

ZnO LIGHTNING ARRESTER EARTHING IMPEDANCE CHARACTERISTICS
UNDER TRANSIENT OVERVOLTAGES

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To my wife Sepideh, to my daughter, Bahar, and to my parents

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ABSTRACT

Lightning arrester in a power system is categorized as a device, which operates in transient conditions. Therefore, the performance of the arrester must be analyzed in transient circumstances. Some particular considerations such as physical (grounding installation) and electrical (impulse current) aspects must be taken. Hence, this research aims to take into account the effect of nonlinear characteristics of the grounding impedance on the residual voltage of the lightning protection system in different discharge conditions. In this issue, the lightning protection system consisting of ZnO and grounding model was adjusted to yield the accurate results in EMTP. For this purpose, IEEE dynamic model of ZnO arrester was adjusted such that the manufacturer's performance test results are achieved. The arrester was connected to the improved circuit model of the grounding electrode system. To analyze the performance of the lightning protection system with different grounding configurations, the system was subjected to the three groups of lightning impulse currents. For this purpose, CIGRE standard, Berger, and 8/20 ($\mu\text{s}/\mu\text{s}$) standard lightning currents were applied as impulse currents. The results shown that the lightning protection system cannot completely protect the power system equipment during the high amplitude and very fast front times of discharge currents, which were experienced under CIGRE and Berger current. In addition, residual voltages of the lightning protection system under standard performance tests for discharge currents less than 5kA do not exceed the protection level, but compare to the manufacturer's results, the residual voltages are considerably increased.

ABSTRAK

Penangkap kilat dalam sistem kuasa dikategorikan sebagai alat yang beroperasi dalam keadaan fana (sementara). Oleh itu, prestasi penangkap kilat mesti dianalisis dalam keadaan fana. Beberapa pertimbangan tertentu seperti aspek fizikal (asas pemasangan pembumian) dan elektrik (arus dorongan) perlu diambil kira. Oleh itu, penyelidikan ini bertujuan untuk mengambil kira kesan ciri-ciri linear rintangan pembumian pada sisa voltan sistem perlindungan kilat dalam keadaan pelepasan yang berbeza. Dalam isu ini, sistem perlindungan kilat terdiri daripada ZnO dan sistem pembumian yang telah diselaraskan untuk menghasilkan keputusan yang tepat dalam EMTP. Bagi tujuan ini, model dinamik IEEE penangkap ZnO telah diselaraskan untuk mencapai keputusan ujian prestasi pengilang. Penangkap kilat ini telah disambungkan kepada model litar baik sistem elektrod pembumian. Untuk menganalisis prestasi sistem perlindungan kilat dengan konfigurasi asas yang berbeza, sistem adalah tertakluk kepada tiga kumpulan arus dorongan kilat. Bagi tujuan ini, kelas CIGRE, Berger dan 8/20 (μs / μs) arus kilat piawai digunakan sebagai arus dorongan. Keputusan menunjukkan bahawa sistem perlindungan kilat tidak dapat melindungi peralatan sistem kuasa semasa amplitud tinggi dan masa depan arus pelepasan yang sangat cepat, di mana ia telah berpengalaman di bawah arus CIGRE dan Berger. Di samping itu, sisa voltan sistem perlindungan kilat di bawah ujian prestasi piawai bagi pelepasan arus kurang dari 5kA tidak melebihi tahap perlindungan, tetapi sisa voltan ini meningkat dengan ketara berbanding dengan keputusan pengeluar.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	xi
	LIST OF FIGURES	xiv
	LIST OF SYMBOLS	xx
1	INTRODUCTION	1
	1.1 Background of the Study	1
	1.2 Statement of the Problem	2
	1.3 Purpose of the Study	3
	1.4 Objectives of the Study	3
	1. 5 Significance of Study	3
	1.6 Scope of Study	4
	1.7 Methodology	4
2	LITERATURE REVIEW	6
	2.1 Introduction	6
	2.2 Earthing System in Fast Transient	7
	2.2.1 Soil Conduction Mechanism	7

2.2.1.1 Thermal Process	7
2.2.1.2 Ionization Process	8
2.2.2 Test Techniques	9
2.2.2.1 Field Test	9
2.2.2.2 Laboratory Test	9
2.2.2.3 Computational Methods Based on the Equivalent Circuits	10
2.2.3 Modeling of the Grounding Impedance	11
2.2.4 Effective Parameters in High Frequency Earthing Systems	15
2.2.4.1 Effect of Lead	15
2.2.4.2 Effect of Electrode Length and Buried Depth	16
2.2.4.3 Effect of Front Time	17
2.2.4.4 Effect of Frequency	19
3 RESEARCH METHODOLOGY	23
3.1 Introduction	23
3.2 Lightning Arrester	24
3.2.1 Arrester Selection	26
3.2.2 Setting and Adjustment of the Arrester	29
3.2.3 Circuit Validation	35
3.3 Lightning Current's Parameter Setting	36
3.4 Approaches to Ground System Modeling	40
3.4.1 Power Frequency Model	41
3.4.2 High Frequency Circuit Model	41
3.4.3 High Frequency Transmission Line Model	44
3.4.5 High Frequency Electromagnetic Approaches in Modeling	45
3.4.5.1 Frequency Dependent Phenomenon	46

3.4.5.2 Soil Ionization Effect	47
3.5 Simultaneous Time and Frequency Dependent Approach	49
3.6 Impulse Coefficients	50
3.7 Electromagnetic Approaches to Model the Grounding Electrode in EMTP	51
3.7.1 Examples of Grounding Electrode under Very Fast Front and Fast Font Durations	52
3.7.2 Use of Electromagnetic Achievements in Improved Model of the Grounding System in EMTP	55
3.7.3 Validation of Improved Modeling Results in Very Fast Front Time Conditions	57
3.7.4 Impulse and Stationary Correction Factor for Vertical Configuration	65
3.7.5 Common Configuration of Grounding Systems in Distribution Level	68
4 FINDINGS AND DISCUSSION	80
4.1 Introduction	80
4.2 Lightning Protection System with Ideal Grounding System Results and Discussion	81
4.2.1 Protection System with Ideal Grounding Model under CIGRE Impulse Currents	81
4.2.2 Protection System with Ideal Grounding Model under Berger Current Setting	84
4.2.3 Protection System with Ideal Grounding Model under Manufacturer Impulse Current Setting	85
4.3 Lightning Protection System with Simple Grounding Model Results and Discussion	86

4.3.1 Protection System with Simple Grounding Model under CIGRE Impulse Currents	86
4.3.2 Protection System with Simple Grounding Model under Current Setting of Berger	90
4.3.3 Protection System with Simple Grounding Model under Manufacturer Impulse Current Setting	92
4.4 Lightning Protection System with Complex Grounding Model Results and Discussion	94
4.4.1 Protection System with Complex Grounding Model under CIGRE Impulse Currents	95
4.4.2 Protection System with Complex Grounding Model under Berger	98
4.4.3 Protection System with Complex Grounding Model under Manufacturer Currents Setting	100
4.5 Summary of the Results	103
5 CONCLUSION	111
5.1 Conclusion	111
5.2 Recommendation for future Research	112
REFERENCES	113
Appendix A	118

LIST OF TABLES

TABLE NO.	TITLE	PAGE
3.1	Typical station and intermediate class arrester characteristics from IEEE Std C62.22-1991	27
3.2	ABB commercial ZnO arrester data sheet	28
3.3	V-I setting points of the frequency dependent model for A0 and A1 nonlinear resistors	30
3.4	Test table of the L1 value	33
3.5	Residual voltage of simulation result and manufacturer data	35
3.6	First negative stroke values based on probability of incidence	37
3.7	Subsequent negative stroke values based on probability of incidence	37
3.8	Lightning current values based on Berger	39
3.9	Manufacturer lightning impulse current setting for performance tests	39
3.10	Input data for Grcev impulse coefficient formula	51
3.11	Physical parameters of grounding system for vertical installation	52
3.12	Soil and electrode parameters of the grounding electrode system	58
3.13	Impulse and stationary voltages of the simulation results based on Grcev data	60

3.14	Soil and electrode parameters of the Electricité de France and Grcev study	61
3.15	Soil and electrode parameters of the 15m long horizontal wire	62
3.16	Soil and electrode parameters of the 3.05m long vertical electrode, F, in clay	63
3.17	Soil and electrode parameters of four parallel vertical electrodes, FGHI, in clay	64
3.18	Correction factors for α and β coefficients in vertical configurations	65
3.19	Correction factor of vertical driven rods with different arrangement under slow front positive impulse current	66
3.20	Correction factor of vertical driven rods with different arrangement under slow front negative impulse current	67
3.21	Generalized correction factor of stationary duration for vertical driven rods	68
3.22	Soil and electrode parameters of the single vertical electrode, case 1	69
3.23	Soil and electrode parameters of the 2-parallel vertical electrode, case 2	69
3.24	Soil and electrode parameters of the 8m long horizontal wire, case 3	69
3.25	Soil and electrode parameters of the 15m long horizontal wire, case 4	69
4.1	First stroke residual voltages and protective margins with ideal ground under CIGRE current	82
4.2	Subsequent stroke residual voltages and protective margins with ideal ground under CIGRE current	83
4.3	Residual voltages and protective margins with ideal ground under Berger current	84

4.4	Residual voltages and protective margins with ideal ground under manufacturer 8/20 ($\mu\text{s}/\mu\text{s}$) current	85
4.5	First and Subsequent stroke residual voltages of power frequency ground model under CIGRE current	90
4.6	ZnO residual voltages with simple ground models under Berger current	92
4.7	ZnO residual voltages with various earthing resistances under manufacturer current	94
4.8	ZnO residual voltages with complex ground models under CIGRE current	98
4.9	ZnO residual voltages with complex ground models under Berger current	100
4.10	ZnO residual voltages with complex ground models under manufacturer current	103

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
2.1	Impedance measurement of the grounding system	12
2.2	Electrode responses to the current impulses in different front times	18
2.3	Measured grounding impedance as a function of front time of the impulse current	19
2.4	Profile of distributed voltage in 50 Hz current injection	20
2.5	Profile of distributed voltage in 500 Hz current injection	20
3.1	Schematic representations of the overvoltages versus time duration in power system	24
3.2	V-I characteristic of the typical ZnO arrester	25
3.3	IEEE ZnO frequency dependent model	29
3.4	V- I Relationships for nonlinear resistor model	32
3.5	Injected current and residual voltage of the arrester in switching test	33
3.6	Injected current and residual voltage of the arrester in lightning test	34
3.7	High frequency gapless ZnO lightning arrester configurations in EMTP	34
3.8	8/20 ($\mu\text{s}/\mu\text{s}$) current waveforms with different amplitude	35
3.9	ZnO residual voltage waveforms with the ideal earthing system	36
3.10	First and subsequent of 95% incidence probability current waveforms	37

3.11	First and subsequent of 50% incidence probability current waveforms	38
3.12	First and subsequent of 5% incidence probability current waveforms	38
3.13	First and subsequent of Berger current waveforms	39
3.14	8/20 ($\mu\text{s}/\mu\text{s}$) manufacturer lightning current waveforms	40
3.15	Simple power frequency model of grounding in static analysis	41
3.16	High frequency circuit model	41
3.17	Relation between soil resistivity and soil water content	43
3.18	High frequency segmented RLC circuit	45
3.19	Surge characteristics of a 10m long electrode in earth with $\rho = 100 \Omega\cdot\text{m}$ for first (a) and subsequent (b) strokes	47
3.20	Computed components of the potential at the injection point for subsequent stroke current injected in a 10 m long electrode in earth with $\rho = 100 \Omega\cdot\text{m}$ [46].	49
3.21	Improved RLC circuit based on electromagnetic approaches	55
3.22	Voltage characteristics of a 10 m long vertical electrode	56
3.23	Voltage characteristics of a 10 m long vertical electrode	57
3.24	Voltage characteristics under first stroke current in a 10 m long vertical electrode	58
3.25	Voltage characteristics under subsequent stroke current in a 10 m long vertical electrode	59
3.26	Voltage characteristics under first stroke current in a 30 m long vertical electrode	59
3.27	Voltage characteristics under subsequent stroke current in a 30 m long vertical electrode	60
3.28	Computational results based on electromagnetic approach in time domain for the circuit, transmission line, and electromagnetic models, (a) first stroke-10m, (b) subsequent stroke-10m, (c) first stroke-30m, (d) subsequent stroke-30m	61

3.29	Comparison of improved circuit result with measurements by Electricité de France (FDE) and Grcev electromagnetic computed result	62
3.30	Measurement and simulation of transient voltages of 15m long horizontal wire	63
3.31	Comparison of Bellaschi measurement and Liew dynamic model simulation with improved model for single vertical driven rod	64
3.32	Comparison of Bellaschi measurement and Liew dynamic model simulation with improved model for 4-parallel driven rod	65
3.33	Stationary correction factor for positive and negative strokes with different vertical driven rod arrangements	67
3.34	Common configurations of grounding systems in distribution level	68
3.35	Voltage characteristics of improved model under Berger current setting	70
3.36	Voltage characteristics of improved model under manufacturer current setting	70
3.37	Voltage characteristics of improved model under CIGRE first stroke current setting	71
3.39	Voltage characteristics of improved model under CIGRE subsequent stroke current setting	71
4.1	First stroke residual voltages with ideal ground under CIGRE current	81
4.2	Subsequent negative stroke residual voltages with ideal ground under CIGRE current	83
4.3	ZnO lightning arrester residual voltages with ideal ground under Berger current	84
4.4	ZnO lightning arrester residual voltages under 8/20 ($\mu\text{s}/\mu\text{s}$) manufacturer current	85
4.5	First stroke residual voltages with 7 Ω earthing resistance	87

4.6	Subsequent stroke residual voltages with 7 Ω earthing resistance	87
4.7	First stroke residual voltages with 11 Ω earthing resistance	87
4.8	Subsequent stroke residual voltages with 11 Ω earthing resistance	88
4.9	First stroke residual voltages with 14.5 Ω earthing resistance	88
4.10	Subsequent stroke residual voltages with 14.5 Ω earthing resistance	88
4.11	First stroke residual voltages with 27 Ω earthing resistance	89
4.12	Subsequent stroke residual voltages with 27 Ω earthing resistance	89
4.13	ZnO residual voltages under Berger current with 7 Ω earthing resistance	90
4.14	ZnO residual voltages under Berger current with 11 Ω earthing resistance	90
4.15	ZnO residual voltages under Berger current with 14.5 Ω earthing resistance	91
4.16	ZnO residual voltages under Berger current with 27 Ω earthing resistance	91
4.17	ZnO residual voltages under manufacturer current with 7 Ω earthing resistance	92
4.18	ZnO residual voltages under manufacturer current with 11 Ω earthing resistance	93
4.19	ZnO residual voltages under manufacturer current with 14.5 Ω earthing resistance	93
4.20	ZnO residual voltages under manufacturer current with 27 Ω earthing resistance	93
4.21	ZnO residual voltages under CIGRE first stroke current with complex ground, case1	95

4.22	ZnO residual voltages under CIGRE subsequent stroke current with complex ground, case1	95
4.23	ZnO residual voltages under CIGRE first stroke current with complex ground, case2	96
4.24	ZnO residual voltages under CIGRE subsequent stroke current with complex ground, case2	96
4.25	ZnO residual voltages based on CIGRE first stroke current with complex ground, case3	96
4.26	ZnO residual voltages under CIGRE subsequent stroke current with complex ground, case3	97
4.27	ZnO residual voltages under CIGRE first stroke current with complex ground, case4	97
4.28	ZnO residual voltages under CIGRE subsequent stroke current with complex ground, case4	97
4.29	ZnO residual voltages under Berger current with complex ground, case1	99
4.30	ZnO residual voltages under Berger current with complex ground, case2	99
4.31	ZnO residual voltages under Berger current with complex ground, case3	99
4.32	ZnO residual voltages under Berger current with complex ground, case4	100
4.33	ZnO residual voltages under manufacturer current with complex ground, case 1	101
4.34	ZnO residual voltages under manufacturer current with complex ground, case 2	101
4.35	ZnO residual voltages under manufacturer current with complex ground, case 3	102
4.36	ZnO residual voltages under manufacturer current with complex ground, case 4	102

4.37	The residual voltages of the lightning protection system with various grounding models under CIGRE first stroke current	104
4.38	The residual voltages of the lightning protection system with various grounding models under CIGRE subsequent stroke current	104
4.39	The residual voltages of the lightning protection system with various grounding models under Berger current	105
4.40	The residual voltages of the lightning protection system with various grounding models under 8/20($\mu\text{s}/\mu\text{s}$) standard current	105

LIST OF SYMBOLS

a	-	Diameter
d	-	Depth
C	-	Capacitance
E_0	-	Critical electric field
I_g	-	Ionization current
I_{max}	-	Maximum impulse current
L	-	Inductance
l	-	Length
R	-	Resistance
S_{max}	-	Maximum slope of impulse current
T_f	-	Front time of impulse current
T_h	-	Tail time of impulse current
ε	-	Permittivity
μ	-	Permeability
π	-	Pi number = 3.14
ρ	-	Soil resistivity

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	MVK Lightning Arrester Manufacturer Data Sheet	121

CHAPTER 1

INTRODUCTION

1.1 Background of Study

In normal operation, lightning arresters according to the micro characteristics (micro varistor) are in a block position until the system is exposed to transient overvoltages. Then in these circumstances, the lightning arrester is short-circuited and it instantly discharges the impulse current and mitigates the overvoltage to less than the desired value (80-85% BIL). In power frequency, a pure resistor characterizes the grounding system of the power system equipment, however, under transient overvoltage circumstances the nonlinear behavior of the grounding system, in relation to the high discharge frequency, requires a complex model of earthing system, which includes resistor, inductor, and capacitor [1]. In these conditions, the residual voltages of the lightning protection system is different when compared to the simple grounding model or power frequency cases. Therefore, the effect of grounding nonlinear characteristics in transient condition should be taken into account [2], [3]. Although many studies that have been conducted in the field of lightning protection systems include gapless ZnO lightning arresters, none of them shows the effect of non-linearity characteristics of the ground impedance under transient conditions on the residual voltage of the system. In the IEEE standard, only the inductive behavior is considered with a length of more than 300m. However,

many studies were done to analyze the soil and impedance behavior [4], [5]. Therefore, it needs more investigations to determine the effects of nonlinearity behavior of the grounding system on the protective performance of the lightning protection system, which includes the surge arrester and grounding system.

1.2 Statement of Problem

To damp the effects of the surge impulses in power system equipment such as transformers, reactors, or cables, use of lightning surge arresters are necessary. Surge arresters are connected between line conductors and earthing system by means of leads and connectors. In a simple configuration, ground electrode is modeled as a resistor and in some surveys, it is neglected. However, in transient conditions, two phenomena affect the ground impedance, which are soil breakdown and electromagnetic effects. Many parameters such as the length of the electrode, soil resistivity, discharge current magnitude, and current front time affect the ground impedance characteristics. In some cases, according to the previously mentioned parameters, the so-called impulse coefficient can be less than one or greater than one, which represents more or less the grounding system efficiency. Therefore, the voltage drop across the ground impedance varies with the effect of these parameters and behavior of the ground system. This voltage drop is represented by $V(t)=R(t).I(t)+X(t)$, where $R(t)$ is the soil breakdown nonlinear resistance, $I(t)$ is the discharge current, and $X(t)$ is the voltage drop related to the frequency dependent phenomena. According to the impulse coefficient of the earthing system (the impulse coefficient defined as $A=Z/R$), the voltage drop in earthing systems can be more or less than the measured value in the simple resistive model. This voltage is to be added to the residual voltage of the ZnO lightning arrester. Therefore, the effects of the grounding impedance characteristics and effective parameters in transient conditions, on the total residual voltage of the lightning protection system should be taken into account.

1.3 Purpose of Study

The aim of this research is to survey the effect of dynamic ground impedance characteristics under transient overvoltage conditions and lightning current parameters on the value of the voltage drop across the whole lightning protection system, which includes the ZnO lightning surge arrester and the ground proper.

1.4 Objectives of Study

The objectives of the study are as follows:

- 1) To improve the model of the grounding system to cope with the various impulse conditions.
- 2) To evaluate the protective performance of the ZnO lightning arrester based on simple and complex grounding models.
- 3) To survey the effects of lightning current amplitude and front time on the protective performance of the lightning protection system.

1.5 Significance of Study

By determining the voltage drop value in different conditions according to the effective parameters of the impulse current for simple and complex models of the grounding systems, accurate data can be used in protection formulas. These data can be taken into account to determine the residual voltage across the lightning protection system during the insulation coordination considerations.

1.6 Scope of Study

The scope of the research is 33kV AC transmission overhead lines, which are protected by gapless ZnO lightning surge arrester grounded by simple and complex earthing system.

1.7 Methodology

This study was conducted to evaluate the effect of grounding system on residual voltage of the lightning protection system. Therefore, three main components of the lightning protection system, which are zinc oxide gapless lightning arrester, grounding system, and the lightning current source were taken into account. In this regard, IEEE-C62.22 was used to set the dynamic model of ZnO lightning arrester in transient conditions for ABB commercial lightning arresters (MVK type) in 33kV overhead transmission lines. A linear resistor was used as an equivalent circuit of the horizontal and vertical rod representing a simple earthing model. While, for the modeling of complex grounding system the improved grounding system based on the electromagnetic approaches was used as grounding system. The validity of the improved model was checked by the computational, simulation and experimental cases. Three types of current sources based on incidence probability, CIGRE impulse current, Berger findings, and ZnO standard performance test (8/20 ($\mu\text{s}/\mu\text{s}$) in different magnitudes) were used as current sources.

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