Metal Oxide Surge Arresters Modelling in Temporary Overvoltage Conditions

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Abstract—**Insulation and protection system as part of the system of high voltage has been improved stability and reliability of distribution system is designed correctly and uses proper equipment. Surge Arrester (SA) is used for protection of lightning and switching surge in distribution system of Provincial Electricity Authority: PEA. This paper to design modelling of Metal Oxide Surge Arresters (MOSA) in 22kV Distribution System by ATP-EMTP program and compares the experimental testing of surge arrester product A. the comparison of test results indicate that leakage currents error less than 4.4 percentage. The proposed model is used for leakage currents of distribution system analysis. Moreover, it will be useful to select or design suitable SAs for using in places with salt conditions, high rainfall, high wind speeds and high humidity.**

Index Terms—**surge arrester, predicting lifetime, distribution system**

I. INTRODUCTION

High voltage systems are often subject to transient overvoltages of internal or external origin. The resultant surges travel along the transmission line and can cause damage to unprotected terminal equipment. Corona losses and the earth return path can attenuate and distort the surges, but the magnitude of the surge may still exceed the insulation level of the equipment. Surge arresters (SAs) provide a limitation of the overvoltage to a chosen protective level.

SAs are used for protection of power system equipment against surge overvoltages because they offer low protection levels and permit the reduction of insulation levels, which has a substantial effect on the cost of high voltage equipment. Early overvoltage protective devices were simple spark gaps capable of supporting essentially no voltage during conduction. Major development steps in the evolution of the arrester technology, which are in the direction of the optimum arrester characteristic, have been made since then.

The ideal SA would be one that would start conduction at a voltage level at some margin above its rated voltage, hold that voltage level with as little variation as possible for the duration of the overvoltage surge and cease conduction as soon as the voltage across the arrester returns to a value close to the rated voltage. Such an arrester would therefore conduct only that current required to reduce the surge voltage to the arrester protective level, and absorb the energy that is associated with the overvoltage [1].

Apart from the ground wires, the installation of SAs is considered the most effective protection against these transient overvoltages, especially for areas with high ground resistances and keraunic level. The arresters are installed between phase and earth and act as bypath for the overvoltage impulse. They are designed to be insulators for nominal operating voltage, conducting at most few milliamperes of current and good conductors, when the voltage of the line exceeds design specifications to pass the energy of the lightning strike to the ground. Several different types of arresters are available (e.g. gapped silicon carbide, gapped or non-gapped metal oxide) and all perform in a similar manner: they function as high impedances at normal operating voltages and become low impedances during surge conditions. The conventional silicon carbide arresters with gaps have been replaced in the last years by gapless metal oxide arresters, providing significant advantages, namely [1]-[3]:
- Superior protective characteristics,
- Higher reliability,
- Better performance under polluted environment,
- Ability to withstand higher temporary overvoltages and
- Multiple voltages surges for longer periods of time.

In comparison to arresters with gaps, metal oxide arresters reliably limit the voltage to low values, due to the high nonlinearity of the V-I characteristic, even for steep impulses, with very fast response time. The main characteristics of a surge arrester are: maximum continuous operating voltage (MCOV), which must be greater than the maximum network operating voltage with a safety margin of 5%, rated voltage, which must be 1.25×MCOV, protection level and capacity to withstand the energy of transient overvoltages.

SAs technology has been characterised by both the gradual improvement of the various arrester components, and more importantly by four successive major steps: the simple spark gap, the valve-type arrester, the introduction of active gaps and the gapless metal oxide arrester. The latter is associated with ZnO varistors, and the two former arresters were made with SiC resistors. The introduction of each arrester had an important impact on protection

levels and cost of the power system equipment as a whole [1]-[5].

The purpose of this paper is to present a simplified model for MOSA for typical temporary overvoltage and better procedures to find its parameters identification from the experiment test. The structure of the proposed model is based on the well-known frequency dependent model recommended by the IEEE W.G 3.4.11 [2] with minor adjustments to give accuracy to the dynamic behavior of the MOSA.

II. METAL OXIDE VARISTOR [1]

The metal oxide varistor (MOV) is made of a ceramic based on zinc Oxide (ZnO), a semiconducting material, with the addition of such selected doping elements such as Bi, Sb, Co and Mn. During the sintering process at the temperature approaching 1200 ℃ the adjacent powder particles are combined in large grains. The nonregular grains containing mainly ZnO are good electrical conductors while their boundaries, in contrast, form an insulating layer not more than 0.2mm. thick. Ten or more was doping metal oxides (about 10 percent by weight) influence both the conductivity of the actual ZnO grains and the properties of grain boundaries. The purity and fineness of the metal oxide powders and the homogeneity of the mixture are therefore, of vital importance to the quality of the end-product. Most of the bismuth oxide accumulates forming as a separate phase at the triple points at which the adjacent grain edges are in contact. The grain boundaries however, are not completely free of bismuth. The fraction of a monolayer of both bismuth and bismuth oxide atoms is found at these boundaries. This interface affects profoundly the behaviour of the ceramic's varistor.

III. THERMAL PERFORMANCE OF ZNO SURGE ARRESTERS

Compared with SiC gapped arresters, ZnO gapless metal oxide arresters offer a protection closer to the ideal. However, because these arresters contain no gaps, a leakage current flows through the material at working voltages which causes power losses and heating of the ZnO elements. This can be dangerous to the stability of the arrester, particularly in the low conduction regime where the V-I characteristic of ZnO material is very sensitive to temperature. Badly dimensioned arresters are exposed to the risk of thermal runaway. A further practical problem relating to power system usage concerns pollution of arresters, which can cause abnormal voltage and current distribution in the arrester in both steady state and transient conditions. [1], [5]-[6]

A. Heat Dissipation Capability and Thermal Stability of ZnO Surge Arresters

In surge arresters, the ZnO valve elements are generally located in an environment consisting of gas or solids which will limit cooling of the valve elements when submitted to their continuous operating voltage. As can be seen on Fig. 1, for the Thermal performance of ZnO surge arresters same applied voltage level, any

temperature rise would increase the current because of the high sensitivity to temperature of the V-I characteristic in the low conduction regime. A sort of positive feedback will occur and may cause damage to the arrester if the material heat is not dissipated. For this reason, thermal stability is one of the most important application criteria for metal oxide surge arresters. It is frequently analysed with the help of a heat loss input heat balance diagram.

The thermal stability of ZnO surge arresters is affected by ambient temperature and heat dissipation capability, impulse degradation and ageing. To obtain thermal stability, the electrical power dissipation in the element must be balanced against heat output to the environment. Near the thermal equilibrium, it is possible to express the thermal dissipation capacity Q of a surge arrester as:
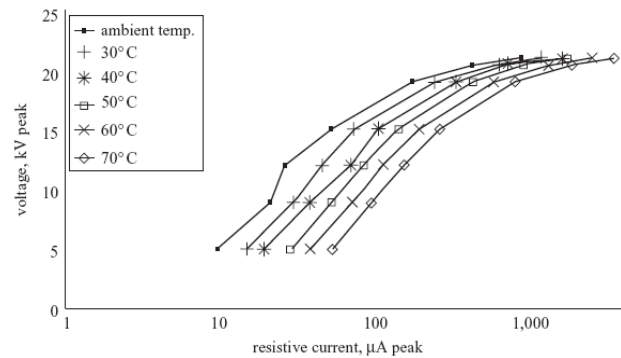

Figure 1.   Temperature dependence of ZnO voltage current characteristic [1]

Bilevel programming problem (BLPP) is a hierarchical optimization problem, which includes an upper levels decision maker and a lower levels decision maker. Both of them have the objective functions and constraint conditions. This problem was proposed by Stackelberg, and known as Stackelberg problem. The mathematical model of this kind of problems can be written as follows:

$$Q = C_T \left(T - T_a \right) \qquad (1)$$

where T is the temperature of ZnO valve elements, T_a the ambient temperature and C_T the thermal dissipation factor. The heat generation, P, which is voltage and material composition dependent, may be approximated by:

$$P = Ae^{-\left(W_C/kT\right)} \qquad (2)$$

where W_C is the activation energy, $k = 0.86 \times 10 \text{eV/K}$ (Boltzmann constant), T is the temperature of the material and A depends on the applied voltage level and the physical dimensions of the valve elements [1], [7]-[9].

B. Thermal Stability of MOSA

Thermal stability is one of the most important application criteria for metal oxide surge arresters. It is frequently analysed with the help of a heat loss-input balance diagram (Fig. 2). As shown in Fig. 2, the power dissipation of a valve element (broken line), due to a constant 50Hz voltage, is extremely temperature dependent. At the same time the ability of the element structure to dispose of heat is nearly proportional to its temperature rise above the ambient (solid line).

Consequently, there are two intersections of the two curves: one at low temperature a so called stable operating point and the other at high temperature – a so called instability threshold. To obtain thermal stability, the electrical power dissipation in the element must be balanced against heat output to the environment. If power dissipation exceeds heat losses from the element, (regions I and III in Fig. 2) then excess energy is stored in the element and its temperature slowly increases. Conversely, if heat loss exceeds power dissipation, temperature of the element decreases, (region II in Fig. 2). Consequently, the valve element temperature always settles at the stable operating point between regions I and II, as long as the initial valve temperature does not exceed the instability threshold.
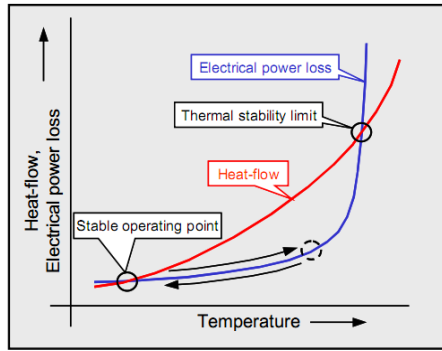

Figure 2. Thermal stability condition of MOV arresters [8]

IV. METAL OXIDE ARRESTERS CIRCUIT MODELS [2]-[5]

MOSA presents a highly non-linear voltage current characteristic (Fig. 3), according to the equation:

$$I = kV^{\alpha} \ , \ a > 1 \tag{3}$$

where:

I is the current through the arrester,

V is the voltage across the arrester,

a is a non-linearity exponent (measure of non-linearity) and

k is a constant depended on the arresters type.

The value characterizes the non-linear V-I characteristic; the greater the value of a, the "better" the varistor. Modern arresters have values of a between 25 and 60.

V-I characteristic must be determined using measurements performed with brief pulse currents, such as an 8/20 μs waveshape, in order to avoid effects such as varistor heating. Furthermore, the interval between the consecutive surges in the laboratory must be sufficiently long to allow varistor revert room temperature prior to the application of the consequent surge. Data and measurements on characteristics of MOSA indicate a dynamic behaviour. The residual voltage of the arrester depends on the current surge waveform shape and increases as the current front time decreases. This increase of the residual voltage could reach approximately 6% when the front time of the discharge current is reduced from 8 μs to 1.3 μs [10]-[13].
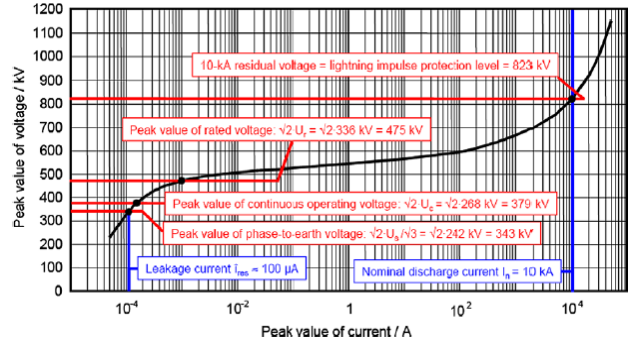

Figure 3. Metal oxide surge arrester's voltage-current characteristic [9].

Based on the above, it can be concluded that MOSA cannot be modelled by only a non-linear resistance, since their response depends on the magnitude and the rate of rise of the surge pulse. MOSA behave differently for various surge waveforms, depending each time on the peak and the slope of the overvoltage. Several frequent dependent models have been proposed, in a way that the model simulation results correspond to the actual behaviour of the arrester. The existing models differ in the parameters' estimation procedure, but all are efficient enough to simulate the frequency-depended behavior of the arresters.

V. THE EXPERIMENT, PROPOSED MODEL AND RESULTS

A. Equipment for the Experimental

The new distribution class MOV arresters are used in this study. The rated voltage, MCOV and rated discharge current are 21kV, 17kV and 5kA, respectively. Those are tested in the High-Voltage Laboratory of Rajamangala University of Technology Lanna Chiang Rai, Chiang Rai. The test circuit of the MOV arresters is provided schematically in Fig. 4. The voltage elevation transformer is supplied by a Variac, thus resulting in a controlled gradual voltage increase. The transformer secondary coil is connected in series resistance R0 = 2MΩ and parallel with a capacitive voltage divider composted by capacitors C1 and C2 respectively. In parallel with the voltage divider is the series connected of the insulator. The voltage across C2 is measured by a scope meter (190B Scope Meter Series: Fluke) and connection to a computer where it is recorded and visually displayed with the use of appropriate software. The technical characteristics of the capacitors C1 and C2 were 224pF, 100kV/50Hz and 2μF, 1000V/50Hz, respectively [12]-[16].

B. Proposed Model

As the proposed model, there 3 parameters composted of resister (R), a capacitor (C) and a nonlinear resistance (A0) in Fig. 5. The resistance R is calculated form (4).

$$R = 0.0002V^3 - 0.0073V^2 + 0.1047V - 0.467 \tag{4}$$

where:

R= resistance of AS (Ω)

V= Testing voltage (kV)

The capacitance of model is stray capacitor of AS can be obtained by measurement and it is 4.75. The nonlinear resistance approximated by V-I Characteristic as shown in Fig. 6 and Fig. 7 is V-I curve of nonlinear resistance in ATP Program.
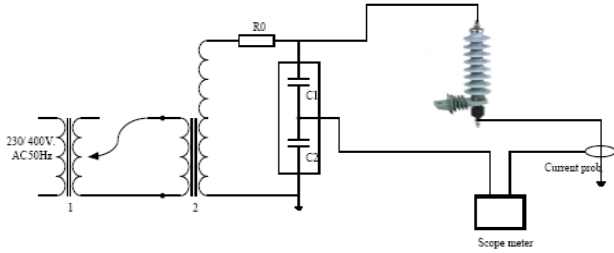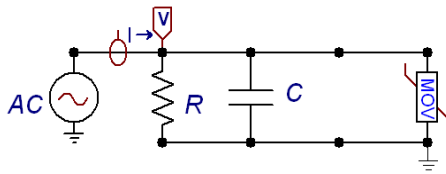

Figure 4. Schematic of testing

Figure 5. Propose modeling

TABLE I. THE LEAKAGE CURRENT WHICH FLOWING THROUGH THE ARRESTER UNDER POWER FREQUENCY AC VOLTAGE

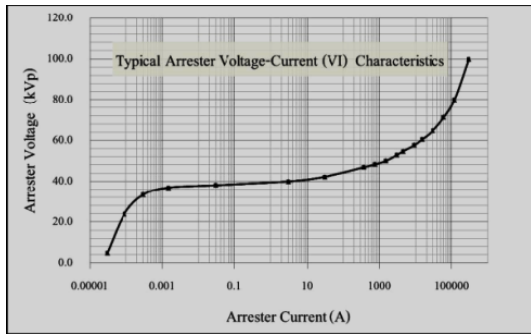| Voltage Level (kVrms)	Leakage current (mA)	Temperature of Arrester T_2(°C)	Temperature of Room T_1(°C)	Difference of Temperature T_2-T_1(°C)
12.7	0.08	32.2	31.2	1
17	0.16	31.5	30	1.5
22.3	0.31	32.2	29	3.2
25	0.6	47.2	30	17.2
25.6	0.8	>52.7	31	21

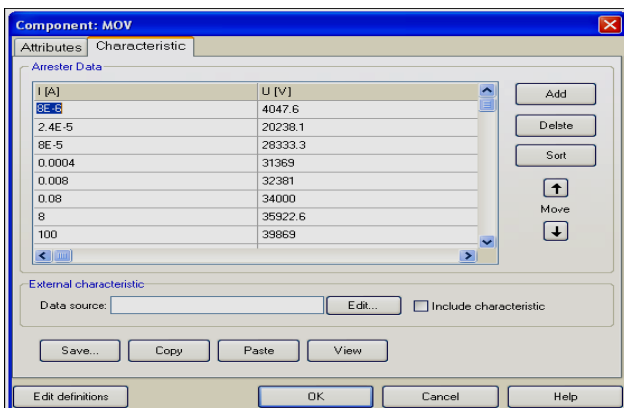Figure 6. V-I Characteristic of arrester [9]

Figure 7. V-I curve of nonlinear resistance in ATP program

C. Experiment and Simulation Results

1) Experiment result

In the experiment, the leakage current which is flowing through the arrester under power frequency AC voltage is a total current. The leakage current is related to increases in temperature. The temperature variation and leakage current for the arrester, as a function of the applied time of voltage, is shown in Fig. 8. The temperature variation with leakage current for the arrester, as a function of the applied time of voltage, is shown in Fig. 9. With a temperature rise occurs, the initial leakage current is higher, until the heat generation is greater than the heat dissipation.
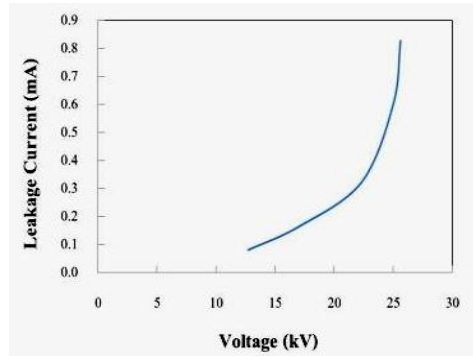

Figure 8. Voltage and current curve of MOV arresters. of MOSA at 12.7kVrms

From Table I, at 17kVrms voltages testing the leakage current are 0.16mA and differential of temperature is 3.2 Celsius. However, because these arresters contain no gaps, a leakage current flows through the material at working voltages which causes power losses and heating of the ZnO elements.
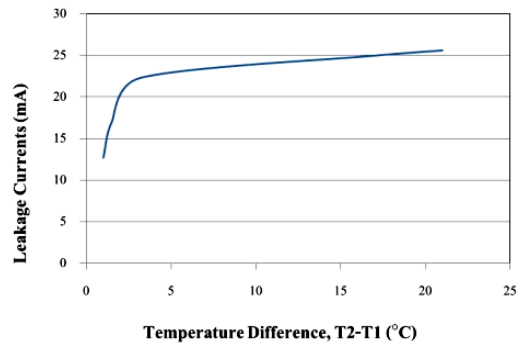

Figure 9. The temperature and current curve.

2) Simulation result

The model presented here derives from the standard model, with some minor differences. The parameter selection is based on the information provided from the performance data sheet. Fig. 5 shows the proposed model implemented on ATP-EMTP with different voltage source magnitude. To put into evidence the accuracy of the proposed model, the comparison between the simulation results and the experimental are shown in Table II. The relative errors are also calculated, the model has a relative error lower than 4.4% for overvoltage under power frequency. Fig. 10 shows the results of the residual voltage test simulation.
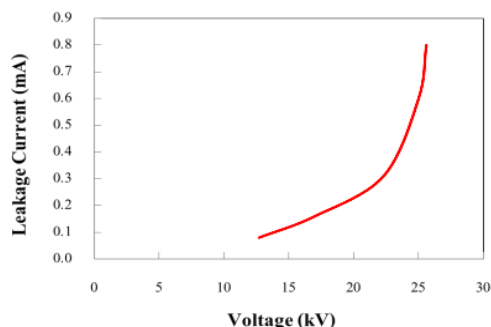
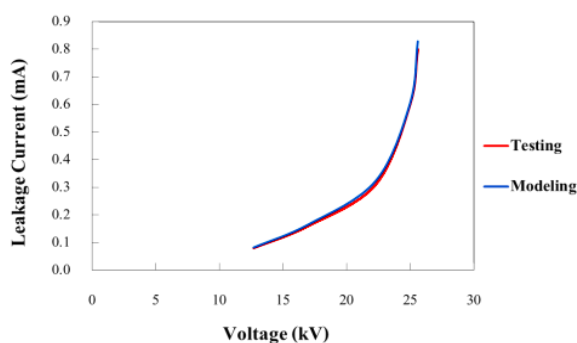Figure 10. Simulation propose model at 12.7kVrms

Figure 11. Compare of experiment and Simulation propose model of MOSA at 12.7kVrms

TABLE II. THE COMPARE EXPERIMENT AND SIMULATION OF MOSA UNDER POWER FREQUENCY AC VOLTAGE

Voltage Level (kVrms)	LC of experiment (mA)	LC of Simulation Model (mA)	% Errors
12.7	0.08	0.0818	2.31
17	0.16	0.165	3.32
22.3	0.31	0.324	4.37
25	0.6	0.605	0.77
25.6	0.8	0.829	3.57

VI. CONCLUSIONS

Metal oxide surge arresters are used for protection of high and low voltage electric devices against overvoltages. Mathematical models of MOSA should properly represent current-voltage dependencies of varistors during influence overvoltages. The results of computer simulations were compared with the experimental data in Table II and Fig. 11. In this experiment, the temperature of MOSA depends on leakage current and power loss. Thus, analysis of thermal images can be help in the assessment and prediction of the leakage current of MOSA. The propose model was verified experimentally of medium rate voltage. For voltage current of MOSA under power frequency AC voltage the model has a maximal errors is 4.4 presented the proposed model is used for leakage currents of distribution system analysis. Moreover, it will be useful to predicting lifetime of Zinc Oxide surge arresters

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