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EVALUATION OF LIGHTENING SURGE EFFECT ON 11kv DISTRIBUTION LINES

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ABSTRACT

Voltage induced on overhead transmission lines due to lightning phenomena is one of the major reasons for the flashover and outages. The basic insulation level of the distribution lines are lower, therefore, the problems caused by the lightning strokes in the vicinity of the transmission lines become more apparent. Determination of the maximum voltages induced on the overhead line by direct stroke is a complex problem. Distributions circuits typically are not insulated to withstand direct lightning strokes, as a result, direct strikes will cause a flashover between phase to phase or phase to ground depending upon the arc path. For estimating the flashover due to direct strokes, it is necessary to calculate the maximal voltage induced on the line. The effect of direct lightning on distribution lines have been analyzed with different conductor sizes, terminal impedances, variation in span lengths, addition of a cable & surge arrester etc. It is observed, with simulation fo different models on EMTP, that these factors have considerable effect on the voltage induced on distribution lines due to lightning phenomena. This will be helpful for further research/investigations about each factor affecting the induced voltage.

INTRODUCTION

On many transmission lines lightning impulse is the main cause of unscheduled supply interruptions. A number of methods for estimating tripouts rates have been deployed. The voltages produced on overhead lines by lightning might be due to indirect or direct strokes. Therefore a lightning stroke to a transmission line conductor injects a transient current of several thousand amperes. The aim of this paper is to obtain maximum over voltage value that might be occurred on the distribution system for analysis purpose. Various circuit configurations be selected from the existing 11 KV distribution system. This involved a limited amount of field data study from WAPDA.

OBJECTIVE

The objective to calculate induced over voltage from lightning, it is one of the main cause of medium-voltage distribution systems outages. As a consequence, their evaluation has been for years, and is still, one of the most important problems in designing and coordinating the protection of overhead power lines. A better knowledge of the over-voltages experienced on a simple 11 KV circuit could improve our ability to select equipment such as switches, arresters and BILs level of Transformer. It would also provide input into the design parameters for live line tools, cover-up equipment, insulation levels and barriers used to build or maintain such distribution systems.

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PHYSICAL PHENOMENA OF LIGHTNING

The physical phenomena of lightning shows that cloud acquire charge or at least become polarized, so that electric fields of considerable strength is created within the clouds and between the cloud and adjacent masses such as earth and other clouds. When these fields become excessive, to such an extent that the dielectric of intervene space can no longer support the electrical stress, a breakdown or lightning flash occurs, this is usually a high current discharge.

EFFECT ON TRANSMISSION LINE

When the lightning stroke struck to a transmission line, that lightning direct connect to the line or it completes a circuit with close mutual coupling to line. Frequently line will be raised to such a potential that further flashes will occur to grounded structures. Or the grounded structures may be raised to such a potential that they flashover to the line. In this way another path is introduced for current and other source for transients is created. The effects of lightning are conducted to remote parts of the system where surges impinge on terminal equipment and even enter industrial plants, commercial buildings or private homes.

BREAKDOWN OF AIR

As the charges build up within the cloud and by induction on the earth below, a point is reached locally within the cloud where the electric field is sufficient to cause breakdown. In air at atmosphere pressure this is approximately 30KV/cm[2]. However in the cloud with the high moisture content at lower pressure because of its altitude, it is conjectured that local breakdown may occur at lower gradient, perhaps as low as 10KV/cm[2].

INTERACTION BETWEEN LIGHTNING AND THE POWER SYSTEM

When lightning strikes a power line, a current is injected into the power system. Voltage which will rise, depends upon the current magnitude, waveshape and the impedance through which it flows. If it is tower that is truck, the impedance of the tower will be of concern. The voltage drop down the tower will appear across the line insulation. If the magnitude of voltage is excessive, flashover of the insulation will occur between tower and phase conductor called "Backflashover"[11] and a fault will be placed on the system.

FLASHOVER FROM DIRECT LIGHTNING STRIKES

On actual in –service lines, multiple flashovers often occur on unprotected structures adjacent to the strike point. There lightning caused flashovers will result in an arc path through which current may flow. This arc path is of low impedance and the currents that flow during a lightning flashover can be expected to be close to calculated values assuming zero fault impedance. Such arcs generally will not be self-extinguishing, and the fault must be cleared before the insulation level of the line can be re-established.

DISTRIBUTION LINE INSULATION LEVEL

Basic insulation levels of overhead distribution lines becomes a very cumbersome procedure due, in part, to the multiplicity of designs, all of which have numerous variations. For accurate results, each design and variation would have to be studied individually. Therefore a wide variety of (BIL's), configurations, shielding, footing resistances, protective schemes, lines, because of these many variables, only rough estimates of the lightning performance of these lines has been possible.

PROTECTION OF DISTRIBUTION LINE

Surge/Lightning arresters are used widely to protect the distribution lines against lightning. It is common practice to protect overhead lines against lightning at least in areas where they are deemed to be vulnerable. Such protection may extend the entire length of line, or it may be confined to the first few miles adjacent to the substation or switching station. In the latter case the assumption is that surges produced by any lightning strike to the unprotected section of the line will have been reduced to manageable proportions by the time they reach the end of the line by flashover along the line and/or corona and other attenuating effects experience by the surge in its progress along the line. The primary function of the distribution surge arrester is to protect the insulation of distribution class oil-filled transformers.

OPERATING PRINCIPLE OF SURGE ARRESTER

When the suppressor/lightning arrester operates an arc is established in the gap, this arc must be quenched when the surge is passed or the resistor will be destroyed by the current that would continue, once conditions are restored to normal. To meet this requirement, quenching elements have been introduced like ZnO and SiC into the suppressor.

LOCATION OF ARRESTER OTHER THAN SUBSTATION

Arresters have been introduced for the protection of transmission and distribution lines as an alternative to overhead ground wires. They are placed out at intervals on the poles or towers. Voltage across the line insulator at the point of installation is controlled by the MOV (Metal Oxide Varistors) and kept below flashover voltage of the insulator to avoid back flashover, which is most frequent form of lightning outage. The voltage across the line insulation is greatly influenced by the high tower footing resistance.

MATHEMATICAL REPRESENTATION

The entire lightning event is referred to as a flash and the individual pulses are referred to as strokes and when this current injects on phase conductor, voltage waves radiate from the point of contact in both directions along the conductor and down the tower if flashover occurred across insulator to tower. These waves rapidly encounter discontinuities, which initiate reflected waves, which generate another waves when they return to the stricken point. In this way a large number of waves are generated in short order. The effect of these waves will depend on the change of surge impedance at this discontinuity.

The potential difference across the suspension insulators is of particular concern since a flashover can occur and a fault be placed on the phase if this voltage becomes excessive.

When direct lightning strikes on overhead phase-conductor, magnitude of the current and high frequency nature of the stroke causes voltage surges to be propagated in both directions from the point of strike and the two traveling voltage waves originates having magnitude:

$$e = \frac{1}{2} * Z * i$$

Where

e = Voltage induced
Z = Surge impedance
i = Current

APPLICATION OF EMTP

Relevant data available within WAPDA sorted out as per requirements of Electromagnetic Transient Program (EMTP). EMTP is a computer package used to simulate high speed power system transients. After selection of different models, they were simulated on EMTP with different options and maximum overvoltage value that occurred on the selected distribution system were taken.

LIMITATIONS

There are certain limitations which were not considered during research. However, these cannot be totally eliminated but overlooked as the requirement of EMTP package, likely each span between towers represented separately as a line, and only a few spans near to substation are modeled. For each short distances, losses in series resistances and differences in modal travel time are negligible. Effect of corona and frequency contain in surge are also not considered.

ASSUMPTIONS

In lightning surge studies, many simplifying assumptions are made. For example, the waveshape and amplitude of the current source representing the lightning stroke is obviously not well known.

Lightning wave assumed as per IEEE standard, 4,197. 1.2/50 μsec with 30kAmp of current magnitude.

Inductance of surge arrester lead was assumed 0.001 mHenry, approximately.

Wave speeds are approximately equal to the speed of the light, with surge impedance in phase quantities.

Only six spans near to surge arrester assumed with different span lengths, reflections from the other section whose surge impedance assumed to be 37.6 ohm and 300.0 ohm.

We have supposed six spans of 11 kV line and tower Nos. ranging from P0 to P6.

Travel time is the min time taken by the wave to travel between two nodes and we assumed 10% of shortest travel time for output time scale. It is because better output obtained from analytical point of view.

It is very important to know that electrically whose section treated as one span for lightning stroke but we suppose only mechanical supports at different intervals.

Surge impedance on 11 kv line are calculated for conductor type Panther, Rabbit, Dog and Osprey which are mostly used. Input data required to calculate the surge impedance on EMTP.

DATA INPUT

CONDUCTOR TYPE	PANTHER	RABBIT	OSPREY	DOG
Diameter of conductor	21.0	10.05	22.35	14.15
D.C resist. At 20oC (Ω/km)	0.1363	0.5426	0.1022	0.273
Height of conductor At pole			9.448 m	
Height of conductor From ground in mid span			9.144 m	
Tower footing Resistance			0.5 Ω	

Data was feeded and simulated it with EMTP.

Following results for surge impedance were used for selected conductor types further computations in different cases:

CONDUCTOR	SURGE IMPEDANCE
Panther	306.26 Ω
Rabbit	342.7 Ω
Dog	322.2 Ω
Osprey	294.76 Ω
Velocity of wave	2.8449×10^5 km/sec

Following ten cases were selected, in which location for lightning is different, therefore we have different outputs for each case at different locations. The outputs for each case are summarized in a table and only one sample output is attached, for details of input & output see [16].

Case No. 1: Lightning stroke striking on conductor (Panther) away from substation and surge arrester is not enabled.

Case No. 2: Lightning stroke striking on conductor (Panther) away from substation and surge arrester is enabled.

Case No. 3: Lightning stroke striking very close to surge arrester approximately one span away from the arrester enabled.

Case No. 4: Surge impedance of conductor increased by approximately 100 ohm with arrester enabled.

Case No. 5: Surge impedance of conductor decreased by approximately 100 ohm with arrester enabled.

Case No. 6: Lightning stroke striking on conductor (Panther) away from substation with arrester enabled. Underground cable supposed in last two spans.

Case No. 7: Lightning stroke striking on conductor (Rabbit) away from substation. Arrester enabled and span lengths changed.

Case No. 8: Lightning stroke striking on conductor (Dog) away from substation. Terminal impedance changed with change in span lengths.

Case No. 9: Lightning stroke striking very far away from substation on conductor (Osprey). Terminal impedance and span lengths remains same as in case No. 9.

DISCUSSION ON OUTPUT

Surge arrester effectively reduced the induced voltages as can be seen by comparing case No. 1 & 2. In case No.1, one end is open and voltage is almost at constant level, however, in case No. 2 by the installation of arrester, the induced voltage reduced at all the locations. This is because the voltage at the terminals of arrester are set at the preset value i.e about 11.2 kV.

In each case at different locations rise to its peak value and then decreases because these waves rapidly encounter discontinuities due to change of impedance which initiates reflected waves. A large number of waves are generated in short order. The effect of these waves depends upon the change of surge impedance at the discontinuity like terminal impedance. In some cases there is a negative dip in the wave front because at that moment surge impedance of the conductor is lower than terminal impedance, the reflected and incident waves having opposite signs and act to reduce for a very short period otherwise vice-versa.

In each case there is a time delay at each location other than the strike point, it is because the time taken by the wave to travels that particular distance between the stricken point and the point where the output is obtained, it travels approximate with the speed of light.

Following possibilities might be possible after lightning surges originate on the distribution lines as discussed above:

(1) Flashover between phase due to breakdown strength of air i.e. 30 kV/cm and minimum phase spacing of 72 cm for 11 kV suspension type structure 106 cm for tension type structure.

EXAMPLE

30 kV/cm * 72 cm = 2.16 MV, it means 2.16 MV voltage magnitude required for two closed phases for flashover. In this way the flashover between the two phases would be occurred when the lightning falls away from arrester installed point.

(2) Flashover from insulator to tower.

Basic impulse Insulation Level (BIL) for 11 kV distribution system is = 95 kV

Withstand voltages of insulators used in the system are:

<u>Pin type suspension insulator</u>

Critical Impulse positive voltage = 90 kV
Critical Impulse negative voltage = 110 kV

<u>Ball and Socket type tension insulator</u>

50% impulse positive = 120 kV
50% impulse negative = 125 kV

From the insulator data it is clear that flashover path from conductor to tower through insulator is more frequent and quicker than any other flashover only when insulators are earthed.

(3) Flashover between two circuit.

It is not practically possible because circuit spacing between two circuits are more than the top circuit to earth i.e. tower in this case and it is recommended that resistance should not be more than 0.5 ohm to provide resistance free path from conductor to tower in case of flashover occurred.

The above results are summarized in Table 1 and shown in the figure attached.

TABLE 1

Variation in Parameters	Effect of induced Voltage
% change in surge impedance	% Change in voltage
Increase by 33%	Increase by 24.35%
Decrease by 33%	Decrease by 26.4%
Terminal impedance decreases by 20.2% and conductor surge impedance by 6%	Voltage decreased by 7%
Introduction to underground cable	Voltage decreased by 97%
Effect of surge arrester	Voltage decreased by 62%

CONCLUSION

Following conclusions are based upon the outputs obtained for all cases.

By introducing different types of conductors, it has been found that change in conductors surge impedance directly affects the induced voltage from 2.84MV to 3.86MV, also about 4.8MV in some cases.

By introduction of surge arrester induced voltage effectively reduced from 10.5 MV to 4.0 MV with same input conditions.

It has been observed that decrease in terminal impedance results slightly decrease in induced voltage.

It has been found that, when the lightning strike away from the arrester, the induced voltage persists for more time as compare to surge striking near to arrester.

Introduction of a underground cable cause direct effect on induced voltage on the line. It has been found that the induced voltage is reduced from 3.04 MV to 62.53 MV.

SUGGESTION FOR FUTRE WORK

In this thesis, the arrester selected at the terminal station, however it is suggested to install arrester at the intermediate points to avoid outages of distribution lines.

Simulation of 11KV line with increase in BIL level.

Installation o shielwire.

Increase in Nos of insulators.

Change in phase spacing.

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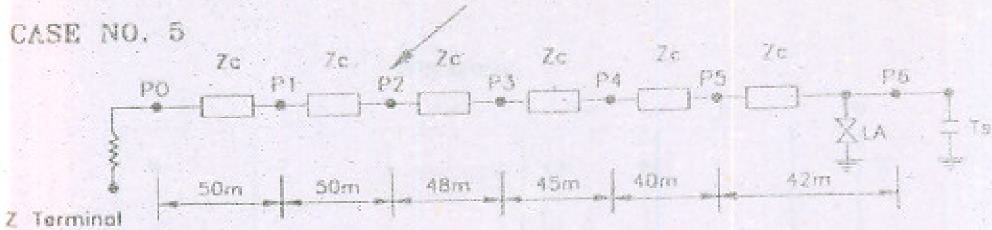
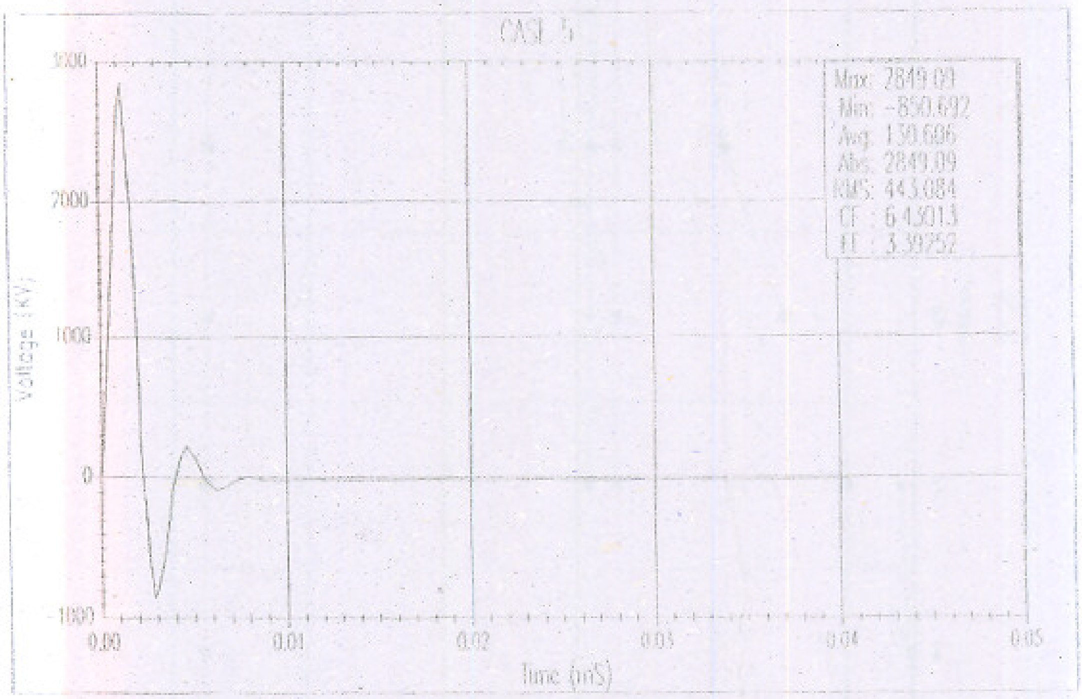
CASE NO. 5





Output at P2 where lightning stroke striking

Voltage magnitude rise upto 2.8MV within 1.0μsec. In case No.2 magnitude of induced voltage is 3.8MV impedance is 306.2Ω and in case No.2 voltage is 4.8MV with increase in impedance by 100Ω. Now in this case the impedance decrease by 100Ω and induced voltage is also decrease in similar way i.e. e = 1/2 * Z * I. Negative voltage is because the impedance difference at P0 is high & when reflection and refraction took place the net resultant voltage induced at this point is negative.

COMPARISON OF INDUCED VOLTAGES IN DIFFERENT CASES

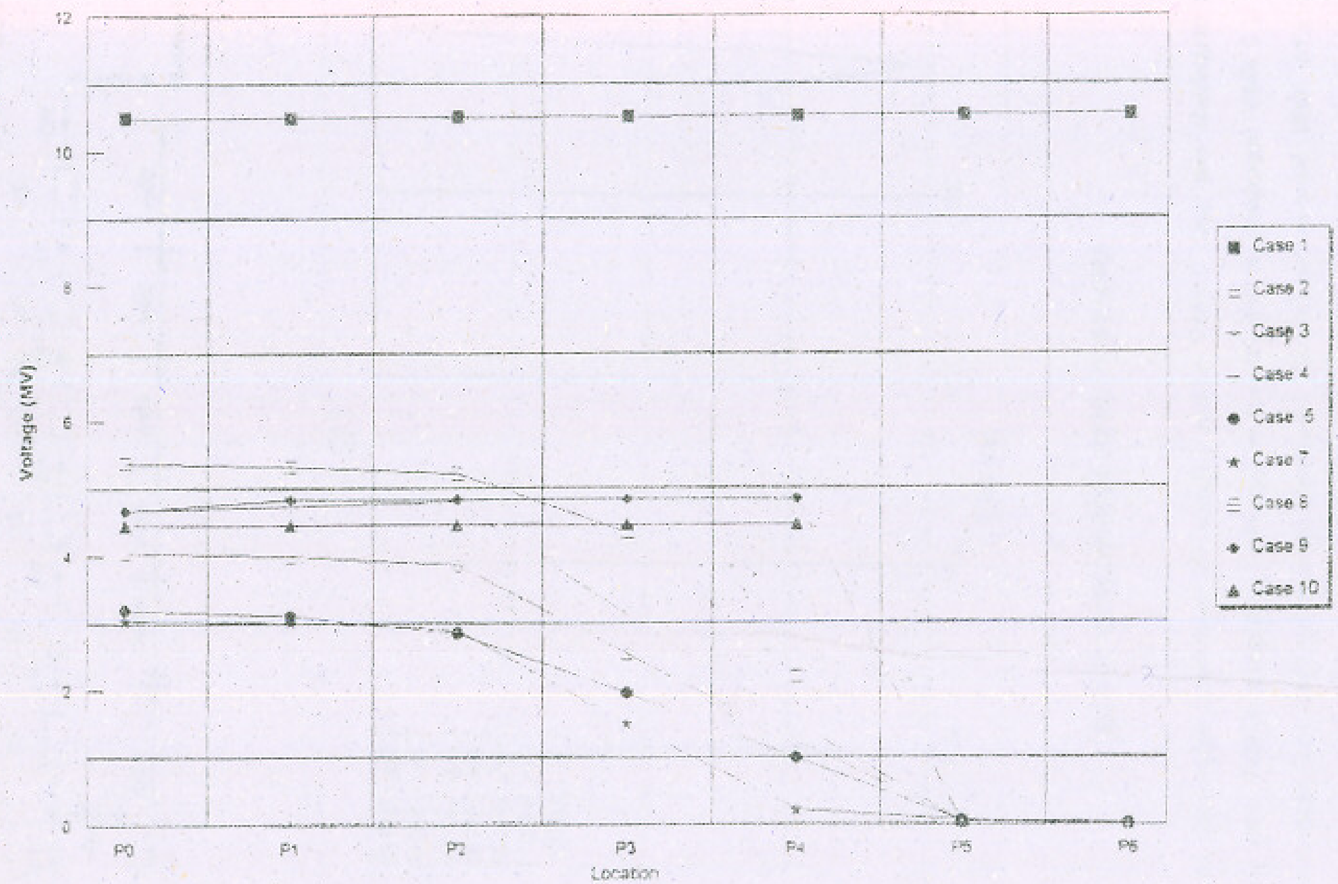
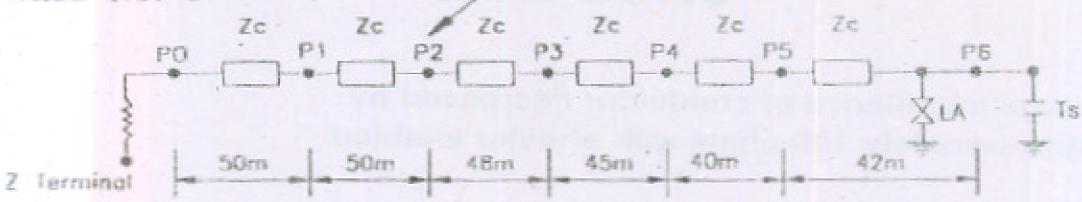
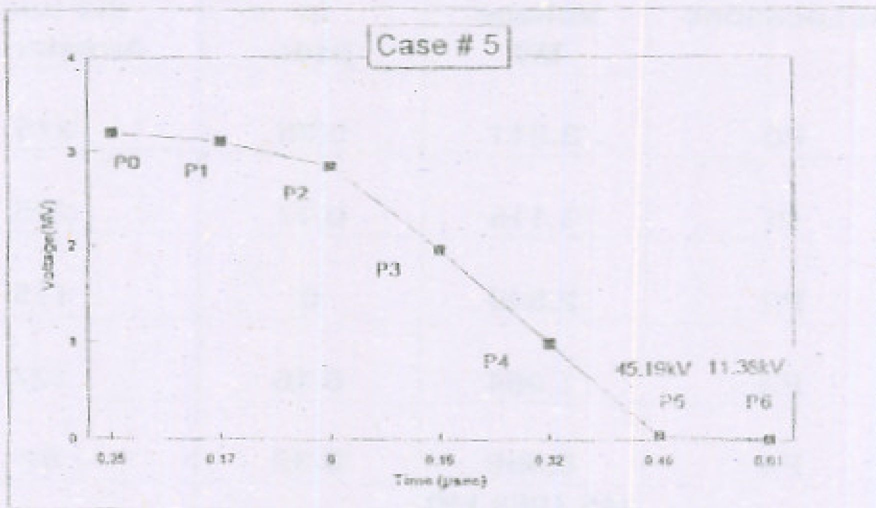


Fig - 7

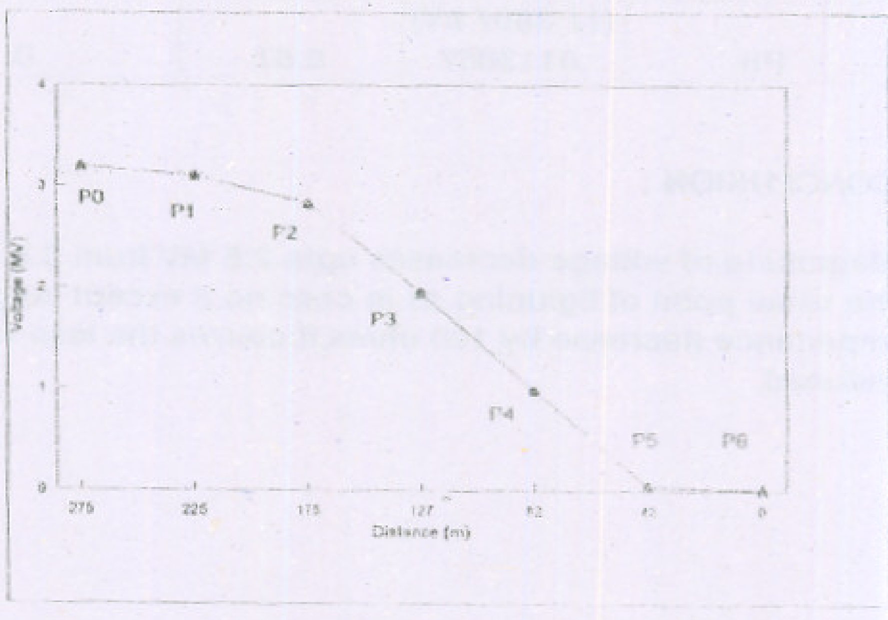
CASE NO. 5



Zc
P0
P1
P2
P3
P4
P5
P6
LA
Ts
50m
50m
48m
45m
40m
42m
Z Terminal



Case # 5
Voltage(MV)
Time (µsec)
P0
P1
P2
P3
P4
P5
P6
45.19kV
11.36kV



Voltage (MV)
Distance (m)
275
225
175
127
82
42
0
P0
P1
P2
P3
P4
P5
P6

CASE No.5

Surge impedance of conductor decreased by approximately 100 ohms with arrester enabled

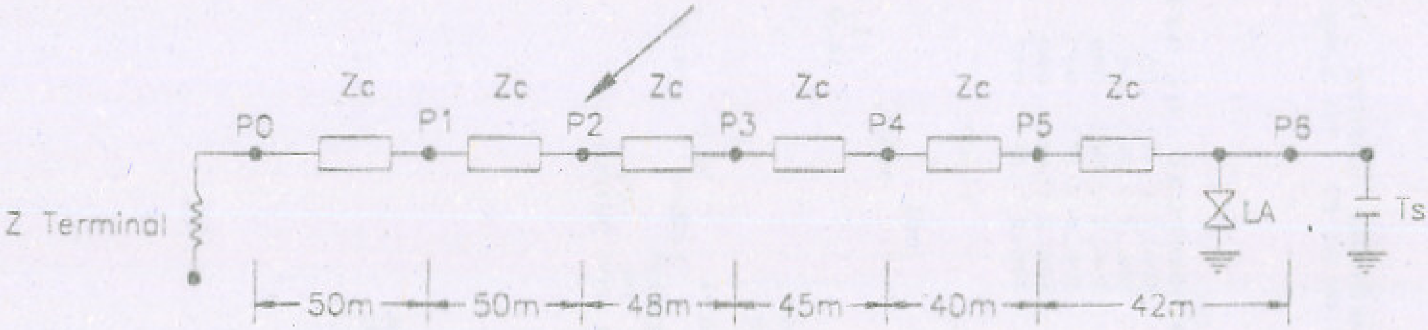
Reading taken at Locations	Peak Voltage MV	Time Delay in µsec	Distance from the Surge Arrester (m)
P0	3.211	0.35	275
PI	3.115	0.17	225
P2	2.849	0	175
P3	1.964	0.16	127
P4	0.996	0.32	82
P5	(45.1968 kV) .0451968	0.46	42
P6	(11.3867 kV) .0113867	0.61	0

CONCLUSION :

Magnitude of voltage decreases upto 2.8 MV from 3.8 MV at the same point of lightning as in case no.2 except surge impedance decrease by 100 ohms,it causes the less voltage induced.

CASE NO. 5

Lighting wave striking on P2 and arrester is enabled at P6, surge impedance Zc is decreased by 100 ohms i.e 206.2 ohms from 306.2 ohms assumed in case No. 2.



Z.Terminal'	=376.0 ohms
Zc(Panther)	=206.20 ohms
Lead Inductance of (Lightning Arrester)	=0.001 m.Henry
Transformer (Ts) Capacitance	=.003uF

```
C   11 KV TRANSMISSION LINE LIGHTNING  STUDIES - PANTHER CONDUCTOR
C   CASE 1-LIGHTNING ON CONDUCTOR AT P2 - NO SURGE ARRESTOR
BEGIN NEW DATA CASE
  0.5E-8 80.0E-6       0.        0
   40000        1.      1       1       1       0       0       1
C  LINE TERMINATION
  P0                          376.00
C  LINE MODEL USING K.C. LEE UNTRANSPOSED LINE MODEL
-1P0     P1                               306.2 2.8E5 .05     1
-1P1     P2                               306.2 2.8E5 .05     1
-1P2     P3                               306.2 2.8E5 .048    1
-1P3     P4                               306.2 2.8E5 .045    1
-1P4     P5                               306.2 2.8E5 .040    1
-1P5     P6                               306.2 2.8E5 .042    1
C  TRANSFORMER REPRESENTATION
  P6                                          0.003
C  SURGE ARRESTOR
  P5     P6                             .001
92P6                                           5555.
                       9.0                                  -1.
                      .6954                                 16.9
                      9999.
BLANK CARD TERMINATING BRANCHES
BLANK CARD TERMINATING SWITCHES
C    SOURCE CARDS
C  14P0            8980.          50.0        50.0
13P5     -1          30.                 1.2E-6      15.0      50.E-6         0
BLANK CARD TERMINATING SOURCE CARDS
  P1     P2     P3    P4     P5     P6     P0
BLANK CARD TERMINATING NODE VOLTAGE OUTPUT
 1450.5     6.00           P1
 1450.5     6.00           P2
 1450.5     6.00           P3
 1450.5     6.00           P4
 1450.5     6.00           P5
 1450.5     6.00           P6
 1450.5     6.00           P0
BLANK CARD TERMINATING PLOTTING
BLANK CARD TERMINATING THE CASE
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