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XLF2 - A PROGRAM FOR ANALYSIS AND SENSITIVITY EVALUATION OF COMPLEX LOAD FLOWS BY THE COMPLEX LAGRANGIAN METHOD

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XLF2 - A PROGRAM FOR ANALYSIS AND SENSITIVITY EVALUATION OF COMPLEX LOAD FLOWS BY THE COMPLEX LAGRANGIAN METHOD

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Abstract

XLF2 is a package of six subroutines for solving steady-state power flow equations in the compact complex mode and/or to determine the exact sensitivities of any number of functions w.r.t. network control variables. The user is required to supply a main program and a subroutine for finding the derivatives of the specified functions w.r.t. complex bus voltages and their conjugates. The package prepares the complex consistent form of the power flow equations and calls the Harwell package ME28 to solve them. The sensitivities are determined by implementing the generalized, complex adjoint approach to power network sensitivities by Bandler and El-Kady. The package has been tested by solving a load flow problem for the IEEE 118-bus system, calculating sensitivities for a 26-bus system, minimizing transmission losses and minimizing transmission losses subject to line overloading constraints taking single outages into account for a 6-bus system. The package and documentation have been developed for the CDC 170/730 system with the NOS 1.4 level 552 operating system and the Fortran Extended (FTN) Version 4.8 compiler. The report includes a listing of the programs, the results for the test cases and a user's guide.

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I. INTRODUCTION

The Fortran package called XLF2 has been designed to solve power flow problems of moderate to large size. It employs the complex notation introduced by Bandler and El-Kady [1], which was implemented in the previous package XLF1 [2]. The present package, however, exploits the sparsity of the system of complex equations, and solves the system by using the Harwell package ME28 [3].

The main purpose of XLF2 is to evaluate the exact partial derivatives of any function or state w.r.t. practical power network control parameters defined by the user. The required first-order sensitivities are determined from formulas derived by Bandler and El-Kady [4,5] in the generalized, complex adjoint approach to power network sensitivities. The user is required to provide a subroutine called AMU for evaluating the derivatives of the functions under consideration w.r.t. complex bus voltages and their complex conjugate. Thus, AMU prepares the right-hand sides of the complex adjoint equations. The main program, supplied by the user, assigns the necessary dimensional storage and reads system data.

The package XLF2 has been investigated by solving a load flow problem for the IEEE 118-bus system. The partial derivatives of a real function, namely, a load bus voltage magnitude w.r.t. several control variables have been obtained for a 26-bus system. A minimum-loss problem and a minimum-loss problem subject to line overloading constraints taking single outages into account have been solved for a 6-bus system. These results illustrate the versatility of the package, however, the user has to familiarize himself/herself with the notation and theory introduced by Bandler and El-Kady to exploit all the features completely.

At McMaster University, it is available in the form of a library of binary relocatable subroutines which are linked with the user's program by the appropriate call to the main subroutine XLF2. The library is available in the group indirect file LIBXLF2 under the charge RJWBAND. The package calls subroutines ME28A, ME28B and ME28C from the Harwell Subroutine Library [3], hence ME28 must be available when XLF2 is used. The general sequence of NOS commands to use XLF2 may be as follows:

```
/GET(LIBXLF2,LIBCHSM/GR)      - fetch the libraries,
/LIBRARY(LIBXLF2,LIBCHSM)     - indicate the libraries to the loader,
/FTN(...,GO)                  - compile, load and execute the program.
```

II. SUBROUTINES AND VARIABLES

This section describes the subroutines (Fig. 1) and the variables that could be of interest to the user. The essential information regarding the dimensions and initialization is summarised in Table I. A comprehensive explanation of various features is included in the comment statements in the program listing.

Fig. 1 highlights the overall organization of the program units. The package XLF2 can be used effectively by a user possessing a relatively sophisticated understanding of optimal power flow problems.

In a typical optimization problem, for example, the subroutines YMATRX, RHSLD, STMEQ2, ME28A, ME28C, RST2 and AMU are required in the first call to XLF2. In consecutive calls to XLF2, if the line para-

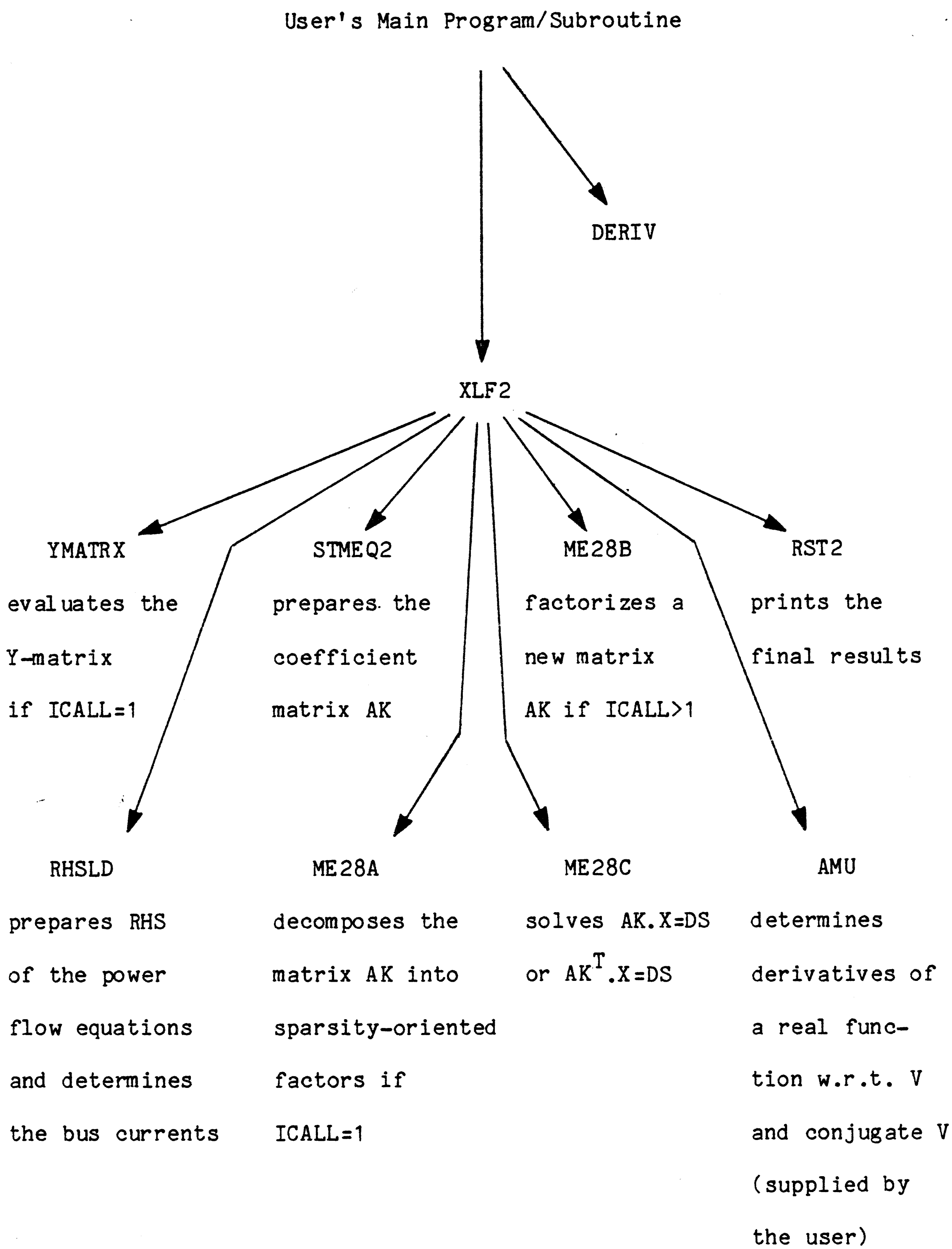

Fig. 1 Overall organization of the XLF2 package.

TABLE I

ESSENTIAL INFORMATION ON DIMENSIONS,

INITIALIZATION AND DEFAULT VALUES

Variable Name	Initialized by User (1)	Dimensions in Program	Default Value (2)
Integer Variables			
IAC, JAC	Yes if ICHTL=1 or 2	--	--
IADJ	Yes	--	1
IAPP	Yes (normally 0)		0
ICALL	Yes		1
ICHTL	Yes		0
ICN	No	LICN	--
ICYM	No	NYM (twice the number of lines)	--
IDER	Yes	--	0
IE	No	--	--
IKEEP	No	10 * NB	--
ILOAD	Yes	--	1
IOUT	Yes	--	6
IRN	No	LIRN	--
IRYM	No	NYM	--
ITMAX	Yes	--	10
IW	No	10 * NB	--
IWRITE	Yes	--	0
JVECT	No	IE	--
KA	Yes	NB	--
LICN	Yes	2 to 4 times IE	--
LIRN	Yes	2 times IE	--
LNTAP	Yes	--	3
NB	Yes	--	--

TABLE I (continued)

Variable Name	Initialized by User (1)	Dimensions in Program	Default Value (2)
Real Variables			
APP	Yes	--	0.0
SHTLC	Yes if ICHTL=1	--	0.0
TOLV	Yes	--	10^{-4}
Complex Variables			
AI	No	NB	--
AK	No	LICN	--
CC	Yes if ICHTL=1	--	(0.0, 0.0)
CV	No	NB	--
DS	No	2 * NB	--
DYM	No	NB	--
S	Yes	NB	--
SL	Yes	NB	--
V	Yes	NB	--
W	No	2 * NB	--
YM	No	NYM	--
ZC	Yes if ICHTL=1	--	--

(1) Variables may be initialized by any means other than a DATA statement in the main program.

(2) The user may take advantage of the default values to avoid initializing some variables.

meters do not change, e.g., problems other than line contingencies (the Y-matrix is updated under the user's control in the calling program), subroutines RHSLD, STMEQ2, ME28B, ME28C, RST2 and AMU are required.

Subroutines

XLF2 This is the main subroutine of the XLF2 package, which is typically called by the user's main program or subprogram. The main subroutine call is

CALL XLF2(V,CV,AI,S,SL,DS,AK,DYM,KA,NB,YM,ICN,IRN,IW,IKEEP, JVECT,LIRN,LICN,W,IRYM,ICYM,NYM)

This subroutine solves the load flow solution if ILOAD≠0 and determines the solution of the adjoint system of equations if IDER≠0 and IADJ=1 by calling subroutines AMU, ME28A, ME28B, ME28C, RHSLD, RST2, STMEQ2 and YMATRX. Subroutines ME28A, ME28B and ME28C are the subroutines of the Harwell package ME28 [3].

AMU This is a user supplied subroutine, which determines the derivatives of the real function under consideration w.r.t. V and the conjugate of V. The user is expected to consult Bandler and El-Kady [4] for basic theory and implementation of the required computer code. This subroutine should be declared as

SUBROUTINE AMU(V,CV,AI,S,NB,DS,IDER,YM,DYM,ICYM,IRYM,NYM,KA,IOUT)

DERIV This subroutine evaluates the derivative of a real function of the power system network w.r.t. one user-specified control variable at a time, using the solution of the adjoint system of equations. The user can call this subroutine from his main program or construct his own subroutine to determine derivatives [4,5] with the help of Table I of Bandler and El-Kady [5].

Subroutine DERIV should be declared as

SUBROUTINE DERIV(V,CV,DS,KA,NB,L1,L2,JD,DF)

ME28A This subroutine decomposes the coefficient matrix AK into factors, using a pivotal strategy designed to compromise between minimum fill-in and maximum accuracy, which is lost through roundoff.

ME28B This subroutine factorizes a new matrix AK of the same pattern, using a pivotal sequence determined by an earlier entry to ME28A.

ME28C This subroutine uses the factors produced by ME28A (or ME28B) to solve AK.X=DS or AK^T.X=DS.

Note: ME28A, ME28B and ME28C are called from subroutine XLF2, therefore, the package ME28 must be made available.

RHSLD This subroutine determines the RHS vector DS of the load flow equations, and bus current vector AI.

RST2 This subroutine prints the final results in an appropriate format.

STMEQ2 This subroutine prepares the coefficient matrix AK of the network equations. See equation (16) of Bandler and El-Kady [1].

YMATRX This subroutine determines the admittance matrix of a given power network.

Integer Variables

IA, JA (IA, JA) represents a transmission line connecting buses IA and JA.

IAC, JAC (IAC, JAC) represents a transmission line whose parameters have been altered by the user.

IADJ = 0 when the change occurs in the RHS of the adjoint system of equations only. This value is used when derivatives of two or more functions are to be evaluated at the same operating point.

= 1 when a fresh calculation of the adjoint system of equations is required. This value is used when derivatives at a new operating point are required.

Default value is 1.

IAMUF = -1 indicates that the user has not supplied subroutine AMU.

IAPP = 1 if the coefficient matrix of the network equations is not to be updated when the maximum modulus of the complex correction voltages < APP.

Default value is 0.

ICALL = 1 for the first call by the user's program. Subroutine YMATRX is called to calculate the Y-matrix of the power network. Consequently, subroutine ME28A of the package ME28 is called to decompose the coefficient matrix of the system of linearized complex equations.

< 1 for the first call by the user's program when the Y-matrix has been calculated earlier in the user's program and stored in the vectors IRYM, ICYM, YM and DYM. Subroutine ME28A is called but subroutine YMATRX is not called.

> 1 for subsequent calls. This value indicates that the previous decomposition of the coefficient matrix is to be reused and subroutine YMATRX is not to be called.

Default value is 1.

ICHTL = 0 if there is no alteration in the line data file. Normally, it is zero for load flow analysis.

= 1 if parameters of one line have been altered by the user (i.e., the parameters of one line differ from the line data file and the user does not want to change the line data file).

= 2 if one line is to be removed for contingency analysis.

Default value is 0.

ICN Integer array of length LICN. ICN(K) holds the column index of the non-zero elements stored in AK(K), K=1,...,IE. On output from ME28A, it holds the column indices of the factors of matrix AK. This must not be altered by the user in the subsequent calls of XLF2.

ICYM Array of length NYM holds the column index of the non-zero elements stored in YM(K), K=1,...,NYM.

IDER = 0 if derivatives of the function are not required.

= M if derivatives of the Mth function are required.

Default value is 0.

IE Total number of non-zero elements in the coefficient matrix of equation (16) of Bandler and El-Kady [1].

IFLAG On exit from ME28A and ME28B, a value of zero indicates that the subroutine has been executed successfully. Possible non-zero values of IFLAG are given below [3].

+1 successful decomposition on a structurally singular matrix (ME28A only).

+2 successful decomposition on a numerically singular matrix (ME28A only).

+I (I=1,2,...,N). Warning: Very small pivot in zone I (ME28B only).

-1 matrix structurally singular. This means that the non-zero pattern is such that the matrix will be singular for all possible numerical values of the non-zero elements (ME28A only).

-2 matrix numerically singular.

-3 LIRN too small.

-4 LICN too small.

-5 LICN and LIRN too small.

-6 LICN and LIRN too small.

-7 Insufficient space for block triangularization phase (ME28A only).

-8 LIRN < IE.

-9 LICN < IE.

-10 IE $\leq$ 0.

-11 1 $\leq$ 2NB $\leq$ 32767 violated.

-12 row or column index out of range.

-13 non-zero element was not present in the factors after a previous call to ME28A (ME28B only).

-14 more than one non-zero element in the same position in the matrix. Action taken is to proceed with the value equal to the sum of the duplicate elements.

IKEEP Array of length 10*NB. It is preserved between subsequent calls of XLF2 and generally may not be referenced by the user.

ILOAD = 0 if the load flow solution is not to be determined.

$\neq$ 0 if the load flow solution is to be determined.

Default value is 1.

IOUT Tape number for output file.

Default value is 6.

IRN Array of length LIRN. On entry to ME28A and ME28B, IRN(K) holds the row index of the non-zero elements stored in AK(K), K=1,...,IE. It is used as work space by ME28A and need not be preserved for any subsequent calls of XLF2.

IRYM Array of length NYM holds the row index of the non-zero elements stored in YM(K), K=1,...,NYM.

IT Current iteration number in determining the load flow solution.

ITMAX Maximum number of iterations for determining the load flow solution after which the program will stop.
Default value is 10.

IW Array of length 10*N. It is used as work space by the subroutines ME28A and ME28B.

IWRITE = 0 prints the final load flow solutions only.
= 1 prints the intermediate results as well.
= 2 suppresses all the printouts.
Default value is 0.

JD Variable used in subroutine DERIV to specify the desired derivative. The following are the values of JD to be used for this purpose.
= 1 determines the derivative w.r.t. real power of a user-specified bus.
= 2 determines the derivative w.r.t. reactive power of a load bus.
= 3 determines the derivative w.r.t. modulus of voltage of a generator bus specified by the user.
= 4 determines the derivative w.r.t. real component of the slack bus voltage.

= 5 determines the derivative w.r.t. the conductance of the line between two buses specified by the user.

= 6 determines the derivative w.r.t. the susceptance of the line between two buses specified by the user.

= 7 determines the derivative w.r.t. the total shunt conductance at the bus specified by the user.

= 8 determines the derivative w.r.t. the total shunt susceptance at the bus specified by the user.

JVECT Array of length IE. JVECT(K) contains column index of the non-zero elements stored in AK(K), K=1,...,IE for calling ME28B. It is not altered by XLF2.

KA Array of dimension NB identifying the type of bus.

KA(I) = 0 if the Ith bus is a load bus.

= 1 if the Ith bus is a generator bus.

= 2 if the Ith bus is the slack bus.

Note: The last bus is taken as the slack bus.

L1 Index of the bus w.r.t. whose parameter a derivative is to be evaluated.

L1, L2 Line w.r.t. whose parameter a derivative is to be evaluated.

LICN This variable must be set by the user to the length of arrays AK and ICN. Since the decomposition is returned in AK and ICN, LICN should be large enough to accommodate this and ordinarily be 2 to 4 times as large as IE.

Restriction: LICN $\geq$ IE.

LIRN This variable must be set by the user to the length of the array IRN. LIRN need not be very much greater than IE.

Restriction: LIRN $\geq$ IE.

LNTAP Tape number for the line data file.

Default value is 3.

N = NB-1.

N2 = 2*NB.

NB Total number of buses.

NYM Number of non-zero off-diagonal elements of the admittance matrix.

Real Variables

APP When the maximum of the modulus of the complex correction bus voltages becomes < APP, the coefficient matrix of the system equations will not be updated and the current coefficient matrix is used.

Default value is 0.0.

SHTLC Altered value of the half shunt susceptance of the transmission line (IAC, JAC).

TOLV Tolerance over the modulus of bus voltages to which accuracy the final solution is required, i.e., when the maximum of the modulus of the complex correction bus voltages becomes < TOLV the execution will stop.

(U Variable to control the choice of pivots, set to 0.10.)

Complex Variables

AI NB dimensional array of bus currents.

AK LICN dimensional array and AK(K), K=1,...,IE holds the non-zero elements of the coefficient matrix. On exit from ME28A, AK holds the non-zero elements in the factors of the coefficient matrix. It is preserved between calls to subroutines ME28A, ME28B and ME28C, and should be preserved in the subsequent calls of XLF2.

CC Altered transformer tap (complex) in transmission line (IAC, JAC).

CPX, CPY, CPZ used as complex dummy variables in the program.

CV NB dimensional array of the conjugate of V.

DS N2 dimensional array, which represents the right-hand side as well as the correction voltages in determining the load flow solution. It also represents the right-hand side vector of the adjoint system of equations and the adjoint voltages in determining the solution of the adjoint system of equations.

DYM NB dimensional array of the diagonal elements of the admittance matrix.

S N dimensional array of complex load bus powers as well as generator bus active power and modulus of voltage represented as $P_G + j|V_G|$.

SL NB dimensional array of the static loads as p.u. impedances.

V NB dimensional array of bus voltages.

W Array of length N2 used as work space.

YM NYM dimensional array, which stores the non-zero off-diagonal elements of the admittance matrix.

ZC Altered impedance of the transmission line (IAC, JAC).

Available Common Blocks

```
COMMON/XLF2ID/ITMAX,TOLV,ICHTL,IWRITE,IDER,ILOAD,ICALL,IADJ,
    IAPP,APP,ICA,JAC,ZC,SHTLC,CC,IOUT,LNTAP
COMMON/AMUFL/IAMUF
COMMON/XLF2ME/IFLAG
```

III. HOW TO USE THE PACKAGE

In order to use the XLF2 package, the user has to prepare the programs and a data file in the following manner.

Main Program

The main program must provide the dimensions and execute reading of the number of buses, the tolerance over the modulus of the bus voltages to which accuracy the final solution is required, the maximum number of iterations, the specified bus powers, the initial bus voltages, the types of buses, parameters of the transmission element whose parameters have been altered by the user, and suitable values of variables IADJ, IAPP, ICALL, IAC, ICHTL, IDER, ILOAD, IWRITE, JAC and APP. The user calls subroutines XLF2 and DERIV appropriately from his main program or subroutine. The transmission element data is read in the subroutine YMATRIX.

Subroutined AMU

The derivatives of the function under consideration w.r.t. bus voltages and conjugate of bus voltages are provided by this subroutine if IDER $\neq$ 0. The user can employ the admittance matrix, which is available in vectors YM, ICYM, IRYM and DYM, bus current vector AI, bus voltage vector V and its conjugate in the calculation of the derivatives.

Transmission Element Data File

The transmission element data file must be available on tape (unit) LNTAP arranged in free format and in the following sequence.

READ (LNTAP,*) ICODE, IA, JA, A1, A2, A3, A4, A5

where

ICODE		code to identify data card.
	= 4	for a transmission element representing a transmission line.
	= 7	for a transmission element representing a transformer.
IA, JA		(IA,JA) represents a transmission element connecting buses IA and JA.
A1		identifies the circuit number if ICODE = 4.
		identifies the type of transformation ratio if ICODE = 7.
	= 0	for fixed tap.
	= 1	for real transformation ratio.
	= 2	for complex transformation ratio.
A2		denotes the branch type if ICODE = 4.
		series resistance of the line if ICODE = 7.
A3		series resistance of the line if ICODE = 4.
		series reactance of the line if ICODE = 7.
A4		series reactance of the line if ICODE = 4.
		real part of the transformation ratio if ICODE = 7.

A5 half shunt susceptance of the line if ICODE = 4.

imaginary part of the transformation ratio if ICODE = 7.

This program does not use A1 or A2 if ICODE = 4 and A5 if ICODE = 7. Furthermore, XLF2 solves only the load flow equations with fixed complex transformation ratios. All features implied by the options have, therefore, not been implemented by XLF2.

Dimensions and Initialization

For the purpose of dimensioning and initializations, Table I should be referred to. Note that the last bus is taken as the slack bus in the examples included in this report.

How to Determine the Load Flow Solution Only

The user should prepare the transmission element data file in free format, as described in this section, and put it on tape LNTAP. The user can call subroutine XLF2, assigning proper values to the variables which follow.

IWRITE = 0, 1 or 2

ICALL = 1 signifies the first call of XLF2

ILOAD = 1 signifies that the load flow solution is required

IDER = 0 signifies that the solution of the adjoint system is not required

TOLV = desired accuracy over bus voltages

ITMAX = maximum number of iterations to be performed

ICHTL = 0 signifies that there is no change in the transmission element parameters

IAPP = 0 signifies that the coefficient matrix will be updated exactly

APP = as desired, when the maximum of the modulus of the complex correction voltage < APP, coefficient matrix AK is not updated

IOUT = the tape number for the output file

LNTAP = the tape number for the transmission element data file.

The load flow solution of a 118-bus power system is determined in Example 1.

How to Determine the Load Flow Solution and Sensitivities

The user should prepare subroutine AMU and the transmission element data file as described earlier. First, the user calls subroutine XLF2, assigning proper values to the variables which follow.

IWRITE = 0, 1 or 2

ICALL = 1

ILOAD = 1

IDER = 1

IADJ = 1

TOLV = desired accuracy

ITMAX = maximum number of load flow iterations

ICHTL = 0

IAPP = 0

APP = as desired

IOUT = the tape number for the output file

LNTAP = the tape number for the transmission element data file.

Then, the user calls subroutine DERIV an appropriate number of times for determining all the required sensitivities. The load flow solution and sensitivities of a load bus voltage magnitude for a 26-bus system are determined in Example 2.

To determine the sensitivities only, the user should set ILOAD = 0, assuming that the load flow solution is already available.

How to Use XLF2 in Optimizing a Power System

The user can use XLF2 to determine the load flow solution and/or derivatives of one or more real objective and constraint functions w.r.t. control variables (designable parameters). If derivatives are required, the user must supply subroutine AMU.

The first call of XLF2 in the user's program should be with the following values of the parameters.

ICALL = 1

ILOAD = 1

IDER = 1

IADJ = 1

IWRITE = 0, 1, or 2

ITMAX = as desired

ICHTL = 0

IAPP = 0

APP = as desired

IOUT, LNTAP = the tape numbers for output and transmission element data files, respectively.

For consecutive calls, set ICALL > 1 (say 2) if the transmission element parameters are not changed during optimization.

After each call of XLF2, subroutine DERIV is called an appropriate number of times by the user to determine the desired derivatives of the objective functions and constraints by supplying the proper values of L1, L2 and JD. Two distinct optimization problems have been reported in Examples 3 and 4, involving minimum loss for a 6-bus power system.

IV. EXAMPLES

Example 1

The load flow solution of the 118-bus power system [6,7] is determined by the package XLF2 in this example. The listing of the main program is given on page 23. The input data files TL118 and BUS118 are created on two separate tapes:

1) TAPE3 = TL118 transmission element data file, to be read in the subroutine YMATRX by the package.

   The line quantities, namely, resistance, reactance and line charging are expressed in per unit with a 100 MVA base. The line charging is taken as one-half of the total charging of the line and the transformer ratio as determined by the actual transformer tap positions and the voltage bases.

2) TAPE5 = BUS118, is read in the main program and consists of complex voltage, power generation and load in per unit at every bus, based on a 100 MVA base. The static load is expressed in terms of susceptance per unit on a 100 MVA base and is directly added to the diagonal entries of DYM in subroutine YMATRX.

The load flow commences with a flat-voltage profile and terminates whenever the iteration limit and/or accuracy is reached. The solution has been found quite sensitive to the control variables, the line contingencies and the selection of the slack bus.

The listing of input data files is given on pages 24-28 and final load flow is reported on pages 29-31.

```
      PROGRAM MAIN(INPUT,OUTPUT,TL118,BUS118,TAPE5=BUS118,TAPE6=OUTPUT,T
     1APE3=TL118)
C
      COMPLEX V(118),CV(118),AI(118),S(118),DS(250),AK(3200),DYM(118),YM
     1(1000),W(250),ZC,CC,S1,S2,SL(118)
      DIMENSION KA(118), ICN(3200), IRN(1600), IW(5200), IKEEP(5000), IC
     1YM(1000), IRYM(1000), JVECT(1600)
      COMMON /XLF2ID/ ITMAX,TOLV,ICHTL,IWRITE,IDER,ILOAD,ICALL,IADJ,IAPP
     1,APP,IAC,JAC,ZC,SHTLC,CC,IOUT,LNTAP
C
C     THIS IS THE MAIN PROGRAM FOR SOLVING THE POWER FLOW EQUATIONS
C
C     OF A 118-BUS POWER NETWORK USING THE COMPUTER PROGRAM PACKAGE
C
C     CALLED XLF2
C
C     ******************************************************************
C
      NB=118
      ITMAX=7
      ICHTL=0
      IWRITE=0
      TOLV=0.000001
      V(NB)=CMPLX(1.03,0.0)
      IDER=0
      ILOAD=1
      APP=0.01
      IAPP=0
      ICALL=1
      N=NB-1
      LIRN=1600
      LICN=3200
      DO 10 I=1,N
      READ (5,20) KA(I),V(I),S1,S2,AA
      S(I)=S1-S2
      SL(I)=CMPLX(0.0,AA)
      IF (KA(I).NE.1) GO TO 10
      AV=CABS(V(I))
      S(I)=CMPLX(REAL(S(I)),AV)
10    CONTINUE
      SL(NB)=(0.0,0.0)
      CALL XLF2 (V,CV,AI,S,SL,DS,AK,DYM,KA,NB,YM,ICN,IRN,IW,IKEEP,JVECT,
     1LIRN,LICN,W,IRYM,ICYM,NYMD
      STOP
C
20    FORMAT (4X,I2,1X,2F5.3,1X,2F6.4,13X,3F5.2)
      END
```

```
4 1 2 1. 1. .0303 .099 .0127
4 1 3 1. 1. .0129 .0424 .00515
4 4 5 1. 1. .0218 .058 .00105
4 3 5 1. 1. .0241 .108 .0142
4 5 6 1. 1. .0119 .054 .00715
4 6 7 1. 1. .0046 .0208 .00275
4 8 9 1. 1. .0024 .0305 .581
7 8 5 1. 0. .0267 1.02 0.
4 9 10 1. 1. .0026 .0322 .615
4 4 11 1. 1. .0209 .0688 .00875
4 5 11 1. 1. .0203 .0682 .0087
4 11 12 1. 1. .006 .0196 .0025
4 2 12 1. 1. .0187 .0616 .00785
4 3 12 1. 1. .0484 .16 .0203
4 7 12 1. 1. .0086 .034 .00435
4 11 13 1. 1. .0223 .0731 .0094
4 12 14 1. 1. .0215 .0707 .0091
4 13 15 1. 1. .0744 .2444 .03135
4 14 15 1. 1. .0595 .195 .0251
4 12 16 1. 1. .0212 .0384 .0107
4 15 17 1. 1. .0132 .0437 .0222
4 16 17 1. 1. .0454 .1801 .0233
4 17 18 1. 1. .0123 .0505 .0065
4 18 19 1. 1. .0119 .0493 .0057
4 19 20 1. 1. .0252 .117 .0149
4 15 19 1. 1. .012 .0394 .00505
4 20 21 1. 1. .0183 .0849 .0108
4 21 22 1. 1. .0209 .097 .0123
4 22 23 1. 1. .0342 .159 .0202
4 23 24 1. 1. .0135 .0492 .0249
4 23 25 1. 1. .0156 .08 .0432
7 26 25 1. 0. .0382 1.04 0.
4 25 27 1. 1. .0318 .163 .088
4 27 28 1. 1. .0191 .0855 .0108
4 28 29 1. 1. .0273 .0943 .0119
7 30 17 1. 0. .0388 1.04 0.
4 8 30 1. 1. .0043 .0504 .257
4 26 30 1. 1. .008 .086 .454
4 17 31 1. 1. .0474 .1563 .01995
4 29 31 1. 1. .0108 .0331 .00415
4 23 32 1. 1. .0317 .1153 .05865
4 31 32 1. 1. .0298 .0958 .01255
4 27 32 1. 1. .0229 .0755 .00965
4 15 33 1. 1. .038 .1244 .01595
4 19 34 1. 1. .0752 .247 .0316
4 35 36 1. 1. .0022 .0102 .00135
4 35 37 1. 1. .011 .0497 .0066
4 33 37 1. 1. .0415 .142 .0183
4 34 36 1. 1. .0087 .0268 .00285
4 34 37 1. 1. .0226 .0594 .0049
7 38 37 1. 0. .0375 1.07 0.
4 37 39 1. 1. .0321 .106 .0135
4 37 40 1. 1. .0593 .168 .021
4 30 38 1. 1. .0046 .054 .211
4 39 40 1. 1. .0184 .0605 .00775
4 40 41 1. 1. .0145 .0478 .0061
4 40 42 1. 1. .0555 .183 .0233
4 41 42 1. 1. .041 .135 .0172
4 43 44 1. 1. .0608 .2454 .03035
4 34 43 1. 1. .0413 .1681 .02115
4 44 45 1. 1. .0224 .0901 .0112
4 45 46 1. 1. .04 .1356 .0116
4 46 47 1. 1. .038 .127 .0158
4 46 48 1. 1. .0601 .189 .0236
4 47 49 1. 1. .0191 .0625 .008
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4 42 49 1. 1. .0358 .1615 .086
4 76 69 1. 1. .0614 .0544 .043
4 45 49 1. 1. .0684 .186 .0222
4 48 49 1. 1. .0179 .0505 .0063
4 49 50 1. 1. .0267 .0752 .00935
4 49 51 1. 1. .0486 .137 .0171
4 51 52 1. 1. .0203 .0588 .007
4 52 53 1. 1. .0405 .1635 .0203
4 53 54 1. 1. .0263 .122 .0155
4 49 54 1. 1. .0399 .1451 .0734
4 75 69 1. 1. .0145 .0481 .0365
4 54 55 1. 1. .0169 .0707 .0101
4 54 56 1. 1. .0228 .0595 .00365
4 55 56 1. 1. .0249 .0551 .00185
4 56 57 1. 1. .0343 .0966 .0121
4 50 57 1. 1. .0474 .134 .0166
4 56 58 1. 1. .0343 .0966 .0121
4 51 58 1. 1. .0255 .0719 .00895
4 54 59 1. 1. .0503 .2293 .0299
4 56 59 1. 1. .0407 .1224 .05525
4 12 117 1. 1. .0329 .14 .0268
4 55 59 1. 1. .0474 .2158 .02825
4 59 60 1. 1. .0317 .145 .0188
4 59 61 1. 1. .0328 .15 .0194
4 60 61 1. 1. .0226 .0535 .0073
4 60 62 1. 1. .0123 .056 .00735
4 61 62 1. 1. .0082 .0376 .0049
7 63 59 1. 0. .0386 1.04 0.00
4 63 64 1. 1. .0017 .02 .108
7 64 61 1. 0. .0268 1.02 0.
4 38 65 1. 1. .009 .0986 .523
4 64 65 1. 1. .0027 .0302 .19
4 49 66 1. 1. .009 .0459 .0248
4 68 116 1. 1. .0203 .0541 .0124
4 62 66 1. 1. .0482 .218 .0289
4 62 67 1. 1. .0258 .117 .0155
7 66 65 1. 0. .037 .94 0.
4 66 67 1. 1. .0224 .1015 .0134
4 68 65 1. 1. .0214 .056 .319
4 47 118 1. 1. .0844 .2778 .03545
4 49 118 1. 1. .0985 .324 .0414
7 118 68 1. 0. .037 .99 0.
4 118 70 1. 1. .03 .127 .061
4 24 70 1. 1. .1022 .4115 .051
4 70 71 1. 1. .0088 .0355 .0044
4 24 72 1. 1. .0488 .196 .0244
4 71 72 1. 1. .0446 .18 .0222
4 71 73 1. 1. .0086 .0454 .0059
4 70 74 1. 1. .0401 .1323 .01685
4 70 75 1. 1. .0428 .141 .018
4 118 75 1. 1. .0405 .122 .062
4 74 75 1. 1. .0123 .0406 .00515
4 76 77 1. 1. .0444 .148 .0184
4 118 77 1. 1. .0309 .101 .0519
4 75 77 1. 1. .0601 .1999 .0249
4 77 78 1. 1. .0238 .0524 .0063
4 78 79 1. 1. .0055 .0244 .00325
4 77 80 1. 1. .0109 .0332 .035
4 114 115 1. 1. .0023 .104 .0114
4 79 80 1. 1. .0156 .0704 .00935
4 68 81 1. 1. .0018 .202 .404
7 81 80 1. 0. .037 .95 0.
4 77 82 1. 1. .0298 .0853 .0487
4 82 83 1. 1. .0112 .0366 .019
4 83 84 1. 1. .0625 .132 .0129

4	83	85	1.	1.	.043	.148	.0174
4	84	85	1.	1.	.0302	.0641	.00615
4	85	86	1.	1.	.035	.123	.0138
4	86	87	1.	1.	.0283	.2074	.02225
4	85	88	1.	1.	.02	.102	.0138
4	85	89	1.	1.	.0239	.173	.0235
4	88	89	1.	1.	.0139	.0712	.00965
4	89	90	1.	1.	.0164	.0652	.0794
4	27	115	1.	1.	.0164	.0741	.053
4	90	91	1.	1.	.0254	.0836	.0107
4	89	92	1.	1.	.008	.0383	.0481
4	32	114	1.	1.	.0135	.0612	.0207
4	91	92	1.	1.	.0387	.1272	.01635
4	92	93	1.	1.	.0258	.0848	.0109
4	92	94	1.	1.	.0481	.158	.0203
4	93	94	1.	1.	.0223	.0732	.0094
4	94	95	1.	1.	.0132	.0434	.00555
4	80	96	1.	1.	.0356	.182	.0247
4	82	96	1.	1.	.0162	.053	.0272
4	94	96	1.	1.	.0269	.0869	.0115
4	80	97	1.	1.	.0183	.0934	.0127
4	80	98	1.	1.	.0238	.108	.0143
4	80	99	1.	1.	.0454	.206	.0273
4	92	100	1.	1.	.0648	.295	.0386
4	94	100	1.	1.	.0178	.058	.0302
4	95	96	1.	1.	.0171	.0547	.00735
4	96	97	1.	1.	.0173	.0885	.012
4	98	100	1.	1.	.0397	.179	.0238
4	99	100	1.	1.	.018	.0583	.0108
4	100	101	1.	1.	.0277	.1262	.0164
4	92	102	1.	1.	.0123	.0559	.0073
4	101	102	1.	1.	.0246	.112	.0147
4	100	103	1.	1.	.016	.0525	.0268
4	100	104	1.	1.	.0415	.204	.02705
4	103	104	1.	1.	.0466	.1584	.02035
4	103	105	1.	1.	.0535	.1625	.0204
4	100	106	1.	1.	.0605	.229	.031
4	104	105	1.	1.	.0099	.0378	.00495
4	105	106	1.	1.	.014	.0547	.00715
4	105	107	1.	1.	.053	.183	.0236
4	105	108	1.	1.	.0261	.0703	.0092
4	106	107	1.	1.	.053	.183	.0236
4	108	109	1.	1.	.0105	.0288	.0038
4	103	110	1.	1.	.0391	.1813	.02305
4	109	110	1.	1.	.0278	.0762	.0101
4	110	111	1.	1.	.022	.0755	.01
4	110	112	1.	1.	.0247	.064	.031
4	17	113	1.	1.	.0091	.0301	.00385
4	32	113	1.	1.	.0615	.203	.0259

0001	1	1.15	0.00	0.100	0.000	-3.00	3.000	0.51	0.27	0.00
0002	0	1.00	0.00	0.000	0.000	0.000	0.000	0.20	0.09	0.00
0003	0	1.00	0.00	0.000	0.000	0.000	0.000	0.39	0.10	0.00
0004	1	1.10	0.00	0.200	0.000	-3.00	3.000	0.90	0.12	0.00
0005	0	1.00	0.00	0.000	0.000	0.000	0.000	0.00	0.00	-.40
0006	1	1.052	0.00	0.150	0.000	-.130	0.500	0.52	0.22	0.00
0007	0	1.00	0.00	0.000	0.000	0.000	0.000	0.19	0.02	0.00
0008	1	1.09	0.00	0.100	0.000	-3.00	3.000	0.50	0.00	0.00
0009	0	1.00	0.00	0.000	0.000	0.000	0.000	0.00	0.00	0.00
0010	1	1.075	0.00	4.500	0.000	-1.47	2.000	0.00	0.00	0.00
0011	0	1.00	0.00	0.000	0.000	0.000	0.000	0.70	0.23	0.00
0012	1	1.051	0.00	0.850	0.000	-.350	1.500	0.37	0.10	0.00
0013	0	1.00	0.00	0.000	0.000	0.000	0.000	0.34	0.16	0.00
0014	0	1.00	0.00	0.000	0.000	0.000	0.000	0.14	0.01	0.00
0015	1	0.97	0.00	0.120	0.000	-.300	0.300	0.90	0.30	0.00
0016	0	1.00	0.00	0.000	0.000	0.000	0.000	0.25	0.10	0.00
0017	0	1.00	0.00	0.000	0.000	0.000	0.000	0.11	0.03	0.00
0018	1	0.97	0.00	0.100	0.000	-.160	0.500	0.60	0.34	0.00
0019	1	0.96	0.00	0.200	0.000	-3.00	3.000	0.45	0.25	0.00
0020	0	1.00	0.00	0.000	0.000	0.000	0.000	0.18	0.03	0.00
0021	0	1.00	0.00	0.000	0.000	0.000	0.000	0.14	0.08	0.00
0022	0	1.00	0.00	0.000	0.000	0.000	0.000	0.10	0.05	0.00
0023	0	1.00	0.00	0.000	0.000	0.000	0.000	0.07	0.03	0.00
0024	1	0.91	0.00	0.150	0.000	-3.00	3.000	0.30	2.00	0.00
0025	1	0.97	0.00	2.200	0.000	-.470	3.500	0.00	2.00	0.00
0026	1	1.01	0.00	3.140	0.000	-9.99	10.00	0.00	0.00	0.00
0027	1	.823	0.00	0.120	0.000	-3.00	3.000	0.82	0.13	0.00
0028	0	1.00	0.00	0.000	0.000	0.000	0.000	0.17	1.66	0.00
0029	0	1.00	0.00	0.000	0.000	0.000	0.000	0.24	0.99	0.00
0030	0	1.00	0.00	0.000	0.000	0.000	0.000	0.00	0.00	0.00
0031	1	.783	0.00	0.100	0.000	-3.00	3.000	0.43	0.99	0.00
0032	1	.872	0.00	0.200	0.000	-3.00	3.000	0.59	0.23	0.00
0033	0	1.00	0.00	0.000	0.000	0.000	0.000	0.23	0.09	0.00
0034	1	.959	0.00	0.150	0.000	-.080	0.600	0.59	0.26	0.14
0035	0	1.00	0.00	0.000	0.000	0.000	0.000	0.33	0.09	0.00
0036	1	.963	0.00	0.100	0.000	-.080	0.400	0.31	0.17	0.00
0037	0	1.00	0.00	0.000	0.000	0.000	0.000	0.00	0.00	-.25
0038	0	1.00	0.00	0.000	0.000	0.000	0.000	0.00	0.00	0.00
0039	0	1.00	0.00	0.000	0.000	0.000	0.000	0.27	0.11	0.00
0040	1	0.97	0.00	0.100	0.000	-3.00	3.000	0.76	0.23	0.00
0041	0	1.00	0.00	0.000	0.000	0.000	0.000	0.37	0.10	0.00
0042	1	1.10	0.00	0.120	0.000	-3.00	3.000	1.10	0.23	0.00
0043	0	1.00	0.00	0.000	0.000	0.000	0.000	0.18	0.07	0.00
0044	0	1.00	0.00	0.000	0.000	0.000	0.000	0.16	0.08	0.10
0045	0	1.00	0.00	0.000	0.000	0.000	0.000	0.53	0.22	0.10
0046	1	1.00	0.00	0.200	0.000	-1.00	1.000	0.28	0.10	0.10
0047	0	1.00	0.00	0.000	0.000	0.000	0.000	0.34	0.00	0.00
0048	0	1.00	0.00	0.000	0.000	0.000	0.000	0.20	0.11	0.15
0049	1	1.02	0.00	2.040	0.000	-.850	2.100	0.87	0.30	0.00
0050	0	1.00	0.00	0.000	0.000	0.000	0.000	0.17	0.04	0.00
0051	0	1.00	0.00	0.000	0.000	0.000	0.000	0.17	0.08	0.00
0052	0	1.00	0.00	0.000	0.000	0.000	0.000	0.18	0.05	0.00
0053	0	1.00	0.00	0.000	0.000	0.000	0.000	0.23	0.11	0.00
0054	1	0.95	0.00	0.480	0.000	-3.00	3.000	0.13	0.32	0.00
0055	1	0.95	0.00	0.100	0.000	-.080	0.500	0.63	0.22	0.00
0056	1	0.95	0.00	0.120	0.000	-.200	0.500	0.84	0.18	0.00
0057	0	1.00	0.00	0.000	0.000	0.000	0.000	0.12	0.03	0.00
0058	0	1.00	0.00	0.000	0.000	0.000	0.000	0.12	0.03	0.00
0059	1	0.99	0.00	1.550	0.000	-.600	2.000	2.77	1.13	0.00
0060	0	1.00	0.00	0.000	0.000	0.000	0.000	0.78	0.03	0.00
0061	1	1.00	0.00	1.600	0.000	-1.00	3.000	0.00	0.00	0.00
0062	1	1.00	0.00	0.150	0.000	-.300	0.300	0.77	0.14	0.00
0063	0	1.00	0.00	0.000	0.000	0.000	0.000	0.00	0.00	0.00
0064	0	1.00	0.00	0.000	0.000	0.000	0.000	0.00	0.00	0.00
0065	1	1.00	0.00	3.910	0.000	-6.00	1.000	0.00	0.00	0.00

0066	1	1.05	10.00	3.920	0.000	-.670	4.000	0.39	0.18	0.00
0067	0	1.00	0.00	0.000	0.000	0.000	0.000	0.28	0.07	0.00
0068	0	1.00	0.00	0.000	0.000	0.000	0.000	0.00	0.00	0.00
*069	0	1.00	0.00	0.000	0.000	0.000	0.000	0.33	0.15	0.00
0070	1	0.98	0.00	0.500	0.000	-.100	0.400	0.66	0.20	0.00
0071	0	1.00	0.00	0.000	0.000	0.000	0.000	0.00	0.00	0.00
0072	1	0.98	0.00	0.200	0.000	-1.00	1.000	0.32	0.00	0.00
0073	1	0.99	0.00	0.150	0.000	-1.00	1.000	0.21	0.00	0.00
0074	1	0.96	0.00	0.100	0.000	-.300	0.300	0.68	0.27	0.12
0075	0	1.00	0.00	0.000	0.000	0.000	0.000	0.47	0.11	0.00
0076	1	.945	0.00	0.100	0.000	-.080	0.230	0.68	0.36	0.00
0077	1	1.01	0.00	0.120	0.000	-.200	1.000	0.61	0.28	0.00
0078	0	1.00	0.00	0.000	0.000	0.000	0.000	0.71	0.26	0.00
0079	0	1.00	0.00	0.000	0.000	0.000	0.000	0.39	0.32	0.20
0080	1	1.04	0.00	4.770	0.000	-1.65	2.800	1.30	0.26	0.00
0081	0	1.00	0.00	0.000	0.000	0.000	0.000	0.00	0.00	0.00
0082	0	1.00	0.00	0.000	0.000	0.000	0.000	0.54	0.27	0.20
0083	0	1.00	0.00	0.000	0.000	0.000	0.000	0.20	0.10	0.10
0084	0	1.00	0.00	0.000	0.000	0.000	0.000	0.11	0.07	0.00
0085	1	0.99	0.00	0.200	0.000	-.080	0.230	0.24	0.15	0.00
0086	0	1.00	0.00	0.000	0.000	0.000	0.000	0.21	0.10	0.00
0087	1	1.01	0.00	0.150	0.000	-1.00	10.00	0.00	0.00	0.00
0088	0	1.00	0.00	0.000	0.000	0.000	0.000	0.48	0.10	0.00
0089	1	1.00	0.00	6.070	0.000	-2.10	3.000	0.00	0.00	0.00
0090	1	0.99	0.00	0.100	0.000	-3.00	3.000	1.73	0.42	0.00
0091	1	0.98	0.00	0.120	0.000	-1.20	1.000	0.22	0.00	0.00
0092	1	.992	0.00	0.500	0.000	-.030	0.090	0.65	0.10	0.00
0093	0	1.00	0.00	0.000	0.000	0.000	0.000	0.12	0.07	0.00
0094	0	1.00	0.00	0.000	0.000	0.000	0.000	0.30	0.16	0.00
0095	0	1.00	0.00	0.000	0.000	0.000	0.000	0.42	0.31	0.00
0096	0	1.00	0.00	0.000	0.000	0.000	0.000	0.38	0.15	0.00
0097	0	1.00	0.00	0.000	0.000	0.000	0.000	0.15	0.09	0.00
0098	0	1.00	0.00	0.000	0.000	0.000	0.000	0.34	0.08	0.00
0099	1	1.01	0.00	0.200	0.000	-1.00	1.000	0.62	0.00	0.00
0100	1	1.02	0.00	2.520	0.000	-.500	1.550	0.37	0.18	0.00
0101	0	1.00	0.00	0.000	0.000	0.000	0.000	0.22	0.15	0.00
0102	0	1.00	0.00	0.000	0.000	0.000	0.000	0.05	0.03	0.00
0103	1	1.01	0.00	0.500	0.000	-.150	1.000	0.23	0.16	0.00
0104	1	0.97	0.00	0.100	0.000	-.600	0.230	0.38	0.25	0.00
0105	1	.965	0.00	0.100	0.000	-.200	0.500	0.31	0.26	0.20
0106	0	1.00	0.00	0.000	0.000	0.000	0.000	0.43	0.16	0.00
0107	1	0.95	0.00	0.120	0.000	-2.00	0.500	0.62	0.12	0.06
0108	0	1.00	0.00	0.000	0.000	0.000	0.000	0.02	0.01	0.00
0109	0	1.00	0.00	0.000	0.000	0.000	0.000	0.08	0.03	0.00
0110	1	.973	0.00	0.120	0.000	-.100	0.230	0.39	0.30	0.06
0111	1	0.98	0.00	0.360	0.000	-1.00	10.00	0.00	0.00	0.00
0112	1	0.98	0.00	0.120	0.000	-1.00	10.00	0.80	0.13	0.00
0113	1	0.99	0.00	0.120	0.000	-1.00	2.000	0.12	0.00	0.00
0114	0	1.00	0.00	0.000	0.000	0.000	0.000	0.08	0.03	0.00
0115	0	1.00	0.00	0.000	0.000	0.000	0.000	0.22	0.07	0.00
0116	1	1.00	0.00	0.120	0.000	-9.99	10.00	0.00	0.00	0.00
0117	0	1.00	0.00	0.000	0.000	0.000	0.000	0.20	0.08	0.00
*118	2	1.03	0.00	5.160	0.000	-9.99	10.00	3.00	0.00	0.00

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LOAD FLOW SOLUTION OF 118-BUS POWER SYSTEM

LOAD BUSES

V(2) = 1.07043 − J .17255	V(3) = 1.09935 − J .17455
V(5) = 1.07282 − J .08335	V(7) = 1.04274 − J .13169
V(9) = 1.08770 + J .12954	V(11) = 1.04435 − J .14183
V(13) = 1.01042 − J .15540	V(14) = 1.01789 − J .14799
V(16) = 1.02431 − J .13731	V(17) = .97668 − J .09880
V(20) = .92612 − J .12674	V(21) = .91506 − J .10358
V(22) = .91342 − J .06491	V(23) = .91953 + J .01440
V(28) = .65415 − J .03798	V(29) = .71049 − J .06307
V(30) = 1.04849 − J .01358	V(33) = .95004 − J .14401
V(35) = .95094 − J .14973	V(37) = .96155 − J .12382
V(38) = 1.04009 − J .04400	V(39) = .94370 − J .18666
V(41) = .96981 − J .23207	V(43) = .94448 − J .15706
V(44) = .96482 − J .12640	V(45) = .97308 − J .09906
V(47) = 1.01304 − J .03379	V(48) = 1.01507 − J .02675
V(50) = .99661 − J .03004	V(51) = .96248 − J .05480
V(52) = .95210 − J .06353	V(53) = .94010 − J .06065
V(57) = .96570 − J .04964	V(58) = .95394 − J .05852
V(60) = .99042 + J .03003	V(63) = 1.01916 + J .04514
V(64) = 1.01411 + J .07093	V(67) = 1.01893 + J .07014
V(68) = 1.01939 + J .04743	V(69) = .94918 − J .05496
V(71) = .98331 − J .04739	V(75) = .96785 − J .04862
V(78) = .99846 + J .05185	V(79) = 1.00423 + J .06389
V(81) = .99793 + J .11004	V(82) = .98330 + J .11061
V(83) = .97432 + J .14418	V(84) = .96032 + J .20832
V(86) = .96012 + J .23841	V(88) = .93935 + J .30079
V(93) = .96327 + J .21015	V(94) = .97686 + J .16243
V(95) = .97093 + J .13520	V(96) = .98436 + J .12222
V(97) = 1.00427 + J .11702	V(98) = 1.01775 + J .11711

V(101) = .97432 + J .19435	V(102) = .95976 + J .24675
V(106) = .96058 + J .04471	V(108) = .96562 + J .03618
V(109) = .96665 + J .02991	V(114) = .85262 - J .07927
V(115) = .82930 - J .07915	V(117) = 1.02424 - J .16499

GENERATOR BUSES:

Q(1) = 1.87671	V(1) = 1.13115 - J .20734
Q(4) = 1.49047	V(4) = 1.08982 - J .14932
Q(6) = -.33099	V(6) = 1.04492 - J .12183
Q(8) = .11990	V(8) = 1.08999 + J .00516
Q(10) =-1.46915	V(10) = 1.04326 + J .25928
Q(12) = -.48252	V(12) = 1.04136 - J .14206
Q(15) = -.28033	V(15) = .96028 - J .13697
Q(18) = .09572	V(18) = .96103 - J .13163
Q(19) = -.21509	V(19) = .95013 - J .13731
Q(24) = -.68610	V(24) = .91000 - J .00179
Q(25) = 1.01409	V(25) = .95783 + J .15320
Q(26) = -.85349	V(26) = .99222 + J .18869
Q(27) = .37179	V(27) = .82100 - J .05740
Q(31) = .00325	V(31) = .77883 - J .08070
Q(32) = .77907	V(32) = .86863 - J .07663
Q(34) = -.31467	V(34) = .94723 - J .14979
Q(36) = .21873	V(36) = .95092 - J .15203
Q(40) = -.91181	V(40) = .94707 - J .20967
Q(42) = 2.37892	V(42) = 1.06987 - J .25568
Q(46) = -.13749	V(46) = .99823 - J .05942
Q(49) = -.11140	V(49) = 1.01998 - J .00679
Q(54) = -.77869	V(54) = .94945 - J .03231
Q(55) = -.07745	V(55) = .94849 - J .05357
Q(56) = -.34633	V(56) = .94857 - J .05212
Q(59) = .69849	V(59) = .98997 - J .00733
Q(61) = -.12711	V(61) = .99764 + J .06867
Q(62) = -.15584	V(62) = .99875 + J .05004
Q(65) =-5.98038	V(65) = .99378 + J .11140

Q(66) = 4.20968	V(66) = 1.04467 + J .11516
Q(70) = -.22994	V(70) = .97903 - J .04356
Q(72) = .31571	V(72) = .97887 - J .04715
Q(73) = .12668	V(73) = .98866 - J .05158
Q(74) = -.31007	V(74) = .95789 - J .06364
Q(76) = -.44483	V(76) = .94434 - J .03543
Q(77) = .13413	V(77) = 1.00821 + J .06019
Q(80) = .90427	V(80) = 1.03245 + J .12513
Q(85) = -.07269	V(85) = .95887 + J .24632
Q(87) = .05974	V(87) = .97282 + J .27153
Q(89) = -.49926	V(89) = .92722 + J .37453
Q(90) = .38655	V(90) = .95418 + J .26390
Q(91) = -.20485	V(91) = .94392 + J .26347
Q(92) = -.13253	V(92) = .95289 + J .27581
Q(99) = -.21949	V(99) = 1.00075 + J .13637
Q(100) = .96894	V(100) = 1.00679 + J .16362
Q(103) = .47483	V(103) = 1.00371 + J .11257
Q(104) = -.32016	V(104) = .96740 + J .07100
Q(105) = -.44500	V(105) = .96354 + J .05307
Q(107) = -.07726	V(107) = .95000 + J .00019
Q(110) = -.41365	V(110) = .97281 + J .01923
Q(111) = -.01844	V(111) = .97885 + J .04749
Q(112) = .36308	V(112) = .97936 - J .03535
Q(113) = .82172	V(113) = .98440 - J .10511
Q(116) = -.43424	V(116) = .99812 + J .06121
SLACK BUS	
P(118) = -.71832	Q(118) = 1.40688

TOTAL NUMBER OF ITERATIONS TAKEN BY XLF2 = 6

NUMBER OF ITERATIONS PERFORMED WITHOUT UPDATING COEFFICIENT MATRIX = 2

TOTAL EXECUTION TIME TAKEN BY XLF2 = 5.365 SECONDS

Example 2

This example deals with the evaluation of the load flow solution and the sensitivities of a real function, $|V_6|$, with respect to various control variables for the 26-bus power system [2]. The listing of the main program and subroutine AMU are given on pages 33-35. Two input data files TL26 and BUS26 are created:

1) TL26 transmission element data file.

2) BUS26 bus data file.

These files are found on page 36. The program output is presented on pages 37-40.

The control variables used for sensitivity evaluation are as follows:

1. load buses - real power, reactive power, lumped shunt conductance and shunt susceptance
2. generator buses - voltage magnitude, real power, lumped shunt conductance and shunt susceptance
3. transmission element quantities - transmission line conductance and line susceptance.

```
      PROGRAM MAIN(INPUT,OUTPUT,TL26,BUS26,TAPE5=BUS26,TAPE6=OUTPUT,TAPE
     13=TL26)
C
      COMPLEX V(26),CV(26),AI(26),S(26),DS(52),AK(800),DYM(26),W(52),ZC,
     1YM(200),CC,SL(26)
      DIMENSION KA(25), IRYM(200), ICYM(200), ICN(800), IRN(600), IW(120
     10), IKEEP(1000), JVECT(600)
      COMMON /XLF2ID/ ITMAX,TOLV,ICHTL,IWRITE,IDER,ILOAD,ICALL,IADJ,IAPP
     1,APP,IAC,JAC,ZC,SHTLC,CC,IOUT,LNTAP
C
C     THIS IS THE MAIN PROGRAM FOR SOLVING THE POWER FLOW EQUATIONS
C
C     AND DETERMINING THE DERIVATIVES OF A REAL FUNCTION SUPPLIED BY
C
C     THE USER W.R.T. VARIOUS CONTROL PARAMETERS USING THE COMPUTER
C
C     PROGRAM PACKAGE CALLED XLF2. A 26-BUS POWER SYSTEM IS SOLVED
C
C     *******************************************************************
C
      ICALL=1
      IADJ=1
      IDER=1
      ILOAD=1
      LIRN=600
      LICN=800
      IAPP=0
      APP=0.01
      ITMAX=7
      ICHTL=0
      IWRITE=0
      TOLV=1.0E-6
      READ (5,150) NB
      N=NB-1
      DO 10 I=1,N
      READ (5,160) S(I),V(I),KA(I)
   10 CONTINUE
      READ (5,170) V(NB)
C
C     DETERMINING THE LOAD FLOW SOLUTION AND THE SOLUTION OF THE
C     ADJOINT SYSTEM OF EQUATIONS
C
      DO 20 I=1,NB
      SL(I)=(0.0,0.0)
   20 CONTINUE
      CALL XLF2 (V,CV,AI,S,SL,DS,AK,DYM,KA,NB,YM,ICN,IRN,IW,IKEEP,JVECT,
     1LIRN,LICN,W,IRYM,ICYM,NYMD
C
C     DERIVATIVES W.R.T. LOAD BUS QUANTITIES
C
      WRITE (6,70)
      WRITE (6,80)
      DO 30 I=1,N
      IF (KA(I).NE.0) GO TO 30
      CALL DERIV (V,CV,DS,KA,NB,I,L2,1,DF1)
      CALL DERIV (V,CV,DS,KA,NB,I,L2,2,DF2)
      CALL DERIV (V,CV,DS,KA,NB,I,L2,7,DF3)
      CALL DERIV (V,CV,DS,KA,NB,I,L2,8,DF4)
      WRITE (6,100) I,DF1,DF2,DF3,DF4
   30 CONTINUE
      WRITE (6,90)
C
C     DERIVATIVES W.R.T. GENERATOR BUS QUANTITIES
C
      WRITE (6,110)
```

```
      DO 40 I=1,N
      IF (KA(I).NE.1) GO TO 40
      CALL DERIV (V,CV,DS,KA,NB,I,L2,3,DF1)
      CALL DERIV (V,CV,DS,KA,NB,I,L2,1,DF2)
      CALL DERIV (V,CV,DS,KA,NB,I,L2,7,DF3)
      CALL DERIV (V,CV,DS,KA,NB,I,L2,8,DF4)
      WRITE (6,100) I,DF1,DF2,DF3,DF4
40    CONTINUE
      WRITE (6,90)
C
C     DERIVATIVES W.R.T. LINE QUANTITIES
C
      REWIND 3
      WRITE (6,120)
50    READ (3,*) ICODE,L1,L2,A1,A2,A3,A4,A5
      IF (EOF(3).NE.0) GO TO 60
      IF (ICODE.EQ.7) GO TO 50
      CALL DERIV (V,CV,DS,KA,NB,L1,L2,5,DF1)
      CALL DERIV (V,CV,DS,KA,NB,L1,L2,6,DF2)
      WRITE (6,140) L1,L2,DF1,DF2
      GO TO 50
60    WRITE (6,130)
      STOP
C
C
70     FORMAT (*1*,3X,*DERIVATIVES OF /V(6)/*,//)
80     FORMAT (*0*,3X,*LOAD BUS QUANTITIES - TOTAL DERIVATIVES*,//,3X,66(
     1*-*),//,3X,*BUS*,9X,*REAL*,9X,*REACTIVE*,9X,*SHUNT*,10X,*SHUNT*,/,
     215X,*POWER*,9X,*POWER*,8X,*CONDUCTANCE*,4X,*SUSCEPTANCE*,//,3X,66(
     3*-*),/,1X)
90     FORMAT (/,3X,66(*-*))
100    FORMAT (1X,I5,4F15.6)
110    FORMAT (*1*,3X,*GENERATOR BUS QUANTITIES - TOTAL DERIVATIVES*,//,3
     1X,66(*-*),//,3X,*BUS*,7X,*VOLTAGE*,9X,*REAL*,12X,*SHUNT*,10X,*SHUN
     2T*,/,13X,*MAGNITUDE*,7X,*POWER*,8X,*CONDUCTANCE*,4X,*SUSCEPTANCE*,
     3//,3X,66(*-*),/,1X)
120    FORMAT (*1*,3X,*LINE QUANTITIES - TOTAL DERIVATIVES*,//,4X,42(*-*)
     1,//,6X,*LINE*,9X,*LINE*,13X,*LINE*,/,16X,*CONDUCTANCE*,6X,*SUSCEPT
     2ANCE*,//,4X,42(*-*),/,1X)
130    FORMAT (4X,42(*-*),/)
140    FORMAT (5X,I3,*,*,I3,F13.6,2X,F15.6)
150    FORMAT (10I5)
160    FORMAT (4F10.5,I5)
170    FORMAT (2F10.5)
       END
C
C
       SUBROUTINE AMU (V,CV,AI,S,NB,DS,IDER,YM,DYM,ICYM,IRYM,NYM,KA,IOUT)
C
       COMPLEX V(1),CV(1),AI(1),S(1),DS(1),YM(1),DYM(1)
       DIMENSION ICYM(1), IRYM(1)
C
C      THIS SUBROUTINE DETERMINES THE DERIVATIVES OF THE REAL FUNCTION
C
C      /V(6)/ W.R.T. V AND CONJUGATE OF V, I.E., RHS OF EQUATION (75)
C
C      OF SOC-257. THIS SUBROUTINE IS SUPPLIED BY THE USER
C
C      ******************************************************************
C
       DO 10 I=1,NB
       DS(I)=(0.0,0.0)
       DS(NB+I)=(0.0,0.0)
10     CONTINUE
       AV1=CABS(V(6))
```

```
      AV1=0.5/AV1                                                   AMU 190
      DS(6)=AV1*CV(6)                                               AMU 200
      DS(NB+6)=CONJG(DS(6))                                         AMU 210
      RETURN                                                        AMU 220
      END                                                           AMU 230-
```

26				
-0.82	-0.21	1.0	0.0	0
0.0	0.0	1.0	0.0	0
-0.57	-0.17	1.0	0.0	0
-0.48	-0.21	1.0	0.0	0
-0.43	-0.11	1.0	0.0	0
-0.40	-0.1	1.0	0.0	0
-1.11	-0.27	1.0	0.0	0
-0.23	-0.06	1.0	0.0	0
-0.67	-0.21	1.0	0.0	0
-1.02	-0.27	1.0	0.0	0
-0.43	-0.14	1.0	0.0	0
-0.43	-0.12	1.0	0.0	0
0.0	0.0	1.0	0.0	0
0.0	0.0	1.0	0.0	0
0.0	0.0	1.0	0.0	0
-1.31	-0.30	1.0	0.0	0
-0.03	-0.01	1.0	0.0	0
2.80	1.07	1.07	0.0	1
1.45	1.05	1.05	0.0	1
2.80	1.0	1.0	0.0	1
1.10	1.02	1.02	0.0	1
-0.56	0.89	0.89	0.0	1
-0.04	1.0	1.0	0.0	1
-0.05	1.0	1.0	0.0	1
0.63	1.0	1.0	0.0	1
1.01	0.0			

```
4,16,23,1,1,0.0,0.432,0.0
7,2,10,1,0.0,0.0150,1.03,0.0
4,9,10,1,1,0.1494,0.3392,0.4120
4,9,12,1,1,0.0658,0.1494,0.0182
4,9,14,1,1,0.0618,0.2397,0.0319
4,11,14,1,1,0.0676,0.2620,0.0349
4,6,19,1,1,0.0129,0.0532,0.0074
4,7,19,1,1,0.0906,0.3742,0.0437
4,6,7,1,1,0.0921,0.3569,0.0475
4,11,22,1,1,0.0513,0.2118,0.0248
4,8,11,1,1,0.0865,0.3355,0.0447
4,17,22,1,1,0.0281,0.1869,0.0237
4,8,21,1,1,0.0735,0.2847,0.0379
4,17,21,1,1,0.0459,0.3055,0.0387
4,1,4,1,1,0.0619,0.2401,0.0319
4,4,21,1,1,0.0610,0.2365,0.0315
7,20,21,1,0.0,0.0305,0.97,0.0
7,15,1,1,0.0,0.0147,0.89,0.0
4,2,13,1,1,0.0086,0.0707,0.3017
4,1,7,1,1,0.0199,0.0785,0.0404
4,15,20,1,1,0.0107,0.0617,0.4471
4,2,18,1,1,0.0074,0.0608,0.2593
7,1,3,1,0.0,0.0392,.98,0.0
7,24,3,1,0.0,0.1450,0.98,0.0
7,5,21,1,0.0,0.1750,0.99,0.0
7,5,25,1,0.0,0.1540,1.03,0.0
7,13,26,1,0.0,0.0131,1.03,0.0
7,26,16,1,0.0,0.0392,0.96,0.
4,23,26,1,1,0.0,0.3140,0.0
4,12,26,1,1,0.0533,0.1210,0.0147
4,19,26,1,1,0.0610,0.2521,0.0295
4,6,26,1,1,0.0513,0.1986,0.0265
```

LOAD FLOW SOLUTION OF 26-BUS POWER SYSTEM

LOAD BUSES

V(1) = 1.03276 + J .07729	V(2) = 1.06437 + J .09434
V(3) = 1.04236 + J .05495	V(4) = .98590 + J .09787
V(5) = .97408 + J .25981	V(6) = 1.03244 + J .05542
V(7) = 1.01318 + J .01806	V(8) = .94412 + J .04026
V(9) = .96137 - J .10877	V(10) = 1.03697 + J .06924
V(11) = .89822 - J .09922	V(12) = .96704 - J .07406
V(13) = 1.04633 + J .01572	V(14) = .93882 - J .10713
V(15) = .92734 + J .09701	V(16) = 1.03526 - J .04712
V(17) = .93176 + J .02780	

GENERATOR BUSES

Q(18) = -.40042	V(18) = 1.03970 + J .25282
Q(19) = .18722	V(19) = 1.04555 + J .09658
Q(20) = .77951	V(20) = .97058 + J .24078
Q(21) = -.02939	V(21) = .99384 + J .22951
Q(22) = -.17746	V(22) = .88559 - J .08849
Q(23) = -.11439	V(23) = .99965 - J .02655
Q(24) = -.16451	V(24) = .99895 + J .04584
Q(25) = .16913	V(25) = .93592 + J .35222

SLACK BUS

P(26) = .13341	Q(26) = -.05129

TOTAL NUMBER OF ITERATIONS TAKEN BY XLF2 = 5

NUMBER OF ITERATIONS PERFORMED WITHOUT UPDATING COEFFICIENT MATRIX = 2

TOTAL EXECUTION TIME TAKEN BY XLF2 = .766 SECONDS

DERIVATIVES OF /V(6)/

LOAD BUS QUANTITIES - TOTAL DERIVATIVES

BUS	REAL POWER	REACTIVE POWER	SHUNT CONDUCTANCE	SHUNT SUSCEPTANCE
1	.000416	.003612	-.000446	.003874
2	-.000019	-.000003	.000022	-.000004
3	.000560	.002894	-.000610	.003154
4	-.000053	.001956	.000052	.001920
5	-.000689	-.000000	.000700	-.000000
6	.008807	.037494	-.009415	.040082
7	.002370	.008613	-.002433	.008845
8	-.000627	.000021	.000560	.000019
9	-.000132	.000007	.000124	.000006
10	-.000023	-.000005	.000025	-.000006
11	-.000516	.000014	.000422	.000011
12	-.000060	-.000001	.000056	-.000001
13	-.000003	-.000001	.000003	-.000001
14	-.000309	.000012	.000276	.000010
15	.000224	.003030	-.000194	.002634
16	0.000000	0.000000	0.000000	0.000000
17	-.000633	.000009	.000550	.000008

GENERATOR BUS QUANTITIES — TOTAL DERIVATIVES

BUS	VOLTAGE MAGNITUDE	REAL POWER	SHUNT CONDUCTANCE	SHUNT SUSCEPTANCE
18	-.000060	-.000018	.000020	0.000000
19	.760458	-.001371	.001512	0.000000
20	.047441	-.000697	.000697	0.000000
21	.008785	-.000689	.000717	0.000000
22	.000124	-.000594	.000470	0.000000
23	0.000000	0.000000	0.000000	0.000000
24	.021261	.000579	-.000579	0.000000
25	.000000	-.000689	.000689	0.000000

LINE QUANTITIES -- TOTAL DERIVATIVES

LINE	LINE CONDUCTANCE	LINE SUSCEPTANCE
16, 23	0.000000	0.000000
9, 10	-.000007	.000019
9, 12	-.000000	.000002
9, 14	-.000004	.000000
11, 14	-.000007	-.000001
6, 19	-.001403	-.001018
7, 19	-.000542	-.000590
6, 7	.000938	.000891
11, 22	-.000001	-.000000
8, 11	.000018	-.000014
17, 22	.000012	-.000004
8, 21	.000026	-.000012
17, 21	.000033	-.000011
1, 4	-.000063	.000071
4, 21	-.000227	-.000123
2, 13	.000000	-.000001
1, 7	-.000259	-.000207
15, 20	-.000326	-.000283
2, 18	.000001	.000000
23, 26	0.000000	0.000000
12, 26	-.000002	.000004
19, 26	.000064	-.000134
6, 26	.001868	.001477

Example 3

This example deals with the optimization of a 6-bus power system using packages XLF2 and MFNC [8]. The package MFNC minimizes the objective function with general constraints using the Han-Powell algorithm [9,10]. The aim of this example is to determine the optimal value of the voltages and active powers of the generators such that transmission losses during normal operation are minimum.

The problem is formulated as follows. The total transmission losses are given by

$$F = \sum_{i=1}^{6} P_i ,$$

where P_i is the active power injected at bus i. The constraints assumed on the control variables are

$$0.9 \leq V_i \leq 1.1, \qquad i = 4,\ldots,6,$$

$$-0.3 \leq P_4 \leq 4.0,$$

$$-0.3 \leq P_5 \leq 4.0,$$

where V_i is the modulus of the voltage of bus i. These variables are renamed in the program as X(I), I=1,...,5.

The listing of the main program, subroutines AMU and FDF, as required by MFNC, are given on pages 43-45. Two input data files TL6 and BUS6 are created:

1) TL6 transmission element data file.

2) BUS6 bus data file.

Input data files TL6 and BUS6 are listed on page 46. The program output is reported on pages 47.

This problem was also solved with an approximation, in which optimization is started with an exact load flow solution and appropriate exact first derivatives, continuing as follows:

<u>Step 1</u> An iteration of the optimization procedure is carried out. This gives new values of the control variables.

<u>Step 2</u> One iteration of the complex Newton method is executed using the current values of the voltages, which results in an approximate load flow solution. The coefficient matrix is updated at this solution and used to calculate exact derivatives corresponding to this solution.

<u>Step 3</u> The procedure of Step 1 followed by Step 2 is repeated until the optimization convergence criterion is satisfied.

<u>Step 4</u> An exact load flow solution is determined.

The results are reported on page 48.

The package can handle constraints on state variables such as load bus voltages, argument of bus voltages, generator reactive power and slack bus powers.

```
      PROGRAM MAIN(INPUT,OUTPUT,TL6,BUS6,TAPE5=BUS6,TAPE3=TL6,TAPE6=OUTP
     1UT)
C
      DIMENSION X(5), G(5), DC(6,10), C(10), WW(1500)
      COMMON /MNFDF/ NCOUNT
      EXTERNAL FDF
C
C     THIS IS THE MAIN PROGRAM FOR MINIMIZING TRANSMISSION POWER
C
C     LOSSES IN A 6-BUS POWER NETWORK USING PACKAGES XLF2 AND MFNC
C
C     ******************************************************************
C
      NV=5
      NCOUNT=1
      L=10
      LEQ=0
      X(1)=1.02
      X(2)=1.04
      X(3)=1.04
      X(4)=-0.3
      X(5)=1.25
      EPS=1.0E-6
      MAXF=100
      IWW=1500
      IOUT=6
      IPR=1
      WRITE (6,10)
      CALL SECOND (TM1)
      CALL MFNC2A (FDF,NV,L,LEQ,X,EPS,MAXF,WW,IWW,IFLAG)
      CALL SECOND (TM2)
      CPU=TM2-TM1
      WRITE (6,20) CPU
      WRITE (6,30) IFLAG,EPS,MAXF
      WRITE (6,40) (X(I),I=1,NV)
      WRITE (6,50) WW(1)
      STOP
C
10    FORMAT (*1RESULTS FOR EXAMPLE 3*,//,13X,*V4*,12X,*V5*,12X,*V6*,14X
     1,*P4*,12X,*P5*,/)
20    FORMAT (*0CPU TIME = *,F6.3,* SECONDS*)
30    FORMAT (* IFLAG    = *,I2,/,* DXNORM   =*,E13.5,/,* F. EVAL. = *,I
     12)
40    FORMAT (*0SOLUTION*,/,5(/F15.5))
50    FORMAT (*0TOTAL TRANSMISSION POWER LOSSES =*,F10.6)
      END
C
C
      SUBROUTINE FDF (NV,L,X,F,G,C,DC,KN)
C
      COMPLEX V(6),CV(6),AI(6),S(6),DS(12),AK(200),DYM(6),W(12),ZC,YM(10
     10),CC,SL(6)
      DIMENSION KA(6), IRYM(50), ICYM(50), ICN(200), IRN(150), IW(400),
     1IKEEP(300), JVECT(150), X(5), G(5), C(10), DC(KN,10)
      COMMON /XLF2ID/ ITMAX,TOLV,ICHTL,IWRITE,IDER,ILOAD,ICALL,IADJ,IAPP
     1,APP,IAC,JAC,ZC,SHTLC,CC,IOUT,LNTAP
      COMMON /MNFDF/ NCOUNT
C
C     THIS SUBROUTINE EVALUATES THE OBJECTIVE FUNCTION, CONSTRAINTS
C
C     AND THEIR DERIVATIVES W.R.T. V4, V5, V6, P4 AND P5
C
C     *******************************************************************
C
C     WRITING OF THE CONTROL VARIABLES
```

```
C
      WRITE (6,60) NCOUNT,(X(I),I=1,NV)
C
C     INITIALIZATION OF THE VARIABLES AND READING OF DATA
C
      IF (NCOUNT.NE.1) GO TO 20
      ITMAX=7
      TOLV=1.0E-4
      LIRN=150
      LICN=200
      APP=0.01
      ICALL=1
      PWL=0.0
      ICHTL=0
      IWRITE=2
      IDER=1
      ILOAD=1
      IADJ=1
      READ (5,70) NB
      N=NB-1
      DO 10 I=1,N
      READ (5,80) S(I),V(I),KA(I)
      SL(I)=(0.0,0.0)
      IF (KA(I).EQ.0) PWL=PWL+REAL(S(I))
10    CONTINUE
      READ (5,90) V(NB)
      SL(NB)=(0.0,0.0)
20    IAPP=0
      S(4)=CMPLX(X(4),X(1))
      S(5)=CMPLX(X(5),X(2))
      V(6)=CMPLX(X(3),0.0)
C
C     DETERMINATION OF THE OBJECTIVE FUNCTION F AND ITS DERIVATIVES
C     W.R.T. V4, V5, V6, P4 AND P5
C
      CALL XLF2 (V,CV,AI,S,SL,DS,AK,DYM,KA,NB,YM,ICN,IRN,IW,IKEEP,JVECT,
     1LIRN,LICN,W,IRYM,ICYM,NYM)
      ICALL=2
      NCOUNT=NCOUNT+1
      F=REAL(CV(NB)*AI(NB)+CV(4)*AI(4)+CV(5)*AI(5))+PWL
      IF (IWRITE.EQ.2) GO TO 30
      WRITE (6,100) F
30    CALL DERIV (V,CV,DS,KA,NB,4,L2,3,G(1))
      CALL DERIV (V,CV,DS,KA,NB,5,L2,3,G(2))
      CALL DERIV (V,CV,DS,KA,NB,6,L2,4,G(3))
      CALL DERIV (V,CV,DS,KA,NB,4,L2,1,G(4))
      CALL DERIV (V,CV,DS,KA,NB,5,L2,1,G(5))
C
C     DETERMINATION OF CONSTRAINTS AND THEIR DERIVATIVES
C
      C(1)=1.1-X(1)
      C(2)=1.1-X(2)
      C(3)=1.1-X(3)
      C(4)=4.0-X(4)
      C(5)=4.0-X(5)
      C(6)=X(1)-0.9
      C(7)=X(2)-0.9
      C(8)=X(3)-0.9
      C(9)=X(4)+0.3
      C(10)=X(5)+0.3
      DO 40 J=1,NV
      DO 40 I=1,L
40    DC(J,I)=0.0
      DO 50 I=1,NV
      DC(I,I)=-1.0
```

```
      DC(I,NV+I)=1.0
50    CONTINUE
      RETURN
C
60    FORMAT (1X,I5,3(F13.8,1X),1X,2(1X,F13.8))
70    FORMAT (10I5)
80    FORMAT (4F10.5,I5)
90    FORMAT (2F10.5)
100   FORMAT (*0TOTAL POWER LOSS =*,E12.5)
      END
C
C
      SUBROUTINE AMU (V,CV,AI,S,NB,DS,IDER,YM,DYM,ICYM,IRYM,NYM,KA,IOUT)
C
      COMPLEX V(1),CV(1),AI(1),S(1),DS(1),YM(1),DYM(1)
      DIMENSION KA(1), ICYM(1), IRYM(1)
C
C     THIS SUBROUTINE DETERMINES THE DERIVATIVES OF THE REAL FUNCTION
C
C     CONSIDERED W.R.T. V AND CONJUGATE OF V, I.E., THE RHS OF EQUATION
C
C     (75) OF SOC-257. THIS SUBROUTINE MUST BE SUPPLIED BY THE USER.
C
C     THE FUNCTION CONSIDERED HERE IS THE TOTAL TRANSMISSION LOSSES
C
C     ***************************************************************************
C
      NB2=NB+NB
      DO 10 I=1,NB2
      DS(I)=(0.0,0.0)
10    CONTINUE
      DO 20 I=1,NYM
      IF (KA(IRYM(I)).EQ.0) GO TO 20
      DS(ICYM(I))=DS(ICYM(I))+CV(IRYM(I))*YM(I)
      DS(IRYM(I))=DS(IRYM(I))+CONJG(YM(I))*CV(ICYM(I))
20    CONTINUE
      DO 40 I=1,NB
      IF (KA(I).EQ.0) GO TO 30
      DS(I)=DS(I)*0.5+CV(I)*REAL(DYM(I))
      DS(I+NB)=CONJG(DS(I))
      GO TO 40
30    DS(I)=0.5*DS(I)
      DS(I+NB)=CONJG(DS(I))
40    CONTINUE
      RETURN
      END
```

```
     6
  -2.4      0.0      1.0      0.0      0
  -2.4      0.0      1.0      0.0      0
  -1.6     -0.4      1.0      0.0      0
  -0.3      1.02     1.02     0.0      1
   1.25     1.04     1.04     0.0      1
   1.04     0.0
```

```
4,1,4,1,1,0.05,.2,0.0
4,1,5,2,1,0.025,0.1,0.0
4,2,3,1,1,0.1,0.4,0.0
4,2,4,1,1,0.1,0.4,0.0
4,2,5,1,1,0.05,0.2,0.0
4,3,4,1,1,0.15,0.6,0.0
4,3,6,2,1,0.0375,0.15,0.0
4,2,6,4,1,0.01875,0.075,0.0
```

RESULTS FOR EXAMPLE 3

	V4	V5	V6	P4	P5
1	1.02000000	1.04000000	1.04000000	-.30000000	1.25000000
2	1.05735618	1.10000000	1.10000000	.07581156	1.56283773
3	1.10000000	1.07179740	1.08959142	.77151963	2.13993385
4	.95093332	1.10000000	1.10000000	1.29936952	2.54975364
5	1.03615700	1.08387614	1.09404926	.99758974	2.31545346
6	1.10000000	1.10000000	1.10000000	1.28780494	2.53383248
7	1.10000000	1.10000000	1.10000000	1.26323715	2.49944817
8	1.10000000	1.10000000	1.10000000	1.26114621	2.46614640
9	1.10000000	1.10000000	1.10000000	1.29132665	2.38614408
10	1.10000000	1.10000000	1.10000000	1.36008255	2.30807626
11	1.10000000	1.10000000	1.10000000	1.42740655	2.27482124
12	1.10000000	1.10000000	1.10000000	1.44690003	2.28202310
13	1.10000000	1.10000000	1.10000000	1.44683823	2.28774944

CPU TIME = 2.465 SECONDS
IFLAG = 0
DXNORM = .10000E-05
F. EVAL = 13

SOLUTION

1.10000
1.10000
1.10000
1.44684
2.28775

TOTAL TRANSMISSION POWER LOSSES = .224461

RESULTS FOR EXAMPLE 3

	V4	V5	V6	P4	P5
1	1.02000000	1.04000000	1.04000000	-.30000000	1.25000000
2	1.05735618	1.10000000	1.10000000	.07581156	1.56283773
3	1.10000000	1.03464361	1.10000000	.61761213	2.01339832
4	.90000000	1.10000000	1.07163421	1.77478366	2.92268653
5	1.04883204	1.05136437	1.09274290	.91366266	2.24603043
6	1.08202619	1.04051712	1.09745079	.72160602	2.09511517
7	1.10000000	1.10000000	1.03378915	1.47786843	2.70543597
8	1.08578391	1.10000000	1.10000000	1.27992481	2.52906139
9	1.10000000	1.10000000	1.10000000	1.22838643	2.47024699
10	1.08720552	1.10000000	1.10000000	1.27477097	2.52317995
11	1.08592607	1.10000000	1.10000000	1.27940943	2.52847324
12	1.08579812	1.10000000	1.10000000	1.27987327	2.52900257
13	1.08578533	1.10000000	1.10000000	1.27991966	2.52905551
14	1.08578391	1.10000000	1.10000000	1.27992481	2.52906139

CPU TIME = 1.487 SECONDS
IFLAG = -3
DXNORM = .10000E-05
F. EVAL = 14

SOLUTION

1.08578
1.10000
1.10000
1.27992
2.52906

TOTAL TRANSMISSION POWER LOSSES = .227806

Example 4

This example deals with optimization of the 6-bus power system using packages XLF2 AND MMLC [11]. MMLC is a Fortran package for linearly constrained minimax optimization described by Hald and Madsen [12]. The aim of this example is to determine the optimum control variables (the voltages and active power of the generators) such that active power transmission losses during normal operation are minimum and transmission lines are not overloaded during single line outages. The single outages considered are (1,4), (2,3), (2,4), (2,5) and (3,4), respectively.

We formulate the problem as follows. The objective function is:

$$f_1 = \sum_{i=1}^{6} P_i$$

and the error functions are

$$f_i = |I_{jk}| - C_{jk} , \qquad i = 2,3,...,36$$

Function f_1 is the total active power loss in the network and functions f_2, f_3,..., f_{36} are the differences between magnitude of the current flowing in the line and current carrying capacity of the line. The functions f_2, f_3,..., f_{36} are defined in Table II on page 50. P_i is the active power injected at bus i, I_{jk} and C_{jk} are the current flowing and the current carrying capacity of the line connecting nodes j and k, respectively.

The constraints on the control variables under consideration are

$$0.9 \leq V_i \leq 1.1, \qquad i = 4,...,6,$$

$$-0.3 \leq P_4 \leq 4.0,$$

$$-0.3 \leq P_5 \leq 4.0,$$

TABLE II

LINE OUTAGES AND CORRESPONDING MINIMAX FUNCTIONS

Function	Line Outage	Line for Which Function is Defined
f_2	1,4	1,5
f_3		2,3
f_4		2,4
f_5		2,5
f_6		3,4
f_7		3,6
f_8		2,6
f_9	2,3	1,4
f_{10}		1,5
f_{11}		2,4
f_{12}		2,5
f_{13}		3,4
f_{14}		3,6
f_{15}		2,6
f_{16}	2,4	1,4
f_{17}		1,5
f_{18}		2,3
f_{19}		2,5
f_{20}		3,4
f_{21}		3,6
f_{22}		2,6

Table II Continued

Function	Line Outage	Line for Which Function is Defined
f_{23}	2,5	1,4
f_{24}		1,5
f_{25}		2,3
f_{26}		2,4
f_{27}		3,4
f_{28}		3,6
f_{29}		2,6
f_{30}	3,4	1,4
f_{31}		1,5
f_{32}		2,3
f_{33}		2,4
f_{34}		2,5
f_{35}		3,6
f_{36}		2,6

where V_i is the modulus of the voltage of bus i. These variables are renamed in the program as X(I), I=1, ..., 5. The current carrying capacities of the lines are given in Table III.

The listing of the main program, subroutines AMU and FDF, as required by MMLC are given on pages 54-58. Two input data files TL6 and BUS6 are created:

1) TL6 transmission element data file.

2) BUS6 bus data files.

Input data files TL6 and BUS6 are listed on page 59. The program output is reported on pages 60-62, displaying results of minimizing w.r.t. $\underset{\sim}{x}$

$$\max\{f_1, f_1+f_2, f_1+f_3, \ldots, f_1+f_{36}\}$$

s.t. lower and upper bounds on the variables, namely,

$$\underset{\sim}{\ell} \leq \underset{\sim}{x} \leq \underset{\sim}{u}.$$

We observe that the minimax problem formulated is appropriate as an exact penalty function implementation of the original problem [13].

The results indicate the same amount of reduction in objective function as obtained in Example 3. The gradient verification has been performed by the optimization package MMLC.

TABLE III

CURRENT CARRYING CAPACITIES OF TRANSMISSION LINES

Line	Capacity (p.u.)
1,4	2
1,5	4
2,3	2
2,4	2
2,5	2
2,6	8
3,4	2
3,6	4

```
      PROGRAM MAIN(INPUT,OUTPUT,TL6,BUS6,TAPE5=BUS6,TAPE3=TL6,TAPE6=OUTP
     1UT)
C
      DIMENSION X(5), DF(36,5), DC(10,5), C(10), WW(1500), F(36)
      COMMON /MNFDF/ NCOUNT
      EXTERNAL FDF
C
C     THIS IS THE MAIN PROGRAM FOR OPTIMIZING A 6-BUS POWER NETWORK
C
C     CONSIDERING OVERLOADING OF LINES DURING CONTINGENCIES AND
C
C     POWER LOSS IN THE NETWORK USING PACKAGES XLF2 AND MMLC
C
C     (SOC-292)
C
C     ********************************************************************
C
      NV=5
      NCOUNT=1
      M=36
      L=10
      LEQ=0
      IC=10
      X(1)=1.02
      X(2)=1.04
      X(3)=1.04
      X(4)=-0.3
      X(5)=1.25
      C(1)=1.1
      C(2)=1.1
      C(3)=1.1
      C(4)=4.0
      C(5)=4.0
      C(6)=-0.9
      C(7)=-0.9
      C(8)=-0.9
      C(9)=0.3
      C(10)=0.3
      DO 10 I=1,L
      DO 10 J=1,NV
   10 DC(I,J)=0.0
      DO 20 I=1,NV
      DC(I,I)=-1.0
      DC(I+NV,I)=1.0
   20 CONTINUE
      DX=0.1
      EPS=1.0E-6
      MAXF=100
      KEQS=3
      IWW=1500
      ICH=6
      IPR=-10
      CALL MMLC1A (FDF,NV,M,L,LEQ,C,DC,IC,X,DX,EPS,MAXF,KEQS,WW,IWW,ICH,
     1IPR,IFALL)
      DO 40 I=1,M
      IF (I.NE.1) GO TO 30
      W1=WW(1)
      WRITE (6,50) I,WW(I)
      GO TO 40
   30 WW(I)=WW(I)-W1
      WRITE (6,60) I,WW(I)
   40 CONTINUE
      STOP
C
   50 FORMAT (//,3X,*OBJECTIVE FUNCTION        F*,I2,4X,F10.6)
```

```
   60 FORMAT (3X,*ERROR      FUNCTION        F*,I2,4X,F10.6)
      END
C
C
      SUBROUTINE AMU (V,CV,AI,S,NB,DS,IDER,YM,DYM,ICYM,IRYM,NYM,KA,IOUT)
C
      COMPLEX V(1),CV(1),AI(1),S(1),DS(1),YM(1),DYM(1),CPX,AIL,CYM
      DIMENSION KA(1), ICYM(1), IRYM(1)
      COMMON /AMUFDF/ CAPL,IRCYM,ICCYM,CYM,FC
C
C     THIS SUBROUTINE DETERMINES THE DERIVATIVES OF THE OBJECTIVE
C
C     FUNCTION AND ERROR FUNCTIONS CONSIDERED W.R.T. V AND CONJUGATE
C
C     OF V, I.E., THE RHS OF EQUATION (75) OF SOC-257.
C
C     **********************************************************************
C
      NB2=NB+NB
      DO 10 I=1,NB2
      DS(I)=(0.0,0.0)
   10 CONTINUE
      IF (IDER.GT.1) GO TO 50
C
C     DERIVATIVES OF THE TOTAL POWER LOSS W.R.T. V AND CONJUGATE
C     OF V
C
      DO 20 I=1,NYM
      IF (KA(IRYM(I)).EQ.0) GO TO 20
      DS(ICYM(I))=DS(ICYM(I))+CV(IRYM(I))*YM(I)
      DS(IRYM(I))=DS(IRYM(I))+CV(ICYM(I))*CONJG(YM(I))
   20 CONTINUE
      DO 40 I=1,NB
      IF (KA(I).EQ.0) GO TO 30
      DS(I)=DS(I)*0.5+CV(I)*REAL(DYM(I))
      DS(I+NB)=CONJG(DS(I))
      GO TO 40
   30 DS(I)=0.5*DS(I)
      DS(I+NB)=CONJG(DS(I))
   40 CONTINUE
      RETURN
C
C     DERIVATIVES OF EXCESSIVE CURRENT (OVERLOADING) OF LINE
C     (IRCYM,ICCYM) W.R.T. V AND CONJUGATE OF V
C
   50 AIL=(V(ICCYM)-V(IRCYM))*CYM
      ABSAIL=CABS(AIL)
      FC=ABSAIL-CAPL
      CPX=(0.5/ABSAIL)*CYM*CONJG(AIL)
      DS(IRCYM)=-CPX
      DS(ICCYM)=CPX
      DS(IRCYM+NB)=CONJG(DS(IRCYM))
      DS(ICCYM+NB)=CONJG(DS(ICCYM))
      RETURN
      END
C
C
      SUBROUTINE FDF (NV,M,X,DF,F)
C
      COMPLEX V(6),CV(6),AI(6),S(6),DS(12),AK(200),DYM(6),W(12),ZC,YM(10
     10),CC,SL(6),CYM,VO(6)
      DIMENSION KA(6), IRYM(50), ICYM(50), ICN(200), IRN(150), IW(400),
     1IKEEP(300), JVECT(150), X(5), DF(36,5), F(36), LBUS1(8), LBUS2(8),
     2 CP(8)
      COMMON /XLF2ID/ ITMAX,TOLV,ICHTL,IWRITE,IDER,ILOAD,ICALL,IADJ,IAPP
```

```
     1,APP,IAC,JAC,ZC,SHTLC,CC,IOUT,LNTAP
      COMMON /AMUFDF/ CAPL,IRCYM,ICCYM,CYM,FC
      COMMON /MNFDF/ NCOUNT
C
C     THIS SUBROUTINE EVALUATES THE OBJECTIVE FUNCTION AND ERROR
C
C     FUNCTIONS, AND THEIR DERIVATIVES W.R.T. V4, V5, V6, P4 AND P5
C
C     *******************************************************************
C
C
C     INITIALIZATION OF THE VARIABLES AND READING OF DATA
C
      IF (NCOUNT.NE.1) GO TO 30
      ITMAX=7
      TOLV=1.0E-4
      LIRN=150
      LICN=200
      APP=0.01
      PWL=0.0
      READ (5,180) NB
      N=NB-1
      DO 10 I=1,N
      READ (5,190) S(I),V(I),KA(I)
      SL(I)=(0.0,0.0)
      IF (KA(I).EQ.0) PWL=PWL+REAL(S(I))
   10 CONTINUE
      READ (5,200) V(NB)
      SL(NB)=(0.0,0.0)
      NL=5
      DO 20 I=1,NL
      READ (5,180) LBUS1(I),LBUS2(I)
   20 CONTINUE
      READ (5,*) (CP(I),I=1,8)
   30 ICHTL=0
      IWRITE=2
      IDER=1
      ILOAD=1
      ICALL=1
      IADJ=1
      IAPP=0
      APP=0.01
      S(4)=CMPLX(X(4),X(1))
      S(5)=CMPLX(X(5),X(2))
      V(6)=CMPLX(X(3),0.0)
C
C     SENSITIVITY EVALUATION
C
C     DETERMINATION OF THE FUNCTION F(1) AND ITS DERIVATIVES W.R.T.
C     V4, V5, V6, P4 AND P5
C
      CALL XLF2 (V,CV,AI,S,SL,DS,AK,DYM,KA,NB,YM,ICN,IRN,IW,IKEEP,JVECT,
     1LIRN,LICN,W,IRYM,ICYM,NYMD
      DO 40 I=1,N
      VO(I)=V(I)
   40 CONTINUE
      F(1)=REAL(CV(NB)*AI(NB)+CV(4)*AI(4)+CV(5)*AI(5))+PWL
      CALL DERIV (V,CV,DS,KA,NB,4,L2,3,DF(1,1))
      CALL DERIV (V,CV,DS,KA,NB,5,L2,3,DF(1,2))
      CALL DERIV (V,CV,DS,KA,NB,6,L2,4,DF(1,3))
      CALL DERIV (V,CV,DS,KA,NB,4,L2,1,DF(1,4))
      CALL DERIV (V,CV,DS,KA,NB,5,L2,1,DF(1,5))
C
C     DETERMINATION OF THE FUNCTIONS F(2),...,F(M) AND THEIR
C     DERIVATIVES W.R.T. V4, V5, V6, P4 AND P5
```

```
C
      NF=1
      DO 90 I=1,NL
      ICHTL=2
      IAC=LBUS1(I)
      JAC=LBUS2(I)
      IDER=2
      ILOAD=1
      IADJ=1
      IAPP=0
      CALL YMATRX (YM,SL,DYM,ICYM,IRYM,NB,NYM,ICHTL,IAC,JAC,ZC,SHTLC,CC,
     1LNTAP)
      DO 80 J=1,NYM,2
      KL=1+J/2
      CAPL=CP(KL)
      IF (IRYM(J).NE.IAC) GO TO 50
      IF (ICYM(J).NE.JAC) GO TO 50
      GO TO 80
   50 NF=NF+1
      CYM=YM(J)
      IRCYM=IRYM(J)
      ICCYM=ICYM(J)
      ICALL=-1
      IF (ILOAD.EQ.0) GO TO 70
      DO 60 K=1,N
      V(K)=VO(K)
   60 CONTINUE
   70 CALL XLF2 (V,CV,AI,S,SL,DS,AK,DYM,KA,NB,YM,ICN,IRN,IW,IKEEP,JVECT,
     1LIRN,LICN,W,IRYM,ICYM,NYM)
      IADJ=0
      ILOAD=0
      F(NF)=FC
      CALL DERIV (V,CV,DS,KA,NB,4,L2,3,DF(NF,1))
      CALL DERIV (V,CV,DS,KA,NB,5,L2,3,DF(NF,2))
      CALL DERIV (V,CV,DS,KA,NB,6,L2,4,DF(NF,3))
      CALL DERIV (V,CV,DS,KA,NB,4,L2,1,DF(NF,4))
      CALL DERIV (V,CV,DS,KA,NB,5,L2,1,DF(NF,5))
   80 CONTINUE
   90 CONTINUE
      M=NF
      IF (NCOUNT.NE.1) GO TO 120
      DO 110 I=1,M
      IF (I.GT.1) GO TO 100
      WRITE (6,150) I,F(I)
      GO TO 110
  100 WRITE (6,160) I,F(I)
  110 CONTINUE
  120 NCOUNT=NCOUNT+1
      DO 130 I=1,N
      V(I)=VO(I)
  130 CONTINUE
      DO 140 I=2,M
      F(I)=F(I)+F(1)
      DO 140 J=1,5
      DF(I,J)=DF(I,J)+DF(1,J)
  140 CONTINUE
      IF (IWRITE.EQ.2) RETURN
      WRITE (6,170)
      WRITE (6,210)
      WRITE (6,220) (F(I),I=1,M)
      RETURN
C
C
C
  150 FORMAT (//,3X,*OBJECTIVE FUNCTION        F*,I2,4X,F10.6)
```

```
160 FORMAT (3X,*ERROR      FUNCTION        F*,I2,4X,F10.6)
170 FORMAT (3X,*RESULTS FOR EXAMPLE 4*,//)
180 FORMAT (10I5)
190 FORMAT (4F10.5,I5)
200 FORMAT (2F10.5)
210 FORMAT (/,* FUNCTION VALUES *,/)
220 FORMAT (7E10.3)
    END
```

DATE : 83/01/04 TIME : 10.40.08 PAGE : 1
LINEARLY CONSTRAINED MINIMAX OPTIMIZATION (MMLC PACKAGE) (V:82.04)

INPUT DATA

NUMBER OF VARIABLES (N) 5

NUMBER OF FUNCTIONS (M) 36

TOTAL NUMBER OF LINEAR CONSTRAINTS (L) 10

NUMBER OF EQUALITY CONSTRAINTS (LEQ) 0

STEP LENGTH (DX) 1.000E-01

ACCURACY (EPS) 1.000E-06

MAX NUMBER OF FUNCTION EVALUATIONS (MAXF) 100

NUMBER OF SUCCESSIVE ITERATIONS (KEQS) 3

WORKING SPACE (IW) 1500

PRINTOUT CONTROL (IPR) . . . . -10

STARTING POINT :

OBJECTIVE	FUNCTION	F 1	.679781
ERROR	FUNCTION	F 2	-1.460385
ERROR	FUNCTION	F 3	-1.865692
ERROR	FUNCTION	F 4	-1.732124
ERROR	FUNCTION	F 5	-.403045
ERROR	FUNCTION	F 6	-1.737342
ERROR	FUNCTION	F 7	-2.034335
ERROR	FUNCTION	F 8	-3.799789
ERROR	FUNCTION	F 9	-1.469856
ERROR	FUNCTION	F10	-2.074735
ERROR	FUNCTION	F11	-1.360047
ERROR	FUNCTION	F12	-1.083878
ERROR	FUNCTION	F13	-1.561488
ERROR	FUNCTION	F14	-1.828323
ERROR	FUNCTION	F15	-4.071949
ERROR	FUNCTION	F16	-1.739157
ERROR	FUNCTION	F17	-1.723920
ERROR	FUNCTION	F18	-1.804261
ERROR	FUNCTION	F19	-.640349
ERROR	FUNCTION	F20	-1.323313
ERROR	FUNCTION	F21	-1.693862
ERROR	FUNCTION	F22	-4.088049
ERROR	FUNCTION	F23	-.756041
ERROR	FUNCTION	F24	-2.735892
ERROR	FUNCTION	F25	-1.812340
ERROR	FUNCTION	F26	-.706418
ERROR	FUNCTION	F27	-1.222036
ERROR	FUNCTION	F28	-1.568948
ERROR	FUNCTION	F29	-3.972661
ERROR	FUNCTION	F30	-1.589204
ERROR	FUNCTION	F31	-1.940896
ERROR	FUNCTION	F32	-1.805939
ERROR	FUNCTION	F33	-1.164933

ERROR	FUNCTION	F34	-.876180
ERROR	FUNCTION	F35	-2.095615
ERROR	FUNCTION	F36	-3.737762

VARIABLES

1	1.020000000000E+00
2	1.040000000000E+00
3	1.040000000000E+00
4	-3.000000000000E-01
5	1.250000000000E+00

FUNCTION VALUES

1	6.797805740095E-01
2	-7.806044694628E-01
3	-1.185911848434E+00
4	-1.052343328220E+00
5	2.767351864767E-01
6	-1.057561800640E+00
7	-1.354554282091E+00
8	-3.120008413367E+00
9	-7.900754591102E-01
10	-1.394954702386E+00
11	-6.802660195274E-01
12	-4.040976270661E-01
13	-8.817075201286E-01
14	-1.148542649134E+00
15	-3.392168177741E+00
16	-1.059376491937E+00
17	-1.044139580464E+00
18	-1.124480790548E+00
19	3.943192478884E-02
20	-6.435324052426E-01
21	-1.014081349415E+00
22	-3.408268490756E+00
23	-7.626060986584E-02
24	-2.056111281736E+00
25	-1.132559654326E+00
26	-2.663739580692E-02
27	-5.422554377650E-01
28	-8.891675465525E-01
29	-3.292879951633E+00
30	-9.094236211321E-01
31	-1.261115782309E+00
32	-1.126158582588E+00

33	-4.851522403202E-01
34	-1.963995082995E-01
35	-1.415834616244E+00
36	-3.057981253372E+00

VERIFICATION OF PARTIAL DERIVATIVES PERFORMED.

SOLUTION

	VARIABLES		FUNCTION VALUES
1	1.100000000000E+00	1	2.244612319664E-01
2	1.100000000000E+00	2	-1.411457803368E+00
3	1.100000000000E+00	3	-1.648248579551E+00
4	1.446254599048E+00	4	-9.881627875253E-01
5	2.288546445214E+00	5	-1.405313785873E+00
		6	-1.236645712002E+00
		7	-2.705198935354E+00
		8	-5.973987748816E+00
		9	-1.029037309640E+00
		10	-2.239280258114E+00
		11	-1.506176833464E+00
		12	-1.214804312234E+00
		13	-1.439957170568E+00
		14	-2.441148497022E+00
		15	-6.357781770077E+00
		16	-8.441028699910E-01
		17	-2.419149272411E+00
		18	-1.634842576862E+00
		19	-1.025693735929E+00
		20	-1.374915190319E+00
		21	-2.649925634086E+00
		22	-6.145912428640E+00
		23	-1.480797457361E+00
		24	-1.685378233296E+00
		25	-1.660093562041E+00
		26	-1.125196264100E+00
		27	-1.301585789740E+00
		28	-2.673603372988E+00
		29	-6.040951998634E+00
		30	-8.946913708791E-01
		31	-2.371107587079E+00
		32	-1.501556889566E+00
		33	-1.335270319090E+00
		34	-1.076067259037E+00
		35	-2.373745667316E+00
		36	-6.388970805396E+00

TYPE OF SOLUTION (IFALL) 1

NUMBER OF FUNCTION EVALUATIONS 19

NUMBER OF SHIFTS TO STAGE-2 1

EXECUTION TIME (IN SECONDS) 18.480

OBJECTIVE	FUNCTION	F 1	.224461
ERROR	FUNCTION	F 2	-1.635919
ERROR	FUNCTION	F 3	-1.872710
ERROR	FUNCTION	F 4	-1.212624
ERROR	FUNCTION	F 5	-1.629775
ERROR	FUNCTION	F 6	-1.461107
ERROR	FUNCTION	F 7	-2.929660
ERROR	FUNCTION	F 8	-6.198449
ERROR	FUNCTION	F 9	-1.253499
ERROR	FUNCTION	F10	-2.463741
ERROR	FUNCTION	F11	-1.730638
ERROR	FUNCTION	F12	-1.439266
ERROR	FUNCTION	F13	-1.664418
ERROR	FUNCTION	F14	-2.665610
ERROR	FUNCTION	F15	-6.582243
ERROR	FUNCTION	F16	-1.068564
ERROR	FUNCTION	F17	-2.643611
ERROR	FUNCTION	F18	-1.859304
ERROR	FUNCTION	F19	-1.250155
ERROR	FUNCTION	F20	-1.599376
ERROR	FUNCTION	F21	-2.874387
ERROR	FUNCTION	F22	-6.370374
ERROR	FUNCTION	F23	-1.705259
ERROR	FUNCTION	F24	-1.909839
ERROR	FUNCTION	F25	-1.884555
ERROR	FUNCTION	F26	-1.349657
ERROR	FUNCTION	F27	-1.526047
ERROR	FUNCTION	F28	-2.898065
ERROR	FUNCTION	F29	-6.265413
ERROR	FUNCTION	F30	-1.119153
ERROR	FUNCTION	F31	-2.595569
ERROR	FUNCTION	F32	-1.726018
ERROR	FUNCTION	F33	-1.559732
ERROR	FUNCTION	F34	-1.300528
ERROR	FUNCTION	F35	-2.598207
ERROR	FUNCTION	F36	-6.613432

ACKNOWLEDGEMENTS

The authors would like to thank Dr. W.M. Zuberek, who critically examined this package, its description and computer representation.

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APPENDIX

LISTING OF THE XLF2 PACKAGE

Subroutine	Number of Lines (source text)	Number of Words (compiled code)	Listing from page
XLF2	395	1555	65
RST2	135	1141	71
YMATRX	126	356	73
RHSLD	59	341	75
STMEQ2	124	437	76
AMU	27	112	78
DERIV	223	644	78

```
      SUBROUTINE XLF2 (V,CV,AI,S,SL,DS,AK,DYM,KA,NB,YM,ICN,IRN,IW,IKEEP,
     1JVECT,LIRN,LICN,W,IRYM,ICYM,NYMD
C
      COMPLEX V(1),CV(1),AI(1),S(1),SL(1),DS(1),AK(1),DYM(1),ZC,W(1),CC,
     1YM(1)
      DIMENSION KA(1), ICN(1), IRN(1), IW(1), IKEEP(1), IRYM(1), ICYM(1)
     1, JVECT(1)
      COMMON /XLF2ID/ ITMAX,TOLV,ICHTL,IWRITE,IDER,ILOAD,ICALL,IADJ,IAPP
     1,APP,IAC,JAC,ZC,SHTLC,CC,IOUT,LNTAP
      COMMON /XLF2ME/ IFLAG
      COMMON /AMUFL/ IAMUF
      DATA ITMAX/10/,TOLV/1.0E-4/,ICHTL/0/,IWRITE/0/,IDER/0/,ILOAD/1/,IC
     1ALL/1/,IADJ/1/,IAPP/0/,APP/0.0/,SHTLC/0.0/,CC/(0.0,0.0)/,IOUT/6/,L
     2NTAP/3/
C
C     THIS IS THE MAIN SUBROUTINE OF THE PACKAGE XLF2.  IT GIVES THE
C
C     SOLUTION OF THE POWER SYSTEM LOAD FLOW PROBLEM REPRESENTED
C
C     IN THE CONSISTENT COMPLEX FORM AND SOLVES THE ADJOINT SYSTEM OF
C
C     EQUATIONS USING THE HARWELL PACKAGE ME28 (SEE DOCUMENT SOC-D2)
C
C     A DESCRIPTION OF ALL THE SUBROUTINES AND VARIABLES CALLED BY
C
C     THIS SUBROUTINE NOW FOLLOWS
C
C     **************************** SUBROUTINES ***************************
C
C     AMU       THIS SUBROUTINE WHICH IS SUPPLIED BY THE USER DETERMINES
C               THE DERIVATIVES OF THE REAL FUNCTION CONSIDERED BY THE
C               USER W.R.T. V AND CONJUGATE V
C
C     DERIV     THIS SUBROUTINE EVALUATES THE DERIVATIVE OF A REAL
C               FUNCTION W.R.T. ONE CONTROL VARIABLE AT A TIME OF THE
C               POWER SYSTEM NETWORK USING THE SOLUTION OF THE ADJOINT
C               SYSTEM OF EQUATIONS. THE USER CAN CALL THIS SUBROUTINE
C               TO DETERMINE DERIVATIVES IN HIS MAIN PROGRAM OR PROVIDE
C               HIS OWN SUBROUTINE  TO DETERMINE DESIRED DERIVATIVES
C               WITH THE HELP OF TABLE I OF SOC-257
C
C     ME28A     THIS SUBROUTINE DECOMPOSES AK INTO FACTORS USING
C               A PIVOTAL STRATEGY DESIGNED TO COMPROMISE BETWEEN
C               MAINTAINING SPARSITY AND CONTROLLING LOSS OF ACCURACY
C               THROUGH ROUND-OFF
C
C     ME28B     THIS SUBROUTINE FACTORIZES A NEW MATRIX AK OF THE
C               SAME PATTERN USING THE PIVOTAL SEQUENCE DETERMINED BY
C               AN EARLIER ENTRY TO ME28A
C
C     ME28C     THIS SUBROUTINE USES THE FACTORS PRODUCED BY ME28A OR
C               ME28B TO SOLVE AK * X = DS OR TRANSPOSE(AK) * X = DS
C
C     RHSLD     THIS SUBROUTINE CALCULATES VECTOR DS FOR LOAD FLOW
C               EQUATIONS AND BUS CURRENT VECTOR AI
C
C     RST2      THIS SUBROUTINE WRITES THE FINAL LOAD FLOW SOLUTION
C
C     STMEQ2    THIS SUBROUTINE PREPARES THE LHS OF THE SYSTEM
C               EQUATIONS IN THE COMPLEX CONSISTENT FORM (SEE EQUATION
C               (16) OF SOC-242)
C
C     YMATRX    THIS SUBROUTINE DETERMINES THE ADMITTANCE MATRIX OF
C               THE GIVEN POWER NETWORK AND STORES IT IN THE VECTORS YM,
C               ICYM, IRYM AND DYM
```

```
C
C     ************************* INTEGER VARIABLES *************************
C
C     IAC,JAC   (IAC,JAC) IS THE TRANSMISSION LINE WHOSE PARAMETERS
C               HAVE BEEN ALTERED BY THE USER
C
C     IADJ      = 0 WHEN RHS OF THE ADJOINT SYSTEM OF EQUATIONS HAS
C                   BEEN CHANGED. THIS VALUE IS USED WHEN DERIVATIVES
C                   OF TWO OR MORE FUNCTIONS ARE TO BE EVALUATED
C                   AT THE SAME OPERATING POINT
C               = 1 FRESH CALCULATION OF THE ADJOINT SYSTEM OF EQUATIONS
C                   IS REQUIRED. THIS VALUE IS USED WHEN DERIVATIVES
C                   AT A NEW OPERATING POINT ARE REQUIRED
C
C     IAMUF     = -1 INDICATES THAT THE USER HAS NOT SUPPLIED SUBROUTINE
C                    AMU
C
C     IAPP      = 1 IF THE COEFFICIENT MATRIX OF THE SYSTEM EQUATIONS
C                   ARE NOT TO BE UPDATED WHEN CORRECTION VOLTAGES < APP
C
C     ICALL     = 1 FOR THE FIRST CALL OF SUBROUTINE XLF2 IN THE USER'S
C                   MAIN PROGRAM. SUBROUTINE YMATRX IS CALLED TO
C                   CALCULATE THE Y-MATRIX OF THE POWER NETWORK AND
C                   SUBROUTINE ME28A OF THE PACKAGE ME28 IS CALLED TO
C                   DECOMPOSE THE COEFFICIENT MATRIX OF THE SYSTEM OF
C                   LINEARIZED COMPLEX EQUATIONS
C               > 1 FOR SUBSEQUENT CALLS. WITH THIS VALUE THE PREVIOUS
C                   DECOMPOSITION OF THE COEFFICIENT MATRIX IS REUSED,
C                   SUBROUTINE YMATRX IS NOT CALLED
C               < 1 FOR THE FIRST CALL IN THE USER'S MAIN PROGRAM WHEN
C                   THE Y-MATRIX IS CALCULATED EARLIER IN THE USER'S
C                   MAIN PROGRAM AND STORED IN THE VECTORS IRYM, ICYM,
C                   YM AND DYM. SUBROUTINE ME28A IS CALLED BUT
C                   SUBROUTINE YMATRX IS NOT CALLED
C
C     ICHTL     = 0 IF THERE IS NO ALTERATION IN THE LINE DATA
C                   FILE REQUIRED BY THE USER
C               = 1 IF PARAMETERS OF ONE LINE HAVE BEEN ALTERED
C               = 2 IF ONE LINE IS TO BE REMOVED FOR CONTINGENCY
C                   ANALYSIS
C
C     ICN       ARRAY OF LENGTH LICN. ON ENTRY ICN(K) MUST
C               HOLD THE COLUMN INDEX OF THE NON-ZERO ELEMENT STORED IN
C               AK(K), K = 1,...,IE. ON OUTPUT, IT HOLDS THE COLUMN
C               INDICES OF THE FACTORS OF THE MATRIX AK. THESE ENTRIES
C               ARE PRESERVED BETWEEN A CALL TO SUBROUTINE ME28A AND
C               SUBSEQUENT CALLS TO ME28B OR ME28C. ICN MUST NOT BE
C               ALTERED BY THE USER IN SUBSEQUENT CALLS OF XLF2
C
C     ICYM      ARRAY OF LENGTH NYM HOLDS THE COLUMN INDEX OF THE
C               NON-ZERO ELEMENT STORED IN YM(K), K=1,...,NYM
C
C     IDER      = 0 IF DERIVATIVES OF THE FUNCTION ARE NOT REQUIRED
C               = M IF DERIVATIVES OF THE MTH FUNCTION ARE REQUIRED
C
C     IE        TOTAL NUMBER OF NON-ZERO ELEMENTS IN THE COEFFICIENT
C               MATRIX OF EQUATION (16) OF SOC-242
C
C     IFLAG     INTEGER VARIABLE. ON EXIT FROM ME28A, A VALUE OF ZERO
C               INDICATES THAT THE SUBROUTINE HAS PERFORMED SUCCESSFULLY.
C               FOR NON-ZERO VALUES, SEE SECTION II
C
C     IKEEP     ARRAY OF LENGTH 5*N2. IT NEED NEVER BE REFERENCED
C               BY THE USER AND IS PRESERVED BETWEEN CALLS TO SUBROUTINE
C               ME28A AND ME28B OR ME28C. IKEEP MUST BE PRESERVED BY THE
```

```
C               USER IN SUBSEQUENT CALLS OF XLF2
C
C     ILOAD     = 0 IF THE LOAD FLOW SOLUTION IS NOT TO BE DETERMINED
C               # 0 IF THE LOAD FLOW SOLUTION IS TO BE DETERMINED
C
C     IOUT      THE TAPE NUMBER FOR OUTPUT FILE
C
C     IRN       ARRAY OF LENGTH LIRN. ON ENTRY TO ME28A,
C               IRN(K) MUST HOLD THE ROW INDEX OF THE NON-ZERO STORED
C               IN AK(K), K = 1,...,IE. IT IS USED AS WORKSPACE BY
C               ME28A, IS ALTERED BY ME28A, AND NEED NOT BE PRESERVED
C               FOR ANY SUBSEQUENT CALLS
C
C     IRYM      ARRAY OF LENGTH NYM HOLDS THE ROW INDEX OF THE NON-ZERO
C               STORED IN YM(K),K=1,...,NYM
C
C     IT        CURRENT ITERATION NUMBER
C
C     ITMAX     MAXIMUM NUMBER OF ITERATIONS AFTER WHICH THE PROGRAM
C               WILL STOP
C
C     IW        ARRAY OF LENGTH 10*NB. IT IS USED AS WORKSPACE
C               BY THE SUBROUTINES ME28A AND ME28B
C
C     IWRITE    = 0 PRINTS THE FINAL LOAD FLOW SOLUTION ONLY
C               = 1 ALSO PRINTS INTERMEDIATE RESULTS
C               = 2 SUPRESSES ALL PRINTOUTS
C
C     JVECT     ARRAY OF LENGTH IE. JVECT(K) MUST CONTAIN THE ROW
C               INDEX OF THE NON-ZERO STORED IN AK(K), K = 1,...,IE
C
C     KA        NB DIMENSIONAL ARRAY IDENTIFYING THE TYPE OF BUS
C               KA(I)= 0 IF THE ITH BUS IS A LOAD BUS
C                    = 1 IF THE ITH BUS IS A GENERATOR BUS
C                    = 2 IF THE ITH BUS IS A SLACK BUS
C
C     LICN      INTEGER VARIABLE WHICH MUST BE SET BY THE USER
C               TO THE LENGTH OF ARRAYS AK AND ICN. SINCE THE
C               DECOMPOSITION IS RETURNED IN AK AND ICN, LICN SHOULD
C               BE LARGE ENOUGH TO ACCOMMODATE THIS AND SHOULD
C               ORDINARILY BE 2 TO 4 TIMES AS LARGE AS IE.
C               RESTRICTION: LICN > IE
C
C     LIRN      INTEGER VARIABLE WHICH MUST BE SET BY THE USER
C               TO THE LENGTH OF ARRAY IRN. LIRN NEED NOT TO BE VERY
C               MUCH GREATER THAN IE. RESTRICTION: LIRN > IE
C
C     LNTAP     THE TAPE NUMBER FOR THE LINE DATA FILE
C
C     N         = NB-1
C
C     N2        = 2*NB
C
C     NB        TOTAL NUMBER OF BUSES
C
C     NYM       NUMBER OF THE NON-ZERO OFF DIAGONAL ELEMENTS OF THE
C               ADMITTANCE MATRIX
C
C     ************************** REAL VARIABLES **************************
C
C     APP       WHEN CORRECTION VOLTAGES BECOMES < APP, THE COEFFICIENT
C               MATRIX OF THE SYSTEM EQUATIONS WILL NOT BE UPDATED AND
C               THE CURRENT COEFFICIENT MATRIX IS REUSED
C
C     SHTLC     ALTERED VALUE OF HALF SHUNT SUSCEPTANCE OF THE
```

```
C               TRANSMISSION LINE (IAC,JAC)
C
C     TOLV      TOLERANCE OVER BUS VOLTAGES TO THE ACCURACY THE
C               FINAL SOLUTION IS REQUIRED
C
C     ************************ COMPLEX VARIABLES ***********************
C
C     AI        NB DIMENSIONAL ARRAY OF BUS CURRENTS
C
C     AK        LICN DIMENSIONAL ARRAY AND AK(J), J=1,...,IE HOLDS
C               THE NON-ZERO ELEMENT OF THE COEFFICIENT MATRIX. ON
C               EXIT FROM ME28A, AK HOLDS THE NON-ZERO ELEMENTS IN
C               THE FACTORS OF THE COEFFICIENT MATRIX. IT IS
C               PRESERVED BETWEEN CALLS TO SUBROUTINES ME28A, ME28B
C               ME28C. IT SHOULD BE PRESERVED IN THE SUBSEQUENT CALLS
C               OF XLF2
C
C     CC        ALTERED TRANSFORMER TAP IN TRANSMISSION LINE (IAC,JAC)
C
C     CPX,CPY,CPZ  COMPLEX DUMMY VARIABLES IN ALL SUBROUTINES
C
C     CV        NB DIMENSIONAL ARRAY OF THE CONJUGATE OF V
C
C     DYM       NB DIMENSIONAL ARRAY OF DIAGONAL ELEMENTS OF THE
C               ADMITTANCE MATRIX
C
C     DS        N2 DIMENSIONAL ARRAY WHICH REPRESENTS RIGHT HAND SIDE
C               AS WELL AS CORRECTION VOLTAGES IN DETERMINING THE LOAD
C               FLOW SOLUTION AND RIGHT HAND SIDE VECTOR OF THE ADJOINT
C               SYSTEM OF EQUATIONS (SEE EQUATION (75) OF SOC-257) AS
C               WELL AS THE ADJOINT VOLTAGES IN DETERMINING THE SOLUTION
C               OF THE ADJOINT SYSTEM OF EQUATIONS
C
C     S         N DIMENSIONAL ARRAY OF LOAD BUS POWERS, AND GENERATOR
C               BUS ACTIVE POWER AND MODULUS OF VOLTAGE, WHICH IS
C               REPRESENTED AS P +J/V /
C                                G    G
C
C     SL        NB DIMENSIONAL ARRAY OF THE STATIC BUS LOADS
C
C     V         NB DIMENSIONAL ARRAY OF BUS VOLTAGES
C
C     W         ARRAY OF LENGTH N2 WHICH IS USED AS WORKSPACE
C
C
C     YM        NYM DIMENSIONAL ARRAY WHICH STORES THE NON-ZERO OFF
C               DIAGONAL ELEMENTS OF THE ADMITTANCE MATRIX
C
C     ZC        ALTERED IMPEDANCE OF TRANSMISSION LINE (IAC,JAC)
C
C     *****************************************************************
C
      CALL SECOND (T1)
      N=NB-1
      IF (APP.LT.TOLV) APP=TOLV
      U=0.1
      IT=0
      ITA=0
C
C     CALCULATION OF THE VECTOR CV
C
      DO 10 I=1,N
      CV(I)=CONJG(V(I))
      IF (KA(I).EQ.1) GO TO 10
      S(I)=CONJG(S(I))
```

```
10     CONTINUE                                                         XLF2610
       CV(NB)=CONJG(V(NB))                                              XLF2620
       N2=NB+NB                                                         XLF2630
       IF (IDER.EQ.0) N2=N+N                                            XLF2640
C                                                                       XLF2650
C      DETERMINATION OF THE LOAD FLOW SOLUTION                          XLF2660
C                                                                       XLF2670
       IF (ICALL.NE.1) GO TO 20                                         XLF2680
       CALL YMATRX (YM,SL,DYM,ICYM,IRYM,NB,NYM,ICHTL,IAC,JAC,ZC,SHTLC,CC,XLF2690
      1LNTAP)                                                           XLF2700
20     IF (ILOAD.EQ.0) GO TO 150                                        XLF2710
30     IT=IT+1                                                          XLF2720
       IF (IAPP.EQ.1) ITA=ITA+1                                         XLF2730
       IF (IWRITE.NE.1) GO TO 40                                        XLF2740
       WRITE (IOUT,220) IT                                              XLF2750
40     CALL RHSLD (V,CV,AI,S,DS,KA,NB,N,IWRITE,ILOAD,IDER,YM,IRYM,ICYM,DYXLF2760
      1M,NYM,IOUT)                                                      XLF2770
       IF (IAPP.EQ.1) GO TO 70                                          XLF2780
       IF (IT.GT.1) GO TO 50                                            XLF2790
       IF (ICALL.GT.1) GO TO 50                                         XLF2800
C                                                                       XLF2810
C      PRERARATION OF THE SYSTEM EQUATIONS                              XLF2820
C                                                                       XLF2830
       CALL STMEQ2 (V,CV,AI,AK,KA,NB,N,ICN,IRN,IE,IDER,ILOAD,YM,DYM,ICYM,XLF2840
      1IRYM,NYM,IOUT)                                                   XLF2850
C                                                                       XLF2860
C      DECOMPOSITION OF THE COEFFICIENT MATRIX AK FOR THE FIRST         XLF2870
C      ITERATION                                                        XLF2880
C                                                                       XLF2890
       CALL ME28A (N2,IE,AK,LICN,IRN,LIRN,ICN,U,IKEEP,IW,IFLAG)         XLF2900
       IF (IFLAG.LT.0) WRITE (IOUT,200) IFLAG                           XLF2910
       GO TO 60                                                         XLF2920
50     CALL STMEQ2 (V,CV,AI,AK,KA,NB,N,JVECT,IRN,IE,IDER,ILOAD,YM,DYM,ICYXLF2930
      1M,IRYM,NYM,IOUT)                                                 XLF2940
C                                                                       XLF2950
C      DECOMPOSITION OF THE COEFFICIENT MATRIX AK FOR THE CONSECUTIVE   XLF2960
C      ITERATIONS                                                       XLF2970
C                                                                       XLF2980
       CALL ME28B (N2,IE,AK,LICN,IRN,JVECT,ICN,IKEEP,IW,W,IFLAG)        XLF2990
       IF (IFLAG.LT.0) WRITE (IOUT,200) IFLAG                           XLF3000
60     IF (IFLAG.LT.0) GO TO 180                                        XLF3010
C                                                                       XLF3020
C      SOLUTION OF THE LINEARIZED POWER FLOW EQUATIONS                  XLF3030
C                                                                       XLF3040
70     CALL ME28C (N2,AK,LICN,ICN,IKEEP,DS,W,1)                         XLF3050
C                                                                       XLF3060
C      UPDATING OF VECTORS V AND CV                                     XLF3070
C                                                                       XLF3080
       DO 80 I=1,N                                                      XLF3090
       V(I)=V(I)+DS(I)                                                  XLF3100
       CV(I)=CONJG(V(I))                                                XLF3110
80     CONTINUE                                                         XLF3120
       IF (IWRITE.NE.1) GO TO 100                                       XLF3130
       WRITE (IOUT,240)                                                 XLF3140
       WRITE (IOUT,250)                                                 XLF3150
       DO 90 I=1,N                                                      XLF3160
       WRITE (IOUT,260) I,V(I),DS(I)                                    XLF3170
90     CONTINUE                                                         XLF3180
       WRITE (IOUT,280)                                                 XLF3190
100    IF (IT.EQ.ITMAX) GO TO 140                                       XLF3200
C                                                                       XLF3210
C      CHECKING THE ACCURACY OF THE SOLUTION                            XLF3220
C                                                                       XLF3230
       IF (IAPP.EQ.1) GO TO 120                                         XLF3240
       DO 110 I=1,N                                                     XLF3250
```

```
      ABSDS=CABS(DS(I))
      IF (ABSDS.GT.APP) GO TO 30
110   CONTINUE
      IAPP=1
      IF (APP.GT.TOLV) GO TO 30
      GO TO 140
120   DO 130 I=1,N
      ABSDS=CABS(DS(I))
      IF (ABSDS.GT.TOLV) GO TO 30
130   CONTINUE
140   CALL RST2 (V,CV,S,DS,AI,KA,NB,N,YM,DYM,ICYM,IRYM,NYM,IWRITE,IOUT)
      IF (IWRITE.EQ.2) GO TO 150
      WRITE (IOUT,230) IT
      WRITE (IOUT,210) ITA
C
C     DETERMINATION OF THE SOLUTION OF ADJOINT SYSTEM OF EQUATIONS
C
150   IF (IDER.EQ.0) GO TO 180
      IF (IADJ.EQ.0) GO TO 170
      IF (ILOAD.NE.0) GO TO 160
C
C     PREPARATION OF THE LHS OF SYSTEM EQUATIONS
C
      CALL RHSLD (V,CV,AI,S,DS,KA,NB,N,IWRITE,ILOAD,IDER,YM,IRYM,ICYM,DY
     1M,NYM,IOUT)
      CALL STMEQ2 (V,CV,AI,AK,KA,NB,N,ICN,IRN,IE,IDER,ILOAD,YM,DYM,ICYM,
     1IRYM,NYM,IOUT)
C
C     DECOMPOSITION OF THE COEFFICIENT MATRIX
C
      CALL ME28A (N2,IE,AK,LICN,IRN,LIRN,ICN,U,IKEEP,IW,IFLAG)
      GO TO 170
160   CALL STMEQ2 (V,CV,AI,AK,KA,NB,N,JVECT,IRN,IE,IDER,ILOAD,YM,DYM,ICY
     1M,IRYM,NYM,IOUT)
      CALL ME28B (N2,IE,AK,LICN,IRN,JVECT,ICN,IKEEP,IW,W,IFLAG)
C
C     CALCULATION OF THE RHS OF THE ADJOINT EQUATIONS
C
170   IAMUF=0
      CALL AMU (V,CV,AI,S,NB,DS,IDER,YM,DYM,ICYM,IRYM,NYM,KA,IOUT)
      IF (IAMUF.EQ.-1) RETURN
C
C     DETERMINATION OF THE SOLUTION OF THE ADJOINT SYSTEM
C
      CALL ME28C (N2,AK,LICN,ICN,IKEEP,DS,W,0)
180   DO 190 I=1,N
      IF (KA(I).EQ.1) GO TO 190
      S(I)=CONJG(S(I))
190   CONTINUE
      IF (IWRITE.EQ.2) RETURN
      CALL SECOND (T2)
      TIME=T2-T1
      WRITE (IOUT,270) TIME
      RETURN
C
C
200   FORMAT (/,* IFLAG = *,I2)
210   FORMAT (1H0,* NUMBER OF ITERATIONS PERFORMED WITHOUT UPDATING*,/,*
     1                             COEFFICIENT MATRIX = *,I2,/)
220   FORMAT (1H1,* ITERATION NO.  *,I2,* OF XLF2 *,/)
230   FORMAT (1H0,* TOTAL NUMBER OF ITERATIONS TAKEN BY XLF2 = *,I2,/)
240   FORMAT (/,*  BUS NO.              VOLTAGE                  VOLTAGE CORR
     1ECTION VECTOR   *,/)
250   FORMAT (*                REAL            IMAGINARY             REAL
     1  IMAGINARY  *,/)
```

```
260   FORMAT (1X,I5,2X,2E14.5,4X,2E14.5)
270   FORMAT (1X,* TOTAL EXECUTION TIME TAKEN BY XLF2 =*,F7.3,* SECONDS
     1*)
280   FORMAT (/,1X,68(*-*),/)
      END
C
C
      SUBROUTINE RST2 (V,CV,S,DS,AI,KA,NB,N,YM,DYM,ICYM,IRYM,NYM,IWRITE,
     1IOUT)
C
      COMPLEX V(1),CV(1),AI(1),S(1),DS(1),YM(1),DYM(1),CPX,CPY,CPZ
      DIMENSION ICYM(1), IRYM(1), KA(1)
C
C     THIS SUBROUTINE WRITES FINAL RESULTS
C
C     ************************************************************************
C
C     CALCULATION OF BUS CURRENTS
C
      DO 10 I=1,NB
      AI(I)=DYM(I)*V(I)
10    CONTINUE
      DO 20 I=1,NYM
      AI(IRYM(I))=AI(IRYM(I))+YM(I)*V(ICYM(I))
20    CONTINUE
C
C     WRITING OF FINAL BUS CURRENTS AND MISMATCHES
C
      IF (IWRITE.NE.1) GO TO 50
      WRITE (IOUT,190)
      WRITE (IOUT,390)
      WRITE (IOUT,300)
      WRITE (IOUT,310)
      DO 40 I=1,N
      IF (KA(I).EQ.1) GO TO 30
      DS(I)=S(I)-CV(I)*AI(I)
      GO TO 40
30    DS(I)=S(I)-CMPLX(REAL(CV(I)*AI(I)),CABS(V(I)))
40    WRITE (IOUT,200) I,AI(I),DS(I)
      WRITE (IOUT,320) NB,AI(NB)
      WRITE (IOUT,390)
C
C     WRITING OF FINAL LOAD BUS VOLTAGES
C
50    IF (IWRITE.EQ.2) RETURN
      WRITE (IOUT,290)
      WRITE (IOUT,380)
      WRITE (IOUT,210) NB
      WRITE (IOUT,380)
      WRITE (IOUT,220)
      I=1
60    IF (I.GT.N) GO TO 160
      IF (KA(I).EQ.0) GO TO 70
      I=I+1
      GO TO 60
70    J=I+1
80    IF (J.GT.N) GO TO 140
      IF (KA(J).EQ.0) GO TO 90
      J=J+1
      GO TO 80
90    IF (AIMAG(V(I)).LT.0.0) GO TO 100
      IF (AIMAG(V(J)).LT.0.0) GO TO 120
      WRITE (IOUT,230) I,V(I),J,V(J)
      GO TO 130
100   IF (AIMAG(V(J)).LT.0.0) GO TO 110
```

```
      P=REAL(V(I))
      Q=-AIMAG(V(I))
      WRITE (IOUT,330) I,P,Q,J,V(J)
      GO TO 130
110   P=REAL(V(I))
      Q=-AIMAG(V(I))
      P2=REAL(V(J))
      Q2=-AIMAG(V(J))
      WRITE (IOUT,340) I,P,Q,J,P2,Q2
      GO TO 130
120   P2=REAL(V(J))
      Q2=-AIMAG(V(J))
      WRITE (IOUT,350) I,V(I),J,P2,Q2
130   I=J+1
      GO TO 60
140   IF (AIMAG(V(I)).LT.0.0) GO TO 150
      WRITE (IOUT,240) I,V(I)
      GO TO 160
150   P=REAL(V(I))
      Q=-AIMAG(V(I))
      WRITE (IOUT,360) I,P,Q
C
C     WRITING OF GENERATOR BUS REACTIVE POWERS AND VOLTAGES
C
160   WRITE (IOUT,250)
      DO 180 I=1,N
      IF (KA(I).NE.1) GO TO 180
      QG=-AIMAG(CV(I)*AI(I))
      IF (AIMAG(V(I)).LT.0.0) GO TO 170
      WRITE (IOUT,260) I,QG,I,V(I)
      GO TO 180
170   P=REAL(V(I))
      Q=-AIMAG(V(I))
      WRITE (IOUT,370) I,QG,I,P,Q
180   CONTINUE
C
C     WRITING OF SLACK BUS POWER
C
      CPX=CV(NB)*AI(NB)
      P=REAL(CPX)
      Q=-AIMAG(CPX)
      WRITE (IOUT,270)
      WRITE (IOUT,280) NB,P,NB,Q
      WRITE (IOUT,380)
      RETURN
C
190   FORMAT (1H1,* FINAL BUS CURRENTS AND MISMATCHES*,/)
200   FORMAT (I6,2X,2E14.5,4X,2E14.5)
210   FORMAT (*             LOAD FLOW SOLUTION OF*,I3,*-BUS POWER SYSTEM
     1*)
220   FORMAT (* LOAD BUSES*,/)
230   FORMAT (1X,*V(*,I3,*) =*,F8.5,* + J*,F7.5,6X,*V(*,I3,*) =*,F8.5,*
     1+ J*,F7.5,/)
240   FORMAT (1X,*V(*,I3,*) =*,F8.5,* + J*,F7.5,/)
250   FORMAT (* GENERATOR BUSES*,/)
260   FORMAT (1X,*Q(*,I3,*) =*,F8.5,17X,*V(*,I3,*) =*,F8.5,* + J*,F7.5,/
     1)
270   FORMAT (* SLACK BUS*,/)
280   FORMAT (1X,*P(*,I3,*) =*,F8.5,17X,*Q(*,I3,*) =*,F8.5,/)
290   FORMAT (*1*)
300   FORMAT (*  BUS NO.        BUS CURRENT(AI)                  MISMATCHE
     1S(DS)        */)
310   FORMAT (*              REAL          IMAGINARY            REAL
     1  IMAGINARY  *,/)
320   FORMAT (I6,2X,2E14.5,/)
```

```
330   FORMAT (1X,*V(*,I3,*) =*,F8.5,* - J*,F7.5,6X,*V(*,I3,*) =*,F8.5,*
     1+ J*,F7.5,/)
340   FORMAT (1X,*V(*,I3,*) =*,F8.5,* - J*,F7.5,6X,*V(*,I3,*) =*,F8.5,*
     1- J*,F7.5,/)
350   FORMAT (1X,*V(*,I3,*) =*,F8.5,* + J*,F7.5,6X,*V(*,I3,*) =*,F8.5,*
     1- J*,F7.5,/)
360   FORMAT (1X,*V(*,I3,*) =*,F8.5,* - J*,F7.5,/)
370   FORMAT (1X,*Q(*,I3,*) =*,F8.5,17X,*V(*,I3,*) =*,F8.5,* - J*,F7.5,/
     1)
380   FORMAT (/,1X,61(*-*),/)
390   FORMAT (1X,68(*-*),/)
      END
C
C
      SUBROUTINE YMATRX (YM,SL,DYM,ICYM,IRYM,NB,NYM,ICHTL,IAC,JAC,ZC,SHT
     1LC,CC,LNTAP)
C
      COMPLEX YM(1),DYM(1),Y,SL(1),CPX,CPY,CPZ,C,YL,ZC,CC
      DIMENSION ICYM(1), IRYM(1)
C
C     THIS SUBROUTINE DETERMINES THE Y-MATRIX OF A GIVEN POWER
C
C     NETWORK AND STORES IN THE VECTORS YM, ICYM, IRYM AND DYM.
C
C     THE LINE DATA FILE IS PUT ON TAPE LNTAP
C
C     A DESCRIPTION OF ALL THE NEW VARIABLES USED IN THIS SUBROUTINE
C
C     NOW FOLLOWS
C
C     ************************* INTEGER VARIABLES ************************
C
C     IA,JA     (IA,JA) REPRESENTS A TRANSMISSION LINE CONNECTING
C               BUSES IA AND JA
C
C     ICODE     CODE TO IDENTIFY DATA CARD
C               = 4 FOR THE TRANSMISSION LINE WITHOUT TRANSFORMER
C               = 7 FOR THE TRANSMISSION LINE HAVING TRANSFORMER
C
C     ************************** REAL VARIABLES *************************
C
C     A1        IDENTIFIES THE CIRCUIT NUMBER IF ICODE = 4
C               IDENTIFIES THE TYPE OF TRANSFORMATION RATIO IF
C               ICODE = 7
C               = 0 FOR FIXED TAPE
C               = 1 FOR REAL TRANSFORMATION RATIO
C               = 2 FOR COMPLEX TRANSFORMATION RATIO
C
C     A2        DENOTES BRANCH TYPE IF ICODE = 4
C               SERIES RESISTANCE OF THE LINE IF ICODE = 7
C
C     A3        SERIES RESISTANCE OF THE LINE IF ICODE = 4
C               SERIES REACTANCE OF THE LINE IF ICODE = 7
C
C     A4        SERIES REACTANCE OF THE LINE IF ICODE = 4
C               REAL PART OF THE TRANSFORMATION RATIO IF ICODE = 7
C
C     A5        HALF SHUNT SUSCEPTANCE OF THE LINE IF ICODE = 4
C               IMAGINARY PART OF THE TRANSFORMATION RATIO IF ICODE = 7
C
C     *******************************************************************
C
C     INITIALIZATION OF VECTOR DYM
C
      DO 10 I=1,NB
```

```
      DYM(I)=(0.0,0.0)
10    CONTINUE
      NYM=0
C
C     READING OF LINE DATA
C
      REWIND LNTAP
20    READ (LNTAP,*) ICODE,IA,JA,A1,A2,A3,A4,A5
      IF (EOF(LNTAP).NE.0) GO TO 80
C
C     CHECK WHETHER LINE DATA IS TEMPORARILY ALTERED
C
      IF (ICHTL.EQ.0) GO TO 40
      IF (IA.NE.IAC) GO TO 40
      IF (JA.NE.JAC) GO TO 40
      IF (ICHTL.NE.1) GO TO 30
      Y=1.0/ZC
      YL=CMPLX(0.0,SHTLC)
      C=CC
      IF (C.EQ.(0.0,0.0)) GO TO 50
      GO TO 70
30    NYM=NYM+1
      YM(NYM)=(0.0,0.0)
      ICYM(NYM)=JA
      IRYM(NYM)=IA
      NYM=NYM+1
      YM(NYM)=(0.0,0.0)
      ICYM(NYM)=IA
      IRYM(NYM)=JA
      GO TO 20
40    IF (ICODE.EQ.7) GO TO 60
C
C     DETERMINATION OF THE ELEMENTS FOR Y-MATRIX FROM THE LINE
C     PARAMETERS WHEN THE LINE DOES NOT CONTAIN A TRANSFORMER
C
      CPX=CMPLX(A3,A4)
      Y=1.0/CPX
      YL=CMPLX(0.0,A5)
50    CPX=Y+YL
      NYM=NYM+1
      YM(NYM)=-Y
      ICYM(NYM)=JA
      IRYM(NYM)=IA
      NYM=NYM+1
      YM(NYM)=-Y
      ICYM(NYM)=IA
      IRYM(NYM)=JA
      DYM(IA)=DYM(IA)+CPX
      DYM(JA)=DYM(JA)+CPX
      GO TO 20
C
C     DETERMINATION OF THE ELEMENTS FOR Y-MATRIX FROM THE LINE
C     PARAMETERS WHEN THE LINE CONTAINS A TRANSFORMER
C
60    Y=1.0/CMPLX(A2,A3)
      C=CMPLX(A4,A5)
70    CPX=1.0/C
      CPZ=Y*CONJG(CPX)
      CPY=CPZ*CPX
      NYM=NYM+1
      YM(NYM)=-CPZ
      ICYM(NYM)=JA
      IRYM(NYM)=IA
      DYM(IA)=DYM(IA)+CPY
      NYM=NYM+1
```

```
      YM(NYM)=-Y*CPX
      ICYM(NYM)=IA
      IRYM(NYM)=JA
      DYM(JA)=DYM(JA)+Y
      GO TO 20
80    DO 90 I=1,NB
      DYM(I)=DYM(I)+SL(I)
90    CONTINUE
      RETURN
      END
C
C
      SUBROUTINE RHSLD (V,CV,AI,S,DS,KA,NB,N,IWRITE,ILOAD,IDER,YM,IRYM,I
     1CYM,DYM,NYM,IOUT)
C
      COMPLEX V(1),CV(1),AI(1),S(1),DS(1),YM(1),DYM(1),CPX,CPY
      DIMENSION KA(1), IRYM(1), ICYM(1)
C
C     THIS SUBROUTINE DETERMINES VECTOR DS FOR THE LOAD FLOW EQUATIONS
C
C     AND BUS CURRENT VECTOR AI
C
C     ******************************************************************
C
C     CALCULATION OF BUS CURRENTS
C
      DO 10 I=1,NB
      AI(I)=DYM(I)*V(I)
10    CONTINUE
      DO 20 I=1,NYM
      AI(IRYM(I))=AI(IRYM(I))+YM(I)*V(ICYM(I))
20    CONTINUE
      IF (ILOAD.EQ.0) RETURN
C
C     CALCULATION OF DS(I) FOR THE LOAD BUSES
C
      DO 40 I=1,N
      IF (KA(I).EQ.1) GO TO 30
      DS(I)=S(I)-CV(I)*AI(I)
      GO TO 40
C
C     CALCULATION OF DS(I) FOR GENERATOR BUSES
C
30    ABSV=CABS(V(I))
      DS(I)=S(I)-CMPLX(REAL(CV(I)*AI(I)),ABSV)
40    CONTINUE
      DS(NB)=(0.0,0.0)
      IF (IDER.NE.0) N=NB
      DO 50 I=1,N
      DS(I+N)=CONJG(DS(I))
50    CONTINUE
      N=NB-1
C
C     WRITING OF VECTORS AI AND DS
C
      IF (IWRITE.NE.1) RETURN
      WRITE (IOUT,100)
      WRITE (IOUT,70)
      WRITE (IOUT,90)
      DO 60 I=1,N
      WRITE (IOUT,80) I,AI(I),DS(I)
60    CONTINUE
      WRITE (IOUT,80) NB,AI(NB)
      WRITE (IOUT,100)
      RETURN
```

```
C
70     FORMAT (*  BUS NO.*,7X,*BUS CURRENT(AI)*,17X,*MISMACHES(DS)*,/)
80     FORMAT (I6,2X,2E14.5,4X,2E14.5)
90     FORMAT (15X,*REAL*,8X,*IMAGINARY*,10X,*REAL*,9X,*IMAGINARY*,/)
100    FORMAT (/,1X,68(*-*),/)
       END
C
C
       SUBROUTINE STMEQ2 (V,CV,AI,AK,KA,NB,N,ICN,IRN,IE,IDER,ILOAD,YM,DYM
      1,ICYM,IRYM,NYM,IOUT)
C
       COMPLEX V(1),CV(1),AI(1),AK(1),YM(1),DYM(1),CPX,CPY
       DIMENSION KA(1), ICN(1), IRN(1), IRYM(1), ICYM(1)
C
C      THIS SUBROUTINE PREPARES THE LHS OF SYSTEM EQUATIONS IN THE
C
C      COMPLEX CONSISTENT FORM (SEE EQUATION (16) OF SOC-242)
C
C      *******************************************************************
C
       IE=0
       IF (IDER.NE.0) N=NB
                                                                S      S*
C
C      CALCULATION OF THE OFF DIAGONAL ELEMENTS OF MATRICES K  AND K
C      IN THE EQUATION (16) OF SOC-242 FOR LOAD BUSES
C
       DO 30 I=1,NYM
       IROW=IRYM(I)
       ICOL=ICYM(I)
       IF (IROW.EQ.NB) GO TO 30
       IF (IDER.NE.0) GO TO 10
       IF (ICOL.GT.N) GO TO 30
10     IF (KA(IROW).EQ.1) GO TO 20
       IE=IE+1
       AK(IE)=YM(I)*CV(IROW)
       IRN(IE)=IROW
       ICN(IE)=ICOL
       IE=IE+1
       AK(IE)=CONJG(AK(IE-1))
       IRN(IE)=IROW+N
       ICN(IE)=ICOL+N
       GO TO 30
C                                                                 -
C                                                              S   S
C      CALCULATION OF THE OFF DIAGONAL ELEMENTS OF MATRICES K , K
C                 -
C       S*        S*
C      K   AND K   IN THE EQUATION (16) OF SOC-242 FOR GENERATOR BUSES
C
20     IE=IE+1
       CPX=0.5*CV(IROW)*YM(I)
       AK(IE)=CPX
       IRN(IE)=IROW
       ICN(IE)=ICOL
       IE=IE+1
       AK(IE)=CONJG(AK(IE-1))
       IRN(IE)=IROW+N
       ICN(IE)=ICOL+N
       IE=IE+1
       AK(IE)=CONJG(CPX)
       IRN(IE)=IROW
       ICN(IE)=N+ICOL
       IE=IE+1
       AK(IE)=CONJG(AK(IE-1))
       IRN(IE)=IROW+N
```

```
      ICN(IE)=ICOL
30    CONTINUE
      N1=NB-1
C                                                            -
C                                                   S    S    S*
C     CALCULATION OF THE DIAGONAL ELEMENTS OF MATRICES K  ,  K  ,  K
C        -
C         S*
C     AND K    FOR LOAD BUSES
C
      DO 50 I=1,N1
      IF (KA(I).EQ.1) GO TO 40
      IE=IE+1
      AK(IE)=DYM(I)*CV(I)
      IRN(IE)=I
      ICN(IE)=I
      IE=IE+1
      AK(IE)=CONJG(AK(IE-1))
      IRN(IE)=I+N
      ICN(IE)=I+N
      IE=IE+1
      AK(IE)=AI(I)
      IRN(IE)=I
      ICN(IE)=N+I
      IE=IE+1
      AK(IE)=CONJG(AK(IE-1))
      IRN(IE)=I+N
      ICN(IE)=I
      GO TO 50
C                                                            -
C                                                   S    S   S*
C     CALCULATION OF THE DIAGONAL ELEMENTS OF MATRICES K  ,  K  ,  K
C        -
C         S*
C     AND K    FOR GENERATOR BUSES
C
40    CPX=0.5*(CV(I)*DYM(I)+CONJG(AI(I)))
      CPY=CMPLX(0.0,0.5)/CABS(V(I))
      IE=IE+1
      AK(IE)=CPY*CV(I)+CPX
      IRN(IE)=I
      ICN(IE)=I
      IE=IE+1
      AK(IE)=CONJG(AK(IE-1))
      IRN(IE)=I+N
      ICN(IE)=I+N
      IE=IE+1
      AK(IE)=CPY*V(I)+CONJG(CPX)
      IRN(IE)=I
      ICN(IE)=I+N
      IE=IE+1
      AK(IE)=CONJG(AK(IE-1))
      IRN(IE)=I+N
      ICN(IE)=I
50    CONTINUE
      N=NB-1
      IF (IDER.EQ.0) RETURN
      IE=IE+1
      AK(IE)=(1.0,0.0)
      IRN(IE)=NB
      ICN(IE)=NB+NB
      IE=IE+1
      AK(IE)=(1.0,0.0)
      IRN(IE)=NB+NB
      ICN(IE)=NB
```

```
      RETURN
      END
C
C
      SUBROUTINE AMU (V,CV,AI,S,NB,DS,IDER,YM,DYM,ICYM,IRYM,NYM,IOUT)
C
      COMPLEX V(1),CV(1),AI(1),S(1),DS(1),YM(1),DYM(1)
      DIMENSION ICYM(1), IRYM(1)
      COMMON /AMUFL/ IAMUF
C
C     THIS PARTICULAR SUBROUTINE IS NOT USED BY THE PACKAGE. IT IS
C
C     INCLUDED HERE TO SATISFY PROGRAMMING REQUIREMENTS IN CASE
C
C     THE USER DOES NOT SUPPLY AN APPROPRIATE SUBROUTINE NAMED AMU
C
C     WHEN IDER=0
C
C     ******************************************************************
C
      WRITE (IOUT,10)
      IAMUF=-1
      RETURN
C
10    FORMAT (/,* ERROR - MISSING SUBROUTINE AMU. IDER = 1 OR > 1 AND*,/
     1,* SUBROUTINE AMU HAS NOT BEEN PROVIDED. SET IDER=0 IF ONLY*,/,* T
     2HE LOAD FLOW SOLUTION IS REQUIRED. IF THE SOLUTION OF *,/,* THE AD
     3JOINT SYSTEM OF EQUATIONS IS ALSO NEEDED PUT IDER > 0*,/,* AND SUP
     4PLY SUBROUTINE AMU. DS IS CONSEQUENTLY NOT THE *,/,* SOLUTION OF T
     5HE ADJOINT SYSTEM OF EQUATIONS*)
      END
C
C
      SUBROUTINE DERIV (V,CV,DS,KA,NB,L1,L2,JD,DF)
C
      COMPLEX V(1),CV(1),DS(1),CPX
      DIMENSION KA(1)
C
C     THIS SUBROUTINE EVALUATES THE DERIVATIVE OF A REAL FUNCTION
C
C     W.R.T. ONE CONTROL VARIABLE AT A TIME OF THE POWER SYSTEM
C
C     NETWORK USING THE SOLUTION OF THE ADJOINT SYSTEM OF EQUATIONS
C
C     A DESCRIPTION OF ALL THE NEW VARIABLES USED IN THIS SUBROUTINE
C
C     NOW FOLLOWS
C
C     ************************* INTEGER VARIABLES **********************
C
C     JD         = 1 DETERMINES DERIVATIVE W.R.T. REAL POWER OF A USER
C                    SPECIFIED BUS
C                = 2 DETERMINES DERIVATIVE W.R.T. REACTIVE POWER OF
C                    A LOAD BUS SPECIFIED BY THE USER
C                = 3 DETERMINES DERIVATIVE W.R.T. MODULUS OF VOLTAGE
C                    OF A GENERATOR BUS SPECIFIED BY THE USER
C                = 4 DETERMINES DERIVATIVE W.R.T. REAL COMPONENT OF THE
C                    SLACK BUS VOLTAGE
C                = 5 DETERMINES DERIVATIVE W.R.T. THE CONDUCTANCE OF THE
C                    LINE BETWEEN TWO BUSES SPECIFIED BY THE USER
C                = 6 DETERMINES DERIVATIVE W.R.T. THE SUSCEPTANCE OF THE
C                    LINE BETWEEN TWO BUSES SPECIFIED BY THE USER
C                = 7 DETERMINES DERIVATIVE W.R.T. THE SHUNT CONDUCTANCE
C                    OF A USER-SPECIFIED BUS
C                = 8 DETERMINES DERIVATIVE W.R.T. THE SHUNT SUSCEPTANCE
```

```
C                   OF A USER-SPECIFIED BUS
C
C     L1        INDEX OF THE BUS W.R.T. WHOSE PARAMETER A DERIVATIVE
C               IS TO BE DETERMINED
C
C     L1,L2     LINE W.R.T. WHOSE PARAMETER A DERIVATIVE IS TO BE
C               DETERMINED
C
C     ************************ REAL VARIABLES *************************
C
C     DF        THE DERIVATIVE OF A REAL FUNCTION
C
C     *****************************************************************
C
      GO TO (10,20,30,40,50,140,230,240), JD
C
C     EVALUATION OF THE DERIVATIVE W.R.T. REAL POWER OF A USER
C     SPECIFIED BUS
C
10    DF=2.0*REAL(DS(L1))
      RETURN
C
C     EVALUATION OF THE DERIVATIVE W.R.T. REACTIVE POWER OF A USER
C     SPECIFIED LOAD BUS
C
20    DF=2.0*AIMAG(DS(L1))
      RETURN
C
C     EVALUATION OF THE DERIVATIVE W.R.T. MODULUS OF VOLTAGE OF A
C     USER-SPECIFIED GENERATOR BUS
C
30    DF=-2.0*AIMAG(DS(L1))
      RETURN
C
C     EVALUATION OF THE DERIVATIVE W.R.T. REAL COMPONENT OF SLACK BUS
C     VOLTAGE
C
40    DF=2.0*REAL(DS(NB))
      RETURN
C
C     EVALUATION OF THE DERIVATIVE W.R.T. THE CONDUCTANCES OF THE
C     LINE BETWEEN TWO BUSES SPECIFIED BY THE USER
C
50    IF (L1.EQ.NB) GO TO 100
      IF (KA(L1).NE.0) GO TO 60
      IF (L2.EQ.NB) GO TO 110
      IF (KA(L2).NE.0) GO TO 70
C
C     EVALUATION OF THE DERIVATIVE W.R.T. THE CONDUCTANCE OF THE
C     LINE BETWEEN TWO LOAD BUSES
C
      CPX=(DS(L1)*CV(L1)-DS(L2)*CV(L2))*(V(L2)-V(L1))
      DF=2.0*REAL(CPX)
      RETURN
60    IF (L2.EQ.NB) GO TO 120
      IF (KA(L2).NE.1) GO TO 80
C
C     EVALUATION OF THE DERIVATIVE W.R.T. THE CONDUCTANCES OF THE
C     LINE BETWEEN TWO GENERATOR BUSES
C
      A1=REAL(DS(L1))
      A2=REAL(DS(L2))
      CPX=A1*CV(L1)-A2*CV(L2)
      CPX=CPX*(V(L2)-V(L1))
      DF=2.0*REAL(CPX)
```

```
      RETURN
C
C     EVALUATION OF THE DERIVATIVE W.R.T. THE CONDUCTANCE OF THE
C     LINE BETWEEN LOAD AND GENERATOR BUSES
C
70    IGEN=L2
      ILOAD=L1
      GO TO 90
80    IGEN=L1
      ILOAD=L2
90    A1=REAL(DS(IGEN))
      CPX=A1*CV(IGEN)-DS(ILOAD)*CV(ILOAD)
      CPX=CPX*(V(ILOAD)-V(IGEN))
      DF=2.0*REAL(CPX)
      RETURN
C
C     EVALUATION OF THE DERIVATIVE W.R.T. THE CONDUCTANCE OF THE
C     LINE BETWEEN LOAD AND SLACK BUSES
C
100   IF (KA(L2).EQ.1) GO TO 130
      CPX=DS(L2)*CV(L2)*(V(NB)-V(L2))
      DF=2.0*REAL(CPX)
      RETURN
110   CPX=DS(L1)*CV(L1)*(V(NB)-V(L1))
      DF=2.0*REAL(CPX)
      RETURN
C
C     EVALUATION OF THE DERIVATIVE W.R.T. THE CONDUCTANCES OF THE
C     LINE BETWEEN GENERATOR AND SLACK BUSES
C
120   CPX=CV(L1)*(V(NB)-V(L1))
      DF=2.0*REAL(DS(L1))*REAL(CPX)
      RETURN
130   CPX=CV(L2)*(V(NB)-V(L2))
      DF=2.0*REAL(DS(L2))*REAL(CPX)
      RETURN
C
C     EVALUATION OF THE DERIVATIVE W.R.T. THE SUSCEPTANCE OF THE
C     LINE BETWEEN TWO BUSES SPECIFIED BY THE USER
C
140   IF (L1.EQ.NB) GO TO 150
      IF (KA(L1).EQ.1) GO TO 160
      IF (L2.EQ.NB) GO TO 170
      IF (KA(L2).EQ.1) GO TO 180
C
C     EVALUATION OF THE DERIVATIVE W.R.T. THE SUSCEPTANCE OF THE
C     LINE BETWEEN TWO LOAD BUSES
C
      CPX=(DS(L1)*CV(L1)-DS(L2)*CV(L2))*(V(L2)-V(L1))
      DF=-2.0*AIMAG(CPX)
      RETURN
C
C     EVALUATION OF THE DERIVATIVE W.R.T. THE SUSCEPTANCE OF THE
C     LINE BETWEEN SLACK AND LOAD BUSES
C
150   IF (KA(L2).EQ.1) GO TO 210
      CPX=DS(L2)*CV(L2)*(V(NB)-V(L2))
      DF=-2.0*AIMAG(CPX)
      RETURN
C
C     EVALUATION OF THE DERIVATIVE W.R.T. THE SUSCEPTANCE OF THE
C     LINE BETWEEN TWO GENERATOR BUSES
C
160   IF (L2.EQ.NB) GO TO 220
      IF (KA(L2).EQ.0) GO TO 190
```

```
      A1=REAL(DS(L1))
      A2=REAL(DS(L2))
      CPX=A1*CV(L1)-A2*CV(L2)
      CPX=CPX*(V(L2)-V(L1))
      DF=-2.0*AIMAG(CPX)
      RETURN
C
C     EVALUATION OF THE DERIVATIVE W.R.T. THE SUSCEPTANCE OF THE
C     LINE BETWEEN LOAD AND SLACK BUSES
C
170   CPX=DS(L1)*CV(L1)*(V(NB)-V(L1))
      DF=-2.0*AIMAG(CPX)
      RETURN
C
C     EVALUATION OF THE DERIVATIVE W.R.T. THE SUSCEPTANCE OF THE
C     LINE BETWEEN LOAD AND GENERATOR BUSES
C
180   ILOAD=L1
      IGEN=L2
      GO TO 200
190   ILOAD=L2
      IGEN=L1
200   A1=REAL(DS(IGEN))
      CPX=A1*CV(IGEN)-DS(ILOAD)*CV(ILOAD)
      CPX=CPX*(V(ILOAD)-V(IGEN))
      DF=-2.0*AIMAG(CPX)
      RETURN
C
C     EVALUATION OF THE DERIVATIVE W.R.T. THE SUSCEPTANCE OF THE
C     LINE BETWEEN SLACK AND GENERATOR BUSES
C
210   CPX=CV(L2)*V(NB)
      DF=-2.0*REAL(DS(L2))*AIMAG(CPX)
      RETURN
C
C     EVALUATION OF THE DERIVATIVE W.R.T. THE SUSCEPTANCE OF THE
C     LINE BETWEEN GENERATOR AND SLACK BUSES
C
220   CPX=CV(L1)*V(NB)
      DF=-2.0*REAL(DS(L1))*AIMAG(CPX)
      RETURN
C
C     EVALUATION OF THE DERIVATIVE W.R.T. SHUNT CONDUCTANCE OF A BUS
C
230   A1=CABS(V(L1))
      A1=A1*A1
      A2=REAL(DS(L1))
      DF=-2.0*A1*A2
      RETURN
C
C     EVALUATION OF THE DERIVATIVE W.R.T. SHUNT SUSCEPTANCE OF A BUS
C
240   IF (KA(L1).EQ.1) GO TO 250
      A1=CABS(V(L1))
      A1=A1*A1
      A2=AIMAG(DS(L1))
      DF=2.0*A1*A2
      RETURN
250   DF=0.0
      RETURN
      END
```

SOC-293

XLF2 - A PROGRAM FOR ANALYSIS AND SENSITIVITY EVALUATION OF COMPLEX LOAD FLOWS BY THE COMPLEX LAGRANGIAN METHOD

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Key Words: Load flow analysis, nonlinear equations, power system simulation, contingency analysis, power system optimization

Abstract: XLF2 is a package of six subroutines for solving steady-state power flow equations in the compact complex mode and/or to determine the exact sensitivities of any number of functions w.r.t. network control variables. The user is required to supply a main program and a subroutine for finding the derivatives of the specified functions w.r.t. complex bus voltages and their conjugates. The package prepares the complex consistent form of the power flow equations and calls the Harwell package ME28 to solve them. The sensitivities are determined by implementing the generalized, complex adjoint approach to power network sensitivities by Bandler and El-Kady. The package has been tested by solving a load flow problem for the IEEE 118-bus system, calculating sensitivities for a 26-bus system, minimizing transmission losses and minimizing transmission losses subject to line overloading constraints taking single outages into account for a 6-bus system. The package and documentation have been developed for the CDC 170/730 system with the NOS 1.4 level 552 operating system and the Fortran Extended (FTN) Version 4.8 compiler. The report includes a listing of the programs, the results for the test cases and a user's guide.

Description: Contains Fortran listing, user's manual. The listing contains 1089 lines, of which 567 are comments.

Related Work: SOC-242, SOC-243, SOC-253, SOC-254, SOC-255, SOC-256, SOC-257, SOC-258, SOC-270, SOC-283, SOC-296.

Price: $250.00. Source deck or magnetic tape: $500.00. Availability subject to signed author-purchaser agreement.