FAST TRANSIENT SIMULATION OF IEEE RECOMMENDED SURGE ARRESTER MODEL ON A TRANSMISSION LINE USING ALTERNATIVE TRANSIENT PROGRAM (ATP)

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ABSTRACT

This study presents the outcomes of the performance evaluation simulation residual voltage output resulting from lightning arrestors IEEE Recommended model. This simulation uses software Alternative Transient Program - Electromagnetic transients Programmed (ATP-EMTP). This software is very appropriate in examining the behavior of the system, especially a high voltage system lines. As a result of the comparison can be made in the system of 132kV transmission line between systems that are not supplied with lightning arrestors, system supplied with lightning arrestors with conventional styles and systems supplied with lightning arrestors IEEE Recommended model. The results of the simulation study comparisons can be made by taking into account the peak voltage at sub transient conditions. This situation can determine the 132kV transmission line system can protect the equipment properly. Selection lightning 10kA with the 8μs fast front surge and trailing the current time is 20μs is appropriate in the circumstances lightning eruption in Malaysia. In this research, 132kV transmission line parameter tower need to be enclosed by the actual value of the output to the accurate or almost accurate in determining the ability of a lightning arrester in the system.

ABSTRAK

Kajian ini membentangkan hasil simulasi penilaian prestasi lebihan voltan yang terhasil daripada keluaran penangkap kilat model *IEEE Recommended*. Simulasi ini menggunakan perisian *Alternative Transient Program - Electromagnetic Transients Programme (ATP-EMTP)*. Perisian ini amatlah bersesuaian dalam menguji kelakuan sistem litar terutamanya sistem talian voltan tinggi. Hasilnya perbandingan boleh dibuat dalam sistem talian penghantaran 132kV diantara sistem yang tidak dibekalkan dengan penangkap kilat, sistem yang dibekalkan dengan penangkap kilat jenis konvesional dan sistem yang dibekalkan dengan penangkap kilat model *IEEE Recommended.* Hasil kajian simulasi dapat dibuat perbandingan dengan mengambilkira voltan puncak pada keadaan *sub transient*. Keadaan ini boleh menentukan sistem talian penghantaran 132kV dapat melindungi peralatannya dengan baik. Pemilihan letusan kilat10kA dengan nilai *fast front surge* sebanyak 8µs dan nilai masa arus mengekor adalah 20µs adalah bersesuaian dengan keadaan letusan kilat di Malaysia. Dalam kajian ini juga, parameter pencawang talian penghantaran 132kV perlu di masukan dengan nilai sebenar bagi menghasilkan keluaran yang tepat atau hampir tepat dalam menentukan kebolehupayaan sesebuah penangkap kilat dalam sistem ini.

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LIST OF SYMBOLS

Z_c	-	Surge Impedance
v	-	Phase Velocity
ZnO	-	Zink Oxide
U_s or V_s	-	Voltage Input
V_c	-	Voltage Operation
V_r	-	Rated Voltage
I_n	-	Current Nominal Discharge
L_{body}	-	Self-Inductance
R_{grain}	-	resistance of zinc oxide grains
A_0, A_1	-	Non-Linear Resistances
MCOV	-	Maximum Continuous Operating Voltage
CFO	-	Critical Flashover

CHAPTER 1

INTRODUCTION

1.1 Research Background

In the development of technology nowadays, all the system has been simplified for the convenience and comfort of humans and most of the systems in which there is renewed with electrical and electronic systems in it. The uses of electrical and electronic systems are widely used, and the technology has been improved. Both electrical and electronic system used has its own protection system to protect the components in this system. Production of electrical or electronic systems requires a power supply to run this system. Power supplied through the transmission line grid system supplied either single phase or three phases.

Power supply through transmission line also requires protection to prevent damage to the lines, equipment or harm to consumers. Accordingly, there are various devices that regulate and protect the transmission line, equipment or a user in the system, one of the devices is a transmission line lightning surge arrestors.

1.1.1 Surge Arrester in Transmission Line

Power system consistency demands continue to rise in priority and because of this purpose electrical service providers are pursuing earnings to provide this desired improvement. An effective method of reducing lightning related outages on transmission lines is by the strategic application of surge arresters. Since the early 1990's cost effective and lightweight arresters have been available for installation on transmission lines. Surge arresters can also be an effective means for transmission line cost control as when they are used in switching surge control, voltage uprating projects and compact line construction. Surge arrester is a device used in power system above 1000V to protect other apparatus, lines and users from lightning and switching surge.

There are two rudimentary reasons to install transmission line surge arresters on a system. The most common purpose is to reduce or eliminate lightning induced outages due to flashover of insulators. Surge arresters avoid lightning flashovers by maintaining the voltage across insulators on a transmission line below the insulation withstand capability [1].

The second and less common purpose of this type of surge arrester is to eliminate insulator flashover due to switching surges. In both cases, the objective is to reduce or eliminate flashover of system insulators. In both cases, a study of the system is generally carried out to determine the finest location for the arresters to fulfil the desired results.

For switching surge control, the arresters need only be located where the switching surges reach amplitude that exceeds the insulator string switching surge withstands levels. This could be just a few locations along the entire transmission line. For lightning surge control, the zone of protection is seldom more than one span from the arrester therefore arresters need to be located at nearly every tower and sometimes on each phase.

Implementation of this research includes the simulation of the characteristics of the transmission line system. Simulation is rendered using Alternative Transient Program (ATP), where all activities can be viewed and analysed. In this paper ATP-EMTP (Electromagnetic Transients Programme) used to create a model of the power system and to simulate lightning strike at the grounding wire on the overhead line and its impact on underground cables and surge arresters [2]. This design focuses on IEEE recommended model of reference for many other models. In this simulation, transient characteristics can be identified and measured in determining the rate of discharge currents on earth through lightning arrestors that have been modelled.

In this work, a simulation of the dynamic behaviour of metal oxide surge arrester models (MOSA'S) associated with fast impulse tests will be done. The modelling results compared with the data reported on the manufacturer's catalogue were given to demonstrate the MOSA'S models accuracy.

Data on characteristics of metal-oxide surge arresters indicates that these devices have dynamic characteristics that are significant for overvoltage coordination studies involving fast front surges and for their location [3].

1.2 Problem Statements

Based on existing models and previous studies, the writing will focus on a comparison of data between the modelling used. Only a few studies have been made detailing a model as a general study gives a clear picture about the behaviour of the model. In a comparative study, the data retrieved and compares the percentage error occurred. This analysis depends on the materials used, location data retrieved, installation factors and other needs in making a comparison between models. However the data is valid and correct for each model and can be used. It depends on the electricity transmission industry players in determining the type of model to be used. Each model has its strengths and advantages, so in this study the selection model used in the IEEE recommended to analyse, review, define the parameters in turn produce the features of this model.

The author will review the effectiveness of IEEE recommended model in the medium transmission line suitable on diverse parameters. Results of this analysis will provide guidance in general usage models of IEEE recommended to industry players, particularly the installation of medium transmission lines.

It is very difficult to develop a real lightning bolt on the transmission lines in the data collection process. This situation also affects the risk to the author by the lack of equipment and limited time, and then the best option is to use simulation to determine the superlative parameters to produce the desired output. The software suitable for the study were using Alternative Transient Program - Electromagnetic Transient Program (ATP-EMTP) in determining the production of timely and accurate data, this software will examine the advantages and disadvantages as well as the behaviours of this model on the medium transmission lines.

1.3 Research Objectives

The purpose of the research is to accomplish objectives as follow;

1. To simulate the transmission line using Alternative Transient Program - Electromagnetic Transient Program (ATP-EMTP).
2. To design IEEE surge arrestor model in ATP-EMTP.
3. To analysis and compare the simulation output surge arrestor model.

1.4 Research Scopes

As the research's boundaries, the author has set several limitations describes as follow;

1. Design the IEEE surge arrester model and simulate in 132kV transmission line tower model.
2. Analysed the surge arrester parameters at 10kA (8/20μs) lightning strike.
3. Analysed the lightning resistance only.

1.5 Organisation of Proper Report

Chapter 1, summarizes the project background and elaborates on the project by touching the surge arrester in transmission line. In this chapter also describes the problem statement, objectives and scope of the project. The dissertation is introduced in this chapter.

Chapter 2 reviews literatures, including description of system transmission lines, transmission line fault, Metal Oxide Surge Arrester (MOSA), Modelling Surge Arrester and lastly explanation detail in the headlines IEEE Recommended Model of Surge Arrester.

Chapter 3 describes the methodology of the dissertation. ATP-EMTP software is introduced and described. Modelling of transmission line and tower, cross-arms, insulator strings and tower surge impedance are explained briefly in this chapter and also Methodology flow chart is presented in this chapter as well. Gantt chart is shown for the actual progress of the state.

Chapter 4 elaborates on results and analysis in ATP-EMTP simulation of modeling guidelines for 132kV overhead transmission-line. Modelling of lightning source and AC voltage source are explained briefly in this chapter. It also describes the findings made in the simulation results and analysis process for each of the resulting data. Presents the results of simulations together with necessary analysis explanations.

Finally, Chapter 5 discusses the conclusions of the dissertation, and recommends possible future research.

CHAPTER 2

SURGE ARRESTER FOR LIGTHNING PROCTECTION A REVIEW

2.1 Transmission Line System

The transmission line has to be represented by means of several multi-phase un-transposed distributed parameter line spans on both sides of impact point. The representation can be obtained by using either a frequency-dependent, or a constant parameter, model [24]. ATP-EMTP offers a few models that have been used for transmission-line system:

a) Bergeron: constant-parameter K.C. Lee or Clark models

b) PI: nominal PI-equivalent (short lines)

c) J. Marti: Frequency-dependent model with constant transformation matrix

d) Noda: frequency-dependent model

e) Semlyen: frequency-dependent simple fitted model.

Model commonly used in transmission lines are model Bergeron, PI model, and model J. Marti. In Malaysia, Bergeron model widely used in transmission lines. Phase wire connected to the grounding wire transmission line towers.

The Bergeron model basically is based on distributed LC-parameter travelling wave line model with lumped resistance. This time-domain Bergeron model is commonly used in power system transient fault analyses. It represents in distributed method, the L and the C elements of a PI section. It also is estimated equivalent by means of an infinite number of PI Sections, except that the resistance is lumped (1/2 in the middle of the line, 1/4 at each end) [25].

The Bergeron Model has a lossless distributed parameters' line as described by the following two values:

Surge Impedance, $$Zc = \sqrt{\frac{L}{C}} \qquad (1)$$

Phase Velocity, $$v = \frac{1}{\sqrt{LC}} \qquad (2)$$

Similar to PI Sections Model, Bergeron Model accurately represents only fundamental frequency (50Hz) therefore the surge impedance is constant. It also represents impedances at other frequencies, for as long as losses do not change [25]. Figure 2.1 shows an actual model of a Bergeron tower for 132kV transmission line in Malaysia, courtesy of TNB.

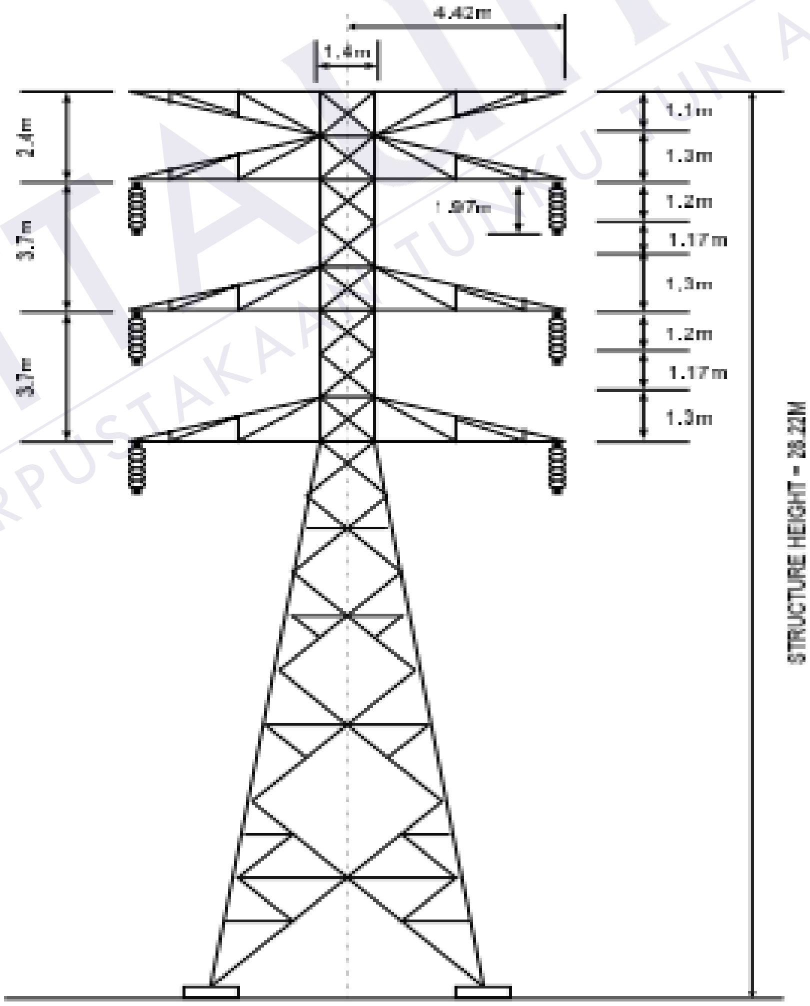

Figure 2.1: Bergeron Model [25]

2.2 Transmission Line Fault

Transmission line is a vital part in power system. Faults in transmission line causes instability and damage to equipment. Therefore, it is necessary to protect the electric power system from faults. For efficient protection, fault should be detected quickly for immediate isolation of faulty line from the system. Subsequently fault classification and its location must be performed for restoration and speed recovery of the system [19].

Many faults on transmission line circuits are weather related such as icing, wind, and lightning. The fault rate during severe storms increases dramatically. Much of the physical and electrical stresses from these events are well beyond the design capability of distribution circuits. Overhead circuits are designed to NESC (IEEE C2-1997) mechanical standards and clearances, which prescribe the performance of the line itself to the normal severe weather that the poles and wires and other structures must withstand. Most storm failures are from external causes, usually wind blowing tree limbs or whole trees into wires. These cause faults and can bring down whole structures [20].

Lightning causes many faults on distribution circuits. While most are temporary and do not do any damage, 5 to 10% of lightning faults permanently damage equipment such as transformers, arresters, cables, insulators. Distribution circuits do not have any direct protection against lightning-caused faults since distribution insulation cannot withstand lightning voltages. If lightning hits a line, it causes a fault nearly 100% of the time. Since most lightning-caused faults do not do any permanent damage, reclosing is used to minimize the impact on customers. After the circuit flashes over (and there’s a fault), a re-closer or reclosing circuit breaker will open and, after a short delay, reclose the circuit. It is important to properly protect equipment from lightning. Transformers and cables are almost always protected with surge arresters. This prevents most permanent faults caused by lightning [20].

2.3 Metal Oxide Surge Arrester (MOSA)

Surge arrester is a protective device that protects the system from any damage occurs. Surge arrester is installed on the generation system, transmission line or distribution system. Structural materials with sensitive molecular therein are intended to divert the high voltage to ground. Most of the materials used to build the structure of the Metal Oxide Surge Arrester (MOSA).

Line surge arresters are installed in parallel connection with the insulator clusters of transmission lines. When the transmission lines are strikes by lightning strike, the lightning current distribution will change, one part of which flows into neighbour towers and the other into the ground through towers. The surge arrestors will work when the lightning current is beyond a certain value. Most of the current is transmitted to conductors of nearby towers through the surge arrestors. While the lightning current is passed, it will produce coupling current in conductors because of electromagnetic interaction between conductors. As the lightning current distributed by the surge arrestors is far beyond the current in conductors and the electromagnetic interaction will raise the potential of the conductors, the voltage between conductors and top of towers is less than the flashover voltage of insulator clusters, which will avoid flashover in insulator clusters [9].

Figure 2.2 shows the resulting voltage in high voltage electrical system where the peak voltage between phases to earth continuously shown in per unit (pu), depending on the length of time it is produced.

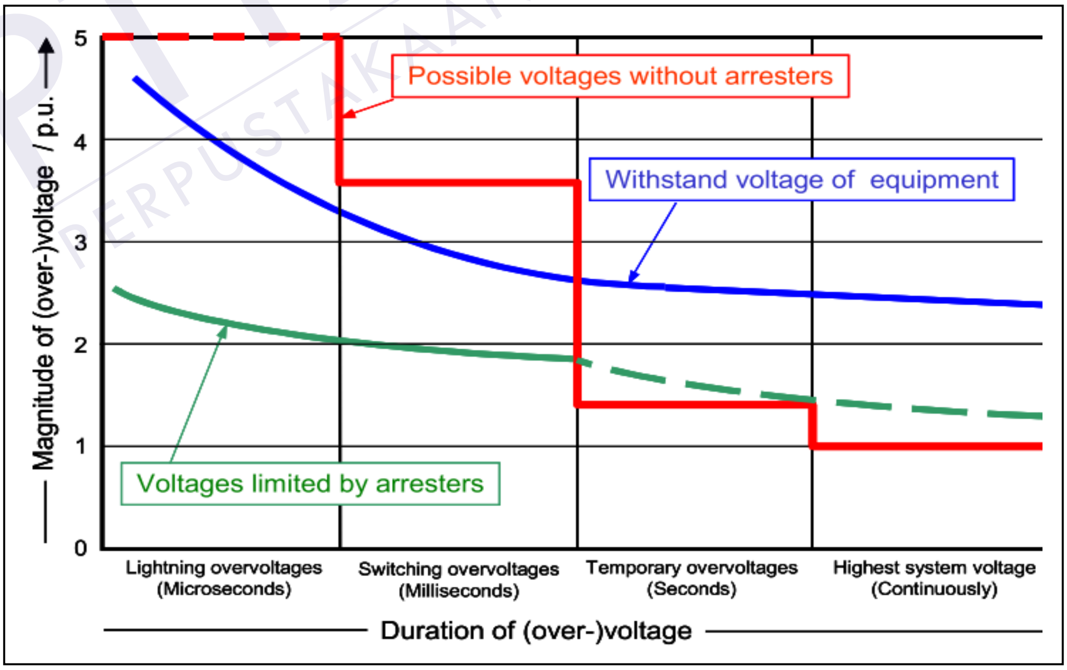

Figure 2.2: Magnitude Of Voltages And Over Voltages In A High Electrical Power System Versus Duration Of Their Appearance [26]

Time axis is divided into four regions, namely the 'Lightning Overvoltage' in microseconds, Switching Overvoltage in milliseconds, Temporary Overvoltage in seconds and Highest Continuously be reflected in the system voltages. If seen in figure 2.2, lightning and switching are at risk of damage and accidents than others even if the timing is very small in the absence of the surge arrester. Damage will occur due to resistance is low voltage equipment against overvoltage. However, the presence of surge arrester provides protection to equipment if lightning and switching occurs.

MOSA are widely used as protective devices against switching and lightning overvoltage in power electrical systems. Phase to ground surge arresters are commonly installed at power transformer terminals and some protection effect for near connected equipment in a substation is supposed. The installation of other additional surge arresters in a substation may be required to effectively protect all connected equipment, when a fast overvoltage enters a substation from a line [4].

Figure 2.3: A ZnO 20kV Surge Arrester [28]

Constructively, MOSA have a simple structure, comprising one or more columns of cylindrical blocks varistors. A ZnO 20kV surge arrester is shown in figure 2.3.

Installation of the transmission line surge arrester is installed in parallel with the protected equipment. This is due to the current flow and voltage flash and not directly on the equipment but it will be routed to the surge arrester through online and is aimed at protecting insulator string to dramatically improved the lightning withstand level, reduce lightning trip-out rate and reach the purpose of lightning protection.

When the tower was struck by lightning, a part of lightning current flow through overhead ground wire to the adjacent tower, and other part of lightning current flow through the tower to the ground. The grounding resistance of tower has transient resistance feature, so impulse grounding resistance is always used to manifest it [6].

When lightning current surpass a certain level, the operation of arrester also can shunt the current. Most of the lightning current flows through arrester to lead and then transmits to adjacent tower. As the electromagnetic induction effect between the leads, when lightning current flow through lightning shield line and leads, coupling components occurs in leads and lightning shield line respectively. As the shunt current of arrester is far more than the lightning current shunt from lightning shield line. The effect of shunt leads to the improvement of lightning potential, which let the potential difference between lead and tower top less than the flashover voltage of insulator string. Flashover may not occur in insulator. Thus, line arrester has good holding potential effect. That's the prominent characteristics of line arrester. It can be prove that the protection range of arrester is just the tower installed arrester and its own line insulator string, whether it is lightning counterattack or lightning shielding failure [7].

The distinctive feature of an MO resistor is its extremely nonlinear voltage-current or U-I characteristic, rendering unnecessary the disconnection of the resistors from the line through serial spark-gaps, as is found in the arresters with SiC resistors. Silicon Carbine (SiC), which is found in the surge arrester where the model is rarely applied. Within it has the structure of a gap between arrester semiconductors. For the MO surge arrester it was built without a gap arrester structure.

Bayadi et al (2003) validate the appropriate modelling of MOSA's dynamic characteristics is very important for arrester location and insulation coordination studies. For switching surge studies, metal oxide arrester can be represented simply with their nonlinear U-1 characteristics. However, such a practice will not be appropriate for lightning surge studies because the MOSA exhibits dynamic characteristics such that the voltage across the arrester increases as the time to crest of the arrester current decreases and the arrester voltage reaches a peak before the arrester current peaks.

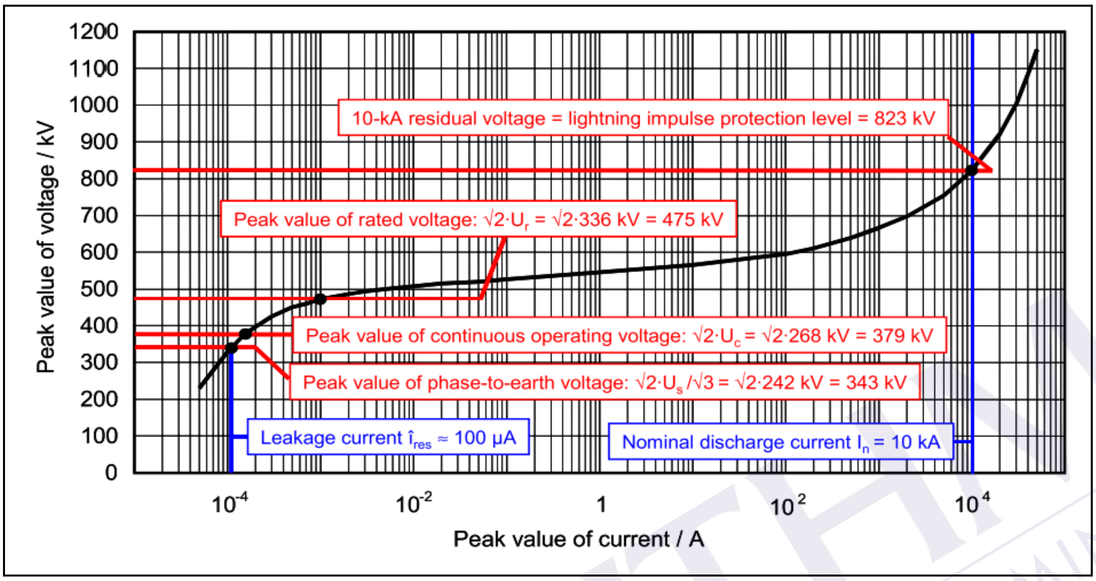

Figure 2.4: U-I Characteristic of typical MO surge arrester in a solidly earthed neutral 420kV system [26]

Further clarification of features MO Surge Arrester can be detailed, example data above is taken to indicate that the typical value can be determined by the Metal Oxide Surge Arrester (MOSA) are connected between phase to earth in 420kV system neutral solid. The readings at nominal discharge current is 10kA will be pointed at 823kV residual voltages where the value is being diverted to the surge arrester when lightning is generated in proportion. U_s means the system voltage of 420kV, there is another term that is commonly used is V_s (voltage input). On the characteristic shown is evidenced by a calculation value $\sqrt{2}.V_s / \sqrt{3}$ = 343kV [27].

At U_c value or may be referred to as V_c is the continuous operation at the surge arrester. This value is the operation without resistance through the lightning arrester. In the graph on the V_c taken from measurements set by the selected type of 268kV surge arrester (datasheet) which is almost 11% higher than the operating voltage of the continuous phase to earth [27].

Competencies surge arrester features overvoltage while managing surplus in the short period of 10 seconds and some manufacturers allow up to 100 seconds which also produces the leakage current value (found in the resistance component) and the current gives rise to a temperature of surge arrester. In Figure 2.4, the resistive component of the leakage current on the current 100µs where the cause is 0.75mA. The actual cause of the temporary time limit is the sudden great increase is in the temperature and the frequent rise in leakage current surge arrester which will shift the current impulse at ground. The addition of a continuous process also resulted in the inability of the surge arrester to return to cool and produce thermally unstable, if it continues to happen then it will reach the level of self-destruction or thermal runaway.

Rated voltage, V_r and continuous operating voltage, V_c has a distinctive relationship, where the ratio was close to 1.25 with few exceptions, so the voltage rating of $V_r = 1.25.V_c = 336kV^2$ [27].

The U-I characteristic also determine the relationship between the power frequency voltage. Minimal voltage increase will lead to an increase of current. It is reserved for transient events within a time range of milli and microseconds, in other words, for switching and lightning overvoltages. The use of power frequency voltage in this area will cause damage to the surge arrester in a moment.

U-I characteristic in the region reflect current larger 100A surge arrester protection features and it is a parameter for the lightning impulse protective level. This shows the voltage drop through the surge arrester terminals when nominal discharge current flows through it. According to the IEC 60099-4 standard , lightning impulse current amplitude is assigned to several classes, from 1.5kA to 20kA . For high-voltage surge arrester only class and 20 kA and 10kA usual taken. The nominal discharge current reflects some characteristics of the surge arrester . Two 10kA surge arrester can be described by different characteristics of each. For example in Figure 2.4, 10kA choose where the statement " Lightning impulse protective level is 823kV 'means the maximum voltage drop at the terminal 823kV, when impressing a lightning impulse current of 8 µs of the virtual front time, 20 µs of virtual time to half - value on the tail and a peak value of 10 kA . This can be seen in figure 2.4 above.

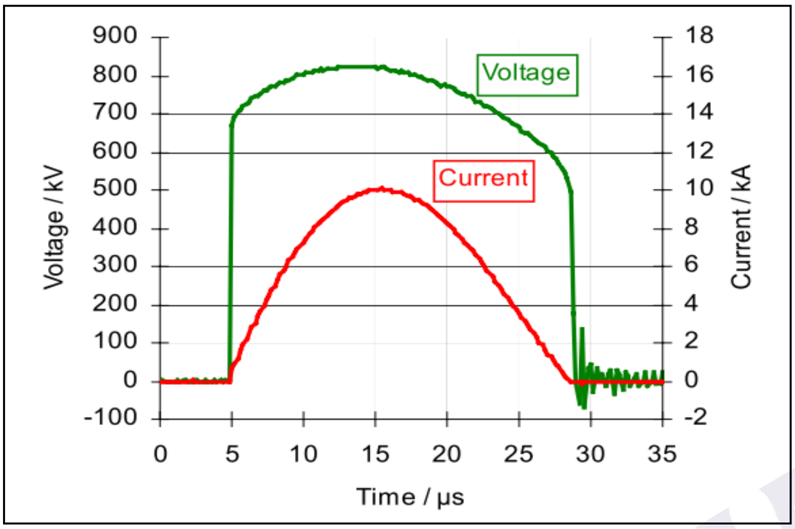

Figure 2.5: Residual Voltage of the Sample Arrester (V_r =336kV) at nominal discharge current (I_n = 10kA) [27]

A lightning impulse protective level of 823 kV terminal means the peak surge arrester current neutralize the normal operation voltage phase to earth, it depends on the factor of 2.4 (divided by ; 823kV/343kV) in the current amplitude increased up to magnitude 8 times (from 100µA to 10kA). In Figure 2.5, the voltage will be revealed at a safe pace through the surge arrester on where in the past 10kA current rating [27].

Generally the U-I characteristic can be explained in detail the characteristics of the surge arrester and it becomes a reference for each used.

2.4 Modelling Surge Arrester

There are various models in developing surge arrester, most of the models are named with the name of the creator of the model. Most of these models are used for comparison in determining the characteristics of the model. Among the greatest often used model is the Conventional or Non-Linear Resistors, Tominaga model, Kim 1 model, Schmidt model, Mardira and Saha model, Haddad model, Pincetti model, Fernandez model and IEEE recommended model. Each model has its own system that gives each model a different justification.

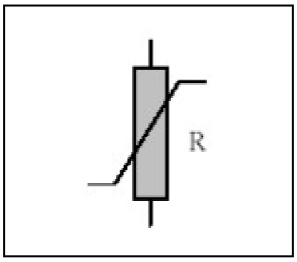

Figure 2.6: Conventional or Non-Linear Resistor Model [3]

In the ATP Program, despite the existence of many types of surge arrester models, the exponential non-linear resistive (in figure 2.6) device is the most widely used. The voltage-current characteristic is represented by several exponential segments, each one defined by equation. (3).

$$i = p\left(\frac{v}{Vref}\right)^{q} \tag{3}$$

In this equation *q* is the exponent, *p* is a multiplier, and *Vref* is an arbitrary reference voltage that normalizes the equation and prevents numerical overflow during exponentiation. The first segment of the device is linear which speeds up the simulation. The second segment is defined by parameters *p*, *q* and a minimum voltage level. When the voltage across the surge arrester reaches a predefined minimum level, the algorithm tries to find a solution to the equation. The more exponential the model, the more precise are the results. The simulation of this model shows that for fast front surges, the peak voltage and current occur at the same time. Therefore it is not suitable to represent phenomena which are frequency dependent [10].

Tominaga et al., (1979) describe that the aim of having a frequency dependent model, based on the preferred performance between voltage and current, led to a model with a varistor in series with an inductance (Figure 2.7). Although the voltage across the device increases with a higher current level, this model is a good approximation to definite situations. For example, a selected inductance for the model could produce accurate results for an 8μs surge front. But for a 2μs surge front, the results would not be satisfactory.

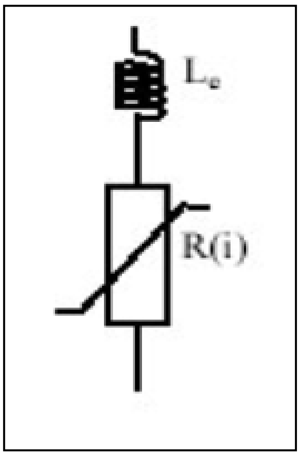

Figure 2.7: The Tominaga et al model [11]

Kim,I et al., (1996) explain it consists of a non-linear inductance in series with a nonlinear resistance. As stated by the authors this model provides a good response characteristic to steep front wave impulse calculation. This model need a computer program to evaluate the nonlinear inductance characteristic and it needs a relatively big number of voltage-current points which are not frequently found in the manufacturer's datasheets.

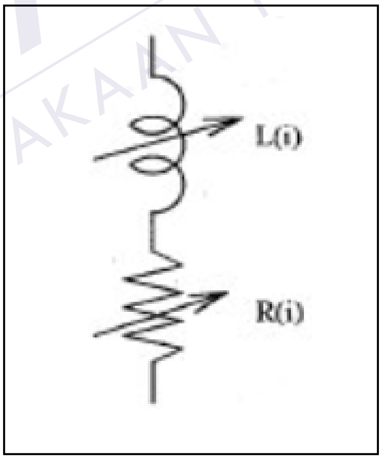

Figure 2.8: The Kim I et al model [8]

W. Schmidt et al., (1989) define the based on their experimental results, the author have established a model for an arrester block shown in figure 2.9. As mentioned by the author, this circuit is able to designate the observed phenomena. The turn-on element A in the equivalent circuit is evaluated from the results of the measurements obtained with the RLC circuit. The other parameters were evaluated from independent measurements or from results described in the literature. The elements R and L are attributed to the ZnO grain, whereas the other elements are related to the grain boundaries. The non-linear resistance consists of the non-linear effect at the grain boundary and the linear resistance of the ZnO grain. The turn-on element A which will account for the dynamic charge distribution at the grain boundary. This function of voltage, rate of rise of voltage and the time constant T for reaching the equilibrium of electrons and holes at the grain boundary. An inductance of 1µH/m was assumed. The simulation of the equivalent circuit resulted in an excellent fit to experiment despite the use of data of other investigators to determine the components of the model. In order to achieve an accurate simulation, it must be done very carefully in the course of other work.

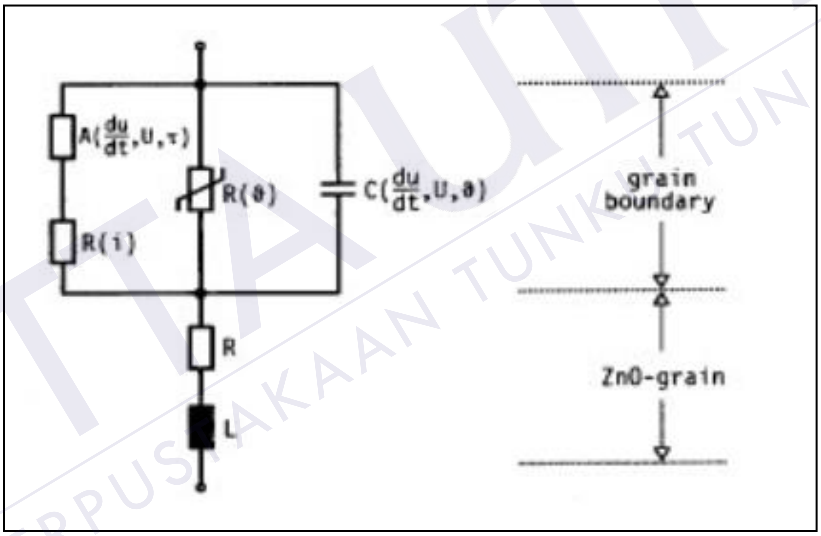

Figure 2.9: The Schmidt et al model [12]

Mardira and Saha, (2011) explicate that the IEEE model was simplified, the resistive devices were eliminated, and another way to describe the parameters was selected (Figure 2.10). The authors state that the model yields good results for a current discharge with an 8x20µs waveform, and does not oblige an iterative process. However, it does not work properly for a wide variety of waveforms.

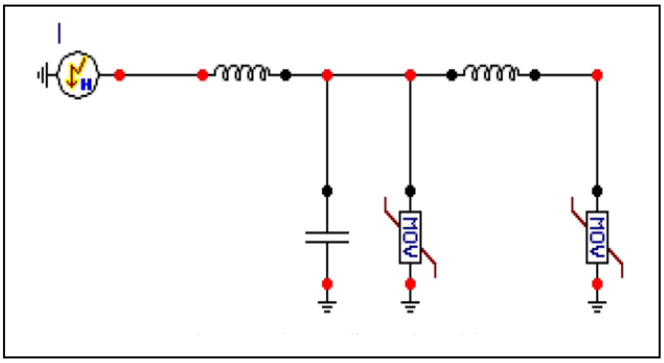

Figure 2.10: The Mardira and Saha Model [13]

The proposed equivalent circuit Haddad model is shown in figure 10. It comprises two series sections which are one to represent the resistance of zinc oxide grains (R_{grain}) and the self-inductance (L_{body}) due to the physical size of the arrester body and a parallel network to represent the properties of the inter granular layers. One branch of the network carries the high amplitude discharge current, so that the ranch has a highly non-linear resistance R_{lg} and a low value inductance L_{c1}. The second branch has a linear resistance R_c and a higher value inductance L_{c2} to account for the delay in low-current fronts and the multiple–current path concept. A capacitive element C_{lg} to represent the arrester shunt capacitance was also included in the equivalent network. The simulation of the model resulted in an excellent fit to experiment conducted in the laboratory despite that the model parameters are determined experimentally which is sometimes difficult to achieve [14].

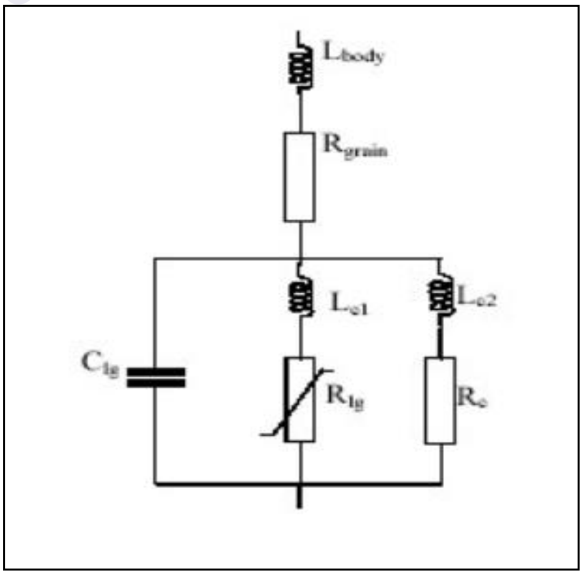

Figure 2.11: The Haddad et al Model [14]

Pincetti et al, (1999) substantiate that in this model, also derived from the IEEE Model, all necessary data are easily collected in datasheets, there is no need for an iterative correction of the parameters, and the model's performance is accurate (Figure 2.12). Besides, the capacitance is eliminated, and only electrical parameters are used. The two parallel resistances are substituted for only one, in order to avoid numerical overflow.

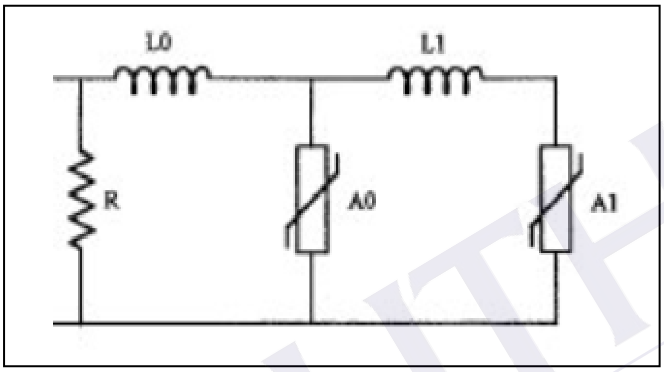

Figure 2.12: The Pincetti et al Model [15]

The proposed model is shown in figure 2.13 and derives from that in IEEE Model. It is intended for the simulation of the dynamic characteristics for discharge currents with front times starting from 8µs. Among the non-linear resistances A_0 and A_1 only the inductance L_1 is taken into account. R_0 and L_0 are neglected. C_0 represents the terminal-to-terminal capacitance of the arrester. The resistance R in parallel to A_0 is intended to avoid numerical oscillations. The model in figure 2.13 works essentially in the same way as that proposed in IEEE Model [16].

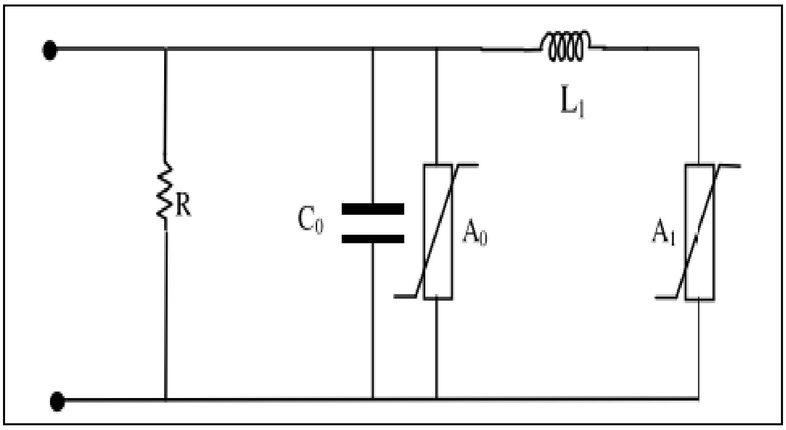

Figure 2.13: The Fernandez et al Model [16]

A model IEEE Working Group, (1992) which can represent the effects mentioned previously over this range of times to crest is shown in Figure 2.14. In this model the non-linear V-I characteristic is represented with two sections of non-linear resistances designated A_0 and A_1. The two sections are separated by an R-L filter. We have two situations:

a. For slow-front surges, the impedance of the R-L filter is extremely low leading to consider that the two nonlinear resistors of the model are practically connected in parallel.
b. For fast-front surges, the impedance of the R-L filter becomes more important. By this fact the high frequency currents are forced by the RL filter to flow more in the non-linear section designated A_0 than in the section designated A_1. Since characteristic A_0 has a higher voltage for a given current than A_1, the result is that the arrester model generates a higher voltage. The inductance L_0 represents the inductance associated with the magnetic fields in the immediate vicinity of the arrester. The resistor R_0 is used to avoid numerical instability when running the model with a digital program. The capacitance C_0 represents the external capacitance associated to the height of the arrester.

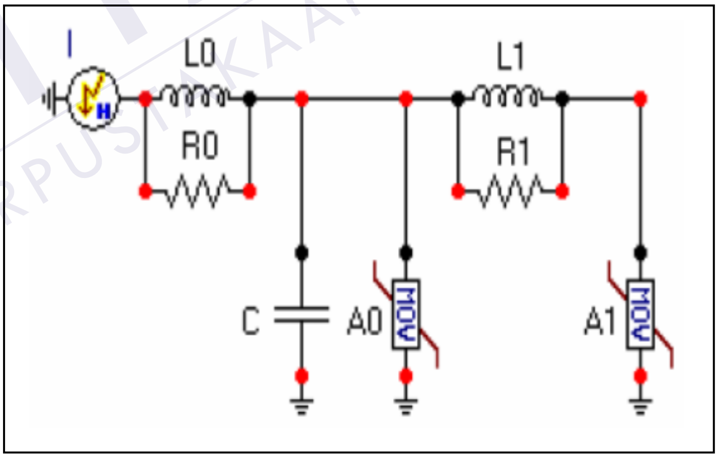

Figure 2.14: The IEEE Model [17]

2.5 IEEE Recommended Model

Research aiming to create a mathematical model of metal oxide surge arresters (MOSA), which enables modelling of current voltage relations in any work conditions, have been carried out for many years. Numerous models are the result of research carried out hitherto. They are presented, among others, in shown in "2.4 Modelling Surge Arrester". Calculations was used on this model of which parameters can be calculated using the experimental values of residual voltages presented in manufacture catalogues and basic dimensions of surge arresters.

The model has been worked out by the IEEE Working Group 3.4.11 (The Institute of Electrical and Electronic Engineering) to calculate voltage-current dependencies in case of impulse currents flow with times of accretion of wave front from 0.5µs to 45µs (Figure 2.15). It contains two non-linear resistors A_0 and A_1 with various voltage-current characteristics, separated by a L_1-R_1 filter.

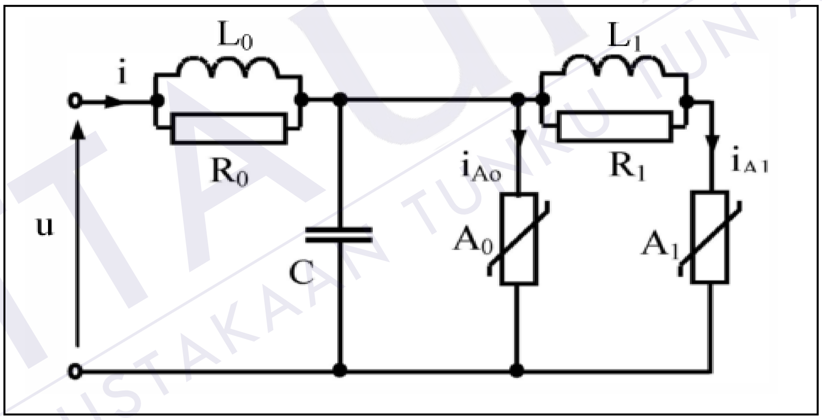

Figure 2.15: Model of surge arresters worked out by IEEE [18]

A capacitor C represents capacitance of the arrester. Towards improve stability of calculations, a resistor R_0 is connected parallel to the inductance L_0. Parameters of linear elements and characteristics of non-linear resistors of the schema can be determinate from results of investigations of arrestor, published in catalogues, as well as from elementary dimensions of the column of varistors. Characteristics of varistors A_0 and A_l of surge arresters with rated discharge current Ir is represented by formulas:

$$A_0 = A_{w_0} \frac{U_{8/20:\, I_r}}{1.6} \quad (4)$$

$$A_1 = A_{w_1} \frac{U_{8/20:I_r}}{1.6} \tag{5}$$

Where $U_{8/20:Ir}$ residual voltage with rated current impulse I_r of times 8/20 µs. A_{w0}, A_{w1} dependencies approximated by use of formulas

$$A_{w0} = c_0 \; i_{A_0}^{0,051} \tag{6}$$

$$A_{w1} = c_0 \; i_{A_1}^{0,0507} \tag{7}$$

iA_0, iA_1 densities of currents in varistors A_0 and A_1 c_0 , c_1 are constants (c_0 = 1.378, c_1 = 1.083)

Parameters of linear elements L_0, R_0, L_1, R_1 and C are expressed by dependencies

$$L_0 = 0.2 \frac{d}{n} \; [\mu H] \tag{8}$$

$$R_0 = 100 \frac{d}{n} \; [\Omega] \tag{9}$$

$$L_1 = 15 \frac{d}{n} \; [\mu H] \tag{10}$$

$$R_1 = 65 \frac{d}{n} \; [\Omega] \tag{11}$$

$$C = 100 \frac{n}{d} \; [pF] \tag{12}$$

where d is height of the column of varistors, m and n are number of parallel varistor columns [17].

As it appears from dependencies (2-10) the basis to calculating the parameters of elements of the model are results of studies of decreased voltage, presented in firm catalogues as well as main dimensions of the column of varistors. Correcting values of constants c_0, c_1 and inductance L_l can augment accuracy of calculations in Figure 2.16 [18].

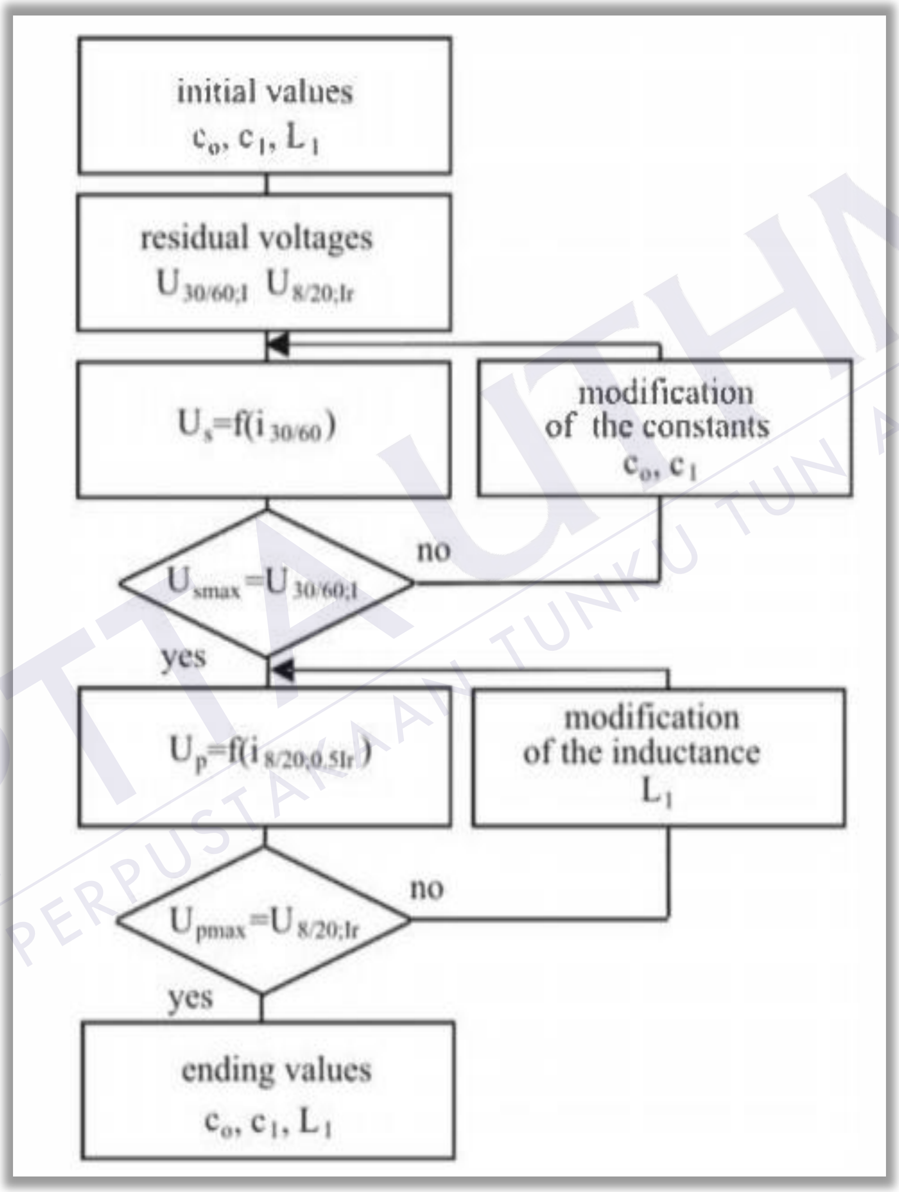

Figure 2.16: The Block Scheme of the Correcting Process of the Model Parameters [18]

As an example, the determination of the metal- oxide model parameters for a one column arrester with an overall length of 1.45 meters. The discharge voltage or residual voltage for this arrester is 248kV and the switching-surge discharge voltage, Vss is 225kV for a 3kA, 300 x l000µs current wave shape [17].

Arrester Information Required

1. d - length of arrester column in meters (use overall dimensions from catalogue data)
2. n - number of parallel columns of metal-oxide disks
3. V_{10} - discharge voltage or residual voltage for a l0kA, 8 x 20us current, in kV.
4. Vss - switching-surge discharge voltage for an associated switching-surge current, in kV

Using the equations presented previously in this report, the initial values for L_0, R_0, L_1, R_1 and C are determined as follows:

$$L_0 = 0.2 \frac{d}{n} \; [\mu H] \tag{8}$$

$$L_0 = 0.2 \frac{1.45}{1} \; [\mu H]$$

$$= 0.29 \mu\text{H}$$

$$R_0 = 100 \frac{d}{n} \; [\Omega] \tag{9}$$

$$R_0 = 100 \frac{1.45}{1} \; [\Omega]$$

$$= 145 \; \Omega$$

$$L_1 = 15 \frac{d}{n} \; [\mu H] \tag{10}$$

$$L_1 = 15 \frac{1.45}{1} \; [\mu H]$$

$$= 21.75 \; \mu\text{H}$$

REFERENCES

1. Karthik Munutkutla, Vijay Vittal, Gerald T.Heydt, Daryl Chipman, Brain Keel, “A Practical Evaluation of Surge Arrester placement for Transmission Line Lightning Protection,” IEEE Transactions on Power Delivery, Vol.25, No.3, July 2010
2. Kresimir Fekete, Srete Nikolovski, Goran Knezevic, Marinako Stojkov, Zoran Kovac, “Simulation of Lightning Transients on 110kV Overhead cable Transmission Line Using ATP-EMTP,” IEEE , 978-1-4244-5795-3/10, 2010
3. A. Bayadi, N.Harid, K. Zehar, S.Belkhiat, “Simulation of Metal Oxide Surge Arrester Dynamic Behavior Under Fast Transient,” The International Conference on Power System Transients, New Orleans, 2003
4. A. Bayadi, N. Harid, K. Zehar, “Dynamic Surge Arrester Protection Performance On High Voltage Systems Using EMTP” 2003
5. Zhao Shaofeng, Gao Hongliang, “Analysis of the Operational Effect of 500kV Line Zinc Oxide Arrester” IEEE, 978-1-4577-1600-3/12, 2012
6. Zhao Zhida.” High Voltage Engineering”,Beijing: China Electric Power Press,2006.
7. He Zebing.”Analysis of Line Type MOA Using in overhead Transmission Line” Master Degree Thesis of South China University of Technology,Guangzhou:2010.
8. Kim, I.; Funabashi, T.; Sasaki, H.; Hagiwara, T.; Kobayashi, M.; “Study of ZnO arrester model for steep Front Wave”, IEEE Transactions on Power Delivery, Vol. 11, Nº2, April pp. 834-841, 1996.
9. Wang Yong, Xie Pu, Zhao Jin Cheng and Zhang Gui Fang,”Simulation of Line Surge Arrester for Lightning Protection in 10kV Transmission Line” Ordance Engineering College, China. CICED 2008.
10. André Meister1, Rafael Amaral Shayani2, Marco Aurélio Gonçalves de Oliveira2, ”Comparison Of Metal Oxide Surge Arrester Models In Overvoltage Studies” International Journal of Engineering, Science and Technology, Vol. 3, No. 11, 2011, pp. 35-45

11. Tominaga, S., Azumi, K., Shibuya, Y., Imataki, M., Fujiwara, Y., Nichida, S., 1979. Protective performance of metal oxide surge arrester based on the dynamic v-i characteristics , IEEE Trans. Power App. Syst., Vol. PAS-98, pp. 1860-1871.
12. W. Schmidt, J Meppelink, B. Richter, K. Feser, L. Kehl and D. Qiu, “Behavior of MO- surge arrester blocks to fast transients”, IEEE Transactions on Power Delivery, Vol. 4, N° 1, pp. 292-300, 1989.
13. Mardira, K. P., Saha, T. K., 2011. A simplified lightning model for metal oxide surge arrester , The University of Queensland – Austrália, Downloaded September 2011
14. A. Haddad and P. Naylor, “Dynamic response of ZnO arresters under high amplitude fast impulse currents”, International power electric conference, pp. 292-297, 1999.
15. Pinceti, P., Giannettoni, 1999. M., A simplified model for zinc oxide surge arresters, IEEE Transactions on Power Delivery, Vol. 14, No. 2, pp.393-398.
16. Fernandez F., Diaz R., “Metal oxide surge arrester model for fast transient simulations” paper 144, International conference on power system transients, IPST’01, 20-24 June 2001.
17. IEEE Working Group 3.4.11, “Modelling of metal oxide surge arresters”, IEEE Transactions on Power Delivery, Vol. 7, N° 1, pp. 302-309, 1992.
18. Saad Dau GECOL, ”Modelling Of Metal Oxide Surge Arresters As Elements Of Overvoltage Protection Systems” International Conference on Lightning Protection (ICLP), Vienna, Austria, 2012.
19. K.Saravanababu, P.Balakrishnan, Dr.K.Sathiyasekar, “Transmission Line Faults Detection, Classification, and Location Using Discrete Wavelet Transform” International Conference on Power, Energy and Control (ICPEC), 2013.
20. T.A Short, “Electric Power Distribution Handbook” CRC Press LLC, 2004.
21. L.Prikler and Høidalen, H. K., “ATPDRAW Version 5.6 for Windows 9x/NT/2000/XP/Vista User’s Manual, 2009.
22. Høidalen, H. K., ATPDRAW Version 3.0 for Windows 9x/NT/2000/XP/Vista User’s Manual, 1996.
23. Alternative Transient Program Online, February 2010.

24. Juan A. Martinez-Velasco, Ferley Castro-Aranda, "Modelling of Overhead Transmission Lines for Lightning Studies" International Conference on Power Systems Transients (IPST'05), Canada, on June 19-23, 2005 Paper No. IPST05 – 047

25. Nor Hidayah Nor Hassan, Ab. Halim Abu Bakar, Hazlie Mokhlis, Hazlee Azil Illias, "Analysis of Arrester Energy for 132kV Overhead Transmission Line due to Back Flashover and Shielding Failure" IEEE International Conference on Power and Energy (PECon) 2012.

26. Volker Hinrichsen, "Metal-Oxide Surge Arresters in High-Voltage Transmission and Distribution Systems" Siemens PTD, Berlin 2001.

27. Volker Hinrichsen, 2001, "Metal-Oxide Surge Arresters Fundamental" 1st Edition, Siemens PTD, Berlin.

28. Christos A. C., Fani A.A, Ioannis F. G, Ioannis A. S. "Simulation of Metal Oxide Surge Arresters Behavior" IEEE 978-1-4244-1668-4, 2008

29. T. Hara, O. Yamamoto, "IEE Proceedings on Generation, Transmission and Distribution," 1996

30. A.R Hileman, "Insulation Coordination for Power System", New York. *Marcel Dekker, Inc*, 1999.

31. IEEE Modelling and Analysis of System Transient Working Group, "Modelling Guideline for Fast Front Transients", IEEE Transaction on Power Delivery, vol. 11,pp-493-506,1996.

32. M. G. Comber, M.G. Vermilye, S.F. LaCasse, R.M. Reedy. "Lightning Protection of Transmission Lines with Polymer-Housed Surge Arresters" EEI T&D Meeting, Palm Beach, FL May 18, 1994

33. A.M. Mousa, "The soil ionization gradient associated with discharge of high currents into concentrated electrodes," IEEE Trans. on Power Delivery, vol. 9, no. 3, pp. 1669-1677, July 1994.

34. M. Jaroszewski, J. Pospieszna, P. Ranachowski, F. Rejmund "Modeling of overhead transmission lines with line surge arresters for lightning over voltages" CIGRE, Poland 2008.

35. S.Bedoui, A. Bayadi, A.Haddad, "Analysis of Lightning Protection with Transmission Line Arrester Using ATP/EMTP: Case of an HV 220kV Double Line" UPEC 2010.