Sailboat Mast charging due to Corona current in an Electric Field

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Corona currents occur in strong electric fields and likely explain some of the strange shocks, popping or buzzing that can occur on a sailboat during a thunderstorm. A good reference on Corona currents can be found here
http://en.wikipedia.org/wiki/Corona_discharge

Several professional research papers' (reference 1 and 2) have a good description of the Corona current mechanism of lightning rods in electric fields.

In the reference is described an experiment with various pointed electrodes mounted vertically to a ground plate with a second plate above the ground plate that a negative voltage is applied to. The basic setup is shown in figure 1. The applied voltage of the upper plate and the distance to the bottom ground plate create an "electric field". I.e., this setup creates a potential voltage of zero at the ground plate that varies with distance though the air up to the top voltage plate. The top voltage is negative similar to the potential created by negative charge at the base of the thunder cloud.

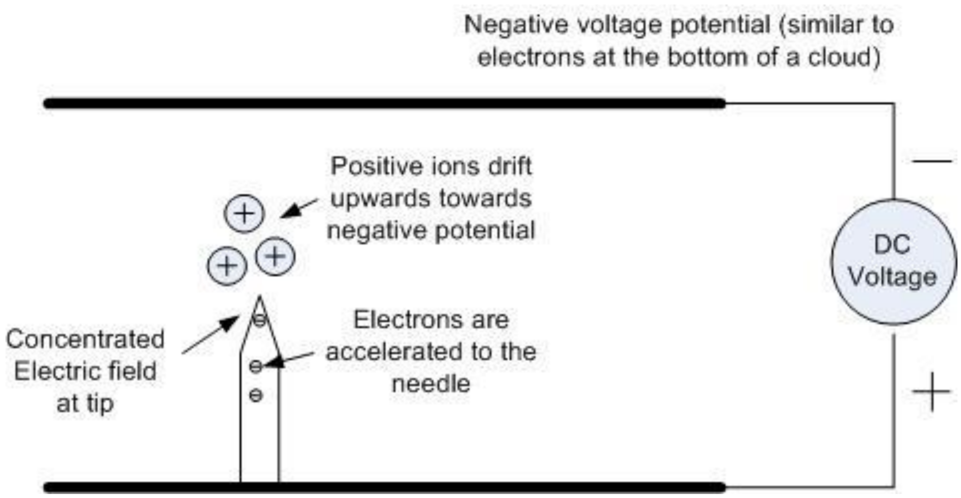


Figure 1.

As the negative voltage of the top plate is increased, at some point the electric field becomes high enough that short duration bursts of current are observed in the pointed electrode. At some higher electric field, the current becomes more constant and a "glow" can be observed around the tip of the needle.

The mechanism for the bursts of current is described in the referenced papers. At a sufficient electric field, when a free electron appears in the air above the electrode, the electron is accelerated towards the tip, liberating more electrons as it travels resulting in an avalanche of electrons from the neutral air molecules above the tip.

The electrons being drawn to the needle top will leave behind a "cloud" or column of positive ion atoms. The positive ions are very massive compared to the electrons (about 60,000 times more mass) and since the ion has the same charge as the electron and therefore will see the same force, the ions have much lower acceleration. The continuing electron avalanche leaves a positive ion charge in the air around the electrode tip which eventually weakens the electric field at the tip and causes the avalanche to cease.

The slowly moving positive ion cloud then drifts toward the upper negative voltage plate or gets blown away by the wind. At some point, the positive charge around the tip has dissipated allowing the field to build again and the process then repeats. How fast the process repeats depends on the strength of the electric field and other factors such as wind strength.

Interestingly, the time period of pulsing of this current is often in the audible range – i.e., we can hear it. Many sailors have reported buzzing noise in rigging and it is likely that they were hearing this Corona current mechanism.

The polarities shown in figure 1 describe "positive" Corona current.

Charging of Sailboat conductors explained by Corona current

If we have a sailboat mast that is initially uncharged and is ungrounded, what happens to it in an electric field?

When the electric field first develops because of a charged cloud drifting overhead, the mast is at ground potential. Since the mast is a conductor, it will have a constant voltage across the entire mast (otherwise current would flow) and this will create an enhanced electric field at the mast tip. This enhanced electric field will induce Corona current at the mast tip from any sort of sharp edge or irregularity and this will add electrons to the mast and release positive air ions in the air which will drift away in the wind or electric field. Figure 2 shows the mast initial charging due to electric fields and Corona current.

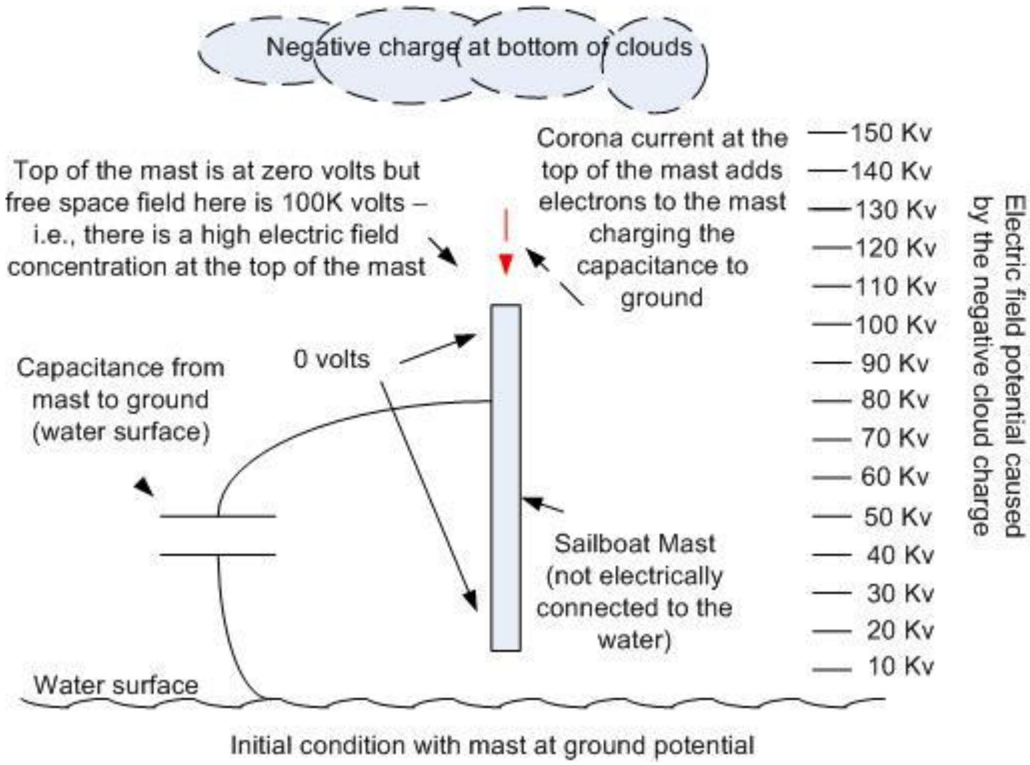
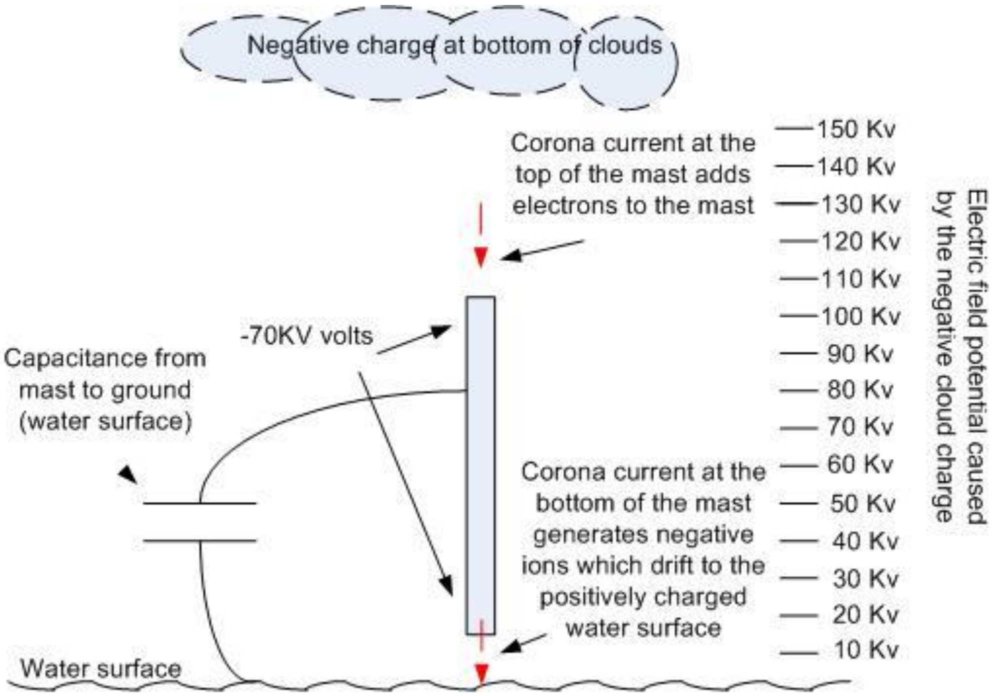


Figure 2. Initial charging of the mast as the negative charge cloud drifts over.

Electrons added to the mast have no place to go so accumulate and according to Coulombs law, will result in the mast voltage potential increasing in the more negative direction. In a model for this, the mast will look like a capacitor to ground (the water surface) and the added electrons will charge this mast capacitor.

As the mast potential voltage rises because of electrons being added, the electric field concentration at the top of the mast will be reduced and the electric field concentration at the bottom of the mast will increase but will be of the opposite polarity. Corona current can be either positive or negative and at the top of the mast, "positive" Corona current can add electrons to the mast and at the bottom of the mast where the field is the opposite, "negative" Corona current will release electrons which combine with neutral atoms to form negative ions which will then drift to ground or in the sailboat case, to the water surface which will be positively charged. Figure 3 shows the equilibrium condition where the mast potential voltage has "charged" and reaches a condition where the Corona current into the mast is equal to the Corona current out of the bottom of the mast.



At equilibrium, the corona current at the top of the mast is equal to the corona current at the bottom of the mast. If positive and negative corona current mechanism were identical, the mast would charge to the free field at the mast's mid point. Since positive and negative Corona current mechanisms are not equal, the mast will charge to something "close" to the free field at its midpoint.

Figure 3.

Zenpole and Corona currents

In the above write up, it is explained that electrons are input to the mast by the Positive Corona current at the top of the mast and this in turn increases the voltage potential of the mast (i.e., a sharp point or object at the top of the mast actually charges the mast). The mast voltage potential increase then in turn creates an electric field at the bottom of the mast which at some point will cause Negative Corona current and release negative ions to the water surface.

It is interesting to note the effect of having the discharge electrode just above the water surface such as the Zenpole implements. Since electric field is a voltage potential over distance, the electrode at the water surface has a very enhanced electric field due to any mast charging simply because the distance between the electrode in the air and the water surface is small. This is of course part of the reason the discharge electrode is optimum just above the water surface but it also has an additional positive effect. Figure 4 shows a mast which is connected to a Zenpole surface electrode and an additional mast which is about 1.5 meter above the water surface (similar to many trailerable sailboats).

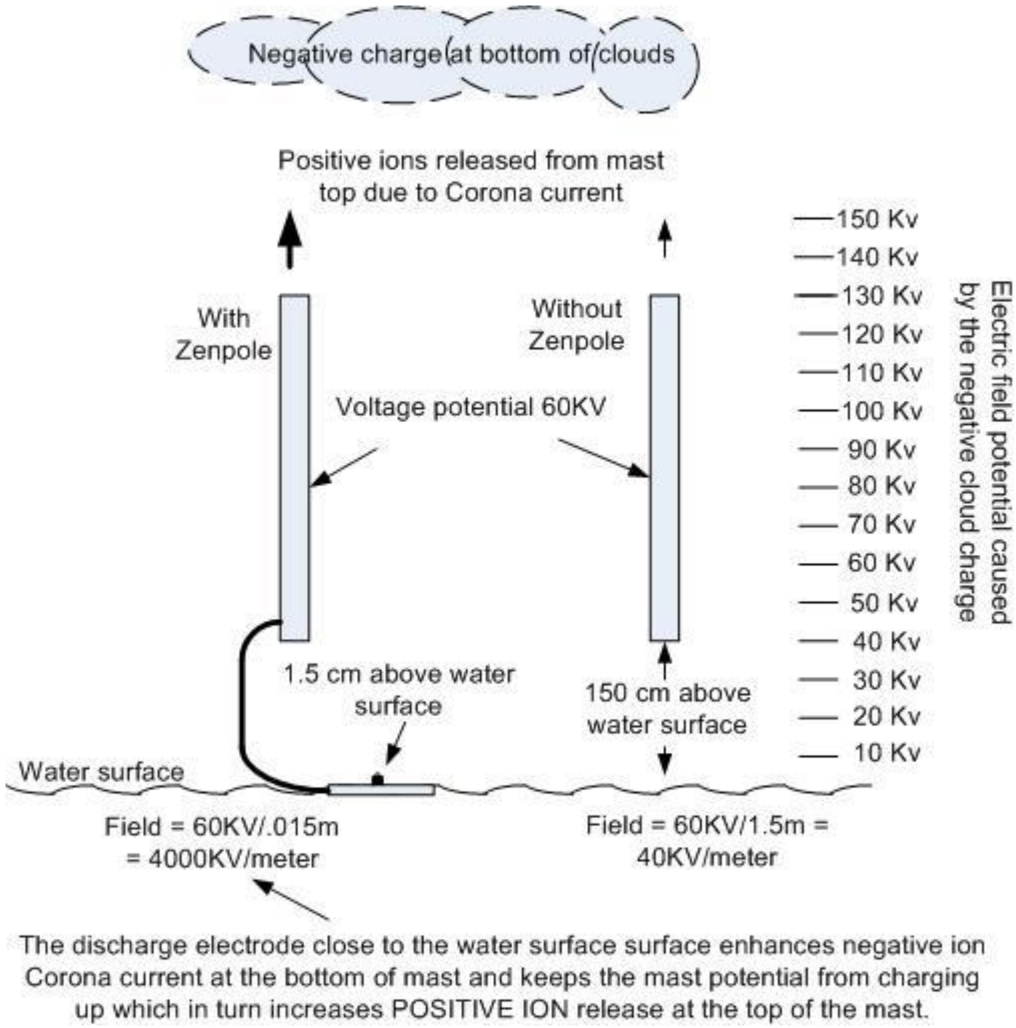


Figure 4.

In Figure 4, we assume that the Corona current at the top of the mast added enough electrons to the mast to cause the mast voltage potential to be 60KV.

But if we look at the electric field (i.e., volts per distance) between the mast connected to the surface electrode, the electric field is one hundred times as large because the distance between the bottom discharge conductor and the water surface is one hundred times smaller for Zenpole.

The result of this is that the Negative Corona current which is releasing negative ions to the water surface is much enhanced for the Zenpole case and since this is “draining” charge from the mast, the Zenpole case should result in the mast potential remaining closer to the ground potential.

And, when the mast voltage remains closer to the ground potential, the electric field at the top of the mast is creating a higher Corona current and releasing a higher concentration of positive ions above the mast. So we can see that placing the discharge electrode very close to the water surface should result in less charging of the mast even without physical grounding to the water and also should result in higher positive ion release at the top of the mast which has the effect of locally weakening the electric field at the tip of the mast.

References

1. "Responses of Lightning Rods to Nearby Lightning" C. Moore, G. Aulich, W. Rison, Langmuir Laboratory for Atmospheric Research, Geophysical Research Center, New Mexico Institute of Mining and Technology (C. 2001)

2. "Lightning Rod Improvement Studies", C. Moore, W. Rison, J. Mathis, G. Aulich, Langmuir Laboratory for Atmospheric Research, Geophysical Research Center, New Mexico Institute of Mining and Technology (1997, final form April 1999)