28th International Conference on Lightning Protection

Topic VI: Lightning Protection of Power Systems

VI-B: Lightning Performance of Transmission Lines

Moderator's Report

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I. Introduction

In total 18 papers have been accepted for ICLP2006 Session VI-B related to the topic "Lightning Performance of Transmission Lines" (see Tables I and II):

- 7 papers for oral presentation and
- 11 papers for poster presentation.

The authors represent 6 countries – China, Italy, Japan, Korea, Russia and South Africa. Majority of papers are from the host country (12, Japan).

II. Allocation of Papers by Subjects

Table III additionally shows the main subjects covered by different papers.

III. Papers for Oral Session

VI-8 "*Direct Lightning Strokes to Phase Conductors of UHV Transmission Lines*" by Jun TAKAMI, Shigemitsu OKABE; Japan

Paper analyses results of 7-years observations related to 79 negative lightning direct strikes to the phase conductors of 500 kV lines. They include records of surge voltage waveforms at substations, current waveforms in Line surge arresters, photos captured by automatic cameras and the determination of stroke position by LPATS. On that basis, using EMTP simulation, the detailed lightning features were retrieved: current amplitude ($I_{50\%}$=14.7 kA), front ($T_{F50\%}$=3 μs) and stroke ($T_{S50\%}$=38 μs) durations of lightning current, phase angle during attachment (positive polarity of wire in 71% of events), and phase conductor subjected to direct strike.

VI-9 "*Experimental Approach of the Lightning Protection Measures for Small-size OPGW*" by Masahito SHIMIZU, Akinori MATSUMOTO, Yutaka GODA; Japan (See also paper VI-35)

Laboratory tests (DC arc, 2 kA, up to 500 C) of small-size Composite Fiber Optic Ground Wires (OPGW) demonstrate the advantages of a low-wind noise (LN-type) OPGW with a projection part and of a standard OPGW with a spiral rod in comparison to a standard OPGW. The criterion used is the number of broken strands.

VI-10 "*Sparkover Characteristics of Long Air Gaps with Negative Switching Impulse*" by Sakae TANIGUCHI, Yoshitomo ICHIJYO, Shigemitsu OKABE, Akira ASAKAWA, Megumu MIKI, Takeshi TAKAHASHI, Takatoshi SHINDO; Japan

Laboratory tests on determination of 50% sparkover voltages (switching impulses of negative polarity, $T_{F50\%}$= 80 μs) for long air gaps rod-rod and rod-plane (d up to 5 m) show more linear $V_{50\%}(d)$ characteristics for first configuration and more saturated for the second. Thus, the sparkover voltages are smaller for rod-plane than for rod-rod electrodes, when d > 4 m. Results of tests in foggy and dry conditions do not differ significantly. More details on electrodes' dimensions are desirable.

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TABLE I
PAPERS FOR ORAL PRESENTATION

Paper number	Authors	Country	Content
VI-8	Takami & Okabe	Japan	Observations of lightning direct strikes to phase conductors of 500 kV lines and retrieving detailed lightning features for 79 events by using EMTP simulation.
VI-9	Shimizu et al.	Japan	Laboratory tests of new small-size OPGW by DC arcs (2 kA, up to 500 C). (See also paper VI-35).
VI-10	Taniguchi et al.	Japan	Laboratory tests on determination of 50% sparkover voltages (switching impulses of negative polarity) for long air gaps (up to 5 m): rod-rod and rod-plane.
VI-11	Narita et al.	Japan	Tests on discharge characteristics of gaps (2-8 m) between long (15-50 m) parallel wires with single-single and single-4-bundle conductors.
VI-12	Geri et al.	Italy	Analysis of lightning response of long mixed EHV line (400 kV cable section of 60-km length between two conventional overhead lines, 10 and 200 km) by means of ATP-EMTP.
VI-13	Abe et al.	Japan	Analysis of lightning caused faults observed at three 500 kV lines with different grounding conditions by EMTP simulation using linear and nonlinear grounding resistance models.
VI-14	Watanabe et al.	Japan	Practice: effect of installation of current-limiting arcing horns upon prevention of simultaneous interruptions on parallel OHL caused by lightning (TL for railways).

VI-11 "*Discharge Characteristics of Long Parallel Electrode to Clarify Lightning Backflashover Phenomena between Ground and Power Wires*" by Shigeru NARITA, Osamu OGURI, Katsumasa NONAKA, Yasuhide KINOSHITA, Hideki MOTOYAMA, Takatoshi SHINDO, Isamu KISHIJIMA; Japan

Results of tests on discharge characteristics of gaps (2 to 8 m) between long (50 m) parallel wires were obtained for single-single and single-4-bundle conductors (spacing 50 and 100 cm), and compared to data for 15-m wire length. Sparkover voltages and *V-t* characteristics are determined for positive and negative, full and short-tail lightning pulses, and interesting new features are discussed. The effects of conductor configurations on the values $V_{50\%}$ are small. The *V-t* characteristic depends on the conductor length: it is shifted to the right-hand side for larger lengths.

VI-12 "*Lightning Performance of Long mixed Overhead-cable EHV lines*" by Alberto GERI, Fabio M. GATTA, Stefano LAURIA; Italy

The response of long mixed EHV line (400 kV cable line (CL) section of 60-km length between two conventional overhead lines (OHL) of 10 and 200-km lengths) during direct lightning strokes to overhead lines is analyzed by means of ATP-EMTP. Shielding failures to OHL are related to limited lightning current values and do not constitute danger for cable insulation. The highest voltages affecting long cable are always at the exposed terminals. Grounding effects of cable sheaths connected to the OHL tower reduce the probability of backflashovers. The effect of surge arresters at different locations is also studied.

VI-13 "*Study of Lightning Fault of Transmission Lines using Nonlinear Grounding Resistance Model*" by Mamoru ABE, Keiichi IKEDA, Takehisa HARA; Japan

Analysis of three actual lightning-caused faults observed at three 500 kV lines with different grounding conditions was performed using EMTP simulation for linear and nonlinear (considering soil ionization) grounding resistance models. Data on lightning current were taken from LLS (with correction). It is shown that, for better reproduction of observation results by simulation, the nonlinear model should be applied in cases of relatively high initial grounding resistance (40 Ohm or more), which is often observed in mountainous areas (with 2000 Ohm·m or more).

VI-14 "*Effect of Installation of Current-Limiting Arcing Horns to Prevent Interruptions Caused by Lightning Stroke*" by Kazuhiro WATANABE, Hirohiko FUKUSHIMA, Satoshi EBINUMA; Japan

Results of noticeable practical improvements achieved in decreasing of interruptions on parallel OHL caused by lightning are presented. Discussed TLs are related to railways application. The effect is achieved by installation of current-limiting arcing horns on one side of each TL tower. Some details of horn construction, and of electric and mechanical tests are discussed.

IV. PAPERS FOR POSTER SESSION

VI-30 "*A Long Tail Waveform of Lightning Current observed with a Transmission Line Fault*" by Norikazu KANAO, Koichiro KAMI; Japan

Case analysis is performed for actual 154 kV TL fault caused by positive lightning current having small peak value (several kiloamperes) and very long (100 ms) wave tail duration. Charge was about 70 C. Current waveform was recorded at some substations. Line arresters were installed in TL that was directly struck by lightning (to phase conductor), but no flashover of arcing horn occurred and small lightning current flowed into the power system. Such lightning current may trip a TL in a power system with neutral point grounded through a resistor. Analysis was conducted by means of ATP-EMTP.

TABLE II
PAPERS FOR POSTER PRESENTATION

Paper number	Authors	Country	Content
VI-30	Kanao & Kami	Japan	Case analysis (using EMTP) of actual 154 kV TL fault caused by positive lightning current having small peak value (several kiloamperes) and very long (100 ms) wave tail duration.
VI-31	Shono et al.	Japan	Results of instrumented observations and analysis of 500 kV TL faults with the goal to investigate the shielding failures.
VI-32	Taniguchi et al.	Japan	Impulse discharge laboratory tests with the 1/50 and 1/10 scale models of 500 kV TL for estimation of polarity and fog effects upon shielding characteristics.
VI-33	Miyachi & Yoda	Japan	Analysis of observed and predicted lightning caused backflashovers for 77 kV lines (35 events).
VI-34	Peter	South Africa	Pre-engineering study with the aim to optimize the placement of arresters on 275 kV TL and to improve its lightning performance.
VI-35	Goda et al.	Japan	Details of DC arc laboratory tests of small-size standard OPGW. (See also paper VI-9).
VI-36	Li et al.	China	Simulation of transient characteristics for TL tower grounding device and of lightning-withstand currents for 110 kV TL insulation using EMTP.
VI-37	Kang et al.	Korea	Estimation of lightning outage rates for 765 kV TLs considering hillside (rake) angle and footing resistance of each tower. Comparison of estimated and actually observed values.
VI-38	Zhou et al.	China	Improved EGM for calculation of TL shielding failures considering ground rake angle. Actual case brief analysis.
VI-39	Futatsuki et al.	Japan	Laboratory tests of 6.6-kV tubular arresters: up to 100 lightning impulse current pulses (8 kA), changes of electric characteristics. Measurements of electron density and temperature in vicinity of creeping discharge channel using a 2-mm model gap.
VI-40	Podporkin et al.	Russia	Results of laboratory tests on application multi-electrode system to enhance the arc-quenching ability of Long Flashover Arresters developed for 6 to 35 kV overhead lines.

VI-31 "*Observation of Lightning Strike Phenomena on 500 kV Transmission Lines*" by Masahiro SHONO, Masahito SHIMIZU, Akinori MATSUMOTO; Japan

Paper discusses the results of faults' observations conducted on two 500 kV TLs with the goal to investigate shielding failures. Previous 5-years observations showed that the distribution of faults-related lightning peak currents (obtained from LLS) contains many events with currents noticeably lower than the theoretical threshold level for backflashover on a 500 kV TL. Instrumentation used: the devices for measurements of peak currents through the legs of towers (Rogowski coil, counter, built-in memory), cameras for observation of the lightning channel, VHF broadband digital interferometers for observation of lightning discharge progression (upward, downward). Case study of observations during last 2 years allowed analyzing six events of lightning strikes to TL and its fault behavior. One of these faults is assumed to be caused by shielding failure.

VI-32 "*Effect of Fog on Lightning Shielding Characteristics*" by Sakae TANIGUCHI, Yoshitomo ICHIJYO, Shigemitsu OKABE, Takeshi TAKAHASHI, Akira ASAKAWA, Megumu MIKI, Takatoshi SHINDO; Japan

This work presents the results of impulse discharge laboratory tests with the 1/50 (1-m gap) and 1/10 (5-m gap) scale models of 500 kV TL. Its aim is to estimate the polarity and fog effects upon TL shielding characteristics. Switching impulses with the front times 210 μs (1-m gap) and 80 μs (5-m gap) were used. HV electrode was arranged so that the distances to the OGW and the upper phase conductor were equal. In case of the 5-m gap, a DC bias voltage was applied to power line wires. Mist was emitted from spray nozzles placed at both ends of the discharge gap; moisture content was up to 2.0 g/m^3. For positive polarity tests, some tend to larger frequency of discharges to the top phase conductor was noticed. In conditions studied, the effects of fog and bias voltage upon features of lightning strikes to TL were found not significant.

VI-33 "*Predicted and observed Lightning Flashover based on EHV Power Line Voltages*" by Iwao MIYACHI, Masayuki YODA; Japan

Analysis of observed and predicted backflashovers on 77 kV lines is performed for 35 lightning events. It is considered that the voltage on a particular horn gap depends on the sinusoidal voltage potential of phase conductor at the instant of lightning strike to the overhead wire or tower. Satisfactory agreement is found for flashover conditions in observed and predicted cases.

VI-34 "*Use of Line Surge Arresters to improve Lightning Performance of a 275kV line: A South African Pre-Engineering Case Study*" by Luthando P. PETER; South Africa

Pre-engineering study was conducted with the aim to optimize the placement of line surge arresters (LSA) on a 275 kV TL. It included use of measured tower footing resistances, actual fault data, peak current values from LPATS, LSA characteristics, and modeling of the TL's lightning performance by means of special software based on EGM approach. Different options of equipping phases by LSA (no LSA, one outer, two outer, all three phases) were explored by simulation of 15000 strokes. In a case study simulation the occurrence of flashover was obtained for larger values of footing resistance and current peak, than

actually observed. As the outcome of the work, it is recommended to equip two sections of TL with the LSA on two outer phases, which should provide about 82 % of expected TL performance improvement.

VI-35 "*DC Arc Tests of OPGW Simulating High Energy Lightning Strike*" by Yutaka GODA, Masahito SHIMIZU, Akinori MATSUMOTO; Japan (See also paper VI-9)

Details of DC arc laboratory tests of small-size standard OPGW (80 mm^2) simulating high-energy lightning strikes are presented. Electric charge varied from 20 to 1200 C and current peak value from 1 to 30 kA. Polarity effects were investigated. Behaviors of arc column and arc roots rotated around the OPWG were observed using high-speed cameras. Tests allow the estimation of current characteristics that caused damage of OPGW in actual TL by comparing the number of broken strands and type of damage. Recommendations on optimal test method and conditions are formulated.

VI-36 "*Lightning Performances of Transmission Lines Based on Whole Transmission Line Model*" by Yu LI, Jinliang HE, Rong ZENG, Bo ZHANG, Weiguang ZHUO, Lichuan WANG, Yurong DENG; China

Paper presents the transient model for simulation of TL tower grounding device taking into account the soil properties and geometry of grounding electrodes. Then by means of EMTP, the potential on tower top, voltage on insulators, ground potential rise, and lightning-withstand currents for insulation of 110 kV TL are determined. The sensitivity of lightning-withstand level to soil resistivity, grounding rod length/depth, current injection point location, and front time duration are investigated.

VI-37 "*The Estimation of Lightning Outage Rates using Geographical Region Information*" by Yeon-woog KANG, Hyun-ju KIM, Joo-sik KWAK, Jung-wook WOO, Dong-jin KWEON, Eung-bo SHIM; Korea

Estimation of lightning outage rates for three 765 kV TLs considering local hillside angle of each tower (as well as of footing resistance and other data) allowed to achieve a reasonable agreement with the actually observed values. The estimation of outage rates for each tower could be helpful in designing of special towers for mountain areas using topographical region information.

VI-38 "*Calculation of Shielding Failure Rate of Transmission Lines with the Improved EGM and the Analysis on Typical Accident*" by Wenjun ZHOU, Bin MA, Fei XU, Jianguo WANG; China

The improved Electro-Geometric Model (EGM) and developed formula of maximum striking distance, which consider the ground rake angle, are proposed. Sensitivity analysis is provided by calculation of shielding failure dependences on ground rake angle, lightning current amplitude, angle of protection, and tower height. Proposed approach is used for brief analysis of an actual trip-out accident caused by lightning stroke to the phase conductor of 500 kV TL. It is concluded that large currents (like 148 kA in the analyzed case) can pass shielding. It is difficult to avoid shielding failures in mountain areas, if special tower design is not suggested.

VI-39 "*Evaluation of Extinction Mechanism and Dynamic Characteristic of Creeping Discharge Type Arrester by Laser Thomson Scattered Measurement* " by Shingo FUTATSUKI, Takeru OKAMURA, Masahisa OTSUBO, Chikahisa HONDA; Japan

Laboratory tests of 6.6-kV tubular arresters for distribution lines: up to 100 lightning heavy-current pulses (8 kA) were applied; changes of electric characteristics (corona inception and 50% flashover voltages, *V-t* curves) with application of different number of pulses are studied. Stabilization of characteristics is observed after application of 10 pulses and continued up to 100 pulses. Laser Thomson scattered measurements of electron density ($\sim 7.6 \cdot 10^{22}$ m^{-3}) and temperature (~2 eV) in vicinity of creeping discharge channel are performed for a model gap of 2 mm.

VI-40 "*Development of Long Flashover Arresters with Multi-Electrode System for Lightning Overvoltage and Conductor-Burn Protection of 6 to 35 kV Overhead Lines*" by Georgij V. PODPORKIN, Vladimir PILSHIKOV, Alexander SIVAEV; Russia

Results of laboratory tests that confirm the effectiveness of the application recently designed multi-electrode system to enhance the arc-quenching ability of Long Flashover Arresters developed for 6 to 35 kV overhead lines with insulated conductors.

TABLE III
DISTRIBUTION OF PAPERS BY SUBJECTS

Subjects	Papers' numbers	
	Oral	Poster
HV&EHV&UHV Transmission Lines:		
- Observations/tests	VI-13, VI-14, VI-8	VI-30, VI-31, VI-32, VI-33, VI-34, VI-37, VI-38
- Simulations / modeling	VI-13, VI-8, VI-12	VI-30, (VI-31), VI-32, VI-33, VI-34, VI-36, VI-37, VI-38
EHV cables	VI-12	
Long Gaps Sparkover & *V-t* Characteristics	VI-10, VI-11	
Overhead Wires	VI-9	VI-35
Shielding Failures	VI-8, VI-12	VI-30, VI-31, VI-32, VI-37, VI-38
Arresters/horns for: -Transmission lines - Distribution lines	VI-14, VI-12	VI-30, VI-34 VI-39, VI-40
Grounding	VI-13	VI-36

V. ACKNOWLEDGMENT

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