ABSTRACT: Behaviour of the recovery curves of the intracloud (IC) and cloud-to-ground (CG) discharges initiated from the lower positive charge pocket in a thunderstorm is examined from the measurements of the electric field and Maxwell current made at the ground surface below the thunderstorm. The IC discharges are distinguished from the CG discharges from the Maxwell current measurements. In case of IC discharges, it is observed that the recovery curves are almost linear when the pre-discharge and after-discharge values of the electric field are not strong enough to produce corona at the ground. The recovery curves become exponential if the pre-discharge field is strong enough to produce corona at the ground. However, a step of much slower rate of change of electric field appears in the exponential recovery curve of discharges if both pre and after-discharge values of electric field can produce corona at the ground. This step is of 4 to 10 s time-duration and always appears when the value of the after-discharge electric field becomes equal to 5-6 kV cm\(^{-1}\). Our observations show that some CG discharges from the lower positive charge pocket trigger a discharge between the main positive and negative charge centers of thunderstorms. From the field recovery curves after such triggered discharges, it is possible to conclude that the rate of charge build-up in the main negative charge center is greater than in the lower positive charge pocket. Charging currents for the lower positive charge pocket and for the negative charge center of main dipole are computed at the point of inflection on recovery curves. Behavior of the recovery curves is interpreted in terms of corona charge released from the ground and the relative rates of charge generation of the main electric dipole and the lower positive charge pocket.

INTRODUCTION

The space charge formed due to coronae ions in the sub-cloud layer can limit the absolute value of the electric field at the ground. Winn and Byerley [1975], Standler and Winn [1979], Chauzy and Raizonville [1982], Chauzy and Soula [1987], and Chauzy et al. [1991] have observed that the magnitude of the electric field a few hundred meters above the ground beneath thunderstorms is several times larger than at the ground. For example, Soula and Chauzy [1991] observe a field of upto 65 kV m\(^{-1}\) at 603 m while the surface field did not exceed 5 kV m\(^{-1}\). Therefore, the inferences drawn about the electrification processes in thundercloud processes, as attempted by Wilson [1920], Wormell [1939], Tamura [1954], Freier [1962] etc. will be erroneous as the field at the ground will be summation of fields due to charges in the thundercloud and the corona space charge.

Standler and Winn [1979] and Soula and Chauzy [1991] have studied the effect of coronae on the behavior of recovery curves for negative lightning discharges. Here, we report our surface measurements of electric field and Maxwell current and discuss the behaviour of recovery curves during both intracloud (IC) and cloud-to-ground (CG) positive discharges in the absence or presence of coronae space charges.

INSTRUMENTATION

Measurements of atmospheric electric field and Maxwell current have been made at the Atmospheric Electricity Observatory at Pune (18° 32’N, 73° 57’E). Electric field is measured with an a.c. field-mill with its sensors flush with the ground. It can measure electric field of ± 12.5 kV m\(^{-1}\) with a response time of 0.1 s. The Maxwell current is measured with a 1 m\(^2\) aluminium plate mounted flush with the ground on four porcelain insulators. It can measure ± 5 nA m\(^2\) with a response time of 0.1 s. The signals from both field-mill and Maxwell current plate were amplified and fed to a data-logger system which recorded and stored the data at a frequency of 10 Hz.

RECOVERY CURVES

Observations were made below thunderstorms during the pre-monsoon and post-monsoon seasons of 2001 and 2002. A variety of field-recovery curves were observed following lightning...
discharges. The IC and CG discharges were differentiated from each other using the criteria of Krider and Musser [1982] i.e. the CG discharges produce an overshoot while the IC discharges have an offset in the after-discharge value of Maxwell current.

i). For discharges in the absence of coronae space charge
When the pre-discharge electric field is strong enough to produce coronae from the sharp points raised above the ground surface, the electric field is generally found to recover exponentially to its pre-discharge value in case of the normal IC and CG negative discharges. The critical field to initiate corona from the ground at this location is found to be 5 – 6 kV m\(^{-1}\). However, when the electric field is less than critical, the recovery curves are found to be linear. This supports the observation of Standler and Winn [1979] and Soula and Chauzy [1991] that the field-recovery is almost linear at a height of a few hundred meters above ground. Figure 1 very well demonstrates the linear and exponential behaviours of the field recovery curves in case of discharges occurring when the surface value of the electric field is smaller or greater than the corona threshold, respectively.

![Figure 1. Recovery curve for the discharges when the surface value of the pre-discharge electric field is below (a) or above (b) corona threshold.](image)

The IC or CG positive discharges involving the lower positive charge centre (LPCC) exhibit almost similar field-changes but of opposite polarity if the pre- and after-discharge values of electric field are less than the critical required for corona to occur at the ground.

ii). For intracloud positive discharges in the presence of coronae space charge
Pawar and Kamra [2002] describe the behaviour of recovery curves of the positive discharges that occur between the LPCC and the main negative charge center in an overhead thundercloud. Figure 2 shows a typical field-change during such a discharge. Pre- and after-discharge electric fields on the ground during this discharge are greater than the critical for the coronae space charge to appear in the subcloud layer. The electric field in the recovery curve of such discharges has a very fast recovery for the first ≤ 5 s until the field drops down to ~5 – 6 kV m\(^{-1}\), has an additional step of very slow /nil/ reversal of the field change for the next ~5s, has almost a linear field recovery for the next 5-10s, and then almost exponential recovery until the field reaches its pre-discharge value. The step of the

![Figure 2. Field recovery curve of a positive discharge between the LPCC and the main negative charge centre](image)
slow field-change occurs in all such recovery curves at 5-6 kV m\(^{-1}\).

The initial very fast recovery in such recovery curves is perhaps due to sudden change in the polarity of corona ions being introduced into the lower atmosphere close to ground. Very slow recovery in the step indicates that the effect due to the growth of main negative charge in thundercloud almost equals or sometimes even exceeds the sum of the effects due to the growth of LPCC and that due to corona charge in the sub-cloud layer. The linear part of the recovery curve where the field is weak and changes its polarity reflects the electrical processes in cloud. Further exponential growth of the electric field is generally attributed to the growing effect of the corona-produced space charge in the sub-cloud layer.

iii). For the multiple-discharge flashes

Our observations made on May 3, 2002 at a distance of about 5 kms from an isolated convective thundercloud show that some CG discharges which occur between the LPCC and ground trigger a discharge between the LPCC and the main negative charge center of thundercloud. Also, some IC discharges that occur between the LPCC and the main negative charge center trigger a CG discharge from the main negative center to the ground. Average ratio of the positive to negative charge destroyed in the two discharges of a single flash decreases from 2.96 in case of first type of flashes to 0.55 in case of second type of flashes. Figure 3 shows the changes in the surface electric field and Maxwell current during and after two such flashes. The recovery curves of both types of flashes always exhibit a positive field-change for the initial 5 – 20 s after the flash. It is possible to conclude from this portion of the recovery curve that the rate of charge build-up in the main negative charge center is greater than in the LPCC. Flashes of each type occur at a regular interval of 1-1.5 min. Moreover, a second group of several similar flashes occur in distinctively different stages of thunderstorm and each stage lasts about 10-15 min. The observation indicates that the charge distribution remains almost similar in a particular stage of the thundercloud.

Some flashes shows more than two discharges each being triggered by the previous one. The field-change changes its polarity several times during such flash intervals (Figure 4).
3). The field-recovery curves after such flashes also always show a positive field-change for initial 5-15 s and then an exponential recovery to its pre-discharge value.

Maxwell current observed during such multiple-discharge flashes changes its polarity several times during the flash interval so that the transient associated with a flash is bipolar. A unique feature of Maxwell current associated with such flashes is that almost all of them have positive overshoots. Magnitude of these overshoots may be as large as 10 nA m$^{-2}$ and it is much higher after the second than the first type of flashes shown in Figure 3.

CONCLUSIONS

Our observations confirm that the corona-produced space charge in the sub-cloud layer significantly affects the recovery curves. Recovery curves of intracloud positive discharges occurring between the LPCC and the main negative charge of the thundercloud exhibit an additional step of slow field recovery when high values of electric field drops down to corona threshold.

The LPCC plays a dominant role in initiating /triggering an IC or CG discharge. From the recovery curves of the flashes having the triggered discharge one can conclude that charge build-up of the main negative charge is faster than that of the LPC.

REFERENCE


