SIEMENS

Transient Protection System

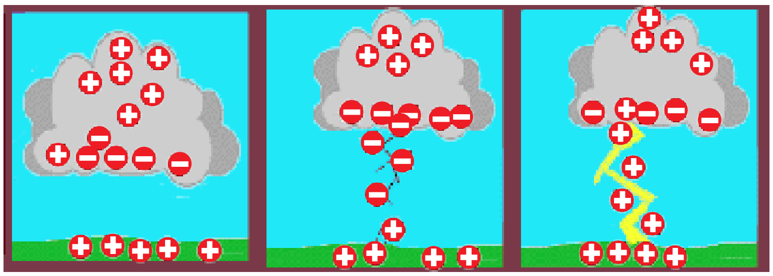
Lightning: Some of the Physics and Effects

Lightning has been the subject of research for decades. The data from this research is available for all to use. A number of institutions have spent many years trying to understand this phenomena. Some of them include, the University of Florida (Gainesville), University of Queensland (Australia), the Soviet Union, and the Electric Power Research Institute. The following information is the result of their research and technical papers.

There are four types/categories of lightning that directly affect objects on the earth's surface: 1. Negative; Cloud to Ground, 2. Positive; Cloud to Ground, 3. Negative; Ground to Cloud, and 4. Positive; Ground to Cloud.

The first lightning type (Negative; Cloud to Ground) for example, is a strike from a negative cloud, down to the positively charged earth (ground). The other three types may be interpreted similarly.

Formation of a Lightning Stroke



In addition to these four types, there is also inter-cloud (Cloud to Cloud) lightning which has an indirect effect on ground and systems on the ground. The cloud to cloud lightning discharges are coupled statically and magnetically into both the power and ground systems.

Accumulated data and research have established that lightning flashes have many unique and distinctive characteristics:

- Lightning voltages are usually greater than 20kV, and can be millions of volts.
- Researchers and observers have determined that when viewed from a distance, lightning usually has a question make shape (?).
- Most lightning occurrences contain multiple strokes.
- Twenty percent (20%) of these occurrences are only one stroke. Eighty percent (80%) are two or more strokes. The mean stroke occurrence is five to six and the maximum has been measured at twenty-five.
- The time between strokes can vary from 100 microseconds to 10 milliseconds during any stroke occurrence.
- The current of a stroke leader will usually range from 30 to 35 kA. A stroke leader is a stream of electrons which appears as a dim spark emerging from a cloud to the ground during the early stages of lightning development.
- One third of the second strokes which occur during multiple stroke occurances are larger in magnitude than the initial stroke.
- The maximum stroke intensities (positive and negative) measured were +300kA and -200kA. These however, will occur less that one percent (1%) of the time.
- The effects of a lightning stroke can be measured and the effects felt, 1.2 to 12.5 miles from the stroke site. This may be due to lightning currents flowing through the ground. In addition during multiple flashes, the location of the terminating strokes have been observed to vary and may be spaced apart from 0.2 to 4.5 miles. These data are based on actual measurements.

- These are long duration current strokes which may last from 10 to 500 ms (30 cycles of 60 Hz lines powers). The amplitude of this long duration stroke may range from 10 to 100 amperes and can flow through the power system. This may help to explain why service entrance suppressors sometimes fail during thunderstorms. The long conduction period and the resulting thermal effects can be the consequence of a lightning storm. Since suppressors are transient devices, the long duration currents may exceed the duty cycle of the device if the device rating is not high enough.

Extensive research has been conducted by the University of Queensland in Australia on the failure mode of suppressor devices during multiple strokes. They have created a multi-pulse (6 stroke) generator that is capable of providing a time interval of between 20 to 130 ms per pulse. This is to simulate the effects of multi-stroke lightning events which may destroy a surge protective device.

This multi-pulse generator uses a series of capacitors that are connected to the pulse forming network by a bar switch which is connected to a pendulum. As the pendulum swings through the charged capacitors, it discharges the capacitors into a pulse-forming network. The time interval between switch contacts is a function of the period of the pendulum. It has been found that fairly short time intervals between pulses will have a severe effect on the performance of surge protective devices and also may cause nuisance fuse operations.

The result of multi-pulse generator testing on surge protective devices has shown that the edge of the zinc oxide metallized area on any MOV is the most critical region when subjected to this kind of pulsing. It was also found that in some cases the temperature can rise to between 800^{o} and 1000^{o} C in isolated "hot spots" in the MOV volume, resulting in failures from punctures of the zinc oxide material. Also, plasma accumulates on the edge of the metallized area and causes additional breakdown regions. The Australian team concluded from their research that the actual rating of an MOV device can be as much as 100 to 150% of the nominal rating for a single pulse; and 60 to 75% of the rating for multiple pulses, if the device is not energized; but may be between 30 to 40% of the rating for multiple pulses if the device is energized.

Summary:

- Lightning induced currents have voltages greater than 20kV
- Stroke Occurrences
  - A. 20% are one stroke
  - B. 80% are 2 - 25 strokes, the average is 5-6 strokes
- Stroke Intensity
  - A. Average single stroke current = 35kA; Maximum = 300kA
  - B. Multiple from 14 to 40 kA with total time 1/2 to 1 second
  - C. Long duration from 10 to 100 amp for up to 1/2 second
- Surge Protection Device Ratings
  - A. Single stroke: 100 - 150% of rating
  - B. Multiple stroke: 60 - 75% of rating
  - C. Multiple stroke: 30 - 40% of rating; if energized

Bibliography:

1. Anderson, R.B. and A.J. Eriksson, "Lightning Parameters for Engineering Application", Electra, 69, 65-102, 1980.
2. Anderson, J.G., "Lightning Performance of Transmission Lines", Transmission Line Reference Book - 345 kV and above, 2nd Ed., pp 545-597, Palo Alto, California, Electric Power Research Institute, 1982.
3. Brook, M., N. Kitagawa, and E.J. Workman, "Quantitative Study of Strokes and Continuing Currents in Lightning Discharges to Ground:, J. Geophys. Res., 67, 649-659, 1962.
4. Casper, P.W., and R.B. Bent, "Results from the LPATS U.S.A. National Lightning Detection and Tracking System for the 1991 Lightning Season", Proc. 21st Int. Conf. on Lightning Protection, Sept. 21-25, 1992, Berlin Germany, pp 339-342.
5. Cianos, N., and E.T. Pierce, "A Ground-Lightning Environment for Engineering Usage", Technical Report 1, Contract L.S.-28177-A3, SRI Project 1834, Stanford Research Institute, Menlo Park, California, August 1972.
6. Darveniza, M., D. Roby, and L.R. Tumma, "Laboratory and Analytical Studies of the Effects of Multipulse Lightning Current on Metal Oxide Arresters", IEEE Transactions on Power Delivery, Vol. 9, No. 2, April 1994, ISSN: 0885-9877, Publisher: IEEE.
7. Jordan, D.M., V.P. Idone, V.A. Rakov, M.A. Uman, W.H. Beasley, and H. Jurenka, "Observed Dart Leader Speed in Natural and Triggered Lightning:, J. Geophys Res., 97, 9951-9957, 1992.
8. Kitagawa, N., M. Brook, and E.J. Workman, "Continuing Currents in Cloud-to-Ground Lightning Discharges", J. Geophys. Res., 67, 637-647, 1962.
9. Master, M.J., M.A. Uman, W.H. Beasley, and M. Darveniza, "Lightning Induced Voltages on Power Lines: Experiment", IEEE Trans. PAS, PAS-103, 2519-2529, 1984.

10. Rakov, V.A., and M.A. Uman, "Long Continuing Current in Negative Lightning Ground Flashes", J. Geophys. Res., 95, 5455-5470, 1990a.
11. Rakov, V.A., and M.A. Uman, "Some Properties of Negative Cloud-to-Ground Lightning Flashes versus Stroke Order", J. Geophys. Res., 95, 5447-5453, 1990b.
12. Rakov, V.A., and M.A. Uman, "Waveforms of First and Subsequent Leader in Negative Lightning Flashes", J. Geophys. Res., 95, 16,561-16,577, 1990c.
13. Rakov, V.A., and M.A. Uman, "Long Continuing Currents in Negative Lightning Ground Flashes: Occurrence Statistics and Hypothetical Mechanism", Proc. Of the USSR Academy of Sciences (Izvestiya AN SSSR, ser.Fizika Atmosfery i Okeana), 27, 375-390, 1991.
14. Rakov, V.A., M.A. Uman, D.M. Jordan, and C.A. Priore III, "Ratio of Leader to Return-Stroke Electric Field Change for First and Subsequent Lightning Strokes", J. Geophys. Res., 95, 16,579-16,687, 1990.
15. Shindo, T. and M.A. Uman, "Consulting Current in Negative Cloud-to-Ground Lightning", J. Geophys. Res., 94, 5189-5198, 1989.
16. Thompson, E.M., M.A. Galib, M.A. Uman, W.H. Beasley, and M.J. Master, "Some Features of Stroke Occurrences in Florida Lightning Flashes", J. Geophys. Res., 89, 4910-4916, 1984.
17. Thottappillil, R., V.A. Rakov, and M.A. Uman, "K and M Charges in Close Lightning Ground Flashes", J. Geophys. Res., 95, 18,631-18,640, 1990.
18. Thottappillil, R., V.A. Rakov, M.A. Uman, W.H. Beasley, M.J. Master, and D.V. Shelukhin, "Lightning Subsequent Stroke Electric Field Peak Greater Than the First Stroke Peak and Multiple Ground Terminations", Geophys. Res., 97, 7503-7509, 1992.
19. Ulman, Martin A., "Lightning", Dover