

THE ARC MODEL BLOCKSET

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ABSTRACT

Since the introduction of the Power System Blockset, the MATLAB program is a suitable tool for the computation of power system transients. In this paper the Arc Model Blockset, a library that contains several arc models to be used in combination with the MATLAB Power System Blockset, is presented. The result is a flexible tool for arc-circuit interaction studies. Computational results are compared with those of EMTP96 and XTrans.

KEYWORDS

circuit breaker, arc model, arc-circuit interaction.

1. INTRODUCTION

Arc models were originally developed for better understanding of the current interruption process in high-voltage circuit breakers and to be able to design interrupting chambers. The physical phenomena during current interruption are, however, so complex that it is still not very well possible to use arc models for circuit breaker design. A very useful application is the study of arc-circuit interaction. For this purpose, the arc model simulates the strongly non linear behavior of the circuit breaker arc. Because of the non linear behavior and the very small time constants involved, a correct numerical treatment of the arc-circuit problem is important.

MATLAB is a well-known and popular general-purpose mathematical program. Since the introduction of the Power System Blockset (PSB) [1,2], the MATLAB program is also a suitable tool for the computation of power system transients. In this paper the Arc Model Blockset (AMB) is introduced, a library containing different arc models to be used in combination with the MATLAB Power System Blockset. The result is a flexible tool for arc-circuit interaction studies. The computational results are compared with two other programs suitable for making arc-circuit interaction studies: EMTP96 (v3.0) and XTrans.

2. MATLAB POWER SYSTEM BLOCKSET

MATLAB Simulink is a software package for modeling, simulating and analyzing dynamic systems [3]. It has a graphical user interface for building models as block diagrams. The PSB block library contains Simulink blocks that represent common components and devices of the electrical power system. The measurement blocks and the controlled sources in the PSB block library act as links between electrical signals (voltages across elements and currents flowing through connecting lines) and Simulink blocks (transfer functions).

3. CIRCUIT BREAKER SWITCHING AND ARC MODELLING

The switching action, the basic function of the circuit breaker, refers to the change from conductor to insulator at a certain voltage level. Before current interruption, the (fault) current flows through the arc channel between the breaker contacts. Because of the non-zero resistance of the arc channel, the current causes a voltage across the contacts of the circuit breaker: the arc voltage. The arc behaves as a non-linear resistance. Thus, both arc voltage and arc current cross the zero-value at the same time instant. If the arc is cooled sufficiently, at the time the current goes through zero, the circuit breaker can interrupt the current, because the electrical power input into the arc channel is zero. During current interruption, the arc resistance increases from practically zero to almost infinite in microseconds. Immediately after current interruption, the transient recovery voltage (TRV) builds up across the circuit breaker contacts. As the hot gas mixture in the interrupting chamber does not change to a complete insulating state instantaneously, the arc resistance is finite and a small current can still flow: the post-arc current.

Black-box arc models are mathematical descriptions of the electrical properties of the arc. This type of models does not simulate the complex physical processes inside the circuit breaker, but describes the electrical behavior of the circuit breaker. Measured voltage and current traces are used to extract the parameters for the differential

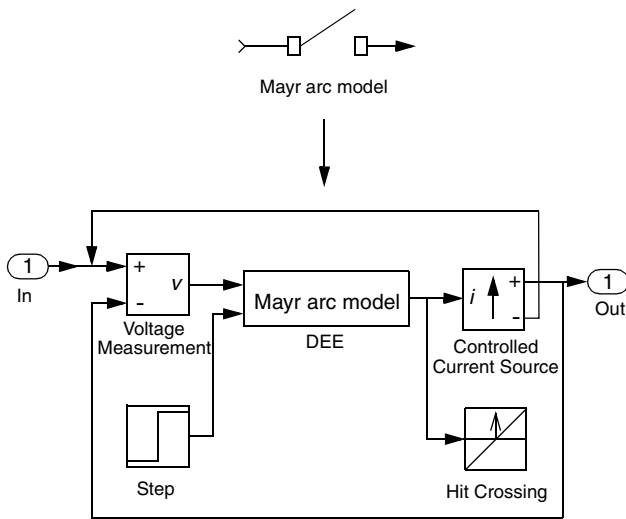


Fig. 1. Implementation of the Mayr arc model

equation(s) describing the non-linear resistance of the electrical arc for that specific measurement.

4. IMPLEMENTATION OF THE ARC MODEL BLOCKSET

The arc models have been modelled as voltage controlled current sources. This approach is visualized in fig. 1, where both the Mayr arc model block and the underlying system are shown. Some of the elements in fig. 1 will be clarified hereunder.

A. DEE: Differential Equation Editor

The equations of the Mayr arc model have been incorporated by means of the Simulink DEE (Differential Equation Editor) block, as shown in fig. 2.

Therefore, the following system of equations is solved:

$$\frac{dx(1)}{dt} = \frac{u(2)}{\tau} \left(\frac{e^{x(1)} u(1)^2}{P} - 1 \right) \quad \left| \quad \frac{d \ln g}{dt} = \frac{u(2)}{\tau} \left(\frac{g u^2}{P} - 1 \right) \quad (1) \right.$$

$$y = e^{x(1)} u(1) \quad \left| \quad i = g u \right.$$

$x(1)$ the state variable of the differential equation which is the natural logarithm of the arc conductance: $\ln(g)$.

$x0$ the initial value of the state variable, i.e. the initial value of the arc conductance: $g(0)$.

$u(1)$ the first input of the DEE block which is the arc voltage: u .

$u(2)$ the second input of the DEE block which represents the contact separation of the circuit breaker: $u(2) = 0$ when the contacts are closed and $u(2) = 1$ when the contacts are being opened.

y the output of the DEE block which is the arc current: i .

g the arc conductance

u the arc voltage

i the arc current

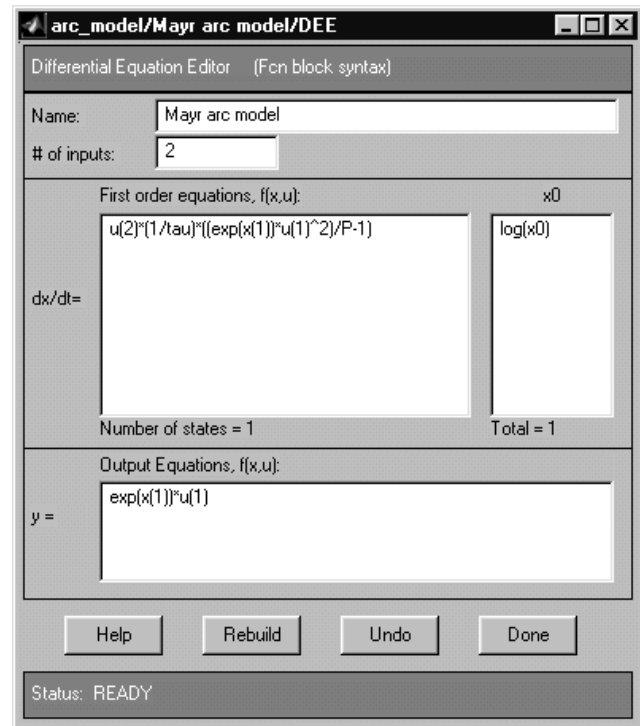


Fig. 2. Mayr equation in the Simulink Differential Equation Editor

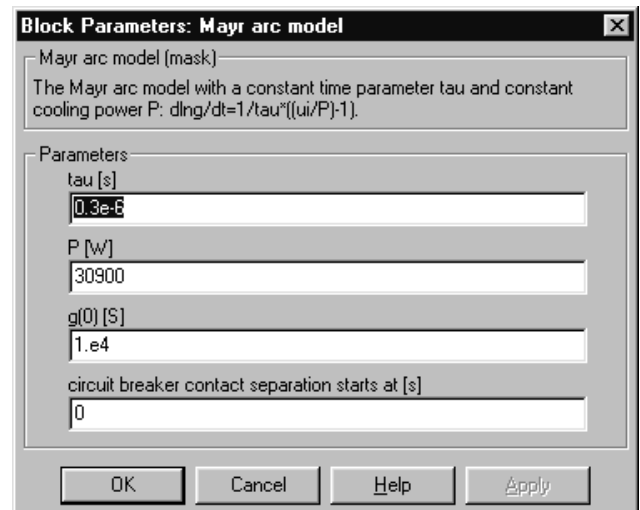


Fig. 3. Mayr arc model dialog

τ the arc time constant

P the cooling power

τ and P are the free parameters of the Mayr arc model which can be set by means of the dialog, as depicted in fig. 3, that appears when the Mayr arc model block is double clicked.

B. Hit Crossing

The Simulink 'Hit crossing' block detects when the input, in this case the current, crosses the zero value. Therefore, by adjusting the stepsize, the block ensures that the simulation finds the zero crossing point. This is of

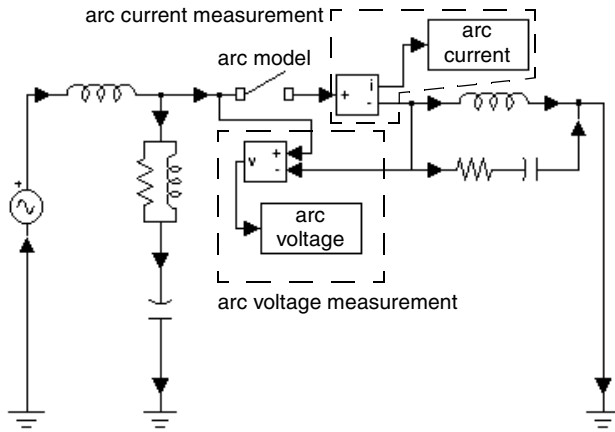


Fig. 4. Mayr arc model in an example test circuit

importance while the voltage and current zero crossing of the circuit breaker, which behaves as a non-linear resistance, is a crucial moment in the interruption process, that should be computed accurately.

C. Step

The Simulink ‘Step’ block is used to control the contact separation of the circuit breaker. A step is made from a value zero to one at the specified contact separation time. When the contacts are closed, the following differential equation is solved:

$$\frac{d \ln g}{dt} = 0 \quad (2)$$

Therefore, the arc model behaves as a conductance with the value $g(0)$. Starting from the contact separation time, the Mayr equation is solved:

$$\frac{d \ln g}{dt} = \frac{1}{\tau} \left(\frac{g u^2}{P} - 1 \right) \quad (3)$$

Both the initial value of the arc conductance $g(0)$ and the time at which the contact separation of the circuit breaker starts, are specified by means of the arc model dialog, as displayed in fig. 3.

5. ARC MODEL COMPUTATIONS

The arc models are implemented in a circuit in a straightforward way. An example of a circuit containing an arc model is shown in fig. 4. When the circuit breaker contact separation starts at $t = 0$ s, the computed voltage and current are displayed in fig. 5 and fig. 6. When the contact separation starts at $t = 9$ ms, the computed voltage and current are as shown in fig. 7.

The results obtained with the MATLAB Simulink/PSB/AMB will be compared with two other computer programs that are capable of making arc-circuit interaction studies: EMTP96 (v3.0) [4] and XTrans [5,6] [7]. Hereunder, in short, the characteristics of the three programs are summarized.

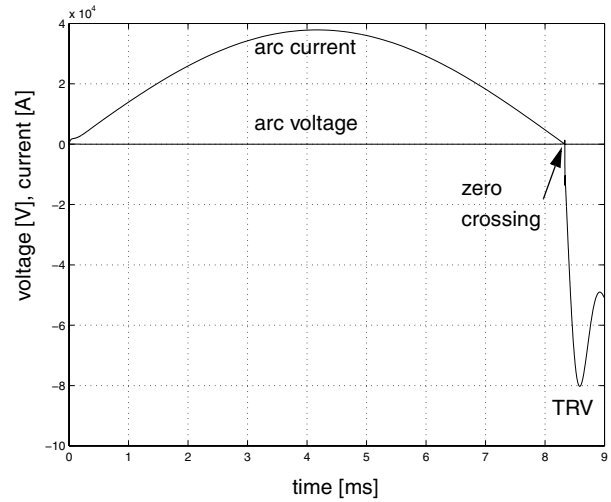


Fig. 5. Computed voltage and current when contact separation starts at $t = 0$ s.

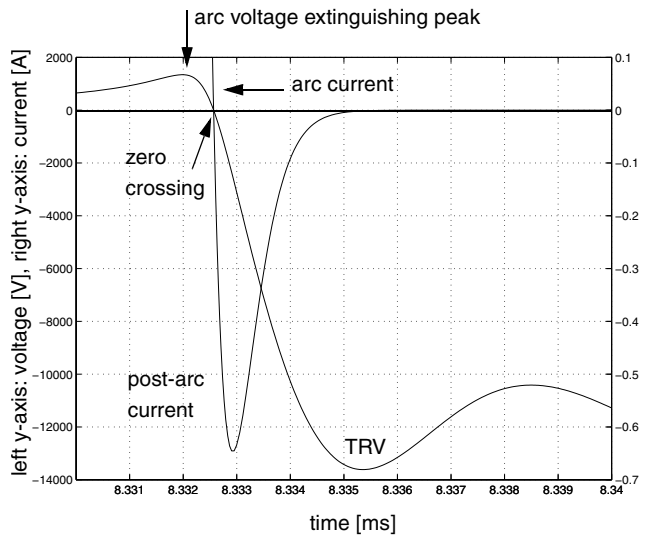


Fig. 6. Computed voltage and current (detail)

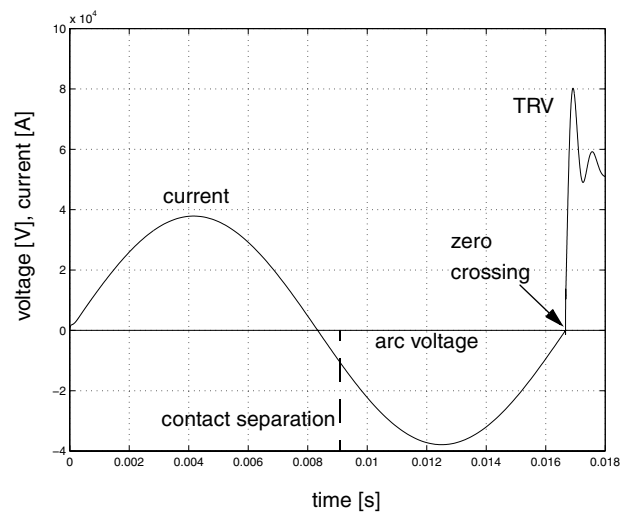


Fig. 7. Computed voltage and current when contact separation starts at $t = 9$ ms.

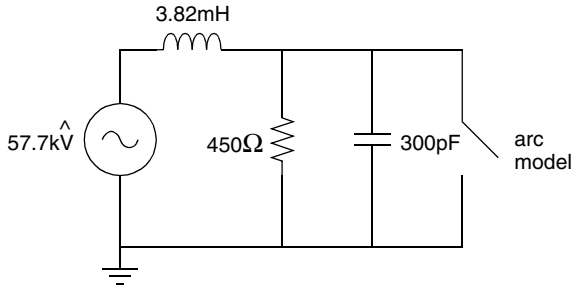


Fig. 8. Benchmark circuit used for comparison (60Hz)
Arc model parameters: $\tau_0 = 1.5\mu\text{s}$, $P_0 = 4\text{MW}$, $\alpha = 0.17$, $\beta = 0.68$

- EMTP96 (v3.0); based on the nodal analysis (NA) method and has a fixed stepsize solver
- XTrans; based on the differential algebraic equations (DAE's) and has a variable stepsize solver
- MATLAB Simulink/PSB/AMB; based on state variables and has multiple variable stepsize solvers

In order to compare the arc-circuit interaction as computed with the three programs, the Schwarz/Avdonin arc model is used, because this arc model is available in all the three computer programs. The Schwarz/Avdonin arc model is described by the following differential equation.

$$\frac{1}{g} \frac{dg}{dt} = \frac{d \ln g}{dt} = \frac{1}{\tau_0 g^\alpha} \left(\frac{ui}{P_0 g^\beta} - 1 \right) \quad (4)$$

- g the arc conductance
- u the arc voltage
- i the arc current
- τ_0 the time constant; free parameter
- α free parameter
- P_0 the cooling constant; free parameter
- β free parameter

The benchmark circuit, in which the circuit breaker interrupts the fault current, is kept as simple as possible and is shown in fig. 8. As the arc 'time constant' is a function of the arc conductance, at the current zero crossing a 'time constant' of about $0.4\mu\text{s}$ results with the arc model parameters and the circuit as specified in fig. 8.

The computed arc voltage peaks and post arc currents are shown in fig. 9, fig. 10 and fig. 11 respectively. It is evident from the figures that all three programs produce (more or less) the same results, but one has to be cautious when using the EMTP96 because of its fixed timestep. Both XTrans and MATLAB Simulink/PSB/AMB have variable stepsize solvers. This is a great advantage when dealing with the non-linear arc models. In the high current interval, the arc-circuit interaction changes not very rapidly and relatively large computational steps can be taken without loss of accuracy. Around current zero, the arc conductance changes very fast and small time steps must be taken to

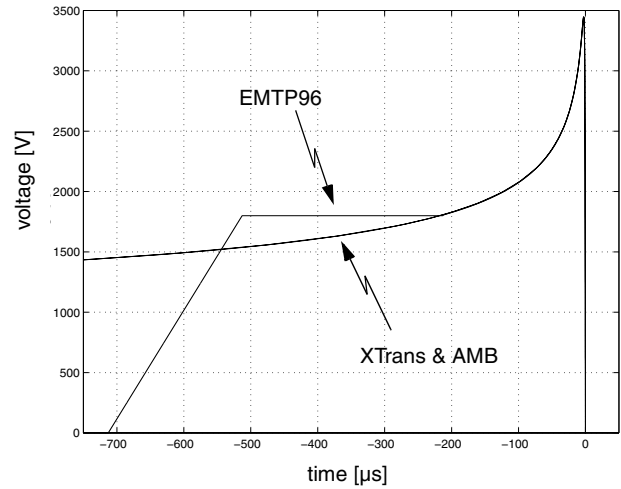


Fig. 9. Computed arc voltages

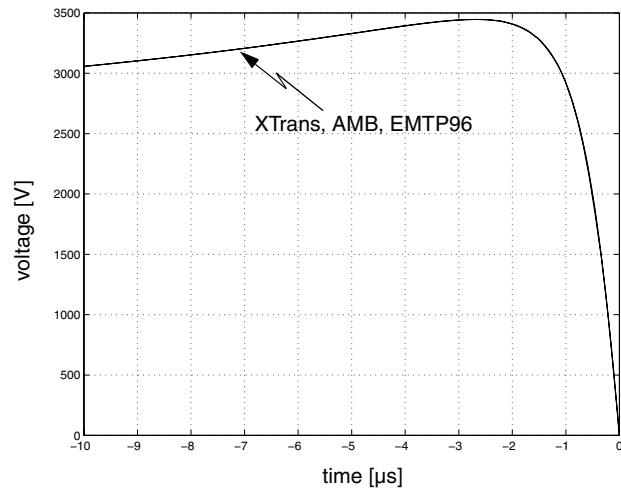


Fig. 10. Computed arc voltages (detail)

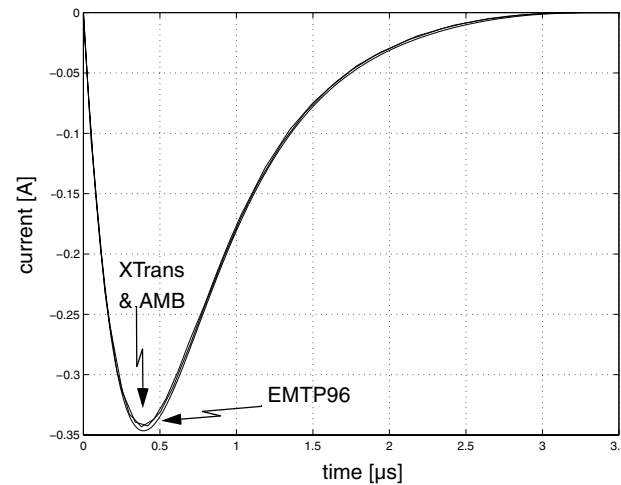


Fig. 11. Computed post-arc currents (EMTP96: $\Delta t = 1.e-8\text{s}$)

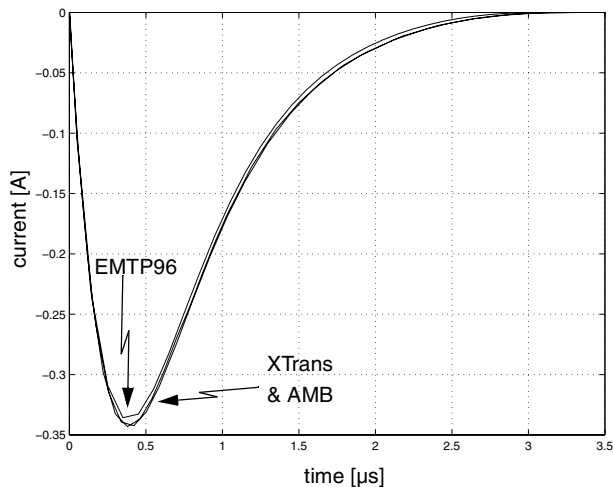


Fig. 12. Computed post-arc currents (EMTP96: $\Delta t = 1.e-7s$)

preserve the computational accuracy. In such a way, the computation time is reasonable while the accuracy is guaranteed. The EMTP96 uses a fixed stepsize solver and the user has to make a choice for the stepsize. In fig. 9, fig. 10 and fig. 11, in the EMTP96 a stepsize of $1.e-8$ has been selected whereas for fig. 12, a stepsize of $1.e-7$ has been chosen: it can be seen that the result of the EMTP96 already begins to diverge. In the EMTP96, the arc model is implemented in a different way than in the other two programs: the arc model is activated only a short time before current zero whereas in the other two programs the arc model is active during the high current phase as well, as can be seen from fig. 9. This can result in a different arc circuit interaction and subsequently different outcomes.

6. HOW TO OBTAIN THE ARC MODEL BLOCKSET

The Arc Model Blockset can be obtained from the homepage of the Electrical Power Systems group of the Delft University of Technology: eps.et.tudelft.nl

The following arc models are, at this moment, incorporated in the Arc Model Blockset (references to literature can be found in the user's guide that comes with the blockset): Cassie, Siemens/Habedank, KEMA, Mayr, Modified Mayr, Schavemaker, Schwarz (Avdonin).

At the website, a demonstration version of the XTrans program can be downloaded too. The demo program is fully functional but equipped with a limited number of models (e.g. an ideal switch is included but no arc models).

7. CONCLUSIONS

In this paper the Arc Model Blockset (AMB) is introduced, being a library that contains several arc models to be used in combination with the MATLAB Power System Blockset (PSB). The computational results have been validated by comparison with the outcome of two other transient

programs capable of making arc-circuit interaction studies: EMTP96 (v3.0) and XTrans. The results of MATLAB PSB/AMB and XTrans, both applying variable stepsize solvers, are identical.

8. ACKNOWLEDGMENT

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