.4.74 | - | Failure of lightning arrestor of 132/33 KV.Transformer at Ashuganj Sub-station. |

| Date | Weather condition | Type of equipment failed |
|---|---|---|
| 14.1.74 | Good | Coupling capacitor potential Device at Siddhirganj Sub-station of Sylhet-Siddhirganj 132 K.V. transmission line. |

5.2. <u>REASONS OF INSULATION FAILURE.</u>

In all the cases of failure of lightning arrestor no details of the system condition was available except the lightning arrestor have been replaced with new one before the putting the line back to service. It is interesting to note that the lightning arrestor failed when the weather condition had been fair and occurance of thunder storm at that time could not be established. The reason of failure of arrestor may be due to deterioration of insulation of the arrestor.

For an effectively earthed system, which is the followed for transmission system in Bangladesh, the line to earth r.m.s voltage under fault condition should not exceed 80% of the highest system voltage. The rated voltage of the lightning arrestor used is 116 K.V.

If the earthing of the particular place deteriorate due to some reason the line to earth voltage under fault condition may rise up to 100% of the highest system voltage, which may be a reason for the failure of lightning arrestor as the rated voltage of the lightning used is 116 KV. It is better risking the lightning arrestor failure than to use the next higher voltage rating of the diverter with substantially reduce degree of protection. A further detailed investigation in this regard in necessary to arrive at a solution and the reason of such failure and forecast remedies thereto.

Incident of insulation failure of Transformer,switches etc. due to over voltages of lightning surge or switching surge are rare. Impulse strength of equipments of 132 KV system is 650 KV. An investigation is necessary whether reduced impulse strength of above equipments can be adopted here considering the local conditions prevailing here as the deduction of impulse strength of equipments will reduce the cost to a considerable extend.

Another factor that endanger insulation properly of the equipments is the ambient temperature and relative humidity of important places of the country in appendix 2. High absolute humidity induces accelerated moisture diffusion into the volume of the insulating material, substantially impairs its electrical properties. Very frequently moisture accumulated in the volume of the insulating material irreversibly impairs its characteristics.

According to Bruchard and Hoffman's the authors[6] of first technoclimatology, classification of regions of the world our country is in the tropical humid zone (TH). The monthly mean temperature of our country exceed $18^{\circ}C$ throughout the year. This climate provides the best conditions for the growth of organisms and the hazards of microbial corrosion must be there. It remains to determine the intensity at which these governing factors impair the operation and service life of the electrical equipments.

The manufacture of electrical equipment suitable for such climatic conditions will involve some extra cost. The extra cost involve for such design and manufacture should be compound with the benefit of tropicalization. Before installing any electrical equipment, the manufacturer must ensure that the equipment must not be endangered by the local climatic conditions.

# CHAPTER -VI.

## 6.1. DISCUSSION & CONCLUSION.

The isokeraunic map could not be prepared as record of thunder storm days of a large number of places throughout country is not available. The map which has been prepared here provide indication about the thunder storm activity of the places shown in it. In order to prepare an exact isokeraunic map, which is difficult for a small country like ours, the Meteoroligical Department, which is responsible for maintaining such records, should be specifically entrusted with the keeping of records for the purpose. The thunder storm data of many recording stations was not reliable and as such those centres have been omitted from the map.

The average storm activity along the two major existing transmission lines have been determined. The results show that the lines experience severe thunder storms. On the other hand tower footing resistance are found to be low.

Outage probability of the transmission line is 0.9 per year per 100 miles of lines. Insulation strength of the transmission line has been found to be 1630 KV and protection level of 15 X $10^4$ Amp of stroke current. Since there has been no field investigation in Bangladesh about the magnitude of the stroke current that might strike the transmission line, we are to remain satisfied with the results of the field investigation of other countries. Stroke current magnitude has been taken from international curves, for calculations.

The outage of the transmission line due to lightning stroke in very small in comparison with total outage as shown in table 9 and 10. On many occasions it has been stated in the interruption report that line tripped due to fault originated in the subtransmission system. Due to lack of proper co-ordination of relay of transmission and sub-transmission system outage of the transmission lines increased.

The major equipment of the 132 KV. transmission system such as oil switchs, transformer etc. have impulse insulation strength of 650 Kv. It has been observed, from operating experience, that incidence of insulation failure has not been reported. Investigation is necessary whether impulse insulation strength of equipments of the transmission system can be lowered by certain step for economic benefit.

Ground resistivity is very low and tower footing resistance is less than 5 ohm. Attempt to improve reliability of the transmission system by further lowering the tower footing resistance may not be economically justified.

## 6.2. SUGGESTION FOR FUTURE WORK.

It has been seen from operating experience that there had been equipments is Bangladesh Power Development from different country of origin. Co-ordination of insulation is a difficult task. Still some work may be done on this issue which may be useful for system operation and may save huge amount cost.

Importance of tower impedance with reference to very low tower footing resistance can be considered for further work.

REFERENCES

1. J. R. Eaton,"Grounding Electric Circuits" General Electric Review June, 1941 PP - 8,9,12 & 17.

2. Wills Maclachlan,"Electrical Resistivity Tests on Barric - Scarborough 110 KV. Transmission Line", a report, dated 12-11-1946 of the Hydro-Electric Power Commission of Ontario,Canada.PP - 4.

3. W.P. Dobson,"Transmission Line Grounding in Rugged Country", a report dated 14-4-1949, of the Hydro-Electric Power Commission of Ontario, Canada, PP - 2.

4. The Wastinghouse Electric Corporation - "Electrical Transmission and Distribution ( a reference books) Published by Westinghouse Electric Corporation", 1955 Chapters 17 & 18.

5. C.B. Harpar - "The Selection of Insulation Levels and Tests for High Voltage Transformers", A Procedings Inst. Elect. Engr. January, 1959, PP - 10.

6. Miroslav Rychtera and Bernarda Bartakova,"Tropicproofing Electrical Equipment", a book 1963, Leonard Hill (Books) Ltd. London, PP - 77 - 80.

7. K. Depporman & J. Thiele,"Ceoelectric Resistivity Survey in Bangladesh, 1968, WAPDA (Water Wing)", PP - 48. a report.

8. Philip Sporn,"Vistas in Electric Power "(a book) Published by Pergamon Press Inc. 1963, PP - 473.

9. Acres International Limited, Consulting Engineers,"Design Transmittals, East-West Inter Connector Projects",Bangladesh Power Development Board, 1970, PP - 2 ( D.T. No.1).

10. A. Cewe -"Lightning Investigation on 220 KV. Steel Tower Transmission Line," a paper, published by Gdansk Technical University, High Voltage Institute, Vol. Tom XX Zeszyt 2, P - 369.

11. S. Szpor - "Electriodynamic Consideration of Lightning Problem II" a paper, Vol. XIX Nr.1, 1971, PP - 35.

12. S. Szpor -"A Proposal of a Method of Lightning Protection Calculations for Transmission Line". "Conference Paper No. C 72 175-3,I. E. E. E. Power Engineering Society, New York, January 30- February 4, 1972,PP-2,5.

13. S. Szpor - "International Curves of Lightning Current and Their Application for Protection Calculas", Conference Paper No. C 72 i76-1, I.E.E.E. Winter Meeting, New York, January 30 - February 4, 1972, PP - 2 & 4.

APPENDIX -1

TABLE 13 SUMMARY OF ANACOM STUDY

| Span feet | Tower footing resistance ohms | Tower-Top voltage per Ampere of stroke current | Mid-Span voltage per Ampere of stroke current | Time lag to insulate (Microseconds) | |
|---|---|---|---|---|---|
| | | | | Tower | Midspan |
| 200 | 5 | 11.6 | 27.5 | 2.0 | 2.0 |
| | 10 | 12.5 | 27.5 | 2.0 | 2.0 |
| | 20 | 16.3 | 28.5 | 2.0 | 2.0 |
| | 50 | 28.8 | 30.5 | 2.0 | 2.0 |
| | 100 | 45.0 | 40.5 | 2.0 | 2.0 |
| 400 | 5 | 13.2 | 45.0 | 2.0 | 2.0 |
| | 10 | 15.0 | 45.0 | 2.0 | 2.0 |
| | 20 | 21.0 | 46.5 | 2.0 | 2.0 |
| | 50 | 36.0 | 48.8 | 2.0 | 2.0 |
| | 100 | 57.5 | 56.3 | 2.0 | 2.0 |
| 600 | 5 | 14.0 | 65.0 | 2.0 | 2.0 |
| | 10 | 15.4 | 65.0 | 2.0 | 2.0 |
| | 20 | 21.5 | 67.5 | 2.0 | 2.0 |
| | 50 | 38.8 | 68.0 | 2.0 | 2.0 |
| | 100 | 64.0 | 72.0 | 2.0 | 2.0 |
| 800 | 5 | 14.0 | 86.0 | 2.0 | 2.0 |
| | 10 | 16.0 | 86.0 | 2.0 | 2.0 |
| | 20 | 22.0 | 87.5 | 2.0 | 2.0 |
| | 50 | 42.0 | 90.0 | 2.0 | 2.0 |
| | 100 | 72.0 | 92.5 | 2.0 | 2.0 |
| 1000 | 5 | 14.0 | 110.0 | 2.0 | 2.0 |
| | 10 | 17.0 | 110.0 | 2.0 | 2.0 |
| | 20 | 24.5 | 110.0 | 2.0 | 2.0 |
| | 50 | 45.0 | 110.0 | 2.0 | 2.0 |
| | 100 | 75.0 | 113.0 | 2.0 | 2.0 |
| 1200 | 5 | 14.0 | 125.0 | 2.0 | 2.0 |
| | 10 | 17.0 | 125.0 | 2.0 | 2.0 |
| | 20 | 24.5 | 125.0 | 2.0 | 2.0 |
| | 50 | 45.0 | 125.0 | 2.0 | 2.0 |
| | 100 | 75.0 | 130.0 | 2.4 | 2.0 |
| 1600 | 5 | 14.0 | 158.0 | 2.0 | 2.0 |
| | 10 | 17.0 | 158.0 | 2.0 | 2.0 |
| | 20 | 24.5 | 158.0 | 2.0 | 2.0 |
| | 50 | 45.0 | 158.0 | 3.2 | 2.0 |
| | 100 | 75.0 | 158.0 | 3.2 | 2.0 |

APPENDIX -2

TABLE NO. 14 RELATIVE HUMIDITY IN % BETWEEN 1931-1960

| Name of the place | Maximum Humidity | | Minimum Humidity | |
|---|---|---|---|---|
| | % Humidity | Months | % Humidity | Months |
| Chittagong | 85 | July | 63 | February |
| Rangamati | 99 | Nov.& Jan. | 50 | February |
| Cox's Bazar | 89 | August | 68 | Jan & Feb. |
| Noakhali | 95 | October | 60 | February |
| Comilla | 96 | October | 54 | February |
| Brahmanbaria | 94 | December | 53 | March |
| Srimangal | 97 | December | 57 | March |
| Sylhet | 97 | July | 51 | March |
| Mymensingh | 94 | July to Sept. | 73 | March |
| Dacca | 95 | June to Dec. | 44 | March |
| Narayanganj | 92 | October | 45 | March |
| Pabna | 95 | Jan.-Dec. | 44 | March |
| Serajganj | 95 | Oct.-Dec. | 50 | March-April |
| Faridpur | 96 | July | 49 | March |
| Jessore | 96 | July-Sept. | 52 | March |
| Satkhira | 96 | July | 53 | March |
| Barisal | 94 | July-Oct. | 56 | Feb.-March |
| Khulna | 95 | July-Sept. | 53 | March |
| Bogra | 87 | August | 37 | March |
| Dinajpur | 93 | July-Aug. | 36 | March |
| Rangpur | 95 | Jan.-Sept. | 42 | March |