Surge Arrester Modeling

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Abstract-- The performance of surge arresters during electromagnetic transients on power systems can be simulated with EMTP-type computer programs. This paper discusses the steps to be performed for deriving the parameters needed to represent gapless metal oxide surge arresters in transient simulations. This paper includes a summary of the mathematical representation, the conversion procedures used to obtain parameters, and guidelines for choosing appropriate parameters.

Index Terms-- Electromagnetic Transients, Surge Arrester, EMTP, Modeling.

I. Introduction

The functions of a surge arrester are:

- Do nothing (conduct little or no current) for normal operating voltages.
- Conduct current during overvoltages (without causing a fault).

Thus, the surge arrester must have an extremely high resistance during normal system operation and a relatively low resistance during transient overvoltages. That is, it must have non-linear voltage versus current (V-I) characteristic

Early overvoltage protective devices used spark gaps connected in series with discs made with a non-linear silicon carbide (SiC) material. The spark gaps provided the high impedance during normal conditions. SiC-type surge arrester models are not discussed here.

The metal oxide varistor (MOV) material used in modern high voltage surge arresters has a highly non-linear voltage versus current characteristic as shown in Figure 1. The V-I characteristic is dependent upon waveshape of the arrester current. Currents with a faster rise time will result in higher peak voltages. The material also has temperature dependence, which is evident only at low current densities. Temperature dependence does not need to be represented in simulations for typical overvoltage studies where the arrester currents exceed 10 amps. The temperature dependence is a factor in the selection of arrester ratings for steady state and temporary overvoltages.

The physical construction of modern high voltage surge arresters consists of metal oxide discs inside a porcelain or polymer insulator. A higher voltage is achieved by adding disks in series. Higher energy ratings are achieved by using larger diameter discs or parallel columns of discs. The highly non-linear V-I characteristic obviates the need for series spark gaps. The electrical characteristics are determined solely by the properties of the metal oxide blocks.

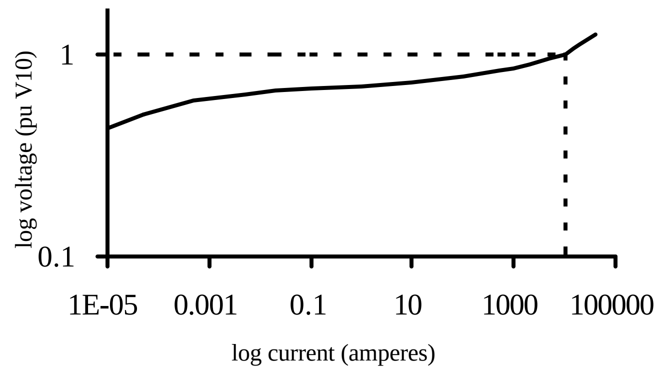

Figure 1 MOV non-linear voltage versus current characteristic.

MOV surge arresters with spark gaps are still marketed by several manufacturers for medium voltage applications. MOV surge arresters with spark gaps can also be represented with the model described below.

II. MODEL MATHEMATICS

A linear resistor has a simple v = iR relationship at any instant of time. Thus, the voltage and current in a linear resistor will have the same shape but with a different magnitude. A non-linear resistor will not have the same voltage and current shape when operated in the non-linear range.

A non-linear V-I characteristic can be defined in various ways. Program developers added new surge arrester models over the to overcome the limitations and deficiencies of existing models. The old model types were left in the program. Of the many types of surge arrester models available in EMTP-type programs, the exponential non-linear resistive device is preferred [1]. The EMTP Type 92 (with the flag 5555. in columns 39-44) seems to be free of any serious limitations or deficiencies.

The V-I characteristic will have several exponential segments, where each segment is defined by:

$$i = p\left(\frac{v}{V_{ref}}\right)^q \qquad (1)$$

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where q is the exponent, p is a multiplier and V_{ref} is an arbitrary reference voltage that normalizes the equation and prevents numerical overflow during exponentiation.

The first segment of the device is linear, which avoid numerical underflow and speeds the simulation. The resistance of this first segment should be very high, and the surge arrester should have little effect on the steady state solution. Steady state surge arrester currents should be less that 0.1 A.

The second segment is defined by the parameters p, q and Vmin. When the voltage exceeds the first Vmin, the algorithm iterates at each time step to find a solution that satisfies the equation (2). Multiple segments are typically used to enhance the accuracy of the model since the exponent decreases as the current level increases. Each segment has its own p, q and Vmin.

III. MODEL CONSTRUCTION

The following data must be collected to construct a surge arrester model:

- Manufacturer's Ratings & Characteristics
- Manufacturer's V vs. I Curves

This data may be found in the manufacturer's literature.

Manufacturers test each disc with a current pulse and record a reference voltage. A typical test current pulse has a 10 kA peak with an 8 x 20 microsecond waveshape. The resulting peak voltage is the reference voltage V10, the voltage at 10 kA for 1 column). The V-I curves often use the V10 value as the 1.00 pu value. The V-I curve can be determined by multiplying the per unit arrester voltages by the V10 for that rating.

The next step is to select:

- A reference voltage proportional to the arrester rating (V10)
- The number of parallel columns of discs,
- The voltage versus current (V-I) characteristic in per unit of the reference voltage.

The choice of arrester V-I characteristic depends upon the type of transient being simulated. The V-I characteristic depends upon waveshape of the arrester current. Currents with a faster rise time will result in higher peak voltages. Manufacturers often publish several curves. The 8 x 20 ìs characteristic applies for typical lightning surge simulations. The front of wave (FOW) characteristic applies for transients with current rise times less than 1 ìs. The 36 x 90 ìs characteristic applies to switching surge simulations. The 1 ms characteristic applies to low frequency phenomena. Manufacturers may supply min and max curves for each test waveshape. The max curve is generally used since it results in the highest overvoltages and conservative equipment insulation requirements. The min curves are used to determine the highest energy levels absorbed by the arrester.

Figure 2 shows the set of six V-I points selected from a sample V-I characteristic for a 36 x 90 microsecond wave.

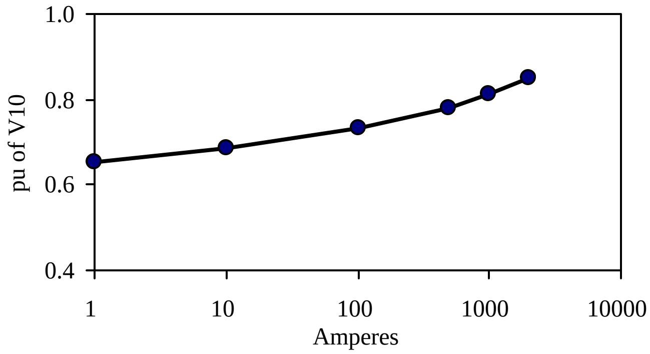

Figure 2 Sample V-I characteristic for a 36 x 90 wave

The set of manufacturer's V-I points must be converted to a set of p, q and Vmin values with the EMTP supplementary routine ARRDAT. ARRDAT need be run only once for each curve, if the input voltages are in per unit of V10 for one column. The V10 and number of columns can both be specified in the output file created by ARRDAT, which is then used as branch input data.

ARRDAT needs to be run only once for any particular V-I characteristic. A different curve should be created for each waveshape (8 x 20 ìs for example) and manufacturing tolerance (maximum or minimum). The voltages are usually given in a per unit fashion where the reference voltage (1.00 per unit) is either the voltage rating or V10, the peak voltage for a 10 kA, 8 x 20 ìs current wave. The units are volts and amps. The reference voltage and number of columns should have a value of 1.0 since they can be specified later to their actual value. See [2] for additional details about ARRDAT.

The output file created by ARRDAT contains p, q and Vmin parameters for the type 92 model. The type 92 exponential model is quite simple to use once the exponents and multipliers have been determined with ARRDAT. Include the output file from ARRDAT into the network input data file in the section for branches and edited in three places:

1. Add the node names to which the arrester will be connected.

2. Change the reference voltage to correspond to the voltage rating of the arrester. The reference voltage (V10) is in volts, therefore the currents will be in amperes and the energy will be in joules. The voltage and current sources in the network model must also conform to these units.

3. Change the number of parallel columns of MOV discs. Note that most arrester applications use only one column. Multiple column designs are usually reserved for applications requiring high energy absorption.

IV. SURGE ARRESTER MODEL TESTING

The surge arrester model can be tested in the circuit of Figure 3 prior to its use in a realistic power circuit. The current source is a type 12 ramp function with a peak magnitude equal to the largest current point of the V-I characteristic. The parallel resistor is in place for computational reasons and has a large value (i.e. 1E9). The results from the printed output can be compared to the manufacturer’s data.

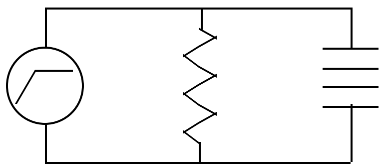

Figure 3 Test circuit for a surge arrester model.

V. SURGE ARRESTER MODEL EXAMPLE

The simple circuit of Figure 4 demonstrates the function of a surge arrester. The surge voltage has an arbitrary triangle waveshape that peaks at 100 kV. The 300 ohm linear resistance represents the surge impedance of an overhead line. Figure 5 shows the V-I characteristic of the surge arrester, which has a rating typical for 34.5 kV applications with a V10 of 67.7 kV.

Figure 6 shows the surge voltage, the arrester voltage and the arrester current. The surge arrester draws little current until the voltage reaches about 45 kV. Until that time, the surge arrester voltage is approximately the same as the surge voltage because the voltage drop across the surge impedance is nearly zero. When the surge arrester draws significant current, the voltage drop across the surge impedance increases, resulting in a lower voltage at the arrester. The peak current is 162.3 A. The voltage drop across the resistor is 0.1623 x 300 = 48.7 kV. The peak arrester voltage is 100 – 48.7 = 51.3 kV.

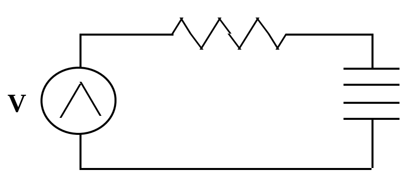

Figure 4 Example of a surge arrester in a simple circuit.

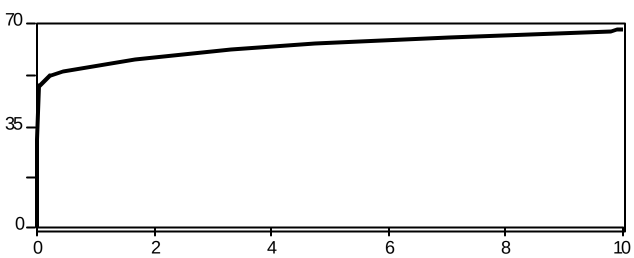

Figure 5 The surge arrester V-I characteristic with the units of kV and kA.

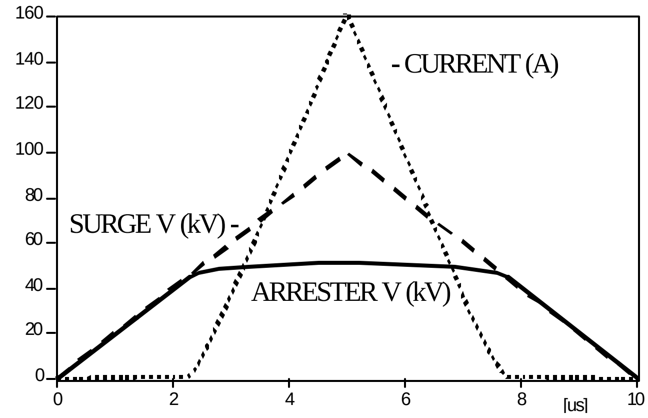

Figure 6 Voltages and current from the example simulation.

VI. FAST FRONT SURGE MODEL

In the example in the previous section, the surge arrester current peaks at the same instant in time as the peak of the surge arrester voltage. The surge arrester model did not have any time dependency. Time dependency is insignificant for slow front switching surges. For fast front surges, those with rise times less than 10 microseconds, the peak of the voltage wave occurs before the peak of the current wave. While fast front models have been developed[3][4], their use has been inhibited due to limited test data. A detailed discussion of fast front models for surge arresters is beyond the scope of this paper.

VII. REFERENCES

[1] D. W. Durbak, "The Choice of EMTP Surge Arrester Models," EMTP Newsletter, Volume 7, Number 3, September 1987

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[4] "IEEE Guide for the Application of Metal-Oxide Surge Arresters for Alternating-Current Systems", IEEE Std C62.22-1991

Daniel W. Durbak was born in Schenectady NY and graduated from Worcester Polytechnic Institute (BSEE), Rensellear Polytechnic Institute (ME Electric Power) and the GE Advanced Course in Engineering. From 1978 to 1986, he worked for General Electric's Electric Utility Systems Engineering Department, contributing to a variety of analytical studies on EHV and HVDC transmission systems. Since joining Power Technologies in 1986, he has consulted on numerous power system studies and has taught many industry courses.