

A Comparison between Three Tools for Electrical Transient Computations

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Abstract: In this paper three tools for electrical transient computations are compared by their computational results and in general terms such as speed, user-friendliness and so on. Besides the well-known EMTP, the transient program XTrans (developed at the Delft University of Technology) and the MATLAB Power System Blockset have been used to simulate the interrupting process of a circuit breaker and the interaction with the network.

Keywords: circuit breaker, arc model, transient computation, EMTP, XTrans, Matlab.

I. INTRODUCTION

Originally arc models were 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 so complex that it is until now not very well possible to use arc models for circuit breaker design. A very useful application is, however, the study of arc-circuit and arc-arc 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.

The number of tools suitable for transient analysis is increasing in the last few years. Besides the well-known EMTP [1,2] (and its variants like ATP, EMTDC etc.), the Power Systems Laboratory of the Delft University of Technology introduced the transient program XTrans two years ago [3,4]. Furthermore, the general purpose mathematical program MATLAB is getting more and more powerful and can be used for electrical transient computations as well.

EMTP, which uses the trapezoidal rule for numerical integration, is a very established tool for transient analysis. It is robust and there are many advanced circuit element models available. The EPRI EMTP96 version features even three types of circuit-breaker models.

The XTrans program, which uses the BDF (Backward Differentiation Formulas) for numerical integration, is - because of the adjustable stepsize - more suited for arc-circuit interaction studies. At this moment, there are ten circuit breaker models implemented (and the number is increasing).

The MATLAB program, which contains several (stiff) ODE-solvers with both fixed and variable stepsize, is - with the introduction of the Power System Blockset - getting to be a suitable aid for power system transients.

As the number of tools for electrical transient analysis is growing, a comparison in terms of computational speed, user-friendliness and differences in computed results is made in this paper. The three programs will be compared by simulating the interruption process of a circuit breaker. For comparison, each program will compute the interruption of the same circuit breaker model in the same circuit.

II. TEST CASE FOR COMPARISON

The electric arc is the switching element in a high-voltage circuit breaker. The electric arc behaves as a non-linear resistance. Thus, both arc voltage and arc current cross the zero-value at the same time instant. When the cooling of the arc is sufficient, a current-zero crossing is the moment at which the circuit breaker interrupts the current (note: the electrical power input equals zero!). During the current interruption, the arc resistance increases from practically zero to almost infinity within a very short time interval (microseconds). Because of the fast phenomena, the interruption process of the circuit breaker is an ideal test case to compare the three programs for use in transient computations.

The arc interruption is a very complex process. Therefore, modeling of the electric arc has a long history and a large number of models is available. In order to compare the three programs, the same arc model must be used throughout. In the EMTP96, only three arc models are available [5,6]. In XTrans (in which over ten arc models are available by now) and the MATLAB Power System Blockset (in the following called

PSB), arc models can be implemented rather easily. Therefore, the well-accepted Schwarz arc model [7], which is available in the EMTP96 program as the Avdonin model, will be used.

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

- 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 circuit, in which the circuit breaker interrupts the short circuit current, is kept as simple as possible and is shown in fig. 1. The arc model parameters are obtained from the paper of St-Jean [8].

III. EMTP (ELECTRO-MAGNETIC TRANSIENTS PROGRAM)

Work on this well-known transient analysis tool started in the early days of computers, i.e. the 1960s [1,2]. It became popular when Dommel (as its creator) and Scott-Meyer, both with the Bonville Power Administration, made the source code public domain. This was both its strength and its weakness, for many people spent time on program-development. However, their actions were not always as concerted as they should have been. This resulted in a huge amount of code for every conceivable circuit element, which at times was rather unreliable without much documentation. This problem has now been amended in the EPRI/EMTP version. The EPRI Group has recoded, tested and extended most parts of the program over and over again in a concerted effort to improve its reliability and functionality. Circuit breaker models are an example of extended functionality. They were added in 1987 [5] and very much improved in 1997 [6] and are not available in the public domain version of the program: the ATP.

The EMTP uses the trapezoidal rule for numerical integration. The stepsize of the calculation is fixed. EMTP96 has a

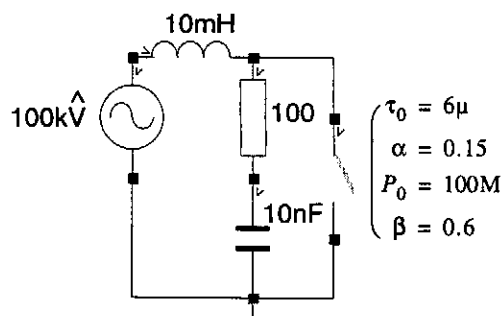


Fig. 1. Circuit used for comparison

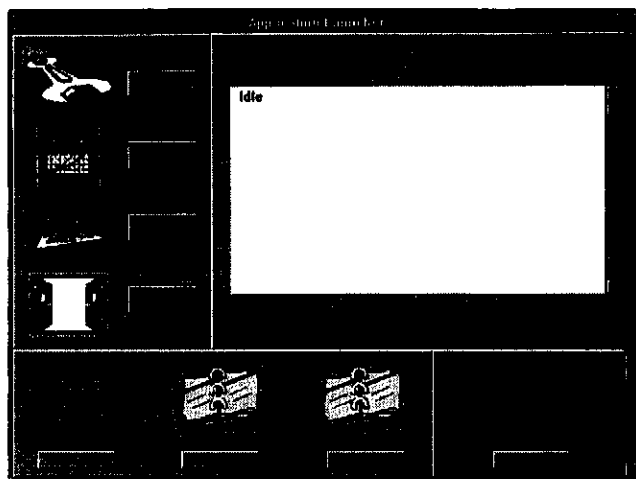


Fig. 2. EMTP96: graphical user interface

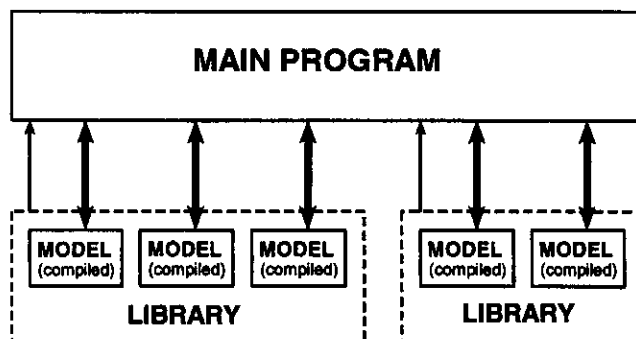


Fig. 3. XTrans program structure

'graphical user interface' which allows the user to approach the various components of the program graphically as shown in fig. 2. Nonetheless, the circuit and parameter input is by means of formatted text files ('cards').

IV. XTRANS TRANSIENT PROGRAM

The Power Systems Laboratory of the Delft University of Technology introduced the transient program XTrans two years ago [3,4]. The program was developed especially for analysis of arc-circuit interaction, which involves non-linear elements in relation to stiff differential equations. Therefore, the program is based on the use of Differential Algebraic Equations (DAE's). The calculations are performed with a variable stepsize and adjustable accuracy of the computed currents, voltages and e.g. conductances.

The program runs on a Windows computer and uses dynamic link libraries (dll's) that contain the compiled code of the elements. Therefore the models are separate from the main program. The models can be created and incorporated in the main program easily. The program structure is shown in fig. 3. The XTrans graphical user interface is shown in fig. 4.

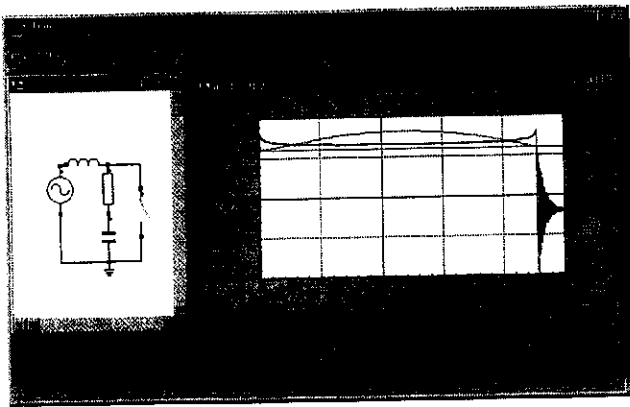


Fig. 4. XTrans: graphical user interface

V. MATLAB POWER SYSTEM BLOCKSET (PSB)

After the introduction of the Power System Blockset (PSB), for modeling and simulating electric power systems within the MATLAB Simulink environment, the general purpose mathematical program MATLAB is a suitable aid for power system transients. The Power System Blockset is developed at TEQSIM Inc. and Hydro-Québec.

Simulink is a software package for modeling, simulating and analyzing dynamical systems. It provides a graphical user interface for building models as block diagrams. The PSB block library contains Simulink blocks that represent common components and devices found in electrical power networks. 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 lines) and Simulink blocks (transfer functions) and vice versa respectively. The circuit, built up with the PSB with the accompanying scopes with output are shown in fig. 5.

VI. COMPUTATIONAL COMPARISON

The simulations have been performed on a 200MHz Pentium/Win95 PC. The computation times are summarized in table 1.

TABLE 1. COMPUTATION TIMES

Program	computation time [sec]	simulated time [msec]
EMTP96	6	2.55
XTrans	2	9.1433
PSB	8	9.1433

The computation times can be compared but with some caution. Both Xtrans and EMTP96 have the same computation times as specified in table 1 when the same computation is repeated. However, this is not the case with PSB; in the first run, the state-space representation of the

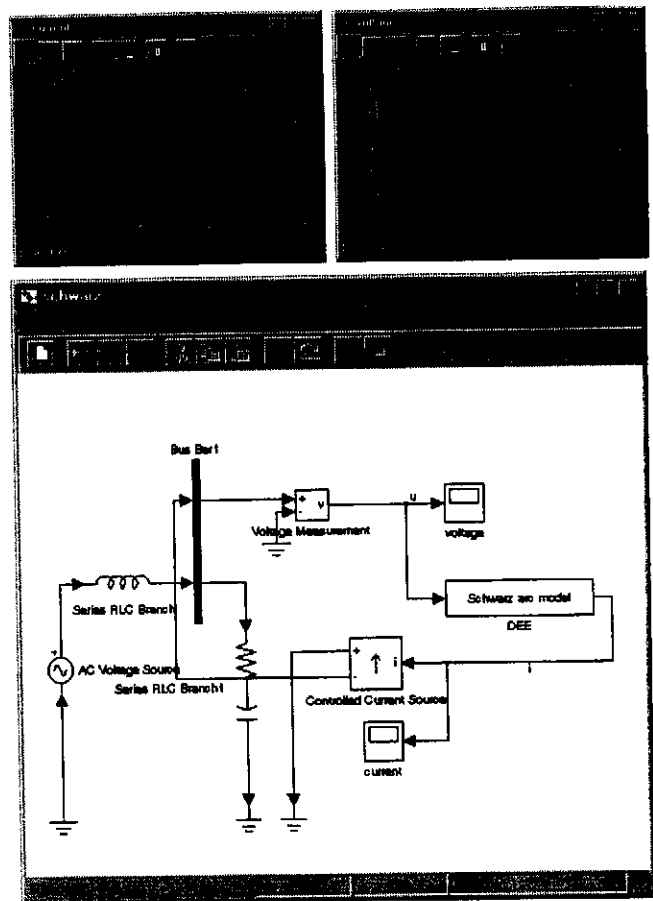


Fig. 5. MATLAB/Simulink/Power System Blockset Graphical user interface: circuit and scope-output

electrical circuit is computed. In following runs with the same circuit, this processing is skipped and computation times of 0.5 seconds result.

Another remark concerns the computation time of the EMTP96. The simulated time in EMTP96 is shorter than in the other two programs (see table 1), since in the EMTP96 the arc model is implemented differently [6]: the arc model is activated a short time before current zero (as can be observed from fig. 6). In XTrans and the PSB, the arc model is active during the high current phase as well (i.e. active during the whole simulation time). However, despite the shorter simulated time in the EMTP96, the computation time is three times higher than that of XTrans.

Before interruption, the short-circuit current flows through the arc channel of the circuit breaker. Because of the non-zero resistance of the arc channel, this short circuit current causes a voltage across the contacts of the circuit breaker: the arc voltage. The computed arc voltages (i.e. before current zero) are put together in one plot which is shown in fig. 6. When the arc voltages are displayed in greater detail (fig. 7), the curve computed by the EMTP96 is clearly distinguishable from the ones computed with the other two programs.

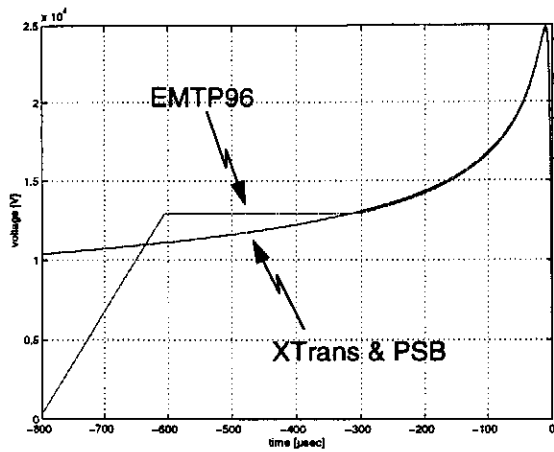


Fig. 6. Computed arc voltages

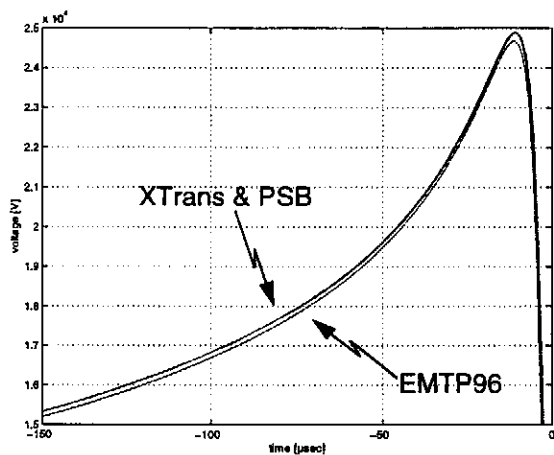


Fig. 7. Computed arc voltages (detail)

After interruption, the transient recovery voltage (TRV) builds up over the circuit breaker. Because the arc resistance is building up (and is non-infinite) at that time, a small current results: the post-arc current. The computed post arc currents (i.e. after current zero) are put together in one plot, which is shown in fig. 8. The peak value of the post-arc current computed by the EMTP96 is larger than those computed by XTrans and PSB.

In order to make a quantitative comparison between the three programs, the critical cooling power of the arc model is determined. That means that the cooling constant P_0 is lowered till the circuit breaker is just capable of interrupting the short circuit current. The critical cooling power as computed in the different programs is shown in table 2.

The three programs can be used for arc-circuit interaction studies as shown in this section. However, when arc-arc interaction studies are made or other computations where

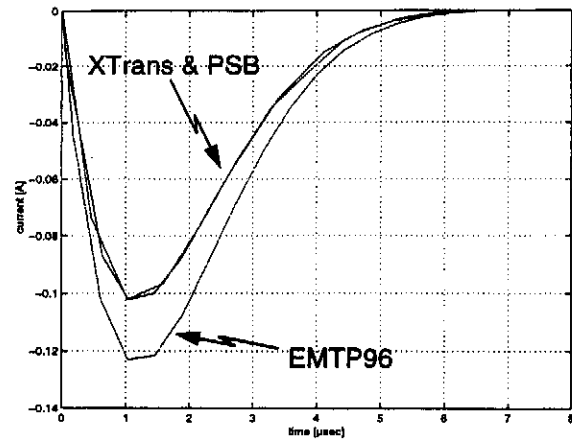


Fig. 8. Computed post-arc currents

TABLE 2. COMPUTED CRITICAL COOLING POWER

Program	critical P_0 [MW]
EMTP96	34
XTrans	33
PSB	33

multiple arc models are involved, XTrans or PSB must be used as the EMTP96 does not allow multiple arc models in the same subnetwork.

VII. GENERAL COMPARISON

In addition to the computational comparison by means of the arc-circuit interaction, the three transient programs have been compared with respect to several general items as well, that are summarized in table 3. We realize, however, that a comparison like this can not be objective and is based on our opinion only.

TABLE 3. GENERAL COMPARISON BETWEEN EMTP96, XTRANS AND MATLAB POWER SYSTEM BLOCKSET

Item	EMTP96	XTrans	PSB
user-friendliness	-	+	+/-
computational speed	+/-	+	+
variable stepsize	-	+	+
multiple numerical integration routines	-	-	+
flexibility	-	-	+

TABLE 3. GENERAL COMPARISON BETWEEN EMTP96, XTRANS AND MATLAB POWER SYSTEM BLOCKSET (CONTINUED)

Item	EMTP96	XTrans	PSB
creation of new models	-	+/-	+/-
number of circuit element models	+	-	-
well-accepted	+	-	-
export functionality	+	+	+

Hereunder, a description concerning each item follows.

A. User-friendliness

EMTP96 has a 'graphical user interface' which allows the user to approach the various components of the program graphically. Nonetheless, the circuit and parameter input is by means of formatted text files ('cards'). A new user will undoubtedly encounter problems to get his circuit working in the EMTP96. Both PSB and XTrans have a 'real' graphical user interface where everything can be controlled by mouse actions. XTrans is self-explanatory; it has the same 'look and feel' as other Windows-programs. PSB requires some knowledge of MATLAB and Simulink.

B. Computational speed

EMTP96 is not easy to compare with PSB and XTrans as the arc models are implemented in a different way. Nevertheless, the fixed stepsize in the EMTP will result in rather long computation times when very fast phenomena must be computed accurately (i.e. small stepsize).

C. Variable stepsize

EMTP96 does not have a variable stepsize. This is one of the drawbacks of the EMTP. XTrans has a variable stepsize. PSB allows the user to select one of the available ODE-solvers with a fixed or a variable stepsize.

D. Multiple numerical integration routines

PSB is the only program where multiple numerical integration routines can be selected; either with a fixed or a variable stepsize.

E. Flexibility

EMTP96 and XTrans are not flexible. This is because they are dedicated programs. PSB is very flexible, because the user can use the general-purpose MATLAB environment and programming language for controlling the computations and further analysis.

F. Creation of new models

To create new models in the EMTP96, deep inside knowledge of the EMTP-program is required. To create new models in

XTrans, some knowledge on object oriented programming is required. New models are compiled into a separate dll (dynamic link library) and then linked by means of a simple point and click procedure, to the (unchanged) XTrans program. In PSB, the user can create new models by using the available library blocks. By grouping the blocks together a new model can be created easily.

G. Number of circuit element models

EMTP96 contains a large number of advanced models, such as frequency-dependent line and cable models (note that the number of arc models is rather limited). Both XTrans and PSB are rather new and the number of models is still rather limited compared with the EMTP. However, as XTrans was primarily developed for arc-circuit interaction studies, it contains over ten arc models.

H. Well-accepted

The EMTP program is very well accepted and has a lot of users all over the world. Both XTrans and PSB are rather new and the group of users is still limited.

I. Export functionality

Both XTrans and EMTP96 are able to export plots and numerical values. XTrans can export the graph of the circuit as well. PSB can export numerical values to the MATLAB workspace. Both XTrans and PSB can make use of the Windows clipboard.

VIII. CONCLUSIONS

In this paper three tools for electrical transient computations are compared by their computational results and in general terms such as speed, user-friendliness and so on. EMTP scores best where the number of circuit element models is concerned. For larger simulations, involving many elements, EMTP is probably the best solution. XTrans is superior when we look to user-friendliness. It is believed that XTrans is the best tool to use for arc-circuit and arc-arc interaction studies and smaller simulations. MATLAB is unbeatable where programming freedom and flexibility are concerned. Therefore, the MATLAB Power System Blockset can be used when dedicated studies are required and when the circuit computations are embedded in software.

IX. REFERENCES

- [1] H.W. Dommel: 'A Method for Solving Transient Phenomena in Multiphase Systems', *Proceedings of the second Power System Computation Conference 1966*, Stockholm, Sweden, Report 5.8.
- [2] H.W. Dommel: 'Digital Computer Solution of Electromagnetic Transients in Single- and Multiphase Networks', *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-88, No. 4, April 1969, pp. 388-399.
- [3] N.D.H. Bijl and L. van der Sluis: 'New Approach to the Calculation of Electrical Transients, Part I: Theory', *European Transactions on*

Electrical Power Engineering (EPEP), Vol. 8, No. 3, May/June 1998, pp. 175-179.

- [4] N.D.H. Bijl and L. van der Sluis: 'New Approach to the Calculation of Electrical Transients, Part II: Applications', *European Transactions on Electrical Power Engineering (EPEP)*, Vol. 8, No. 3, May/June 1998, pp. 181-186.
- [5] V. Phaniraj and A.G. Phadke: 'Modelling of Circuit-Breakers in the Electromagnetic Transients Program', *IEEE Proceedings on Power Industry Computer Applications (PICA)*, 1987, pp. 476-482.
- [6] J. Mahseredjian, M. Landry and B. Khodabakhchian: 'The New EMTP Breaker Arc Model', *Proceedings on IPST (International Conference on Power Systems Transients)*, 1997, pp. 245-249.
- [7] J. Schwarz: 'Dynamisches Verhalten eines Gasbeblasenen, Turbulenzbestimmten Schaltlichtbogens', *ETZ-A*, Bd. 92 (1971), pp. 389-391.
- [8] G. St-Jean and R.F. Wang: 'Equivalence between Direct and Synthetic Short-Circuit Interruption Tests on HV Circuit Breakers', *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-102, No. 7, July 1983, pp. 2216-2223.

X. BIOGRAPHIES



Pieter H. Schavemaker was born in Velsen, the Netherlands on November 30, 1970. He obtained his M.Sc. in Electrical Engineering from the Delft University of Technology in 1994. After graduation, he performed research on power system state estimation with the Power Systems Laboratory for one year. In 1995, he started as an application engineer programming Substation Control Systems with ABB in The Netherlands. Since 1996 he has been with the Power Systems Laboratory where he is currently Assistant Professor. He is

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Adriaan J.P. de Lange was born in Alkmaar, the Netherlands on October 21, 1957. He obtained his M.Sc. in Electrical Engineering from the Delft University of Technology in 1986. In 1988, he started working in industry first as a mechanic and tester, later as an engineer and finally as project manager until 1996, mostly with 'Siemens AG Bereich KWU', building fossil power plants in the Netherlands and abroad. In 1996 he started a Ph.D. research on 'Three Phase Synthetic Testing of HV

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Lou van der Sluis was born in Geervliet, the Netherlands on July 10, 1950. He obtained his M.Sc. in electrical engineering from the Delft University of Technology in 1974. He joined the KEMA High Power Laboratory in 1977 as a test engineer and was involved in the development of a data acquisition system for the High Power Laboratory, computer calculations of test circuits and the analysis of test data by digital computer. In 1990 he became a part-time professor and since 1992 he has been employed as a full-time professor at the

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