Triggered Lightning Analysis Gives New Insight into Over Current Effects on Surge Protective Devices

YANG Shao-Jie[1], CHEN Shao-Dong[1] , ZHANG Yi-Jun[2],
DONG Wan-Sheng[2], WANG Jian-Guo[3], ZHOU Mi.[3], ZHENG Dong.[2], YU Hui[2]

1. Lightning Protection Center of Guangdong Province, Guangzhou 510080, Guangdong Province, China;
2. Chinese Academy of Meteorological Sciences, Haidian District, Beijing 100081, China;
3. High Voltage and Insulation Research Institute of Wuhan University, Wuhan 430072, Hubei Province, China

ABSTRACT: Using artificially triggered lightning to investigate physical parameters of lightning discharges has become a new research tool in perfecting the design and application of surge protective devices. Research into the effects of lightning electromagnetic pulse coupling to overhead lines has usually employed high-voltage tests accompanied by simulation calculations. Our triggered lightning experiments allow us to directly observe the over current characteristics caused by the coupling of actual lightning strokes onto overhead transmission lines. Calculations of one such triggered lightning event recorded at Conghua Lightning Experiment Site (with multiple return strokes, peak return stroke of 26.4 kA, and a mean waveform 22/69 μs) showed that corresponding single discharge energy from even a relatively small lightning stroke is much greater than that generated in the high-voltage impact tests. The experiment damaged the 20kA (I_n) rated SPD even though the SPD's I_{Max} was much higher than the lighting peak current. This suggested that surge protective devices should be used which combine higher peak current ratings and a current-sharing MOV design should be employed for better protection of overhead power lines.

1. INTRODUCTION

In high voltage transmission lines (110kV+) direct lightning strikes accounts for only 10% of insulation breakdown incidents. However, in the nearby low-voltage power distribution systems, the fault rate caused by lightning-induced overvoltage of those same strikes is over 90%. Matsuo and Zanetta [1997] documented that the potential damage to electronic equipment in power transmission systems increased as the nominal voltage decreased. This becomes important as we witness two trends in modern electronic devices: A) they are being used on a more massive scale every year for data collection, system control and communications. B) Signal voltages become ever lower causing the equipment to become more sensitive to electromagnetic disturbances.

In China and around the world many methods have been developed in the attempt to understand the electromagnetic fields around the lightning channel. These mostly employ mathematical models. [Thottappillil and Rakov, 2001; Rubinstein and Uman, 1989; Rubinstein, 1996] Data obtained from real observations of induced overvoltage are relatively rare, because of lightning's instantaneity and huge destructive force.

Rocket lightning technology has now developed to a point where artificial lightning-arresting technology is allowing us to directly record and acquire vital data concerning lightning-caused overvoltage plus study first-hand the effectiveness of lightning protection of power distribution systems. When lightning strikes a power line (or near a power line) a high voltage and current will be transmitted along that line to a far place. This will adversely affect any connected electronic devices. Direct lightning (or induction) can produce overvoltage on a power transmission line in the form of a wave. If the line has an open circuit at both ends, this voltage wave will be reflected at the end. Some energy will be consumed during this transfer and if there is an earthing wire or SPD on this line, energy will be diverted to the earth. This paper analyzes a triggered lightning event that occurred on August 12, 2008. In particular we have studied the characteristics of the induced overcurrent through an SPD. Its current waveform is compared with the waveform produced in a high-voltage lab. The SPD, though able to survive a test impulse in a high voltage laboratory, was damaged by the lightning strike. The reasons why the induced overcurrent damaged the SPD are analyzed.

2. TEST LAYOUT AND MEASURING INSTRUMENTS

Rockets are used to trigger lightning at the Conghua artificial lightning experiment site. The triggered lightning point is shown in Figure 1. On Aug. 12, 2008 a triggered lightning strike induced a charge into the 1200m overhead power line. The power line runs through the monitoring station and out through a 52m buried cable which powers an Automatic Weather Station (AWS) which is mounted on wooden poles. The AWS is powered by a live line and neutral line and is about 1200m from the nearest transformer. Data collected by the Automatic Weather System (wind, precipitation, relative humidity, etc.) is transmitted to a computer in the Monitoring Station via a fiber optic cable. The triggered lighting point on the ground is 20.5m away from the Automatic Weather System Collector and 29.6m away from the nearest overhead line.

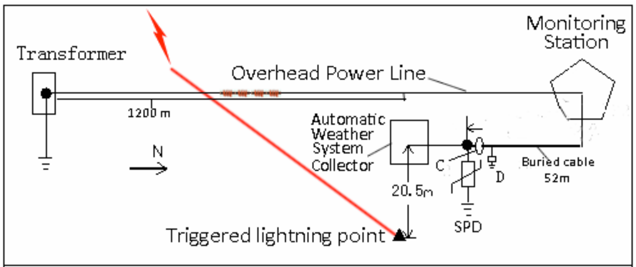

Fig. 1 Test layout at Conghua Lightning Experimental Test Station. (C is the Rogowsky coil. D is the divider.)

Just in front of the AWS station a Surge Protective Device (SPD) was installed. The SPD was imported from Germany, of typical design using small zinc oxide varistors: I_n=20kA, I_{Max} = 40kA, and U_p≤1.75kV.

Installed alongside the SPD were a Rogowsky Coil (C) and an Impact Divider (D). The impact divider is a capacity-resistance type, which has one end connected with Line L and the other end earthed. The Rogowsky coil is a core-through type, which measures the breakdown current discharges of the SPD and has the live line run through its center. The voltage dividing ratio of the divider is 204.9:1 and 203:1. The band width of the Rogowsky coil is 150MHz. To protect the collector system from being damaged if the induced overvoltage or overcurrent is too large, the signals are attenuated by 100 times and then collected and recorded by a high voltage insulated optical fiber data collection system, at a sampling rate of 5M/s and a sampling length of 0.8s. When the induced overvoltage is higher than the SPD's varistor's voltage, the residual voltage is limited to a certain range. All the measuring instruments and systems were tested and calibrated by the High Voltage and Insulation Technology Institute of Wuhan University on the site.

3. THE TRIGGERED LIGHTNING STRIKE

On 17:09:21, the rocket electrode successfully triggered a negative lightning (hereinafter referred to as F170921). When the induced overvoltage of line coupling was transmitted to the Rogowsky coil, the event's residual voltages and related overcurrents were recorded. The discharge process of F170921 consisted of an initial strike (IS), initial continuous currents and 8 subsequent return strokes (typical for the strikes captured by our rockets.) The 8th return stroke was the largest, recorded at -26.4kA. Second largest was the 4th at -24.4kA. The smallest was the 1st return stroke at -6.6kA. The waveform of the induced overcurrents is shown in Figure 2.

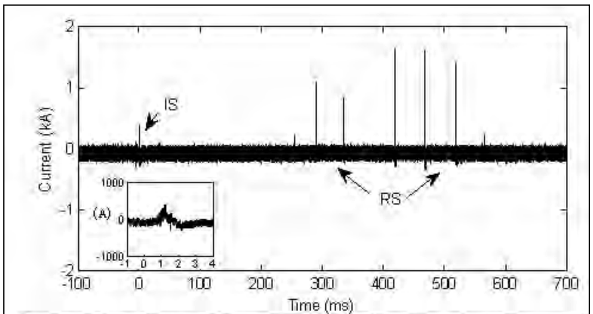

Fig. 2. Waveforms of the initial stroke and 1st 7 return strokes measured by the Rogowsky coil (F17091)

3.1 Continuous induced current at the initial stage

Figure 2 is the waveform of the overcurrents that ran through the SPD, as measured at the Rogowsky Coil after F170921 was successfully triggered. The overcurrents can be divided into the initial stage (IS) and the return stage (RS). The IS currents fell between 470A and 220A (see enlarged window in Fig. 3). The lower 220A current lasted far longer than the 470A current.

3.2 SPD overcurrents at return stage

Figure 3 shows the main peak of the induced overcurrents of 7 of the 8 F170921 return strokes. After the 8 return strokes, subsequent induced currents do exist, but are very weak. The peaks of the overcurrents are in a range of 0.22~1.64kA during the return strokes. The width of the return stroke wavetails (to ½ the peak current

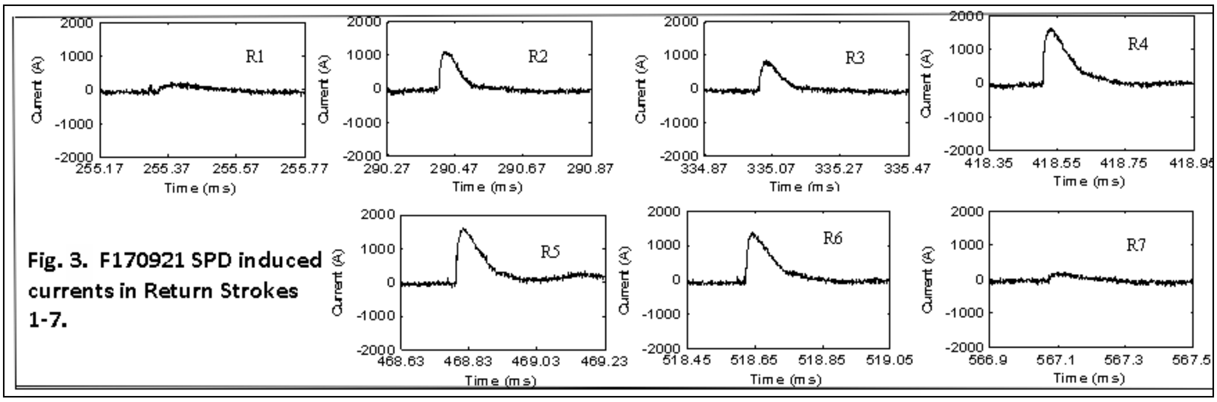

Fig. 3. F170921 SPD induced currents in Return Strokes 1-7.

level) had a geometric mean of 63.3µs and the 10%~90% of current peak rise time had a mean of 15.6µs, corresponding to a current gradient of 0.04kA/µs or 1/1000 of the power source gradient of the triggered lightning.

F170921 Initial Strike current had duration (10%~90% of current peak rise time) of 0.5µs. The width of its wavetail (to ½ the peak current) was 29.5µs. In the return strokes, the wavefront periods (10%-90% of peak currents) ranged from 14～48µs (22µs on average.) The durations of the wavetails (to ½ the peak current) ranged from 29～96µs (69µs on average).

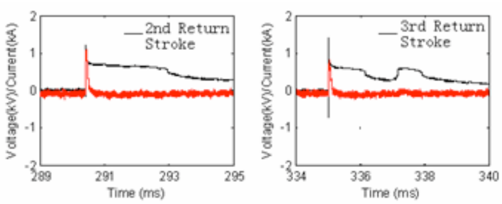

Fig. 4. Comparisons of voltage and current in return strokes R2 and R3. Black equals voltage; Red equals current.

The main peaks of the induced currents as shown above accounts for only a small part of the total continuation period of the residue voltages. Figure 4 compares the residual voltages and overcurrents for the 2nd and 3rd return strokes and shows that a majority of the continuation period sees weak subsequent discharge currents (~100A). The residual voltages for the return strokes are in a range of 0.6~8.1ms or 3.1ms on average.

4. CONCLUSIONS AND DISCUSSION

1) The initial strike of F170921 produced a current waveform of 0.5/29.5 µs. The average waveform of the return strokes was 22/69µs. Compare these figures with the two waveforms currently used to test SPDs in the high voltage lab: 8/20 µs and 10/350 µs.

2) The peak currents through the SPD ranged from 220A to 1.64kA.

3) After the experiment with the triggered lightning F170921, it was found that the SPD (40kA I_{Max}; 20kA

I_n) had become damaged with obvious burns. This occurred despite the fact that the maximum SPD discharge was under 2kA—way below the SPD's rating.

4) The duration of continuous residual voltages and currents through the SPD was in milliseconds. The residual voltages lasted about 3.1ms on average during most of which time the current was under 100 amps. Even though the amplitude of the lightning strike was relatively low, the multiple impacts at short time intervals plus the long discharge duration of the return strokes were obviously above the tolerance level of this type of SPD.

5) The causes of the damage are analyzed as follows:

(a) The lightning current induced on the overhead line was about 22/69µs. Thus more energy was discharged than had it been an 8/20µs waveform which could have damaged the SPD;

(b) The single lightning F170921 included 8 return strokes at intervals of tens to hundreds of milliseconds and the continuous voltages and currents in a short period of time could have damaged the SPD;

(c) A current higher than 1mA (or even 1A) must have been running through the SPD for milliseconds producing a voltage higher than the SPD rated voltage which the MOV could not handle.

5) The accident here tells us that with regard to the protection of important overhead lines SPDs should be employed which have higher-rated protection levels and which use a design of individually-fused multiple protection paths that are able to share the overcurrent.

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