# DECNCM - A FORTRAN PACKAGE FOR LOAD FLOW ANALYSIS WITH THE AID OF DECOMPOSITION

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Abstract

DECNCM is a package of thirteen Fortran subroutines for solving load flow problems by the complex Newton method using the decomposition technique. The version implemented uses standard sparse matrix techniques to represent the power system bus admittance matrix as well as the Jacobian matrix required by the Newton method. The set of associated linearized equations is solved with the use of decomposition method by an appropriate call to the package CSDSLE. The package DECNCM and documentation have been developed for use on the CDC 170/730 system with the NOS 1.4 level 552 operating system and the Fortran Extended (FTN) version 4.8 compiler.

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# I. INTRODUCTION

In practical load flow problems the number of nonlinear equations which have to be solved varies from tens to thousands. This report describes the package DECNCM for solving medium size load flow problems by the Newton complex method [1,2]. The Newton complex method for solving load flow equations has been previously implemented in the packages XLF1 [3], XLF2 [4] and LFNWT [5] as a direct method while the package DECNCM decomposes the system of linearized Jacobian equations and solves them with the aid of the package CSDSLE [6].

The package DECNCM is written in Fortran IV for the CDC 170/730 system. At McMaster University it is available in the form of a library of binary relocatable subroutines, which is linked with the user's program by appropriate call statements. The name of the library is LIBDNCM. The library is available as a group indirect file under the charge RJWBAND. Package DECNCM calls subroutine CSDSLE1 of the package CSDSLE; the package CSDSLE must thus be also available when DECNCM is used.

The general sequence of NOS commands to use the package DECNCM may be as follows:

/GET, LIBDNCM, CSDSLE/GR. - fetch the libraries,
/LIBRARY, LIBDNCM, CSDSLE. - indicate the libraries to the loader.

The user should prepare the main program and the auxiliary subroutine INDICAT. The main program formulates the sparse bus admittance matrix and the vector of bus control variables of the power system (e.g., using subroutine FRPR of the package), defines the system decomposition and also calls the subroutine LFNCD of the package to solve the load flow problem. The user prepared subroutine INDICAT initializes some parameters required by the CSDSLE package.

The package DECNCM implements advanced techniques for solving load flow problems [1,2,6,7] and also makes use of existing software [5,7,8]. It is assumed in this report that the user has these documents available.

This document contains the user's manual of the package DECNCM presented together with illustrative examples. A Fortran listing of the package is found in [9].

## II. GENERAL DESCRIPTION

The package DECNCM solves load flow problems using the Newton complex method, when the power system is described by the bus admittance matrix in a sparse form and by the vector of bus control variables. Sparse systems of linear complex equations associated with the Newton method are solved by the package using decomposition techniques. The power system decomposition must be defined on entry to the package.

The package DECNCM contains also a group of subroutines for reading data describing power systems and also for formulation of the bus admittance matrix and the vector of bus control variables. It is advised to use these subroutines in the user's program to prepare information needed by the package for solving the load flow problem. The subroutine for data reading uses standard formatted data files as described in [8].

The Newton complex method is an iterative exact method for solving load flow equations. In the package the user may control the iterative procedure (i.e., the required accuracy of the solution, upper bound on the total number of iterations and upper bound on the total iteration time) by setting appropriate values of some arguments. In each iteration of the Newton method the set of nonlinear load flow equations is replaced by the set of associated linearized equations. The solution of linearized equations determines corrections of bus voltages. After obtaining new values of bus voltages, the iterative procedure can be continued or terminated.

The matrix and the right-hand side vector of the linearized equations are voltage dependent, and thus they must be updated in every iteration. The package DECNCM creates the matrix and the right-hand side vector of the linearized equations using formulas presented in [1]. Then the system of linearized equations is decomposed as is required by the package CSDSLE.

The package CSDSLE uses associate Coates graphs [10] to represent a system of linear equations. A decomposition of linear equations is equivalent to the decomposition of the associated Coates graph. In the complex Newton method each bus is described by two linearized equations. Therefore each bus corresponds to two vertices of the Coates graph; the power system decomposition defined on entry to the package determines the decomposition of linearized equations performed by the package DECNCM.

The package CSDSLE is a general package for solving large systems of sparse decomposed equations and thus it has many options to meet different requirements. In application to the power system load flow analysis values of some optional parameters have been fixed. Clearly, the package DECNCM uses local storage only, however, it is possible to create a mass storage file describing the system of decomposed linear equations. Matrices and right-hand side vectors of all subsystems are updated in each iteration and a new solution for the entire system is determined. The iterative procedure for solving load flow equations is organized in such a way that the matrices of all subsystems are bifactorized only once in the first iteration and in subsequent iterations a new solution is recalculated using the results of bifactorization.

After obtaining the solution of linearized equations, the package DECNCM updates bus voltages and the iterative procedure is repeated until one of the following conditions is satisfied:

- the demanded accuracy of the solution is attained,
- the iteration limit is reached,
- the time limit is reached.

## III. STRUCTURE OF THE PACKAGE

The package DECNCM is composed of thirteen subroutines and it has two entries.

Logically, the first entry is that one which is used to read data describing power systems and to prepare information needed for solving load flow problems. The second (main) entry is used for solving load flow problems when the system is described by the sparse bus admittance matrix and the bus control variables.

### First Entry (Subroutine FRPR)

The structure of the package corresponding to the first entry is shown in Fig. 1. Subroutine FRPR is the main package subroutine for data preparation. It distributes the workspace provided by the user into a set of vectors used by remaining subroutines, reads data describing an analyzed system (call to subroutine RDAT), renumbers buses as is required by the package CSDSLE and also creates the bus admittance matrix and the vector of bus control variables (calls to subroutines FORMYT and FORMU). It also checks formal correctness of some parameters defined by the user and sets the return flag appropriately.

Essentially, subroutines RDAT, FORMYT and FORMU of the package DECNCM are very similar to subroutines RDAT, FORMYT and FORMU of the package TTM1 [7]. The only difference is that subroutine FRPR renumbers buses and these indices are used by FORMYT and FORMU to formulate the bus admittance matrix and the vector of bus control variables. It is required by the CSDSLE package that the buses common for different subsystems of a decomposed power system (partition buses) must be labelled with highest numbers.

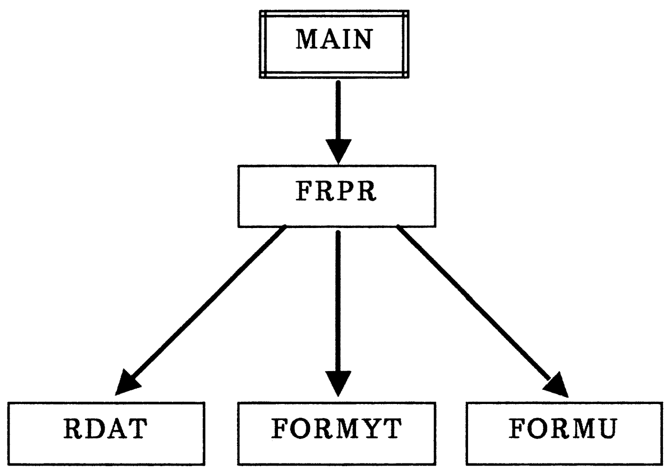


Fig. 1 Structure of the DECNCM package corresponding to the first entry (subroutine FRPR).

On return from subroutine FRPR, complex vector YT stores row by row all nonzero elements of the bus admittance matrix; each row begins with the diagonal element. Vector JRYT stores indices of such elements. Vector ICYT contains column indices of the elements stored in YT.

Secnd Entry (Subroutine LFNCD)

The structure of the package corresponding to the second (main) entry is shown in Fig. 2. Subroutine LFNCD is the main subroutine for solving the load flow problem. It organizes the workspace provided by the user into a set of vectors used by the remaining subroutines, calls appropriate subroutines for solving the load flow problem with the use of decomposition, updates bus voltages and also controls the iterative procedure.

The right-hand side vector and the matrix of linearized equations are formulated for the entire system by subroutines RHSLD and FORMK and then decomposed by subroutines DECDS and DECAK, respectively. Function subprogram CCURR calculates the value of a current injected into a bus for the given values of bus voltages. Subroutine MDDTF is designed as a link between packages DECNCM and CSDSLE. It organizes the complex workspace CMPLXWA required by the package CSDSLE. It also initializes the values of some optional parameters of the package CSDSLE. Subroutine INTRN identifies and renumbers vertices of a partition subgraph of the associated Coates graph. It is required by the CSDSLE package that vertices of all partition subgraphs have to be numbered consecutively starting from 1. Subroutine DGR calculates degrees of partition vertices of the associated Coates graph. Subroutine INDICAT shown in Fig. 2 is prepared by the user separately for each problem to be solved. Its aim is to define a mode of work for the CSDSLE package by setting the values of those optional parameters which are not initialized in subroutine MDDTF.

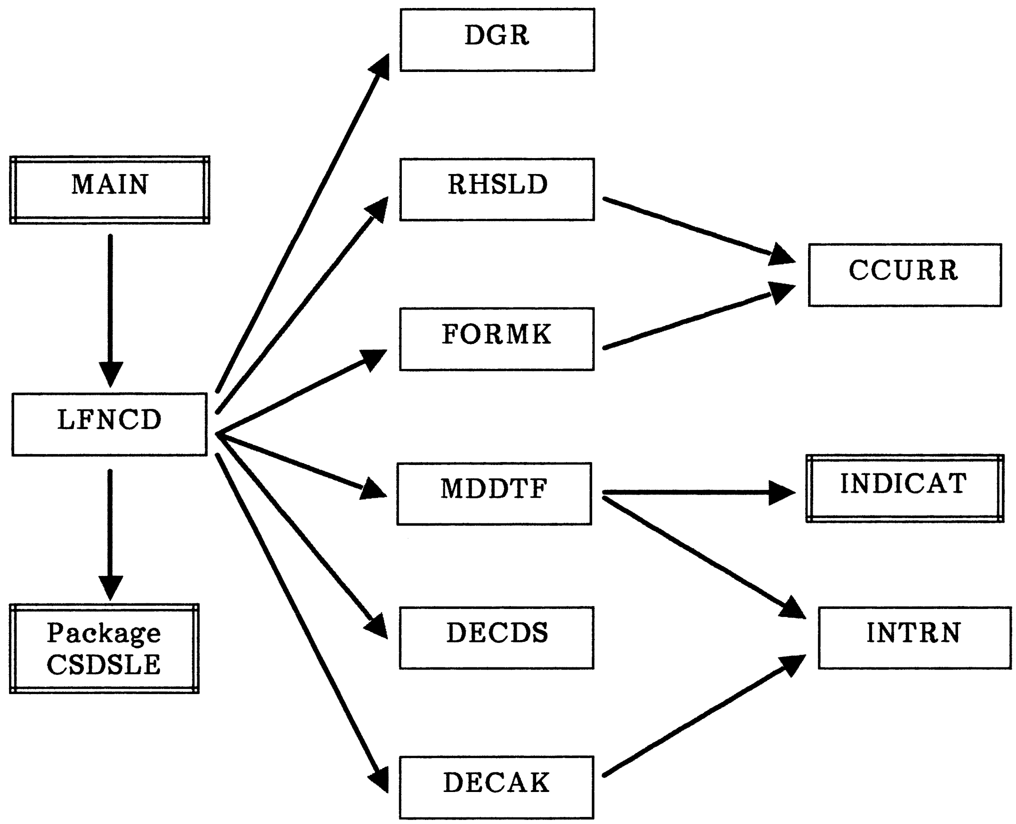


Fig. 2 Structure of the DECNCM package corresponding to the second entry (subroutine FRPR).

## IV. LIST OF ARGUMENTS

First Entry (Subroutine FRPR)

The subroutine call is

CALL FRPR(YT, JRYT, ICYT, BCV, V, BNR, BTYP, IBV, WS, LWS, NB, NTL, NBV, INPT, OTPT, IFLAG, IWRITE).

The arguments are as follows.

YT is a COMPLEX vector of dimension NB+2*NTL. On return from the subroutine, it stores all nonzero elements of the bus admittance matrix [7].

JRYT is an INTEGER vector of dimension NB+1. On return, it contains the row indices of the sparse bus admittance matrix [7] using bus indices defined by vector BNR.

ICYT is an INTEGER vector of length 2*(NB+NTL). On return from the subroutine, the first NB+2*NTL elements of ICYT contain the column indices of the sparse bus admittance matrix [7] using bus indices defined by vector BNR. The last NB entries of ICYT are used as workspace by the subroutine.

BCV is a REAL vector at dimension 2*NB. On exit from the subroutine, it stores the values of bus control variables [7] using bus indices defined by vector BNR.

V is a COMPLEX vector of dimension NB. On return, it stores the initial values of bus voltages in rectangular coordinates using bus indices defined by vector BNR.

BNR is an INTEGER vector of dimension NB. On return, BNR(i) is the index of the ith bus appearing on input. The buses are ordered in such a way that partition buses have highest indices and BNR(BNR(i)) = i (i=1,2,...,NB).

BTYP is an INTEGER vector of dimension NB of bus types (0 for load bus, 1 for generator bus and 2 for slack bus).

IBV is an INTEGER vector. On input, it stores original indices of partition buses. Not altered by the subroutine.

WS is a REAL vector of length LWS used by the package as workspace.

LWS is the length of the workspace WS. It must be at least LWS = 7*NB+9*NTL.

NB is an INTEGER variable. On entry, it must be at least as large as the number of buses. On return, NB is equal to the number of buses.

NTL is an INTEGER variable. On entry, it must be at least as large as the number of transmission lines. On return, NTL is equal to the number of transmission lines.

NBV is an INTEGER variable. On entry, it must be equal to the number of partition buses. Not altered by the subroutine.

INPT is an INTEGER argument which must be set to the input unit number. Not altered by the subroutine.

OTPT is an INTEGER argument which must be set to the output unit number. Not altered by the subroutine.

IFLAG is the return flag from the subroutine. INTEGER parameter.

IWRITE is an INTEGER parameter that controls printed output. Not altered by the subroutine.

Second Entry (Subroutine LFNCD)

The subroutine call is

CALL LFNCD (YT, JRYT, ICYT, BCV, V, BNR, BTYP, DEC, IBV, IBL, CMPWA, INTWA, NB, NTL, ITEL, TIMEL, VEPS, INPT, OTPT, IWRITE)

where arguments

YT, JRYT, ICYT, BCV, BNR, BTYP, IBV, NB, NTL, INPT, OTPT, IWRITE

have the same meaning as defined on exit from subroutine FRPR. All these arguments are not altered by LFNCD.

The other arguments of subroutine LFNCD are as follows.

V is a COMPLEX vector of dimension NB. On entry, it must contain initial values of bus voltages (rectangular coordinates). On return, V contains the solution found by the package. Bus indices defined by vector BNR are used.

DEC is an INTEGER vector that must be defined on input to the subroutine in the following way:

DEC(1) = NS (total number of subsystems),

DEC(2) = NBV (total number of partition buses),

DEC(2*i+1) = N (total number of buses of the ith subsystem),

DEC(2*i+2) = NINT (number of internal buses of the ith subsystem),

i=1,2,...,NS.

Vector DEC is not altered by the subroutine.

IBL is an INTEGER vector. On entry, it must contain a list of buses of all subsystems. List of buses of the ith subsystem should be followed by a list of buses of the (i+1)th subsystem (i=1,2,...,NS-1). All internal buses of a subsystem must appear before the partition buses.

CMPWA is a COMPLEX vector used by the package as workspace. The length of CMPWA should be at least LW = LW1+LW2, where

LW1 = (33*NB)/2+12*NTL+4*NS+2**(NS-2)+NBV+18,

LW2 is the length of workspace CMPLXWA needed by the package CSDSLE [6]. LW2 should be equal to the value of parameter IM(4) declared by the user in subroutine INDICAT.

INTWA is an INTEGER vector used as workspace by the package CSDSLE. The length of INTWA should be as is required by CSDSLE [6].

ITEL is an INTEGER variable. On entry, ITEL is the upper bound on the number of iterations. On return, ITEL is equal to the number of iterations performed by the package.

TIMEL is a REAL variable. On entry, TIMEL is the upper bound on total iteration time (in seconds). On return, TIMEL is the value of the total iteration time.

VEPS is a REAL variable. On entry, VEPS is the required accuracy of the solution. The iterative procedure terminates when the maximal value of the modulus of the corrections of bus voltages is not greater than VEPS. On return, VEPS is the attained accuracy of the solution.

## V. SUBROUTINE INDICAT

Subroutine INDICAT defines a mode of work for the package CSDSLE by setting the values of some optional parameters. Normally, when CSDSLE is used, the user is supposed to initialize two integer vectors IN and IM to define a job for the package [6]. However, when it is used in conjunction with DECNCM most elements of these vectors are setting in the package DECNCM (subroutine MDDTF).

Subroutine INDICAT has to be prepared by the user individually for each job. The subroutine headline is

SUBROUTINE INDICAT (IN, IM)

and must be followed by the declaration of two INTEGER vectors IN and IM, as shown in examples 1 and 2. In the subroutine, the user should initialize the following parameters:

IN(7) indicator for printing results generated by the package CSDSLE

= 0 only part of intermediate results is printed out,

= 1 all printouts are suppressed,

= 2 all intermediate results are printed out,

= 3 only the solution of linear decomposed equations is printed out, IN(11) the length of the basic record in double CM words [6],

IN(12) the length of the addressing record in CM words [6],

IN(16) maximum number of linearized Jacobian equations for any subsystem,

IN(17) maximum area predicted for sparse analysis (usually 1-2 times the number of nonzero elements of the maximal submatrix),

IN(18) the number of nonzero elements in the maximum submatrix,

IN(23) the indicator for operations on random files

= 0 random access file will be created,

= 1 random access file will be updated,

= 2 program is executed without creating a random access file,

IN(27) -IN(L) store numbers of external nodes for the substitute subgraphs of the decomposition (L=26+NMS, where NMS is the highest index of decomposition subgraphs) [6],

IM(3) the length of integer working area INTWA [6],

IM(4) the length of complex working area CMPXWA [6].

More details concerning vectors IN and IM are found in [6].

## VI. GENERAL INFORMATION

<u>Input/Output</u>

The input and output unit numbers (parameters INPT, OTPT) must be defined by the user. Printed output generated by the package DECNCM is controlled by the parameter IWRITE. Possible values of IWRITE are

- when entry FRPR is used

$\leq 0$ all prints are suppressed,

= 1 input data identifier [8], the number of buses and the number of transmission lines are printed out,

- 2 as above, and additionally data describing buses and transmission lines is printed out,

≥ 3 as above, and additionally bus admittance matrix and vector of bus control variables are printed out,

- when entry LFNCD is used

≤ 0 all printouts are suppressed,

= 1 for each iteration the following information is printed: iteration number, obtained accuracy, iteration time, total execution time. The load flow solution is also printed in the following manner: total number of iterations, attained accuracy, total execution time and vector of bus voltages in rectangular coordinates,

= 2 as above, and additionally for each iteration vector of bus voltages is printed out,

≥ 3 as above, and additionally for each iteration matrix and right-hand side vector of linearized equations, decomposed matrix and decomposed right-hand side vector are printed out.

More prints may also appear due to call to the package CSDSLE (see description of subroutine INDICAT).

Error Diagnostics

A successful return from FRPR is indicated by the value of IFLAG equal to zero. If the length LWS of the workspace vector WS has been declared too small, then on return IFLAG = -1.

More diagnostics may appear due to call to the package CSDSLE [6].

# VII. EXAMPLES

In this section we determine the load flow solution for the General Electric optimized 118-bus power system [8,11] using the decomposition method.

## Example 1

In this example the 118-bus power system is decomposed into two subsystems, as shown in Fig. 3. The partition buses are: 49, 65, 75. Subsystem $S_1$ has 60 buses, i.e., 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 70, 71, 72, 73, 74, 113, 114, 115, 117 and the partition buses 75, 65, 49. Subsystem $S_2$ also has 60 buses, i.e., 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 66, 67, 68, 69, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 116 and the partition buses 75, 65, 49. For the decomposition purposes the slack bus and all transmission lines incident with the slack bus have been removed from the system, since the slack bus is eliminated from the load flow equations.

The main program AD118C and the user's subroutine INDICAT are shown on pages 19-20. The required accuracy of the solution is VEPS = $10^{-6}$, the bound on iteration time is TIMEL = 8.0 seconds. Before calling subroutine LFNCD for solving the load flow problem, the main program calls subroutine FRPR to read data and to formulate the load flow problem. Two output files are used to separate printed output generated by the packages DECNCM and CSDSLE: RS2 is used for the results produced by DECNCM and OUTPUT for the results produced by CSDSLE.

Because of the size of the workspace program AD118C is submitted to the batch queue with the following job description:

```
100/JOB
110/DECMP, JC6, STALL.
120/USER
130/CHARGE
140/SETJSL, 100.
150/MFL, 250000.
160/MAP, OFF.
170/GET, AD118C.
180/FTN, I = AD118C, ER.
190/GET, LIBDNCM, CSDSLE/GR.
200/LIBRARY, LIBDNCM, CSDSLE.
210/GET, B118 = B118FVB/GR.
220/LGO.
230/REWIND, RS2.
240/SAVE, RS2.
250/EOR
260/EOF
```

The results of analysis (contents of the file RS2) are reported on pages 21-22.

Example 2

In this example the 118-bus power system is decomposed into three subsystems $S_1$, $S_2$ and $S_3$ as shown in Fig. 4. Subsystem $S_1$ has 44 buses, i.e., 68, 69, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 116 and the partition buses 70, 65. Subsystem $S_2$ has 48 buses, i.e., 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 38, 71, 72, 73, 113, 114, 115, 117 and the partition buses 70, 65, 43, 37. Subsystem $S_3$ has 30 buses, i.e., 39, 40, 41, 42, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 66, 67 and the partition buses 65, 43, 37.

The main program AD118A and the user's subroutine INDICAT are on pages 24-25. The structure of the main program is the same as in Example 1. The results of analysis are reported on pages 26-27.

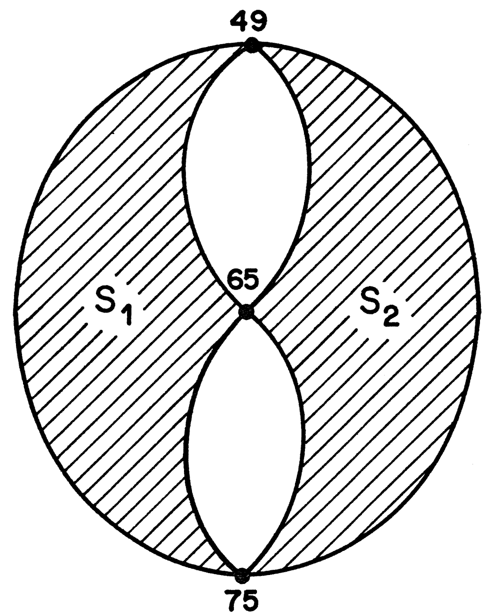


Fig.3 Decomposition of the 118-bus power system into two subsystems.

```
C
C
C
      PROGRAM AD118C(B118,RS2,OUTPUT,TAPE4=B118,TAPE5=RS2,TAPE6=OUTPUT)
C
C
C     THIS IS THE MAIN PROGRAM FOR THE LOAD FLOW SOLUTION OF 118-BUS
C     POWER SYSTEM DECOMPOSED INTO 2 SUBSYSTEMS
C
C
      INTEGER BTYP(120),JRYT(120),ICYT(600),BNR(120),INTWA(5600),DEC(6),
     1IBV(3),IBL(120),INTN(234),OTPT
      COMPLEX YT(480),V(118),CMPWA(27000),BCV(118)
      DATA DEC/2,3,60,57,60,57/,IBV/49,65,75/,IBL/1,2,3,4,5,6,7,8,9,10,1
     11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,3
     23,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,70,71,72,73,74,113,
     3114,115,117,75,65,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,
     466,67,68,69,76,77,78,79,80,81,82,83,84,85,86,87,88,89,90,91,92,93,
     594,95,96,97,98,99,100,101,102,103,104,105,106,107,108,109,110,111,
     6112,116,75,65,49/
C
      INPT=4
      OTPT=5
      NB=118
      NTL=179
      LW=2500
      NBV=DEC(2)
      ITEL=7
      TIMEL=8.0
      VEPS=1.E-6
      WRITE (OTPT,30)
      IWRITE=1
      CALL FRPR (YT,JRYT,ICYT,BCV,V,BNR,BTYP,IBV,CMPWA,LW,NB,NTL,NBV,INP
     1T,OTPT,IFLAG,IWRITE)
      IF (IFLAG.EQ.0) GO TO 10
      WRITE (OTPT,20) IFLAG
      STOP
   10 CALL LFNCD (YT,JRYT,ICYT,BCV,V,BNR,BTYP,DEC,IBV,IBL,CMPWA,INTWA,NB
     1,NTL,ITEL,TIMEL,VEPS,INPT,OTPT,IWRITE)
      STOP
   20 FORMAT (///" RETURN FLAG FROM FRPR:",I3)
   30 FORMAT (///" LOAD FLOW ANALYSIS OF 118-BUS POWER SYSTEM DECOMPOSED
     1 INTO 2 SUBSYSTEMS")
      END
```

```
C
C
C
      SUBROUTINE INDICAT (IN,IM)
C
C     THIS SUBROUTINE INITIALIZES VECTORS IN,IM OF THE PACKAGE
C     CSDSLE FOR SOLVING THE LOAD FLOW PROBLEM OF 118-BUS SYSTEM
C     DECOMPOSED INTO 3 SUBSYSTEMS
C
      INTEGER IN(1),IM(1)
      IN(7)=1
      IN(11)=10000
      IN(12)=8
      IN(16)=120
      IN(17)=1600
      IN(18)=900
      IN(23)=2
      IN(27)=0
      IM(3)=5600
      IM(4)=22000
      RETURN
      END
```

LOAD FLOW ANALYSIS OF 118-BUS POWER SYSTEM DECOMPOSED INTO 2 SUBSYSTEMS

```
IT = 1      EPS = .552789E+00      ITERATION TIME  1.435      TOTAL TIME  1.435

IT = 2      EPS = .274071E+00      ITERATION TIME   .956      TOTAL TIME  2.391

IT = 3      EPS = .520783E-01      ITERATION TIME   .954      TOTAL TIME  3.345

IT = 4      EPS = .304111E-02      ITERATION TIME   .953      TOTAL TIME  4.298

IT = 5      EPS = .170602E-04      ITERATION TIME   .959      TOTAL TIME  5.257

IT = 6      EPS = .501194E-09      ITERATION TIME   .944      TOTAL TIME  6.201
```

RESULTS OF ANALYSIS

```
NUMBER OF ITERATIONS:         6
ACCURACY OBTAINED:    .5012E-09
ANALYSIS TIME:            6.201 SECONDS
```

VECTOR OF BUS VOLTAGES

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1 | .1131154E+01 | -.2073442E+00 | 2 | .1070434E+01 | -.1725546E+00 | 3 | .1099347E+01 | -.1745540E+00 |
| 4 | .1089318E+01 | -.1493176E+00 | 5 | .1072816E+01 | -.8335380E-01 | 6 | .1044921E+01 | -.1218338E+00 |
| 7 | .1042741E+01 | -.1316939E+00 | 8 | .1039988E+01 | .5158380E-02 | 9 | .1087701E+01 | .1295432E+00 |
| 10 | .1043263E+01 | .2592805E+00 | 11 | .1044351E+01 | -.1418269E+00 | 12 | .1041355E+01 | -.1420563E+00 |
| 13 | .1010420E+01 | -.1554003E+00 | 14 | .1017892E+01 | -.1479868E+00 | 15 | .9602801E+00 | -.1369749E+00 |
| 16 | .1024305E+01 | -.1373130E+00 | 17 | .9766769E+00 | -.9880275E-01 | 18 | .9610268E+00 | -.1316340E+00 |
| 19 | .9501290E+00 | -.1373133E+00 | 20 | .9261188E+00 | -.1267406E+00 | 21 | .9150635E+00 | -.1035848E+00 |
| 22 | .9134150E+00 | -.6491303E-01 | 23 | .9195265E+00 | .1439859E-01 | 24 | .9099982E+00 | -.1790455E-02 |
| 25 | .9578254E+00 | .1532010E+00 | 26 | .9922181E+00 | .1835884E+00 | 27 | .8209962E+00 | -.5739547E-01 |
| 28 | .6541473E+00 | -.3798097E-01 | 29 | .7164857E+00 | -.6307192E-01 | 30 | .1048490E+01 | -.1357554E-01 |
| 31 | .7788301E+00 | -.8070127E-01 | 32 | .8685268E+00 | -.7662607E-01 | 33 | .9500378E+00 | -.1440093E+00 |
| 34 | .9472291E+00 | -.1497936E+00 | 35 | .9509448E+00 | -.1497260E+00 | 36 | .9509230E+00 | -.1520342E+00 |
| 37 | .9615536E+00 | -.1238196E+00 | 38 | .1040093E+01 | -.4400465E-01 | 39 | .9437033E+00 | -.1866626E+00 |
| 40 | .9470677E+00 | -.2096731E+00 | 41 | .9698135E+00 | -.2320731E+00 | 42 | .1069872E+01 | -.2556820E+00 |
| 43 | .9444833E+00 | -.1570553E+00 | 44 | .9648199E+00 | -.1264041E+00 | 45 | .9730750E+00 | -.9905998E-01 |
| 46 | .9982331E+00 | -.5941838E-01 | 47 | .1013043E+01 | -.3379384E-01 | 48 | .1015073E+01 | -.2674572E-01 |
| 49 | .1019977E+01 | -.6793184E-02 | 50 | .9966142E+00 | -.3004193E-01 | 51 | .9624816E+00 | -.5480375E-01 |
| 52 | .9520957E+00 | -.6352520E-01 | 53 | .9401026E+00 | -.6064964E-01 | 54 | .9494503E+00 | -.3231193E-01 |
| 55 | .9484884E+00 | -.5356975E-01 | 56 | .9485691E+00 | -.5212238E-01 | 57 | .9657029E+00 | -.4964003E-01 |
| 58 | .9539417E+00 | -.5852125E-01 | 59 | .9899729E+00 | -.7327872E-02 | 60 | .9904233E+00 | .3002790E-01 |
| 61 | .9976396E+00 | .6866820E-01 | 62 | .9987473E+00 | .5003790E-01 | 63 | .1019157E+01 | .4514303E-01 |
| 64 | .1014107E+01 | .7093303E-01 | 65 | .9937752E+00 | .1114944E+00 | 66 | .1044672E+01 | .1151617E+00 |
| 67 | .1018931E+01 | .7014152E-01 | 68 | .1019394E+01 | .4743419E-01 | 69 | .9491795E+00 | -.5495855E-01 |
| 70 | .9790313E+00 | -.4356183E-01 | 71 | .9833127E+00 | -.4739319E-01 | 72 | .9788653E+00 | -.4714659E-01 |
| 73 | .9885554E+00 | -.5157947E-01 | 74 | .9578880E+00 | -.6364430E-01 | 75 | .9678515E+00 | -.4861864E-01 |
| 76 | .9448355E+00 | -.3543199E-01 | 77 | .1003205E+01 | .6018745E-01 | 78 | .9984616E+00 | .5155367E-01 |
| 79 | .1004229E+01 | .6389453E-01 | 80 | .1032445E+01 | .1251264E+00 | 81 | .9979264E+00 | .1100380E+00 |
| 82 | .9833045E+00 | .1106084E+00 | 83 | .9742228E+00 | .1441808E+00 | 84 | .9608152E+00 | .2083192E+00 |
| 85 | .9588681E+00 | .2463166E+00 | 86 | .9601226E+00 | .2384085E+00 | 87 | .9728155E+00 | .2715327E+00 |
| 88 | .9398531E+00 | .3007938E+00 | 89 | .9272153E+00 | .3745287E+00 | 90 | .9541777E+00 | .2639033E+00 |
| 91 | .9439197E+00 | .2634684E+00 | 92 | .9522354E+00 | .2758142E+00 | 93 | .9632725E+00 | .2101500E+00 |
| 94 | .9768605E+00 | .1624264E+00 | 95 | .9709323E+00 | .1351965E+00 | 96 | .9843644E+00 | .1222245E+00 |
| 97 | .1004269E+01 | .1170213E+00 | 98 | .1017750E+01 | .1171058E+00 | 99 | .1000751E+01 | .1363747E+00 |
| 100 | .1006791E+01 | .1636235E+00 | 101 | .9743176E+00 | .1943542E+00 | 102 | .9597591E+00 | .2467534E+00 |
| 103 | .1003707E+01 | .1125707E+00 | 104 | .9673979E+00 | .7100165E-01 | 105 | .9635397E+00 | .5305907E-01 |
| 106 | .9605820E+00 | .4471243E-01 | 107 | .9500000E+00 | .1868818E-03 | 108 | .9656249E+00 | .3618235E-01 |
| 109 | .9666488E+00 | .2990906E-01 | 110 | .9723099E+00 | .1923349E-01 | 111 | .9788485E+00 | .4749235E-01 |
| 112 | .9793623E+00 | -.3534801E-01 | 113 | .9844040E+00 | -.1051132E+00 | 114 | .8526225E+00 | -.7926591E-01 |
| 115 | .8293034E+00 | -.7914731E-01 | 116 | .9931247E+00 | .6121346E-01 | 117 | .1024244E+01 | -.1649939E+00 |

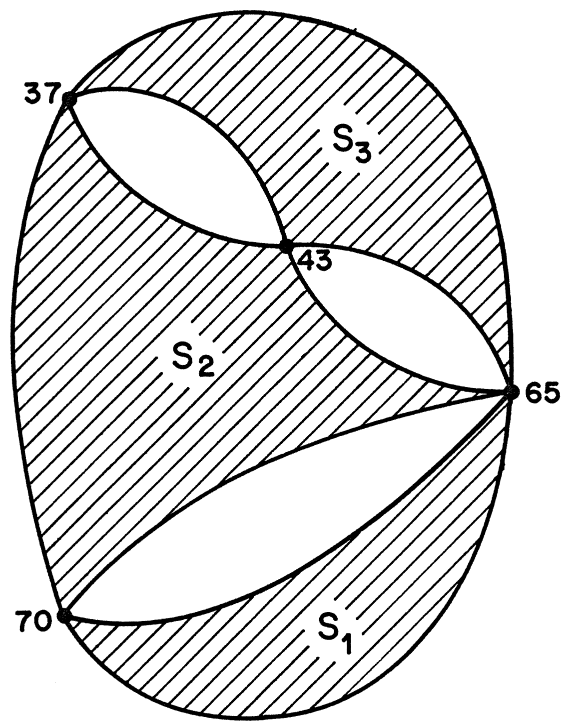


Fig.4 Decomposition of the 118-bus power system into three subsystems.

```
C
C
C
      PROGRAM AD118A(B118,RS1,OUTPUT,TAPE4=B118,TAPE5=RS1,TAPE6=OUTPUT)
C
C
C     THIS IS THE MAIN PROGRAM FOR THE LOAD FLOW SOLUTION OF 118-BUS
C     POWER SYSTEM DECOMPOSED INTO 3 SUBSYSTEMS
C
C
      INTEGER BTYP(120),JRYT(120),ICYT(600),BNR(120),INTWA(4100),DEC(8),
     1IBV(4),IBL(122),INTN(234),OTPT
      COMPLEX YT(480),V(118),CMPWA(24000),BCV(118)
      DATA DEC/3,4,44,42,48,44,30,27/,IBV/37,43,65,70/,IBL/68,69,74,75,7
     16,77,78,79,80,81,82,83,84,85,86,87,88,89,90,91,92,93,94,95,96,97,9
     28,99,100,101,102,103,104,105,106,107,108,109,110,111,112,116,70,65
     3,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25
     4,26,27,28,29,30,31,32,33,34,35,36,38,71,72,73,113,114,115,117,70,6
     55,43,37,39,40,41,42,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,5
     69,60,61,62,63,64,66,67,65,43,37/
C
      INPT=4
      OTPT=5
      NB=118
      NTL=179
      LW=2500
      NBV=DEC(2)
      ITEL=7
      TIMEL=8.0
      VEPS=1.E-6
      IWRITE=1
      WRITE (OTPT,30)
      CALL FRPR (YT,JRYT,ICYT,BCV,V,BNR,BTYP,IBV,CMPWA,LW,NB,NTL,NBV,INP
     1T,OTPT,IFLAG,IWRITE)
      IF (IFLAG.EQ.0) GO TO 10
      WRITE (OTPT,20) IFLAG
      STOP
   10 CALL LFNCD (YT,JRYT,ICYT,BCV,V,BNR,BTYP,DEC,IBV,IBL,CMPWA,INTWA,NB
     1,NTL,ITEL,TIMEL,VEPS,INPT,OTPT,IWRITE)
      STOP
   20 FORMAT (///" RETURN FLAG FROM FRPR:",I3)
   30 FORMAT (///" LOAD FLOW ANALYSIS OF 118-BUS POWER SYSTEM DECOMPOSED
     1 INTO 3 SUBSYSTEMS")
      END
```

```
C
C
C
      SUBROUTINE INDICAT (IN,IM)
C
C     THIS SUBROUTINE INITIALIZES VECTORS IN,IM OF THE PACKAGE
C     CSDSLE FOR SOLVING THE LOAD FLOW PROBLEM OF 118-BUS SYSTEM
C     DECOMPOSED INTO 3 SUBSYSTEMS
C
      INTEGER IN(1),IM(1)
      IN(7)=1
      IN(11)=10000
      IN(12)=10
      IN(16)=96
      IN(17)=1200
      IN(18)=600
      IN(23)=2
      IN(27)=0
      IN(28)=6
      IM(3)=4100
      IM(4)=19200
      RETURN
      END
```

LOAD FLOW ANALYSIS OF 118-BUS POWER SYSTEM DECOMPOSED INTO 3 SUBSYSTEMS

| | | | |
|---|---|---|---|
| IT = 1 | EPS = .552789E+00 | ITERATION TIME 1.474 | TOTAL TIME 1.474 |
| IT = 2 | EPS = .274071E+00 | ITERATION TIME 1.005 | TOTAL TIME 2.479 |
| IT = 3 | EPS = .520783E-01 | ITERATION TIME 1.017 | TOTAL TIME 3.496 |
| IT = 4 | EPS = .304111E-02 | ITERATION TIME 1.013 | TOTAL TIME 4.509 |
| IT = 5 | EPS = .170602E-04 | ITERATION TIME 1.023 | TOTAL TIME 5.532 |
| IT = 6 | EPS = .501192E-09 | ITERATION TIME 1.022 | TOTAL TIME 6.554 |

RESULTS OF ANALYSIS

NUMBER OF ITERATIONS: 6
ACCURACY OBTAINED: .5012E-09
ANALYSIS TIME: 6.554 SECONDS

VECTOR OF BUS VOLTAGES

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1 | .1131154E+01 | -.2073442E+00 | 2 | .1070434E+01 | -.1725546E+00 | 3 | .1099347E+01 | -.1745540E+00 |
| 4 | .1089818E+01 | -.1493176E+00 | 5 | .1072816E+01 | -.8335380E-01 | 6 | .1044921E+01 | -.1218338E+00 |
| 7 | .1042741E+01 | -.1316939E+00 | 8 | .1089988E+01 | .5158380E-02 | 9 | .1087701E+01 | .1295432E+00 |
| 10 | .1043263E+01 | .2592805E+00 | 11 | .1044351E+01 | -.1418269E+00 | 12 | .1041355E+01 | -.1420563E+00 |
| 13 | .1010420E+01 | -.1554003E+00 | 14 | .1017892E+01 | -.1479868E+00 | 15 | .9602801E+00 | -.1369749E+00 |
| 16 | .1024305E+01 | -.1373130E+00 | 17 | .9766769E+00 | -.9880275E-01 | 18 | .9610268E+00 | -.1316340E+00 |
| 19 | .9501290E+00 | -.1373133E+00 | 20 | .9261188E+00 | -.1267406E+00 | 21 | .9150635E+00 | -.1035848E+00 |
| 22 | .9134150E+00 | -.6491303E-01 | 23 | .9195265E+00 | .1439859E-01 | 24 | .9099982E+00 | -.1790455E-02 |
| 25 | .9578254E+00 | .1532010E+00 | 26 | .9922181E+00 | .1886884E+00 | 27 | .8209962E+00 | -.5739547E-01 |
| 28 | .6541473E+00 | -.3798097E-01 | 29 | .7104857E+00 | -.6307192E-01 | 30 | .1048490E+01 | -.1357554E-01 |
| 31 | .7788301E+00 | -.8070127E-01 | 32 | .8686268E+00 | -.7662607E-01 | 33 | .9500378E+00 | -.1440093E+00 |
| 34 | .9472291E+00 | -.1497936E+00 | 35 | .9509448E+00 | -.1497260E+00 | 36 | .9509230E+00 | -.1520342E+00 |
| 37 | .9615536E+00 | -.1238196E+00 | 38 | .1040093E+01 | -.4400465E-01 | 39 | .9437033E+00 | -.1866626E+00 |
| 40 | .9470677E+00 | -.2096731E+00 | 41 | .9698135E+00 | -.2320731E+00 | 42 | .1069872E+01 | -.2556820E+00 |
| 43 | .9444833E+00 | -.1570553E+00 | 44 | .9648199E+00 | -.1264041E+00 | 45 | .9730750E+00 | -.9905998E-01 |
| 46 | .9982331E+00 | -.5941888E-01 | 47 | .1013043E+01 | -.3379384E-01 | 48 | .1015073E+01 | -.2674572E-01 |
| 49 | .1019977E+01 | -.6793184E-02 | 50 | .9966142E+00 | -.3004193E-01 | 51 | .9624816E+00 | -.5480375E-01 |
| 52 | .9520957E+00 | -.6352520E-01 | 53 | .9401026E+00 | -.6064964E-01 | 54 | .9494503E+00 | -.3231193E-01 |
| 55 | .9484384E+00 | -.5356975E-01 | 56 | .9485691E+00 | -.5212238E-01 | 57 | .9657029E+00 | -.4964003E-01 |
| 58 | .9539417E+00 | -.5852125E-01 | 59 | .9899729E+00 | -.7327872E-02 | 60 | .9904233E+00 | .3002790E-01 |
| 61 | .9976396E+00 | .6866820E-01 | 62 | .9987473E+00 | .5003790E-01 | 63 | .1019157E+01 | .4514303E-01 |
| 64 | .1014107E+01 | .7093303E-01 | 65 | .9937752E+00 | .1114044E+00 | 66 | .1044672E+01 | .1151617E+00 |
| 67 | .1018931E+01 | .7014152E-01 | 68 | .1019394E+01 | .4743419E-01 | 69 | .9491795E+00 | -.5495855E-01 |
| 70 | .9790313E+00 | -.4356183E-01 | 71 | .9833127E+00 | -.4739319E-01 | 72 | .9788653E+00 | -.4714659E-01 |
| 73 | .9886554E+00 | -.5157947E-01 | 74 | .9578880E+00 | -.6364430E-01 | 75 | .9678515E+00 | -.4861864E-01 |
| 76 | .9448355E+00 | -.3543199E-01 | 77 | .1008205E+01 | .6018745E-01 | 78 | .9984616E+00 | .5185367E-01 |
| 79 | .1004229E+01 | .6389453E-01 | 80 | .1032445E+01 | .1251264E+00 | 81 | .9979264E+00 | .1109380E+00 |
| 82 | .9833045E+00 | .1106084E+00 | 83 | .9743228E+00 | .1441808E+00 | 84 | .9603152E+00 | .2083192E+00 |
| 85 | .9588681E+00 | .2463166E+00 | 86 | .9601220E+00 | .2384085E+00 | 87 | .9728155E+00 | .2715327E+00 |
| 88 | .9393531E+00 | .3007938E+00 | 89 | .9272153E+00 | .3745287E+00 | 90 | .9541777E+00 | .2639033E+00 |
| 91 | .9489197E+00 | .2634684E+00 | 92 | .9528854E+00 | .2758142E+00 | 93 | .9632725E+00 | .2101500E+00 |
| 94 | .9768605E+00 | .1624264E+00 | 95 | .9709323E+00 | .1351965E+00 | 96 | .9843644E+00 | .1222245E+00 |
| 97 | .1004269E+01 | .1170213E+00 | 98 | .1017750E+01 | .1171058E+00 | 99 | .1000751E+01 | .1363747E+00 |
| 100 | .1006791E+01 | .1636235E+00 | 101 | .9743176E+00 | .1943542E+00 | 102 | .9597591E+00 | .2467534E+00 |
| 103 | .1008707E+01 | .1125707E+00 | 104 | .9673979E+00 | .7100165E-01 | 105 | .9635397E+00 | .5366907E-01 |
| 106 | .9605820E+00 | .4471243E-01 | 107 | .9500000E+00 | .1868818E-03 | 108 | .9656249E+00 | .3613235E-01 |
| 109 | .9666483E+00 | .2990906E-01 | 110 | .9728099E+00 | .1923349E-01 | 111 | .9788485E+00 | .4749235E-01 |
| 112 | .9793623E+00 | -.3534601E-01 | 113 | .9844040E+00 | -.1051132E+00 | 114 | .8526225E+00 | -.7926591E-01 |
| 115 | .8293034E+00 | -.7914731E-01 | 116 | .9981247E+00 | .6121346E-01 | 117 | .1024244E+01 | -.1649939E+00 |

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