N-AREA RELIABILITY PROGRAM (NARP)

PROGRAM DESCRIPTION AND USER GUIDE

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NOTICE

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1.0 INTRODUCTION

The N-Area Reliability Program (NARP) is a computer program for the calculation of reliability performance indices in a multi-area interconnected electric power system. System components modeled are the generating units in each area and the transmission links (equivalents) between areas. Thus, the program is intended primarily as a tool for generation capacity planning within the context of an interconnected power system.

The program uses a Monte Carlo simulation approach to reflect the effects of chance events such as generator and transmission link failures as well as deterministic operating rules and policies. In effect, the Monte Carlo simulation procedure creates artificial histories of interconnected system operation from which the desired reliability performance measures or indices can be obtained.

This report describes the features and methods of the program as well as the data input and use of the program.

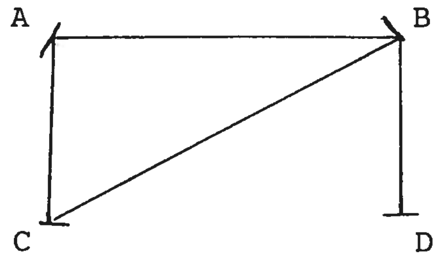
2.0 BASIC FEATURES AND CAPABILITIES

The present version of NARP is designed to compute reliability indices for a single study year. Study of an expansion pattern through time can be accomplished through a series of such single-year studies.

Basic program features and capabilities are summarized in the sections which follow and are described in greater detail in Section 6.0 of the report.

2.1 TRANSMISSION NETWORK

The transmission network of the interconnected system is modeled as an equivalent network of transmission links between pairs of areas as shown in the following figure. Each area is assumed to have a single transmission bus to which all area generators and loads are connected. That is, the program does not model or consider the effects of transmission limitations within an area. Further, physical transmission lines between areas are not explicitly modeled but are reflected in the equivalent transmission links between areas. Thus, a first step in use of the NARP program is the development of an appropriate transmission network equivalent.



The program is dimensioned for up to 15 interconnected system areas and up to 60 total transmission links.

Flows in the transmission network are modeled using a D-C load flow approach. That is, only real power flows are modeled and var flows and voltage conditions are not considered.

Key features of the transmission network model are outlined as follows.

* Each transmission link (between two areas) is modeled as a multi-state line with up to 6 capacity states. Each capacity state is characterized by a probability and an admittance. This multi-state line modeling approach permits, through an appropriate equivalencing approach, the modeling of the actual transmission network for purposes of generation expansion planning.

* Transmission link capacities for each capacity state can be specified as a function of the direction of power flow in the link. This feature enables the user to reflect transmission constraints internal to areas or other constraints not explicitly considered in the network model.

* Transmission link capacities can be modified by input data factors to reflect the dependence of link transfer capability upon the statuses of specified generating units. This feature enables the user to reflect area internal transmission constraints arising from the loss of specified generating units. Thus, use of the feature allows partial recognition of the effects of internal transmission limitations without explicit modeling of the internal transmission network.

* Constraints on the algebraic sum of flows in transmission links terminating on each area can be specified. This feature enables the user to further constrain the total imports (or exports) to an area where that may be appropriate.

2.2 GENERATING UNITS

The NARP program is dimensioned for up to 600 total generating units with no additional restriction on the number of generating units in each area.

* Generating unit forced outages are modeled considering two or three-state unit models. Each unit state is characterized by a probability and a capacity.

* Generating unit ratings can be specified on a seasonal basis, four seasons per year. It is assumed that season dates are the same in all areas of the interconnected system.

* Generator planned outages are modeled deterministically with up to two planned outages per year for each generating unit. Planned outage schedules can be pre-specified or automatically determined to levelize risk. A mixture of pre-specified and automatically determined planned outages is permitted.

2.3 LOADS

The basic load data for each area of the interconnected system consists of an 8760 hour chronological load cycle in EEI format. This load cycle is used to create a per unit load cycle for each area. Alternative area load cycles are then created using user specified peak loads and assuming no change in load cycle shape.

Load forecast uncertainty for each area is modeled assuming that load forecast errors are normally distributed (distributed according to a normal probability distribution). Further, it is assumed that area load forecasts are unbiased, that is there are equal probabilities of positive and negative load forecast errors. Thus, it is assumed that the mean (average) value of load forecast error is zero and accordingly the normal probability distribution of load forecast error for an area is completely specified by the standard deviation of the forecast error distribution. The standard deviation of load forecast error for each area must be derived from load forecasting data and supplied as input data to the NARP program.

The program assumes that the same load forecast error distribution expressed in percent of the nominal forecasted load, applies for all hourly loads of an area. Further, the program assumes that all area load forecast errors are perfectly correlated. That is, the program assumes that the loads in the various areas scale up and down together in response to load forecast errors.

Normal probability distributions of load forecast uncertainty are approximated for computational purposes by a five-step discrete distribution. Thus, considering load forecast uncertainty, five load scenarios are created for each area. These load scenarios are: nominal forecast, nominal forecast $\pm$ one standard deviation, and nominal forecast $\pm$ 2.5 standard deviations. The probabilities of these load scenarios are readily given by a normal probability distributional table and are:

$$P\,(\text{nominal forecast}) = P\,(-.5\delta \le x \le .5\delta) = .382$$
$$P\,(\text{nominal forecast} - \delta) = P\,(-1.5\delta \le x \le -.5\delta) = .242$$
$$P\,(\text{nominal forecast} + \delta) = P\,(.5\delta \le x \le 1.5\delta) = .242$$
$$P\,(\text{nominal forecast} - 2.5\delta) = P\,(-\infty \le x \le -1.5\delta) = .067$$
$$P\,(\text{nominal forecast} + 2.5\delta) = P\,(1.5\delta \le x \le \infty) = .067$$

Load forecast uncertainty is reflected in the reliability calculation process by studying, in turn, each load scenario as defined above. Each load scenario yields a set of reliability indices reflecting that scenario; then expected reliability indices are computed which reflect all load scenarios and their respective probabilities. This is expressed mathematically as follows:

$$E(I) = \text{expected value of reliability index } I$$

$$= \sum_{i=1}^{5} I_i\, P_i$$

where:

I_i = value of reliability index associated with load scenario i

P_i = probability of load scenario i

2.4 AREA INTERCHANGES

The following features are available to model the effects of area interchanges of power and jointly-owned or co-generation units.

* Firm MW contracts between all pairs of areas can be specified. These contracts can be modified as often as daily.

* Percentage entitlements to the available capacities of jointly-owned generating units or other out-of-area generating units such as co-generation units can be specified. These entitlements create area interchanges which are modified as unit available capacities change.

* Emergency interchanges between areas can be modeled on a load-loss sharing or no-load-loss sharing basis. In no-load-loss sharing, areas with positive margins assist areas with negative margins to the extent possible within transmission limitations, but without sharing in load loss. In load-loss sharing, areas attempt to share resources so as to minimize interconnected system load loss.

2.5 RESTART CAPABILITY

The program has been provided with a restart capability. The contents of arrays are stored into the file DUMP after a specified number of replications. If the execution of the program is interrupted for any reason, the program can be restarted beginning with the replication when the DUMP was last updated.

3.0 RELIABILITY INDICES AND MEASURES

The following reliability indices are computed for each area as well as for the interconnected system as a whole.

LOLE - Expected number of daily peak load loss events per year.

HLOLE - Expected number of hours of load loss per year.

EUE - Expected unserved energy per year in MWh.
XLOL - Expected magnitude of a load loss event given the occurrence of a load loss in MW.

As an option, indices can be computed for daily peak loads only. If this option is chosen, only LOLE and XLOL indices are computed.

Each of the above indices are also separated into two components: "generation constrained" and "transmission constrained" as a further aid to system analysis. The "generation constrained" indices reflect those load loss events which are due to lack of available generating capacity. (Generation constrained loss events are defined as loss events for which the available generating capacity in the interconnected system is less than the interconnected system load.) Similarly, "transmission constrained" indices reflect those load loss events which are due to lack of available transmission transfer capability. (Transmission constrained loss events are defined as loss events for which the available generating capacity in the interconnected system is greater than the interconnected system load.)

The above reliability indices are expected values and as such indicate the long-term average reliability that can be expected. These indices do not, therefore, indicate the year-to-year or event-to-event variation in reliability performance which can be experienced. This additional valuable information is, however, available from the Monte Carlo simulation. Thus, the NARP program provides the following additional output:

* Probability distribution of number of daily peak load loss events per year.

* Probability distribution of number of hours of load loss per year.

* Probability distribution of unserved energy per year.

The NARP program also provides, as an output option, a file giving the flows in all transmission lines whenever a transmission constraint is encountered. This output file can be analyzed to gain further insight into the performance of the transmission network model.

4.0 GENERAL PROGRAM LOGIC

The purpose of this section is to describe the general logic and procedure of the simulation program.

The simulation proceeds sequentially through time as described in the following steps. Here it is assumed that hourly reliability indices are to be computed and hence the simulation process steps through time hourly. The process is similar if only daily peak reliability indices are to be calculated except that the process steps through time from daily peak to daily peak where the time of daily peak is defined as the time of interconnected system peak.

1) Each hour the status of each generator and transmission link is randomly and independently drawn according to the probability distribution of generating unit and transmission link states specified by the user. [As an alternate, generator and transmission link states can be drawn once per day. It is recommended that generator and transmission link states be drawn once an hour if hourly reliability indices (HLOLE and EUE) are of significant, or primary, interest. However, if daily peak indices are of sole, or primary, interest, it is recommended that generator and transmission link states be drawn once per day. The effect of this is reduced computer time at the expense of less rapid convergence of the hourly reliability indices.]

2) The generating capacity available in each area is determined by summing the available capacities of individual generating units. Two capacities are found for each area:

    (a) the capacity associated with generating units located in the area regardless of ownership, and

    (b) the capacity associated with generating units owned by the area regardless of location.

3) The native load for each area is updated to the current hour.

4) Scheduled transfers between areas are determined from input data. Similarly, transfers associated with jointly-owned or out-of-area generating units are determined based on the availability statuses of the units and the area ownership percentages. Scheduled transfers and transfers associated with jointly-owned units are added algebraically to give net scheduled transfers between areas.

5) The margin in each area is found by subtracting area native load from available generating capacity located in the area. If this margin is positive for all areas, the clock advances to the next hour and the process is repeated. [If load forecast uncertainty is being modeled, the above process is begun with the highest load scenario in all areas. If all area margins are positive, no lower load scenarios need be considered and the clock is advanced to the next hour.]

6) If any area has negative margin, the following procedure is followed in an effort to obtain the necessary relief from other areas.

   (a) If only one area has a negative margin, a simplified test not requiring a load flow solution is tried first. In this approach, the total capacity assistance available from areas which are directly connected to the negative-margin area is found. Here the capacity assistance available from an area is the minimum of: (a) the area margin, or (b) the capacity of the transmission link between the area and the negative-margin area. The total available capacity assistance from areas directly connected to the negative-margin area is just the sum of the capacity assistances available from these areas. Then if the total available capacity assistance is greater than the capacity shortfall in the negative-margin area, it is assumed that adequate capacity can be imported to eliminate the load loss and the clock is advanced to the next hour. Otherwise, the transmission module is called.

   (b) If more than one area has negative margin, the transmission module is called directly.

7) The D-C load flow transmission module employs a two-step procedure in seeking to eliminate loss-of-load events. First, a load flow is conducted using area loss injections associated with net scheduled transfers as well as injections associated with desired emergency transfers. If this load flow produces a solution without violation of transmission capacity limits, the clock is advanced to the next hour. Otherwise, a linear programming approach is employed in an effort to find a feasible load flow solution or to minimize the amount of load loss. [The linear programming approach can consider two modes of emergency assistance: loss-sharing or no-loss sharing. Further, the linear programming approach can enforce constraints on the sum of flows around each area.] If load loss persists after the optimization step, load-loss statistics are collected.

8) The simulation process is continued until the specified number of years have been simulated or until the specified convergence criterion has been satisfied.

5.0 CONVERGENCE OF RESULTS

An important issue in Monte Carlo simulation programs such as NARP is the number of years of artificial history which must be created to achieve an acceptable level of statistical convergence in the reliability indices (expected values) of interest. Here the degree of statistical convergence of a reliability index (expected value) is measured by the standard deviation of the estimate of the reliability index obtained from the simulation data. This can be expressed mathematically as follows.

Let I_i = value of reliability index obtained from simulation data for year i

N = number of years of simulated data available

Then $\bar{I} = \sum_{i=1}^{N} I_i / N$

= estimate of the expected value of the index I

and $S_I = \sqrt{(S^2/N)}$

= standard deviation of the estimate I

where $S^2 = \sum_{i=1}^{N} \frac{(I_i - \bar{I})^2}{N}$

Note that S_I, the standard deviation of the estimate $\bar{I}$, varies as $1/\sqrt{N}$ where N is the number of simulated years and will approach zero as the N approaches infinity. Clearly, S_I can never be made to be zero in practice and so the computed estimates of the reliability indices (expected values) will always contain some uncertainty. The goal here is to reduce the uncertainty in the computed reliability indices to an acceptable level and to understand the degree of uncertainty which remains.

The NARP program provides the following procedure for controlling and monitoring the degree of statistical convergence of the computed reliability indices.

1) Program input includes:

   (a) the maximum number of years to be simulated, and

   (b) the desired final standard deviation of a specified reliability index.

2) The program will automatically continue the simulation process until one or the other of the above criteria are satisfied.

As a further aid in judging convergence, and the rate of convergence, computed reliability indices can be outputted every n years of simulation where n is an input variable.

The number of years of simulated history required to achieve a given degree of statistical convergence in reliability indices is very system dependent. In general, systems which have "low variance" converge in fewer years than systems with "high variance". A "low variance" system is characterized by:

1) many generators, all of which are small in comparison to load;

2) a strong transmission network which allows mutual assistance between areas with few limitations;

3) relatively low capacity reserve levels implying relatively low system reliability.

It follows that choosing appropriate, and computer cost effective, convergence criteria can only be accomplished through experience in use of the NARP program on a particular system.

6.0 MODELS AND METHODS

This section describes in greater detail the most important models and methods which are employed in the NARP program.

6.1 GENERATING UNIT MODEL

The NARP program permits generating units to be modeled as two or three-state units for purposes of modeling unit forced outages. A two-state unit is considered to be:

1) fully available, or

2) totally unavailable.

The probability of the totally unavailable state is specified in input data and in the so-called forced outage rate of the unit (FOR). The probability of the fully available state is then (1-FOR).

A three-state unit is considered to be:

1) fully available,

2) totally unavailable, or

3) partially unavailable due to a forced derating event.

The probabilities of the totally unavailable and derated states are FOR and DFOR, respectively, and are specified in input data. The probability of the fully available state is then (1-FOR-DFOR). The expected magnitude of the forced derating is specified in input data in percent of unit capacity.

The use of three-state models is recommended for all but small generating units. It is well established that three-state models offer significant accuracy improvements over two-state models for units which experience significant numbers of derating events as is typical for thermal units.

The generating unit models described above define the probability distribution of available capacities for a unit. The state of a unit is then defined in the simulation process through the following procedures.

1) A uniformly distributed random number is drawn from the range 0-1. [Each generator has a dedicated random number generator to facilitate convergence and comparison of simulation results when studies are being made of the sensitivities of reliability indices to changes in the system.]

2) The random number drawn in 1), N, is then used to determine the state of the unit according to the specified probability distribution through the following procedure:

(a) Unit fully available if

$$N \geq FOR + DFOR$$

居中这个反而是 totally unavailable

(b) Unit totally unavailable if

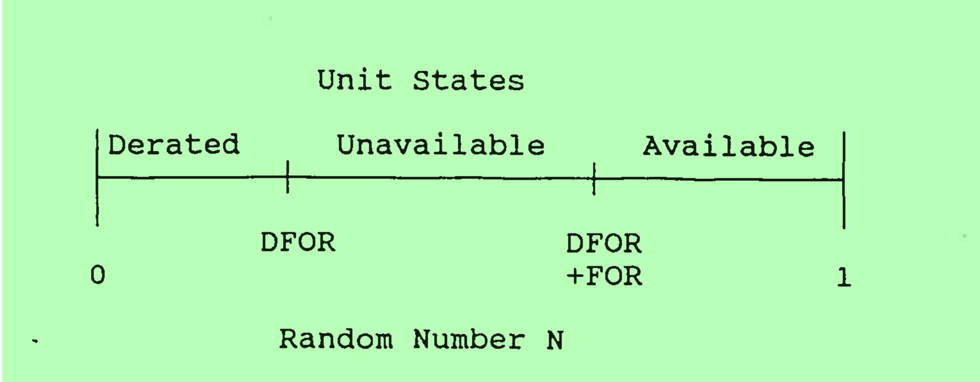
$$FOR + DFOR > N \geq DFOR$$

(c) Unit derated if

$$N < DFOR$$

The above process of mapping from a random number N to a unit state can be visualized using the following diagram. Here it should be clear that if N is equally likely to take on any value between 0 and 1, the unit will reside in each of its states for the desired proportions of time, namely:

Derated	-	DFOR per unit of the time
Totally Unavailable	-	FOR per unit of the time
Fully Available	-	1-DFOR-FOR per unit of the time



The NARP program also provides for seasonal variation in the capacities of generating units. Four seasons per year are considered and the dates of seasons are assumed to be the same in all areas.

6.2 GENERATOR PLANNED OUTAGES

The program can accept either pre-scheduled planned outages or prepare such a schedule automatically. For units which are pre-scheduled, the starting week and the duration of outage in weeks needs to be specified. In specifying this data, it should be noted that the smallest unit of time used in planned outages is a week. For automatic scheduling of units, the following data is to be specified:

1) Plant within which unit is installed.

2) Unit planned outage duration in weeks.

3) Periods within which planned outages are forbidden.

Unit planned outages are then scheduled in a manner which tends to maximize the resultant system reliability through reserve levelization while enforcing the forbidden period constraints and allowing only one unit in a plant to be on planned outage in any week. In scheduling planned outages, "effective" capacity of each unit is calculated using the following equation:

EC_i = effective capacity of the unit i

$$= C_i - M \cdot \log R_i \tag{1}$$

where

$$R_i = 1 - FOR_i \left(1 - e^{C_i/M}\right) \tag{2}$$

M = slope of the capacity outage probability graph with capacity on the y-axis (linear) and probability on the x-axis (log-scale).

and

FOR_i = forced outage rate of unit i

It can be seen from equations (1) and (2) that the effective capacity of a unit would equal the units rated capacity if the unit were perfectly reliable.

The detailed scheduling algorithm is outlined as follows:

1) The product of effective capacity and planned outage duration is found for each unit and the resulting products are summed for each plant.

2) Plants are ranked in priority order based on the sums of unit effective capacity X duration, largest first. Likewise, units are ranked in priority order within a plant on the basis of rated capacity X duration, largest first.

3) Unit planned outages are then scheduled sequentially using the plant priority order and unit priority within a plant. The scheduling process minimizes the sum of weekly peak load and effective capacity on planned outage in any week while observing the constraints on forbidden periods and only one unit per plant out in any week.

6.3 TRANSMISSION LINK MODEL

Transmission links between areas are modeled as six-state lines with each state characterized by a probability, an admittance, and capacities in the forward and backward flow directions. The forward direction of flow in a link is arbitrarily chosen.

Transmission link states are chosen in the simulation process in a manner similar to that used for generating units. The procedure is to draw a uniformly distributed random number using the dedicated random number generator provided for each transmission link. The random number is then used to select a state according to the state probability distribution specified in input data.

The NARP program also provides for transmission link capacities to be modified as a function of the status of specified key generating units. This feature permits some recognition of the influence of internal transmission limitations on area transfer capabilities.

6.4 TRANSMISSION NETWORK MODEL

The objective of the transmission network model is to determine whether the loads at the various nodes can be satisfied by the available generation without the flows through tie lines exceeding their capabilities and the algebraic sum of flows at any node exceeding a specified value. If the loads cannot be satisfied, then this module determines the load loss at each node. This module has two policies for sharing the available capacity amongst various areas.

1) No-Load-Loss Sharing

Under this policy, an area will provide emergency assistance to other areas only to the extent of its surplus capacity. The first obligation is the area's own load. An area will, therefore, help other areas only after its own demand has been met.

2) Load-Loss Sharing

Under this policy the areas share the loss of load. The objective here is to minimize pool load loss. The areas, therefore, help each other even at the expense of losing their own load to achieve this objective.

6.4.1 INPUT

The input to the transmission module consists of the following data.

1) Net power injection and load at each node.

Generation at a node less the load gives the margin at the node. This margin is the net power injection into the node. The net injection is positive if the generation at the node exceeds the load and negative if the load is more than generation. In calculating the net injection, the firm contracts are regarded as load obligations at the sending node and load reductions at the receiving node. For no-loss sharing only, the net injections at nodes need be input to the transmission module. For loss sharing, the area loads also need to be specified.

2) The admittance and tie line capability of each link for the current status of the system. The factors to modify the tie line capacities, depending on the direction of flow should also be specified.

A given area generally has more than one generation and load buses. Similarly, there may be more than one transmission line between any two areas. The admittance and capacity used here are those of the equivalent network. These should be so determined that a DC load flow performed using these values would give approximately the same flows as those obtained using an a.c. load flow on the original network. A method for developing this equivalent network is described in the

3) Constraint on the sum of flows at each node.

The transmission module assures that the algebraic sum of flows at a given node will not exceed the specified value for that node. If the user does not want to impose this constraint then the value specified should be equal to or greater than the sum of capacities of the tie lines connected to that node.

4) Loss sharing policy.

6.4.2 METHODOLOGY

The overall procedure for determining the loss of load in various areas consists of the following steps.

1) The scheduled transfers due to firm contracts and jointly owned units are algebraically added to determine the net scheduled transfers. Since the objective is to determine the reliability, the scheduled transfers to an area are adjusted so as not to exceed the load loss to the area. For example if in area i, the capacity is greater than the load, then even though this area is entitled to a transfer from some other area, this entitlement is set to zero. These adjusted transfers are then input to the network flow module to determine feasible transfers and line flows. The various steps of the network flow module are described later.

2) If the load in each area can be satisfied by the capacity in each area together with the feasible scheduled transfers determined in step 1, then no further computation is necessary, otherwise the program goes to step 3.

3) (a) For loss sharing policy the net injection at each node is now calculated by subtracting load from capacity. These net injections are then input to the network flow module.

(b) For no loss sharing, the feasible scheduled transfers are subtracted from the net injections (capacity - load), the line constraints are modified by the flows calculated in step 1 and the sum of flow constraints are also modified by the flows calculated in step 1. The network flow module is now called to determine the loss of load. The line flows calculated in this step need to be algebraically added to the line flows calculated in step 1 to obtain net line flows.

Procedure for Network Flow Calculations

The overall procedure consists of the following steps.

1) Assign injections at all nodes and perform a D.C. load flow.

2) Check the constraints. If the line flows are within the line capabilities, then exit; otherwise go to step 3.

3) Perform optimization procedure.

The DC load flow takes much less time than the optimization procedure. Therefore, Step 1 is an attempt to find a feasible solution without performing the optimization.

Details

Assignment of injections:

For performing a DC flow calculation, the injections need to be assigned such that the sum of positive injections is equal to the sum of negative injections. If there is sufficient generation available in the pool, the sum of positive injections is greater than the sum of negative injections. In this situation, the transmission module scales down all positive injections in the same ratio so as to make their sum equal to the negative injections.

?

If the sum of negative injections is greater than the sum of positive injections, then the available generation is not enough and some load needs to be curtailed. In the no-loss sharing policy, all negative injections are scaled down in the same ratio so as to make their sum equal to the positive injections. In the loss sharing policy, all <u>loads</u> are scaled down in the same ratio so that the sum of negative injections is equal to the sum of positive injections.

D.C. Load Flow

The network flow calculations in the transmission module are made using DC load flow. The following assumptions underlie this method.

1) Only real power is considered.

2) Voltage at each bus is assumed fixed at 1 per unit.

3) Resistance of transmission lines is ignored.

The D.C. load flow or linearized power flow model is usually expressed by the following equation.

$$B\theta = I \qquad (1)$$

where matrix B is such that

b_{ij} = ijth element of B

= -(the susceptance between nodes i and j),

if $i = j$.

b_{ii} = sum of the susceptances connected to node i

θ = node voltage angle vector

I = bus injection vector

Therefore:

$$\theta = ZI \qquad (2)$$

where

$Z = B^{-1}$, is the bus impedance matrix

Once θ has been determined, the line flows can be determined by equation (3).

f_{ij} = flow from node i to j

$$= (\theta_i - \theta_j)\ r_{ij} \qquad (3)$$

where

r_{ij} = susceptance between nodes i and j.

It should be noted that if there is a change in the status of a line, matrix can be readily modified using techniques described in [1]. This avoids the inversion of B for every flow calculation.

Optimization Procedure

If the DC load flow after the assignment of injections does not give a feasible solution, then the program enters the optimization phase. The optimization procedure is based on linear programming (revised simplex method) and it assigns positive margins or curtails negative margin/load so as to minimize the loss of load for the pool. Minimization is performed under the following constraints.

1) For no-loss sharing, the load curtailment at a node is less than or equal to the negative injection at the node. For loss sharing, the curtailment can be up to the actual load at the node.

2) Flows in the tie lines are within their capabilities.

3) The sum of flows at any node is less than the specified value.

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[1] M. L. Baughman and F. C. Schweppe, "Contingency Evaluation: Real Power Flows from a Linear Model",

IEEE Paper 70CP 689-PWR, July, 1970.

Mathematically, the problem can be formulated as:

$$\text{Loss of Load} = \text{Min}\ \Sigma c_K$$

Subject to (4)

$$B\theta + g + c = d$$

$$g \le g^{max}$$

$$c \le d$$

$$f \le f^f$$

$$-f \le f^r$$

$$s \le s^{max}$$

where

d = vector of net negative injections for no-loss sharing and actual loads for loss sharing

g = vector of net positive injections for no load-loss sharing and actual generation plus scheduled transfers for load-loss sharing

c = vector of negative injection curtailments for no loss sharing and load curtailments for load loss sharing

c_K = kth element of c

g^{max} = vector of max available net positive injection for no-loss sharing and max generation for loss sharing

s = vector of sum of flows at nodes

s^{max} = max possible values for s

f^f, f^r = indicate max flow capabilities in the forward and reverse directions of tie lines

f and s are related to θ and the tie line susceptance by equation 3.

6.5 LOAD FORECAST UNCERTAINTY

Load forecast uncertainty is modeled assuming area load forecast errors are normally distributed about the nominal forecast for the area. The normal distribution of load deviations about the nominal load forecast is characterized by a standard deviation expressed in percent of the nominal load and a mean value of zero. The normal distribution is approximated by a five-step discrete distribution for purposes of computation.

The load forecast deviations in all areas are assumed to be perfectly and positively correlated. That is, the loads in all areas are assumed to scale up and down together.

The effects of load forecast uncertainty are computed, in effect, by computing the reliability indices for each of the five load scenarios corresponding to the five discrete load forecast states described above. The reliability indices for each load scenario are then multiplied by the probability of the scenario and added to yield the expected reliability indices considering load forecast uncertainty. It is well known that reliability indices computed considering load forecast uncertainty are higher (less reliable) than when only the nominal load forecast is considered.

The NARP program displays in its output the reliability indices associated with each load scenario as well as the expected reliability indices. This permits direct assessment of the influence of load level on the computed reliability indices.

17.0 INPUT DATA PREPARATION

The creation of input data files for the NARP program is described in this section. The section is intended to be read and used in conjunction with the data input prompts shown on the computer screen.

7.1 STRUCTURE OF FILES

There are three input files, one intermediate file created by the program and two output files. The three input files are INPUTB, INPUTC and LEEI and the primary output file is called OUTPUT. Another file TRAOUT is used for printing out the transmission module results, if so desired. The hourly load data for each area is contained in LEEI and the rest of the data are contained in INPUTB. The INPUTC file is used for deleting or modifying the data in INPUTB. After the run, all the files except the following are deleted.

1. INPUTB, INPUTC and LEEI remain unchanged
2. OUTPUT is retained
3. TRAOUT is retained if IR is nonzero in ZZMC data
4. DUMP is retained if IR is nonzero in ZZMC data

Error checking:

1. If any of the input files INPUTB, INPUTC or LEEI does not exist, an error message is printed and the program execution is aborted.
2. If the OUTPUT file exists, it is overwritten.
3. For a restart run, the following checks are made.
   (i) If II=0 and TRAOUT does not exist, a new file is created and a message is printed.
   (ii) If II=1 and TRAOUT does not exist, an error message is printed and program execution is aborted.
   (iii) If II=1 and TRAOUT exists, the new results are appended to the old file.

7.2 FILE INPUTB

A copy of the base data file INPUTB is shown in Figure 1. The file has 9 cards including the termination card. Headings are provided for ease of input and to make the file self explanatory. Detailed descriptions are provided in the following sections for clarification. The first two letters in each card name are ZZ and the remaining two letters indicate type of data input through this card. All cards, except ZZTC are format-free. Therefore any text type information, like unit or area name, needs to be enclosed by quotation marks. The input can be more readily understood by referring to INPUTB for the sample study in Figure 2. It should be pointed out that the program ignores any blank lines in the data. The program also ignores any text or information before the ZZTC card and after the ZZND card. Also the program expects a fixed number of lines for the description of each card. For example, the program expects three lines for the description of card ZZLD after which it expects data.
Error checking:

1. NARP expects ZZ data sets to be in sequence. If the data set is not in sequence in INPUTB or INPUTC, an error message is printed and the program is aborted.

Card ZZTC: Title Card

The purpose of this card is to provide title of the output. Data inserted under this card is simply reproduced. This is the only formatted card in this file and has the following format:

S.N. Description

where:

S.N. = The line number occupying the first two columns. It is read by an I2 format. Therefore a single digit number, for example, line number 5, should be typed as b5 (b stands for blank).

Description = Information to be printed on the title page of the output. Each line should be typed between columns 3-80.

The title can consist of up to 20 lines and therefore S.N. here must not exceed 20.

Error Checking:

If S.N. exceeds 20, this number as well as corresponding data are ignored and a message is printed.

Card ZZMC: Miscellaneous

This card contains the following data:

1. Seed
2. Definition of seasons
3. Convergence parameters
4. Frequency of drawing the status of generators and transmission lines
5. Frequency of data collection
6. Specification for the probability distribution of EUE
7. Printout options

This card has the following format:

SEED LS ENDING WEEKS WHERE WHEN KVS KVT KVL CVT FIN STEP FREQ MAXE II IJ IR IN D M

The variables are defined in the following:

SEED = The basic seed used by the program to create seeds for generators and transmission lines. SEED should be a seven-digit integer.

LS = 0 indicates load-loss sharing between areas
= 1 indicates that areas do not share loss of load

IW1 = Ending week of the first season, the beginning week is assumed to be the first week.

IW2, IW3 = Ending weeks for the second and third season, the ending week of the fourth season is assumed to be 52.

VARIABLES FOR CONVERGENCE TEST:

WHERE: 1 = Convergence will be based on area statistics. The specific area whose statistics are to be used for convergence is to be specified under KVL.
2 = Convergence will be based on pool statistics.

WHEN: 1 = Hourly statistics are to be used for convergence
2 = Peak statistics are to be used for convergence

KVS: 1 = LOLE is to be used for convergence. If WHEN=1, this is hourly LOLE and with WHEN=2, it is peak LOLE
2 = EUE is to be used for convergence. This option can be used for WHEN=1 only, i.e., when hourly statistics are used for convergence.

KVT: 1 = Weighted average of statistics, considering forecast error is to be used for convergence
2 = Use only the no forecast error statistic

KVL: Area number (used only if WHERE=1) for convergence

CVT: 0 = Program stops when standard deviation of the tested statistic is less than (.025*MEAN), i.e. the true value lies between ± 5% of the estimate with confidence level of 95%.
>0 = Program stops when standard deviation is less than (CVT*MEAN), i.e. the true value lies approximately between ± (2 CVT) percent of the estimate with 95% level of confidence.

FIN: Time to end simulation if no convergence. It should be an integer number of years.

OTHER VARIABLES:

STEP: 1 = Stats are collected every hour.
24 = Daily peak stats only are collected

FREQ:	1	=	Hourly Monte Carlo draws of generator and line status are used.
	24	=	Daily Monte Carlo draws are used.
MAXE:			Defines the upper limit of the prob distribution of Expected Unserved Energy, in MWHRS.
II:	0	=	Transmission mod results are not printed.
	1	=	Transmission mod results are printed into file TRAOUT.
IJ:	0	=	Only final statistics are printed.
	1	=	In addition to final statistics, results after each replication are also printed.
IR:	0	=	Delete DUMP after the run.
	1	=	Retain DUMP after the run.
IN:			Interval, in number of replications, for storing the contents of arrays for restart.
D:	0	=	Input data from INPUTB and INPUTC is not printed.
	1	=	Input data is printed.
M:	0	=	Planned outage schedules are not printed.
	1	=	Planned outage schedules are printed.

Notes:

If the file DUMP exists, it is assumed that this is a restart run.

For a restart, only the following data may be changed over the original run:

1. Title under card ZZTC
2. Convergence parameters CVT and FIN
3. Printout options II, IJ, D and M.

Error Checking:

1. If the number of entries is less than required, an error message is printed and the program is aborted.
2. If seasons are not feasible, an error message is printed and the program is aborted.

Card ZZLD: System Data

The purpose of this card is to specify data which is applicable to a given area. This card has the following format:

ZZLD: SYSTEM DATA. AREA NAME IN FOUR LETTERS.

S.N.	AREA NAME	PEAK (MW)	LFU %	OUTAGE WINDOW BEG WK	END WK	FORBIDDEN BEG WK	PERIOD END WK	SUM OF FLOWS CONSTRAINT

Where:

S.N. = Serial Number.

The serial number in this and subsequent types of cards identifies each entry uniquely and specifies the sequence of data entries. After reading, the data entries are arranged by the program in the sequence specified under SN. The serial number can have up to three decimal places. This helps in deleting lines and inserting new lines through INPUTC file.

Area Name = The name of the area. It can have up to four letters and must be enclosed by quotes.

Peak = Annual peak in the area, in MW.

LFU% = Load forecast uncertainty, one standard deviation expressed as percentage of the mean

Outage Window = The weeks during which planned maintenance can be performed.
BEG WK: Beginning week of the outage window
END WK: Ending week of the outage window

Forbidden Period = A part of the outage window during which planned maintenance is not allowed.

Sum of Flows Constraint = The algebraic sum of flows at this node is not to exceed this value.

Example: If outage window is 2 to 50 weeks and the forbidden period is 31 to 32, then planned maintenance can be performed from 2 to 30 and 33 to 50 week.

Notes: The restrictions on outage window and forbidden period apply only if the program schedules the units (Automatic mode in ZZUD) for planned maintenance. If predetermined scheduling is used, then these restrictions do not apply.

Error Checking:

An error message is printed and the program is aborted for the following errors:

1. If the number of entries in any row is fewer than required
2. If the S.N. are not in sequentially ascending order in INPUTB
3. If the peak load is negative or greater than 90000 MW
4. If load forecast uncertainty is negative or greater than 20
5. If the beginning of outage window is before week 1 or ending after 52
6. If the forbidden period falls outside the outage window

Card ZZUD: Unit Data

The purpose of this card is to specify data for each unit. The following format is used:

S.N. UN NAME LOC CAP1 CAP2 CAP3 CAP4 DFOR FOR DER P/A B1 D1 B2 D2

Where:

S.N.	=	Serial number (see ZZLD)
UN NAME	=	Unit name is six alphanumeric characters. The first four letters are the plant number and the next two numbers identify the unit.
LOC	=	Area of location, up to four letters.
CAPI	=	Unit capacity, MW, in the ith season (see ZZLD)
DFOR	=	Derated forced outage rate
FOR	=	Forced outage rate
DER	=	Percent derating due to partial failure. This is different from the seasonal derating which can be specified using CAPI.
P/A	=	Predetermined (1) or automatic (0) scheduling.
B1,D1	=	Beginning week and duration of the first outage. In the automatic mode B1 is ignored.
B2,D2	=	Beginning week and duration of second outage. In the automatic mode, B2 is ignored.

Notes:

1. In scheduling the planned outages, the program does not take out two units belonging to one plant at the same time. Also the program can accept up to two planned outages per year for each unit.

2. The program schedules units for planned outage by adjusting them into valleys in the load cycle. Therefore for any area having only generation, planned outages must be predetermined by the user.

3. It is possible to mix the automatic and predetermined outages, i.e., the planned outage on some units can be scheduled by the program while the others can be predetermined. However, this mixing can not be done within a given plant.
4. If the program cannot schedule a unit in the automatic mode, it will print a message to indicate this and schedule the unit using B1,D1 and B2,D2 parameters.

Error checking:

A warning is printed for the following conditions:

1. The first SN in INPUTB is not 1

An error message is printed and the program is aborted for the following conditions:

1. Number of entries in INPUTB and INPUTC exceeds 1000
2. Number of entries in any row is fewer than required
3. Area of location of unit does not match any area in ZZLD data
4. If FOR or DFOR is negative or greater than 1
5. If derating is negative or greater than 100
6. If mode of planned outage is mixed (automatic and predetermined) within a plant
7. If the maintenance is automatic but area of location has no load
8. For preplanned maintenance, if B1 is earlier than the beginning of the first outage window or duration is greater than the window
9. For preplanned maintenance, if B2 is earlier than the beginning of the second outage window or duration is greater than the window
10. If the total maintenance time in a plant is greater than the window

Card ZZFC: Firm Contracts

This card is for specifying the firm interchanges of power, MWs, between areas. The following format is used for input of these interchanges:

S.N. FROM AREA TO AREA BEG DAY END DAY MW

Where:

S.N. = Serial number (see description under ZZLD)

From Area = Name of the area sending power

To Area = Name of the area receiving power.

BEG DAY,
END DAY = Beginning and ending days (1 to 365) of the contract.

MW = Magnitude of the firm interchange, MW, during the period.

Notes:

If the contract between any two areas changes over the year, then the year can be divided into periods of fixed interchange. Then there will be more than one entry for the given pair of areas. The total number of entries must not exceed 1000.

Error checking:

A warning is printed for the following conditions:

1. The first S.N. in INPUTB is not 1

An error is printed and the program is aborted for the following conditions:

1. Number of entries in INPUTB and INPUTC exceeds 1000
2. Number of entries in any row is fewer than required
3. "From" or "To" area does not match any area in ZZLD data
4. Impossible beginning or end day
5. Contract greater than 99999 MW

Card ZZOD: Unit Ownership Data

This card is for specifying the joint ownership of a unit by several areas. This card has the following format:

```
S.N.  UN NAME                  PERCENT OWNERSHIP OF AREA
                          1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
```

Where:

S.N. = Serial number (see ZZLD for description)

UN NAME = Name of the jointly owned unit

PERCENT
OWNERSHIP
OF AREA I = Percentage owned by area I is specified in 0 to 100.0 range.

Notes:

1. The area number derives from the order of the units under ZZLD.

2. If there are N areas, then percent ownership by every area must be specified. Those areas which do not have ownership should be indicated by 0.0 percent.

3. Maximum permissible number of entries under this card is 600.

Error checking:

An error is printed and the program is aborted for the following conditions:

1. Number of entries in INPUTB and INPUTC is greater than 1000
2. Number of percentage entries is fewer than number of areas
3. A jointly owned unit does not exist in ZZUD data
4. Ownership of a unit does not sum to 100 percent
5. Number of jointly owned units is greater than 600

<u>Card ZZTD: Line Data</u>

The purpose of this card is to specify the data for transmission links. The format for this card is as follows:

```
S.N.   LINE NUMBER   FROM  TO  ADM  CAP  CAPR  PROB  (STATE 1)
                               ADM  CAP  CAPR  PROB  (STATE 2)
                               ADM  CAP  CAPR  PROB  (STATE 3)
                               ADM  CAP  CAPR  PROB  (STATE 4)
                               ADM  CAP  CAPR  PROB  (STATE 5)
                               ADM  CAP  CAPR  PROB  (STATE 6)
```

S.N. = Serial number (see ZZLD for description)

Line Number = Line number assigned to the transmission link

From, To = Names of the originating and terminating areas for this line.

ADM, CAP,
CAPR, PROB
(STATE I) = Admittance (negative number), capacity of the line

from originating to terminating area, capacity of the link in the reverse direction and the probability of the line in State I. This set of data must be specified for all of the 6 States. If there are less than six states, zeros should be inserted for remaining states. The probabilities should add to 1.0.

Error checking:

An warning is printed for the following conditions:

1. First S.N. in ZZTD data in INPUTB is not 1

An error is printed and the program is aborted for the following conditions:

1. Number of entries in INPUTB and INPUTC exceeds 1000
2. "From" or "To" area does not match any area in ZZLD
3. Admittance is entered positive
4. Capacity is entered negative
5. Probabilities do not add to 1

Card ZZDD: Line Derating Data

Status of certain units can effect the line rating. For a given line, four units can be specified in a combination such that if all the units in the combination are down, then the line ratings will be multiplied by the derating factors. For a given line, more than one combination can be specified.

The following format is used:

```
ZZDD:  LINE DERATING DATA
S.N.    LINE NUMBER    UNITS DERATING THIS LINE       DERATING FACTORS
                        UNIT1 UNIT2 UNIT3 UNIT4       FORWARD BACKWARD
```

Where:

S.N. = Serial number (see descriptions under ZZLD)

Line Numbers = Transmission link number

Units Derating This Line = Names of units which effect the derating. There must be four entries. If there are less than four units in a combination, then use "xx" for the fictitious members of the combination. The program does expect four entries in a combination.

Notes: The maximum permissible number of entries under this card is 50.

Error checking:

A warning is printed for the following conditions:

1. First S.N. in ZZDD data in INPUTB is not 1

An error is printed and the program is aborted for the following conditions:

1. Number of entries in INPUTB and INPUTC exceeds 1000
2. One of the four units can not be identified either as a unit under ZZUD or as "xx"
3. A line number can not be identified with data under ZZTD
4. If total number of line deratings is greater than 50

Card ZZND: Terminating Card

Any information after this is not read by the program.

INPUT C

7.3 FILE INPUTC

This file is used to modify the INPUTB file for a particular run. In skeleton form, INPUTC is identical to INPUTB. The following operations can be performed using INPUTC.

(i) Delete lines
(ii) Change lines
(iii) Insert new lines

These operations must be performed under the proper card type.

The following operations can be performed for one or more than one line.

Deleting A Line

For ZZTC and ZZMC, the data lines in INPUTC simply overwrite the corresponding lines in INPUTB. Therefore, delete function is not needed for these cards. For other cards, type 0 followed by a blank followed by the S.N. of the entry which is to be deleted. For example 0 2 typed under ZZLD of INPUTC will delete the entry corresponding to SN = 2 under ZZLD of INPUTB.

Changing/Inserting A Line

A line can be overwritten or a new line inserted by using an appropriate SN. For example a line with SN = 2 under ZZUD in INPUTC will overwrite the line with SN = 2 under ZZUD in INPUTB. As another example a line with SN = 1.3 under ZZUD in INPUTC will be inserted between lines with SN = 1 and SN = 2 under ZZUD in INPUTB.

LEEI

7.4 FILE LEEI

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This file contains hourly load data for each area for 8760 hours of the year. The program accepts the data in MW in the EEI format (20x, 12I5). The MW values are then internally converted into per unit values.

Data for different areas is stored sequentially, i.e., first the complete data for area one is input, then the data for area 2 and so on.

For each area, first line is area identification in (A4, 1X, A4) format as

AREA:NAME

The area name is as specified in ZZLD data. This is then followed by area MW data in the EEI format. After reading AREA:NAME, the program checks the day and month in the first line. If the day and month are 0101, then the program reads the remaining data. If the day and month are 9999, then the program assumes that load is 0 for this area and does not expect any more data for this area.

Error checking:

An error is printed and program aborted for the following conditions:

1. Area name does not match with one in ZZLD data
2. If data type is unexpected or if end of data is unexpected
3. If the end of file is encountered unexpected
4. Beginning of data does not correspond to January 1

7.5 FILE TRAOUT

Results of the transmission module are printed out in this file. For each call to the optimization module, the following results are printed out.

(i) LCLOCK, JHOUR and JFLAG in format (5X, I8, 2X, I4, 2X, I1)

where

LCLOCK = Clock time in hours since the start of simulation

JHOUR = Clock time in hours since the start of current replication, each replication having 8760 hours.

JFLAG = 0, if feasible scheduled flows are being determined (Step 1, Sec. 6.4.2)

= 1, if emergency transfers are being calculated

(ii) Units on outage, derated and planned maintenance
The first number indicats the number of units which is followed by the identification of units. The derated units have a negative sign.

(iii) If JFLAG = 0, then the following information is printed

(a) N lines with five numbers in each line in format (5X, F3.0, 4{F10.2, 2X}). Here N is the number of areas and the five numbers are:

Number 1: Area number
Number 2: Scheduled transfer
Number 3: Feasible transfer
Number 4: Generation in the area
Number 5: Area load

(b) NL lines with seven numbers in each line in format (5X, 3{I3, 2X}, 4{F8.0, 2X}). Here NL is the number of tie lines and the seven numbers are:

Number 1: Line number
Number 2: Originating area
Number 3: Terminating area
Number 4: Line admittance
Number 5: Line capacity in forward direction
Number 6: Line capacity in backward direction
Number 7: Flow, in MW

(iv) If JFLAG = 1

(a) N lines with six numbers in each line in format (5X, F3.0, 4{F8.0, 5X}). Here N is the number of areas and the six numbers are:

Number 1: Area number
Number 2: Injections at areas after optimization

Number 3: Amount of injection curtailed for no load-loss sharing and loads curtailed for load-loss sharing option.
Number 4: Injections at areas before optimization
Number 5: Area loads
Number 6: Sum of flow constraint

(b) NL lines with seven numbers in each line in format (5X, 3{I3, 2X}, 4(F8.0, 2X). Here NL is the number of lines and the seven numbers are:

Number 1: Line number
Number 2: Originating area
Number 3: Terminating area
Number 4: Line admittance
Number 5: Line capacity in forward direction (modified for NLS)
Number 6: Line capacity in backward direction (modified for NLS)
Number 7: Flow, in MW

Note: These numbers should be interpreted in the light of Sec. 6.4.2.

7.6 FILE OUTPUT

The output file can be divided into the following sections:

1. A set of tables presenting the input data
2. A set of tables of planned maintenance for each area
3. A set of tables giving results after each replication
4. A set of tables giving the final statistics and their probability distributions.

These sections can be printed selectively by choosing IJ, D and M options in ZZMC data.

<u>Section 1</u>

There is one table in this section corresponding to each card in INPUTB File. The first two tables are not numbered, the remaining tables are numbered sequentially. The data in tables is arranged under descriptive headings and is easily understood.

Section 2

There is one table indicating planned maintenance for each area. For each unit the period of planned maintenance is displayed either by A (if scheduled by the program) or by P if prescheduled.

Each table of planned maintenance is preceded by the display of weekly peaks for that area. Similarly after the table, the weekly peaks plus the capacity on maintenance are displayed.

Section 3

This section is not printed if IJ = 0, in INPUTB. There is one table for each replication. This table gives all the statistics (hourly as well as daily) for each area if STEP=1 in ZZMC. If STEP=24 then only the daily statistics are printed. These statistics are further displayed for each forecast scenario as well as the weighted average of all the forecast scenarios. The number of forecast scenarios is one if the load forecast uncertainty is zero. Otherwise, there are five forecast scenarios. Further for each forecast scenario, statistics are provided to reflect load-loss events due to generation and transmission constraints separately. The indices due to the combined effect are also provided.

The pool statistics are also presented in the same manner as the area statistics.

Section 4

This section first gives a table in the same format as in Section 3. This table gives the final results.

The next table provides a summary of the final statistics and the standard deviations of the HLOLE, EUE and LOLE for each area and the pool. This is then followed by several tables giving the probability distributions of the statistics for each area and the pool.

7.7 FILE INTMDT combined of B and C files

The files INPUTB and INPUTC are combined and the resulting information is contained in INTMDT. The sequence of data in INTMDT is the same as in INPUTB. The text type information is, however, converted into numeric information. All unit names and area names are assigned numbers.

7.8 CONVERGENCE MONITOR

The output of convergence monitor is written onto I/O unit 1. Testing for convergence is started on the sixth replication and then repeated for each subsequent replication. There is only one line for each replication for the first five years. The five numbers in this line are WHERE, WHEN, KVS, KVT and KVL (see ZZMC). There are four lines for each of the subsequent replications and they are formatted as below.

Line 1.

KVS: WHERE WHEN KVS KVT KVL

Line 2.

In this line, the number of years of simulation is printed along with the sum of the statistic over these years.

Line 3.

NEW: This is the statistic for the most recent replication.

XMEAN: Estimate of the statistic, i.e. sum/number of replications.

Line 4.

STD ERR: Standard deviation of the estimate

CONV THRSH: CVTX XMEAN.

If at the end of any replication, STDERR < CONV THRSH, then the following message is printed:

SIMULATION CONVERGED
STD ERR = CONV THRSH =

7.9 File DUMP

This file contains the contents of arrays required for a restart. This file is updated every IN (see ZZMC) replications.

8.0 SAMPLE SYSTEM STUDY

The INPUTB file for a sample system of three areas is shown in Figure 1. The three areas are called A1, A2 and A3. There are thirty-two units in each area.

The INPUTC file for the sample system is shown in Figure 2 and the output results are shown in Figure 3.

FIGURE 1.

File INPUT B

NOTE:ANY INFORMATION BEFORE ZZTC AND AFTER ZZND IS IGNORED.

ZZTC:TITLE CARD

S.N.	DESCRIPTION
1	THIS IS A THREE AREA SYSTEM
2	EACH AREA IS IDENTICAL TO THE IEEE-RTS
3	PLANNED MAINTENANCE IS CONSIDERED

ZZMC:MISCELLANEOUS. LOSS SHARING=0 NO LOSS SHARING=1

SEED	LS	END WKS W1	W2	W3	WHERE	WHEN	KVS	KVT	KVL	CVT	FIN	STEP	FREQ	MAXE	II	IJ	IR	IN	D	M
1345237	1	13	26	39	1	1	1	1	1	0	1000	1	1	1000	0	0	0	5	0	0

ZZLD:SYSTEM DATA. AREA NAME IN FOUR LETTERS.

S.N.	AREA NAME	PEAK (MW)	LFU %	OUTAGE WINDOW BEG WK	END WK	FORBIDDEN PERIOD BEG WK	END WK	SUM OF FLOWS CONSTRAINT
1.	'A1'	3000	0	1	52	31	32	1200.
2.	'A2'	3000	0	1	52	31	32	1200.
3.	'A3'	3000	0	1	52	31	32	1200.

ZZUD:UNIT DATA

UN NAME -UNIT NAME IN SIX LETTERS.FIRST FOUR LETTERS ARE THE PLANT NUMBER AND NEXT TWO NUMBERS IDENTIFY THE UNIT.

LOC - AREA OF LOCATION,FOUR LETTERS.

CAPI - UNIT CAPACITY DURING ITH SEASON.

DFOR - DERATED FORCED OUTAGE RATE.

FOR - FORCED OUTAGE RATE.

DER - PERCENT DERATING.

P/A -PREDETERMINED(1) OR AUTOMATIC(0) SCHEDULING.

B1,D1 - BEGINNING WEEK AND DURATION OF FIRST OUTAGE.

B2,D2 -BEGINNING WEEK AND DURATION OF SECOND OUTAGE.

S.N.	UN NAME	LOC	CAP1	CAP2	CAP3	CAP4	DFOR	FOR	DER	P/A	B1	D1	B2	D2
1	'A10101'	'A1'	12	12	12	12	0.	0.020	0	0	9	2	0	0
2	'A10201'	'A1'	12	12	12	12	0.	0.020	0	0	26	2	0	0
3	'A10301'	'A1'	12	12	12	12	0.	0.020	0	0	33	2	0	0
5	'A10501'	'A1'	12	12	12	12	0.	0.020	0	0	41	2	0	0
6	'A10601'	'A1'	20	20	20	20	0.	0.100	0	0	9	2	0	0
4	'A10401'	'A1'	12	12	12	12	0.	0.020	0	0	38	2	0	0
7	'A10701'	'A1'	20	20	20	20	0.	0.100	0	0	10	2	0	0
8	'A10801'	'A1'	20	20	20	20	0.	0.100	0	0	10	2	0	0
9	'A10901'	'A1'	20	20	20	20	0.	0.100	0	0	33	2	0	0
10	'A11001'	'A1'	50	50	50	50	0.	0.010	0	0	16	2	0	0
11	'A11101'	'A1'	50	50	50	50	0.	0.010	0	0	21	2	0	0
12	'A11201'	'A1'	50	50	50	50	0.	0.010	0	0	27	2	0	0
13	'A11301'	'A1'	50	50	50	50	0.	0.010	0	0	31	2	0	0
14	'A11401'	'A1'	50	50	50	50	0.	0.010	0	0	38	2	0	0
15	'A11501'	'A1'	50	50	50	50	0.	0.010	0	0	41	2	0	0
16	'A11601'	'A1'	76	76	76	76	0.	0.020	0	0	0	2	0	0
17	'A11701'	'A1'	76	76	76	76	0.	0.020	0	0	15	2	0	0
18	'A11801'	'A1'	76	76	76	76	0.	0.020	0	0	30	2	0	0
19	'A11901'	'A1'	76	76	76	76	0.	0.020	0	0	34	2	0	0
20	'A12001'	'A1'	100	100	100	100	0.	0.040	0	0	20	2	0	0
21	'A12101'	'A1'	100	100	100	100	0.	0.040	0	0	27	2	0	0

22	'A12201'	'A1'	100	100	100	100	0.	0.040	0	0	41	2	0	0
23	'A12301'	'A1'	155	155	155	155	0.	0.040	0	0	6	2	0	0
24	'A12401'	'A1'	155	155	155	155	0.	0.040	0	0	11	2	0	0
25	'A12501'	'A1'	155	155	155	155	0.	0.040	0	0	26	2	0	0
26	'A12601'	'A1'	155	155	155	155	0.	0.040	0	0	36	2	0	0
27	'A12701'	'A1'	197	197	197	197	0.	0.050	0	0	8	2	0	0
28	'A12801'	'A1'	197	197	197	197	0.	0.050	0	0	15	2	0	0
29	'A12901'	'A1'	197	197	197	197	0.	0.050	0	0	40	2	0	0
30	'A13001'	'A1'	350	350	350	350	0.	0.080	0	0	31	2	0	0
31	'A13101'	'A1'	400	400	400	400	0.	0.120	0	0	10	2	0	0
32	'A13201'	'A1'	400	400	400	400	0.	0.120	0	0	35	2	0	0
33	'A20101'	'A2'	12	12	12	12	0.	0.020	0	0	9	2	0	0
34	'A20201'	'A2'	12	12	12	12	0.	0.020	0	0	26	2	0	0
35	'A20301'	'A2'	12	12	12	12	0.	0.020	0	0	33	2	0	0
36	'A20401'	'A2'	12	12	12	12	0.	0.020	0	0	38	2	0	0
37	'A20501'	'A2'	12	12	12	12	0.	0.020	0	0	41	2	0	0
38	'A20601'	'A2'	20	20	20	20	0.	0.100	0	0	9	2	0	0
39	'A20701'	'A2'	20	20	20	20	0.	0.100	0	0	10	2	0	0
40	'A20801'	'A2'	20	20	20	20	0.	0.100	0	0	10	2	0	0
41	'A20901'	'A2'	20	20	20	20	0.	0.100	0	0	33	2	0	0
42	'A21001'	'A2'	50	50	50	50	0.	0.010	0	0	16	2	0	0
43	'A21101'	'A2'	50	50	50	50	0.	0.010	0	0	21	2	0	0
44	'A21201'	'A2'	50	50	50	50	0.	0.010	0	0	27	2	0	0
45	'A21301'	'A2'	50	50	50	50	0.	0.010	0	0	31	2	0	0
46	'A21401'	'A2'	50	50	50	50	0.	0.010	0	0	38	2	0	0
47	'A21501'	'A2'	50	50	50	50	0.	0.010	0	0	41	2	0	0
48	'A21601'	'A2'	76	76	76	76	0.	0.020	0	0	0	2	0	0
49	'A21701'	'A2'	76	76	76	76	0.	0.020	0	0	15	2	0	0
50	'A21801'	'A2'	76	76	76	76	0.	0.020	0	0	30	2	0	0
51	'A21901'	'A2'	76	76	76	76	0.	0.020	0	0	34	2	0	0
52	'A22001'	'A2'	100	100	100	100	0.	0.040	0	0	20	2	0	0
53	'A22101'	'A2'	100	100	100	100	0.	0.040	0	0	27	2	0	0
54	'A22201'	'A2'	100	100	100	100	0.	0.040	0	0	41	2	0	0
55	'A22301'	'A2'	155	155	155	155	0.	0.040	0	0	6	2	0	0
56	'A22401'	'A2'	155	155	155	155	0.	0.040	0	0	11	2	0	0
57	'A22501'	'A2'	155	155	155	155	0.	0.040	0	0	26	2	0	0
58	'A22601'	'A2'	155	155	155	155	0.	0.040	0	0	36	2	0	0
59	'A22701'	'A2'	197	197	197	197	0.	0.050	0	0	8	2	0	0
60	'A22801'	'A2'	197	197	197	197	0.	0.050	0	0	15	2	0	0
61	'A22901'	'A2'	197	197	197	197	0.	0.050	0	0	40	2	0	0
62	'A23001'	'A2'	350	350	350	350	0.	0.080	0	0	31	2	0	0
63	'A23101'	'A2'	400	400	400	400	0.	0.120	0	0	10	2	0	0
64	'A23201'	'A2'	400	400	400	400	0.	0.120	0	0	35	2	0	0
65	'A30101'	'A3'	12	12	12	12	0.	0.020	0	0	9	2	0	0
66	'A30201'	'A3'	12	12	12	12	0.	0.020	0	0	26	2	0	0
67	'A30301'	'A3'	12	12	12	12	0.	0.020	0	0	33	2	0	0
68	'A30401'	'A3'	12	12	12	12	0.	0.020	0	0	38	2	0	0
69	'A30501'	'A3'	12	12	12	12	0.	0.020	0	0	41	2	0	0
70	'A30601'	'A3'	20	20	20	20	0.	0.100	0	0	9	2	0	0
71	'A30701'	'A3'	20	20	20	20	0.	0.100	0	0	10	2	0	0
72	'A30801'	'A3'	20	20	20	20	0.	0.100	0	0	10	2	0	0
73	'A30901'	'A3'	20	20	20	20	0.	0.100	0	0	33	2	0	0
74	'A31001'	'A3'	50	50	50	50	0.	0.010	0	0	16	2	0	0
75	'A31101'	'A3'	50	50	50	50	0.	0.010	0	0	21	2	0	0
76	'A31201'	'A3'	50	50	50	50	0.	0.010	0	0	27	2	0	0
77	'A31301'	'A3'	50	50	50	50	0.	0.010	0	0	31	2	0	0
78	'A31401'	'A3'	50	50	50	50	0.	0.010	0	0	38	2	0	0
79	'A31501'	'A3'	50	50	50	50	0.	0.010	0	0	41	2	0	0
80	'A31601'	'A3'	76	76	76	76	0.	0.020	0	0	0	2	0	0
81	'A31701'	'A3'	76	76	76	76	0.	0.020	0	0	15	2	0	0
82	'A31801'	'A3'	76	76	76	76	0.	0.020	0	0	30	2	0	0

```
 83  'A31901'  'A3'  76    76    76    76     0.   0.020  0    0  34   2  0  0
 84  'A32001'  'A3' 100   100   100   100     0.   0.040  0    0  20   2  0  0
 85  'A32101'  'A3' 100   100   100   100     0.   0.040  0    0  27   2  0  0
 86  'A32201'  'A3' 100   100   100   100     0.   0.040  0    0  41   2  0  0
 87  'A32301'  'A3' 155   155   155   155     0.   0.040  0    0   6   2  0  0
 88  'A32401'  'A3' 155   155   155   155     0.   0.040  0    0  11   2  0  0
 89  'A32501'  'A3' 155   155   155   155     0.   0.040  0    0  26   2  0  0
 90  'A32601'  'A3' 155   155   155   155     0.   0.040  0    0  36   2  0  0
 91  'A32701'  'A3' 197   197   197   197     0.   0.050  0    0   8   2  0  0
 92  'A32801'  'A3' 197   197   197   197     0.   0.050  0    0  15   2  0  0
 93  'A32901'  'A3' 197   197   197   197     0.   0.050  0    0  40   2  0  0
 94  'A33001'  'A3' 350   350   350   350     0.   0.080  0    0  31   2  0  0
 95  'A33101'  'A3' 400   400   400   400     0.   0.120  0    0  10   2  0  0
 96  'A33201'  'A3' 400   400   400   400     0.   0.120  0    0  35   2  0  0


ZZFC:FIRM CONTRACTS. AREA INDICATED BY FOUR LETTERS.
S.N.  FROM  AREA   TO  AREA   BEG   DAY   END  DAY    MW
 1.   'A1'         'A2'        1          365         100
 2.   'A2'         'A3'        1          365         100
 3.   'A3'         'A1'        1          365         100
ZZOD:UNIT OWNERSHIP DATA
S.N.     UN NAME                        PERCENT OWNERSHIP OF AREA
                      1  2  3  4  5  6  7  8  9  10  11  12  13  14  15
 1       'A13101'    50 25 25
 2       'A23101'    25 50 25
 3       'A33101'    25 25 50


ZZTD:LINE DATA
S.N.     LINE NUMBER   FROM  TO   ADM  CAP  CAPR  PROB (STATE 1)
                                  ADM  CAP  CAPR  PROB (STATE 2)
                                  ADM  CAP  CAPR  PROB (STATE 3)
                                  ADM  CAP  CAPR  PROB (STATE 4)
                                  ADM  CAP  CAPR  PROB (STATE 5)
                                  ADM  CAP  CAPR  PROB (STATE 6)

 1            1        'A1' 'A2' -120. 300. 300.   0.5
                                 -100. 250. 250.   0.1
                                  -80. 200. 200.   0.1
                                  -60. 150. 150.   0.1
                                  -40. 100. 100.   0.1
                                  -20.  50.  50.   0.1
 2            2        'A1' 'A3' -120. 300. 300.   0.5
                                 -100. 250. 250.   0.1
                                  -80. 200. 200.   0.1
                                  -60. 150. 150.   0.1
                                  -40. 100. 100.   0.1
                                  -20.  50.  50.   0.1
 3            3        'A2' 'A3' -120. 300. 300.   0.5
                                 -100. 250. 250.   0.1
                                  -80. 200. 200.   0.1
                                  -60. 150. 150.   0.1
                                  -40. 100. 100.   0.1
                                  -20.  50.  50.   0.1


ZZDD:LINE DERATING DATA
S.N.   LINE NUMBER   UNITS DERATING THIS LINE      DERATING FACTORS
                     UNIT1  UNIT2  UNIT3  UNIT4    FORWARD  BACKWARD
```

```
1.      1          'A11001'  'A11101'  'XX'  'XX'    .9      .9
2.      2          'A31001'  'A31101'  'XX'  'XX'    .9      .9
3.      3          'A21001'  'A21101'  'XX'  'XX'    .9      .9

ZZND:TERMINATING CARD

DESCRIPTION OF VARIABLES IN CARD ZZMC
-------------------------------------
-------------------------------------
 VARIABLES FOR CONVERGENCE TEST:
  KWHERE : 1 = AREA (TO BE SPECIFIED)
           2 = POOL

  WVWHEN : 1 = HOURLY STATISTICS
           2 = PEAK STATISTICS

  KVSTAT : 1 = LOLE
           2 = EUE (USED ONLY WITH HOURLY STATS)

  KVTYPE : 1 = WEIGHTED AVERAGE OF STATS, CONSIDERING FORECAST ERROR)
           2 = USE ONLY THE NO FORECAST ERROR STATISTIC

   KVLOC : AREA NUMBER (USED ONLY IF KWHERE = 1)

  CVTEST : 0 = STOP WHEN STANDARD DEVIATION OF THE TESTED STATISTIC
               IS LESS THAN (.025*MEAN),I.E.,WHEN WE ARE 95% CONFIDENT
               THE ESTIMATE IS WITHIN 5% OF TRUE VALUE.
          >0 = STOP WHEN STANDARD DEVIATION IS LESS THAN CVTEST.

  FIN    : TIME TO END SIMULATION IF NO CONVERGENCE. IT SHOULD BE
           MULTIPLE OF 8760.

 OTHER VARIABLES:
  STEP : 1 = COLLECT STATS EVERY HOUR.
        24 = DAILY PEAK STATS ONLY.

  FREQ : 1 = USE HOURLY MONTE CARLO DRAWS OF GENERATOR AND LINE STATUS.
        24 = USE DAILY MONTE CARLO DRAWS.

  MAXE   : DEFINES THE UPPER LIMIT OF THE PROB DISTRIBUTION OF EUE.

  II     : 0 = DO NOT PRINT TRANSMISSION MOD RESULTS.
           1 = PRINT TRANSMISSION MOD RESULTS.

  IJ     : 0 = DO NOT PRINT AFTER EACH REPLICATION

  IR     : 0 =DELETE DUMP AFTER THE RUN
           1 = RETAIN DUMP AFTER THE RUN

  IN     :     INTERNAL, IN NUMBER OF REPLICATIONS, FOR STORING
               THE CONTENTS OF ARRAYS FOR RESTART.
           1 = PRINT AFTER EACH REPLICATION

  D      : 0 = DO NOT PRINT INPUT DATA
           1 = PRINT INPUT DATA

  M      : 0 = DO NOT PRINT PLANNED OUTAGE SCHEDULES
           1 = PRINT PLANNED OUTAGE SCHEDULES
```

FIGURE 2.

File INPUT C

```
NOTE:ANY INFORMATION INCLUDED BEFORE ZZTC AND AFTER ZZND IS IGNORED BY THE
PROGRAM.
ZZTC:TITLE CARD
S.N.                 DESCRIPTION           [new STUART NELSON LINK Z & CAPS]

ZZMC:MISCELLANEOUS. LOSS SHARING=0 NO LOSS SHARING=1
SEED    LS  END WKS WHERE WHEN KVS KVT KVL CVT FIN STEP FREQ MAXE II IJ IR IN D M
          W1 IW2 IW3

ZZLD:SYSTEM DATA. AREA NAME IN FOUR LETTERS.
S.N.  AREA NAME      PEAK  LFU  OUTAGE WINDOW    FORBIDDEN PERIOD   SUM OF FLOWS
                     (MW)    %  BEG WK  END WK    BEG WK  END WK     CONSTRAINT

ZZUD:UNIT DATA
UN NAME - UNIT NAME IN SIX LETTERS.  FIRST FOUR LETTERS ARE THE PLANT NUMBER
AND NEXT TWO NUMBERS IDENTIFY THE UNIT.
LOC - AREA OF LOCATION, FOUR LETTERS.
CAPI - UNIT CAPACITY DURING I-TH SEASON.
DFOR - DERATED FORCED OUTAGE RATE.
FOR - FORCED OUTAGE RATE.
DER - PERCENT DERATING.
P/A - PREDETERMINED (1) OR AUTOMATIC (0) SCHEDULING.
B1, D1 - BEGINNING WEEK AND DURATION OF FIRST OUTAGE.
B2, D2 - BEGINNING WEEK AND DURATION OF SECOND OUTAGE.
S.N. UN NAME  LOC    CAP1  CAP2  CAP3  CAP4  DFOR  FOR  DER   P/A  B1  D1 B2 D2

ZZFC:FIRM CONTRACTS. AREA INDICATED BY FOUR LETTERS.  CONTRACT  LOAD FLOW
S.N.  FROM  AREA   TO  AREA    BEG  DAY   END  DAY       MW          MW

ZZOD:UNIT OWNERSHIP DATA
S.N.      UN NAME                     PERCENT OWNERSHIP OF AREA
                    1   2   3   4   5   6   7   8   9  10  11  12  13  14  15

ZZTD:LINE DATA
S.N.      LINE NUMBER   FROM  TO  ADM  CAP  CAPR  PROB (STATE 1)
                                  ADM  CAP  CAPR  PROB (STATE 2)
                                  ADM  CAP  CAPR  PROB (STATE 3)
                                  ADM  CAP  CAPR  PROB (STATE 4)
                                  ADM  CAP  CAPR  PROB (STATE 5)
                                  ADM  CAP  CAPR  PROB (STATE 6)

ZZDD:LINE DERATING DATA
S.N.   LINE NUMBER    UNITS DERATING THIS LINE             DERATING FACTORS
                  UNIT1    UNIT2    UNIT3    UNIT4         FORWARD  BACKWARD

ZZND:TERMINATING CARD

DESCRIPTION OF VARIABLES IN CARD ZZMC
-------------------------------------
 VARIABLES FOR CONVERGENCE TEST:
  KWHERE : 1 = AREA (TO BE SPECIFIED)
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  KVSTAT : 1 = LOLE
           2 = EUE (USED ONLY WITH HOURLY STATS)

  KVTYPE : 1 = WEIGHTED AVERAGE OF STATS, CONSIDERING FORECAST ERROR)
           2 = USE ONLY THE NO FORECAST ERROR STATISTIC
```

```
 KVLOC : AREA NUMBER (USED ONLY IF KWHERE = 1)

CVTEST : O = STOP WHEN STANDARD DEVIATION OF THE TESTED STATISTIC
             IS LESS THAN (.025*MEAN),I.E.,WHEN WE ARE 95% CONFIDENT
             THE ESTIMATE IS WITHIN 5% OF TRUE VALUE.
        >O = STOP WHEN STANDARD DEVIATION IS LESS THAN CVTEST.

FIN    : TIME TO END SIMULATION IF NO CONVERGENCE. IT SHOULD BE
         MULTIPLE OF 8760.

OTHER VARIABLES:
STEP : 1 = COLLECT STATS EVERY HOUR.
      24 = DAILY PEAK STATS ONLY.

FREQ : 1 = USE HOURLY MONTE CARLO DRAWS OF GENERATOR AND LINE STATUS.
      24 = USE DAILY MONTE CARLO DRAWS.

MAXE  : DEFINES THE UPPER LIMIT OF THE PROB DISTRIBUTION OF EUE.

II    : O = DO NOT PRINT TRANSMISSION MOD RESULTS.
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IJ    : O = DO NOT PRINT AFTER EACH REPLICATION

IR     : O =DELETE DUMP AFTER THE RUN
         1 = RETAIN DUMP AFTER THE RUN

IN     :     INTERNAL, IN NUMBER OF REPLICATIONS, FOR STORING
             THE CONTENTS OF ARRAYS FOR RESTART.
         1 = PRINT AFTER EACH REPLICATION

D     : O = DO NOT PRINT INPUT DATA
        1 = PRINT INPUT DATA

M     : O = DO NOT PRINT PLANNED OUTAGE SCHEDULES
        1 = PRINT PLANNED OUTAGE SCHEDULES
```

FIGURE 3.

File OUTPUT