IMPROVEMENT OF LIGHTNING PROTECTION IN LOW VOLTAGE DISTRIBUTION SYSTEMS IN AREAS WITH HIGH ISOKERAUNIC LEVELS

A Dissertation Submitted to the
Department of Electrical Engineering, University of Moratuwa
in partial fulfilment of the requirements for the
Degree of Master of Engineering

by
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Dr. H.J.C.Peiris

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2007

Abstract

This dissertation presents a study meant for improvement of lightning protection in low voltage distribution systems in the areas with high isokeraunic levels. The electricity consumers in Sri Lanka, especially those who live in areas with high isokeraunic levels, suffer considerable damages to their electrical appliances due to lightning. The objective of this project is to assist the electricity distribution authorities in finding remedial measures to overcome the difficulties faced by the consumers.

Beregala in Avissawella, an area severely affected by consequences of lightning, was selected for the study. Two low voltage distribution lines that run across a rural mountainous area were identified for the modeling purpose. The type of conductor, average span of the line and typical electrical loads connected to the line were taken into consideration in modeling the line.

The model of the line as well as the lightning strike was simulated using software PSCAD / EMTDC. The effectiveness of Lightning Surge Arrestors when connected at various points along the distribution line was analyzed. A field study too, was carried out using two distribution lines running across similar ground conditions to gauge the effectiveness of using a shielding conductor in a low voltage overhead distribution line.

Based on the theoretical and the field studies, the report finally presents its findings that might be useful in finding solutions to minimize the damages caused to household electrical appliances due to lightning.

DECLARATION

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

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

P.W. Hendahewa
10th September, 2007

We/I endorse the declaration by the candidate.

UOM Verified Signature

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Senior Lecturer (Gr.1), Department of Electrical Engineering

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Acknowledgement

The idea of this research was brought forward by Dr. H.J.C. Peiris with a view to finding solutions to the difficulties faced due to lightning by the people living in areas with high isokeraunic levels.

Firstly, I should express my gratitude to Dr. H.J.C. Peiris for his excellent guiding and support extended to make this project a success. Then I must give special thanks to Professor J.R. Lucas, The Head of the Department of Electrical Engineering, University of Moratuwa for his valuable support extended.

Further, I must thank all the lecturers engaged in the M.Eng. course sessions who made our vision broad and tried to enhance our knowledge in the field of electrical engineering. I must specially thank Professor Ranjith Perera for his encouragement and support extended throughout the MEng programme.

I must also thank Mr. Sisira Weeratunge, the former Area Engineer of the Ceylon Electricity Board, Avissawella for his support extended by arranging field requirements for the project.

My thanks also go to my wife and two sons for providing me with time and courage in completing this dissertation.

P.W. Hendahewa

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Chapter 1

Introduction

As a result of increasing application of household electrical appliances and electronic devices in domestic and industrial fields, the electric utilities and end users are increasingly concerned about the equipment damage due to over voltage caused by lightning. Unlike in the past, the load equipment is more sensitive to voltage surges. Many new load devices contain power electronic devices and micro-processor based controls that are sensitive to over voltages. The utility consumers are better informed about impulsive transients and are challenging the utilities to improve the quality of supply.

Power quality concerns have created more interest in lightning. Improved lightning protection of overhead distribution lines is being considered as a way of reducing the number of interruptions.

1.1 What is Lightning?

Benjamin Franklin performed the first systematic, scientific study of lightning during the second half of the 18th century [1]. Prior to that time, electrical science had developed to the point where positive and negative charges could be separated. Electrical machines could, by rubbing together two different materials, store the charges in primitive capacitors called Leyden Jars from which sparks could be generated and observed.

While others had previously noted the similarity between laboratory sparks and lightning, Franklin was the first to design an experiment which conclusively proved the electrical nature of lightning. In his experiment, he theorized that clouds are electrically charged, from which it follows that lightning must also be electrical. The experiment involved Franklin standing on an electrical stand, holding an iron rod with one hand to obtain an electrical discharge between the other hand and the ground. If the clouds were electrically charged then sparks would jump between the iron rod and a grounded wire, in this case, held by an insulating wax candle.

This experiment was successfully performed by Thomas Francois D'Alibard of France in May 1752 when sparks were observed to jump from the iron rod during a thunderstorm. G. W. Richmann, a Swedish physicist working in Russia during July 1753, proved that thunderclouds contain electrical charge, and was killed when lightning struck him.

Before Franklin accomplished his original experiment, he thought of a better way to prove his hypothesis through the use of a kite. The kite took the place of the iron rod, since it could reach a greater elevation and could be flown anywhere. During a Pennsylvania thunderstorm in 1752 the most famous kite in history flew with sparks jumping from a key tied to the bottom of damp kite string to an insulating silk ribbon tied to the knuckles of Franklin's hand. Franklin's grounded body provided a conducting path for the electrical currents responding to the strong electric field buildup in the storm clouds.

In addition to showing that thunderstorms contain electricity, by measuring the sign of the charge delivered through the kite apparatus, Franklin was able to infer that while the clouds were overhead, the lower part of the thunderstorm was generally negatively charged.

Little significant progress was made in understanding the properties of lightning until the late 19th century when photography and spectroscopic tools became available for lightning research.

Lightning current measurements were made in Germany by Pockels (1897-1900) who analyzed the magnetic field induced by lightning currents to estimate the current values. Time-resolved photography was used by many experimenters during the late 19th century to identify individual lightning strokes that make up a lightning discharge to the ground.

Lightning research in modern times dates from the work of C.T.R. Wilson who was the first to use electric field measurements to estimate the structure of thunderstorm charges involved in lightning discharges. Wilson, who won the Nobel Prize for the invention of the Cloud Chamber, made major contributions to our present understanding of lightning.

Research continued at a steady pace until the late 1960's when lightning research became particularly active. This increased interest was motivated both by the danger of lightning to aerospace vehicles and solid state electronics used in computers and other devices as well as by the improved measurement and observational capabilities which were made possible by advancing technology.

These studies have revealed that the lightning is a visible discharge of static charges that can occur within a cloud, between clouds or between a cloud and the earth. A build up of opposite charges (one negative and one positive) separated by an insulating air gap can cause the charges to rush toward each other, producing a sudden release of energy. A lightning discharge will have 10,000,000 – 100,000,000 [V] and 1,000 – 300,000 [A]. Lightning strikes buildings or other objects because the materials in them provide easier paths to ground than the air. Lightning is more likely to strike on projecting objects such as poles, wires, trees or building steeples than on larger, flatter surfaces projecting to the same height or lower.

1.2 Background of the study

Damages to household electrical appliances due to lightning have become an acute problem to electricity consumers in certain areas. Especially, the number of complaints is significantly high in the areas with high isokeraunic levels.

Earlier, there had been a practice to employ a shielding conductor in low voltage overhead distribution lines on top of the other conductors to shield against direct lightning strokes. And surge arrestors too had been used in low voltage lines at load connected poles especially in areas with high isokeraunic levels to protect the consumers against surges. However, the practice of using a shield conductor and arrestors had been abandoned by the electricity utilities later.

The electricity consumers in such areas desperately complain about their damages seeking some remedial measures from the electricity utility to protect their valuable electrical appliances. Understanding the importance of a proper study, the electricity distribution utility had sought the assistance of the Department of Electrical Engineering of University of Moratuwa to conduct a project.

1.3 Objectives

1. To investigate the effectiveness of using low voltage surge arrestors to reduce the damages caused by lightning.

   In the early years, there had been a practice to install surge arrestors at the beginning of a service wire in low voltage overhead distribution lines. But, later the use of arrestors at consumer load points was abandoned by the electricity distribution utilities, mainly due to the high costs involved. One of the objectives of this study is to measure the effectiveness of surge arrestors in minimizing damages.

2. To verify whether the damages increase towards the end of a line

   The electricity distribution utilities had observed that the complaints about damages due to lightning was more frequent from the consumers living nearer the end of a low voltage overhead distribution line. The theoretical part of this study would help to verify the claim through modeling the line.

3. To locate best position/ positions along a low voltage distribution line to install lightning arrestors to give the maximum protection

   The high cost of surge arrestors is one of the main reasons for the electricity utilities for not installing surge arrestors in low voltage overhead distribution lines. The cost could be minimized by locating arrestors only at locations that give optimum solution.

4. To conduct a survey to ascertain whether a shielding conductor can reduce the damages due to lightning

Chapter 2

Methodology

The methodology adopted to achieve the objectives could be broadly divided into a theoretical study and a field study.

2.1 Theoretical Study

A theoretical study was carried out to achieve the first three of the objectives mentioned in the previous chapter, i.e., to investigate the effectiveness of using low voltage surge arrestors against lightning, to verify whether the damages increase towards the end of a line, and to locate the best position along the line to install lightning arrestors in order to obtain the optimum results.

Under the theoretical study, the effects of a lightning stroke onto a low voltage distribution line was studied by modeling the selected low voltage distribution line using PSCAD/EMTDC.

PSCAD/EMTDC is a simulation tool for analyzing power systems. PSCAD is the graphical user interface and EMTDC is the simulation engine. PSCAD/EMTDC is most suitable for simulating the time domain instantaneous responses of electrical systems.

Previous studies [2,3,4] have concluded that arrestors installed on just the top phase of a low voltage distribution line could be effective. As such only the top phase was modeled in the study using PSCAD/EMTDC.

2.2 Field Study

The field study was a survey conducted to ascertain whether a shielding conductor can reduce the damages due to lightning.

In the past, Low Voltage overhead distribution lines had been constructed with a shielding wire on top of the other conductors.

However, the shielding wire had been later removed mainly, due to following reasons.

1. Galvanized Irion (GI) wire which had been used for the shielding purpose was very prone to failure. A significant number of LT breakdowns had occurred due to the falling down of shielding conductor onto the live conductors.

2. There was no significant gain against lightning damages even with the use of shielding conductor.

However, some electricity consumers were of the view that, the damages due to lightning had increased with the removal of the shielding conductor. As such, a field study was carried out to ascertain this claim.

Chapter 3

Theoretical Study

3.1 Modeling of the Distribution Line

A low voltage distribution line was modeled using PSCAD/EMTDC software. One of the two overhead distribution lines used for the field study was selected for the modeling.

The low voltage overhead distribution line runs through a hilly terrain. The line span varies between 45 meter and 55 meter lengths due to practical difficulties in locating poles at regular intervals. As such, the line span was assumed as 50 meters in the model.

Typically, two consumers are connected to the line at each pole. The load of a consumer was averaged at 5.75 Amperes so that the average load connected at a pole becomes 11.5 Amperes. This assumption simplified the load resistance value (R_L) to 20 Ohms considering the supply voltage as 230 Volts a.c.

Line Characteristics

Conductor type	Fly (7/3.40 mm^2 All Aluminium Conductors)
Average Span	50 m
Height of a pole	9m
Line Resistance	0.452 Ω/km
Line Inductance	0.886 mH/km
Line Capacitance	32.476 nF/km
No. of Spans	25

Table 3.1 - Line Characteristics

Assumptions

a) A load of 11.5A is connected at every pole
b) Line Span is 50m

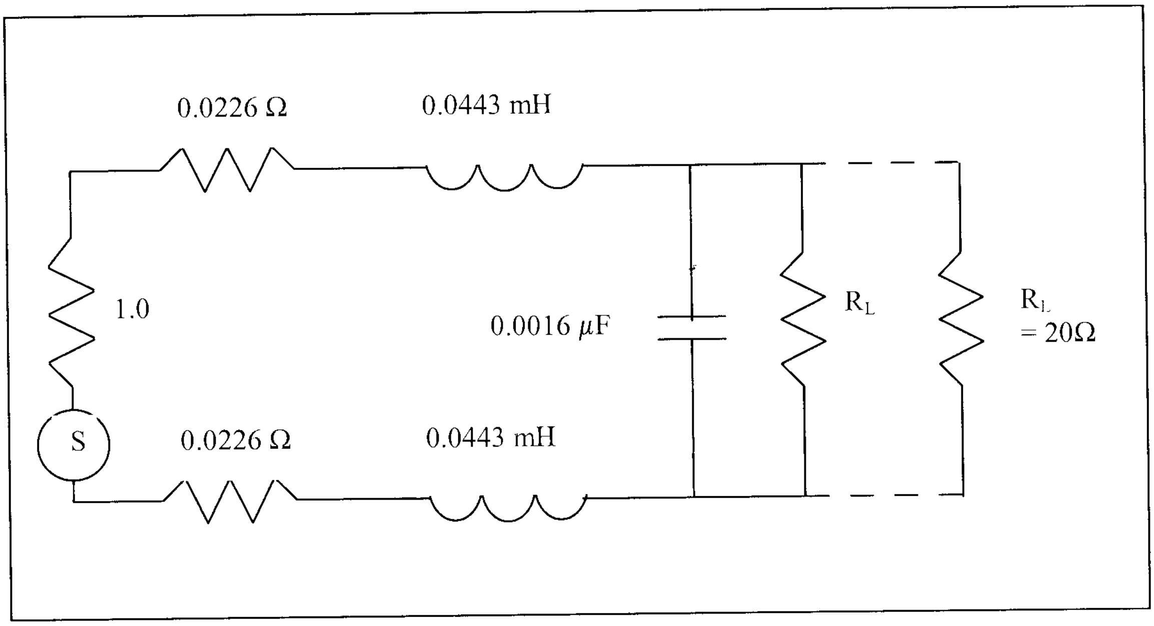
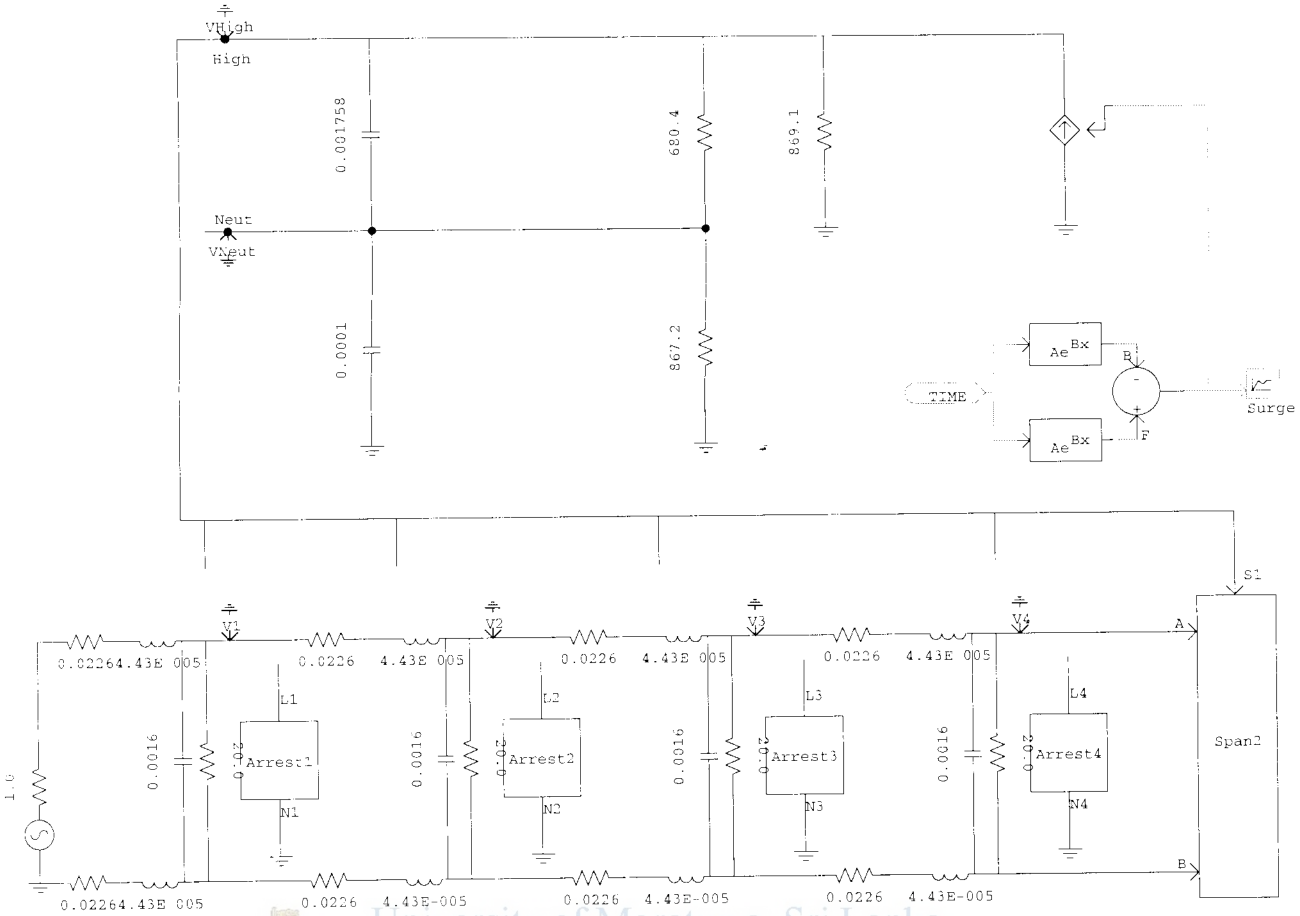
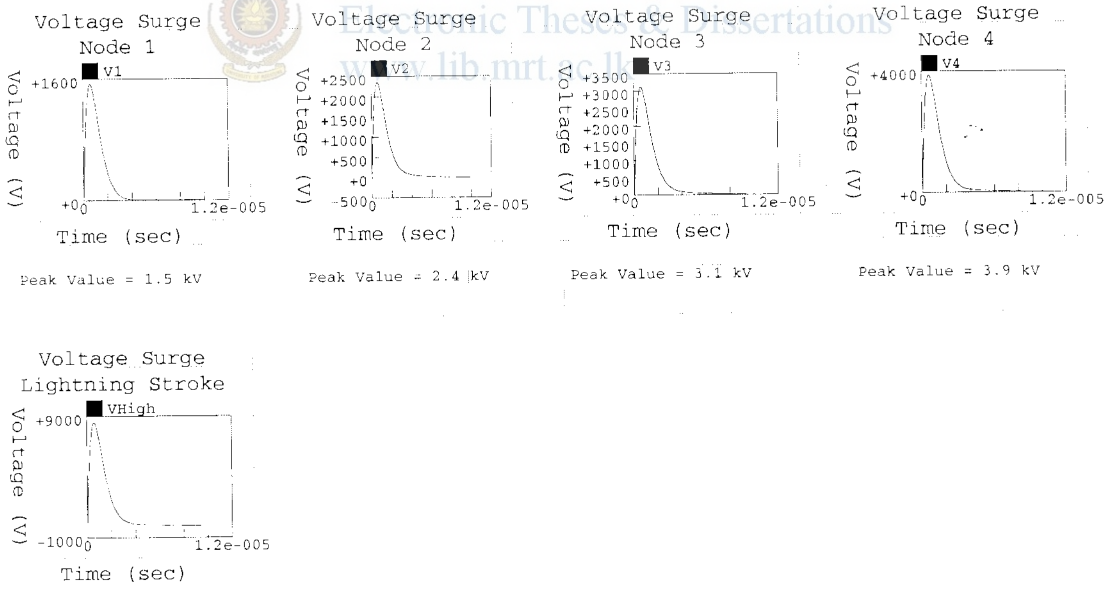


Fig. 3.1 - Model of the line for a length of one span (50m)

3.2 Voltage Distribution along the line without surge arrestors

Figures 3.2 (a), (b), (c), (d) and (e) indicate the voltage profile along the distribution line when a surge is applied to node 10. In this case not a single surge arrestor is connected.





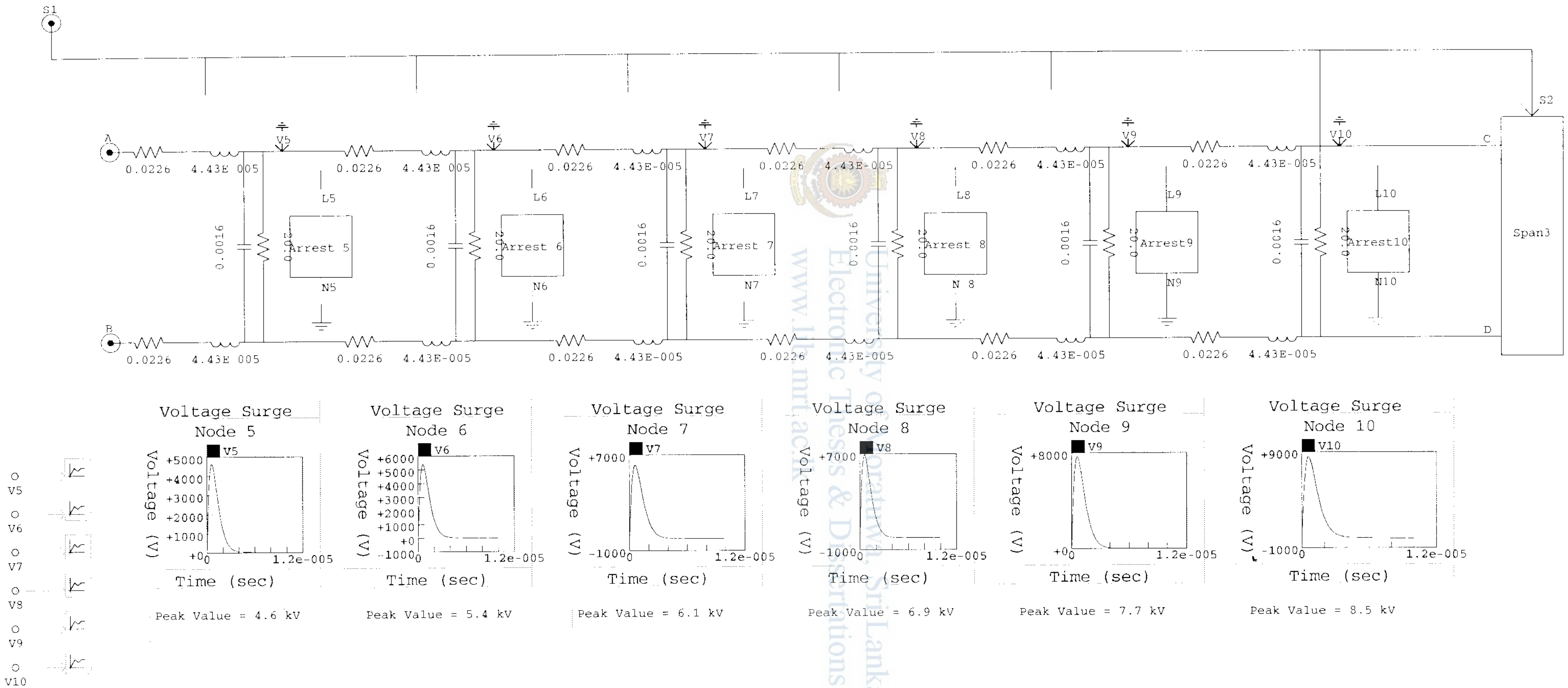
Peak Value = 1.5 kV

Peak Value = 2.4 kV

Peak Value = 3.1 kV

Peak Value = 3.9 kV

Figure 3.2(a) ; Effect of Lightning Surge at nodes 1,2,3 and 4 of the 26-node Overhead Distribution Line when the Lightning strikes at node 10. No arrestor is connected.



Peak Value = 4.6 kV

Peak Value = 5.4 kV

Peak Value = 6.1 kV

Peak Value = 6.9 kV

Peak Value = 7.7 kV

Peak Value = 8.5 kV

Figure 3.2(b) ; Effect of Lightning Surge at nodes 5,6,7,8,9 and 10 of the 26 node Overhead Distribution Line when the Lightning strikes at node 10. No arrestor is connected.

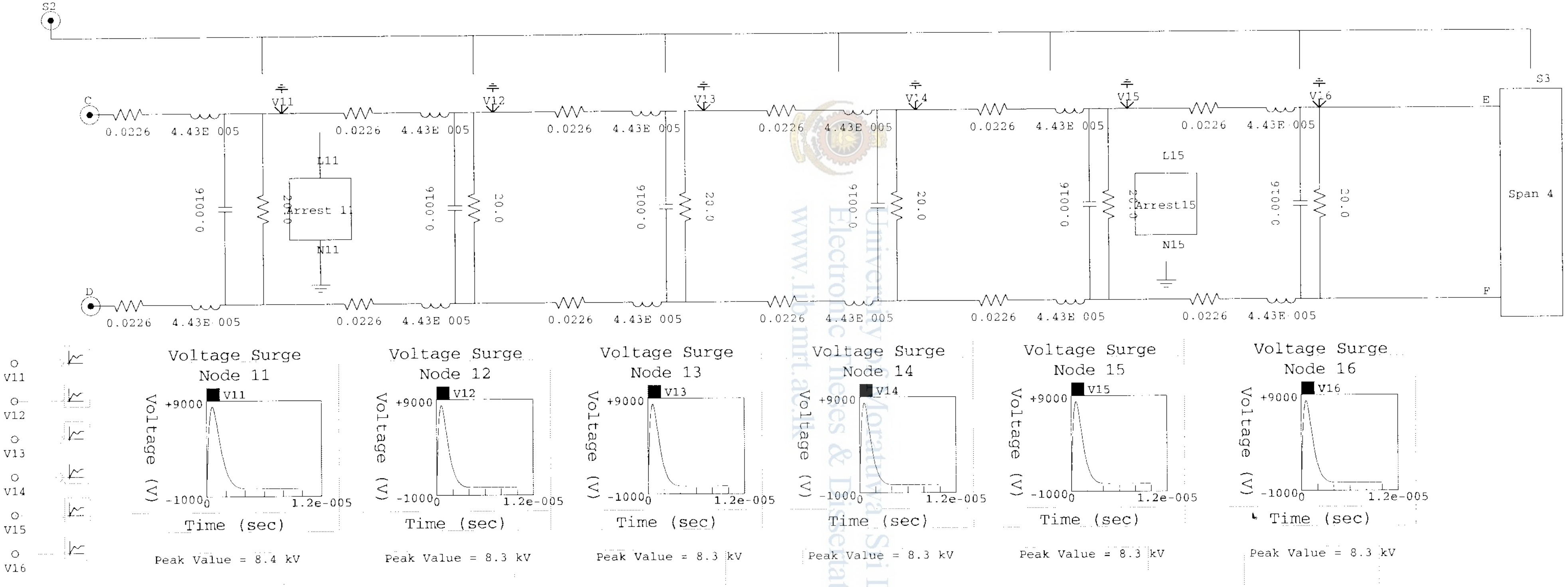


Figure 3.2(c) : Effect of Lightning Surge at nodes 11,12,13,14,15 and 16 of the 26-node Overhead Distribution Line when the Lightning strikes at node 10. No arrestor is connected.

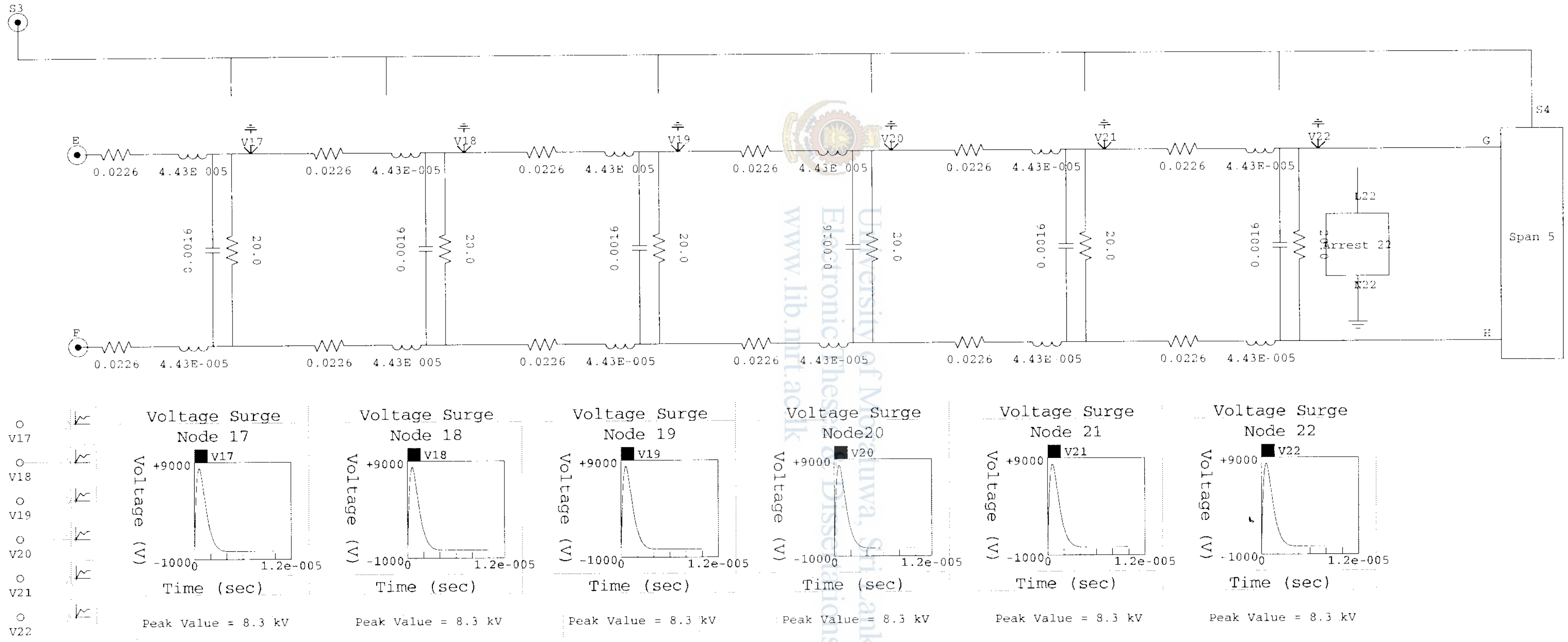


Figure 3.2(d) ; Effect of Lightning Surge at nodes 17,18,19,20,21 and 22 of the 26-node Overhead Distribution Line when the Lightning strikes at node 10. No arrestor is connected.

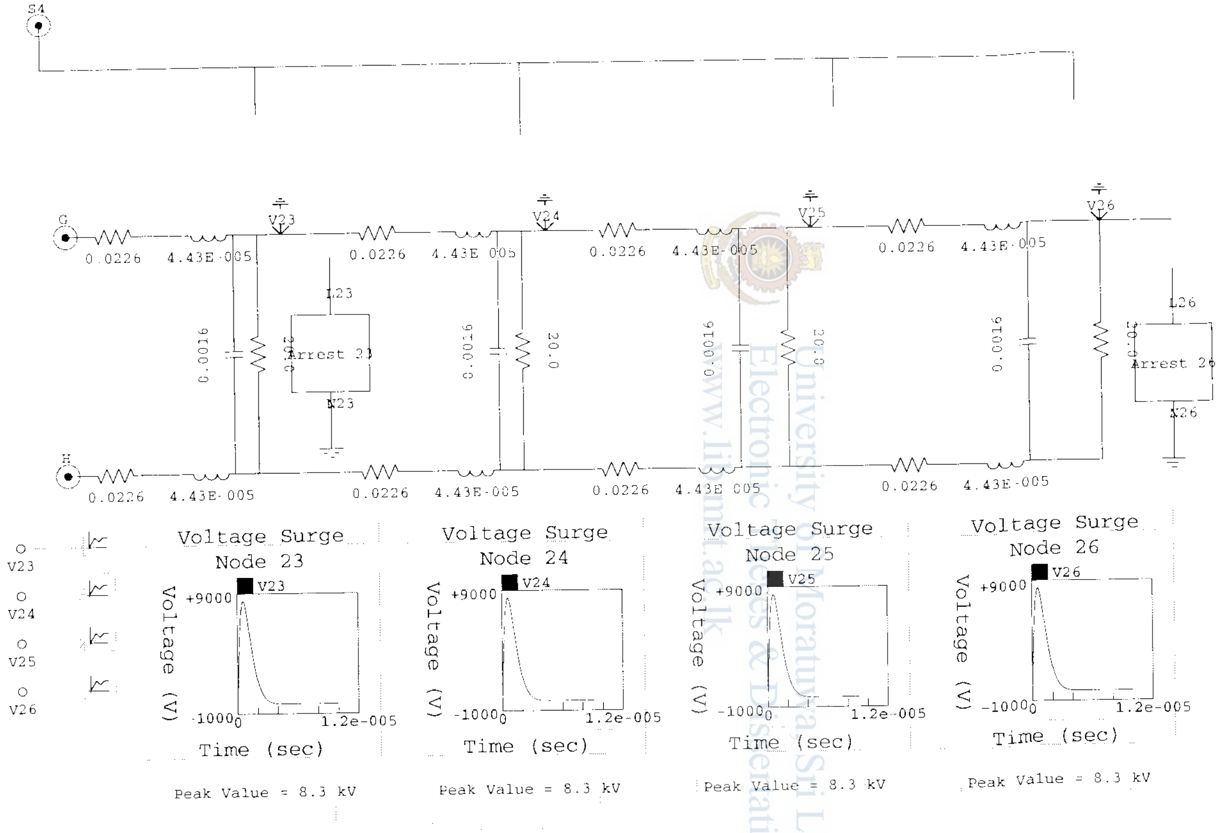


Figure 3.2(e) : Effect of Lightning Surge at nodes 23,24,25 and 26 of the 26-node Overhead Distribution Line when the Lightning strikes at node 10. No arrestor is connected.

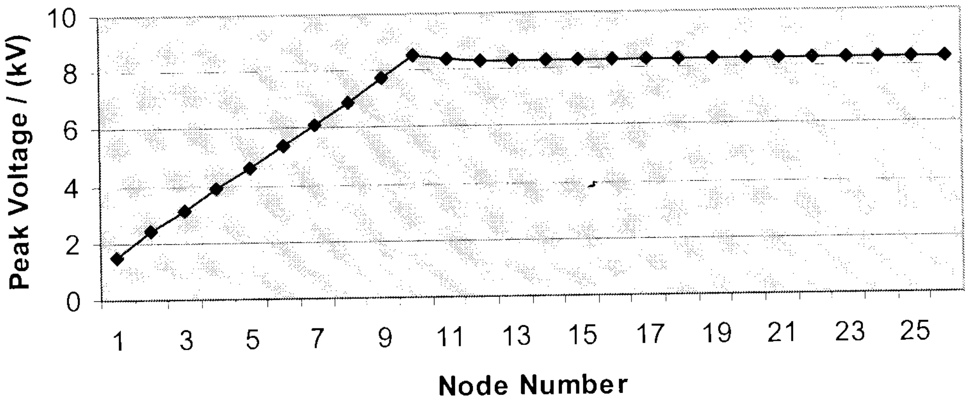
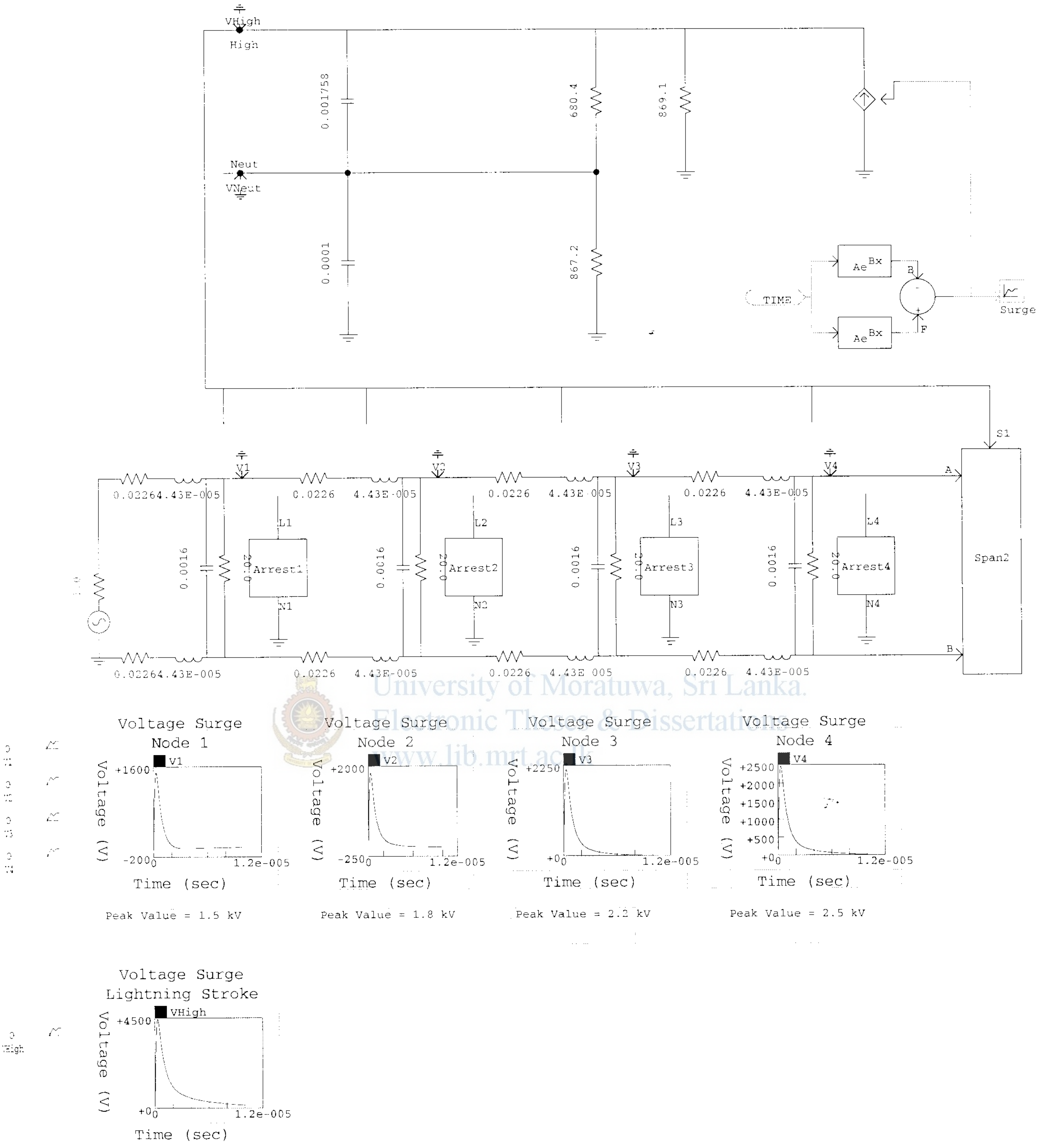


Figure 3.2 (f) - Surge Voltage Profile along the 26-node distribution line when the lightning strikes at node 10. No arrestor is connected

The effect of the lightning stroke on the overhead distribution line is clearly demonstrated in the figure 3.2 (f). The surge voltage is maximum at node 10 where the lightning strikes the line. The magnitude of the voltage surge decreases towards the beginning of the line due to the effect of the transformer earth. The magnitude of the surge voltage remains unchanged, virtually at the maximum value, up to the end of the line since there is no arrestor installed in this case.

3.3 Voltage Distribution along the line with an arrestor at node 15

Figures 3.3 (a), (b), (c), (d) and (e) indicate the voltage profile along the distribution line when a surge is applied to node 10 as in the earlier case but with an arrestor connected to node 15.



Peak Value = 1.5 kV

Peak Value = 1.8 kV

Peak Value = 2.2 kV

Peak Value = 2.5 kV

Figure 3.3(a) ; Effect of Lightning Surge at nodes 1,2,3 and 4 of the 26-node Overhead Distribution Line when the Lightning strikes at node 10. The arrestor is located at node 15.

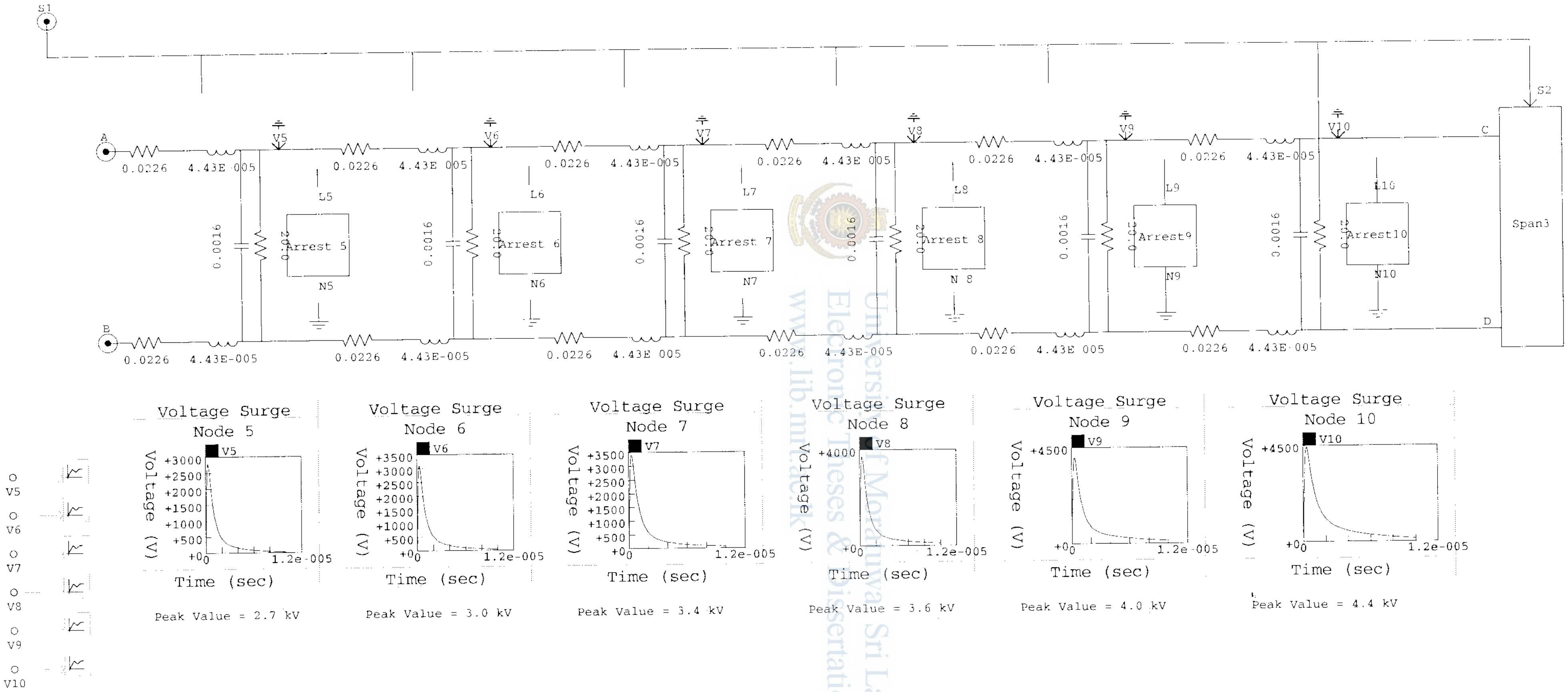


Figure 3.3(b) ; Effect of Lightning Surge at nodes 5,6,7,8,9 and 10 of the 26-node Overhead Distribution Line when the Lightning strikes at node 10. The arrestor is located at node 15.

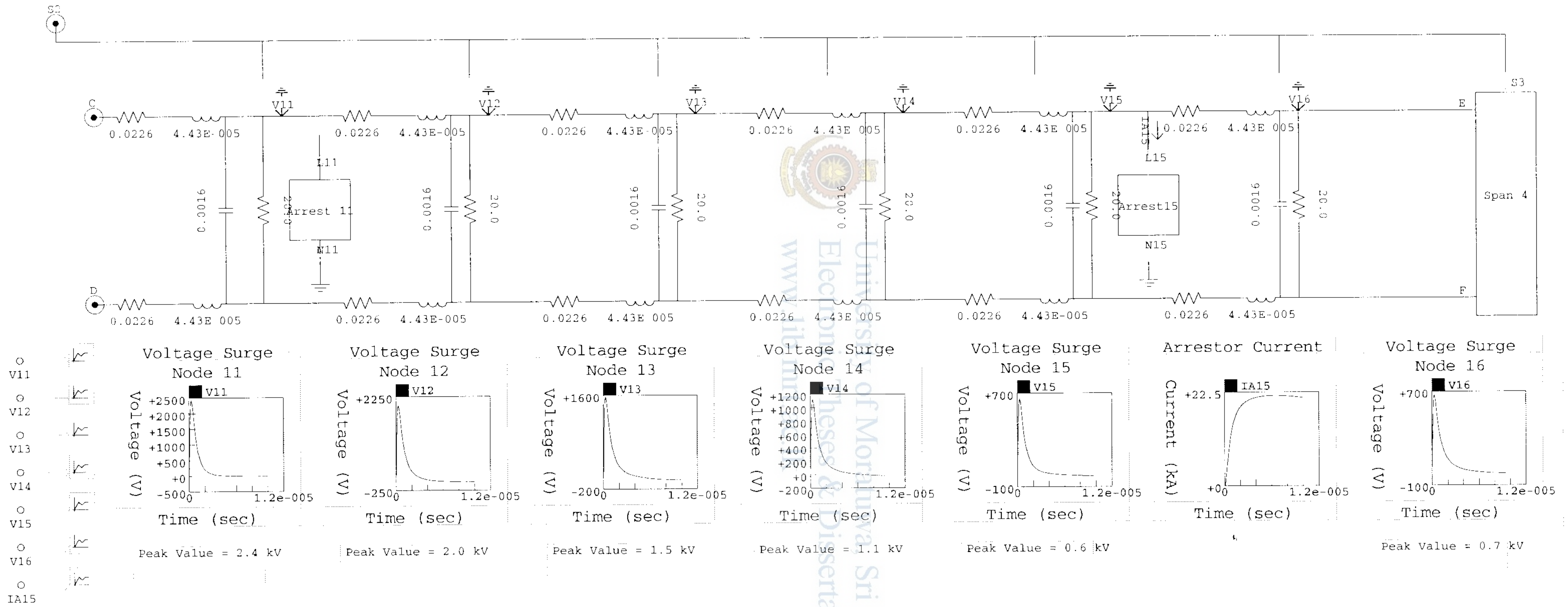


Figure 3.3(c) ; Effect of Lightning Surge at nodes 11,12,13,14,15 and 16 of the 26 node Overhead Distribution Line when the Lightning strikes at node 10. The arrestor is located at node 15.

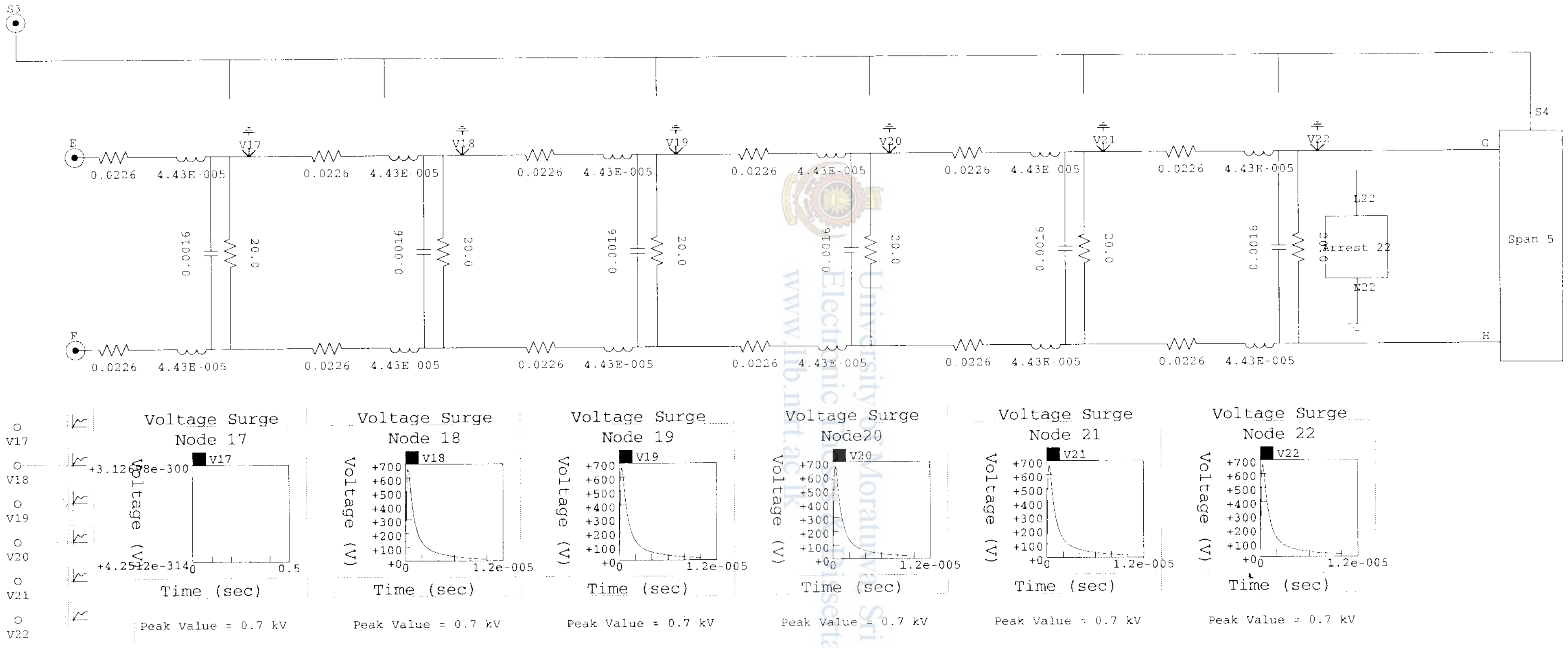


Figure 3.3(d) : Effect of Lightning Surge at nodes 17,18,19,20,21 and 22 of the 26-node Overhead Distribution Line when the Lightning strikes at node 10. The arrestor is located at node 15.

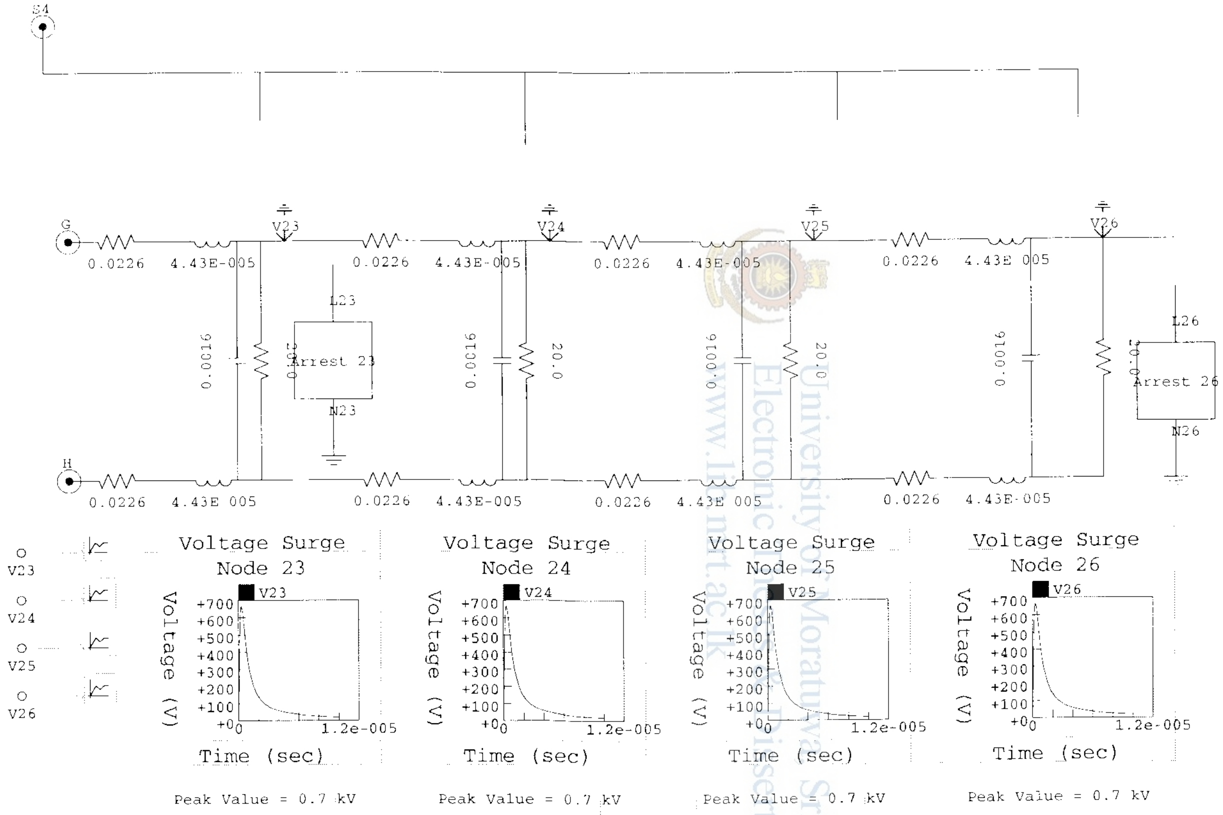


Figure 3.3(e) ; Effect of Lightning Surge at nodes 23,24,25 and 26 of the 26-node Overhead Distribution Line when the Lightning strikes at node 10. The arrestor is located at node 15.

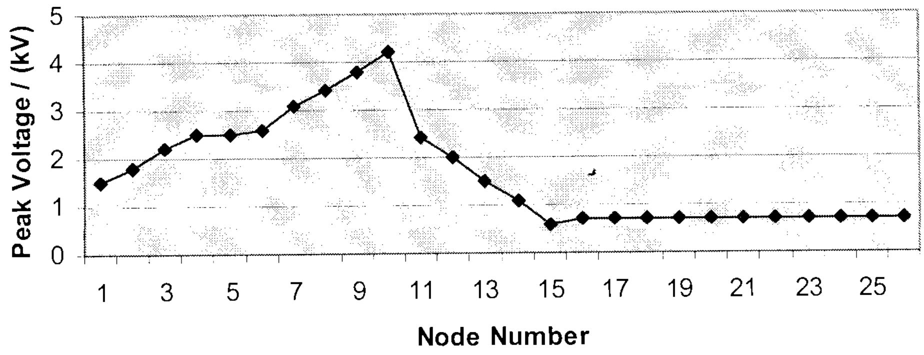


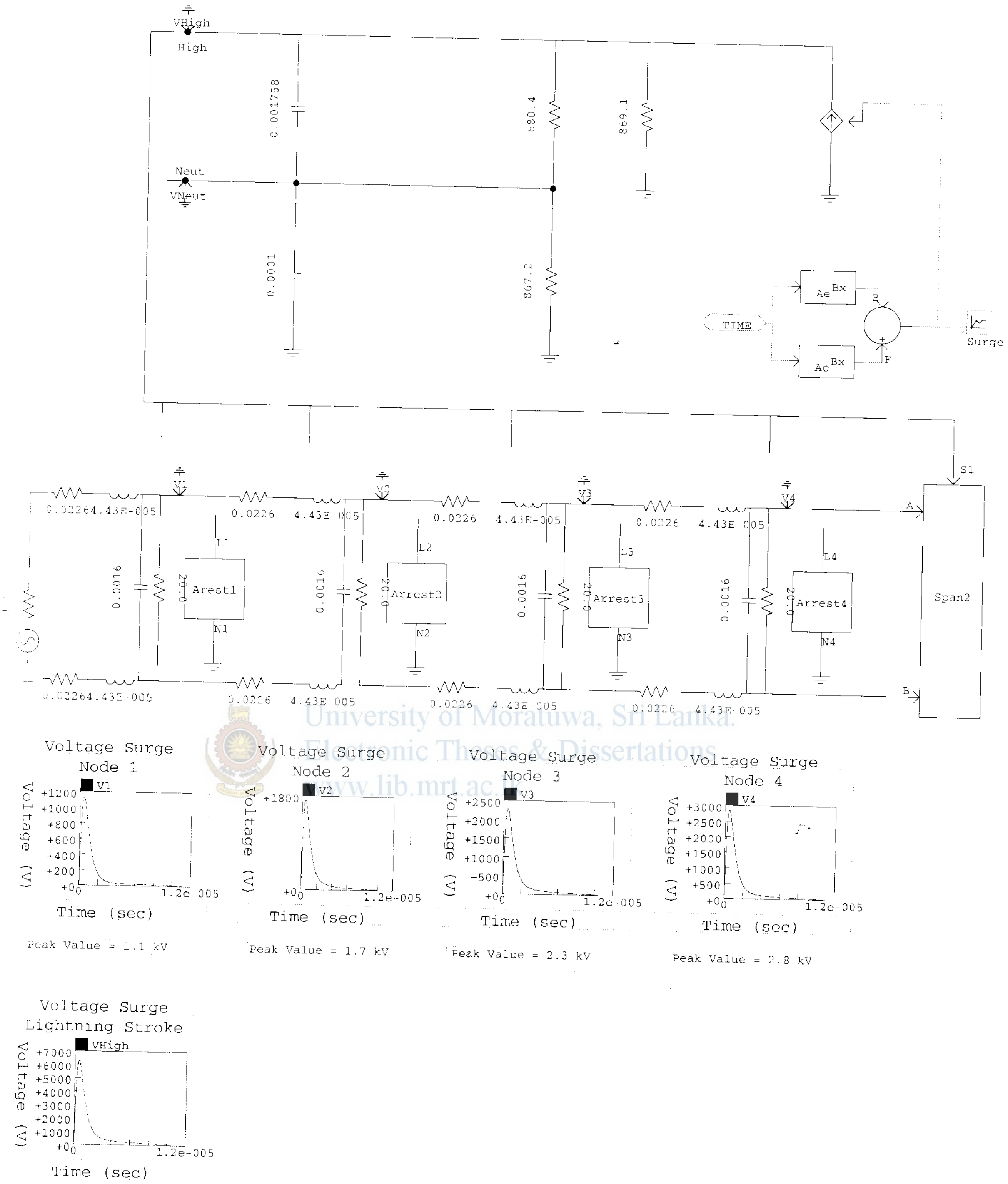
Figure 3.3 (f) - Surge Voltage Profile along the 26-node distribution line when the lightning strikes at node 10. The arrestor is located at node 15

Figures 3.3 (f) shows the effect of the surge arrestor on the voltage profile of the distribution line. In this case too, the surge voltage is maximum at node 10 where the lightning strikes the line and the magnitude of the voltage surge decreases towards the transformer end.

The magnitude has reached its minimum at node 15 where the arrester is connected and gone up slightly at node 16 and virtually remains at that value up to the end of the line.

3.4 Voltage Distribution along the line with an arrestor at node 26

Figures 3.4 (a), (b), (c), (d) and (e) indicate the voltage profile along the distribution line when a surge is applied to node 10 as in the earlier cases but with an arrestor connected at the end of the line (node 26).



Peak Value = 1.1 kV

Peak Value = 1.7 kV

Peak Value = 2.3 kV

Peak Value = 2.8 kV

Figure 3.4(a) : Effect of Lightning Surge at nodes 1,2,3 and 4 of the 26-node Overhead Distribution Line when the Lightning strikes at node 10. The arrestor is located at node 26.

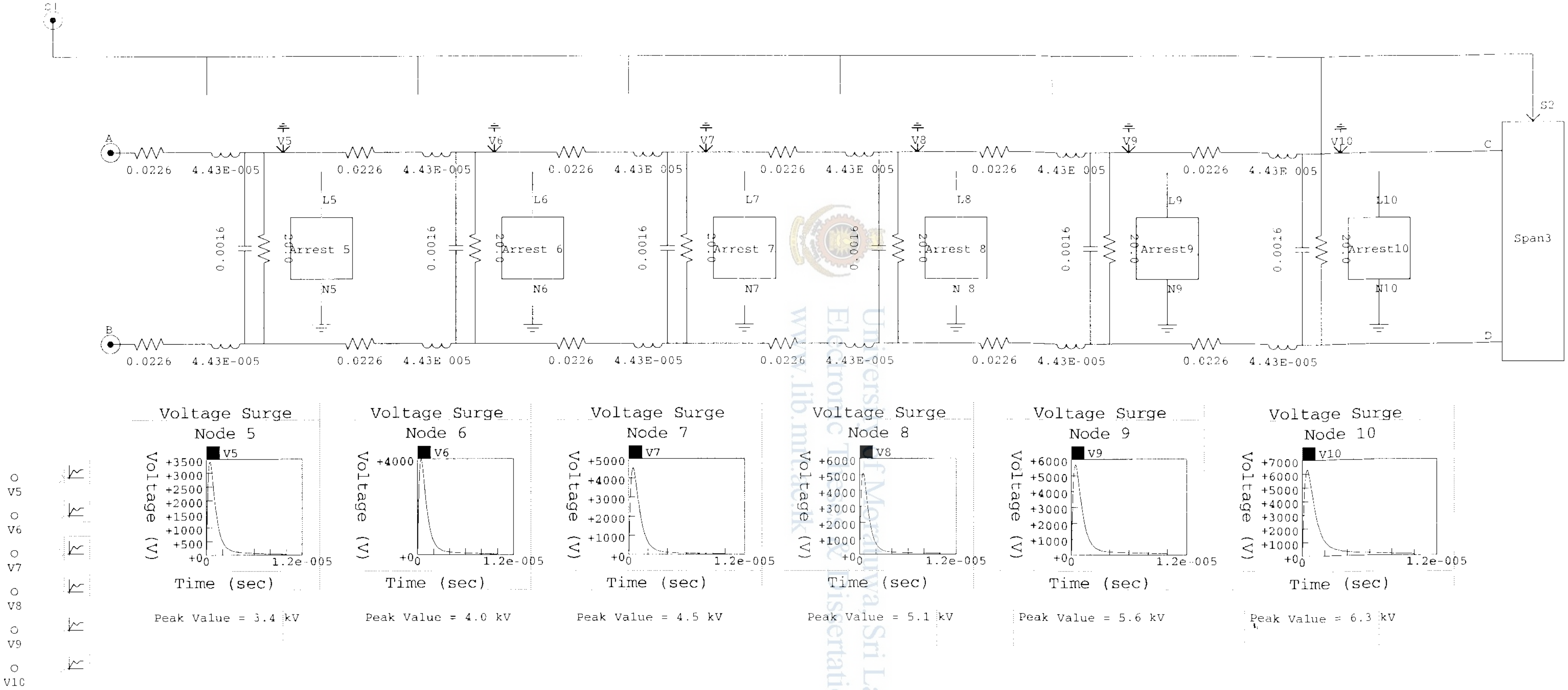


Figure 3.4(b) ; Effect of Lightning Surge at nodes 5,6,7,8,9 and 10 of the 26 node Overhead Distribution Line when the Lightning strikes at node 10. The arrestor is located at node 26.

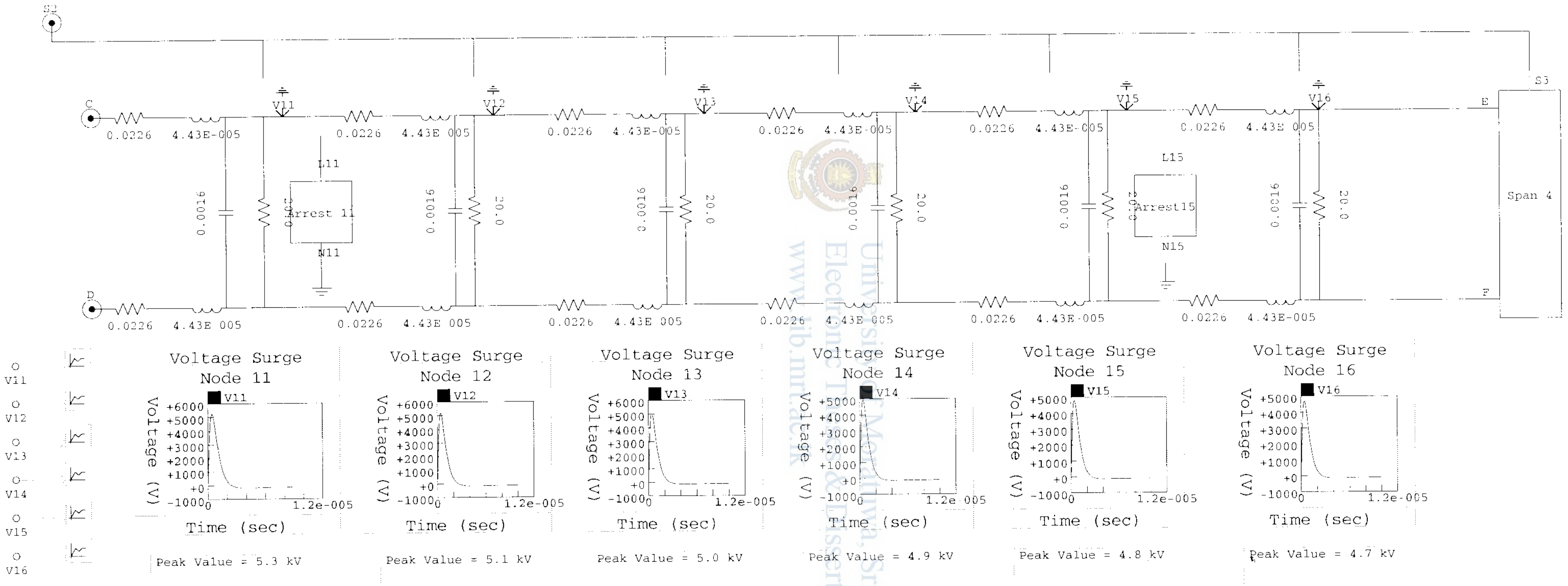


Figure 3.4(c) : Effect of Lightning Surge at nodes 11,12,13,14,15 and 16 of the 26 node Overhead Distribution Line when the Lightning strikes at node 10. The arrestor is located at node 26.

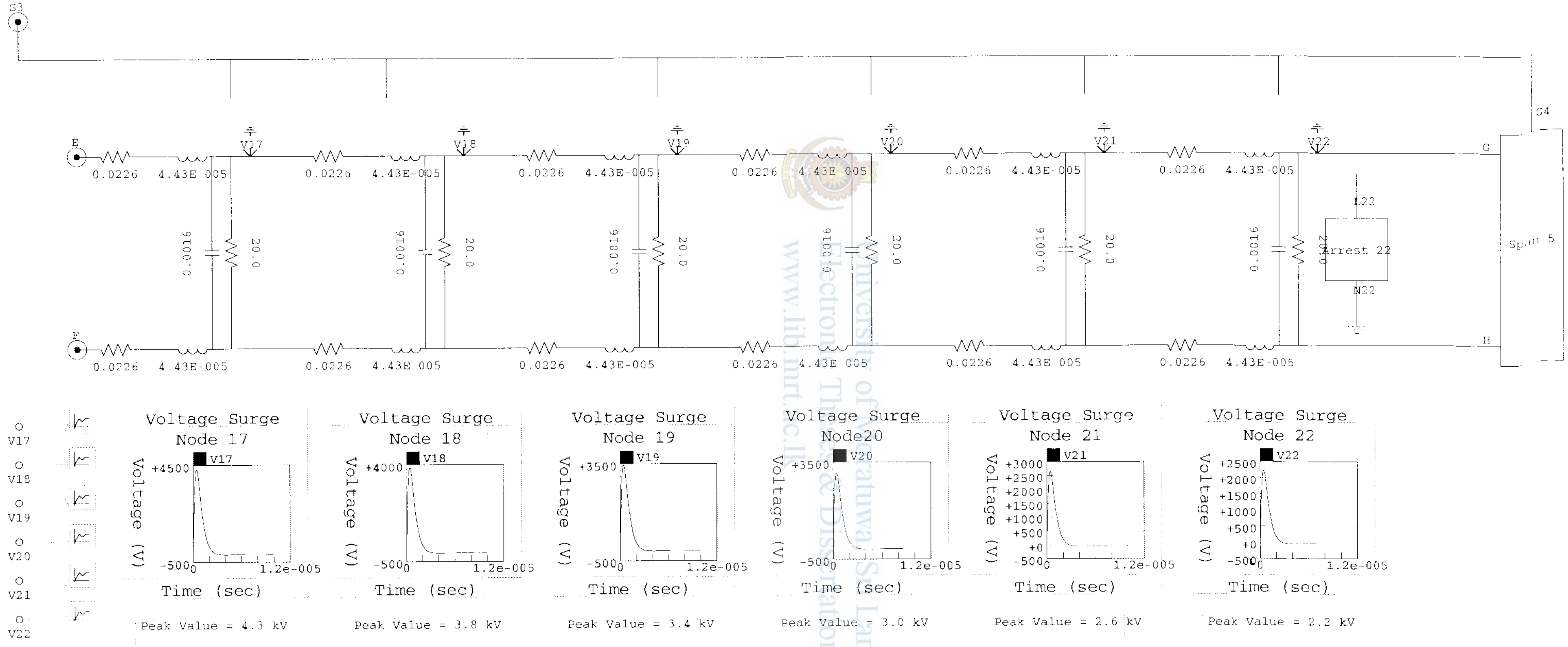


Figure 3.4(d) ; Effect of Lightning Surge at nodes 17,18,19,20,21 and 22 of the 26-node Overhead Distribution Line when the Lightning strikes at node 10. The arrestor is located at node 26.

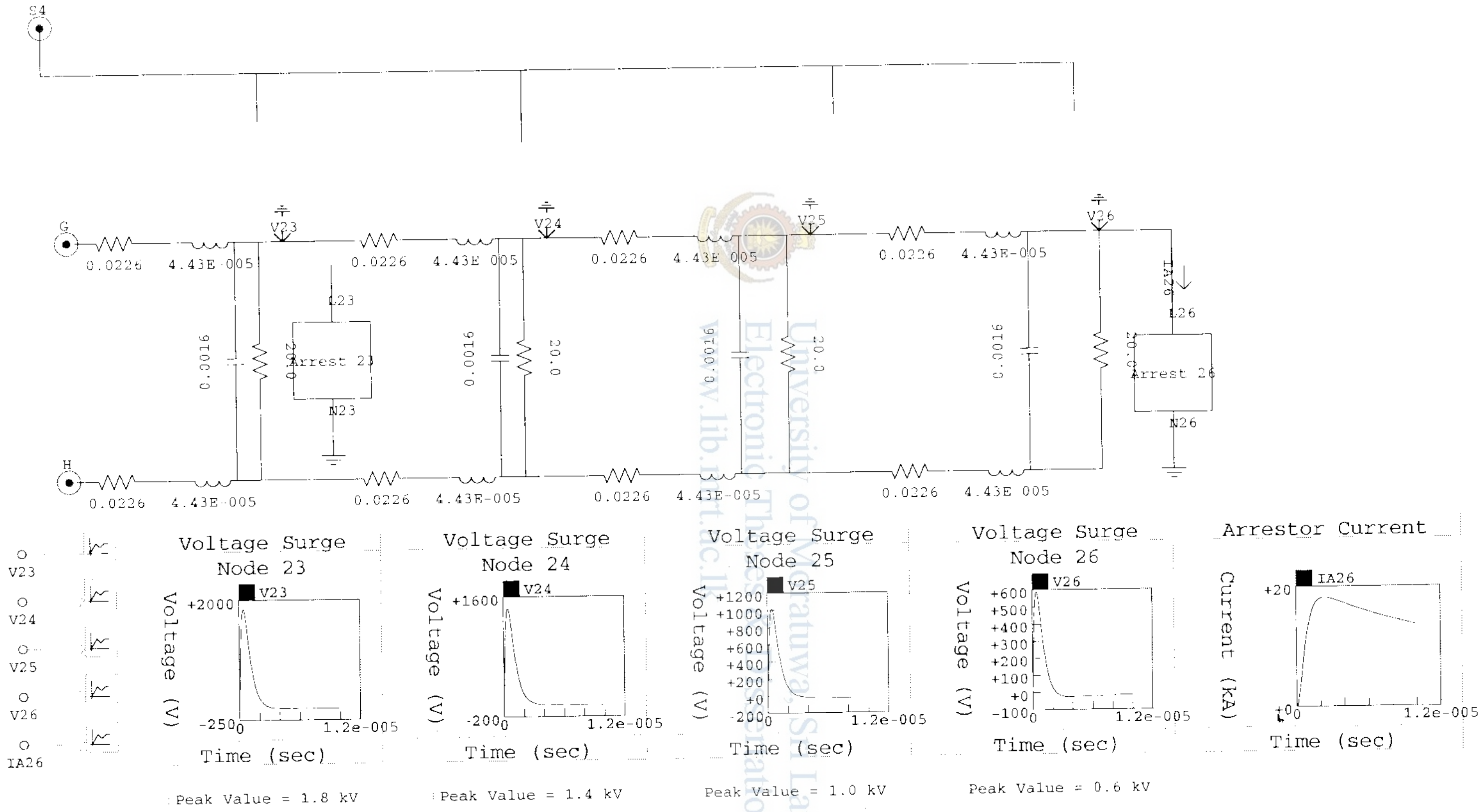


Figure 3.4(e) ; Effect of Lightning Surge at nodes 23,24,25 and 26 of the 26-node Overhead Distribution Line when the Lightning strikes at node 10. The arrestor is located at node 26.

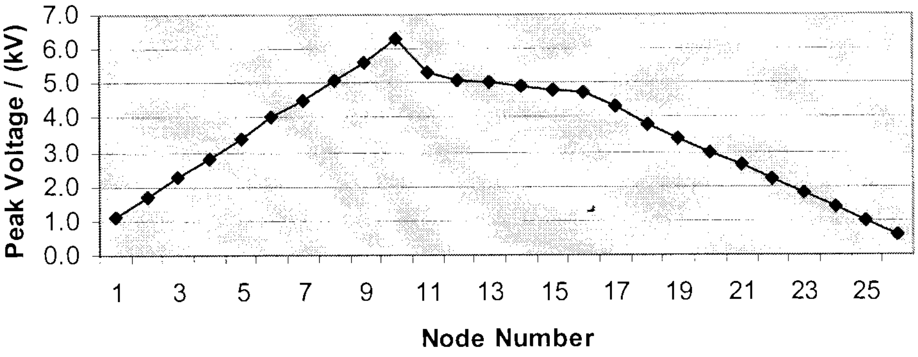


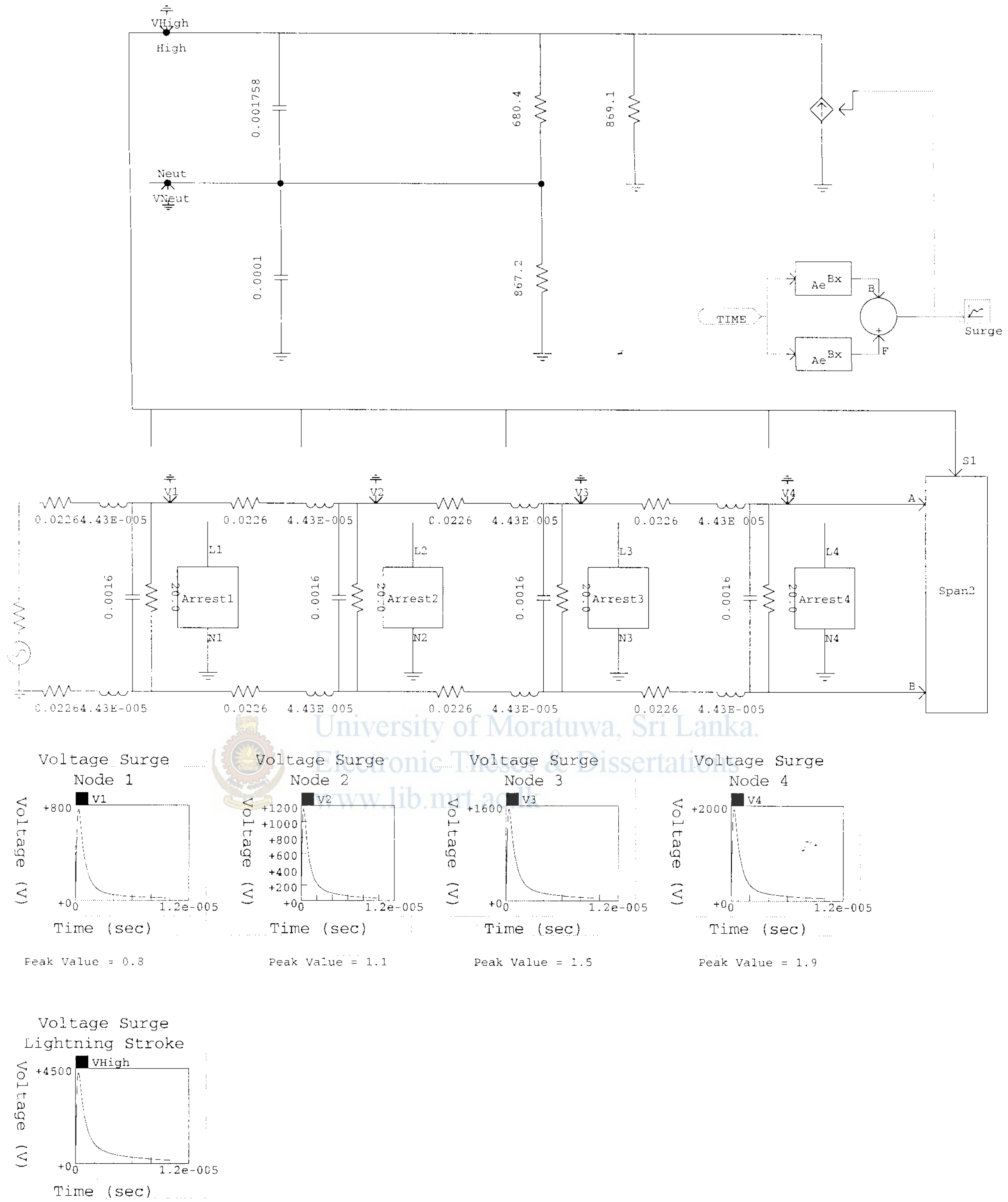
Figure 3.4 (f) - Surge Voltage Profile along the 26-node distribution line when the lightning strikes at node 10. The arrestor is located at node 26

The changes on the voltage profile of the distribution line with the change in position of the lightning arrestor are clearly demonstrated in figure 3.4(f). In this case too, the magnitude of the voltage surge decreases towards the transformer end.

The surge voltage becomes its maximum at node 10 where the lightning strikes the line and gradually decreases towards the end of the line. It takes the minimum value at node 26 where the arrestor is connected.

3.5 Voltage Distribution along the line with arrestors at nodes 15 & 26

Figures 3.5 (a), (b), (c), (d) and (e) indicate the voltage profile along the distribution line when a surge is applied to node 10 as in the earlier cases but with arrestors connected to node 15 & 26.



Peak Value = 0.8

Peak Value = 1.1

Peak Value = 1.5

Peak Value = 1.9

Figure 3.5(a) , Effect of Lightning Surge at nodes 1,2,3 and 4 of the 26 node Overhead Distribution Line when the Lightning strikes at node 10. The arrestors are located at nodes 15 and 26.

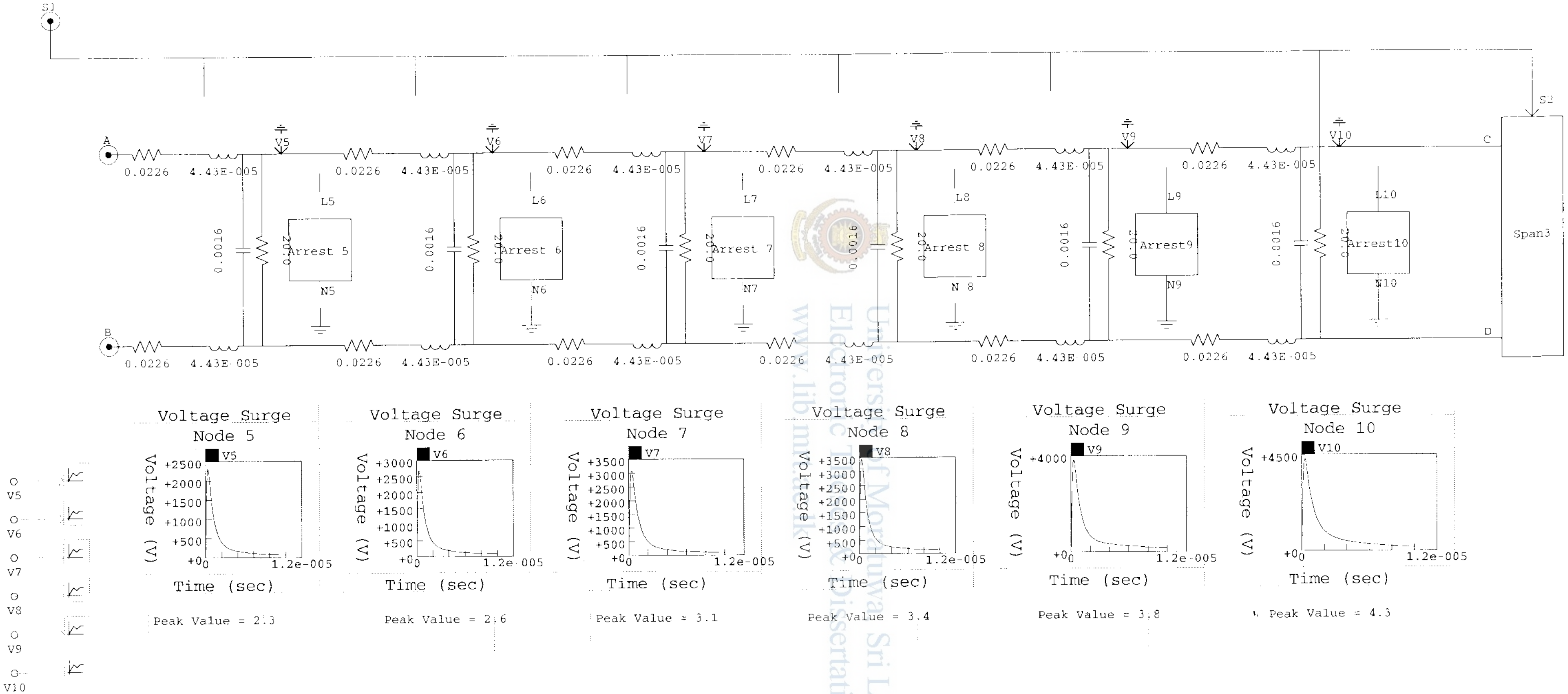


Figure 3.5(b) ; Effect of Lightning Surge at nodes 5,6,7,8,9 and 10 of the 26-node Overhead Distribution Line when the Lightning strikes at node 10. The arrestors are located at nodes 15 and 26.

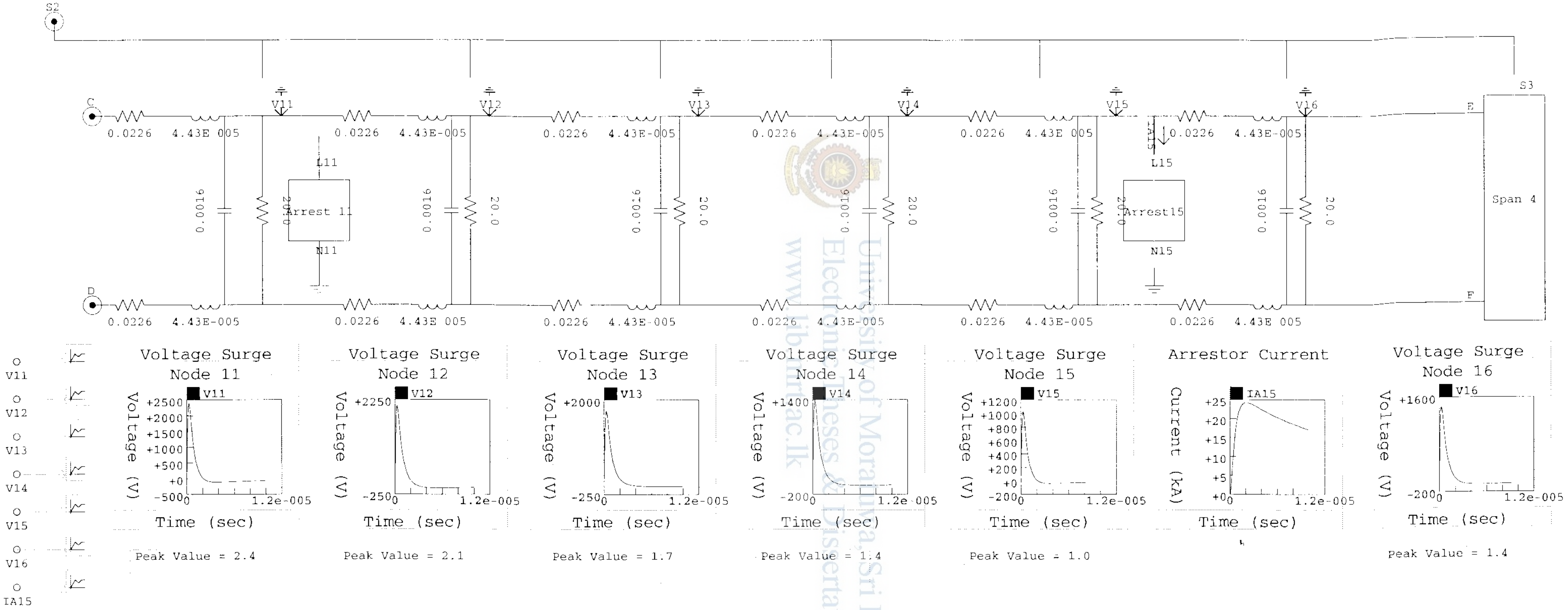


Figure 3.5(c) ; Effect of Lightning Surge at nodes 11,12,13,14,15 and 16 of the 26-node Overhead Distribution Line when the Lightning strikes at node 10. The arrestors are located at nodes 15 and 26.

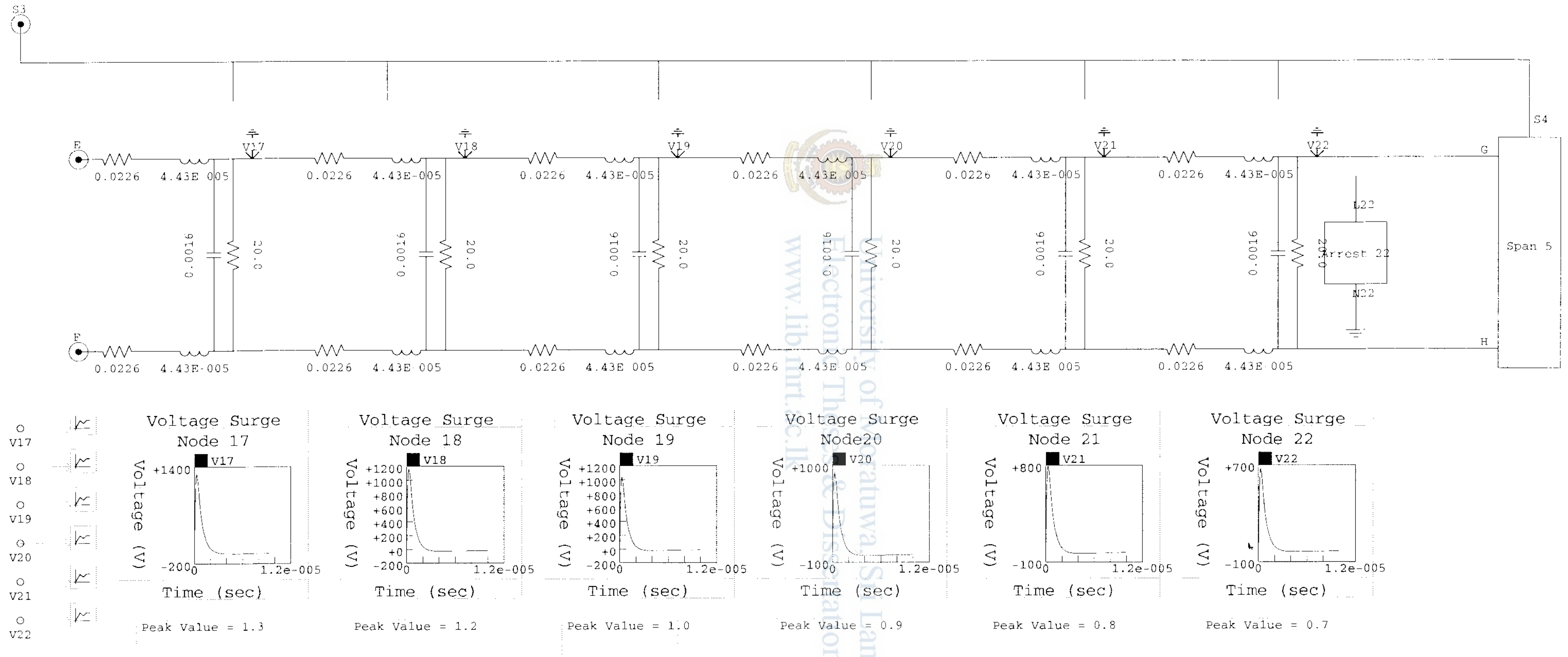


Figure 3.5(d) : Effect of Lightning Surge at nodes 17,18,19,20,21 and 22 of the 26-node Overhead Distribution Line when the Lightning strikes at node 10. The arrestors are located at nodes 15 and 26.

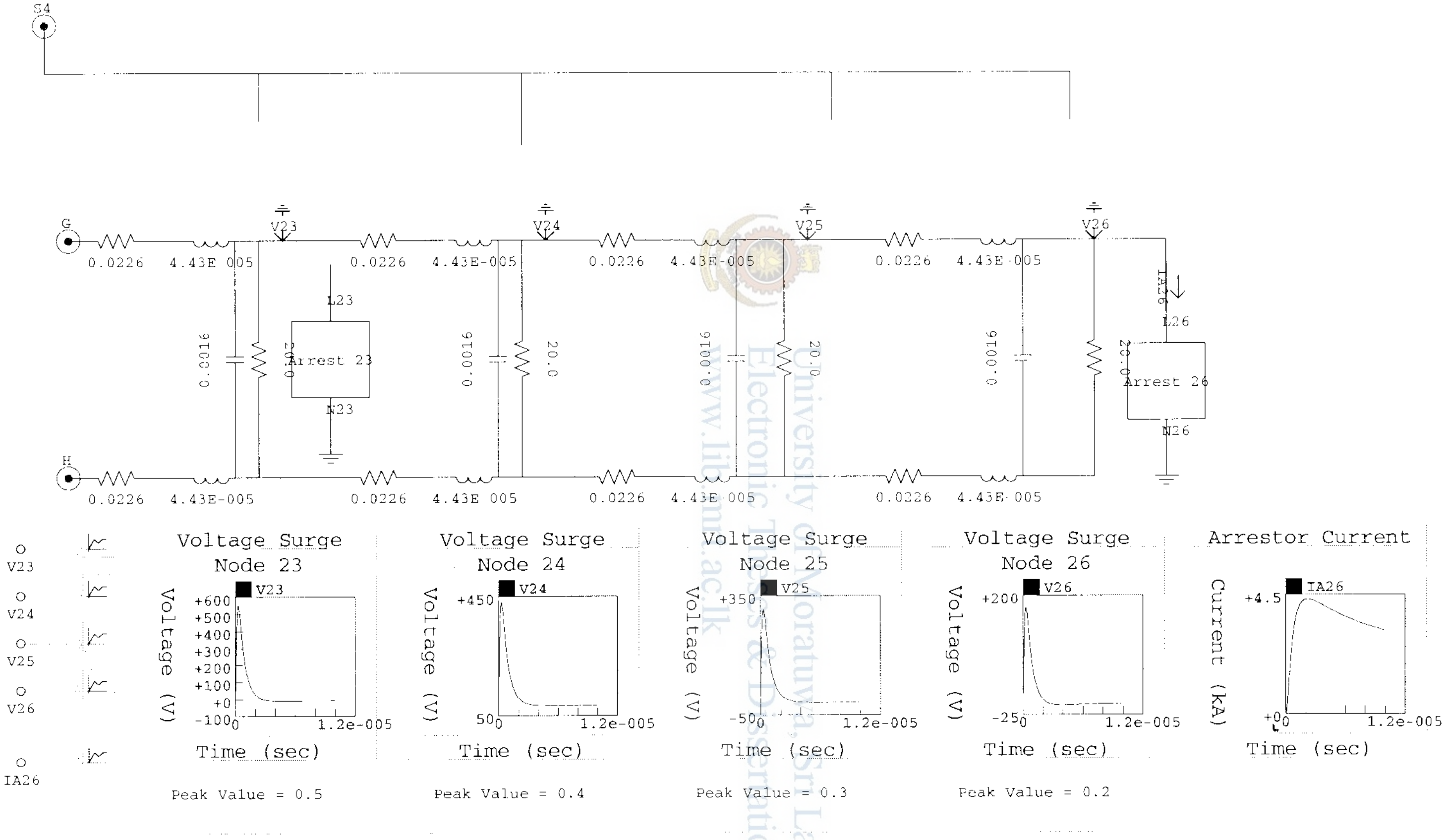


Figure 3.5(e) ; Effect of Lightning Surge at nodes 23,24,25 and 26 of the 26-node Overhead Distribution Line when the Lightning strikes at node 10. The arrestors are located at nodes 15 and 26.

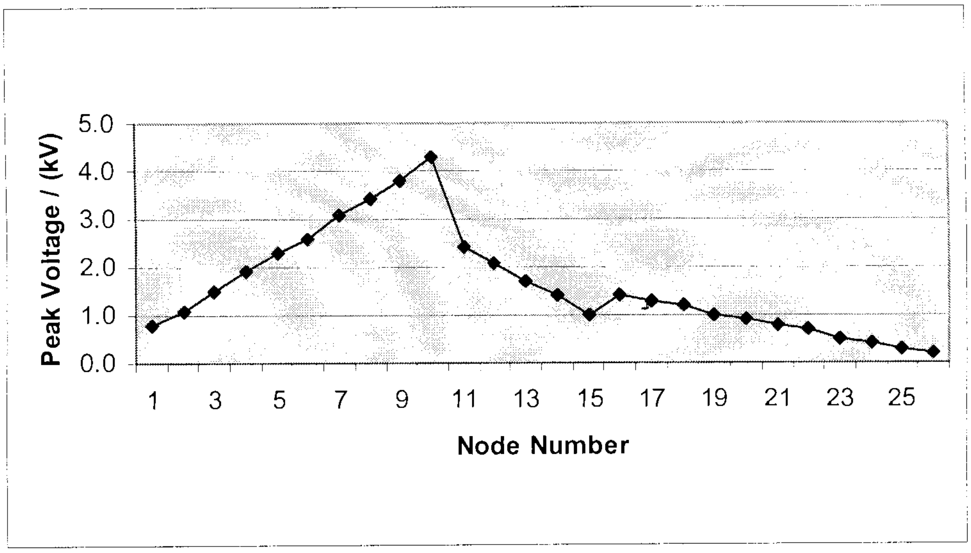


Figure 3.5 (f) - Surge Voltage Profile along the 26-node distribution line when the lightning strikes at node 10. The arrestors are located at nodes 15 and 26

With the use of two arrestors, the magnitudes of the voltage profile as a whole have come down as illustrated in figure 3.5(f). In this case too, the magnitude of the voltage surge decreases towards the transformer end.

The magnitudes of the voltage profile have been taken down by the arrestor at node 15, and the arrestor at the end of the line has decreased the profile further down.

3.6 Voltage Distribution along the line with arrestors at node 4, 15 & 26

Figures 3.5 (a), (b), (c), (d) and (e) indicate the voltage profile along the distribution line when a surge is applied to node 10 as in the earlier cases but with arrestors connected to node 4, 15 & 26.

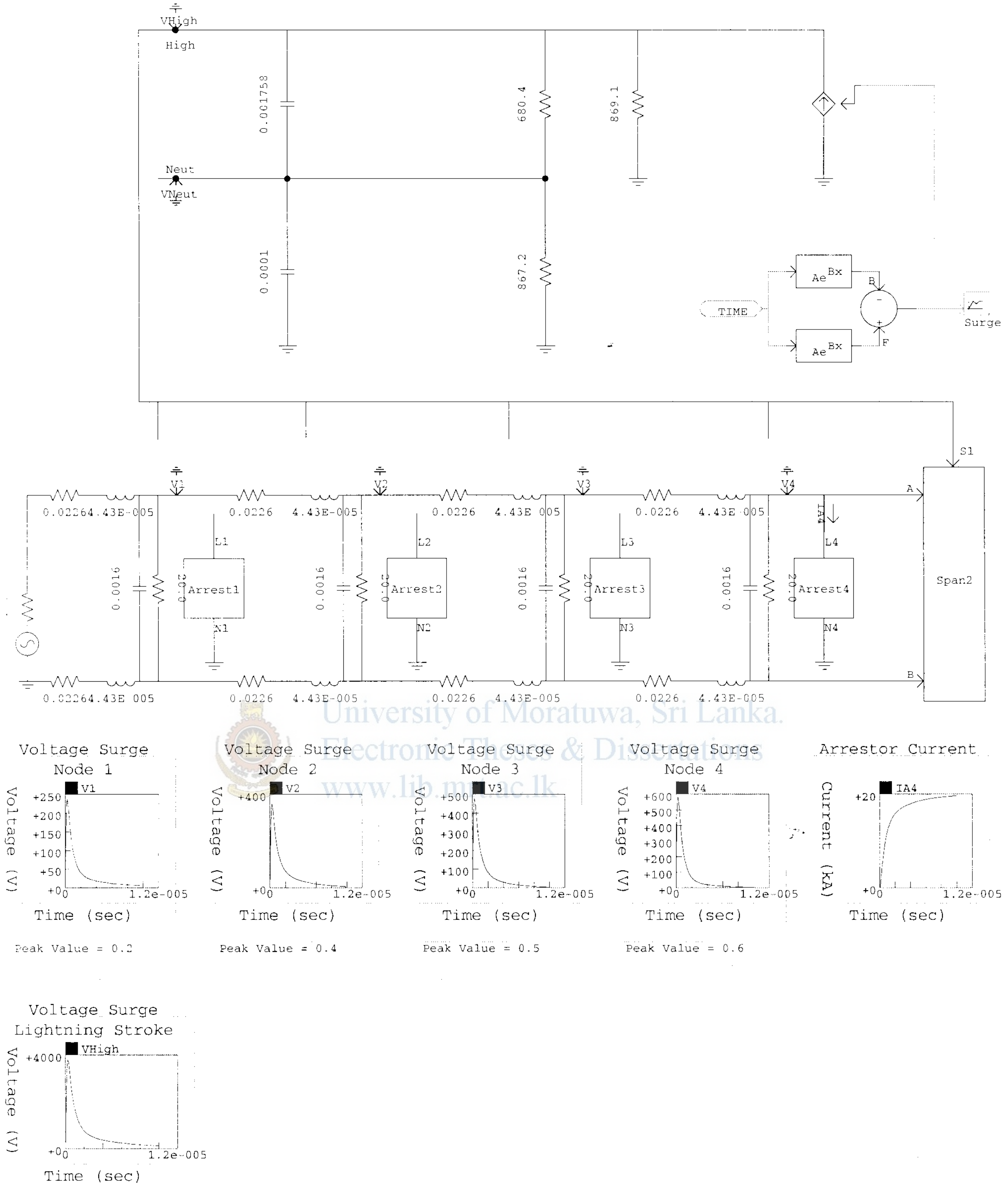


Figure 3.6(a) ; Effect of Lightning Surge at nodes 1,2,3 and 4 of the 26-node Overhead Distribution Line when the Lightning strikes at node 10. The arrestors are located at nodes 4, 15 and 26.

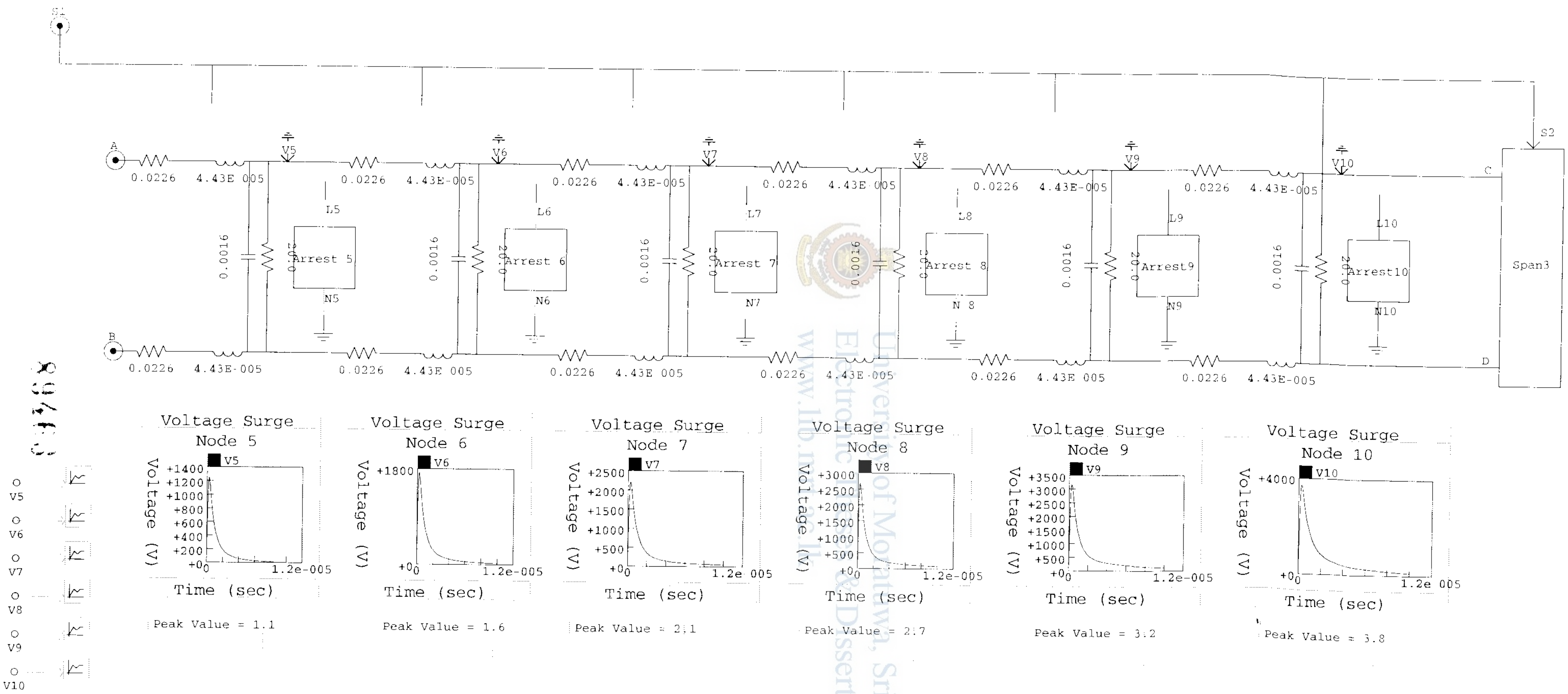


Figure 3.6(b) ; Effect of Lightning Surge at nodes 5,6,7,8,9 and 10 of the 26 node Overhead Distribution Line when the Lightning strikes at node 10. The arrestors are located at nodes 4, 15 and 26.

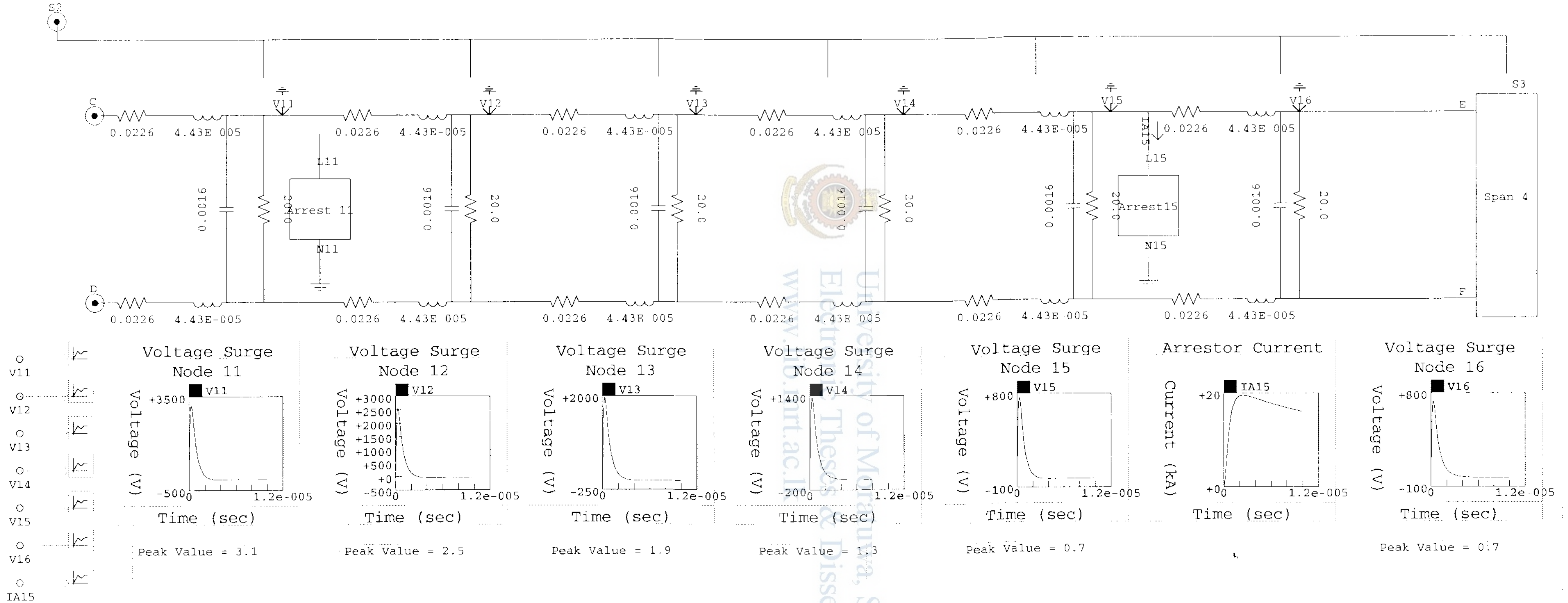


Figure 3.6(c) ; Effect of Lightning Surge at nodes 11,12,13,14,15 and 16 of the 26 node Overhead Distribution Line when the Lightning strikes at node 10. The arrestors are located at nodes 4, 15 and 26.

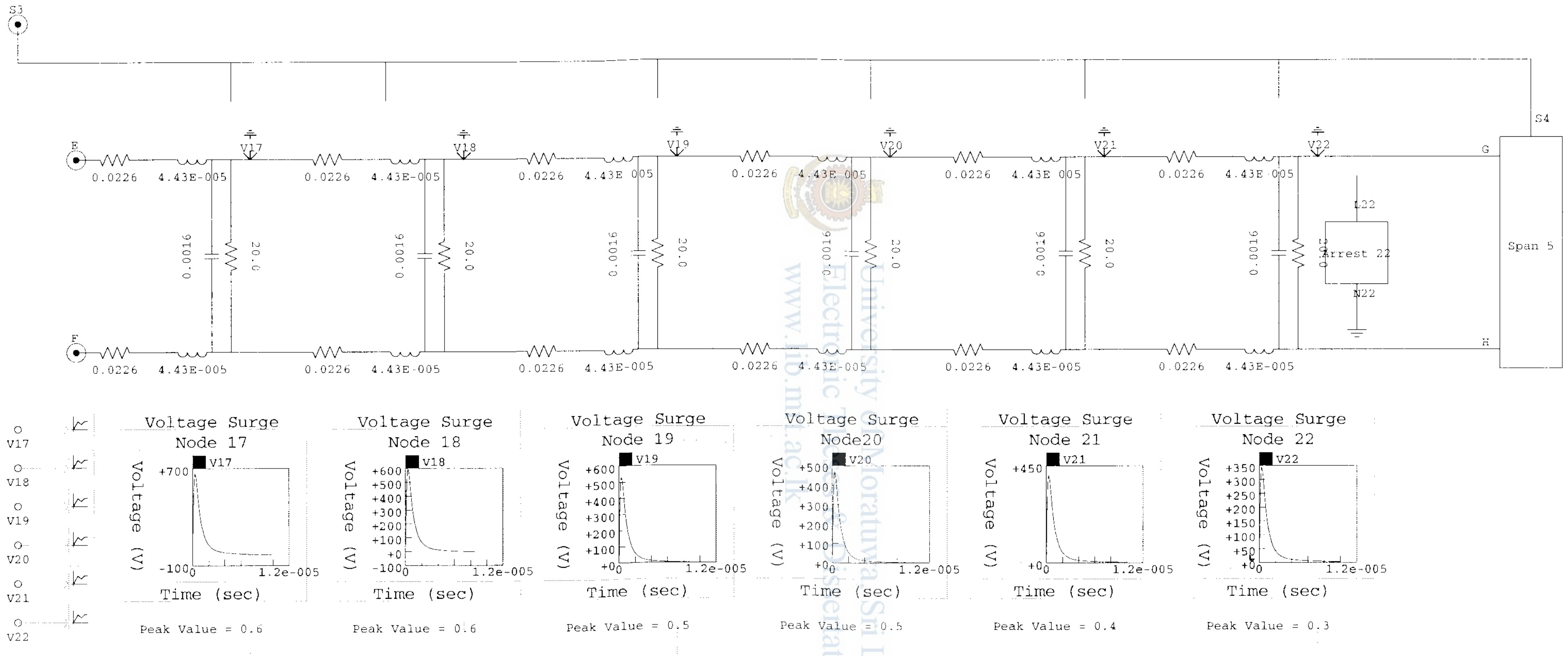


Figure 3.6(d) ; Effect of Lightning Surge at nodes 17,18,19,20,21 and 22 of the 26-node Overhead Distribution Line when the Lightning strikes at node 10. The arrestors are located at nodes 4, 15 and 26.

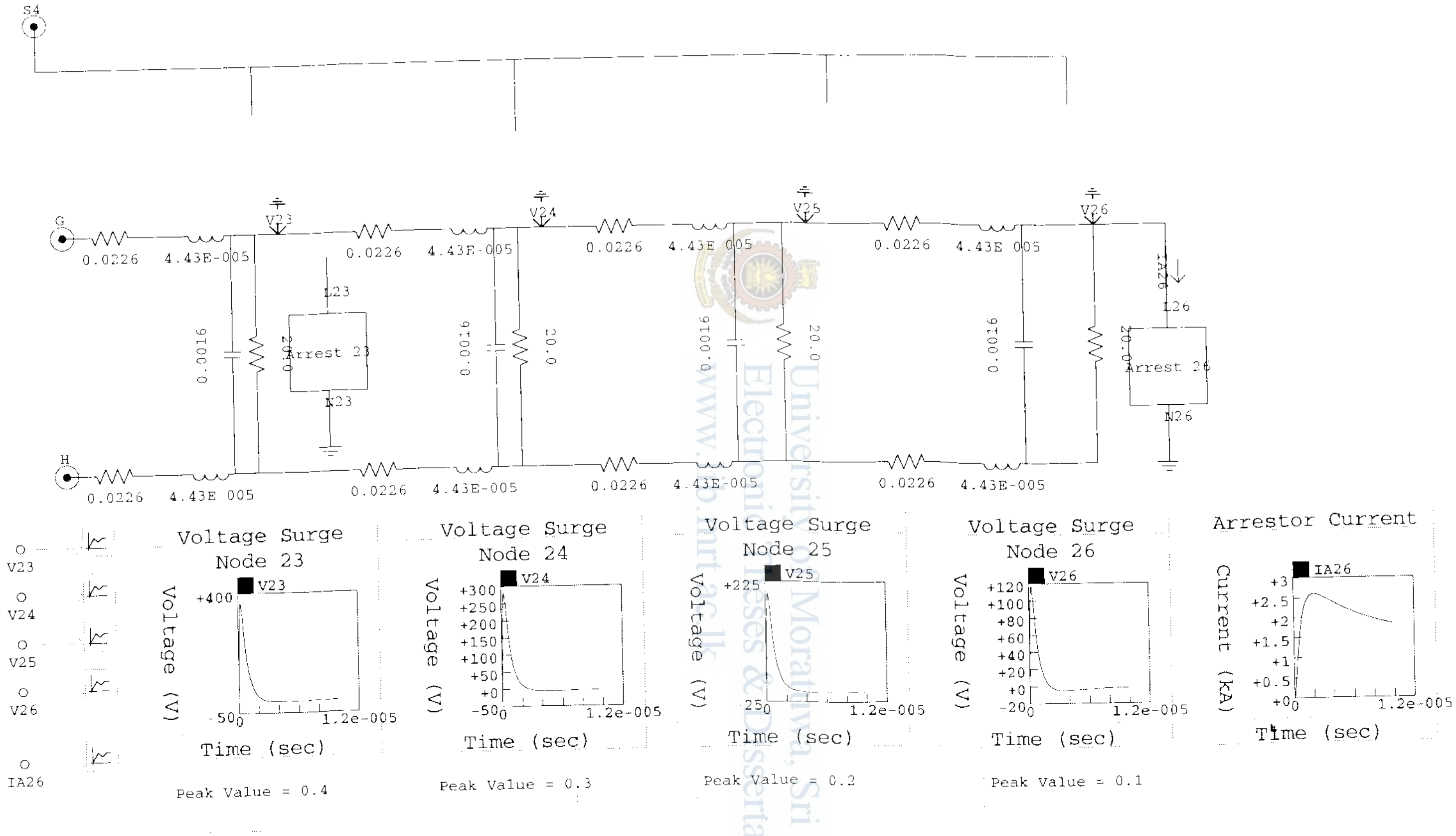


Figure 3.6(e) ; Effect of Lightning Surge at nodes 23,24,25 and 26 of the 26-node Overhead Distribution Line when the Lightning strikes at node 10. The arrestors are located at nodes 4, 15 and 26.

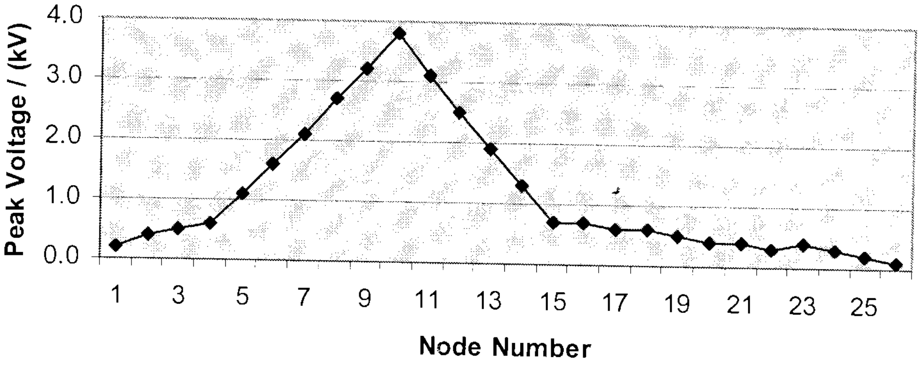


Figure 3.6 (f) - Surge Voltage Profile along the 26-node distribution line when the lightning strikes at node 10. The arrestors are located at nodes 4, 15 and 26

Use of three arrestors has further decreased the magnitudes of voltage profile of the overhead distribution line as demonstrated in figure 3.6(f).

The arrestors at locations 4, 15 and 26 have all contributed in decreasing the magnitudes of the voltage profile and the magnitudes have reached minimum values at these nodes.

3.7 Observations of the Theoretical Study

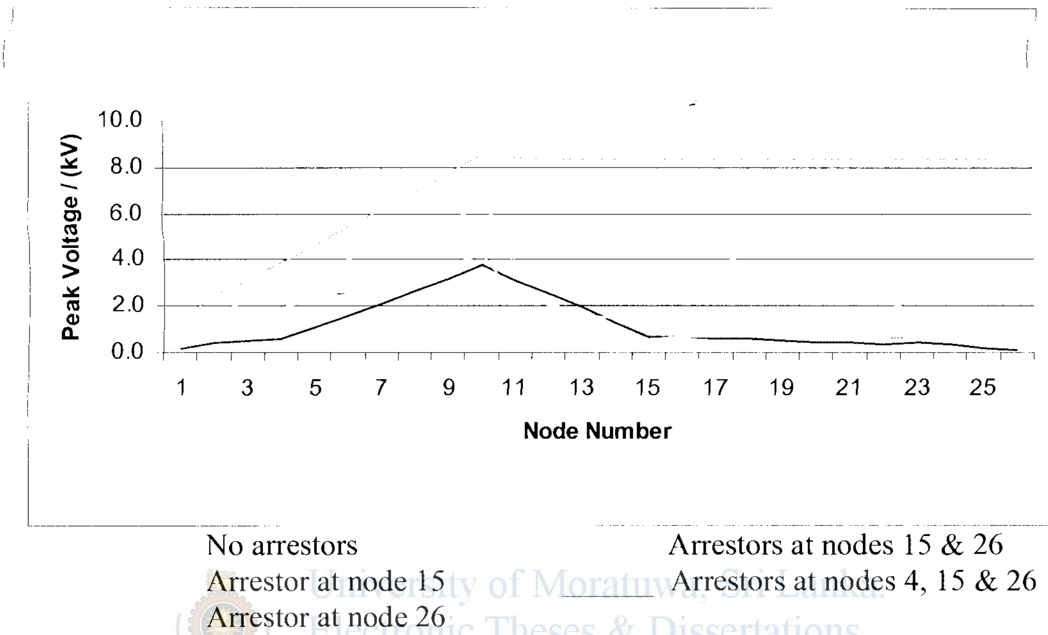


Figure 3.7 - Comparison of Peak Surge Voltages along the 26-pole overhead distribution line by placing arrestors at different locations

In all the cases the Peak Surge Voltage takes the maximum value at the node where the lightning strikes. The magnitude of the surge voltage decreases gradually towards the transformer end where the neutral conductor is earthed through transformer neutral point.

When no arrestors are installed, the voltage surge remains unabated up to the end of the line. As illustrated in Figure 3.7, the use of arrestors decreases the severity of surge voltages significantly. The overall performance against lightning improves with the increase in number of arrestors connected to the overhead distribution line.

Chapter 4

Field Study

Beregala of Ihala Kosgama, an area with a high intensity of lightning was selected for the study.This area comes under the purview of Area Engineer, Avissawella and several letters had been sent by the electricity consumers of this area to the CEB, complaining about electrical damages due to lightning. Some of the consumers are of the view that more damages have occurred since the removal of shielding conductor from distribution lines. As such, a field study was carried out in order to ascertain whether this claim is true.

4.1 Procedure Adopted

Two low voltage distribution lines fed through the same transformer were selected for the study. The transformer is situated by the side of the Colombo – Avissawella main road and the low voltage distribution line runs into the hilly area crossing the main road. After about 10 spans the line is divided into two lines. Both these lines run through two similar terrains, in the sense the degree of vegetation and elevation.

A shielding conductor was introduced into one line while leaving the other line without any. The consumers along the two lines were informed about this study and their help was sought in writing through the Area Engineer, Avissawella.

A consumer survey was carried out to compare the damages due to lightning in the two lines and thus ascertain the effects of the shielding conductor. The damages due to lightning were observed over a period of two years starting from January 2002.

4.2 Results of the Consumer Survey

	Along the Distribution Line with the shield wire		**Along the Distribution Line without shield wire**	
	Number	**Percentage**	**Number**	**Percentage**
No. of consumers surveyed	10	-	10	-
No. of Incidents of Meter damages	4	40%	5	50%
No. of Incidents of Trip Switch damages	4	40%	4	40%
No. of Incidents of TV damages	2	20%	1	10%
No. of Incidents of Refrigerator damages	1	10%	1	10%
No. of Incidents of Lamp damages	10	100%	10	100%
No electrical damages due to lightning	-	0%	-	0%

Table 4.2 - Results of the Consumer Survey

The field study confirms the fact that the damages due to lightning are considerably high in the selected area. The results suggest that the shielding conductor has little or no effect on the protection against damages due to lightning. For instance, percentage of damages of Energy Meters is low (40%) in the line with the shielding conductor while the figure is higher (50%) in the line without the shielding conductor, where as percentage of TV damages is higher (20%) in the first case and lower (10%) in the second case. Percentages of incidents of damage of Trip Switches, Refrigerators and Lamps are same under both circumstances

Chapter 5

Discussion

5.1 More damages occur towards the end of the line?

There is a point in the claim that more damages due to lightning occur towards the end of the line than the beginning. As elaborated in the PSCAD simulation results, when a lightning surge strikes a distribution line, it travels in both directions of the line. It is shown in the simulation that the magnitude of the surge voltage decays towards the beginning of the line due to the transformer earth.

The other portion of the line does not enjoy this advantage and as such the magnitude remains at the same high value unto the end of the line. Therefore the consumers connected towards the end of the line always experience high surge voltages irrespective of the point of lightning strike. In this manner, consumers' claim that the damages occur more often towards the end of the line is explainable.

5.2 Shield Wire Protection

Shield wires are used to avoid direct lightning flashes to the line. Because of their use on transmission lines, shield wires are the first thought that comes in mind for lightning protection. Shield wires can provide effective protection when very low ground resistances are obtainable [4]. Shield wires are placed so that virtually every strike will hit the shield wire. When lightning hits the shield wire, current will flow to ground through the ground impedance, and the ground voltage will rise up. This increase may cause a flashover from the ground lead to one of the unprotected phases, a phenomenon called a back-flashover. The larger the ground impedance is, the larger the ground potential rise is.

Several problems limit the usefulness of a shield wire at distribution voltage levels and this could be the reason for the ineffectiveness of the shield wire as surfaced in the field study.

1. Low BIL: It is difficult to construct a shied wire design and maintain a high BIL because the ground wire must be carried from the shield wire past the phase wires to ground.
2. No effect on Induced Flashovers: The shield wire only reduces the direct hit flashovers. It does not reduce the induced flashovers. Since the addition of a shield wire will probably reduce BIL, this may lead to even more flashovers.
3. Hard to get low grounds: At distribution voltages grounds would have to be less than 10 ohms to be effective.

4. For distribution lines in built-up or forested areas, nearby trees and buildings can intercept a significant number of direct strokes.

5.3 Arrestor Protection

5.3.1 Operation of a Surge Arrestor

Ordinary fuses and circuit breakers are not capable of dealing with lightning induced transients. Surge Arrestors (SA) only conduct under surge conditions. Normally, a SA will do absolutely nothing, much as a fuse does nothing when it is used within its rating. However, once the voltage in the system rises due to the effect of a lightning strike, the SA starts to conduct and diverts the energy away from the load. The surge or overvoltage only lasts for a short time, typically tens of microseconds to a few milliseconds and so the total energy is not huge. Unlike a fuse, however, a surge arrestor can be used many times.

Surge Arrestors are triggered when the applied voltage rises above a given level. This is known as the clamp voltage.

The technology used to perform the clamping meets the following criteria.

a) The surge handling is high enough for the system
b) The clamp voltage is high enough to avoid the SA clipping the supply continuously.
c) The SA should switch off once the surge has passed

To have a sufficiently high surge rating, the devices are usually Metal Oxide Varistors (MOVs) or spark gaps. MOVs have a high surge rating and are available in many different voltage ratings. Spark gaps have very high surge ratings but suffer from power follow-through. Once a spark gap operates it effectively shorts the supply.

5.3.2 Arrestor Spacing

It is difficult to protect distribution line insulation from direct strokes. Simulations show that arrestors may need to be put at every pole for adequate protection. Satisfactory results may be obtained if arrestors are used at every other pole, but the BIL at the unprotected poles would have to be kept high (no ground wires or guy wires at the pole).

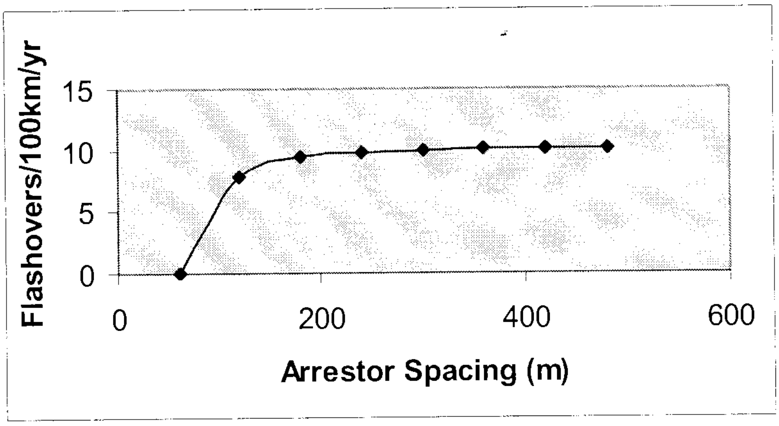


Fig. 5.3.2 - Direct Stroke Flashovers vs. Arrestor Spacing

For nearby strokes, the induced voltages are much less than the direct stroke voltages at the same stroke current level.

5.3.3 Top Phase Arrester Usage

The mechanics of top phase arrestor application are very similar to shield wire protection. When lightning hits the top phase, the top conductor will be effectively grounded after the arrestor on the top phase conducts. Like shield wire designs, performance is very dependent on ground resistance because of the ground potential rise. A drawback is that the arrestors may be exposed to excess energy. Arrestors on the top phase have the same problem as a shield wire design in that it is difficult to maintain a high BIL for the unprotected phases. The presence of an arrestor on one phase only will bring a neutral or ground wire closer to the unprotected phases.

5.3.4 Energy Concerns

There is a concern that if arrestors are used to protect against direct strokes, failure will occur because of excessive energy. Direct strokes can discharge significant amounts of energy through a surge arrester.

5.3.5 Aspect of Arrestor Failures

Surge Arrestors do fail, usually as a result of repeated use, a very high surge current or a combination of both. This means, they have some form of life limits [5].

When arrestors are used in large numbers, a consideration has to be given to the arrestor failures, which are likely to occur. Historically, arrestors on distribution systems have been failing at a rate of up to 1% or more [2]. The arrestor technology has undergone significant changes with the introduction of the Metal Oxide Varistors (MOVs).

However, the consequences of arrestor failures will be more serious than ordinary flashovers of restorable line insulation, since they will require replacement of the arrestors and the line protection will be ineffective in locations with failed arrestors. In the light of this argument, the practice of applying arrestor sets on every pole of the line that is to be protected appears hardly worth recommending.

Consequently, if arrestors are to be used for line protection they must be more widely spaced, so that the total arrestor population is not increased significantly.

5.3.6 Arrestor Duty

The subject of arrestor duty cannot be presented without considering the statistical aspects involved in determining how often an arrestor will be exposed to lightning stroke currents and what percentage of the stroke waveforms will be severe enough to damage the arrestor. Furthermore, for accurate prediction of arrestor energy absorption, it is very important to properly model not only the arrestors but their interactions with the distribution system, other arrestors, the distribution transformers and customer load, since much of the energy duty is caused by the long duration (low frequency) components of the lightning stroke current waveform.

Chapter 6

Conclusions

Based on the theoretical and field studies, the following conclusions can be made.

1. Voltage rises to a maximum value at the node of lightning stroke and surge voltage decreases gradually towards the node where a lightning arrestor is connected and also towards the transformer end where the neutral conductor is earthed through the transformer neutral point.

2. The magnitude remains unchanged towards the end of the line, if no arrestors are installed and as such there is a point in the claim that the damages due to lightning is more frequent towards the end of the line than the beginning.

3. Arrestors can curtail the magnitude of surge voltage drastically and for effective protection surge arrestors are required at each node.

4. There is no significant effect in using an overhead shield wire in low voltage distribution lines against damages to household electrical items.

References:

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[2] McDermott, T.E.; Short, T.A.; Anderson,J.G., "Lightning Protection of distribution lines," IEEE Transactions on Power Delivery, Vol. 9, no.1, pp. 138-152, January 1994

[3] Task Force Report (GE and 8 utilities), "Investigation and Evaluation of Lightning Protective Methods for Distribution Circuits Part I: Model Study and Analysis," IEEE Transactions on Power Apparatus and Systems, Vol.88, no. 8, pp. 1232-1238, August 1969

[4] "Lightning Protective Methods for Distribution Circuits Part II: Application and Evaluation," IEEE Transactions on Power Apparatus and Systems, Vol.88, no. 8, pp. 1239-1247, August 1969

[5] Thomas A Short, "Lightning Protection of Overhead Distribution Lines," November 2000