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BELO HORIZONTE – BRAZIL

USER MANUAL

ULM-ATP

VERSION 1.0
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1 - Introduction

The implementation of ULM in ATP follows a strategy that combines the use of an external code, in the first stage, and ATP, in a second stage. The external code was entirely developed in MATLAB as shown in Fig 1.1. Initially, the user enters the transmission line data through a graphical interface developed in the GUIDE environment of MATLAB [1-2]. The associated code is responsible for calculating the line parameters, the time delays, the characteristic admittance Y_c and the propagation function H required in ULM [3], plus their fitting. In the end, a text file is generated containing the poles and residues of Y_c and H , the elements of the conductance matrix G required in the implementation, and the minimum time delays associated with each mode. This file acts as a link between the external code and ATP, containing all information necessary to perform the transient simulation in ULM.

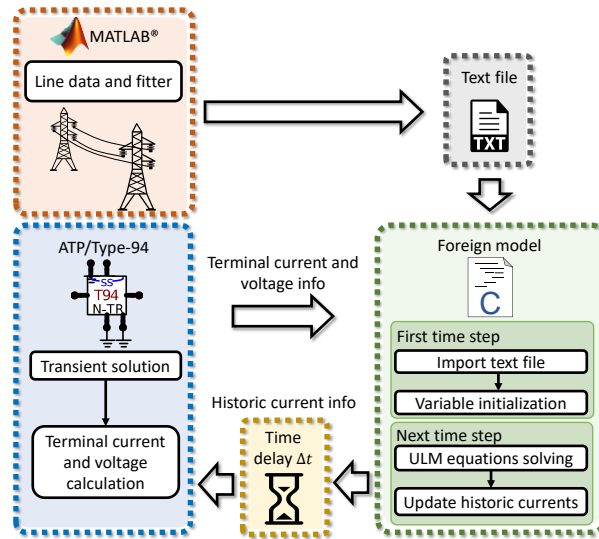


Fig. 1.1. Diagram of the strategy used in the implementation of ULM in ATP.

In the second stage, a foreign model implemented in ATP reads the text file generated by the external code. In this model, the ULM equations were implemented in ANSI C language. The program initializes the variables necessary for calculating the transient in the first time step. From the voltages and currents at the line terminals, the foreign model calculates the history terms, feeding back a type-94 component in ATP at each time step. Since the communication of the foreign model with ATP occurs with a delay of one time step [1], this effect is compensated in the calculation of the current sources containing the history terms. Finally, ATP returns the values of the terminal

voltages and currents to the foreign model.

This document discusses the implementation of ULM as a foreign model in ATP, referred to as ULM-ATP. In the current version, it does not cover the preprocessing code written in MATLAB for performing the per-unit-length parameter calculation and fitting of model parameters. However, it provides detailed instructions on how to prepare the input data for use in the ULM-ATP model.

Users are free to use all support files and codes available on <https://github.com/zanonfelipe/ULMAtp>, but are kindly requested to include reference to the following paper:

Felipe O.S. Zanon, Osis E.S. Leal, Alberto De Conti, Implementation of the universal line model in the alternative transients program, *Electric Power Systems Research*, vol. 197, p. 107311, Aug. 2021, doi: 10.1016/j.epsr.2021.107311.

2- Installation

The ATP software is executed using the file commonly called mytpbig.exe. New functions or new models can be added to the mytpbig.exe file and, consequently, to the ATP software. To incorporate new functions or new models, it is necessary to recompile ATP software. This chapter describes how to add the ulm.c model developed by the authors using the ATPLauncher1.16 tool, developed by Japanese ATP User Group (JAUG), together with the MinGW 5.1.0 compiler. In order to integrate the ulm.c model with ATP software, the user must strictly follow the steps described below.

- 1) Extract all files from “MinGW_5_1_0.zip” to “[dirInstall]\atpmingw\make\MinGW”¹, overwriting existing files and merging existing folders (this step is only necessary if the MinGW compiler is not up to date).
- 2) Copy “fgnmod.f” to “[dirInstall]\atpmingw\make” overwriting the existing file.
- 3) Copy “makefile_c” to “[dirInstall]\atpmingw\make\sample” overwriting the existing file.

If the root directory “[dirInstall]” of the ATP software installation is “C:\ATP” skip to step 4, else do:

- 3.1) open the makefile_c file.
- 3.2) correct the directories entered in the lines 32, 34, 46 and 47 (for more details see chapter 5).
- 4) Copy “ulm.c” to “...[dirInstall]\atpmingw\make\sample”
- 5) Copy “fitULM.txt” to “...\Documents\ATPdata\work”²
- 6) Open ‘ULMtype-94.acp’ and do some configurations:
- 7) Click on ‘ATP’ option on the menu bar
- 8) Select ‘ATP Launcher’
- 9) In the appearing dialog, click on ‘Tools’

¹ [dirInstall] represents the root installation directory of the user defined ATP at the time of installation. The default root directory is c:\ATP.

² ATPDraw software saves ATP cards in the directory called ATP folder. The ATP folder directory is set, by default in ATPDraw software, to the “work” folder. The file fitULM.txt should be copied to this folder. To correctly locate the directory that will be sent to ATP cards by ATPDraw software click on the “Tools” menu, then “Options”. On the ATPDraw Options screen, click the File&Folders tab. ATP cards will be forwarded to the directory described in the textbox called “ATP folder”. Therefore, this is the directory that the fitULM.txt file should be copied to.

10) Select “Make Tpbig.exe”

11) In the appearing dialog, set:

11.1) MyTpbig Directory: “[dirInstall]\mytpbig”

11.2) Make sure that “Make compiled TACS” and “Use Default Makefile” are unchecked.

11.3) Makefile: “[dirInstall]\atpmingw\make\sample\Makefile_c”.

11.4) MinGW Directory: “[dirInstall]\atpmingw\make\MinGW\bin” (an example for installing ATP software in the default directory is shown in Figure 2.1).

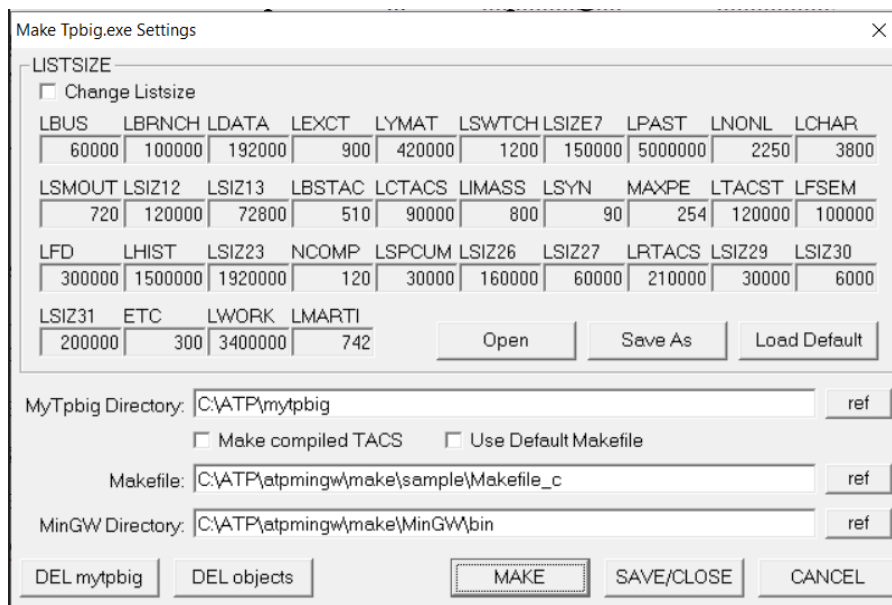


Fig. 2.1 – Make Tpbig.exe Settings.

12) Click on the “Make” button.

13) The message “[dirInstall]\mytpbig\mytpbig.exe was successfully created!!” should appear.

14) Run the simulation.

3- Type94 Configuration

The interface between the ATP software and ULM is performed by the Type 94 Norton TR model. This model allows the inclusion of new line models to ATP. In ATPDraw it is possible to access the Type 94 Norton TR model by right-clicking on the MODELS/TYPE94/NORT-TR menu. The Type 94 Norton TR model configuration screen is shown in Fig. 3.1. In order to assure that the model will work properly, select the “NORTON-transmission” and set the number of line phases in “NumPh” field, as shown in Fig. 3.1. After the initial configuration, it is necessary to edit the standard MODELS code so that it represents the ULM line model. To do this, click on the “Edit” button.

NODE	PHASE	NAME
Left	1	
Right	1	
SSVL	1	
SSVR	1	
SSIL	1	
SSIR	1	

Order: 0 Label:

Comment:

Type 94

Model: Edit

Output: 0 - No Record

☐ THEVENIN ☐ Hide

☐ ITERATED ☐ Protect

☒ NORTON

☒ NORTON-transmission NumPh 3

Edit definitions OK Cancel Help

Fig. 3.1 – Type 94 Norton TR model configuration.

The standard MODELS code for the Type 94 TR model is:

```

MODEL name          -- NB! 6 character name limit
-- Start header. Do not modify the type-94 header.
comment-----
| First, declarations required for any type 94 Norton TR model      |
| - these data and input values are provided to the model by ATP    |
| - these output values are used by ATP                            |
| - these names can be changed, except 'n', but not their order    |
-----endcomment
DATA  n              -- number of phases
      ng {dflt: n*(n+1)/2} -- number of conductances on each side

INPUT lv[1..n]      -- voltage(t) at each left node
      rv[1..n]      -- " " " right node
      lv0[1..n]     -- voltage(t=0) at each left node
      rv0[1..n]     -- " " " right node
      li0[1..n]     -- current(t=0) into each left node
      ri0[1..n]     -- " " " right node
VAR   li[1..n]      -- current(t) into each left node (for plotting)
      ri[1..n]      -- " " " right node " "
      lis[1..n]     -- Norton source(t+timestep) at each left node
      ris[1..n]     -- " " " right node
      lg[1..ng]     -- conductance(t+timestep) at each left node
      rg[1..ng]     -- " " " right node
      -- sequence is 1-gr, 1-2, 1-3..1-n,2-gr,2-3..2-n,...n-gr
      flag          -- set to 1 whenever conductance value is modified
OUTPUT li[1..n],ri[1..n],lis[1..n],ris[1..n],lg[1..ng],rg[1..ng],flag
comment-----
| Next, declarations of user-defined data for this particular model |
| - their value is defined at the time of using the type-94 component |
-----endcomment
-- End header
DATA ...
comment-----
| Next, declarations provate to this model                          |
-----endcomment
VAR ...
...
INIT
...
ENDINIT
EXEC
...
ENDEXEC
ENDMODEL -- End code

```

As described in the standard MODELS code, the user must make any desired changes only after the set of OUTPUT variables. The standard MODELS code already modified to use the ULM model is:

```

MODEL ulm001 -- NB! 6 character name limit
DATA  n              -- number of phases
      ng {dflt: n*(n+1/2)} -- number of conductances
INPUT lv[1..n]      -- voltage(t) at left terminals
      rv[1..n]      -- " " " right terminals
      lv0[1..n]     -- voltage(t=0) at left nodes
      rv0[1..n]     -- " " " right nodes
      li0[1..n]     -- current(t=0) at left terminals
      ri0[1..n]     -- " " " right terminals
VAR   li[1..n]      -- current(t) into left terminals
      ri[1..n]      -- " " " right terminals
      lis[1..n]     -- Norton source(t+timestep) at left terminals

```



```

ris[1..n] -- " " " " " right terminals
lg[1..ng] -- conductance(t+timestep) at left terminals
rg[1..ng] -- " " " " " right terminals
-- sequence is 1-gr, 1-2, 1-3..1-n, 2-gr, 2-3..2-n, ... n-gr
-- on each side separately
flag -- set to one whenever an admittance value is modified
OUTPUT li[1..n], ri[1..n], lis[1..n], ris[1..n], lg[1..ng], rg[1..ng], flag
comment-----
| Next, declarations of user-defined data for this particular model |
| - their value is defined at the time of using the type-94 component |
-----endcomment
VAR Gs[1..n*n], cont
MODEL ulmmmodel FOREIGN ULM_C_LINE {ixdata:1, ixin:12, ixout:12, ixvar:12}
INIT
Gs[1..n] :=[ 2.4768e-3, -6.4529e-4, -4.3270e-4]
Gs[n+1..2*n] :=[-6.4529e-4, 2.7978e-3, -1.0274e-3]
Gs[2*n+1..n*n] :=[-4.3270e-4, -1.0274e-3, 2.7052e-3]
lg[1..ng] :=[1.3988e-3, 6.4529e-4, 4.3270e-4, 1.1251e-3, 1.0274e-3, 1.2451e-3]
rg[1..ng] :=lg[1..ng]
li[1..n] :=0 -- current for this step
ri[1..n] :=0
lis[1..n] :=0
ris[1..n] :=0
cont :=0
ENDINIT
EXEC
IF t=0 THEN
flag := 1 -- conductance values have been changed
ELSE
flag := 0 -- reset flag
ENDIF
cont:=0
li[1..n] :=0
ri[1..n] :=0
FOR i:=1 TO n DO
FOR j:=1 TO n DO
li[i] :=li[i]+ Gs[j+cont]*lv[j]
ri[i] :=ri[i]+ Gs[j+cont]*rv[j]
ENDFOR
cont :=cont+n
li[i] :=li[i]-lis[i]
ri[i] :=ri[i]-ris[i]
ENDFOR
USE ulmmmodel AS ulmline
DATA xdata[1]:=timestep
INPUT xin[1..n] :=lv[1..n]
xin[(n+1)..(2*n)] :=li[1..n]
xin[(2*n+1)..(3*n)] :=rv[1..n]
xin[(3*n+1)..(4*n)] :=ri[1..n]
OUTPUT lis[1..n]:=xout[1..n]
ris[1..n]:=xout[(n+1)..(2*n)]
ENDUSE
li[1..n] :=0
ri[1..n] :=0
ENDEXEC
ENDMODEL -- End code

```

In this example, called ulm001, the line has 3-phases as shown in Fig. 3.1. In this code, **Gs** represents the nodal conductance matrix. However, it is not possible to declare variables of matrix type in MODELS language. For this reason, **Gs** is a vector of size $1 \times n * n$, where n is the number of phases declared in “NumPh” (see Fig. 3.1). Assuming that **G** is the $n \times n$ matrix of nodal conductances of the line, the **Gs** construction logic, to represent **G**, is:

$$Gs[(i-1)*n+1..i*n] \equiv [G(i,1), G(i,2), \dots, G(i,n)]. \quad (3.1)$$

On the other hand, the assembly algorithm of the vectors **lg** and **rg** is slightly different. The assembly of **lg** becomes:

if $i = 1$

$$lg[i..n] = \left[\sum_{j=1}^n G(i, j), -G(i, i+1), \dots -G(i, n) \right], \quad (3.2)$$

elseif $i > 1$

$$lg[(n-1)(i-1) + 2..(n-1)i + 1] = \left[\sum_{j=1}^n G(i, j), -G(i, i+1), \dots -G(i, n) \right] \quad (3.3)$$

Since matrices **lg** and **rg** are equal, it suffices to determine **lg** and then to declare `rg[1..ng] :=lg[1..ng]` in the code.

To use the ULM model with a different configuration from the one presented, the user will only need to change the variables **Gs** and **lg**. The following is an example, called `ulm002`, of a line consisting of 5 conductors.

```
MODEL ulm002
DATA  n                -- number of phases
      ng {dfilt: n*(n+1)/2} -- number of conductances

INPUT lv[1..n]         -- voltage(t) at left terminals
      rv[1..n]         -- " " " " right terminals
      lv0[1..n]        -- voltage(t=0) at left nodes
      rv0[1..n]        -- " " " " right nodes
      li0[1..n]        -- current(t=0) at left terminals
      ri0[1..n]        -- " " " " right terminals
VAR   li[1..n]         -- current(t) into left terminals
      ri[1..n]         -- " " " " right terminals
      lis[1..n]        -- Norton source(t+timestep) at left terminals
      ris[1..n]        -- " " " " " " right terminals
      lg[1..ng]         -- conductance(t+timestep) at left terminals
      rg[1..ng]         -- " " " " " " right terminals
                        -- sequence is 1-gr, 1-2, 1-3..1-n, 2-gr, 2-3..2-n, ... n-gr
                        -- on each side separately
      flag             -- set to one whenever an admittance value is modified
OUTPUT li[1..n], ri[1..n], lis[1..n], ris[1..n], lg[1..ng], rg[1..ng], flag
comment-----
| Next, declarations of user-defined data for this particular model |
| - their value is defined at the time of using the type-94 component |
|-----endcomment
VAR   Gs[1..n*n], cont
MODEL ulmmmodel FOREIGN ULM_C_LINE {ixdata:1, ixin:4*n, ixout:24, ixvar:24}
INIT
Gs[1..n-1]      := [+2.3354e-3, -3.5854e-4, -1.3709e-4, -1.0853e-5, -8.1657e-6]
Gs[n]           := -8.0136e-6
Gs[n+1..2*n-1] := [-3.5854e-4, 2.4065e-3, -3.5824e-4, -1.4212e-5, -1.0308e-5]
Gs[2*n]         := -9.7531e-6
Gs[2*n+1..3*n-1] := [-1.3709e-4, -3.5824e-4, 2.3362e-3, -2.6979e-5, -1.8985e-5]
Gs[3*n]         := -1.7412e-5
```

```

Gs[3*n+1..4*n-1]:=[-1.0853e-5, -1.4212e-5, -2.6979e-5, 2.4451e-3, -6.0005e-4]
Gs[4*n] :=-2.9772e-4
Gs[4*n+1..5*n-1]:=[-8.1657e-6, -1.0308e-5, -1.8985e-5, -6.0005e-4, 2.5558e-3]
Gs[5*n] :=-6.0044e-4
Gs[5*n+1..n*n-1]:=[-8.0136e-6, -9.7531e-6, -1.7412e-5, -2.9772e-4, -6.0044e-4]
Gs[n*n] :=2.4442e-3
lg[1..n] :=[1.8127e-3, 3.5854e-4, 1.3709e-4, 1.0853e-5, 8.1657e-6, 8.0136e-6]
lg[n+1..2*n-1] :=[1.6555e-3, 3.5824e-4, 1.4212e-5, 1.0308e-5, 9.7531e-6]
lg[2*n..3*n-3] :=[1.7775e-3, 2.6979e-5, 1.8985e-5, 1.7412e-5]
lg[3*n-2..3*n] :=[1.4953e-3, 6.0005e-4, 2.9772e-4]
lg[3*n+1..3*n+2]:=[1.3178e-3, 6.0044e-4]
lg[ng] :=1.5109e-3
rg[1..ng] :=lg[1..ng]
li[1..n] :=0 -- current for this step
ri[1..n] :=0
lis[1..n] :=0
ris[1..n] :=0
cont :=0
ENDINIT
EXEC
IF t=0 THEN
    flag := 1 -- conductance values have been changed
ELSE
    flag := 0 -- reset flag
ENDIF
cont:=0
li[1..n] :=0
ri[1..n] :=0
FOR i:=1 TO n DO
    FOR j:=1 TO n DO
        li[i] :=li[i]+Gs[j+cont]*lv[j]
        ri[i] :=ri[i]+Gs[j+cont]*rv[j]
    ENDFOR
    cont :=cont+n
    li[i] :=li[i]-lis[i]
    ri[i] :=ri[i]-ris[i]
ENDFOR
USE ulmmodel AS ulmline
DATA xdata[1]:=timestep
INPUT xin[1..n] :=lv[1..n]
        xin[(n+1)..(2*n)] :=li[1..n]
        xin[(2*n+1)..(3*n)] :=rv[1..n]
        xin[(3*n+1)..(4*n)] :=ri[1..n]
OUTPUT lis[1..n]:=xout[1..n]
        ris[1..n]:=xout[(n+1)..(2*n)]
ENDUSE
ENDEXEC
ENDMODEL -- End code

```

For ULM, the conductance matrix is given by [1]

$$\mathbf{G} = \mathbf{k}_0 + \sum_{n=1}^{N_{pY}} \mathbf{q}_n \quad (3.4)$$

where \mathbf{k}_0 is a real matrix resulting from the fitting of the characteristic admittance matrix (\mathbf{Y}_C), N_{pY} poles required for fitting \mathbf{Y}_C and the matrix \mathbf{q}_n is given by

$$\mathbf{q}_n = \frac{\mathbf{k}_n \Delta t}{2 - a_n \Delta t}; n = 1..N_{py} \quad (3.5)$$

where Δt is the simulation step, $\mathbf{k}_1:\mathbf{k}_{N_{pY}}$ are real or complex matrices of residues associated with each element of \mathbf{Y}_C , and $a_1:a_{N_{pY}}$ are the N_{pY} poles required for fitting \mathbf{Y}_C .

4- fitULM Structure

The line information calculated by the external code is recorded in a text file that stores the necessary information for the transient simulation in ATP [1]. The file follows the structure shown in Figure 4.1, which refers to a 3-phase line. The default for the text file is to insert one element per line, whether it comes from a vector or a matrix. If the element is complex, both the real part and the imaginary part are inserted on the same line. The real part is written at the beginning and the imaginary part is written next. Both are separated by a tab in the text file. The sequence of recording the information is described below:

- Number of phases (n);
 - Number of modes (m);
 - Number of poles p_{Y_c} resulting from the fitting of Y_c
 - Number of poles p_A resulting from the fitting of H ;
 - Vector of poles resulting from the fitting of Y_c , that is, $a_1: a_{p_{Y_c}}$;
 - Matrices of residues $k_1: k_{p_{Y_c}}$ resulting from the fitting of Y_c , included element by element. The $k_{n_{th}}(n, n, p_{Y_c})$ matrix is three-dimensional.
 - First enter the elements from the first row of k_1 , that is $k_1(1,1,1)$, $k_1(1,2,1)$, $k_1(1,3,1)$, for this example. Then, enter the elements from second row of k_1 , and finally the elements from the last row of k_1 , that is, $k_1(3,1,1)$, $k_1(3,2,1)$, $k_1(3,3,1)$.
 - Next, enter the elements of k_2 , following the procedures described above, and repeat for all $k_{n_{th}}$ matrices.
 - Last matrix is k_{15} , in this example. So, enter the elements $k_{15}(1,1,15)$, $k_{15}(1,2,15)$, $k_{15}(1,3,15)$, firstly. Then enter the elements $k_{15}(2,1,15)$, $k_{15}(2,2,15)$, $k_{15}(2,3,15)$, and finally the elements $k_{15}(3,1,15)$, $k_{15}(3,2,15)$, $k_{15}(3,3,15)$.
 - Vector of poles resulting from the fitting of H , that is, $\bar{a}_1: \bar{a}_{p_A}$;
 - Matrices of residues \bar{c}_{ij} resulting from the fitting of H , included element by element. The matrix $\bar{c}_{ij}(n, n, p_A, m)$ has four dimensions.
 - First enter the elements from the first row of $\bar{c}_{1,1}$, that is $\bar{c}_{1,1}(1,1,1,1)$, $\bar{c}_{1,1}(1,2,1,1)$, $\bar{c}_{1,1}(1,3,1,1)$, for this example. Then, enter the elements from second row of $\bar{c}_{1,1}$, and finally the elements from the last row of $\bar{c}_{1,1}$, that is, $\bar{c}_{1,1}(3,1,1,1)$, $\bar{c}_{1,1}(3,2,1,1)$, $\bar{c}_{1,1}(3,3,1,1)$.
 - Next, enter the elements of $\bar{c}_{2,1}$, following the procedures described above, and repeat for all $\bar{c}_{i_{th},1}$ matrices.
 - After, enter the elements from the first row of $\bar{c}_{1,2}$, that is $\bar{c}_{1,2}(1,1,1,2)$, $\bar{c}_{1,2}(1,2,1,2)$, $\bar{c}_{1,2}(1,3,1,2)$. Then, enter the elements from second row of $\bar{c}_{1,2}$, and finally the elements from the last row of $\bar{c}_{1,2}$, that is, $\bar{c}_{1,2}(3,1,1,2)$, $\bar{c}_{1,2}(3,2,1,2)$, $\bar{c}_{1,2}(3,3,1,2)$.
-

- Next, enter the elements of $\bar{\mathbf{c}}_{2,1}$, following the procedures described above, and repeat for all $\bar{\mathbf{c}}_{i_{th},2}$ matrices.
 - Repeat the procedures above for all $\bar{\mathbf{c}}_{i_{th},j_{th}}$ matrices.
 - Last matrix is $\bar{\mathbf{c}}_{14,3}$ in this example. So enter the elements from the first row of $\bar{\mathbf{c}}_{14,3}$, that is $\bar{\mathbf{c}}_{14,3}(1,1,14,3)$, $\bar{\mathbf{c}}_{14,3}(1,2,14,3)$, $\bar{\mathbf{c}}_{14,3}(1,3,14,3)$, for this example. Then, enter the elements from second row of $\bar{\mathbf{c}}_{14,3}$, and finally the elements from the last row of $\bar{\mathbf{c}}_{14,3}$, that is, $\bar{\mathbf{c}}_{14,3}(3,1,14,3)$, $\bar{\mathbf{c}}_{14,3}(3,2,14,3)$, $\bar{\mathbf{c}}_{14,3}(3,3,14,3)$.
 - Time delays;
 - Matrix containing the elements of the independent term \mathbf{k}_0 resulting from the fitting of \mathbf{Y}_c , included element by element. The matrix $\mathbf{k}_0(n, n)$ is two-dimensional.
-

Phases	3	
Modes	3	
Poles Y_c	15	real part imaginary part
Poles H	14	
a_1	-1.0871423042218018e+08	0.0000000000000000e+00
...
a_{15}	-3.2715705587321944e+00	0.0000000000000000e+00
$k_1(1,1,1)$	6.2212264148685833e+01	0.0000000000000000e+00
$k_1(1,2,1)$	1.7977699036837495e+02	0.0000000000000000e+00
$k_1(1,3,1)$	-2.4457904200450531e+02	0.0000000000000000e+00
$k_1(2,1,1)$	1.7977699036843859e+02	0.0000000000000000e+00
$k_1(2,2,1)$	1.9102566032521688e+02	0.0000000000000000e+00
$k_1(2,3,1)$	-2.6457195541040920e+02	0.0000000000000000e+00
...
$k_1(3,3,1)$	-5.6229302802459715e+03	0.0000000000000000e+00
...
$k_{15}(1,1,15)$	-8.4389793285637342e-05	0.0000000000000000e+00
...
$k_{15}(3,3,15)$	-3.3236349781654716e-05	0.0000000000000000e+00
\bar{a}_1	-1.3996907644561276e+02	0.0000000000000000e+00
...
\bar{a}_{13}	-3.5033836293033487e+06	1.5336258500985403e+06
\bar{a}_{14}	-3.5033836293033487e+06	-1.5336258500985403e+06
$\bar{c}_{1,1}(1,1,1,1)$	1.0927377470343650e+01	0.0000000000000000e+00
$\bar{c}_{1,1}(1,2,1,1)$	-4.3460688917835615e+00	0.0000000000000000e+00
$\bar{c}_{1,1}(1,3,1,1)$	4.7642985769289552e+01	0.0000000000000000e+00
$\bar{c}_{1,1}(2,1,1,1)$	8.1195854524057776e+00	0.0000000000000000e+00
$\bar{c}_{1,1}(2,2,1,1)$	6.3600576628933290e+00	0.0000000000000000e+00
$\bar{c}_{1,1}(2,3,1,1)$	1.5473150405889095e+01	0.0000000000000000e+00
...
$\bar{c}_{1,1}(3,3,1,1)$	-1.6969863296586436e+01	0.0000000000000000e+00
$\bar{c}_{2,1}(1,1,2,1)$	1.3657962467599821e+03	0.0000000000000000e+00
...
$\bar{c}_{14,1}(3,3,14,1)$	-1.9218658778567619e+06	1.4711064234975299e+06
$\bar{c}_{1,2}(1,1,1,2)$	-1.4940422135004958e+01	0.0000000000000000e+00
...
$\bar{c}_{14,3}(3,3,14,3)$	-9.8738643417338468e+05	1.0233092518550251e+05
τ_1	9.9859494111212284e-06	
τ_2	1.0007672452117818e-05	
τ_3	1.0007598221403947e-05	
$k_0(1,1)$	2.2766409553979265e-03	0.0000000000000000e+00
$k_0(1,2)$	-6.9618233247604631e-04	0.0000000000000000e+00
...
$k_0(3,3)$	2.1314806829812205e-03	0.0000000000000000e+00

Fig. 4.1 – “fitULM” text file structure.

5- ATP Compilation Files

5.1 - Makefile_c

A makefile gathers the set of instructions necessary for the automatic compilation of a software. For the compilation of ATP software including new functions programmed in C language in mytpbig.exe, the makefile is called “Makefile_c”. This file is responsible for telling the compiler which files and libraries are linked to ATP software, including saying which compiler will do that task. To include the ULM model, the ATP software standard “Makefile_c” file must be modified as described on the next page. The changes were made in lines 21, 47 and 48.

In the “Makefile_c” it is necessary to set some directories, see lines 32, 34 and 46 on the next page. These directories are used to inform the compiler in which folder the libraries, functions and new models are stored therefore they will be incorporated into mytpbig.exe. In addition, the directory where the new executable mytpbig.exe will be stored is also informed (line 32). In cases where the user does not choose installing ATP software and the MINGW compiler in the default directory “C:\ATP”, that is, customized installation, special attention should be given to lines 33, 35, 47 and 48 because it will be necessary to correct the directories so that they correspond to the customization carried out by the user.

```
1  # -----
2  #           By Ms. Felipe O. S. Zanon - UFMG
3  #           Prof. Osis E. S. Leal - UTFPR
4  #           Prof. Alberto De Conti - UFMG
5  # Federal University of Minas Gerais - (UFMG)
6  # Federal University of Technology - Paraná - (UTFPR)
7  # -----
8  CC=gcc
9  FOR=g77
10
11 OBJECTS =dimdef.o \
12          newmods.o \
13          comtac.o \
14          fgnmod.o \
15          usernl.o \
16          analyt.o \
17          devt69.o \
18          usrfun.o \
19          hopcod.o \
20          user10.o \
21          ulm.o
22
23 INSFILE =blkcom.ins \
24          comta1.ins \
25          comta2.ins \
26          comta3.ins \
27          dekspy.ins \
28          tacsar.ins \
29          space2.ins
30
31 CFLAGS = -DUNDERScore -O2
32 FFLAGS = -O2
33 IMAGE= C:\ATP\mytpbig\mytpbig.exe
34
35 LIBRARY = C:\ATP\atpmingw\make\tpbig.a C:\ATP\atpmingw\make\dismg7.a -
lgdi32 C:\ATP\atpmingw\make\MinGW\lib\gcc\mingw32\5.1.0\libgcc.a
36
37 all: $(IMAGE)
38
39 .f.o:
40     $(FOR) -c $(FFLAGS) $<
41 .c.o:
42     $(CC) -c $(CFLAGS) $<
43
44 $(IMAGE) : $(OBJECTS) $(INSFILE)
45     $(FOR) -s -o $(IMAGE) $(OBJECTS) $(LIBRARY)
46
47 ulm.o: C:\ATP\atpmingw\make\sample\ulm.c
48     $(CC) -c $(CFLAGS) C:\ATP\atpmingw\make\sample\ulm.c
49
```


5.2 - fgnmod.f file

In the fgnmod.f file, described in the Fortran programming language, all foreign models are registered. In the subroutine "FGNMOD" it is possible to register foreign models as they are declared in the models present in ATP. In other words, in the fgnmod.f file, the name of the new foreign model is declared, correlating to its respective source code.

The ulm.c follows all the syntax and programming of a common ANSI C code. However, its structure must contain the functions "ULM_i" (function executed in the first time step) and "ULM_m" (executed in the next time steps). These functions must be registered in the file "fgnmod.f" (see lines 63 and 65 of the code described on the next page, taken from the fgnmod.f file used). The variables xdata, xin, xout, xvar are ATP standards and must be present in the C program because they link ATP to MODELS.

In the MODELS code (as in the examples shown in chapter 3) the foreign model is called by the name assigned to its respective line of the variable "refname". ULM was registered on refname line 2 as ULM_C_LINE (see line 19 on the next page).

```

1      SUBROUTINE FGNMOD ( name, namlen, xdata, xin, xout, xvar,
2      1      iniflg, ierflg)
3      IMPLICIT REAL*8 (A-H, O-Z), INTEGER*4 (I-N)
4      DIMENSION xdata(*), xin(*), xout(*), xvar(*)
5      CHARACTER*1 name(*)
6      PARAMETER ( namcnt = 8 )
7      CHARACTER*32 refnam(namcnt)
8      CONTINUE ! -----
9      CONTINUE ! You may increase namcnt above to allow more names:
10     CONTINUE ! -----
11     CONTINUE ! In the following lines, register your foreign model
12     CONTINUE ! names as they are declared in your models:
13     CONTINUE ! - use only uppercase characters for the name here
14     CONTINUE ! - you can use any case for the name in the models
15     CONTINUE ! - make a copy of the modifications you make to this
16     CONTINUE ! file so that you don't lose them when installing
17     CONTINUE ! a newer version of ATP later
18     DATA refnam(1) / 'SAMPLE_MODEL' / ! Do not modify this line
19     DATA refnam(2) / 'ULM_C_LINE' /
20     DATA refnam(3) / ' ' /
21     DATA refnam(4) / ' ' /
22     (:)
47     CONTINUE ! -----
48     CONTINUE ! In the following lines, this is where you call the
49     CONTINUE ! actual foreign subroutines/procedures:
50     CONTINUE ! - actual names may be different from the foreign
51     CONTINUE ! names used in the models
52     CONTINUE ! - notice how each one uses both an
53     CONTINUE ! initialization routine and an execution routine
54     IF ( iname.EQ.1 ) THEN
55     IF ( iniflg.EQ.1 ) THEN
56     CALL sampli(xdata, xin, xout, xvar)
57     ELSE
58     CALL samplm(xdata, xin, xout, xvar)
59     ENDIF
60     CONTINUE ! -----
61     ELSE IF ( iname.EQ.2 ) THEN
62     IF ( iniflg.EQ.1 ) THEN
63     CALL c_ulm_i(xdata, xin, xout, xvar)
64     ELSE
65     CALL c_ulm_m(xdata, xin, xout, xvar)
66     ENDIF
67     CONTINUE ! -----
68     (:)

```

6 - Application example

The example considered in this section is taken from [1]. It deals with a 10-km long 230-kV three-phase line with two shield wires and a 115-kV three-phase horizontal line running in parallel (see [1] for configuration details). A step voltage was applied at the sending end of the 230-kV line, on phase a , assuming all remaining line terminals to be grounded on terminal k (sending end) and open-ended on terminal m (receiving end). The voltages induced on the 115-kV line were calculated considering terminal k grounded and terminal m open-ended. In all simulations, the fitting was performed with complex poles and residues from 10^{-1} to 10^8 Hz considering a shunt conductance of 0.2×10^{-9} S/m. The fitting process considered 20 poles for \mathbf{Y}_C and \mathbf{H} , and the ground return impedance was calculated using Carson's integral equations [5].

Fig. 6.1 shows voltages calculated at the receiving end of the 115-kV line considering the ULM component implemented in ATP (ULM-ATP) and ULM available in EMTP-RV (ULM-RV) for a soil resistivity of 100 Ωm . It is observed that the voltage waveforms calculated with ULM-ATP and ULM-RV are coincident.

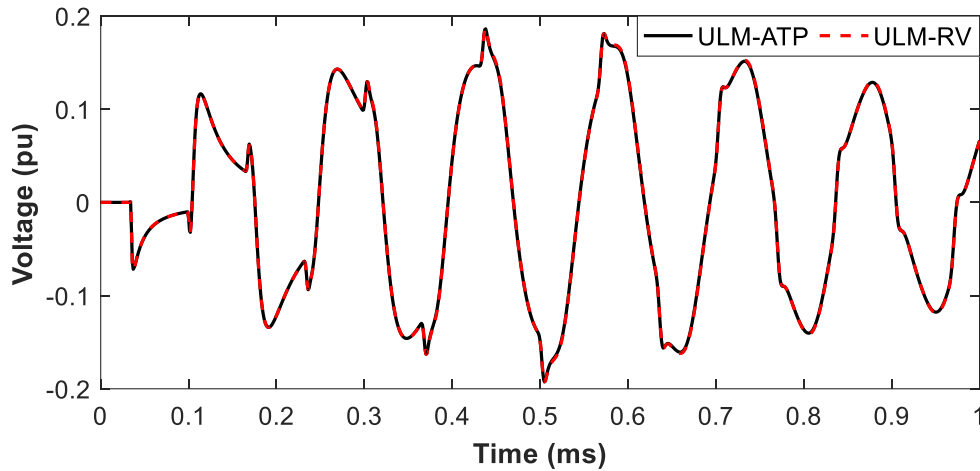


Fig. 6.1 – Voltage at the receiving end of the 115-kV line (phase d). Simulation for 100 $\Omega\text{-m}$ soil assuming constant soil parameters.

The .acp and fitULM.txt files for the simulation of this example are available on the following link: <https://github.com/zanonfelipe/ULMAtp>.

7 - Summary

These documents present instructions and guidelines for implementing ULM in ATP. All files are available at the link <https://github.com/zanonfelipe/ULMAtp>. Users are free to use all support files and codes available for non-commercial activities, but are kindly requested to include reference to the following paper:

Felipe O.S. Zanon, Osis E.S. Leal, Alberto De Conti, Implementation of the universal line model in the alternative transients program, Electric Power Systems Research, vol. 197, p. 107311, Aug. 2021, doi: 10.1016/j.epsr.2021.107311.

8 - Bibliography

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