CONTENTS

LIST OF SYMBOLS and ABBREVIATIONS

SWT:	Strech Wire Technique
V:	Voltage
I(0):	Lightning stroke current
Z:	Line surge impedance
L:	Length (m)
W:	En (m)
H:	Height (m)
Nd:	Lightning Intensity
Nk:	Number of lightning days from the map
Nc:	Number of lightning pulses approved for building
S:	Critical Gap
D:	Protection level parameter
ΔT:	The period of lightening of lightning rods
H:	Height of active lightning rod (m)
Rp:	Protection radius (m)

1. INTRODUCTION

Lightning can simply be the electrical discharge between the earth and an electrically charged cloud. In other words, this discharge may not be just between the cloud and the ground. If all conditions are met, it can occur between two clouds. This electrical discharge is in a high voltage class. The most important event that allows lightning to come to the square is; load disconnection. The load is separated from the cloud and is called the orage cloud, and in this cloud there is an electric field of about 500 V/m. In order for this situation to come to the foreground, the parts we call cloud and place must be in different electrical loads, which means a certain potential difference. For the most part, the clouds have a negative electric charge and the ground is positively charged. Under certain conditions, the clouds may be negatively charged while the other clouds are positively charged. [1] The potential difference that reaches a certain level is that although it is not an air conductor, it creates a conductive channel in the air, and electrical discharge, which we call lightning, begins.

This phenomenon is known as lightning strike among the public, but sometimes it leads towards the cloud, sometimes from the ground to the cloud, depending on the positions of the negative and positive electric charges between the cloud and the ground. It is usually true when it is occur from cloud to ground.

The mentioned lightning event occurs in 4 steps;

Step 1: Negatively charged electrons begin to downward.

Step 2: The positively charged particles are also collected on the floor under the cloud base.

Step 3: When the cloud is close to the ground, minus loads initially lead to an invisible path, and then the electric current starts to flow to the cloud.

Step 4: Positive loads flow into the cloud at a rate of more than 100,000 km/s at the moment.

2. MECHANISM OF LIGHTNING

The energy released in lightning is 1010 joules. This energy can pass in a time of one billionth of a second and increase the temperature of the air column up to 15000 ° C. The resulting lightning current ranges from 2 to 200 kilo Amperes (kA) and the voltage varies from 100 to 1000 Mega Volts (MV), which is the electrical discharge event that occurs and completes in microseconds (μs), which is the power gigawatt (GW) Especially in the 2-3 km gap between the cloud and the ground. Here is the result of this energy that has become the burning and destructive effect of lightning.

3. MATHEMATICAL MODEL OF LIGHTNING

$$\mathbf{V = I * Z} \qquad = \mathbf{I(0)} * \left(\frac{\mathbf{Z*Z(0)}}{\mathbf{Z+Z(0)}}\right) \qquad = \mathbf{I(0)} * \left(\frac{\mathbf{Z}}{\mathbf{1+Z(0)}}\right)$$

The source capacitance of the lightning is not known but it is approximately 1000 to 3000 Ω. Therefore, the $^{Z}/_{Z(0)}$ value is usually less than 0.1 so it can be neglected. So , we can say that, the voltage rise of is approximately **V=I(0)*Z** where ;

Global Capacitor: The average radius of the world, r1 = 6368 km; Thickness of the lightning layer, a=50 km (r_2=6418 km)ε_0=8,854 pF/m=8,854 nF/km εr(air)=1C=4.π.ε_0.εr.r1.r2/(r2-r1) ≈90-100 mF or Planar(cloud-ground) Capacitor: Gap between electrodes=approximately 1-2 km

Average electric field on Earth:
In good weather: 100 V/m = 0.1 kV/m = 0.001 kV/cm
In stormy weather:15-20 kV/m
Field under the cloud:1000 - 10000 V/m = 1 kV/m - 10 kV/m

Cumulus-nimbus
Diameter: about 10 km
Height: about 14-15 km

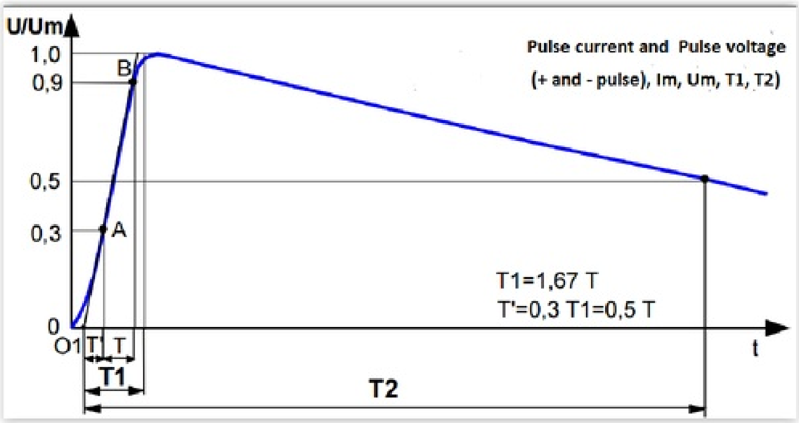
Lightning is a strong electrical discharge phenomenon that occurs in high current (2-400 kA), high voltage (100-1000 MV), largest opening (1-3 km).

Lightning types:
1. Cloud
2. Cloud to cloud
3. From cloud to cloud (above cloud)
4. Cloud to ground

Cloud-to-ground lightning,
(Up or down) and the polarity of the developing charge (positive or negative).
4.1. Negative descent (90%)
4.2. Negative ascent
4.3. Positive descent
4.4. Positive ascent

Properties:
Pre-discharge initial electric field intensity = 10 kV/cm
Pre-discharge step lengths = 10 - 80 m (average 50 m)
Speed of pre-discharge = 50 - 50 000 km/h
Pause between steps = 30 - 100 microseconds

Lightning properties:
Lightning charge = 0,05 - 50 Coulomb
Current = 3 kA - 400 kA (20-60 kA) (800-500 000 A)
The maximum current of negative lightning is up to 25 kA.



Voltage, U = 100-1000 MV (megaVolt)
Current, I = 3 - 400 kA (kiloAmper)

4. LIGHTNING EFFECTS

4.1. Light Effects

4.2. Electrodynamic Effect

The forces acting between the magnetic field generated by the lightning current passing through a beam and the magnetic field of the supply are very small values. Larger forces than those mentioned occur when the lightning current path is in the magnetic field.
As a result of these electrodynamic effects, mutual collision in the antenna and parallel conductors, disconnection of the conductive lines can be observed.

4.3. Pressure and Sound Effect

The thunder is due to the sudden pressure (2-3 atmospheres) increase in the discharge channel due to electrodynamic forces. The propagation of the resulting components is in each direction for low frequencies, such that the channel is perpendicular for high frequencies. As a result, there is a noise that varies according to the distance of the observer and the direction of the channels.

4.4. Electrochemical Effect

These effects can be explained by Faraday's law. Electrolytic breakdowns result in metals such as iron, zinc, lead being released. However, for this event, it is necessary to produce lightning with very high current intensity.

4.5. Thermal Effect

The energy that emerges as heat energy in the lightning event is explained by the Joule Law. Hence, large temperature values can occur at points where electrical resistance is large. Even if there is no effect on conductors with large cross-sections, effects such as superficial melts, color change, coating burnout are observed in small cross-sectional (mm) conductors.

4.6. Electromagnetic Effect

Induction effects are generally the most demanding effects for protection systems. When lightning is close and passes between conductors, it creates high and sometimes destructive induced voltage. Besides, it can create electromagnetic cycles between electrical circuits. For this reason the protection systems are very carefully designed and contain the necessary additional protection measures.

4.7. Indirect Effects

Depending on the structure of the land, the current distribution in the ground may be different. A heterogeneous soil can create dangerous potential differences between two adjacent points.

Lightning causes more than twenty firefighters on average every year in the world, while at the same time it causes a material damage exceeding two billion dollars. There are strong influences such as heat, light, sound, thermodynamics, electrodynamics, electrochemical, electromagnetic field.

5. GENERAL LIGHTNING PROTECTION

Lightning can cause huge disasters when not under control. The basic condition for protection against lightning is the shortest path to lightning discharge flow. However, since the characteristic band of lightning currents is very wide, it is not possible to achieve full protection under all conditions. Nowadays, with the standards applied, the risk is minimized and at least the loss is tried to be overcome.

5.1. Protecting the living from lightning

Passing the lightning current from the body of the living influences the heart with the effect of shock and causes death by stopping the heart. Therefore,

- In case of thunderstorms, you must go inside a safe building. From open spaces should be avoided.
- It should be remembered that the lightest object tilted to the highest objects on the ground should be kept away from high trees, towers or electric poles alone.
- Keep away from metal conductors (such as power lines or metal fences).
- Cars and other vehicles made of closed metal are a shelter for lightning. The metal-framed surroundings form a Faraday cage against lightning. As currents flow through the outer surface of the cage, a protective shield is formed inside.
- Your open, untreated, bare flat oval feet should be squatted closed, your head should be leaning towards yourself and your height should be reduced to the minimum.
- Never dwell at any time. Because if you are in a zone where the lightning has a potential difference, the electric current will flow from your body due to the potential difference between the two extremes of your body.[3]

In addition to the meteorological events, the condition of the surface of the ground is also very important in the lightning storm. Among the most importance factors that occurring lightning are trees and high-metal goods.

5.2.Protecting buildings from lightning

The likelihood of lightning current penetration into the building is significantly reduced by the presence of a properly designed lightning protection system. High voltage installations must be constructed for protection from negative effects of lightning. The resistance and inductance of all overvoltage protection of the earth discharge path must be small as much as possible. Lightning protection systems should consist not of a single system but of bringing together four systems basically. These can be listed as follows:

1-Earthing system with well-designed equipotential system
2-Exterior lightning protection
3-Interior lightning protection

These systems are basically a whole piece that needs to be used. If a structural internal lightning system is not installed, all energy and data lines as well as electronic devices are considered to be at risk. On the other hand, if there is no earthing system in a structure, the internal lightning system can not be integrated. Also, a facility that lacks co-ordination potential may suffer damage due to coupling effects of the external lightning system. These ordered parts can be further increased compared to the desired lightning protection system.

Sudden overvoltages are voltages that occur between a few microseconds and a few milliseconds. Such stresses can be examined in two groups in terms of their formation.

1-Instantaneous Overvoltages due to lightning

During the lightning discharge a current flows between 2,000 and 200,000 amperes. These values create a voltage with direct lightning discharge or magnetic field effect on energy transmission lines and communication lines located on an area of approximately 2 km. If these stresses are above the limits of the installation or device resistance, deterioration, burning, explosions will occur in isolation.

2-Instantaneous overvoltage with electrical switching

The current passing through a conductor forms a magnetic field and the magnetic field suddenly decreases when the current is cut off. The energy that accumulates on the conductor is distributed into the system as voltage through induction. Such tensions are very common.

In a building, there is no need to have an external lightning system in the building in order to generate lightning surges. After reaching the ground, the lightning discharge spreads in the form of circles within an area of 2 km and moves towards the point where the resistance is low. For this reason, it is an obstacle for the interior lightning design.

5.2.1. Grounding System and Equipotential Design

Grounding of inactive (non-stressed) metal parts of electrical power tools (generators, transformers, motors, cutters, disconnectors, poles, lighting elements, refrigerators, etc.) to earth via a conductor is called grounding. The connection to the earth is made with earth electrodes in various shapes. The main aim of the ground is to completely remove the dangerous tensions in the face of the negativity that might come to the scene. There are two points to note when performing grounding:

- Ensure that the resistance between the grounded part and the reference ground (far from the electromotive of the grounded object, at least 20 m) is as small as possible;
- To ensure that there is no potential difference during operation in structure.

The most reliable system that can be preferred when grounding is the equipotential system. All groundings, metal sections are interconnected by equipotential bars. Thus, the voltage differences that may occur are avoided and will be compensated. Even in the event of an outbreak or an error, there is no danger in that there will be equal potential at all points or no potential difference between any two points. In such systems, the static electricity is not generated and the risk of fire is removed.

Grounding System Application Method

In terms of providing a mechanically adequate safety, the superficial earths shall not exceed 0,5 mt. with 1 mt. At a certain depth. Thus, safety is ensured in the time remaining below the freezing point. High voltage grounding equipment should be used to protect structures from lightning. The resistance and inductance of all overvoltage protection devices must be kept as small as possible. For this reason the connection to the grounding electrode should be as flat as possible, without cornering and on the shortest path. For the protection against lightning effects of constructions, the points specified in the related standards (TS 622, TS IEC 61024 and TS IEC 60364-4-443 etc.) and other related legislations (Ministry of Public Works and Settlement Technical Specification Lightning Installation section etc.) shall also be observed. The relevant standards for additional grounding measures to be taken (eg EN 60079-14, etc.) shall be complied with in the regulations and circulars.

Grounding Rules for Communication Facilities around Lightning Protection Facilities

Neighboring Grounding: If there are other earthing devices at a distance of less than 2 m from the earthing protection earthing protection, all earthing devices must be connected to each other. It is recommended that all earthing devices be connected to each other if the earthing devices are between 2 and 20 m. If the earthing device is more than 500 Wmt, It is advisable to connect earthing devices with a distance between them of more than 20 m.

Protecting buildings against lightning: It is recommended that grounding facilities of the communication system be connected with protection against building lightning. For this purpose, the same conductors and elements should be used as they are in the protection against lightning. For this purpose, grounding ring conductors are used many times, or earthing terminals are connected only once.

Vertical metal parts must be wrapped in a sufficient number of construction beams (St 37) to prevent jumps in high buildings (eg steel-concrete telecommunication towers) in which communication facilities are operated and may be exposed to lightning hazards. During the upward movement of the lashing connection conductor, (FPE) should be connected to each floor, but at least 10 mt intervals, and also to the top and bottom of the building, eg vertical metal parts wrapped around the building, such as the iron skeleton.

In this case, there should be easily accessible ports of these parts. If the anti-glare protection facility is kept separate from the operation ground of a main down-center, the grounding facility for the communication system connected to this operation ground can only be connected by means of a lightning protection system via the adder.

In lightning events in Turkey, it is assumed that the generated current is at most 20kA. It is assumed that the lightning current is directed to two heads in the form of a "walking wave" and a current of 10kA can be observed in this case. These waves are weakened for various reasons until they reach the surgeons.

Considering that the distribution transformers are tested with a 20 kV pulse voltage on the low voltage side, the voltage generated in the protection system grounding resistor should not exceed the maximum pulse voltage on the low voltage side when the discharge occurs in the parasites. According to this statement, R = 20kV / 10kA = 2W.

5.2.2. Exterior Lightning Protection

The likelihood of lightning current penetration into the building is significantly reduced by the presence of a properly designed lightning protection system.

Effective Equivalent Area $(Ae) = L.W + 6.H.\ (L + W) + 9.\ \pi.H^2$

Expected number of lightning strikes for the building

$Nd = Ng.Ae.C1.10^6$ (lightning intensity)

$Ng = 0{,}04.Nk^{1,\ 25}$

Nk = Number of lightning days from the map

Number of lightning pulses approved for building

$Nc = 5.5.10^{-3} / C$

$C = C2.C3.C4.C5$

These all expected values basically depends on Figure 5.1

Figure 5.1: Thunderstorm Days Per Year in Turkey

There are basic systems for the protection of lightning and buildings which cause explosion, fires or buildings to be damaged. These;

1) Passive Chatcher

a) Franklin Bar (Lightning Rod)

The passive catches without point lightning, pointed sticks are the oldest among lightning protection methods. The first work on this subject was made by Franklin in the 1760s. Franklin installed the first lightning protection system by putting a pointed iron over the structure to be protected and taking the conductors to the ground so creates the easiest pathway for electricity to flow through. In the said period, the bar used was considered to be a circle that accepted the radius of the bar. Nowadays, the protection diameter is accepted as the rod size. This protection using the Franklin rod was further developed by Melsens in the 1884s, creating a Faraday cage that is now widely used.

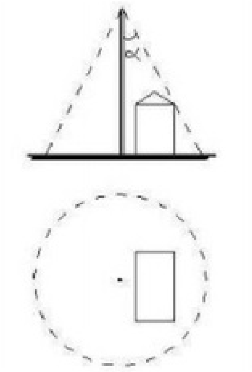


Figure 5.2 : Protection area of Franklin Bar

Application areas are; small structures, mosque, navy lighthouse, special protection in Faradays Cage etc.

b) Faraday Cage

Upon studying that Faraday had done, Melsens suggested in 1884 that the electric field within a conductive cage was zero, suggesting that the shield be enclosed in a conductive cage. This lattice system will be produced by Melen's is as follows:

- The structure to be protected is enclosed in a copper cage, with the roof and side walls being wrapped horizontally and vertically with conductors (copper). Vertical pointed bars are placed at certain intervals on the roof, while the ground is very grounded at the conductors.
- In this way, every point of the building is made equal potential, and in any lightning discharge, dangerous currents flow completely over the grounded copper cage to the building and there is no damage to the building.

From this point of view, the difficulties in implementing the Faraday Cage system, which is considered to be a good protection indeed, and the consequences of conscious or unconscious misapplication are lost. The safety of the Faraday cage depends on the size of the eyes of the cage. The smaller these eyes, the more secure the cage is created.

This is the structure that protects the inner part from the outside electric fields thanks to protection system that is the network with the conductors. Quality of earthing and frequency of conductors increase the protection. If the frequency of conductors is very much, rate of the impermeability to against the electromagnetic wave increase proportional to frequency of conductors [1].

There is no definite application proposal in the cage method, but the recommended order is;

1. Risk account and protection level designation,
2. Capture system, ie cross-section and cross-section in cage conductors, selection of cloches according to roof properties,
3. Repeat the same procedure for the landing conductors, account for the separation distance
4. Selection of the earthing installation,
5. Inner protection and equipotential solutions.

Figure 5.3: Structure of Faraday Cage for Buildings

Usage area of Faraday Cage are; buildings with explosive, flammable, inflammable substances, radio frequency emitting devices, buildings which includes communication with radio, radio frequency modules in electronic card.

c) Stretched Line Technique

Lightning protection method with lightning strikes is done by tensioning between the pillars stood by two or more of the building. The poles should have electrical continuity between the tensioning and the grounding of the poles and should have a minimum 50 mm^2 capacity to carry the stranded lightning current. It is not preferred because it is difficult to apply in high buildings and visually creates an ugly image on the building.

The "s" critical clearance (s = ki (kc / km)) between the object to be protected by the tensioning of the stranded conductors must be carefully considered.

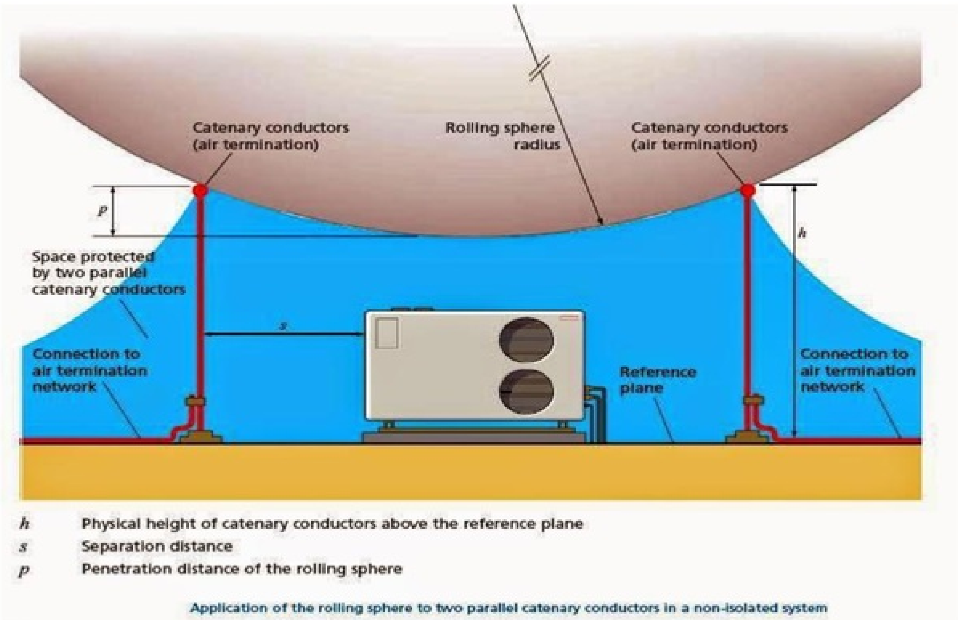


Figure 5.4: Strech Line Technique above air conditioning system

SWTs are useful for air conditioning, small size flammable, explosive and flammable material storage and tanks.

2) Active Catcher

Another method of protection is the working method of active lightning protector: the presence of the metal bar deforms the equipotential plane and takes the zero plane upwards, on top of which the ions at the end of the lightning rod increase the stress intensity at this point. It is assumed that the ions that come out of here continuously neutralize the electric charge in the clouds. Lightning is considered to fall on a lightning rod when falling into a neighboring region at a certain distance. Active lightning protection, from the point where the assembly, protect areas and buildings covered by the specific protection level. [2]

Unlike passive catches, lightning rods are capable of pulling lightning by providing an ionized path or ion to the cloud. The lightning arresters, which differ among themselves in terms of their working principle, are grouped under three headings in this section.

The protection radius of the active lightning rod headers are calculated from the following formulas according to the protection levels.

$\mathbf{Rp^2 = h(2D\text{-}h) + \Delta L\ (2D + \Delta\ L)\ h\ \Delta\ 5\ mt}$

Used in this form;

D: Lightning advancement step or lightning is the jump range along the way. This is the protection level parameter.

- D = 20 m for level I protection
- D = 30 m for level II protection
- D = 45 m for level III protection
- D = 60 m for level IV protection

$\mathbf{\Delta L\ (m) = V\ (m/\mu s).\Delta T\ (m/\mu s);}$

V: The rate of propagation of the ions around the catching bar during lightning is V=1m/µs in the standard.

ΔT: The period of lightening of lightning rods.

ΔL: ΔT is the distance of catching lightning (ie, the distance the ions penetrate into the lightning).

This parameter is determined in laboratory tests according to the production method and characteristics of the products and the varieties according to the generated power.

H: Height of active lightning rod (m)

Rp: Protection radius (m)

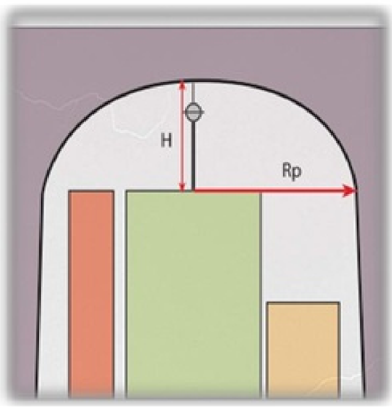


Figure 5.5: Protection volume cross section

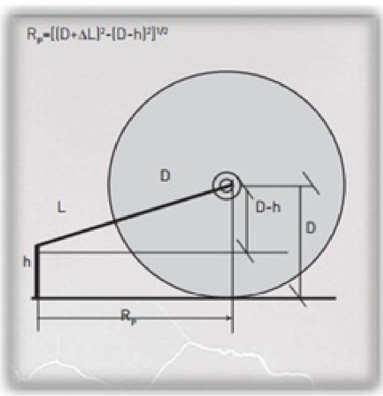


Figure 5.6: Protection radius

5.2.3. Internal Lightning Protection

The lightning pulses generated from distant or cloudy discharges from the cloud have various effects on the medium voltage lines that are elevated above the ground. They are classified according to the switching events they cause. These;

- Inductive load termination (transformers, bobbins, motors)
- Firing and cutting of electric arcs (Arc welding machines)
- Problems in insurance

A "Lightning Protection Concealment Concept" in accordance with IEC 62305-4 is applied to protect a complex electric and telecommunications installation from collisions, both external and direct, as well as from different situations.

Also, if the distance between the main board and the main board is less than 5 meters, the main panel type II (B + C class) protection unit should be used and if the distance is longer than 5 meters, the main panel Type I (Class B) sudden overvoltage pulse suppressors and board type II (Class C) sudden surge suppressors must be installed separately.

1. Class B Surge Protectors

Internal Lightning (Overload Surge Protectors) systems also provide protection for electrical equipment in the building. Class B impact protection will send the first overvoltage to the ground in a safe system. Such products are installed in the building or main building of the installation to protect the building electrical installation and equipment from excessive stress.

2.Class C Surge Protectors

With this type of protection systems, the protection of the main panel as well as the side panels will be ensured, and the strength of the protection and the strength of the products will be increased. Protection systems protect against sudden voltage surges, not against continuous surge voltages.

6. APPLICATION

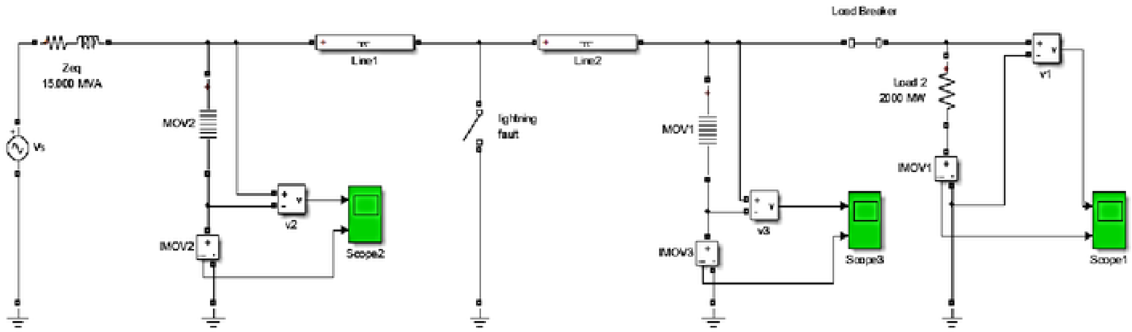


Figure 6.1: Use of Surge(Lightning) Arresters in Transmission System

That transmission line is compensated with series at the middle of electrical installation and also at the end of the system the line is compensated with parallel. The arrester which is in the middle of the line makes switch line to ground. It does not work between 0.1s to 0.4s . And then the arrester brakes the current to the load. If the fault switch closed, the whole fault current and transients flow to ground thanks to arresters.

Firstly, if the fault switch is closed, the capacitor voltage increases and arrester which is in the middle conducts.

Secondly, if the fault switch is opened, there will be occur over voltage at bus. It is controlled by the shunt arrester which is at the end of the lines.

The before line arrester protect the side of generator, after line arrester protect the side of load.

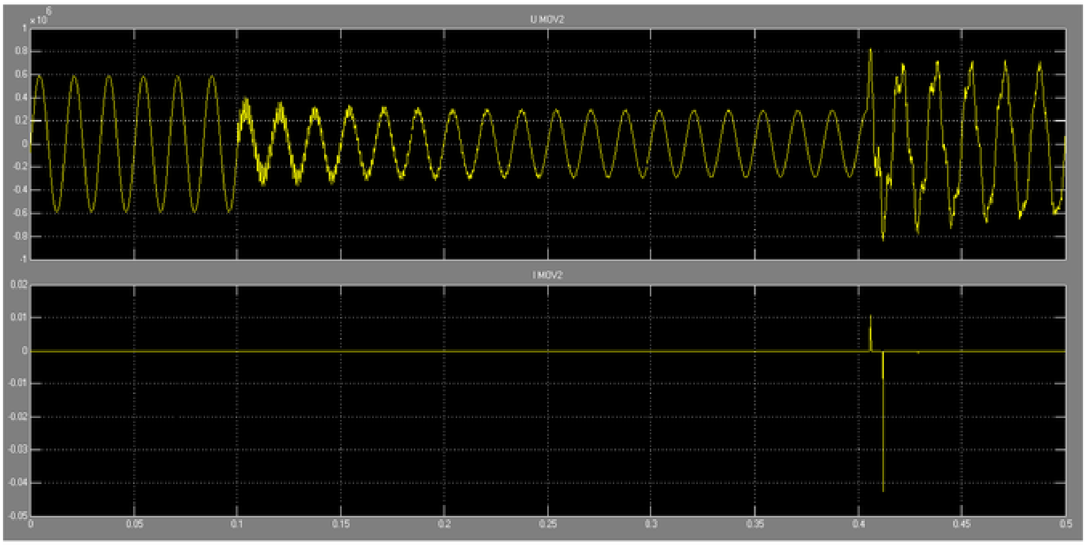


Figure 6.2: Voltage and current chart of the arrester protecting the generator side (upper side voltage graph lower side current graph)

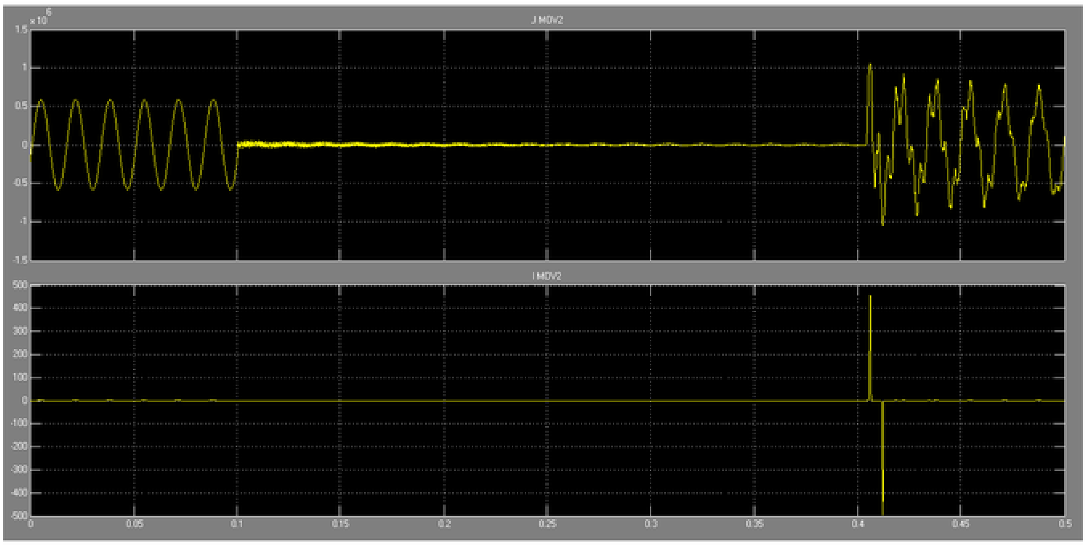


Figure 6.3: Voltage and current chart of the arrester protecting the load side (upper side voltage graph lower side current graph)

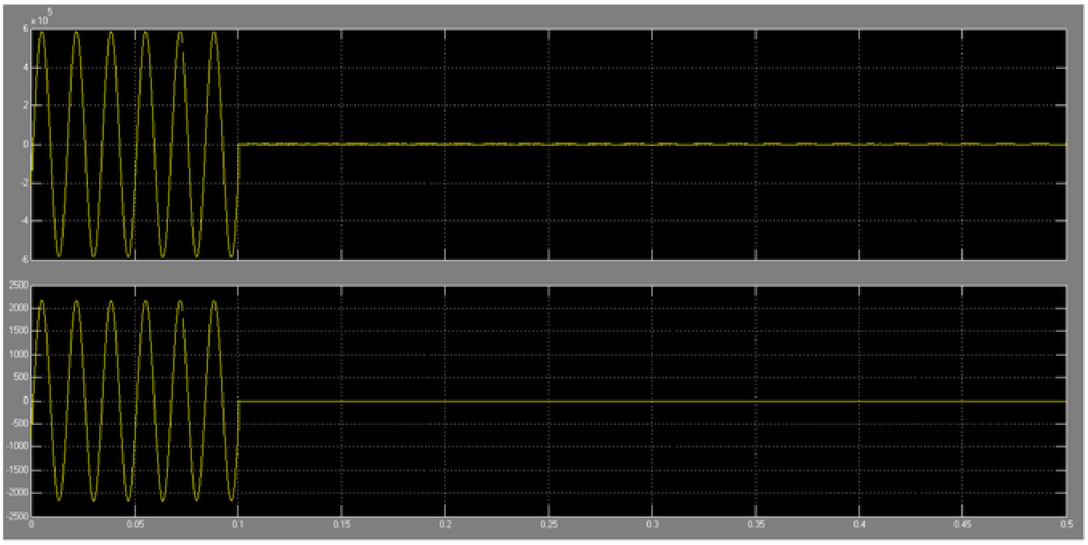


Figure 6.4: Voltage and current chart of the the load (upper side voltage graph lower side current graph)

Note: Application was done with simulink.

7. CONCLUSION

In this study, lightning protection methods are discussed and how living things and buildings can be protected from lightning. If lightning measures are taken, which is a natural phenomenon that can not be avoided, it can be overcome with minimum damage. In lightning protection methods, the most appropriate method should be determined according to the situation of the protected area. Thus, the individual measures taken and the best protection of the buildings can reduce the risk. Lightning and surge voltages, high voltage air lines, underground cables, distribution transformers, insulators, cable glands, and even low voltage receivers. If the construction and operation of the facilities are carried out taking into account the existence of this danger that will cause short or long term interruptions in the electricity facilities, both our national economy will be less damaged and a quality electric energy will be offered to the uninterrupted[4].

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ORIJINALLIK RAPORU

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