

# Metal oxide varistor model with hysteresis loop for ATP/EMTP

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**Abstract** - Metal oxide varistor (MOV) is a basic component of overvoltage protection systems in low-voltage power nets. MOV ensured overvoltage protection by resistance drop during the flows of surge current. So far, during computer simulation MOV was presented as arrangements of linear and non-linear elements. In these models simulation accuracy is determined by elements determine precision. This paper presents method which unambiguously described V-I characteristic of MOV. This method and new discrete MOVs model was used to computer simulation in program EMTP. Additionally the comparison was made between new model of varistor and model MOV which is used in ATP/EMTP. New discrete algorithm can be used to computer implementation of ant non-linear elements. New model is particularly useful when the voltage increase/decrease violently in system which is analyzed.

**Index Terms** - MODELS, non-linear element, discrete model, surge arrester, MOA, MOV.

## I. INTRODUCTION

**S**URGE Protective Devices (SPD's) are designed to reduce the random energy surges of voltage transients and electrical noise on the power supply line. Volatile transients and noise are present in utility power lines, data networks, telephone lines, closed circuit and cable tv feeds, and any other power or control lines connected to electronic equipment.

Surge Protective Devices can be used individually or as part of a coordinated application strategy, called Network Protection, to protect sensitive electronic equipment, in industrial, commercial and residential locations, from the stress and degradation inflicted by voltage transients.

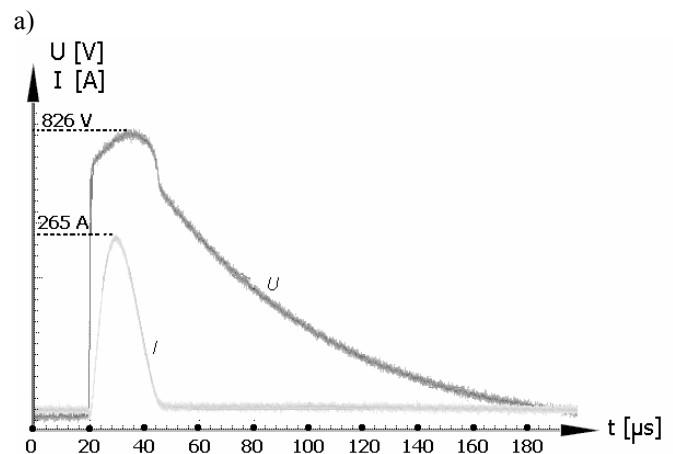
Electrical and electronic equipment are susceptible to disruption by direct lightning strokes, by ESD (electrostatic discharges), by LEMP (lightning electromagnetic pulse), by NEMP (nuclear electromagnetic pulse), and by SEMP (switching electromagnetic pulse). The lightning safety engineer should consider resistive coupling, inductive coupling and capacitive coupling situations in overvoltage analysis. Good model with precise approximation of SPD characteristic is most essential to quality of simulation results.

So far computer simulation in ATP-EMTP uses MOA element or combination of linear and non-linear elements to model SPD. Different models with linear and non-linear

elements create difficulties with approximation of these parameters. Those parameters should be measured in static and dynamic conditions. Another problem appears with MOA element – only 16 points on V-I characteristic. It is very difficult to approximate non-linear V-I characteristic with only 16 points on it. SPD during a current increase behave different then decrease of it. In V-I characteristic appears hysteresis loop. MOA elements don't take it into consideration. But as was written good model with precise approximation of PSD characteristic is most essential to quality of simulation results, so new model should be used.

## II. SURGE ARRESTER WITH HYSTERESIS LOOP

Metal-Oxide surge arresters (MOAs) are part of electric power system. They protect final user from over-voltages during lightning strikes, switching ect. Major task for metal-oxide surge arresters is decrease voltage differential between terminals. MOAs can be represented simply with their nonlinear V-I characteristics (fig. 2.1b). During normal conditions MOAs is represented by the no connection in electric power system (high resistance). After exceeding normal conditions voltage level current increase extremely fast. When surge disappear current decrease imminently but by the different way as it was later. This phenomena makes hysteresis loop in V-I MOAs characteristic (fig. 2.1b).



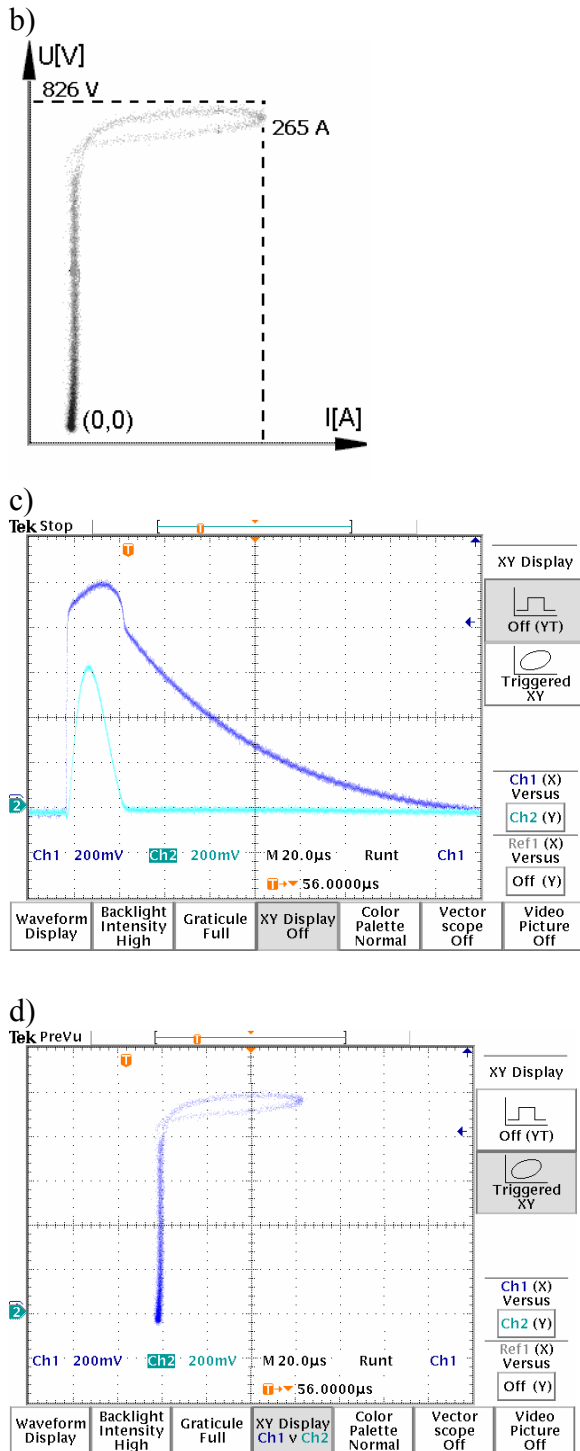


Fig. 2.1 Characteristic of MOA (a) in time domain, (b) nonlinear V-I characteristics, (c) and (d) screen shot direct from digital oscilloscope.

Characteristics presented on figure 2.1 were measured on real MOA element:

- maximum continuous operating voltage (MCOV)  $U_c=275V$
- rated voltage  $U_r<1500V$
- nominal discharge current  $I_n=20kA$
- maximum discharge current  $I_{max}=40kA$

Measurements were made by digital oscilloscope and save to spreadsheet file format. Digital measurement technique allows decreasing measurement error to half AC/DC quantization step. 12bit AC/DC converter in digital oscilloscope allows gathering enough points to draw V-I characteristic. Normally ATP/EMTP allows only 16 points in V-I characteristic. When we have got much more of it, why we shouldn't used it to decrease simulation error. There is no necessary to make any assumptions to approximate MOAs parameters in new model presented below. In new model only 8 point were used to clearly present idea of it. It can be increased to 32768 points (limited by MODELS) [2].

There is no necessary to use any inductances or capacitances in new model and most important, parameter approximation disappears. Necessary phase shift ensure non-linear V-I characteristic and hysteresis loop.

Main improvement in new algorithm is two calculations ways. First, when MOA voltage derivative is greater than zero and the second one, when derivative is less then zero. Of course all calculations are made for discrete time values. When algorithm splits up voltage range in V-I array is calculated. Defined array at the beginning have got limited number of points. Linear approximation is used to calculate rest of it. In last step of algorithm resistance of MOA is calculated. In this point oscillations can appear because step MOA resistance change. Small trick is used in algorithm which is not clearly visible. There is no direct resistance determine from V-I array. And there is no use of previous value of resistance. If one of it will be used, oscillations will appear. Resistance calculation based at vector deviation change. Angle of resistance change is calculated. This angle also makes linear approximation rest of V-I points.

Major disadvantage of new model are measurements. Digital oscilloscope is necessary. Major advantage of new model is possibility to use it with any non-linear element. Of course surge arrester characteristic measurements have got specific resolution - error. It is equal half of AC/DC converter quantization step. These kinds of errors are commonly accepted.

### III. VERIFICATION OF NEW MODEL

Figures number 3.2 and 3.3 show MOV and new model in ATP Draw – circuit diagram for V-I characteristics calculation in EMTP. For test calculations the same V-I characteristics were implemented in both cases. Figures number 3.4 and 3.5 show V-I characteristic of modeled surge arrester. Figures 3.6 and 3.7 show surge arrester current and voltage in time domain. Red lines show curves for new model. Blue lines show curves for MOV element. Calculation results show current and voltage peak values. They are the same in both cases. Visible differences occur when the current and voltage exceed front surge time. New model forces bigger current then the MOA. The hysteresis loop in V-I characteristic provides this phenomenon. Voltage behaves inversely proportional - Ohm's law. Differences between

MOA and new model are small but must be taken into consideration. These differences reduce a little bit surge arrester voltage protection level. In special types of calculation it may be crucial for computation results. Major differences occur when computations of complex building structure are made.

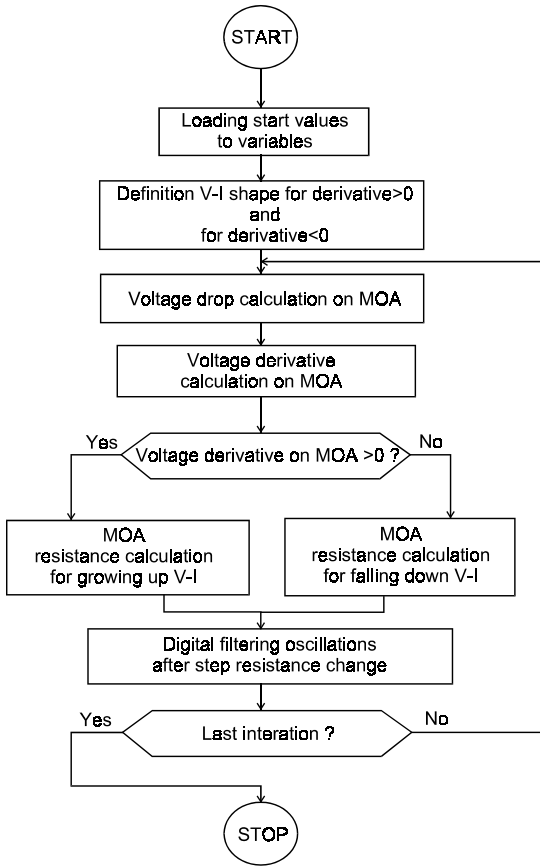


Fig. 3.1 New model algorithm.

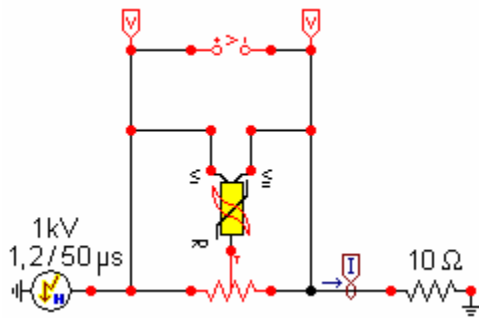


Fig. 3.2 Circuit diagram of MOA new model in ATP/EMTP.

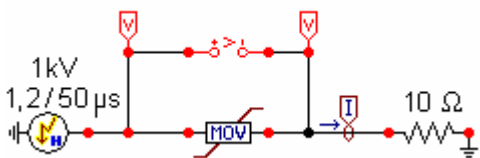


Fig. 3.3 Circuit diagram with standard MOV element.

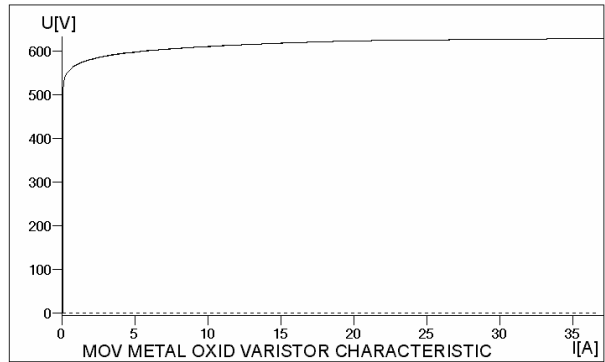


Fig. 3.4 Surge arrester V-I characteristic - MOV model.

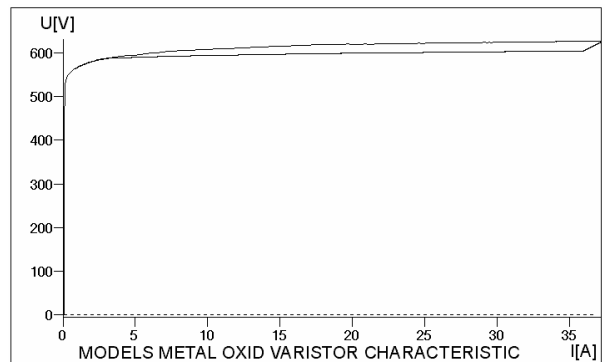


Fig. 3.5 Surge arrester V-I characteristic - new model with hysteresis loop.

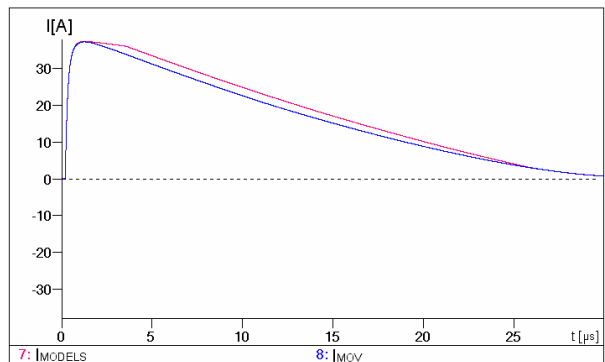


Fig. 3.6 Surge arrester current in time domain - new model with hysteresis loop (red line), MOV (blue line).

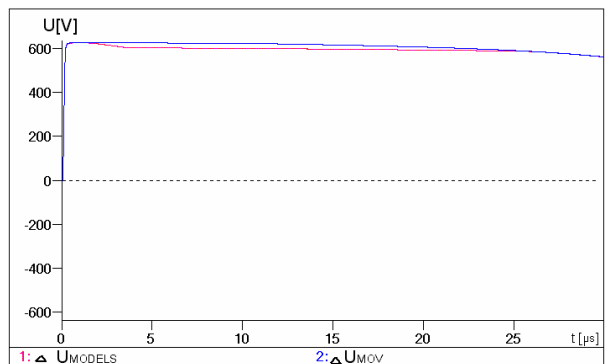


Fig. 3.7 Surge arrester voltage in time domain - new model with hysteresis loop (red line), MOV (blue line).

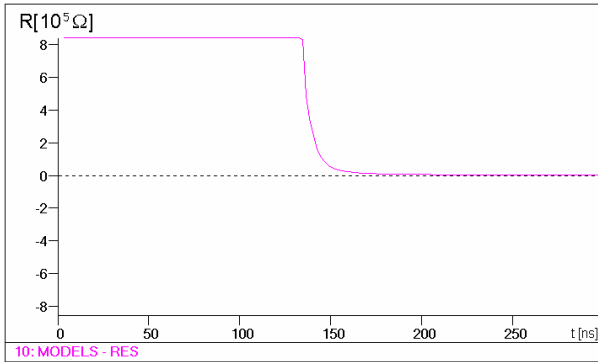


Fig. 3.8 Surge arrester new model resistance change in time domain.

#### IV. CONCLUSIONS

Presented model more precisely approximates surge arrester characteristic. Real MOA V-I characteristic can be directly transferred from digital measurement to computer simulation program. There is no need to approximate any MOA analog parameters. New model can be also use for any non-linear element with hysteresis loop in V-I characteristic or not too. Tricky algorithm eliminates oscillation during step parameter change. It's easy to improve in future by simple ATP/EMTP user.

#### V. REFERENCES

- [1] N. Watson, J. Arrillaga "Power systems electromagnetic transients simulation", The Institution of Electrical Engineers 2003, London, UK.
- [2] L. Dube "User guide to Models in ATP", Handbook for ATP/EMTP.



**Jaroslaw Wiater** received the M.Sc. degree from University of Bialystok, Poland, in 2002. Graduated in power system. Main research area is application of computer technology in damage analysis at electric power substation during direct lightning strikes.