Note: The following is believed to be an accurate approximate to pages 9 through 12 of the March, 1988, issue of "EMTP News," which was published by the Leuven EMTP Center (LEC) in Belgium. Default 1-inch margins and a 12-point Courier (fixed-width) font make the result look believable. Scanning and OCR (optical character recognition) of the original resulted in a file that then was edited using human intelligence by W. Scott Meyer on February 19, 1995. Underlining of section titles was omitted (bold type is used instead), as were quotation marks around request words such as LINE CONSTANTS. Spelling has been checked using the WP 5.1 spelling checker. In reference [7], there is a statement that begins: "as of the end of February, 1988." Well, it remains true today. I.e., as of mid-February, 1995, neither DCG nor any of its agents (e.g., Prof. Dommel) has ever delivered the requested materials to BPA as required by the DCG contract. Finally, no one ever responded to this call for help with any useful suggestion. As far as this writer knows, Prof. Dommel's research using Luis Marti remains "cold fusion." That is, it could not be confirmed or made to work by independent researchers. As for Dr. Liu's telephone number, it has changed from 4402 to 4401. About Li Jin-gui, it is understood that he received a Master's degree from Portland State University after this paper was written, and today is working for a company in California where he sometimes uses ATP.

CALL FOR HELP WITH RATIONAL FUNCTION APPROXIMATIONS TO FREQUENCY-DEPENDENT TRANSFORMATION MATRICES OF CABLES AND LINES

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I. Summary of EMTP Problem with Rational Function Approximations

There is a clear need for assistance with the approximation of frequency-dependent data by rational functions (quotients of polynomials). The technology being sought may well have nothing to do with power systems, or even electrical engineering, since it applies to differential equations that could come from any branch of science or engineering. Any reader with ideas is invited to contact the authors. If a cooperative reader with promising ideas wants to perform his own experiments, representative data could easily be provided for test purposes. This appears to be an ideal problem for academics, particularly those with contacts outside of the power field.

The frequency-dependent representation of transmission lines and cables is based on Fourier transformation, for which data is produced as a function of frequency by LINE CONSTANTS and CABLE CONSTANTS routines of the EMTP [1]. This is frequency-domain data, which can be generated without difficulty for all problems of common interest. To interface with the EMTP, which is based on a time-domain solution, convolution must be used. This leads to the idea of weighting functions [9], if the convolution is performed numerically. But for long lines or small time steps, numerical convolution required more numerical effort and storage than most users could afford to devote, so rational function approximations became popular, leading to the generally much speedier use of recursive convolution [2]. A dozen years ago, the challenge was to find an acceptable rational function approximation (a "fitting"), and the difficulty remains today. Whereas some old problems (e.g., the 3-phase overhead line with constant transformation matrix) have been solved satisfactorily, some new problems have appeared due to more ambitious modeling. When frequency-dependence of the transformation matrix IT] is included, there is difficulty fitting the required functions of frequency for both cables and multiple-circuit overhead lines. The secret of J. Marti fitting was a restriction to real poles only, and the use of Bode's method applied to the magnitude function only [3]. The functions of initial interest seemed to be of minimum-phase-shift type [4], which meant that the angle agreed automatically. But such assumptions are inapplicable to [T] for general cables and overhead lines, and sometimes functions dependent on [T] (e.g., the characteristic admittance Yc). In effect, the clock has been turned back to the start of the decade, before the J. Marti discovery [3]. Although functions are different, researchers have the same problem today. There is need of a fitter that requires minimum user intelligence, is not too complicated mathematically (the computer code must be maintainable), and finally, which fits all frequency-dependent functions of lines and cables.

II. Two Years of BPA Experimentation with Marti Modeling

Today there is more doubt and uncertainty about validity of recursive convolution modeling (including both Marti and SemIyen frequency-dependent modeling) of the EMTP than there was six years ago. The authors have reached this disturbing conclusion after nearly two years of research on the subject. Not only are existing procedures inapplicable to the general cable system, but they have been found to be lacking for important cases of multiple-circuit overhead lines, too.

The problem is not with the simulation code itself (advancing time in the time-step loop), which is believed to be error free [7]. Rather, the supporting programs that produce data for the associated models have been found to be inadequate. Existing EMTP data generators such as SEMLYEN SETUP and JMARTI SETUP are inapplicable to the fitting of certain important functions of cables and lines.

Six or seven years ago, it was understood that the EMTP had no general frequency-dependent model for cables. This is why in 1981 BPA funded three years of research on the subject at the University of British Columbia [5]. Unfortunately, the research did not terminate successfully for general cable systems. Investigations by the authors during 1986 and 1987 discovered the nature and extent of associated problems. The general L. Marti model [6] for cables is unusable for important cases of practical interest (both cables and overhead lines). The simulation model exists, but data is unavailable because the assumptions of the fitter are inapplicable to the configurations of interest.

Existing SEMIYEN SETUP code of the EMTP never was considered seriously as a candidate for the rational function fitting of cables or transformation matrices [T]. It provides a 2nd-order approximation only, and logic has been carefully tuned to the needs of overhead lines. Finally, it is restricted to real poles only.

Existing JMARTI SETUP code provided hope for fitting all functions of cables and transformation matrices [T]. The mechanics of fitting are easy enough. Yes, there were modifications to convert from the use of Zc to Yc (from characteristic impedance to characteristic admittance), and different shapes of functions required adjustments (generally extensions) to the logic. Also, it was necessary to switch modes as a function of frequency, to ensure smoothness of the functions [10]. But these all were mechanical details that presented no great obstacle. The trouble arose when a good approximation was obtained for the magnitude of the function, but the resulting angle involved gross error. It would seem that the fundamental assumption of Marti fitting is invalid for important cases of industry interest. In the terminology of circuit synthesis, the network being approximated is not minimum-phase-shift [4]. One can not merely fit the magnitude and expect the angle to match automatically.

Some cables and overhead lines can be fitted accurately using the Marti procedure, and BPA's single-circuit 500-kV line from John Day to Lower Monumental provides an illustration. For years the transients on this line following a single-line-to-ground fault at the open receiving end have been documented in test cases BENCHMARK DC-31 (data from SEMLYEN SETUP), DC-41 (data from HAUER SETUP), and DCNEW-4 (data from JMARTI SETUP). But all such simulations were based on modeling that assumed a constant [T], which introduced unknown error. Well, with the new model, we finally know for sure that the error was negligible. Transient voltages at the open receiving end are practically unchanged by making [T] frequency-dependent. Vector plots of the two transients are so close that one can detect no difference when the two are superimposed and held up to the light. The added computer burden is not exorbitant. VAX-8650 simulation time for the 2000 steps (TMAX = 0.1 sec) of DCNEW-4 is increased by 59% due to the frequency dependence of [T].

HAUER SETUP is a sophisticated fitting routine [8] that was available in the EMTP early in this decade. it was removed because of its size (over 1OK lines of code), its complexity (only the author knew the details), and most importantly, its difficulty of use. But HAUER SETUP did work, if one knew how. As a separate program, and with the assistance of its author, the code continues to be used at BPA as an alternative to JMARTI SETUP. Unlike Marti modeling, the Hauer modeling allows complex poles, so potentially it is better suited for those cases that Marti modeling can not handle. But the size, complexity, and difficulty of use remain unchanged as liabilities. For this reason, it has not yet been tried as an alternative fitter.

Numerical convolution could be a viable alternative to recursive convolution for some users. A decade ago, it was too expensive of both computer time and memory. But prices have dropped so drastically (perhaps by a factor of 100) that one must rethink past objections. Although no final decision has been made, serious consideration is being given to a return of weighting functions.

III. References Used By the Preceding Text

[1]. W. S. Meyer, T. H. Liu, Editors: "EMTP Rule Book." About 800 pages, these user instructions for the EMTP are published by BPA (for an address, see the principal author preceding the title). This is public-domain documentation.

[2]. A. Semlyen, A. Dabuleanu, "Fast and accurate switching transient calculations on transmission lines with ground return using recursive convolutions," IEEE Trans., vol. PAS-94, pp. 561-571, 1975.

[3]. J. R. Marti, "Accurate modelling of frequency-dependent transmission lines in electromagnetic transients simulations," Proceedings of the IEEE Power Industry Computer Applications (PICA) Conference, Philadelphia, Pennsylvania, 9 pages, May 1981.

[4]. A. Papoulis, "The Fourier Integral and its Applications." McGraw-Hill Book Company, pp.204-208, 1962.

[5]. In the late summer of 1981, BPA awarded a 4-year contract to Prof. H. W. Dommel of the University of British Columbia (Vancouver, B.C., Canada). A cost-reimbursement-type contract that became effective on 17 September 1981, the agreement had a ceiling cost of $125K. Although primarily for writing of the EMTP Theory Book, this contract provided $30K for 3-years of half-time graduate student research into a rigorous cable model. Although not named in the contract, it was understood that Luis Marti, then a graduate student, would begin doctoral research on cable modeling as an extension of J. Marti line modeling [3] and it would be Luis Marti who would receive the $30K of BPA money -- barring some unforeseen circumstance.

[6]. L. Marti, "Simulation of transients in underground cables with frequency-dependent modal transformation matrices," presented at the 1987 IEEE PES Winter Meeting.

[7]. Results of the research of Ref. [5] were first communicated to EMTP specialists at BPA on 6 March 1986, when the contractors hand-delivered a reel of magnetic tape containing only modified portions of the UBC Transients Program. No code for rational function fitting of [T] has ever been delivered to BPA. Following the explanation that work on such code was done at UBC for DCG rather than for BPA, an official BPA request for the code was made by R. M. Hasibar dated 8 August 1986. As of the end of February, 1988, BPA still has not received such materials in spite of its explicit and obvious right to all DCG work under the DCG Agreement. BPA did receive a revised DCG/EPRI Line Constants

Program dated June, 1987, and this has some modified fitting capability. But nowhere to be seen in the User's Manual is any mention of applicability of the fitter to either transformation matrices or cables.

[8]. J. F. Hauer, --State-space modelling of transmission line dynamics via nonlinear optimization," IEEE Trans. PA&S," pp. 4918-4925, December, 1981.

[9]. W. S. Meyer, H. W. Dommel, "Numerical modelling of frequency-dependent transmission line parameters in an electromagnetic transients program," IEEE Trans. PA&S, vol. PAS-93, pp. 1401-1409, Sep/Oct 1974.

[10]. This experimentation was done mainly by W-H Edwin Liu during the summer of 1986. Then a doctoral student at the University of California, Berkeley, Edwin Liu was employed full time by BPA just for the summer via contract with Ronson Management Corporation. No relation of the author, Dr. Edwin Liu now works full time in the power industry on problems of energy control centers.

* Li Jin-gui has been working at BPA since May of 1986. His first year was paid for entirely by his government (BPA provided the working environment only), which sent him to BPA as a Visiting Scholar. Since May of 1987, the coauthor has been self-supporting by means of a one-year contract with BPA.

Editor's Note :

The following article by Robert M. Hasibar of BPA is unchanged except for very minor grammatical corrections from what was submitted by mail to DCG/EPRI's "EMTP Review" on December 2nd, 1987. (See reference [1] from the paper "Recent problems with credibility of DCG/EPRI EMTP Review" by W.S. Meyer further in this issue). It is being printed by "EMTP News" because of general interest in BPA's position about EMTP development, and also because it was curiously missing from the January, 1988, issue of "EMTP Review". When Mr. Hasibar wrote this text, BPA was connected with DCG, but the DCG contract obligating BPA to DCG has since expired (on December 31st, 1987).