Evaluation and Improvement of Lightning Performance of Pole-Mounted Transformers and Medium Voltage (MV) Distribution Lines

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ABSTRACT

This dissertation presents the means to evaluate lightning performance of pole-mounted distribution transformers and Medium Voltage (MV) distribution lines. The main intention is to provide a general bench-mark procedure for analysis of lightning performances of pole-mounted transformers and MV distribution lines and thereby to ensure proper installation and reduction of the high lightning failure rate existing in Sri Lanka.

In installation of HV surge arresters, the separation length between the arrester and the high voltage bushing is of paramount importance. Thus the calculation of the separation lengths and failure rates are first discussed and the drawbacks of the present method of installation are presented. The required separation depends on several factors such as tower configuration, system voltage, tower surge impedance, the length of the earth wire of the arrester etc. Effect of ground flash and residual voltage of arresters impart a considerable contribution to the transformer protection. An alternative approach for this is also presented. The role of the earth resistance and its contribution to High Voltage and Low Voltage failures due to lightning are discussed, indicating typical modes of failure. The determination of a safe value for the earth resistance is also presented

Flashover due to lightning induced surge voltages is of paramount importance in evaluating reliability and power quality of Medium Voltage distribution lines. First, analysis has been done on flashovers due to direct lightning. Next a comprehensive analysis has been done to develop a method to evaluate lightning performance against lightning induced flashes. Accuracy of the algorithms to calculate lightning induced line flashes highly depends on parameters such as wave front time of return stroke current, magnitude of the return stroke current and its probability distribution and the speed of the return stroke current. Having selected the most suitable values for these parameters, a technique has been developed to determine line flashover rates due to induced lightning. Next, cumulative effect of both direct and indirect lightning surges has been discussed. Analysis has been done to study dependence of line flashover rates on line insulation levels, isokeraunic level, line height, wave front time, corona damping, shielding due to near by objects etc. Variation of line flashover rates with above parameters has been discussed. Theoretical results have been compared with practical data as a measure to check adequacy of the developed analysis technique.

The report finally presents simplified preventive measures that can be implemented in Sri Lanka.

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CONTENTS

LIST OF SYMBOLS

β : Reflection coefficient at the transformer

BIL : Basic insulation level (kV)

d : Horizontal span between outermost conductors (m)

de/dt : Rate of rise of surge voltage (kV/μs)

E_t :Peak surge voltage at transformer (kV)

GFD : Ground flash density (strokes/km^2/year)

H : Line height above ground (m)

I_{AM} : Maximum current through the arrester (kA)

I_o : Lightning stroke current, peak value (kA)

I_{ox} : Lightning stroke current, peak value, which exceeds slope S_A at A, at a distance x away from A (kA)

K : corona-damping constant (μs/kVm).

l : Separation between arrester and transformer (m)

MV : Medium voltage

N_g : Number of strokes per km^2 per year

N_f : Number of lightning surges arriving at A with a slope higher than S_A per year.

P_{Io} : Probability of lightning current exceeding I_o.

R_{ai} : Impulse resistance of arrester earth rod. (Ω).

S_A : (de/dt) rate of rise of surge voltage at receiving end (kV/μs)

S_f : Shielding factor due to nearby objects

S_o : (de/dt) rate of rise at point of strike (kV/μs)

t_f : Wave front time (μs)

t_s : Duration between two lightning surges which cause damage to the transformer (yr)

U_l : Line insulation level (kV)

U_p : Arrester residual voltage (kV)

v : Velocity of wave propagation (m/μs)

V_{pk} : Peak value of surge voltage (kV)

V_{Ra} : Voltage developed across earth resistance of arrester earth rod. (kV)

X : Distance in which a surge with an infinite slope will decay to slope S_A at A (m)

Z : Surge impedance of line (Ω)