CHAPTER 4

4.0 RESULTS, ANALYSIS AND ACTIONS

4.1 Effect of Tower and the Geographical situation

In here we are not considering the areas of Mannar, Anuradhapura, Badulla and Hambantota as there were no major lightning incidents reported. As per the table 3.5, the towers located within the region, where iso keraunic level is greater than 60 are under the risk of lightning strikes and lot of damages reported. Rathnapura region is mostly affected during last 3 years of period. If we consider the tower mounted equipment damages such as Microwave antenna, the damages reported mainly in sites where, tower height is greater than 120m from the sea level.

There are two incident that we observed damages occurrence and non-occurrence with the tower erection. For an example: We have observed frequent lightning damages and complain near Madampegama RBS from the date of tower erection. But there is a tower near the Madampegama RBS with the same tower height and from the 150m of air distance. But elevations of the two tower locations are different and Madampegama Tower is located on around 10-20m higher elevation as you can see in below google maps. The Other operator site is located in mentioned area for more than one year before Madampegama tower erection. But there were no such lightning incidents reported with regards to that tower. Therefore simply we can conclude that erection of tower has considerable effect for lightning incidents and also there is a correlation with the tower elevation from the sea level or effective height. Also it is noted that the area is residential having around 26 homes around 100m of perimeter.

Figure 4.1: Elevation of Madampegama site with respect to other operator site

(Source: Author)

Figure 4.2: Contour map -Madampegama site with respect to other operator site

(Source: Author)

The other incident is reported near Agalawatta RBS. There was lot of damages reported near Agalawatta RBS. But we have observed that there were no damages reported to this RBS after the other operator tower erection near this are. We can see that the other operator site has same tower height and located from the 125m of air distance. Same as the Madampegama case, the elevations of the two tower locations are different and Agalawatta Tower is located on around 10-20m lower elevation as you can see in below google maps.

Figure 4.3: Elevation of Agalawatta site with respect to other operator site

(Source: Author)

Figure 4.4: Contour map -Agalawatta site with respect to other operator site

(Source: Author)

The reason for this can be explain using iso keraunic level and tower height from the sea level. Grounded vertical objects produce relatively large electric field enhancement near their upper extremities so that upward-moving connecting leaders from these objects start earlier than from the surrounding ground and therefore, serve to make the object a preferential lightning termination point. With increasing height of an object an increase in the number of lightning discharges is observed with an increasing percentage of upward initiated flashes [12].

4.2 Effect of Indirect Flashes

A one of home located in Nakiyadeniya radio base station has damages due to some of side flashes occurred in the tower. This can happen as there may be shielding failure rate, e.g., the 2% (maximum) of low energy strikes in a 98% lightning protection design as shown above [15]. As per the damages it is obvious that the damages are due to CVM by pass.

If we consider the total mountain as one structure height of 250m (above sea level) and we have installed air terminal on the top of mountain. The home can be considered as a point on the structure that is on the lower part of the structure and that point has been damaged due to CVM bypass as similar as lightning incident happen in Villaputri Building, downtown Kuala Lumpur in year 2005.

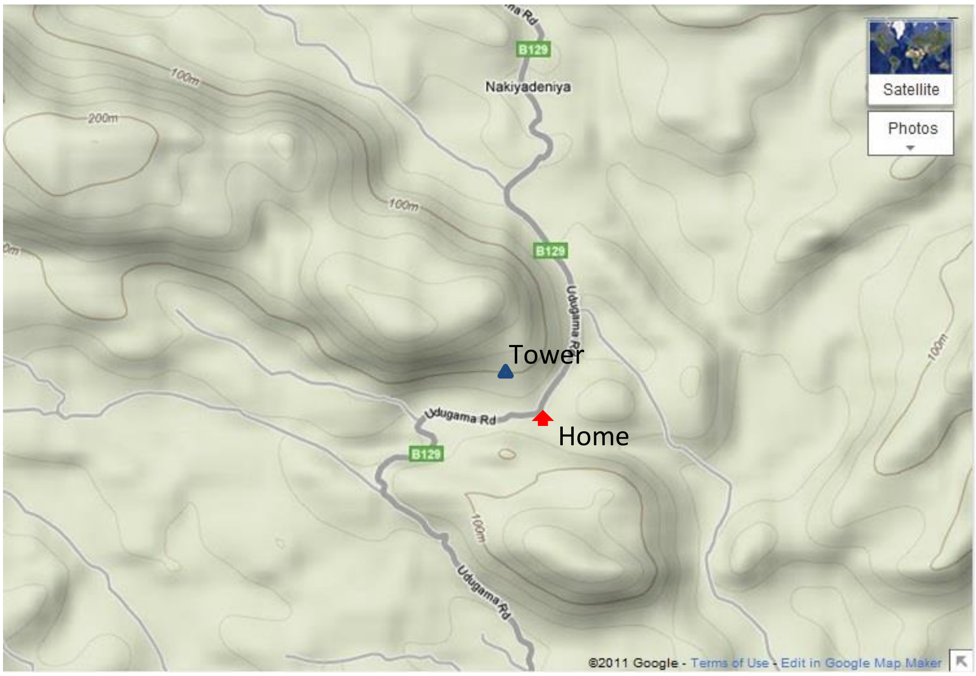


Figure 4.5: Tower location and the home location in Nakiyadeniya lightning incident

(Source: Author)

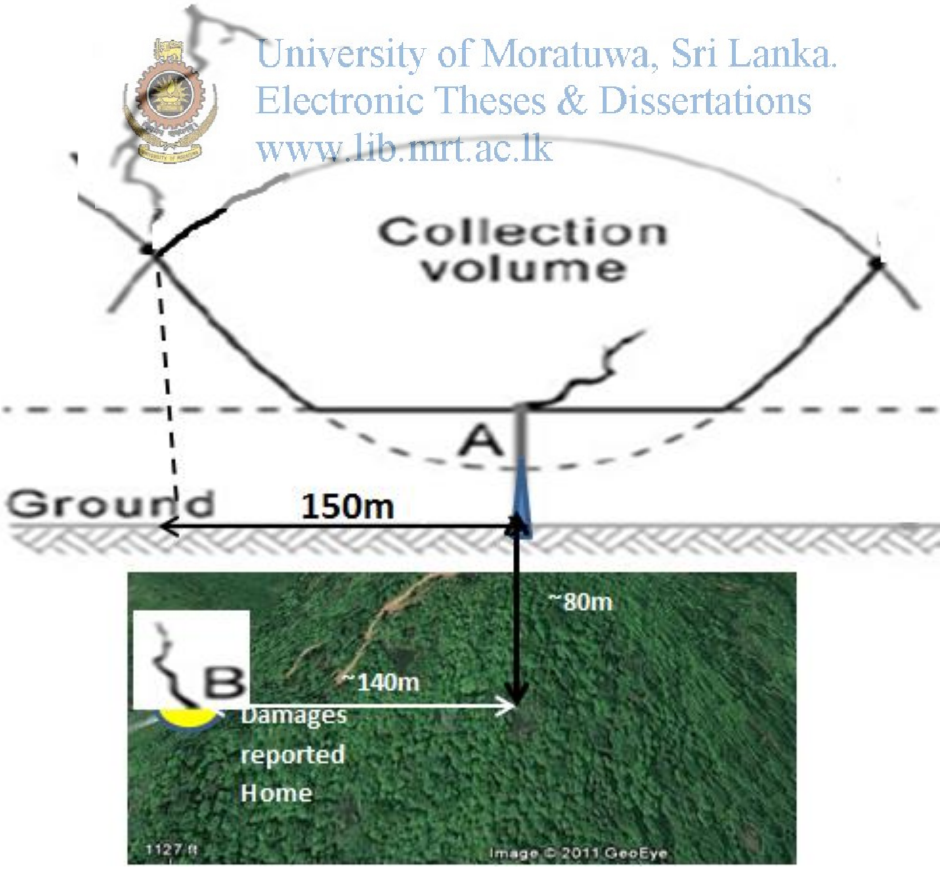


Figure 4.6: Collected volume of the Nakiyadeniya Tower

(Source: Author)

Tower Air terminal height with reference to the see level is around 250m and home located around 110m above the see level. Therefore it is obvious that we can expect such bypasses even there lightning protection zone due to a telecommunication tower. In such cases we have taken care of protecting neighborhoods by creating protection zone for them.

The only thing can do is to protect home is to develop a shielding area for the home. Simply we can route the discharge path through the Airterminals that we are going to use for the creation of shielding area. Then the discharge happen previously through the wall can now be discharge through the Airterminal without damaging any other object.

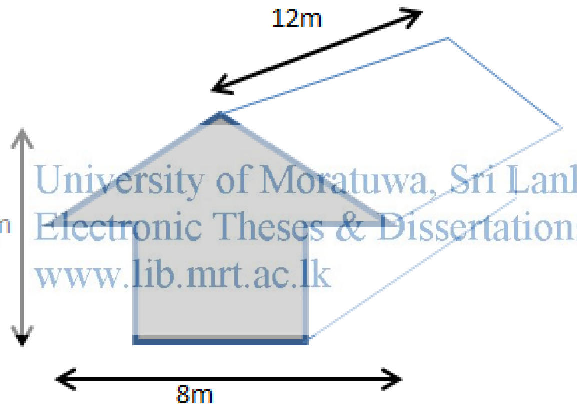


Figure 4.7 Dimensions of the damaged Home

(*Source*: Author)

A lightning rod mounted on 10m GI structure selected for the protection of home. Then for the high risk, we have selected 6.5kA peak current, and then radius of protection is 13m. For more safety we can put 2 lightning rods and have large collected volume.

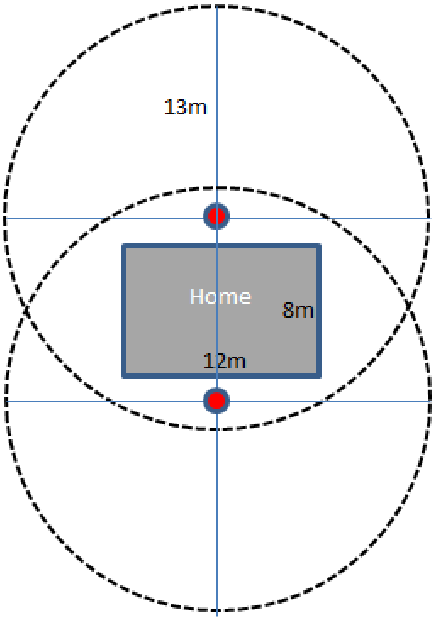


Figure 4.8 Shielding areas proposed around the damaged home

(*Source*: Author)

This system has been implemented on March 2010 and we have no any complaints since the implementation date and it is obvious that the implementations have very effective and fruitful as we have almost passed two year with more than four lightning seasons. The onsite implementations are shown in figure.

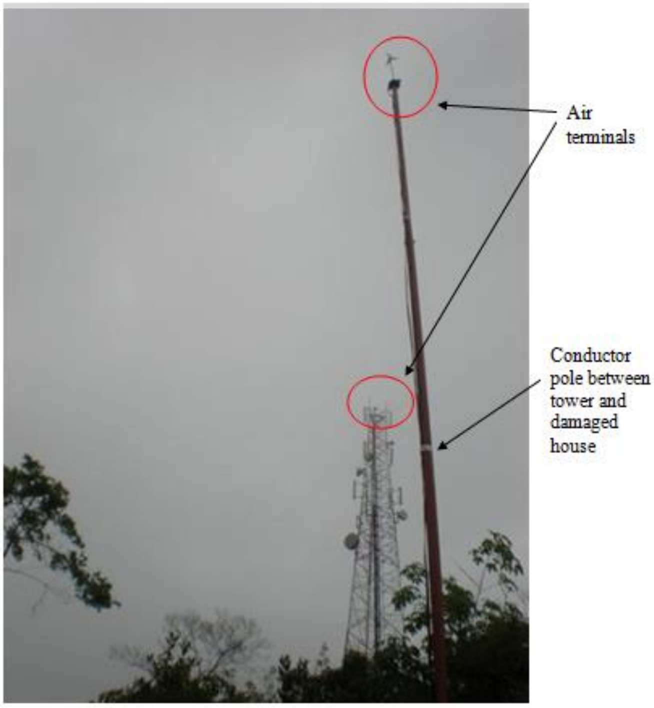


Figure 4.9 Air Terminal installed on tower side near the damaged home

(*Source*: Author)

Figure 4.10 Air Terminal installed on home side

(Source: Author)

4.3 Effect of Power line surge

During the research, it is observed that the most of the damages reported are due to the power line surges. The way of developing surges on power line need to be discussed in this session. There are few possibilities of happening this. Those can be proposed as follows

- The surge voltage developed due to direct lightning induced on power line
- The surge voltage developed due to the direct lightning stroke to tower and then it return to the power line through the surge reduction filter installed at tower equipment cabin

SRF 140 surge reduction filter using as the power line protector model by using Line to Neutral and Neutral to Ground surge arrester and low pass filter as shown in Figure 4.11.

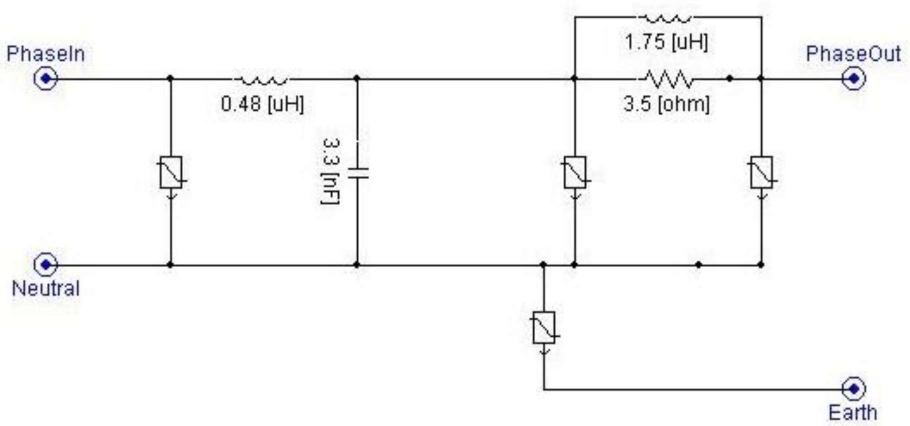


Figure 4.11: Surge reduction filter model

(Source: Author)

For the purpose of surge calculations, it is only the heavy current flow during the return stroke that is of importance. During it has been found that the waveform can be represented by a double exponential of the form

$$i = I\,(e^{-\alpha t} - e^{-\beta t})$$

The parameters of the lightning current surge were taken according to the International Standard IEC 61312-1 [12] for the III and IV protection levels as 10/350 μs 10 kA. The Surge generator and wave shown in Figure 4.12 and Figure 4.13 respectively

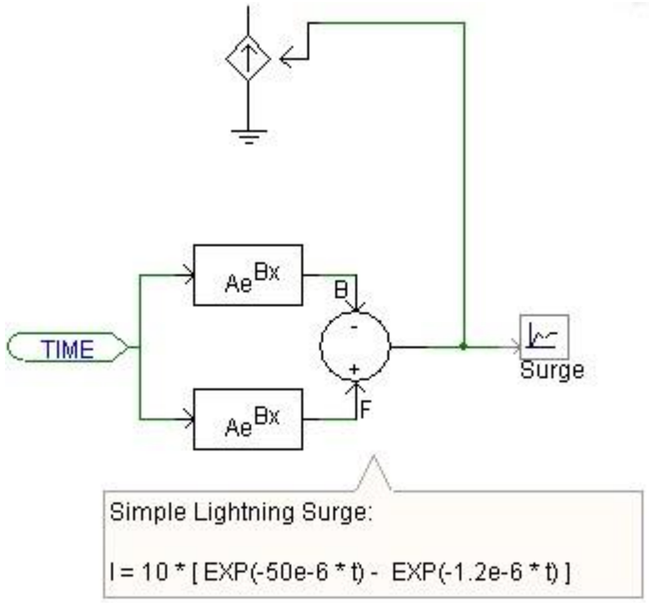


Figure 4.12: Surge Generator

(Source: Author)

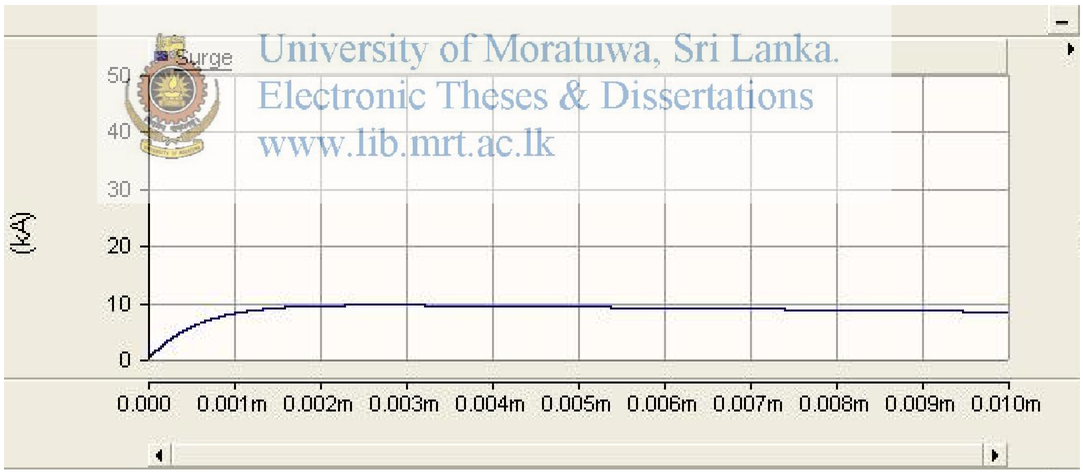


Figure 4.13: Surge wave model

(Source: Author)

The power line arrangement, Lightning strike and earth resistance system combine to a one model and demonstrated in Figure 4.14 to show the RBS power line arrangement from the generation end to the load end. The arrangement inside the doted square shows the RBS. The Armourd cable segment from meter cubicle to the SRF and then to the RBS load is shown there. In one side we can see the neighborhood loads serves from all three feeders from the transformer.

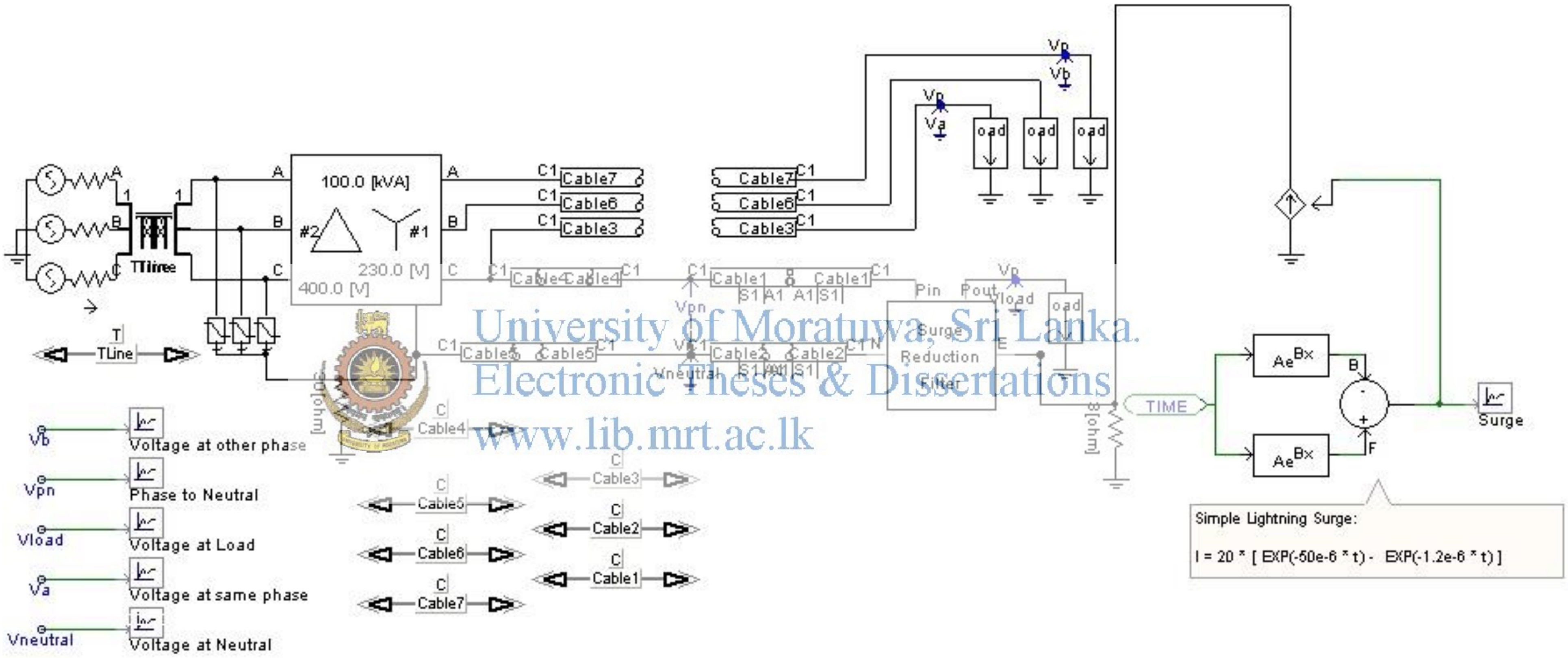


Figure 4.14: Power line model for the telecommunication Radio Base station

(Source: Author)

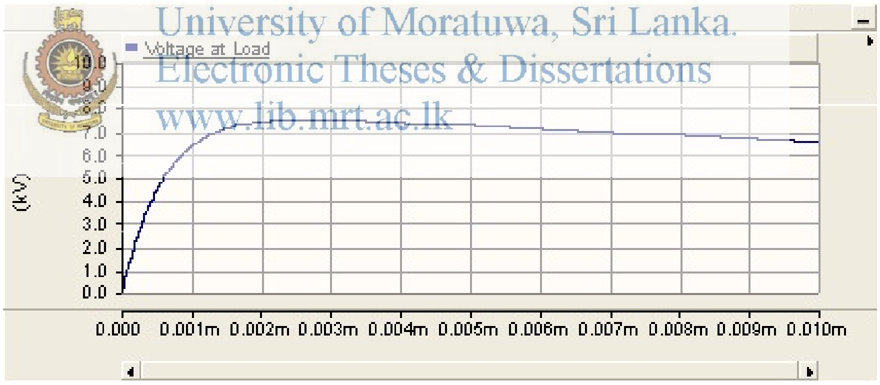
4.3.1 Voltage rise with the effect of earth resistance

The below simulation are based on the direct lightning stroke to tower and then it return to the power line through the surge reduction filter installed at tower equipment cabin. In here we will look at how potential raise in power lines vary with the tower earth resistance value.

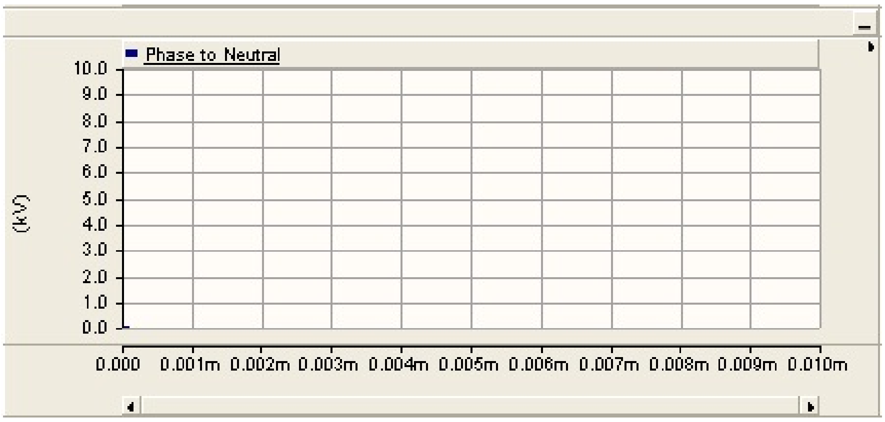
The equivalent resistance for the grounding system is simulated by a resistance as shown in below Figure. The Simulation has done to find the effect on potential rise in phase and neutral in the case of direct lightning strike to the tower

Voltage variations with 100 Ohms Earth resistance systems

With the effect of the lightning strike to the tower, we can see around 7.5kV voltage rise at the power input phase to the SRF, Neutral, Power output from the SRF and at Separate phase from the transformer with respect to the ground and there is no voltage difference in Phase to neutral in RBS having 100 Ohms earth resistance system.



(a)



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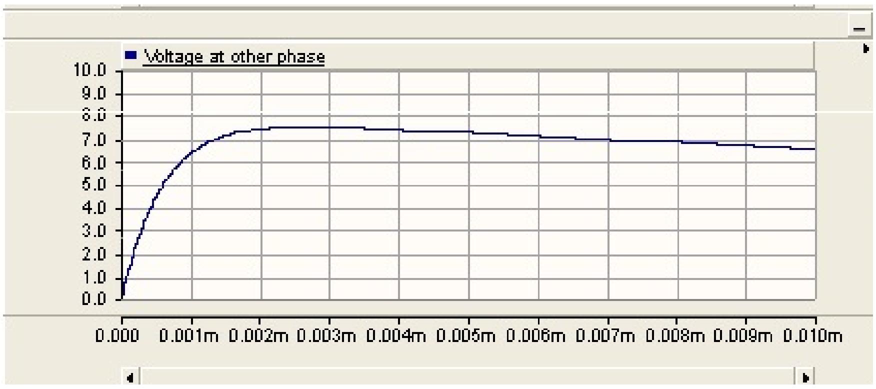

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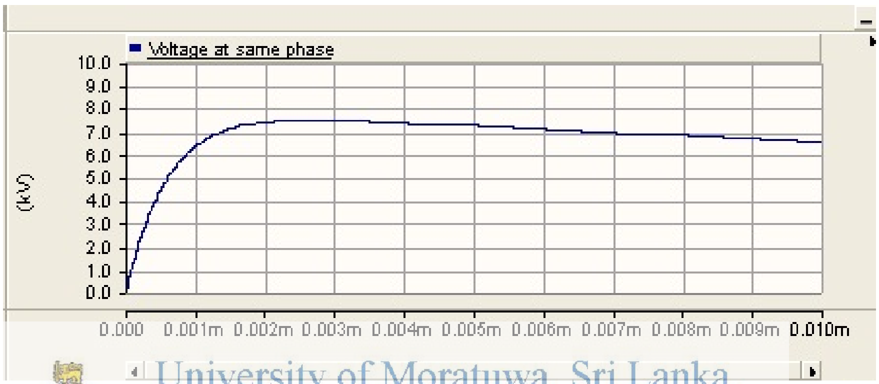

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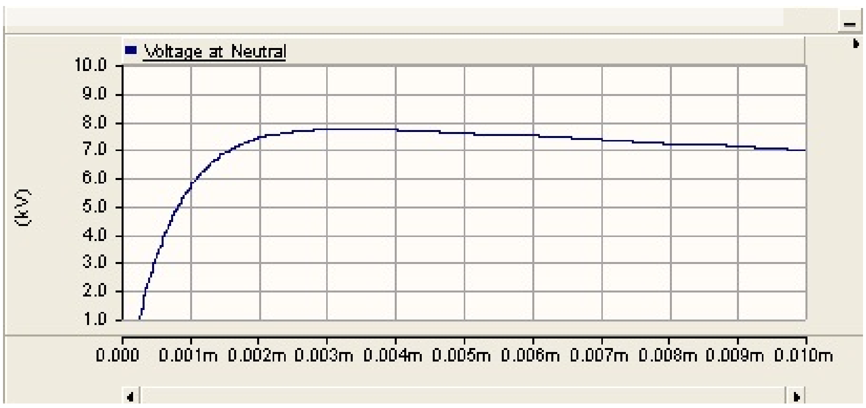
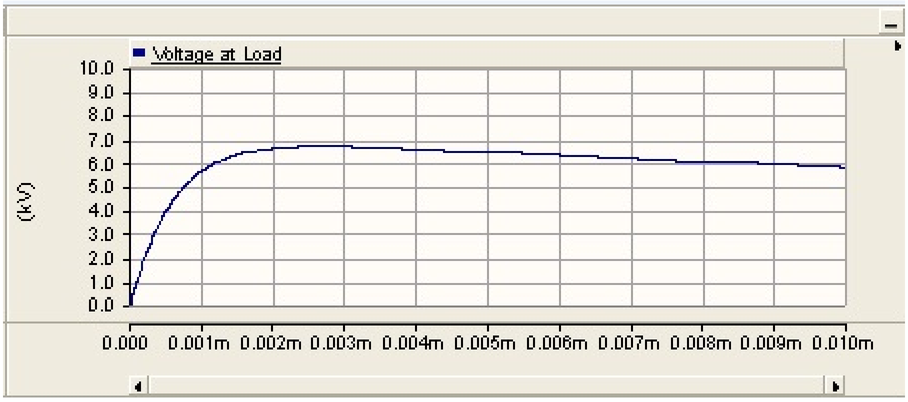


(e)

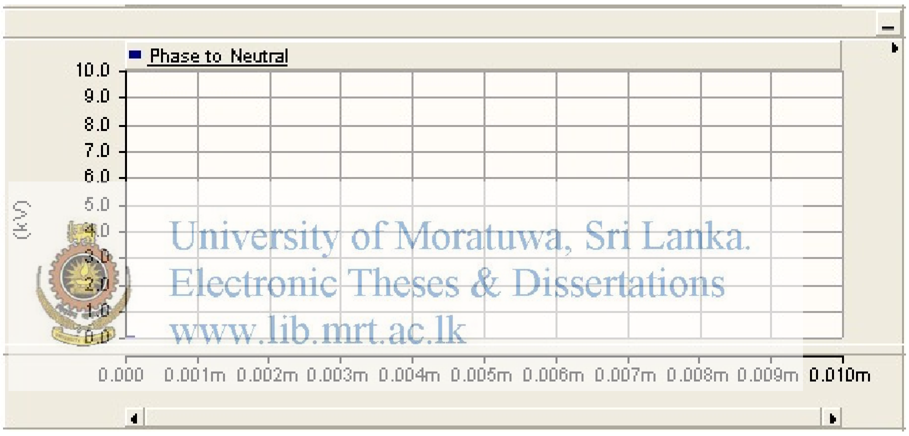
Figure 4.15 Voltage rises in (a) at load (b) Phase to neutral (c) at separate phase (d) Site power input phase (e) at neutral for 100 Ohms earth resistance system

(Source: Author)

Voltage variations with 10 Ohms Earth resistance systems



(a)



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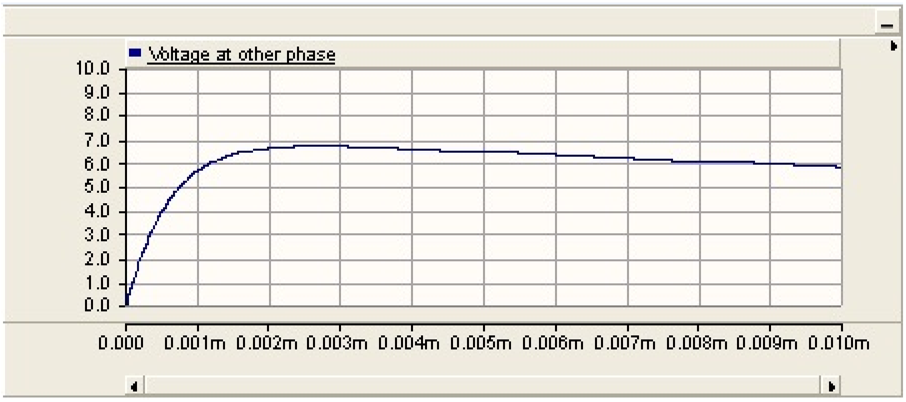

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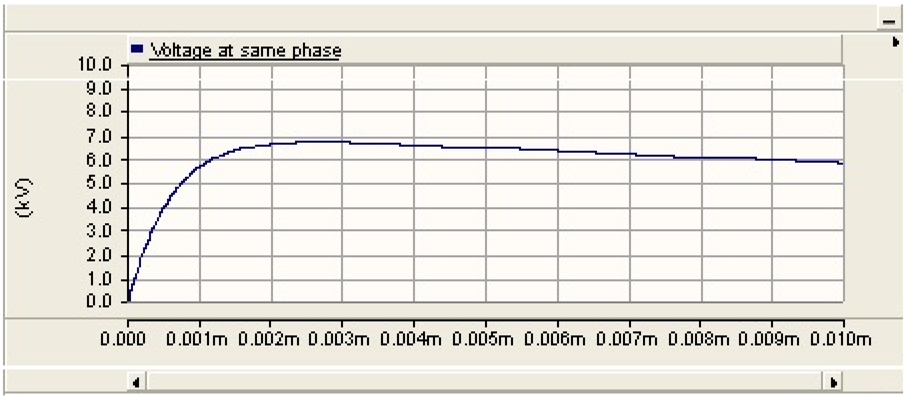

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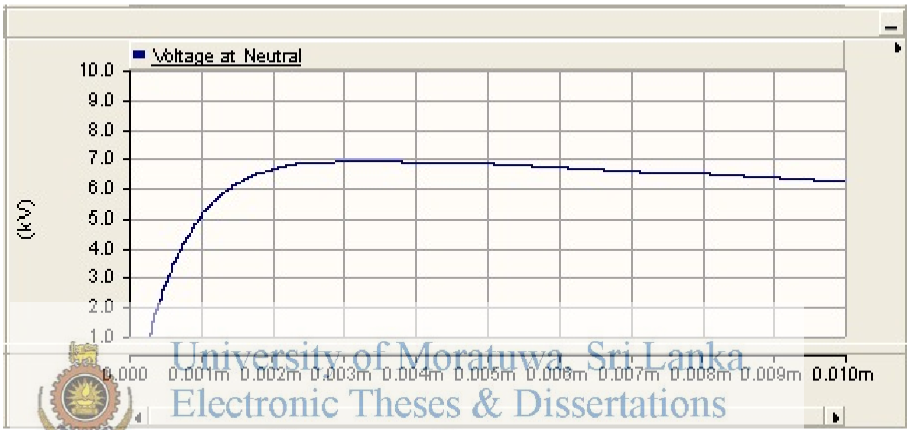


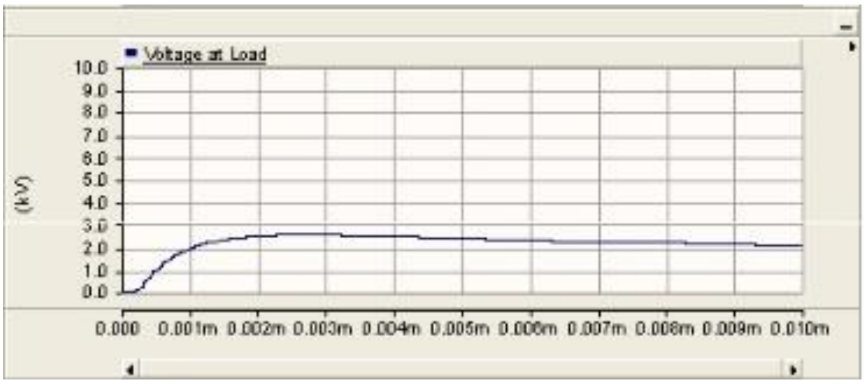
(e)

Figure 4.16 Voltage rises in (a) at load (b) Phase to neutral (c) at separate phase (d) Site power input phase (e) at neutral for 10 Ohms earth resistance system

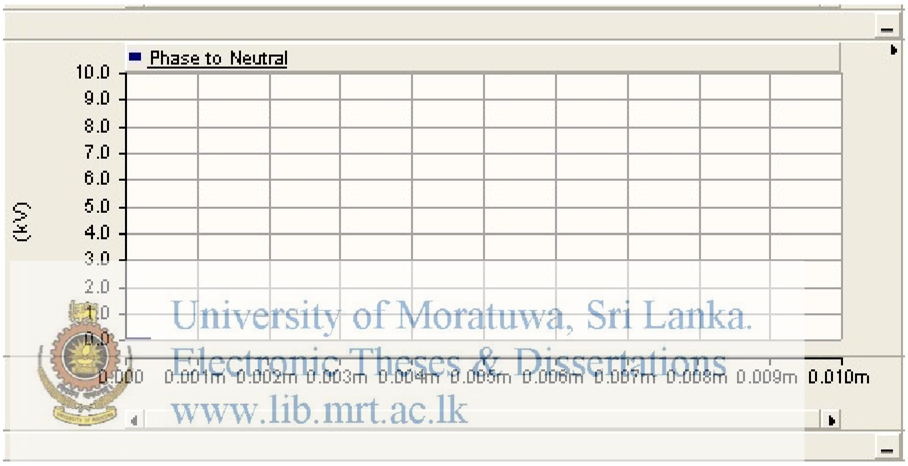
(Source: Author)

With the effect of the lightning strike to the tower, we can see around 7 kV voltage rise in power input phase to the SRF, Neutral, Power output from the SRF, Separate phase from the transformer with respect to the ground and there is no and voltage difference in Phase to neutral. This is not a considerable reduction in voltage rise compared with 100 Ohms earth resistance system.

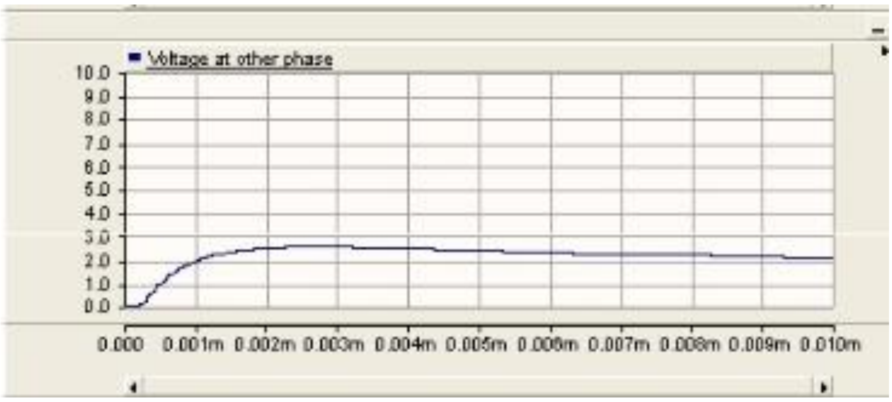
Voltage variations with 1 Ohms Earth resistance systems



(a)



(b)



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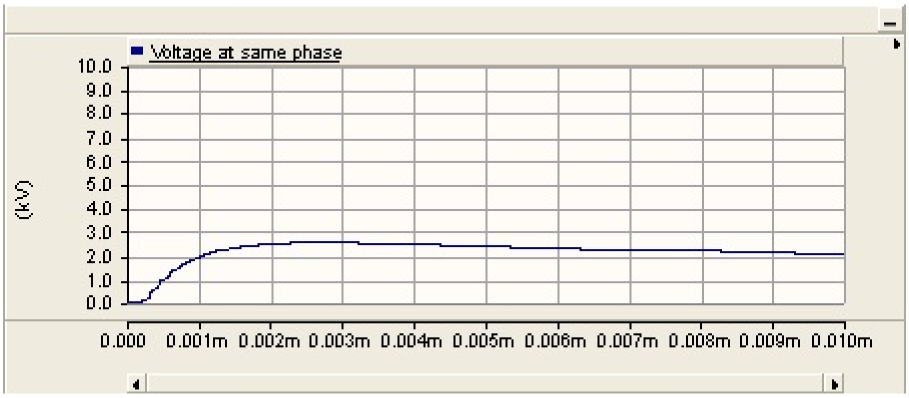
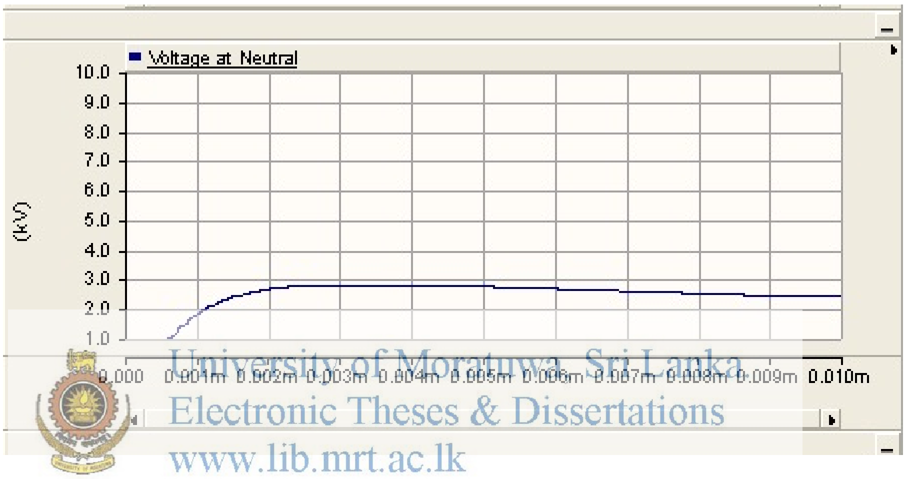


(d)



(e)

Figure 4.17 Voltage rises in (a) at load (b) Phase to neutral (c) at separate phase (d) Site power input phase (e) at neutral for 10 Ohms earth resistance system

(Source: Author)

With the effect of the lightning strike to the tower, we can see around 2.5 kV voltage rise in power input phase to the SRF, Neutral, Power output from the SRF, Separate phase from the transformer with respect to the ground and there is no and voltage difference in Phase to neutral. This is a considerably low value compared with 100 Ohms and 10 Ohms earth resistance system.

By considering the simulation results we can see that the considerably high voltage built up in power lines not only in RBS power in, but also in other transformer feeders. This will cause to lot of electrical equipment damages. During the research data collection, we can see that the earth resistance values in most of the sites are greater than 5 Ohms. With this we can see there may a possibility of more than 7kV voltage rise in electrical systems with respect to the earth. This is basically high value compared with BIL of electrical items and therefore will cause to equipment failures.

4.3.2 Voltage rise with the effect of Secondary sure arresters

Throughout these 3 years of period we have observed lot of electrical equipment damages in neighborhood homes. As a regulation and a habit, we have been installing secondary surge arrester of 20kA class B and we have experienced a good result from that. In such sites we do not have any evidence in damages after the surge arrester installation. For this installation it is cost around Rs. 50,000.00 per home. If there is complains from 20 homes, we need to install surge arrester for all homes and it will cost Rs 1M. Therefore to achieve same effect we have installed only one surge arrester set at the RBS meter cubicle (i.e. at the power entry to the site). The simulation results of the secondary surge arrester installation at the meter cubicle is shown below and will discuss about the effect of the arrangement.

Effect of Phase to Ground secondary surge arrester

Phase to ground surge arrester with 280V Class B protection level has installed as shown in below Figure. In this case earth system resistance kept at 30 Ohms fix.

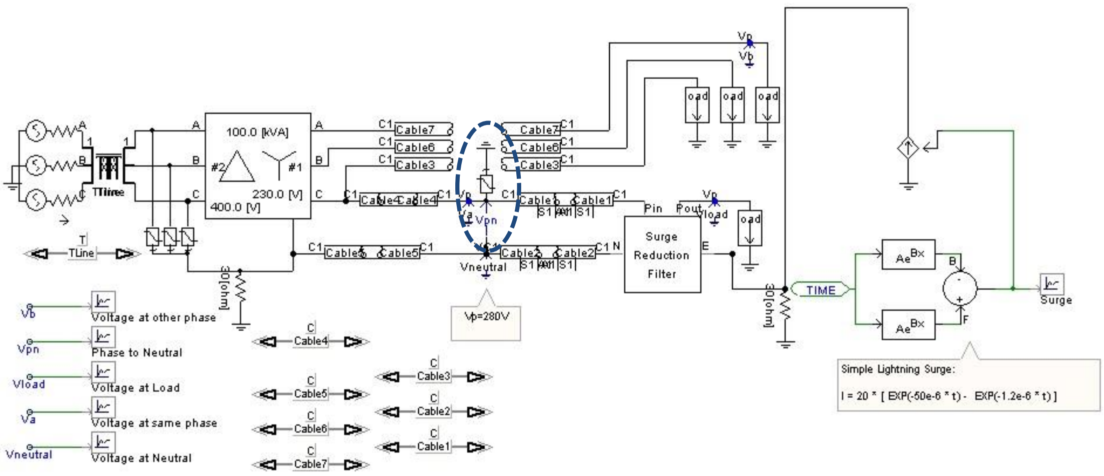
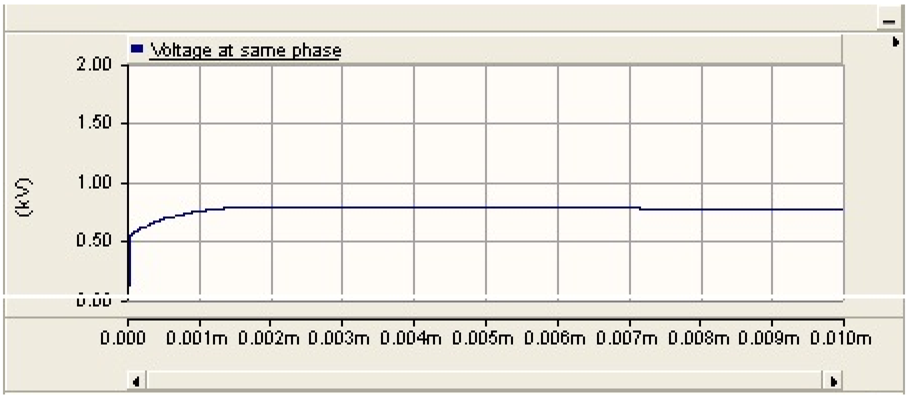


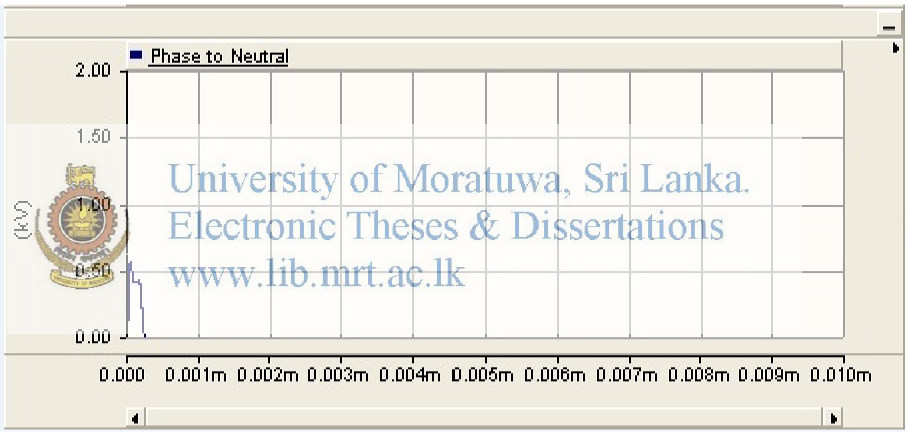
Figure 4.18 Phase to Ground secondary surge arrester

(*Source*: Author)

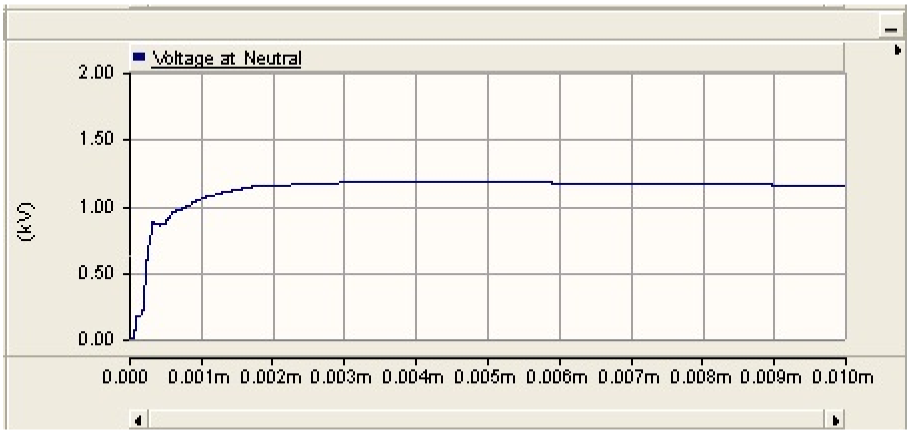
In this simulation we can see the voltage around phase get dropped to around 0.75kV as shown in Figure (a), (d) and (e). At neutral it is around 1.25kV as shown in Figure (c). A remarkable feature in phase to neutral is that at the beginning we can see a voltage spike and then it became to zero as shown in Figure (b). Therefore we can see that the phase to ground surge arrester works effectively to reduce voltage rise due to the lightning surges.



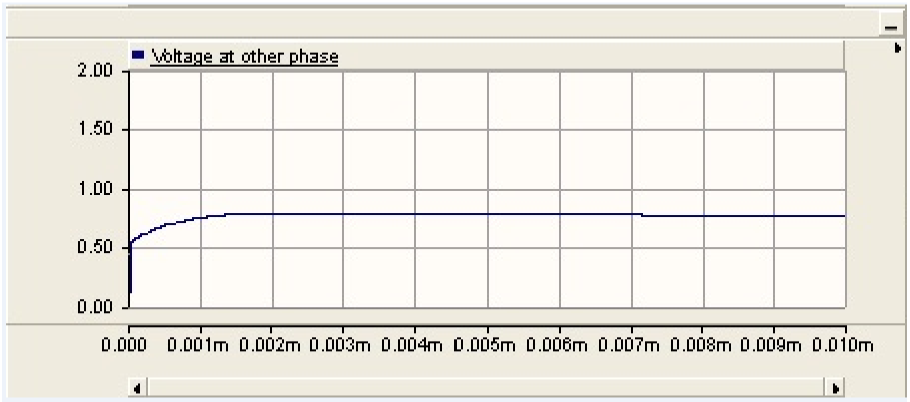
(a)



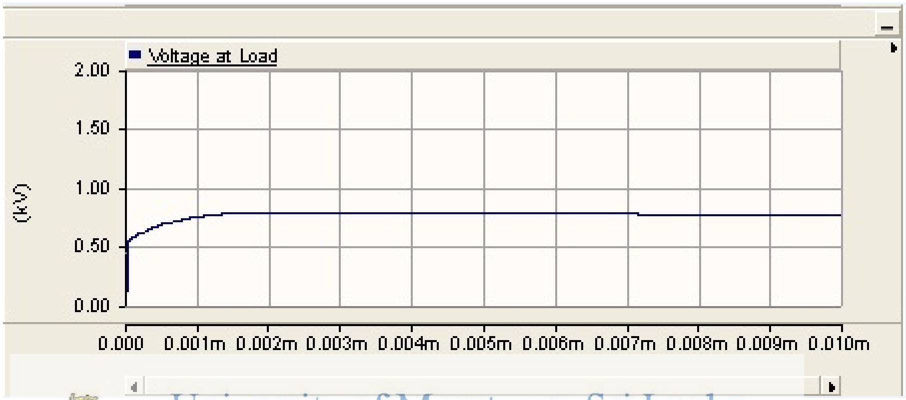
(b)



(c)



(d)



(e)

Figure 4.19 Voltage rises in (a) at same phase (b) phase to neutral (c) at neutral (d) at separate phase (e) at load - for secondary surge arrester installation at phase to ground

(*Source*: Author)

Effect of Neutral to Ground secondary surge arrester

Neutral to ground surge arrester with 280V Class B protection level has installed as shown in below Figure. In this case earth system resistance kept at 30 Ohms fix.

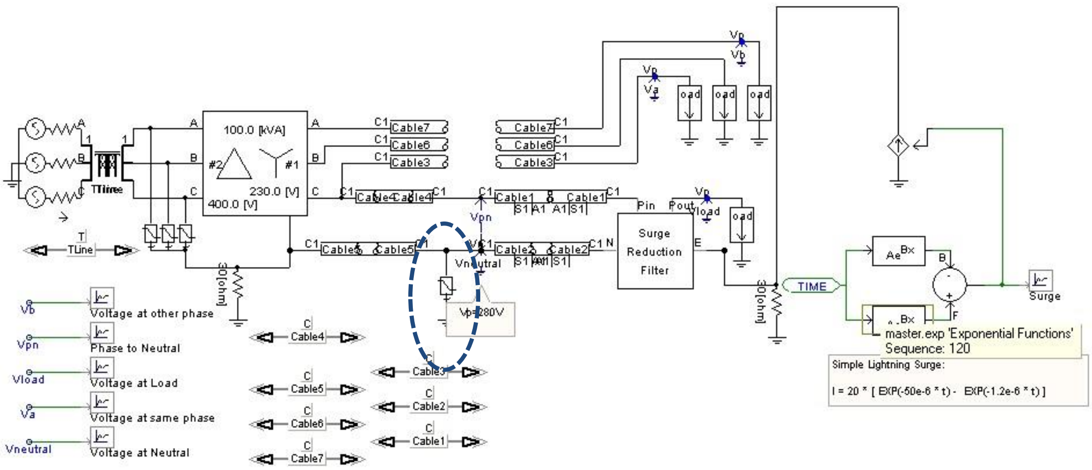
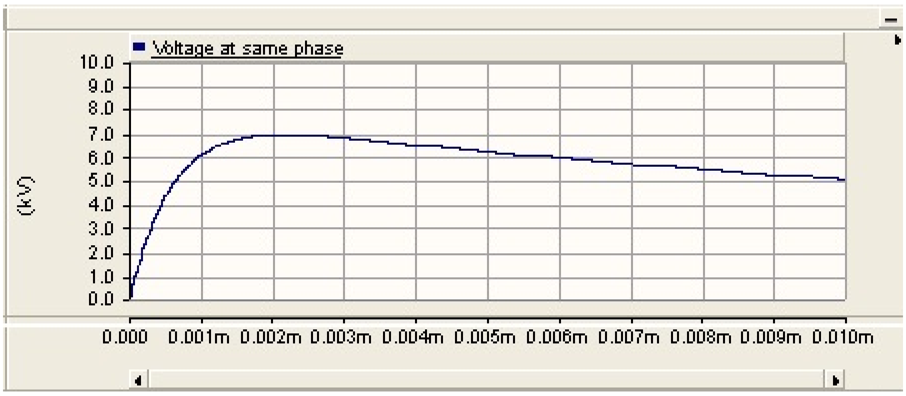


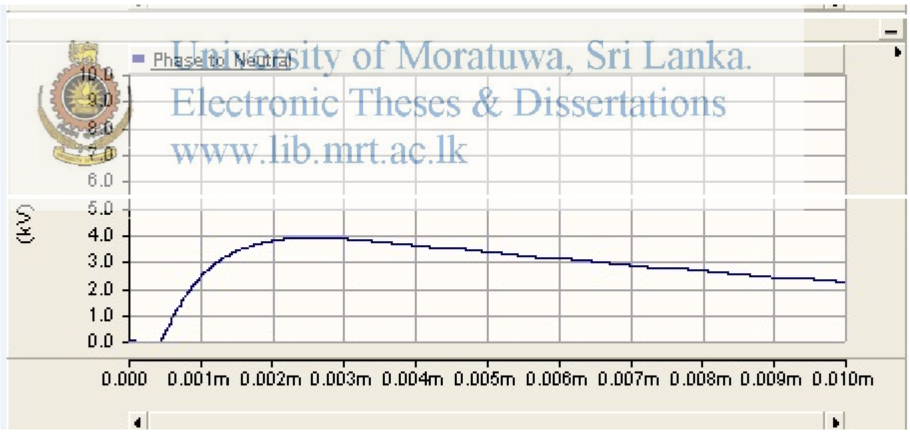
Figure 4.20 Neutral to Ground secondary surge arrester

(*Source*: Author)

In here we cannot see considerable effect due to the surge arrester installation at Neutral to ground. We can see the voltage around phase get dropped to around 7 kV as shown in Figure (a), (d) and (e). There is no any voltage rise at neutral as shown in Figure (c). But we can see phase to neutral voltage rise drop to around 4kV as shown in Figure (d). Therefore we can see that the phase to ground surge arrester does works effectively to reduce voltage rise due to the lightning surges.



(a)



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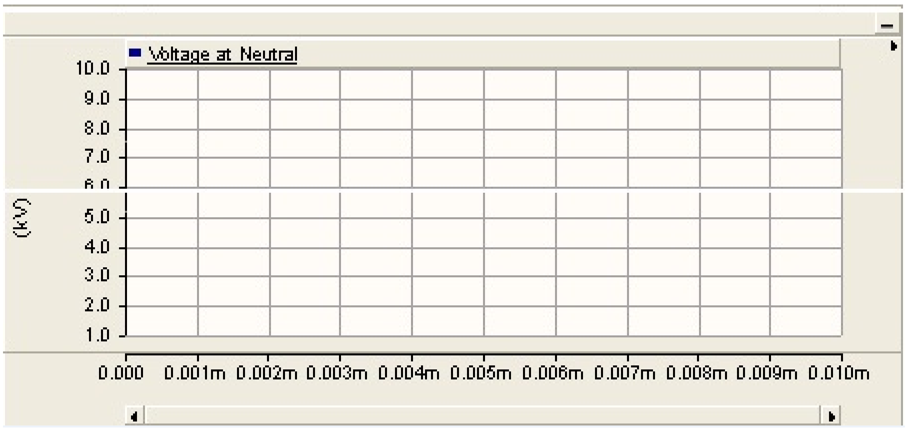
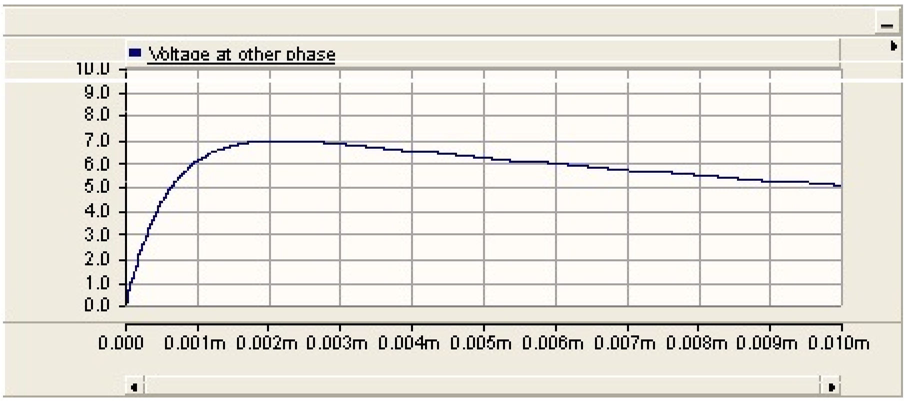


(c)



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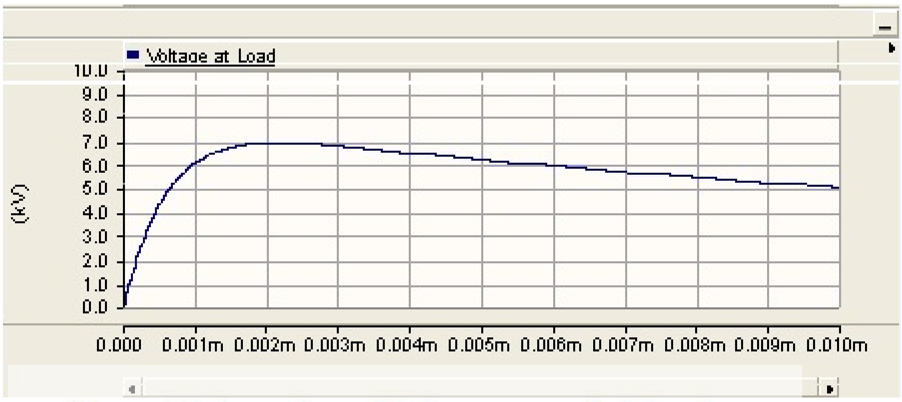


(e)

Figure 4.21 Voltage rises in (a) at same phase (b) phase to neutral (c) at neutral (d) at separate phase (e) at load - for secondary surge arrester installation at Neutral to ground

(Source: Author)

Combine Effect of Phase to Neutral and Neutral to Ground secondary surge arresters

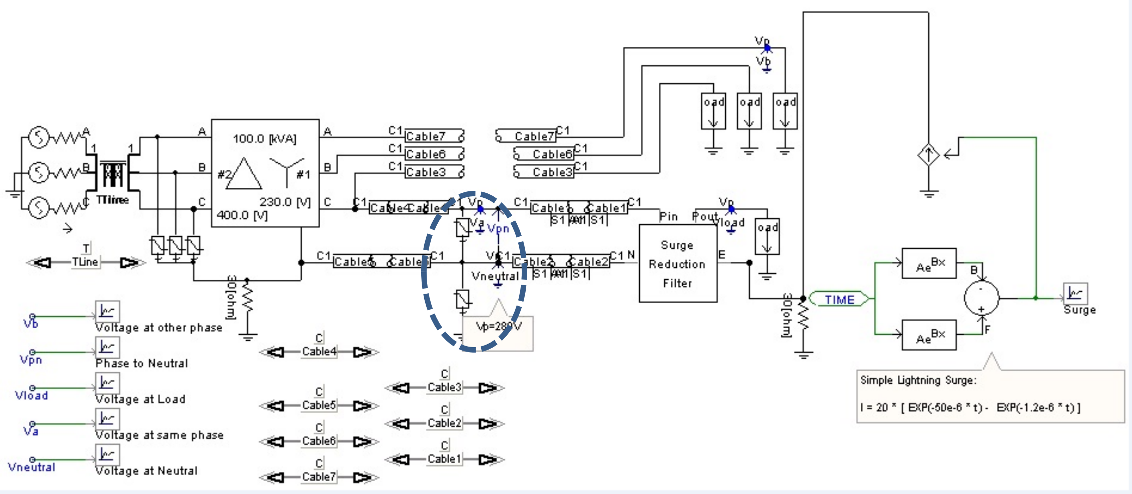
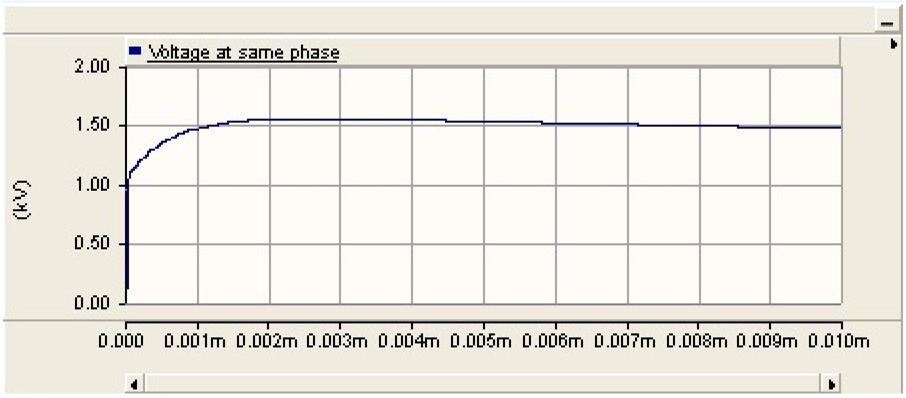


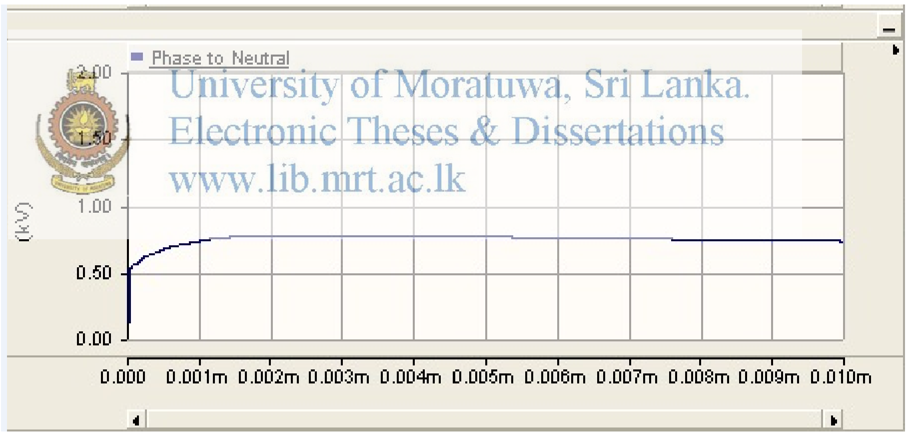
Figure 4.22 Phase to Neutral and Neutral to Ground secondary surge arrester

(Source: Author)

This arrester configuration is also effectively drop the voltage rises. We can see the voltage around phases get dropped to around 1.5 kV as shown in Figure (a), (d) and (e). But we can see phase to neutral and neutral to ground voltage rise, drop to around 0.75kV as shown in Figure (b) and (c). Therefore we can see that the phase to ground surge arrester works effectively to reduce voltage rise due to the lightning surges. But this not good configuration compared with phase to ground arrester configuration.



(a)



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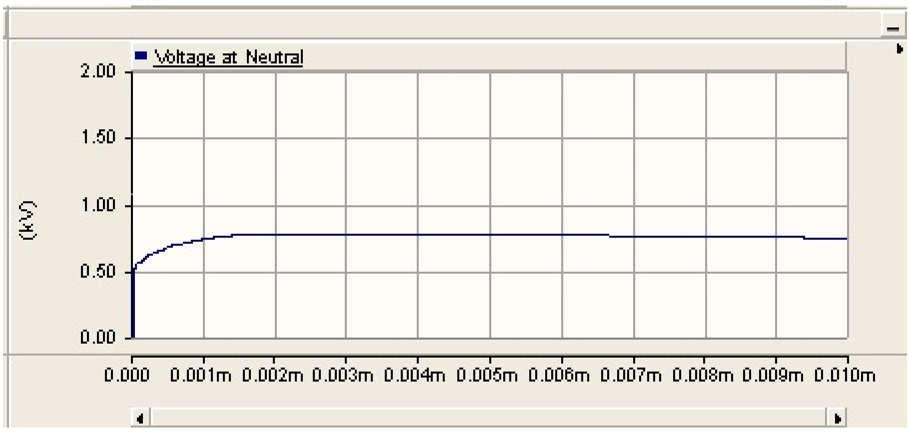

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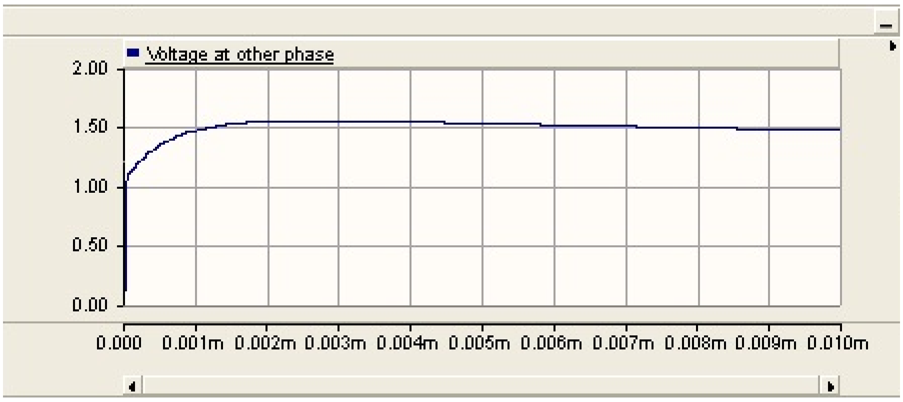

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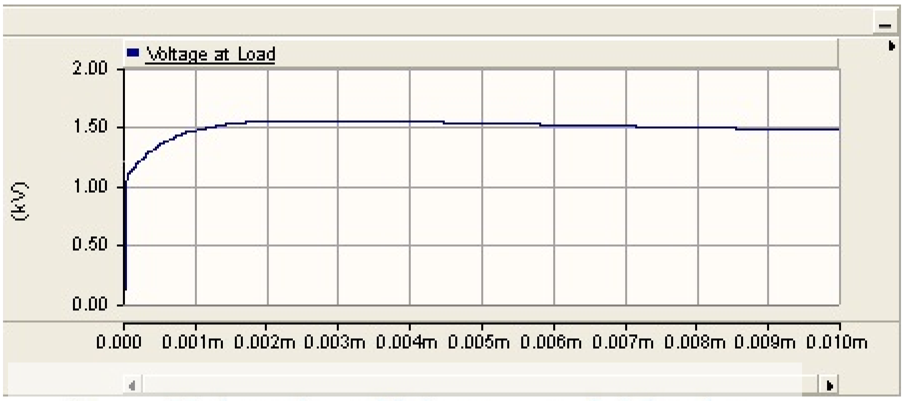


(e)

Figure 4.23 Voltage rises in (a) at same phase (b) phase to neutral (c) at neutral (d) at separate phase (e) at load - for secondary surge arrester installation at Phase to Neutral and Neutral to ground

(Source: Author)

Combine Effect of Phase to Ground and Neutral to Ground secondary surge arresters

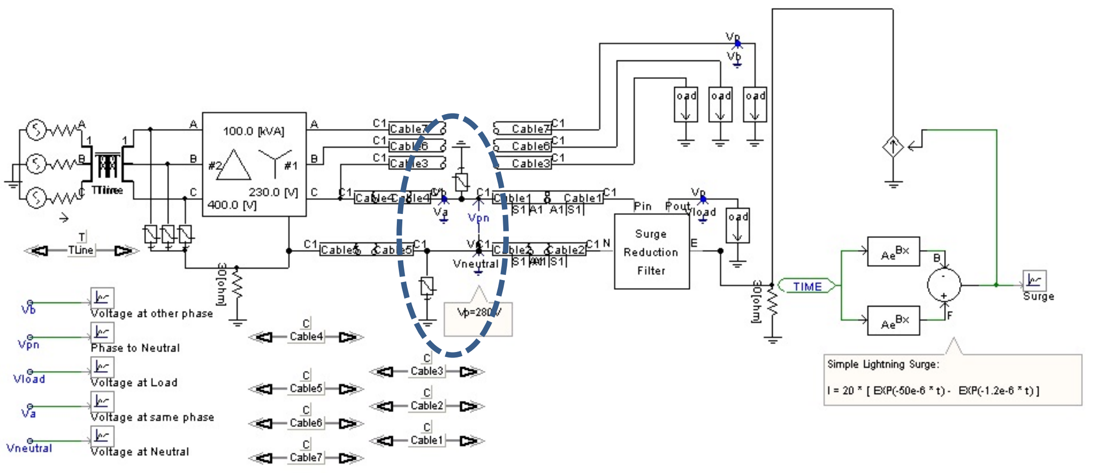
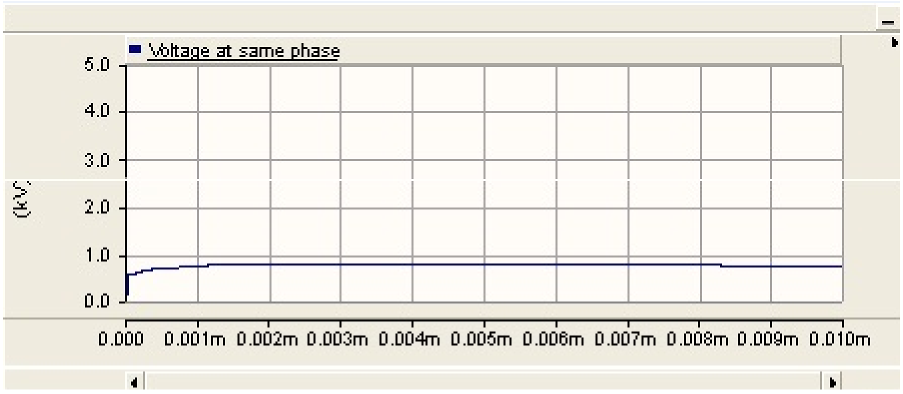
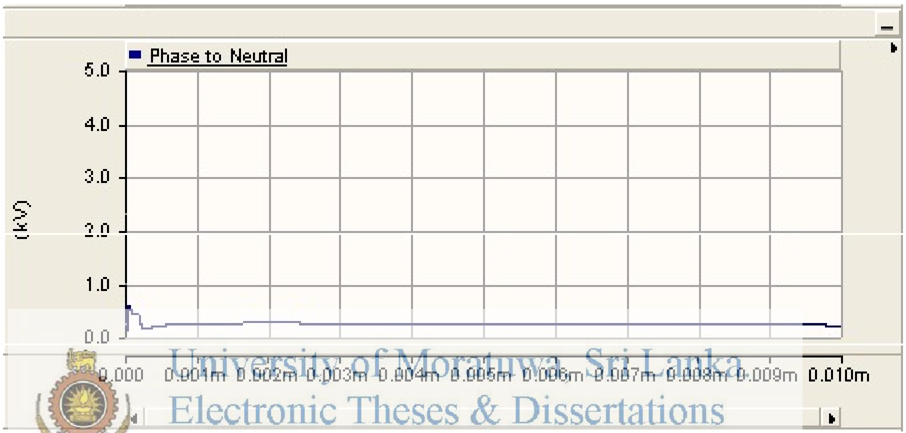


Figure 4.24 Phase to Ground and Neutral to Ground secondary surge arrester

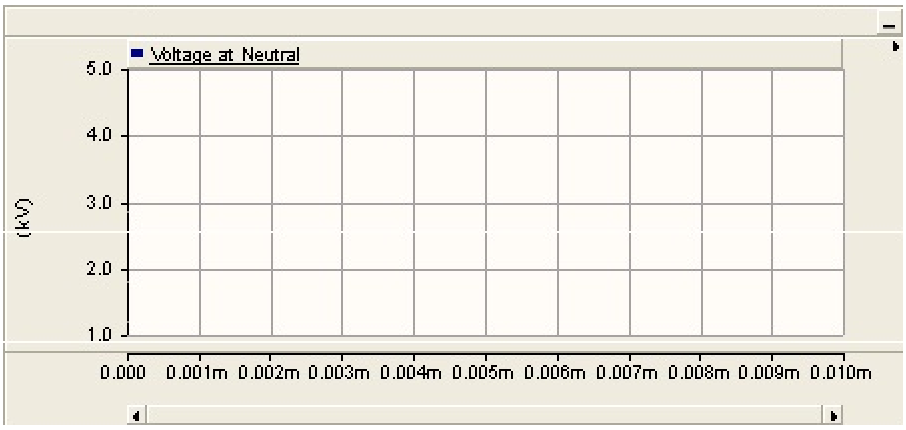
(Source: Author)


Voltage at same phase
(kV)
5.0
4.0
3.0
2.0
1.0
0.0
0.000 0.001m 0.002m 0.003m 0.004m 0.005m 0.006m 0.007m 0.008m 0.009m 0.010m

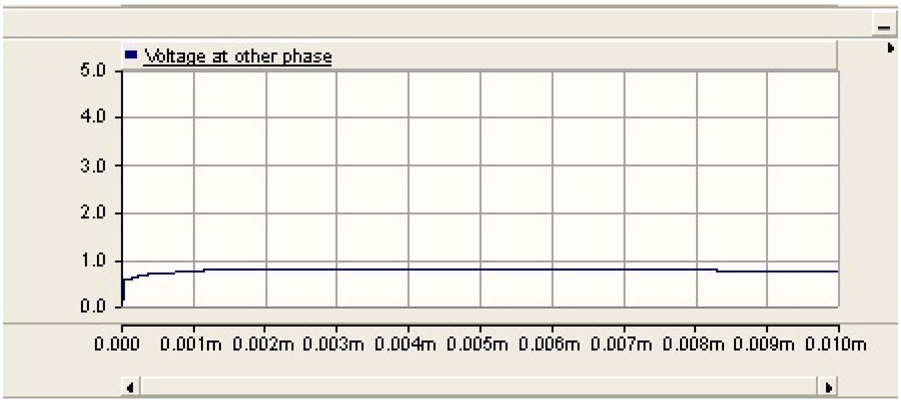
(a)


Phase to Neutral
(kV)
5.0
4.0
3.0
2.0
1.0
0.0
0.000 0.001m 0.002m 0.003m 0.004m 0.005m 0.006m 0.007m 0.008m 0.009m 0.010m

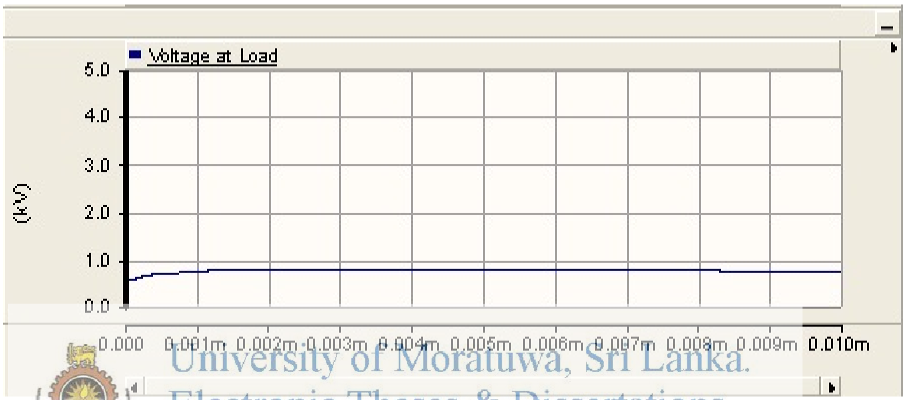
(b)


Voltage at Neutral
(kV)
5.0
4.0
3.0
2.0
1.0
0.000 0.001m 0.002m 0.003m 0.004m 0.005m 0.006m 0.007m 0.008m 0.009m 0.010m

(c)



(d)



(e)

Figure 4.25 Voltage rises in (a) at same phase (b) phase to neutral (c) at neutral (d) at separate phase (e) at load - for secondary surge arrester installation at Phase to Ground and Neutral to ground

(Source: Author)

This configuration is very effective compared with both other configuration proposed under Figure 4.20 and 4.22. This arrester configuration is also effectively drop the voltage rises. We can see the voltage around phases get dropped to around 0.75 kV as shown in Figure (a), (d) and (e). There is no any voltage rise at neutral as shown in Figure (c). But we can see phase to neutral voltage rise drop to around 0.25kV as shown in Figure (b).

If a lightning stroke hits a power line or voltage rise on power line, the only way to protect it is using a lightning arrester. The lightning arrester is a non-linear device that acts as an open circuit to low potentials, but conducts electrical current at very high potentials. When lightning strikes a line protected with a Lightning arrester, the non-linear resistance draws the current to ground. One of the most common lightning arresters is the MOV (metal oxide varistor) lightning arrester, [16]. The MOV has a piece of metal oxide that is joined to the power and grounding line by a pair of semiconductors. The semiconductors have a variable resistance dependent on voltage. When the voltage level in the power line is at the rated voltage for the arrester, the electrons in the semiconductors flow in a way that creates a very high resistance. If the voltage level in the power line exceeds the arrester rated voltage, the electrons behave differently and create a low resistance path that conducts the injected lightning current to the ground system.

But as we can see throughout the simulation results, we have to use them in effective configuration so that only we can reduce the power line damages effectively. Therefore Combine Effect of Phase to Ground and Neutral to Ground secondary surge arresters is suit for the installation near meter cubical (i.e. power input to the RBS) so that we can effectively reduce voltage rise and reduce the damages to both RBS electrical equipment and neighborhood electrical equipment.

This system has been implemented in few sites and we have no any complaints since the implementation date and it is obvious that the implementations have very effective and fruitful as we have almost passed more than two year with more than four lightning seasons. The onsite implementations are shown in Figure

4.4 Effect of Base Band arrester Installation for transmission equipment

Past experience shows that lot of tower mounted transmission equipment and indoor transmission equipment damages due to the lightning 3 years before.

This has happened due to the voltage different between the tower structure and the coaxial cable. Irrespective of the resistance, the inductance alone will contribute to a very high potential difference between the coaxial cable and the tower structures which are essentially at ground potential. But as per the past experience we do not have noticed and spark-over through insulation breakdown.

As a preventive action we have installed base band arrester to both end of the transmission path of all microwave antenna link in the network.

(a) (b)

Figure 4.26: Base band arrester installation (a) at ODU mounted on tower structure (b) at IDU mounted in equipment cabin

(Source: Author)

We have observed ODU and IDU failure rate after the installation during last three years and it has successes 100%. The MW links located in high iso keraunic level areas such as Rathnapura get hanged, but no equipment failure reported. This has been happed due to exceed of no of hits can be managed by the arrester.

4.5 Accuracy of measurements of Earth resistance system

In most of the telecom towers, the measured earth resistance values are in accurate due to overlapping shells of earth due to low space to place current and potential electrode outside the electrical influence of the electrode system. If we look at the detailed earth resistance test carry out for Keselhenawa (Figure 3.6) and Erathna (Figure 3.8) we can clearly see the effect of overlapping shells. We can experience this effect in every RBS due to the unavailability of space to place current and potential electrode outside the electrical influence of the electrode system, irregular shape in earth profile

It can be shown that the actual electrode resistance is measured when the potential probe is located 61.8% of the distance between the center of the electrode and the current probe [11]. But if we consider the total radio base station network it is very difficult to find non-overlapping earth shelf. Sometimes we cannot find where the berried earth electrodes are. If we look at Table 4.1, we can have different values for earth resistance for different current electrode distances. Therefore it is a question that available space for current electrode will give the accurate earth resistance or not. Therefore finalizing the earth resistance for a particular site is somewhat difficult due to the limited space between earth electrode and current electrode.

With regards to the earth resistance measurements, the available distance from earth point to the current electrode position is different in leg to leg and site to site as per the space availability for the measurements. To see the effect, the earth resistance values were measured for different distance in Madampegama sites. Table 4.1 show the earth resistance value measured for different potential and current electrode distances.

E-P distance (m) (62% of the E-C distance)	E-C Distance (m)	Earth Resistance value (Ohms)
18.6	30	8.6
15.5	25	8.9
12.4	20	6.1
9.3	15	5.4
6.2	10	2.8

Table 4.1: Earth resistance measurements for different potential and current electrode distances

(Source: Author)