IEEE PES General Meeting

June 23-27, 2007, Tampa

Lightning Flashover Rate of an Overhead Transmission Line Protected by Surge Arresters

Juan A. Martinez
Univ. Politècnica Catalunya
Barcelona, Spain

Ferley Castro-Aranda
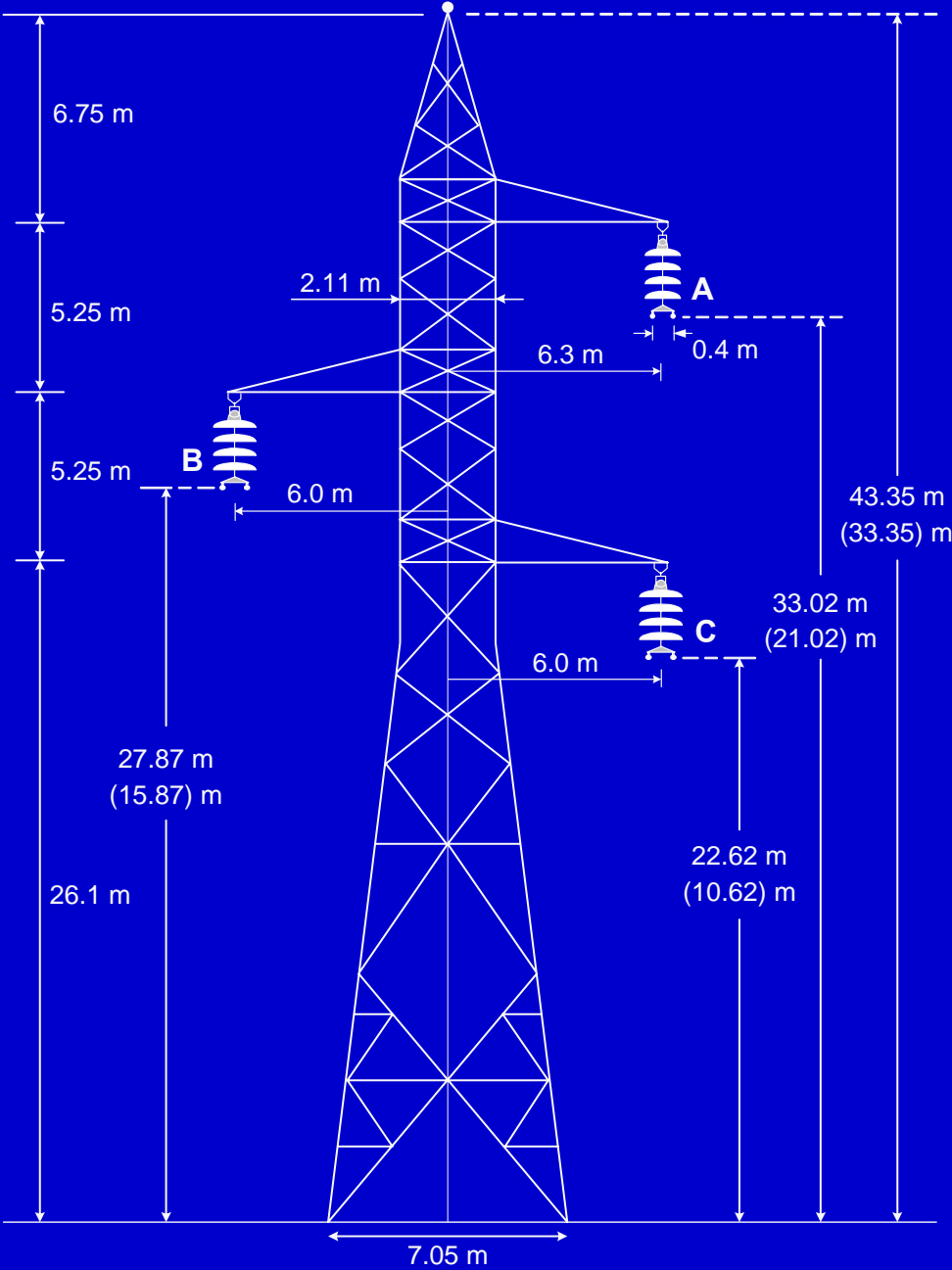**Universidad del Valle**
Cali, Colombia

Introduction

- **Surge arresters improve the lightning performance of lines with a poor shielding or with very high tower footing impedances**
- **Arresters must be selected taking into account energy discharge stresses**
- **Aim of this paper: analyzing the lightning performance improvement of a shielded transmission line after installing surge arresters**
- **The study will be also aimed at estimating the energy absorption capability of arresters**
- **A statistical approach must be used due to the random nature of lightning**

Contents

- **Description of the test line**
- **Modeling guidelines**
- **Features of the Monte Carlo based method**
- **Line and lightning parameters**
- **Lightning flashover rate without arresters**
- **Arrester energy study**
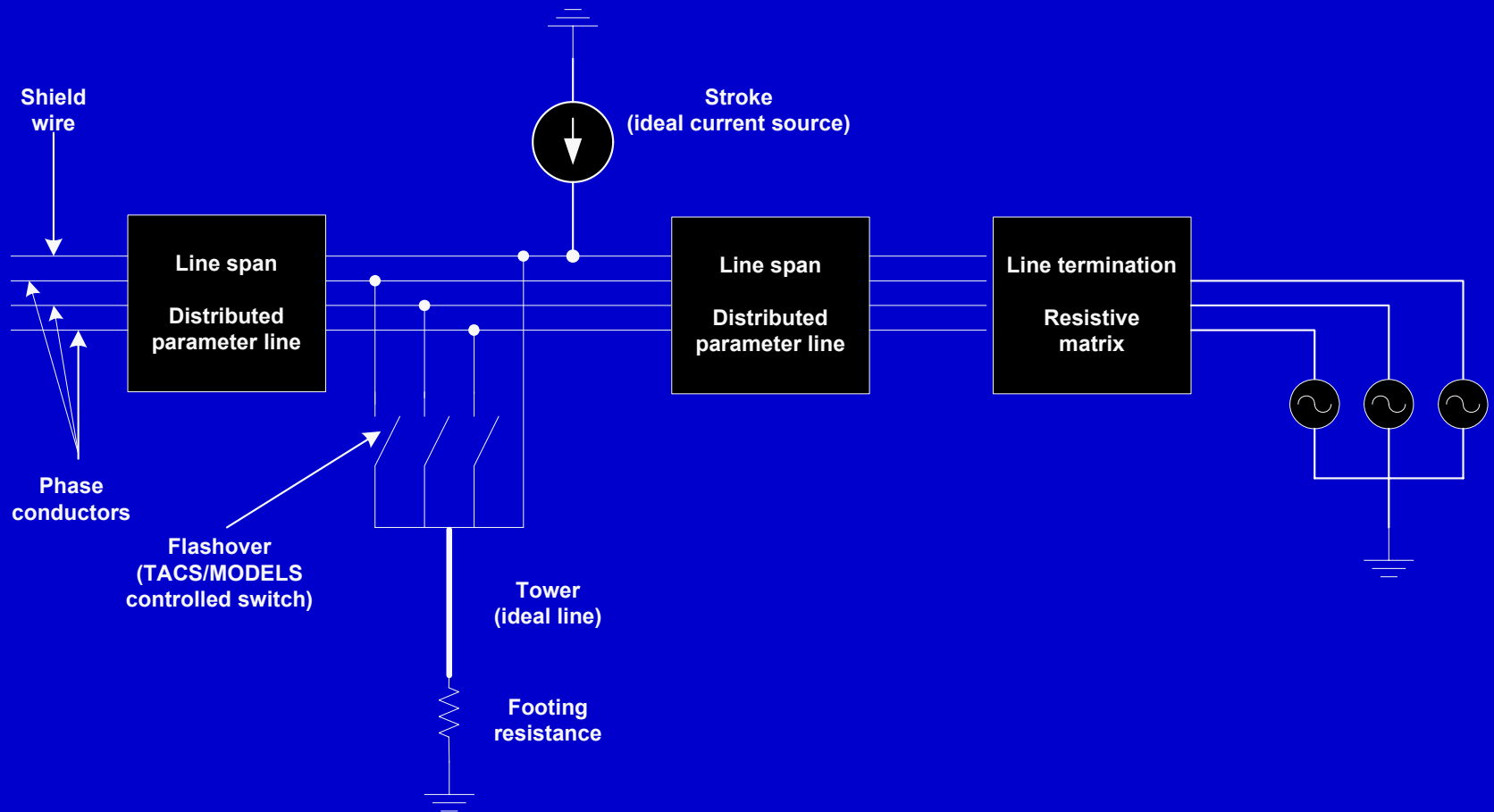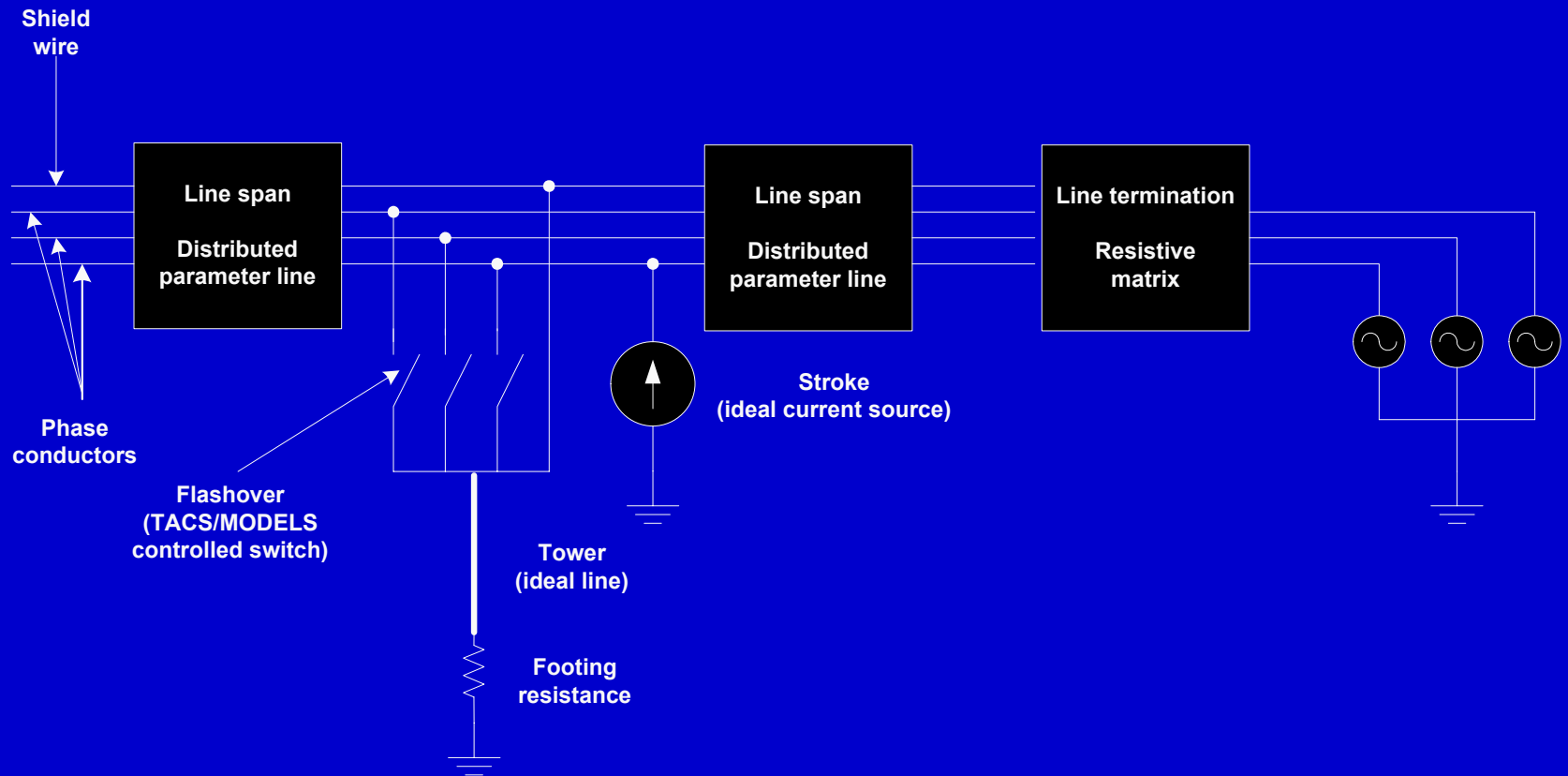- **Lightning flashover rate with arresters**

Test line (400 kV)

6.75 m

5.25 m

2.11 m

A

0.4 m

6.3 m

5.25 m

B

6.0 m

43.35 m
(33.35) m

33.02 m
(21.02) m

C

6.0 m

27.87 m
(15.87) m

22.62 m
(10.62) m

26.1 m

7.05 m

Modeling guidelines

- **Line span model**
- **Line termination**
- **Insulator strings**
- **Towers**
- **Footing impedance**
- **Power frequency phase conductor voltages**
- **Line surge arresters**
- **Return stroke – Waveform, parameters**

Modeling guidelines

Overvoltages originated by strokes to shield wires

Modeling guidelines

Overvoltages originated by strokes to conductors

Lightning stroke parameters

- **Return stroke waveform**
  - ◆ **Concave waveform - Heidler model**

$$i(t) = \frac{I_p}{\eta} \frac{k^n}{1 + k^n} e^{-t/\tau_2}$$
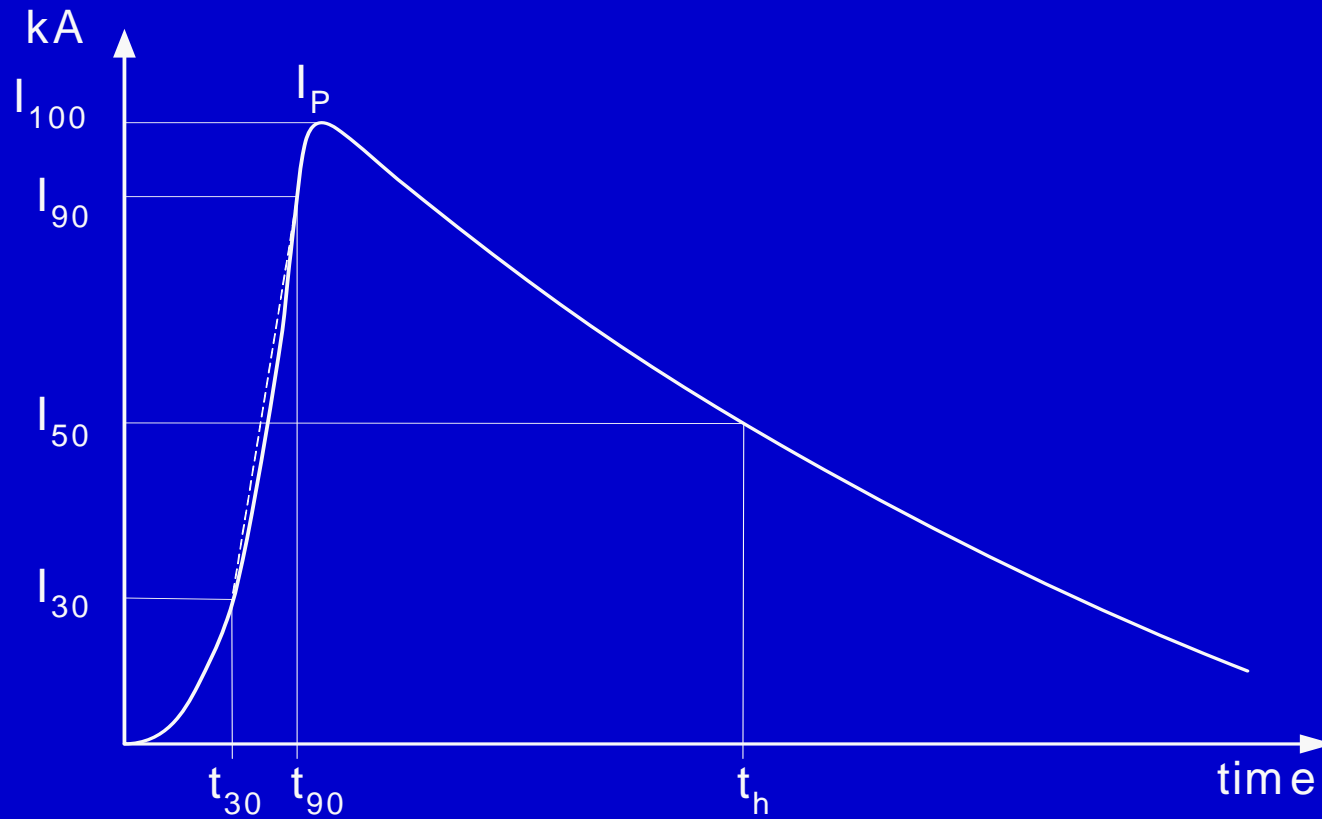
I_p **is the peak current**

η **is a correction factor of the peak current**

n **is the current steepness factor**

$k = t/\tau_1$**, (**τ_1**,** τ_2 **time constants determining current rise and decay-time, respectively)**

Lightning stroke parameters

- **Return stroke waveform**
  - ◆ **Parameters used to define this waveform**
    - • the peak current magnitude, I_{100}
    - • the rise time, t_f (= 1.67 ($t_{90} - t_{30}$))
    - • the tail time, t_h (time interval between the start of the wave and the 50% of peak current on tail)
  - ◆ **The main difficulty to synthesize a concave waveform is the determination of the parameters to be specified in the current expression from those of the return stroke (I_{100}, t_f, t_h)**

Insulator strings

- **Based on the leader progression model (LPM)**
- **When the applied voltage exceeds the corona inception voltage, streamers propagate along the insulator string; if the voltage remains high enough, these streamers will become a leader channel**
- **A flashover occurs when the leader crosses the gap between the cross-arm and the conductor**
- **The total time to flashover can be expressed as follows**

$$t_t = t_c + t_s + t_l$$

t_c is the corona inception time (it is usually neglected)
t_s is the streamer propagation time

$$t_s = \frac{E_{50}}{1.25E - 0.95E_{50}}$$

E_{50} is the average gradient at the critical flash-over voltage
E is the maximum gradient before breakdown

Insulator strings

- **The leader propagation time, t_l, can be obtained from the following equation**

$$\frac{dl}{dt} = k_l V(t) \left[\frac{V(t)}{g-l} - E_{l0} \right]$$

   $V(t)$ is the voltage across the gap

   g is the gap length

   l is the leader length

   E_{l0} is the critical leader inception gradient

   k_l is a leader coefficient

- **The leader propagation stops if the gradient in the un-bridged part of the gap falls below E_{l0}**

Monte Carlo procedure

- **Calculation of random values (lightning stroke parameters, leader channel location, phase conductor voltages, footing resistance, insulator strength)**

- **Application of the electrogeometric model**

- **Overvoltage calculations**

- **If a flashover occurs, the counter is increased and the flashover rate updated**

- **Convergence of the Monte Carlo method**

Line and lightning parameters

- **Models were created using ATP capabilities**
- **Line represented by means of 390-m spans plus a 30-km section as line termination at each side of the point of impact**
- **Tower surge impedance calculated according to the expression suggested by CIGRE**
- **Parameters of insulator equation**

$$k_l = 1.3E\text{-}6 \ m^2/(V^2s) \ ; \ E_{l0} = 570 \ kV/m$$

- **Insulator string striking distance 3.066 m**
- **Only negative single stroke flashes (represented by the Heidler model) were considered**
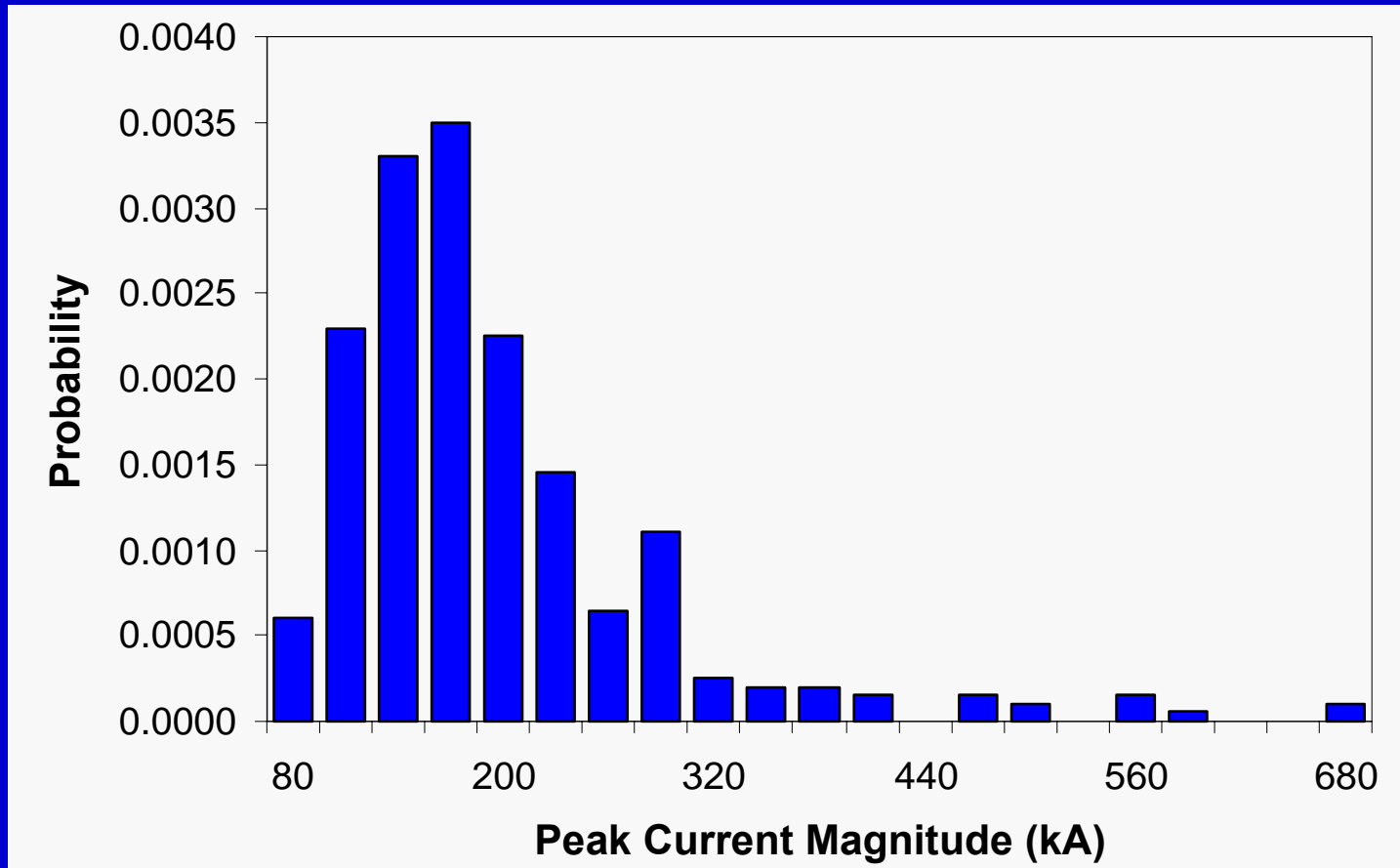
Line and lightning parameters

Probability distributions assumed

- **Stroke parameters determined assuming a log-normal distribution**
- **The reference angle had a uniform distribution, between 0 and 360 degrees**
- **Insulator string parameters determined according to a Weibull distribution, with a standard deviation of 5% for all parameters.**
- **The footing resistance had a normal distribution with a mean value of 50 Ω and a standard deviation of 5 Ω (soil resistivity = 200 Ω.m)**
- **The stroke location was obtained by assuming a uniform ground distribution of the leader**
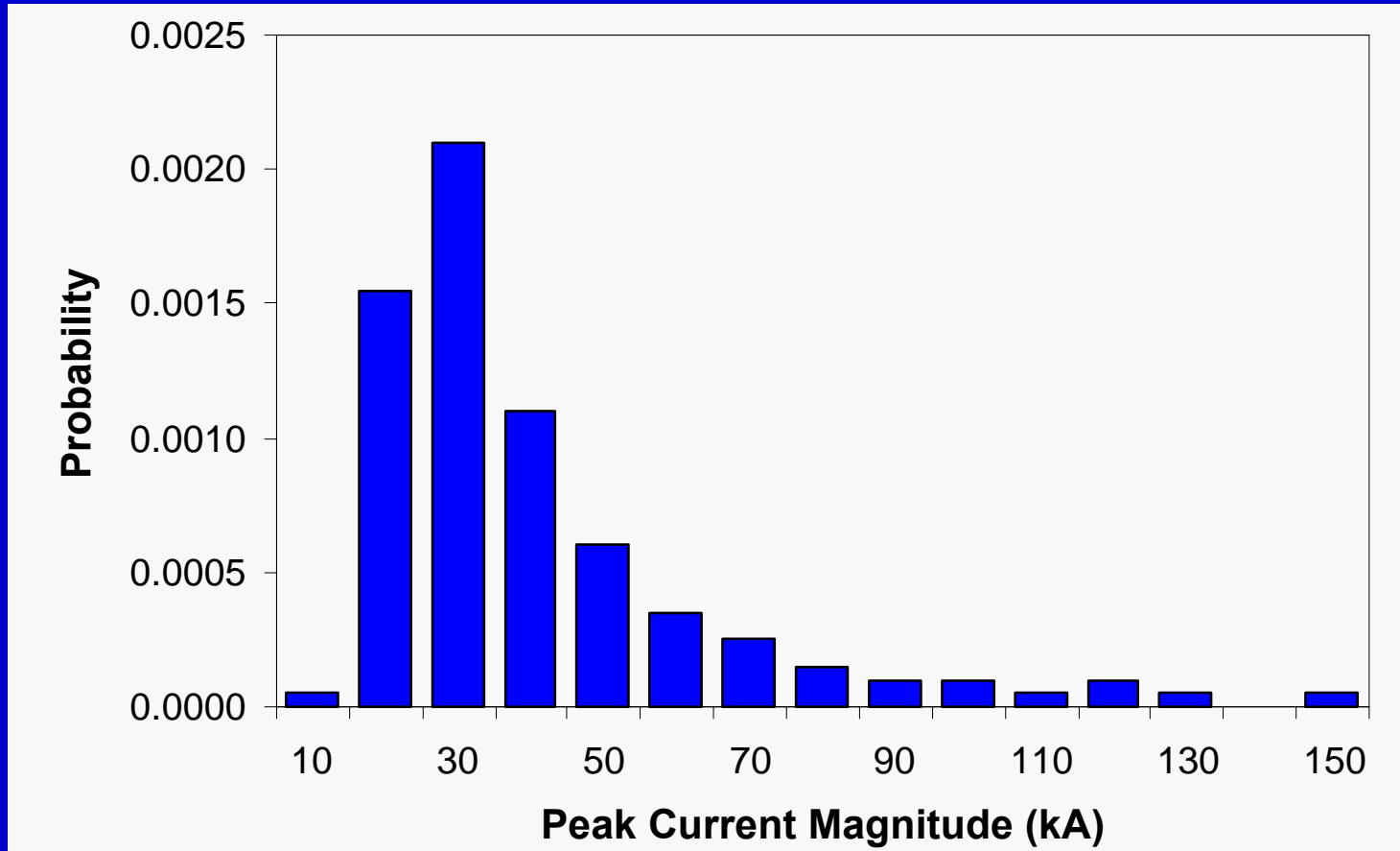
Flasshover rate without arresters

- **Flashover rates after 20000 runs**
  - ◆ **backflashovers = 1.65 per 100 km-year**
  - ◆ **shielding failures = 0.66 per 100 km-year**
- **The total flashover rate was 2.31 per 100 km-year**
- **Values obtained N_g = 1 fl/km^2-year**
- **Too high rate for a transmission line**

Simulation results

Strokes to shield wires that caused flashover
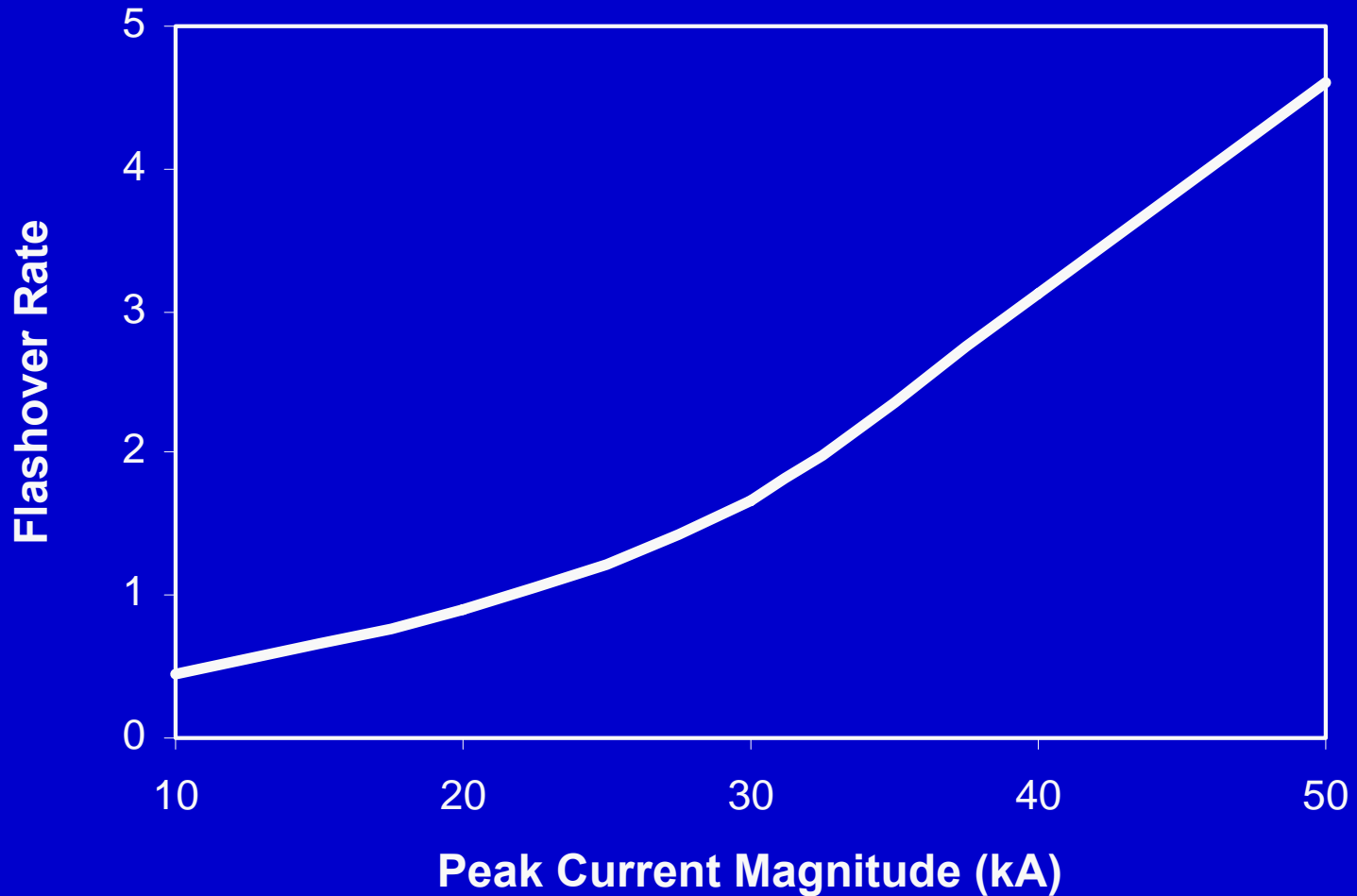
Simulation results

Strokes to phase conductors that caused flashover

Sensitivity analysis

- **Performed to find out the relationship between the flashover rate of the test line and some parameters**
  - ◆ **the median value of the peak current magnitude**
  - ◆ **the rise time of lightning strokes**
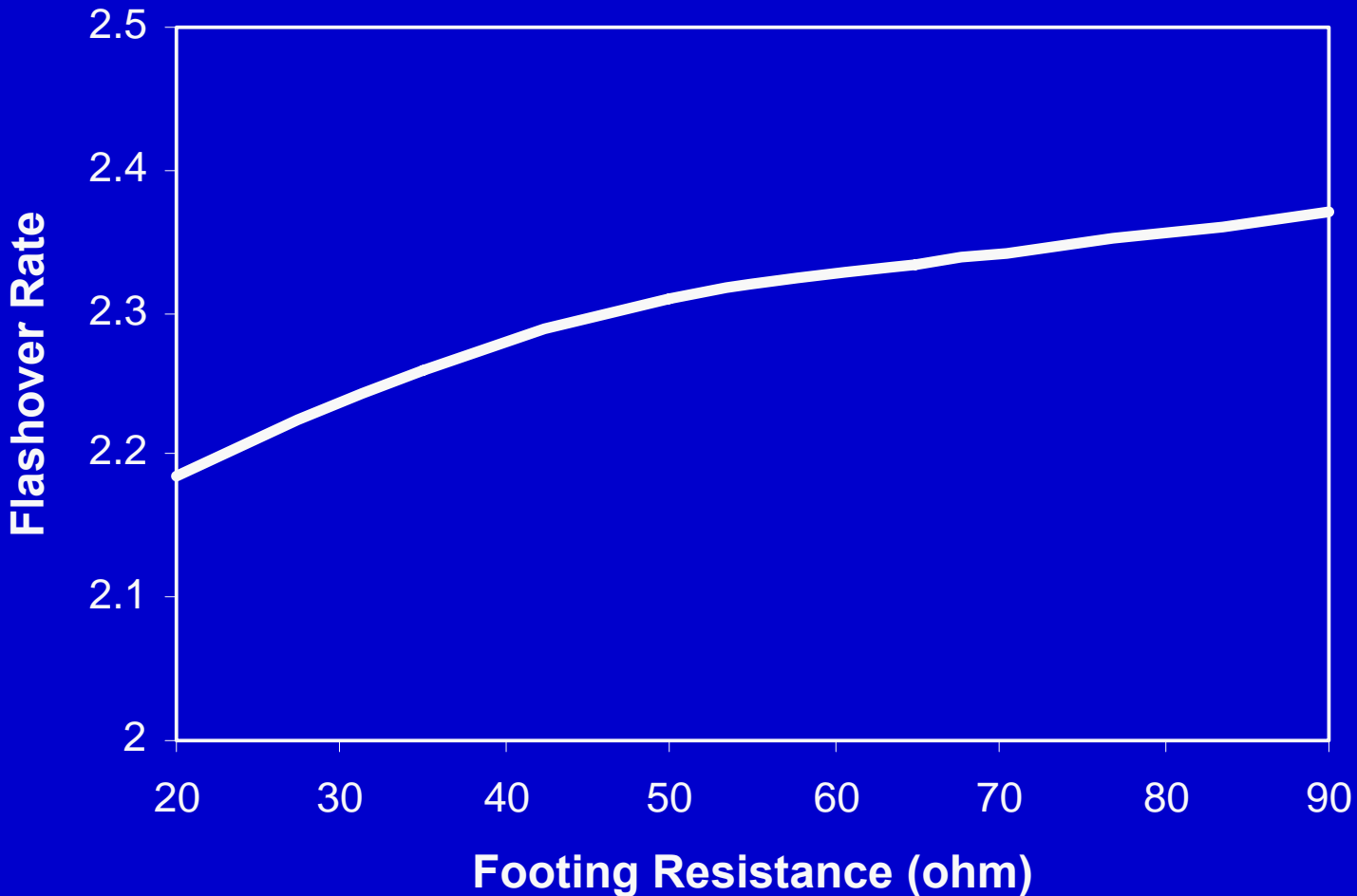 - ◆ **the mean value of the footing resistance at low current and low frequency**

Flashover rate vs. peak current magnitude
(t_f= 2 μs, t_h= 77.5 μs, R_0= 50 Ω, ρ= 200 Ω.m, N_g= 1 fl/km^2-y)

Flashover rate vs. footing resistance
$(I_{100} = 34$ kA, $t_f = 2$ µs, $t_h = 77.5$ µs, $\rho = 200$ Ω.m, $N_g = 1$ fl/km^2-y$)$

Arrester energy studies

Modeling guidelines

- Spans must be represented as multi-phase untrans-posed frequency-dependent distributed-parameter line sections

- No less than 7 spans at both sides of the point of impact have to be included in the model for arrester energy evaluation

- The effect of the arrester lead is negligible when strokes hit either a tower or a phase conductor

- The tail time of the return stroke current has a strong influence; the effect of the rise time very small, or even negligible for low peak current values

Arrester energy studies

Arrester model and parameters

- **Model recommended by IEEE**
- **Values used to obtain the arrester model:**
  - ◆ voltage for a 10 kA, 8/20 μs current, V_{10} = 1007 kV
  - ◆ switching surge discharge voltage for 1 kA, 30/60 μs current, V_{ss} = 735 kV
  - ◆ height of the arrester, d = 3.72 meters
  - ◆ number of parallel columns of MO disks, n = 1
- **Rated voltage selected for the test arrester is 378 kV**

Arrester energy studies

Maximum energy discharged by surge arresters

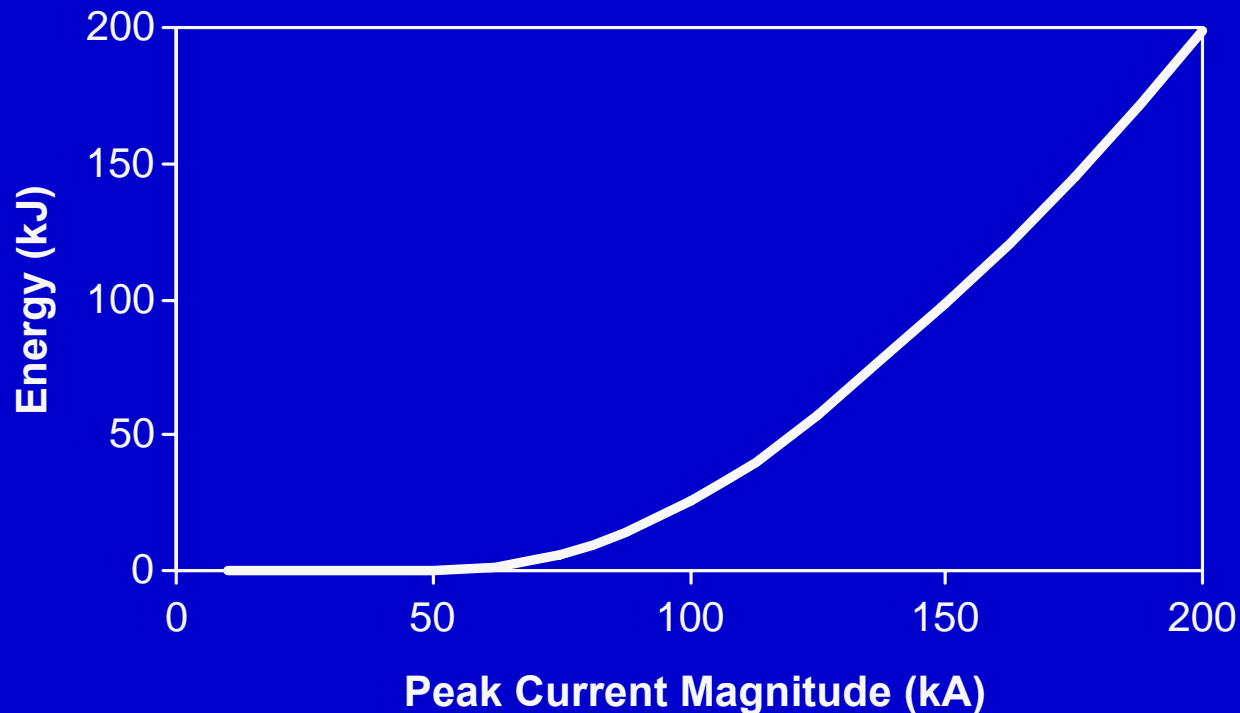| Arresters per tower	Stroke to a tower [1]	Stroke to a phase conductor [2]
A – B – C	96.4 kJ	645.8 kJ
A – B	101.2 kJ	645.8 kJ
B – C	81.7 kJ	651.7 kJ
C – A	90.8 kJ	645.8 kJ
A	97.3 kJ	645.8 kJ
B	88.8 kJ	651.7 kJ

(1) Waveform of the stroke to a tower = 150 kA, 2/50 μs
(2) Waveform of the stroke to a conductor = 50 kA, 2/50 μs
Footing resistance: R_0 = 50 Ω; ρ = 200 Ω.m
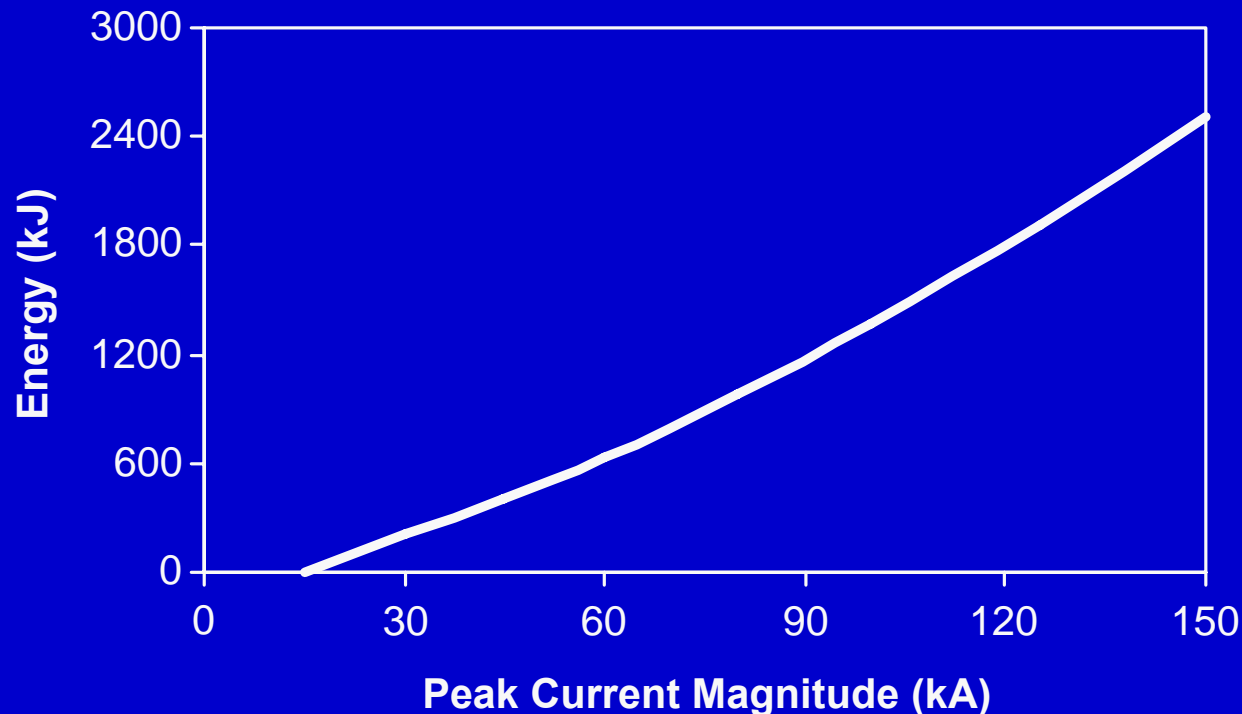
Arrester energy studies

Maximum energy discharged by surge arresters

Stroke to a tower - Footing resistance: R_0 = 50 Ω; ρ = 200 Ω.m

Arrester energy studies

Maximum energy discharged by surge arresters

Stroke to a tower - Footing resistance: $R_0 = 50\ \Omega;\ \rho = 200\ \Omega.m$

Flashover rate with arresters

- **Goal: estimate the improvement of the flashover rate that can be achieved by installing surge arresters at all towers of the test line, but not at all phases**

- **Conclusions derived from the previous results:**
  - **The line has a poor lightning performance, mainly due to an abnormal shielding failure rate**
  - **Arrester failures can be caused by a stroke to a phase conductor, unless arresters with a large energy absorption capability were installed**

- **The flashover rate of the test line with the different combinations of arresters was estimated; it was as-sumed that arresters with a large enough energy absorption capability were installed**

Flashover rate with arresters

Flashover rate with arresters (per 100 km-year)

Arrester Protection	BFOR	SFFOR	Total flashover rate
A – B – C	0	0	0
A – B	0.245	0	0.245
B – C	0.670	0.560	1.230
C – A	0.505	0.100	0.605
A	0.740	0.105	0.845
B	1.000	0.560	1.560

Conclusions

- **The paper has presented the lightning performance improvement of a 400 kV line with a poor shielding**

- **The study has shown that**

  - ◆ **a different degree of improvement can be achieved by installing arresters at all or only some of the line phases**

  - ◆ **the improvement can be very significant when arresters are installed at two phases**

  - ◆ **with the installation of a single arrester per tower, an important reductions of the FR is achieved**

  - ◆ **the installation of arresters with a high energy absorption capability is advisable**