A. Introduction

Thunderclouds accumulate a huge amount of charge and discharge between the cloud and the ground. If electrical facilities are on the moving route of electric charge and cannot endure a gigantic electric charge impact, this will result in the hardware being damaged. This condition is what people know as electrical facilities suffering lightning strikes. But from looking at the development and dissipation of thunderclouds and analyzing the phenomena of gigantic electric charge invading electrical facilities, we have found that there is a significant difference between what happens in reality and what people call 'electrical facilities being strike by lightning'. Because of this difference between people's concept and the reality, the nominal surge current of arrester is increased from 10kA to 100kA. Whether this increase can protect electrical facilities effectively is something you should reconsider after reading this paper.

B. Development and dissipation of thundercloud

According to the description of electricity textbooks, "Thundercloud accumulates a huge amount of electric charges causing air insulation to breakdown and a discharge of lightning flash between cloud and ground appears instantly." Lightning flash will interfere with functions of electrical facilities, so the key point is to study lightning flash and electric charge of the ground.

The thundercloud discharge phenomena can be categorized into intra cloud, inter cloud (both called IC), and cloud to ground discharges.

Lightning's do not always occur when it rains. Thundercloud discharge produces lightning flashes, which only happens under these conditions:

(1) The altitude of thundercloud.

The altitude of thunderclouds between 5,000 and 10,000 meters, and the temperature of inside cloud between -64 to -80 Celsius, so that water molecules freeze into hard ice crystals. The friction between ice crystals cause huge amount of charges in clouds to accumulate and discharge.

(2) The thickness of thunderclouds.

The thickness of thunderclouds must be above 5,000 meters. At this thickness, the clouds will appear very dark in colour when observed from the ground. Ice crystals located here rub against each other even more and produce more friction, hence a stronger discharge.

When the thunderclouds are at the right altitude and thickness, the development and dissipation of thunderclouds can be put into the following steps:

1. Convection formation -

Convection currents cause clouds to become charged.

2. Thundercloud formation

There is discharging in the clouds, IC discharge becomes more obvious in ten minutes to several hours before cloud to ground discharge.

3. Thundercloud Development-

IC discharge intensifies with storm development, and zones with high IC discharge density pinpoint severe storm areas. IC discharge can amount to 90 - 95 % (inter-cloud and intra-cloud) of total lightning activity, which will interfere with electrical facilities.

4. Thundercloud maturation-

IC discharge peaks when the storm cell reaches the climax. IC dischrage peak rate is proportional to storm severity. Total lightning activity correlates with precipitation amount, and the beginning of significant CG activity.

5. Thundercloud decay

CG activity culminates, and fast decay of IC precedes and warns of severe downbursts and hazards at ground level. And end of IC indicates storm dissipation.

Cloud discharge is one of the processes of thundercloud development and dissipation, regardless of whether it is IC or CG discharging, as long as there are electrical facilities that cannot withstand gigantic electrical charge on the route of the electric charge, there will be interference or malfunctioning in these facilities.

C. Impact of instant electric charge on electrical facilities

Electrical engineers focus on direct lightning when it comes to the concept of 'flash or lightning' due to the influence of textbooks. Direct lightning is cloud to ground discharge, but after huge amount of electric charges is being discharged instantly to ground, what type of electric charge moving routes will appear? What is the probability of electrical facilities being strike by direct lightning? Documentations on these issues are rarely available.

Figure 1 shows thunderclouds in the mature stage strongly discharging and the beginning of CG discharge activity appearing as multi-strikes. Why do inter-cloud, intra-cloud and cloud to ground discharge form lightning flashes appear as a tree branch and not in a straight line like a laser source? The reason is because electric charge moves towards an area where there is a high density of strong electric fields, and the distribution of these fields is homogeneous in air, therefore a tree-branched type flash in produced.

Figure1: Inter-cloud, intra-cloud discharge and cloud to ground discharge form a tree-branched type flash.

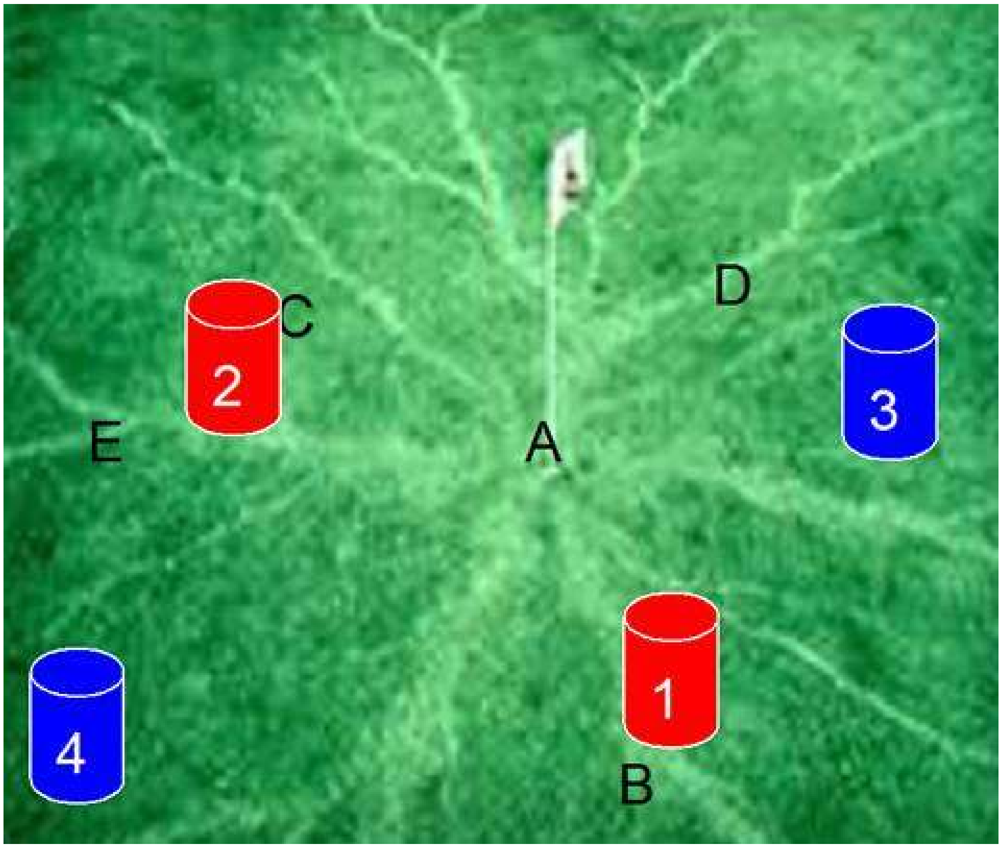
Cloud to ground discharge (multi-strikes) – causes huge amount of electric charges to be instantly released to the ground as shown in Figure 2. Due to the release contact point being asphalt road, it is difficult to trace the electric charge release routes. Figure 3 is showing electric charge release to a normal soil ground forming an electric discharge route. Because the contents of the soil ground is distributed in homogeneously and electric charge moves towards an area where there is a high density of strong electric fields, electric charge routes on soil ground is also the tree-branched type.

2-1:Direct lightning strike on asphalt road.
2-2: Burned marks are caused by multi-strikes.
2-3 ： Enlargement of photo 2-2.
2-4: Enlargement of one of the burned marks caused by multi-strikes.

Figure 2: Effect of multi-strikes and the huge amount of electric charges it carries being released to ground instantaneously.

After electric charge is injected in Point A on Figure 3, the direction it moves is marked as routes B, C, D and E. (The route electric charge moves on can cause conductive lightning surge interferences). If someone is on the electric discharge route, he will be affected by the electric charge, which is what is commonly known as being striked by lightning. This explains why a group of farmers working in fields do not all suffer from lightning strikes if lighting striked the field. Following the same principle, when there are electrical facilities on the electric discharge route that can't endure the impact of electric charge, they malfunction.

If electrical facilities are located on electric charge inject point A, it is reasonable to describe it as being strike by direct lightning. However, if they are located on routes B, C, D and E, where the electric charge is reduced a lot already, describing them as being strike by direct lightning is incorrect.

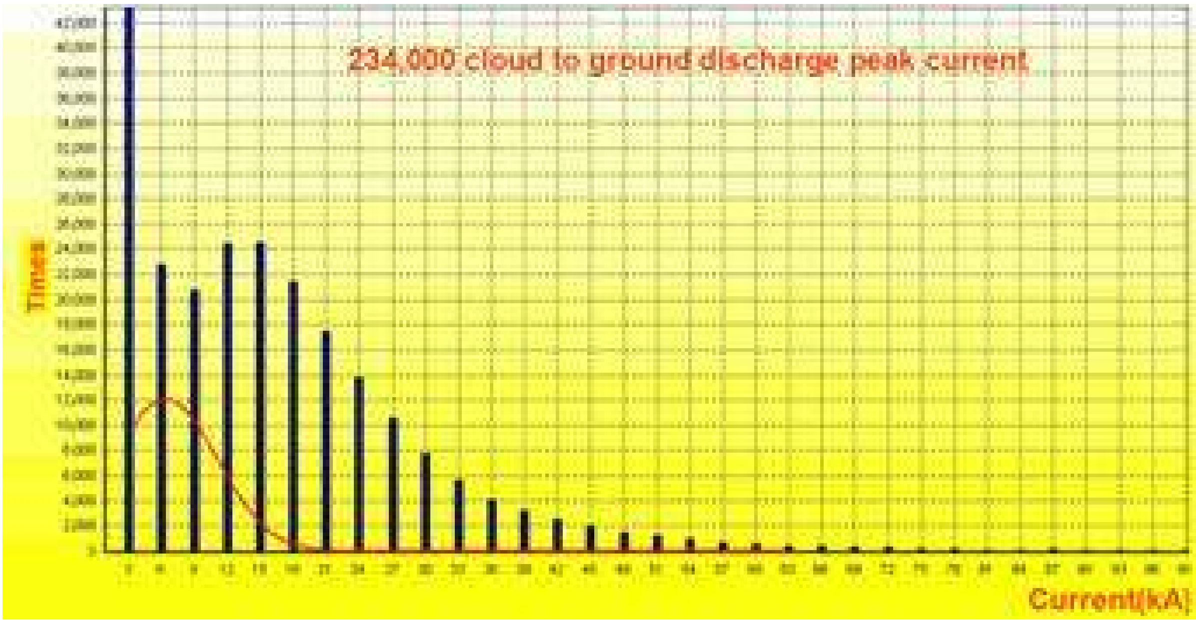


After electric charge is injected in Point A o, the direction it moves is marked as routes B, C, D and E. Electrical facilities 1 and 2 are located on the routes B and E are prone to suffer from interference, but electrical facilities 3 and 4 are not located on the discharge routes,and therefore not affected.

Figure 3: Tree-branched type route formed when lightning strikes a soil ground injecting a lot of charges instantaneously.

Detecting the magnetic signal of lightning to diagnose its occurring time, location, and quantity of electric charge is called the Total Lightning Detection System. (TLDS)

According to TLDS, in the 234,000 discharges that occurred in Taiwan, less than 5% of them were above 40kA (note that these discharges did not all occur on electrical facilities). This is shown in Figure 4. Is the current on the discharge routes still 40kA? In order to protect your electrical facilities, is it more important to protect them against direct lightning which has a low probability of occurring or to protect them against conductive lightning surge which has a higher probability of occurring?



In the 234,000 discharges that occurred in Taiwan, less than 5% of them were above 40kA.

Figure 4: More than 234,000 cloud to ground discharges.

Electric charge on ground also moves towards an area where there is a high density of strong electric fields, therefore, when electrical facilities are powered and being run, there is more electric charge accumulation than when unpowered, making electric charge more prone to being injected into electrical facilities instantaneously via the grounding conductor. The large numbers of moving routes of electric charge in Figure 3 also showed that having low grounding resistance on electrical facilities cannot change the route electric charge travels, on the contrary, this makes electric charge accumulate, thus affecting the electrical facilities.

D. Mathematical analysis

In Figure 3, electrical facility 2 on route B has a stray voltage capacity of $V=1/c\ (\int idt) =1/c \int(q/t)dt$. Taking into account the charge inject time t_1-$t_2$to electrical facility 2 on the route, the formed arcing voltage is shown as formula (1). There is a positive correlation between the severity of impact on electrical facility 2 caused by electric discharge, thundercloud accumulation time, the quantity of cloud to ground discharges and the number of multi-strikes. Using formula (1), we obtain a logarithmic formula (2), which means the arcing voltage decays logarithmically. (Shown in the gray area under curve in Figure 5)

Arcing voltage on electrical facility 2 is often called ground potential rise (GPR) by electrical engineers. Formula (2) describes GPR with an infinite voltage from the starting point to zero after a long decaying time. But in reality, the impact period of huge amounts of electric charge isμS, and so is the decay period.

$$V = \left(\frac{1}{c}\right)\int_{t1}^{t2} i\,dt$$

$$V = \left(\frac{1}{c}\right)\int_{t1}^{t2} \left(\frac{q}{t}\right)dt$$

$$V_{arc} = \sum_{n=1}^{\infty} \left(\frac{q_n}{c}\right)\int_{t1}^{t2} \left(\frac{1}{t}\right)dt \quad t>0 \quad (1)$$

q：Impact of instantaneous electric charge on electrical facility 2.

n：The number of times electric charge affects electrical facility 2.

c：The stray capacity of electrical facility 2.

t_1-t_2：The length of time it takes for electric charge to move from its injecting point on ground to route B.

$$V_{arc} = \left(\frac{Q}{c}\right)\ln t \quad (2)$$

Q：The accumulation charge on electrical facility 2

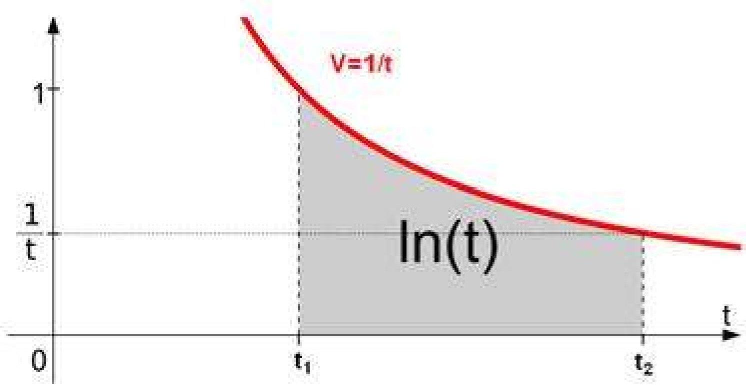


Figure 5: Arcing voltage decays logarithmically.

E. Electric charge and energy converted to voltage

The key to solving the problem of having electrical facilities being strike by lightning is in handling the large amount of instantaneous electric charges. In the past 30 years, many parallel connection arresters have been connected to electrical facilities and are said to have the ability to protect electrical facilities against 100kA (an increase from the original 10kA), but can they really handle large amounts of instantaneous electric charge that invade the facilities via the grounding conductor?

According to electrician regulations, arresters have to be installed at the primary side of service entrance, therefore, the Power Company has already install 20kA nominal surge current arresters on 11kV distribution power line, as shown in Figure 6. Therefore it is unnecessary for users to add more parallel connection arresters. In addition, adding a 40 kA to100 kA arrester in electrical facilities on top of the 20kA arresters already installed on the distribution power line is completely unnecessary.

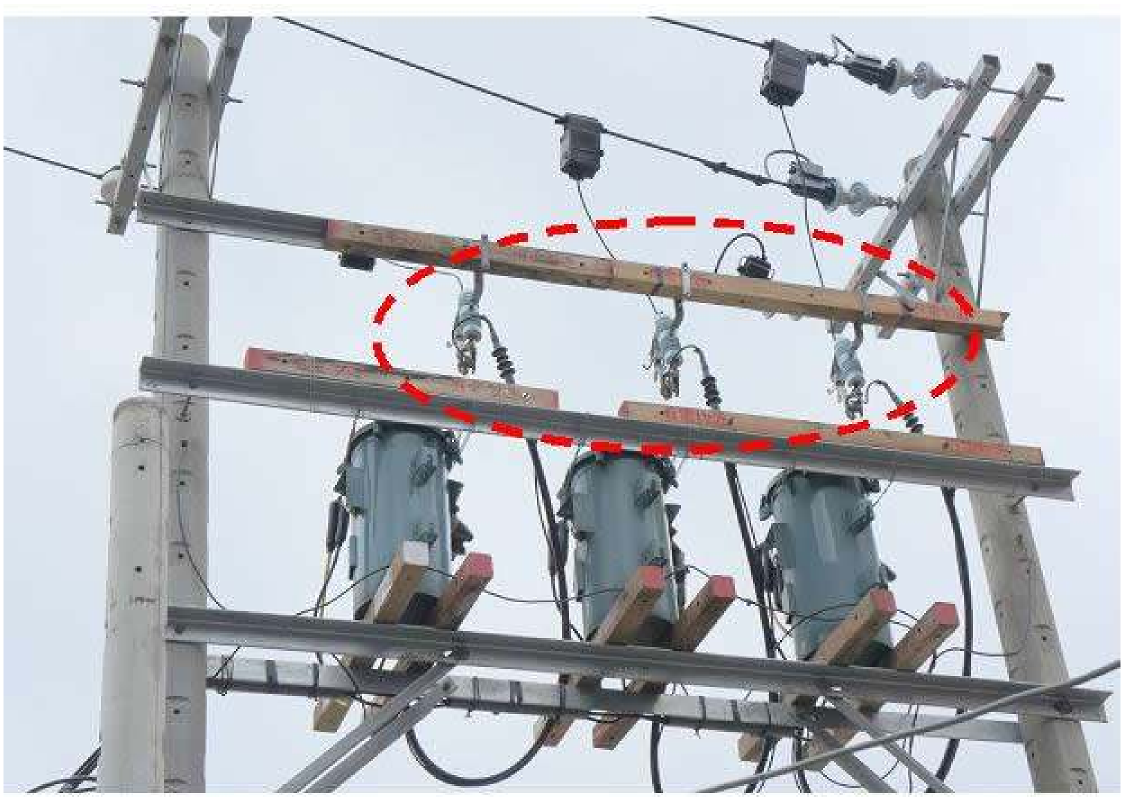


Figure 6: 20kA nominal surge current arresters on 11kV distribution power line. (Circled in red dotted line)

If readers install additional devices in electrical facilities which are able to handle huge amount of electric charge that invade instantly from grounding conductor, the problems caused by lightning strikes can be solved. If these devices are unable to handle the instant invasion problem, using our newly-patented devices, surge energy transfer (SAT) device, which are produced using the newly-patented method- "surge energy transfer circuits" is a good solution.

SET devices are able to handle huge amount of invasive electric charge instantaneously. From the Q=CV formula, the energy of electric charge from the grounding conductor, is shown in formula (3). There is no doubt in energy $E_Q$converting surge energy transfer circuits into voltage.

$$\mathbf{E_Q = 1/2\ CV_{arc}^2}$$

$$\mathbf{= 1/2\ QV_{arc}\ (3)}$$

The waveform in Figure 7 is a typical example of surge energy transfer circuits being converted into voltage. A notebook PC was installed with a SET device and put under working condition (powered), and was then coupled with a 1.2x50μs, 10kV, 8x20μs, 5kA with 500 Joule energy combination wave to L-G of power input. The waveform was measured from the L-G of power output. This surge energy is calculated to have electric charge 0.1 Coulomb.

Using 0.1C electric charge as the diving point, on the left side the harmonic current of load causes the AC waveform to be distorted, on the right side as surge energy is converted into voltage, the converted voltage overlaps with the AC power waveform within 2 cycles (circled by yellow dotted line), during which the harmonic current disappears, causing the peak voltage to increase a little. After surge energy has been converted into voltage, AC waveform becomes distorted again due to the harmonic current of load.

SET devices are able to handle huge amount of invasive electric charge instantaneously and provide effective protection to electrical facilities. Surge energy is converted into voltage which overlaps on AC waveform. The more electric charges there are, the more cycles and peak voltage will overlap on AC waveforrm. The peak value of voltage conversion can be set at a certain range.

Due to surge energy being converted into voltage, converted voltage overlaps with AC power waveform within 2 cycles (circled by yellow dotted line)

Figure 7: A waveform measuring surge energy being converted into voltage

F. Conclusion

When a large amount of electric charge is injected into soil instantaneously forming a tree-branched type route where there exists an electrical facility on top, this is conductive lightning surge interference, not direct lightning strike.

Electrical facilities with low grounding resistance may not change the discharge routes, on the contrary, this accumulates electric charge and have a more severe impact on electrical facilities.

There is a positive correlation between the severity of impact on electrical facility caused by electric discharge, the number of times this occurs, thundercloud accumulation time, the quantity of cloud to ground discharges and the number of multi-strikes.

The key to solving the problem of having electrical facilities being strikes by lightning is in handling the large amount of instantaneous electric charge. If readers install additional devices in electrical facilities which are able to handle huge amount of electric charge that invade instantly from grounding conductor, the problems caused by lightning strikes can be solved. If these devices are unable to handle the instant invasion problem, the use of our newly-patented devices, Surge Energy Transfere device, which are produced using the newly-patented method- "surge energy transfer circuits" is a good solution.

SET devices are able to handle huge amount of invasive electric charge instantaneously. Surge energy is converted into voltage which overlaps on AC. The more electric charges there are the more cycles and peak voltage increases.

Surge energy transfer (SET) devices installed in an electrical facility, as shown in Figure 8 and Figure 9.

Figure 8: Electrical facility, SMR often suffer lightning surge interference

Figure 9: 3 sets of SET with surge counter were installed in SMR of Figure 8.