

# Method to determine the parameters of the electric arc from test data.

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**Abstract** - This work describes the use of the Asturian Method for calculating parameters of the electric arc from test data, in comparison with Amsinck's method. The main advantage of the Asturian Method is that it can be used in oscillograms where reignition is not present, and only one test is enough. This is why this method can be used in most cases.

**Keywords:** Circuit breakers, Parameter estimation, Curve fitting, Modeling, Simulation, EMTP, ATP.

## I. INTRODUCTION

The simulation technique of the electric arc, called "Black Box", is based on the use of current and voltage oscillograms of the circuit breaker opening to relate them to a previously chosen differential equation. The mathematical model able to reproduce the arc in that experiment covers the following steps [1,2]:

1) *Choice of an equation:* The arc is described by a differential equation which relates the conductance variation to the current or its derivative and to voltage. This mathematical equation can have different forms, and its physical interpretation is difficult.

2) *Field or laboratory tests:* Voltage and current oscillograms can be obtained through laboratory tests or through real field tests on circuit breakers. They describe the behavior of the electric arc during the whole process of the circuit breaker opening.

3) *Evaluation of arc parameters:* The complexity of the differential equation chosen often conspires against our intention to keep it simple. In order to improve the quality of the arc representation through a formula it is common practice to introduce a variable number of additional parameters. This forces us to come to a compromise between simplicity and quality of presentation, since an increase in quantity of parameters implies more difficulties in value determination.

4) *Numerical simulations:* Once the arc parameters have been accurately determined and once the electric circuit values associated to the test or to the field test are available, the whole duration of the opening process can be reproduced.

Thus the behavior of this electric arc can be studied under other operational conditions.

## II. BASIC MODELS OF THE ELECTRIC ARC

The first attempts to simulate the behavior of the electric arc during the current break down process were made by A.M. Cassie and O. Mayr in 1930 [1,2,3]. The former considered the electric arc as a constant channel of current and of temperature density -with a strong electric field, and a transversal area that varies directly according to the current- where the loss of energy is proportional to the energy stored by unit of volume, and the conductance proportional to the section of the channel. The latter, on the other hand, claimed that the heat transference to the environment takes place in the whole periphery by conduction and that the conductance varies exponentially to the stored energy. The section and the size of this arc are constant.

The Mayr's model is

$$\frac{1}{g} \frac{dg}{dt} = \frac{1}{\Theta} \left( \frac{v \cdot i}{P_0} - 1 \right)$$

This equation must be applied to represent regions of current zero, while Cassie's model must be applied to large current regions [4,5]:

$$\frac{1}{g} \frac{dg}{dt} = \frac{1}{\Theta} \left( \frac{v^2}{V_0^2} - 1 \right)$$

where:  $g$  is the dynamic conductance,  $\Theta$  is time constant,  $P_0$  is power loss,  $V_0$  is the voltage considered as constant and  $v$  and  $i$  are instantaneous voltage and currents in the arc.

It may be noticed that the models above are described by only two constant parameters:

▷  $\Theta$  and  $P_0$  for Mayr's model

▷  $\Theta$  and  $V_0$  for Cassie's model

Since  $v$  and  $i$  can be measured and/or calculated, but their validity becomes questionable if we have in mind that these parameters cannot be really considered constant because of the variation speed of the existing physical conditions within the interruption chamber.

For this reason many authors [4,5] have proposed  $P_0$  and  $\Theta$  as conductance functions as follows:

$$P_0 = A \cdot g^\alpha \quad \Theta = B \cdot g^\beta$$

where  $A$ ,  $B$ ,  $\alpha$  and  $\beta$  are constants which depend on the type of the extinguisher, its pressure, and the geometrical characteristics of the interruption chamber. In other words, the main problem regarding the electric arc modeling lies in determining the value of these four parameters.

### III. AVAILABLE METHODS TO DETERMINE ELECTRIC ARC PARAMETERS

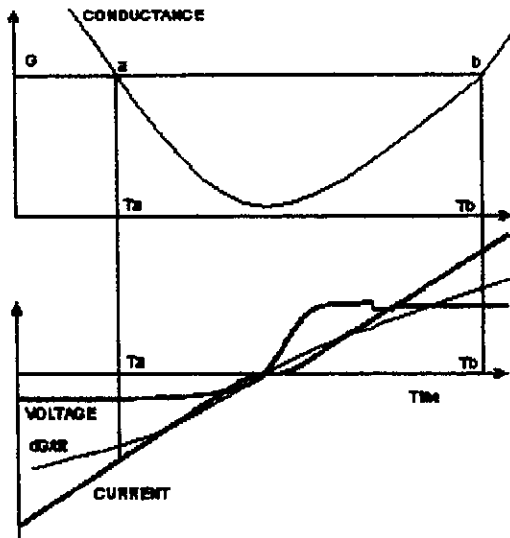


Fig.1. Schematic representation of Amsinck's method.

Amsinck's well known method can only be applied to a test where a reignition of the electric arc is produced while the test is being carried out [2,3]. Mathematically speaking, this method uses the test data to create a conductance table. This table has two parts, a decreasing one before zero current, and another one which increases after the reignition of the arc. See fig. 1.

Applying Mayr's equation to "a" and "b", fig.1, we come to a two-equation system with two questions, represented as follows

$$P_0(g_1) = \frac{g'_a i_b^2 - g'_b i_a^2}{g_1(g'_a - g'_b)} \quad \Theta(g_1) = \frac{g_1(i_b^2 - i_a^2)}{i_a^2 g'_b - i_b^2 g'_a}$$

These formulas, for "n" points, allow by means of functions of approximation to determine  $P_0$  and  $\Theta$ .

There are other less popular methods for calculating the model arc parameters [2], e.g. Stoke's method. This method requires two tests, both with reignitions and different current slopes. Ruppe's method requires at least two tests. Special circuits can also be applied during the tests. The same is valid for Rijanto's method.

### IV. THE ASTURIAN METHOD

It consists in determining equation parameters from the registered values of voltage and current (or its derivative). The derivative of the conductance is calculated for each time, as follows

$$g'_m(t) = \frac{g_m(t - \Delta t) - g_m(t + \Delta t)}{2 \cdot \Delta t}$$

thus a  $g'_m(t)$  value table is formed.

Mayr's equation is expressed as follows

$$\frac{dg}{dt} = \frac{g}{\Theta_e} \left( \frac{ui}{P_{0e}} - 1 \right) = g'_e(t)$$

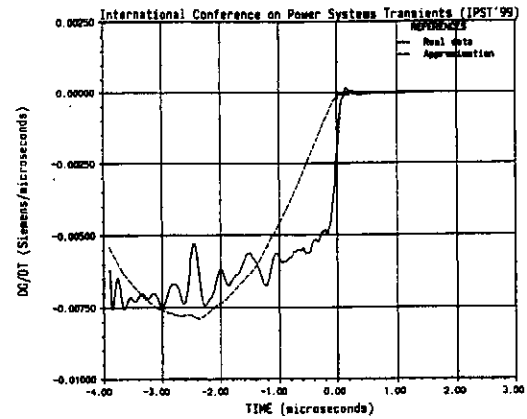


Fig.2. Obtained approximation for a test without reignition.

this way, a pair of values for  $P_0$  and  $\Theta$  can be estimated to fit the equations above. Then if the fitting is made based on minimum squares or other methods between the calculated points with the registered ones, a pair of values for  $P_0$  and  $\Theta$  are obtained. These values better represent the measures obtained.

The approximation resulting from the calculated derivative of the conductance with Mayr's model and constant parameters with the derivative measured for a test without reignition of the electric arc is shown in fig. 2.

The previous steps can be followed in the same way, but this time using Cassie's equation. For this equation  $U_0$  and  $\Theta$  values will also be obtained and will better close the estimated derivative of the conductance with the measured conductance.

### V. COMPARISON BETWEEN THE METHODS

With the purpose of using the mentioned methods on a routine basis some computer programs have been designed. They are meant to calculate the values of the parameter of the equations above automatically. These programs have the graphical options included in this work and the final numerical results are presented later for comparison. They have been applied on oscillograms of a testing group on a SF6 circuit breaker of 145 [kV] of nominal voltage.

#### A. Graphic comparison of the results

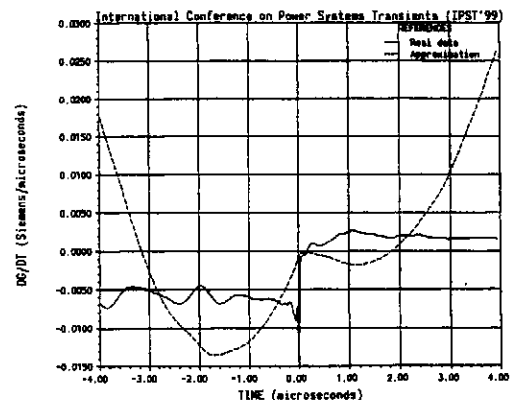


Fig.3. Approximation obtained for the derivative of the conductance using Amsinck's method.

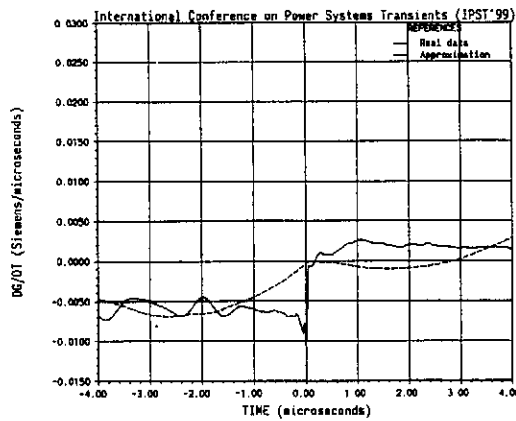


Fig.4. Approximation obtained for the derivative of the conductance using the Asturian Method.

In figures 3 and 4 the approximation obtained for the derivative of the conductance applying Mayr's equation with constant parameters -using the mentioned methods- are presented. The difference between the two approximations is caused by a cut in the data table due to the use of Amsinck's method.

If figure 5 -which represents the conductance variation during a test with reignition- is analyzed in detail, the way in which it gets closer to zero time and then it goes away can be noticed. If an imaginary line which replaces the conductance before zero has "a larger slope"- talking absolute terms- than the ascending portion of the same curve. In other words, the conductance variation before the reignition is greater than in the period after it is produced.

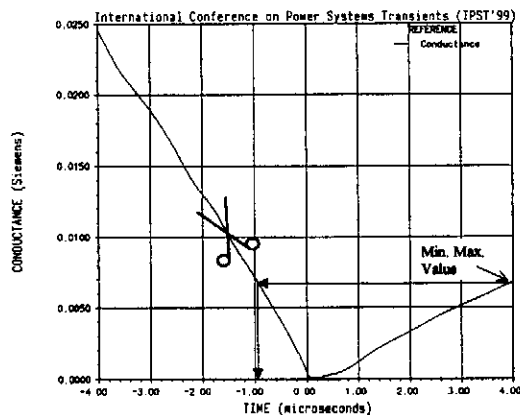


Fig.5. Arc conductance for a test with reignition.

Amsinck's method requires the existence of conductance in both sides of zero current region. Due to the difference in slope between both portions of the curve it results in a cut of useful time for the assessment of the parameter values. It gets stronger as the difference grows.

This way, the conductance value that determines the cut in the data table is the minimum maximum value which in this example can be found at the right end of the conductance curve. Since beyond this point, there is not any other one to the right, this conductance value should be moved to the left portion of the curve, thus getting the cut of the data that are to the left side of the same conductance value.

This data cut, if the fig.5 is analyzed, shows that they are useful only for calculating the existing data on the right of  $-1$  [ $\mu\text{seg}$ ] up to  $4$  [ $\mu\text{seg}$ ] after reignition. This implies a cut of almost 40 % of the data measured in the test.

However, without the limitation represented by the need of existence of conductance on both sides of the reignition, the Asturian Method uses all available points since  $-4$  [ $\mu\text{seg}$ ] before and up to  $+4$  [ $\mu\text{seg}$ ] after the passage of the current through zero. This data cut for Amsinck's method is the reason why a better concordance in the approximation of the derivative of the conductance is obtained for the region near zero, as shown in fig.3. The Asturian Method, instead, calculates parameter values using all data and thus gets a better approximation for the whole data registered, as shown in fig.4.

### B. Numerical comparison of the results

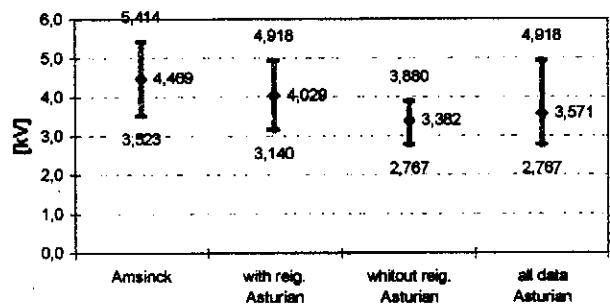


Fig.6. Amsinck vs. Asturian for constant parameters.

The fig.6 represents the calculated values for Cassie's model voltage in a set of ten tests on the same circuit breaker under the same circumstances. It shows medium, maximum and minimum values for each method. The result of the Asturian Method can also be observed in those cases where there was not reignition. The general values for the Asturian Method are also shown. Amsinck gives values 10 % higher than the values given by the Asturian for the same tests.

If, otherwise, the parameter behavior is chosen variable with the conductance for Mayr's model, fig.7 is obtained.

In fig. 7, it can also be noticed how Amsinck's method also results in higher values in respect of the Asturian Method applied to the same oscillograms. In the case of including tests without reignition, the evolution curve is superior to the one reached through the Amsinck's method.

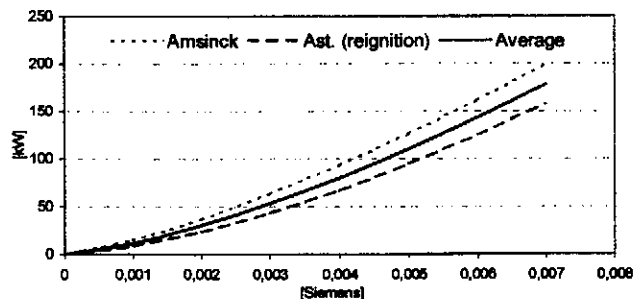


Fig.7. Amsinck vs. Asturian Methods for variable parameters.

## VI. SIMULATIONS

With the purpose of evaluating the behavior of the proposed method, we simulated the circuit breaker test with Alternative Transients Program (ATP) [6].

For this reason, Mayr and Cassie's models have been written in section "Model" of this program [7]. The real value of the electric circuit of the test was included.

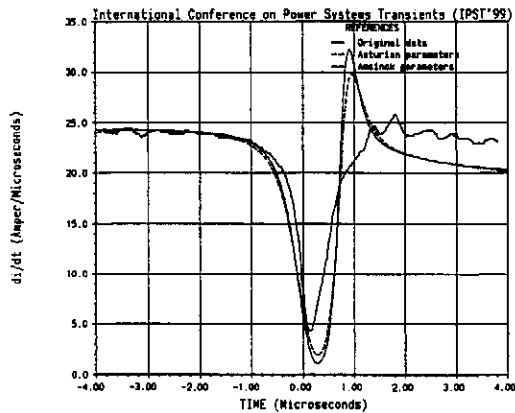


Fig. 8. Result of the simulation of a test with reignition.

Fig. 8 represents the result of a reignition simulation using Cassie's model with constant parameters. The evolution of the real data of the derivative of the current can also be seen here, along with the simulation results using the values of the parameters according to Amsinck's method and to the Asturian Method.

It should be remembered that Cassie's model is more appropriate for high current regions and not near zero as in this case. This gives rise to the divergence of the test result from the simulation. This implies that the difference between the real values and the simulated values is therefore a result of the use of this model and not of the parameter values.

The parameter values used in the simulations were:

Parameter values of Cassie's model		
Parameter	Amsinck	Asturian
U <sub>cass</sub>	3590 [V]	3656 [V]
Tita	0.25 [μseg]	0.31 [μseg]

Parameters values of Mayr's model		
Parameter	Constant	Variable
Po	35100 [W]	2192130.g <sup>0.718828</sup> [W]
Tita	0.3327 [μseg]	1,37719.g <sup>0.329407</sup> [μseg]

Fig. 9 shows a simulation with a successful opening of the circuit breaker. It represents the evolution of the derivative of the current during the test, along with the results of the simulations using Mayr's model, which is the most adequate for the zero current region.

Irrespective of the quality of the simulation of one or the other behavior of the parameters, fig.9 shows the excellent behavior of the Asturian Method to find

parameter values, whether they be constant or variable, for the case of an opening. This cannot be achieved with the other known methods.

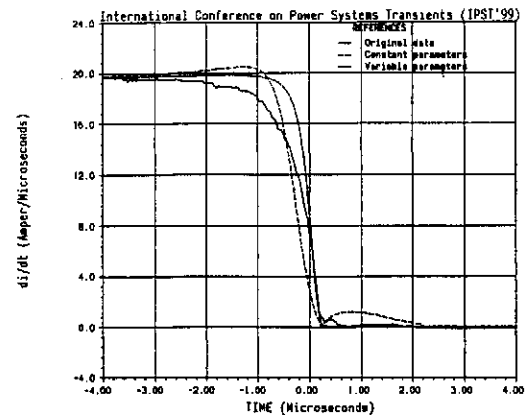


Fig.9. Result of an opening simulation.

## VII. CONCLUSIONS

The introduced method makes it possible to determine the values of the parameters of the electric arc of circuit breakers for its simulation using the Alternative Transients Program or other programs using the data of just one test, in which either there is or there is not reignition.

Because all the values are used for adjusting the model parameters, the Asturian Method obtains a better and wider representation of the electric arc. Besides, using oscillograms obtained with equipment of data acquisition of lower quality, it also showed much better behavior than the rest. Therefore, the Asturian Method has a wider range of uses than the other methods of calculation studied.

Because the opening of a circuit breaker during a test is often a fortuitous fact, the usefulness of the Asturian Method is superior to the one of the Amsinck, because a reignition of the electric arc is not required in order to determine the values of the parameters.

This method can be applied for either determining the values of the parameter ( $P_o$  and  $\Theta$  of Mayr's model and  $U_o$  and  $\Theta$  of Cassie's model) as constants, or the parameters ( $A$ ,  $B$ ,  $\alpha$  and  $\beta$ ) of the function approximating  $P_o$  and  $\Theta$  or  $U_o$  and  $\Theta$ .

The method was used with data which was obtained in tests of circuit breakers of very dissimilar characteristics. This demonstrates that the mathematically correct solution is not always the best one to represent the values of the parameters. In these cases it is suffice to observe the graphical outputs obtained from the calculation program to verify or not the usefulness of the values calculated. Regardless the values obtained through the Asturian Method or Amsinck's method they should be verified before accepting their usefulness to simulate an electric arc.

## VIII. REFERENCES

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