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Research Report
ISSN 0167-9708
Coden: TEUEDE

Eindhoven
University of Technology
Netherlands

Faculty of Electrical Engineering

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EUT Report 95-E-287
ISBN 90-6144-287-7
March 1995

Eindhoven University of Technology Research Reports

EINDHOVEN UNIVERSITY OF TECHNOLOGY

Faculty of Electrical Engineering
Eindhoven, The Netherlands

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CIP-DATA KONINKLIJKE BIBLIOTHEEK, DEN HAAG

Liao, Boshu

Reliability analysis of auxiliary electrical systems and generating units / by Boshu Liao, P. Massee. - Eindhoven : Eindhoven University of Technology, Faculty of Electrical Engineering. - Fig., tab. - (EUT report, ISSN 0167-9708; 95-E-287)
With ref.
ISBN 90-6144-287-7
NUGI 832
Subject headings: electric power stations ; reliability / auxiliary electrical systems ; power plants.

Reliability analysis of auxiliary electrical systems and generating units

Boshu Liao and P. Massee

Abstract
A reliability analysis is applied to the auxiliary electrical system for a generating unit in a base load power station. Several designs for the auxiliary electrical system are possible and the only meaningful way to select the optimum design is by means of reliability indices. In this report the first step in this direction has been taken. In the analysis failures of all kinds of elements such as relays, motors, bus bars etc. are taken into account besides ageing of elements and preventive maintenance. Because of the fact that large motors are present in the system, this is sensitive to voltage dips and therefore the computerprogram REANIPOS has been used for the reliability analysis.

Keywords: electric power stations; reliability/auxiliary electrical systems; power plants.

- Liao, Boshu and P. Massee
  Reliability analysis of auxiliary electrical systems and generating units.
  Eindhoven: Faculty of Electrical Engineering, Eindhoven University of Technology, 1995.
  EUT Report 95-E-287

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1 INTRODUCTION

The generating units play a very important role in electric power systems. The reliability of the units is of vital importance for the reliability of the electric power system. The availability of the generating units is the fundamental element in reliability analysis of the generating systems. It is well known that the availability of a generating unit decreases as the rating of the unit increases. Some large units have very high unavailability, it is not uncommon that a large generating unit has unavailability as high as 20 % [1,2]. The cost of forced-outage of a large generating unit is rather high. It was estimated that the capital cost of one percent increase in forced-outage-rate of a 500 MW nuclear unit was in the order of $10,000,000. The cost of the forced-outage of generating units are so high that the reliability analysis of the units as well as their components or sub-systems is necessary in order to inspect and/or to improve the reliability of the units both in the design phase and operation phase of generating units.

In the reliability evaluation of the generating systems or the bulk power systems, the generating units are usually considered as two or more state components in order to simplify the systems. The reliability data of generating units can be searched from various ways. One way to get the data is to survey the failure reports of similar generating units[9,10].

Generating units are very complex systems themselves. A generating unit has its own sub-systems which have their sub-systems too. The sub-systems of a generating unit have their own failures. Some failures of the sub-systems immediately lead the unit to a forced-outage and others do not lead the unit to a forced-outage but worsen the condition of the operation. The failures of all sub-systems and components contribute to the unavailability of the generating unit . Therefore, in order to analyze the reliability of the generating unit, the unit is considered as a system instead of a component; the reliability of the system is calculated due to the failures of its subsystems.

One of the subsystems of a generating unit is the auxiliary electrical system of the unit. Although the failure of the auxiliary electrical system is only one factor of the unavailability of the generating unit, it is nevertheless one of the most difficult factors to evaluate due to the complexity of the system and the consequences that the unit experiences due to the failures of the auxiliary electrical system.

Basically an auxiliary electrical system is not very different from a distribution substation. The main difference is that all loads in the auxiliary electrical system serve its generating unit while the loads in a substation serve for different plants or appliances. Many research work has been done and published about the reliability analysis of the electric distribution systems or substations. Some research studies are specialized on the reliability analysis of the auxiliary electrical systems, but seldom the work is performed with the Monte Carlo Simulation.

A computer program for reliability analysis of industrial power systems [3] was developed by the Group Electrical Energy Systems, at the Eindhoven University of Technology. In the program called REANIPOS, the Monte Carlo method is combined with the electrical network model. The program REANIPOS was specially developed for industrial power systems, but in some way, it can be modified to analyze the reliability of the generating units and their auxiliary electrical sub-systems.

In this report, the reliability analysis of an auxiliary electrical system as well as the reliability analysis of a generating unit will be discussed.

1-1 The Generating Unit

The large generating unit is a very complex system. A typical thermal generating unit mainly consists of a boiler, a turbine, a generator, a generator transformer, an excitor, a distribution network and a number of circuit breakers. Every main component is supported by its auxiliary system. The mechanical parts of the thermal generating unit are simply shown in Fig 1.1 while the electrical parts are shown in Fig 1.2 .

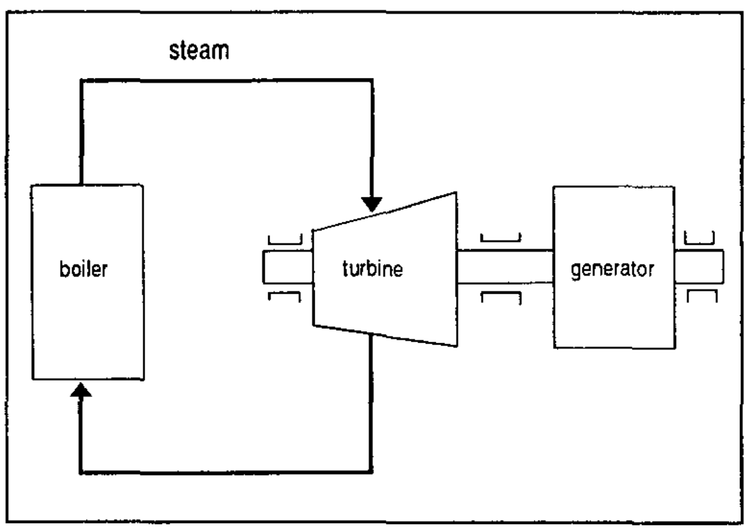

Figure 1.1 The mechanical parts of the thermal generating unit.

1-2 The Auxiliary Electrical System

The main components of the generating unit such as boiler, turbine and generator have their own auxiliary systems. Without their auxiliary systems, the components could not work well. Most equipment in those auxiliary systems is driven by electrical motors. The auxiliary electrical system is the system that supplies energy to those motors and other appliances.

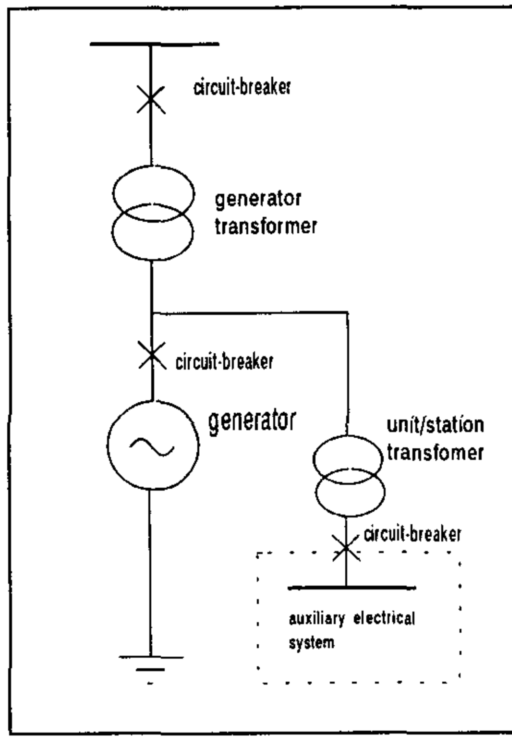

Figure 1.2 The electrical parts of a generating unit.

The equipment in the auxiliary electrical system such as various pumps is classified into two main groups for the purposes of power supply: urgent auxiliaries and service auxiliaries.

The urgent auxiliaries are those directly associated with the running of a unit,such as gas circulator, whose loss would immediately lead to a reduction of the unit output. Some typical urgent auxiliaries are listed below:

Fans, extraction pumps, heater pumps, mills, coal feeders, air pumps, rotary air heaters, water pumps, gas recirculators.

The service auxiliaries are those whose loss would not affect the output of the unit until after a considerable time interval, such as the equipment used for starting up. Usually, the service auxiliaries work for the whole electrical generating station instead of only for one generating unit. Some typical service auxiliaries are listed below:

Dust and ash plant, Cranes, Turbine oil systems, Coal plant, Fire protection plant, Water treatment plant, Cooling water pump house, Boiler control air supply, Lighting and Heating.

For a typical 4*500 MW generating station, the total load of the urgent auxiliary systems is about 4*19 MVA and that of the service auxiliary system is approximately 12 MVA under normal operating conditions.

2 OVERVIEW OF THE REANIPOS PROGRAM

In the program REANIPOS, The Monte Carlo simulation is combined with the electrical network model. The overall structure of the reliability analysis method is shown in Figure 2.1. The Monte Carlo simulation generates stochastic event times, for example, a short circuit in a connection, removal of that short circuit by the protection activity, repair of a bus, maintenance performance of a connection, etc. Such an event removes and/or inserts branches in the electrical network, which represents the electrical behaviour of the primary components of the power system. The changed electrical network is used to calculate the voltage at the loads after the event. The voltage curve at a load during a disturbance is used to determine if the load experiences an interruption due to the event. The statistical results of the interruptions that the load experienced can be calculated by an additional program called REANVIEW.

2-1 The Monte Carlo Simulation

The Monte Carlo method simulates a stochastic process many times over a finite period of time in order to determine the characteristics of the stochastic process from observation. With the development of computer technology, the Monte Carlo simulation has already got widespread use in many technology and science areas. For complex power systems, the number of states of the systems is very big, so that it is very difficult to calculate the reliability of the system with an analytical method. For the Monte Carlo simulation, there is almost no restriction on the system complexity. The flow chart of the Monte Carlo simulation used in REANIPOS is shown in Figure 2.2.

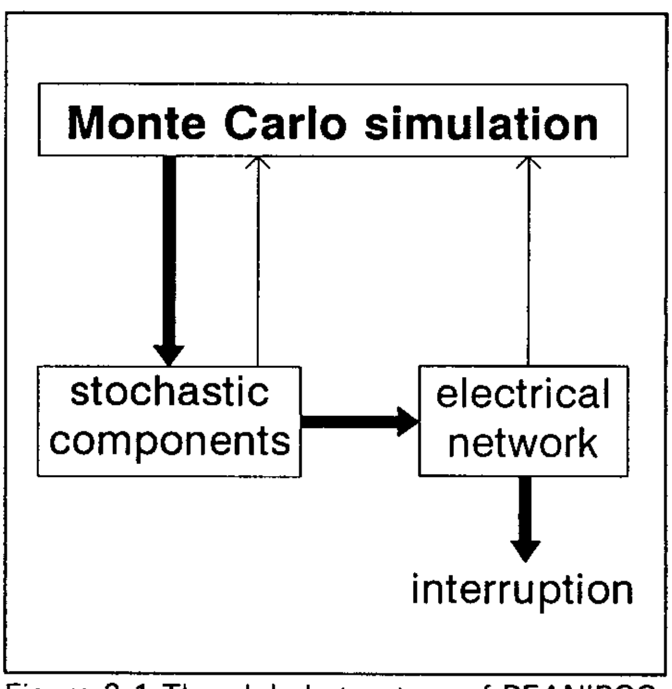

Figure 2.1 The global structure of REANIPOS.

At the start of the "simulation of one period", a time of occurrence is determined for each possible event such as short circuit, attempt to perform maintenance, the end of repair,etc. by taking samples from the appropriate stochastic distributions. All those times are placed in the "event list". All events in this list are processed in chronological order. The stochastic times are drawn from the Weibull distribution, the normal distribution, or the uniform distribution. By means of a Weibull distribution, the ageing of the components can be taken into account. (The characteristic behaviour of the different distributions is discribed in [3].)

During the simulation of one period, always the next event will be taken from the list. The electrical network will be changed by removing or inserting branches or nodes, and the load node voltages will be calculated again. Depending on the type of the event, new events will be inserted into the "event list" and/or old events removed. New events will only be inserted if they are due to occur before the end of the period. If the list is empty, no more events will occur before the end of the period so that the simulation of that period ends.

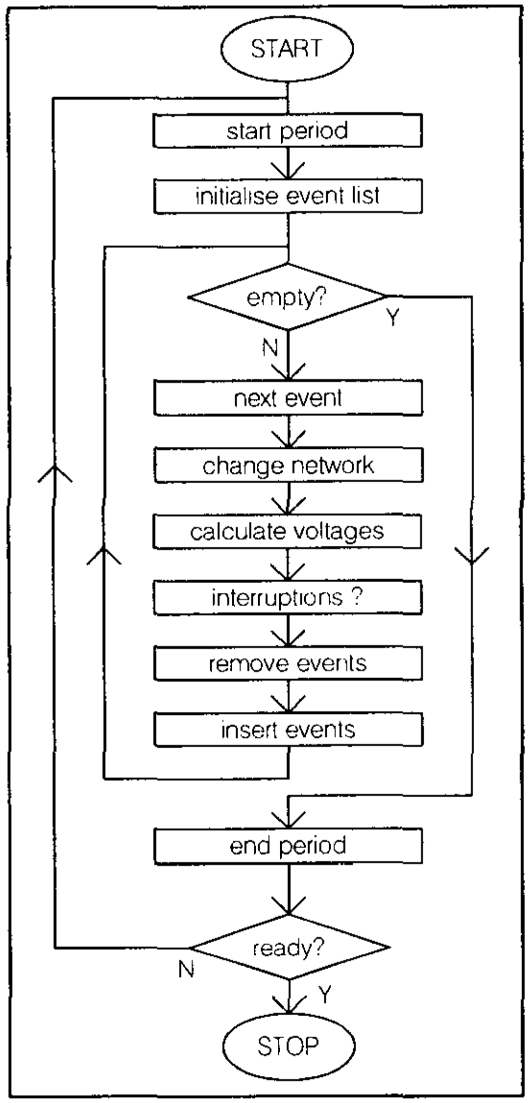

Figure 2.2 The flow chart of the Monte Carlo simulation used in REANIPOS.

This "simulation of one period" will be repeated until the desired accuracy is reached.

2-2 The Power System Model

The power system model used in the REANIPOS program consists of the following components:

connections; relays;

busses;	automatic transfer systems;
loads;	maintenance blocks;
power supplies;	dependent connections;
protection trees;	common-mode failures.

Each connection has a one-to-one relationship to a branch in the electrical network. Any connection may consist of a number of sections which are connected in series. The impedance of a connection is the sum of its section impedances. Each section is a stochastic element which has its own short circuits and/or failures. If any section of the connection has a short circuit, a low-impedance branch is inserted in the electrical network at the fault position. After a certain time, some of the relays intervene; then the low-impedance branch and some related branches or nodes are removed from the network. If any section of the connection has a failure, the connection will be removed from the network immediately. After the connection has been removed from the network, the repair process of the connection begins. After repair, the connection will be inserted again.

By using dependent connections, the user can define n out of k systems for connections. If one or more branches are disconnected for longer than a certain time, a dependent branch will then be removed as well.

Each bus corresponds to a node in the electrical network. The buses have their own short circuits and/or failures.

Loads represent different plants or parts of a plant fed by the power system. The constant voltage sources stand for the power supplies.

A protection tree is used to describe the behaviour of the protection following a short circuit. In case of a short circuit, one or more primary relays are supposed to isolate the short circuit from the healthy part of the power system. If such a relay fails, one or more backup relays will take over. Backup relays also possibly have their own backup relays.

An automatic transfer system is a normally open switch between two busses. The switch is supposed to close when the power supply to any of the two busses fails.

Maintenance blocks are used to perform the preventive maintenance action. In the event "start maintenance", one or more nodes and/or branches are removed from the electrical network and the automatic transfer systems are closed if necessary. At the event " end of maintenance", all of the removed components due to the maintenance activity will be inserted and the automatic transfer systems will be opened again.

2-3 The Interruption Criteria of Loads

The interruption criterion of a load is used to decide wether or not an event leads to an interruption of the power supply to the load. In the REANIPOS program, the maximum-permissable voltage dip is introduced as an interruption criterion. A typical maximum-permissable voltage dip curve is shown in Figure 2.3 (the black curve).

During the event, if the voltage at the load is below the maximum permissable voltage dip curve of the load at any time, the load experiences an interruption. Figure 2.3 shows an example of the use of the interruption criterion. The dotted lines show the voltage shapes of the load during the events 1 , 2 , and 3. For event 1, the voltage of the load is always above the maximum permissable voltage dip curve of the load, so the load does not experience an interruption during event 1. For event 2 and event 3, the voltage of the load comes below the curve, so the load experiences interruption during both events.

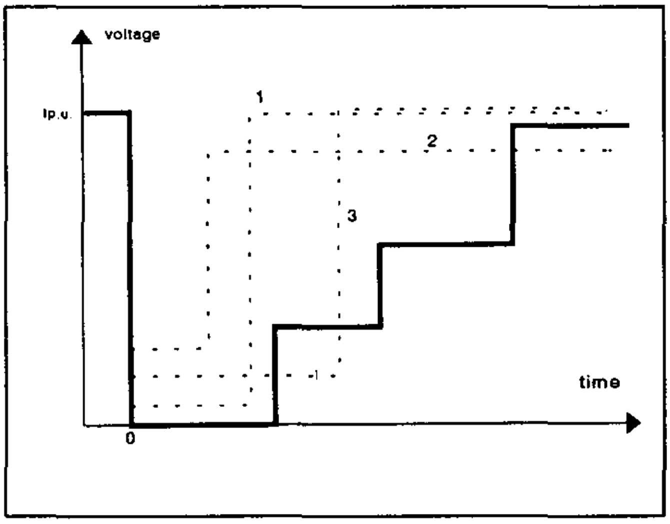

Figure 2.3 The interruption criterion used in REANIPOS.

2.4 The Statistics of Simulation Results -- REANVIEW Program

As the result of the REANIPOS program, an output file is generated. The file includes the Monte Carlo simulation results for interruptions of loads.

In order to get the statistical characteristics of simulations, a program called REANVIEW [15] has been developed. The following statistical facilities are offered by the program:

-The expected number of interruptions per year;
-The expected costs per year;
-The probability density of the number of interruptions per period of the simulation;
-The probability density of the costs of interruptions per period of the simulation;
-The probability density of the duration of an interruption.

3 THE RELIABILITY ANALYSIS OF AUXILIARY ELECTRICAL SYSTEMS

An auxiliary electrical system is very similar to an industrial power system, but all loads in an auxiliary electrical system such as motors and other appliances serve for a generating unit while the loads in an industrial power system serve for different plants or different parts of a plant.

The reliability analysis of the auxiliary electrical system is also different from that of the industrial power system in some way. In the reliability analysis of the industrial power system , what we are interested in is the reliability of the loads. An auxiliary electrical system works only for its generating unit, so in the reliability analysis of the system, what we are interested in is the reliability of the whole system instead of the reliability of the loads themselves. An interruption of a load does not always lead to an interruption of the whole system. Only when the generating unit experiences a forced-outage due to the failure of the auxiliary electrical system, the auxiliary electrical system experiences an interruption.

3-1 Description of The Method

The overall structure of the reliability analysis of auxiliary electrical systems is shown in Figure 3.1.

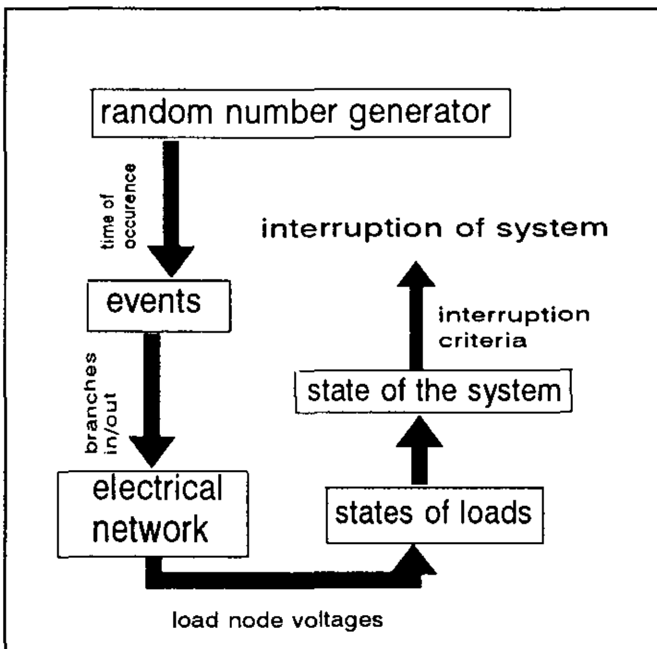

Figure 3.1 The overall structure of the reliability analysis of the electrical auxiliary system

As shown in the figure (see also 2-1), the random number generator provides the time at which events occur. Due to the occurrence of those events, the electrical network is changed by means of removal and/or insertion of branches. The changed network is used to calculate the voltage at all load nodes. The variation of the voltage at a load node is used to determine the state of the load. Every load has its own state (interruption or non-interruption) at any time. The states of all loads at a certain time are combined into the state of the auxiliary electrical system at that time. The state of the system is used to determine if the system experiences an interruption.

3-1-1 STATE OF LOAD AND VOLTAGE SAG

The state of a load is a binary variable. The value 1 represents that the load experiences no interruption while the value 0 means that the load experiences an interruption. Usually, an auxiliary electrical system is a redundant system, therefore, an interruption of one load does not lead to an interruption of the system.

If no disturbance exists in the system, the state of all loads is 1. After a disturbance, if the voltage of a load is recovered, the state of the load is 1, and if the load is disconnected from the system, the load state is 0.

During a disturbance, the state of a load can be determined by the voltage dip at the load node and the interruption criterion of the load.

The interruption criterion of a load is dependent on the type of the load. Different loads usually have different interruption criteria. For example, some loads, such as a motor driving a cooling water pump, can withstand zero voltage for quite a few seconds(possibly hours if a big pond is available and can supply the cooling water when the motor is experiencing an interruption). Some loads, such as computers, can not withstand a voltage dip lasting one hundredth of a second.

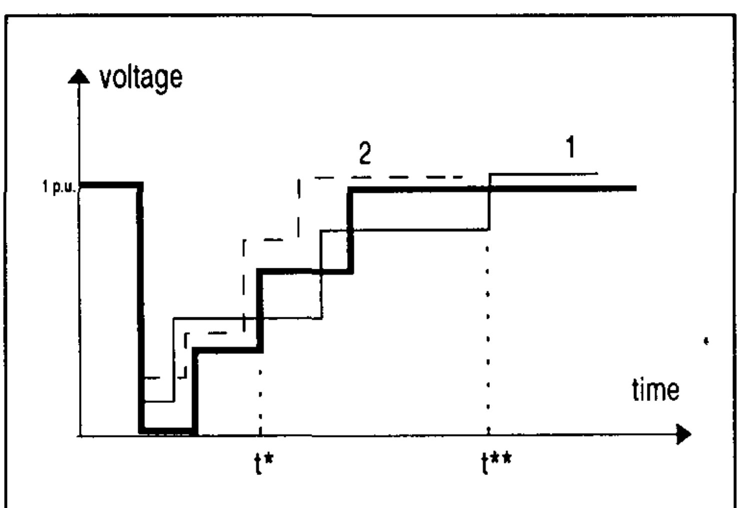

Figure 3.2 The state of a load during a disturbance

For every load in the auxiliary electrical system,a maximum-permissable voltage sag is introduced as an interruption criterion for the load to determine the state of the load. A typical maximum-permissable voltage sag curve(black) is shown in Figure 3.2.

During a disturbance, if the voltage of the load gets below the maximum-permissable voltage dip, the state of the load during the disturbance is 0 and it means that the load experiences an interruption. As shown in Figure 3.2, if the voltage shape of a load during the disturbance is curve 1 , the state of the load between time t* and time t** is 0, it means that the load experiences an interruption. After time t**, the voltage is recovered. When curve 2 is followed , the voltage of the load is always above the criterion, it means that the state of the load is always 1, therefore, the load does not experience an interruption during the disturbance.

3-1-2 STATE OF THE SYSTEM AND INTERRUPTION CRITERION

Usually, an auxiliary system is a redundant system. An interruption of a load does not always lead to an interruption of the system. For example, two motors supply lubricating oil for a generating unit and one is redundant. Due to the failure of some elements in the system, one motor may be disconnected from the system for a while, it means that the motor does experience an interruption. Fortunately,if the other motor works well, the generating unit does not have to be disconnected; it means that the auxiliary system as a whole does not experience an interruption.

The state of an auxiliary electrical system is defined as the combination of the states of all loads in the auxiliary electrical system. For example, an auxiliary electrical system has 5 loads (noted as load No.1 to No.5) for motors and two loads (noted as No.6 and No.7)for computers and other instruments. At time t , if the states of all loads except load No.2 and No.7 are 1 , the state of the system at time t is defined as (1,0,1,1,1,1,0).

The voltages at all loads are calculated for every event; the state of every load is determined by means of the comparison of the voltage shape at the load and the interruption criterion of the load. Then according to the states of all loads,the state of the system is determined for every event.

Such an interruption of the auxiliary electrical system is dependent on the redundancy of the system. According to the redundancy of the system, an interruption set of system states is determined. Any system state in the interruption set leads to an interruption of the auxiliary electrical system. An interruption of the system leads to a forced outage of the generating unit.

For the above example(see figure 3.3), the load No.1 and No.2 are motors for the high pressured oil system and one is redundant; the load No.3 and No.4 are motors for circulating fans for combustion air and one is redundant; the load No.5 is a motor for circulating cooling water system with a very big high pressure pond; and the load No.6 and No.7 supply the other users such as computers and instruments and one is redundant. Because of the redundancy of the system, this is led to an interruption by the failures of both load No.1 and No.2, the failures of both load No.3 and No.4, the failures of both load No.6 and No.7, or a long term failure of load No.5.

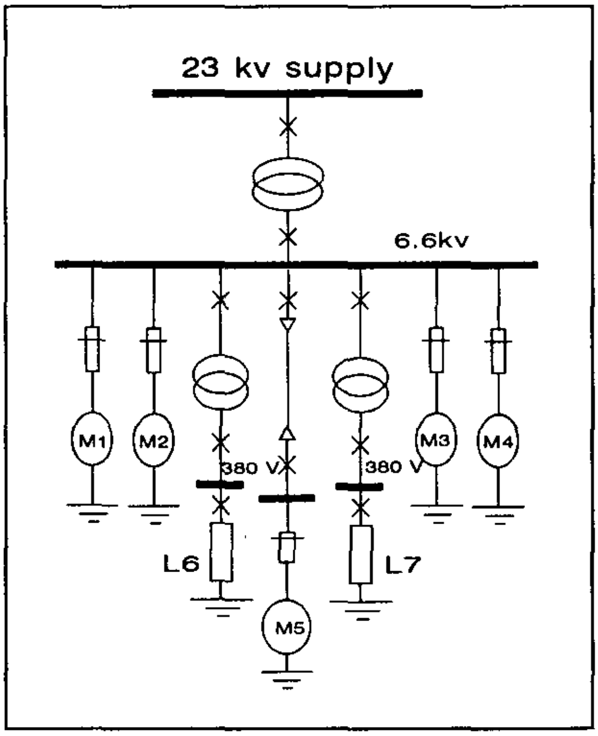

Figure 3.3 An auxiliary electrical system

An interruption set of system states is defined in order to determine wether or not the system experiences an interruption at a certain time. The set is defined such that if the state of the system at an event falls in the interruption set, the system experiences an interruption, otherwise, it experiences no interruption at the event.

For the above example, the interruption set of the system states can been written as follows(x represents either state 1 or state 0).

{ (0,0,x,x,x,x,x), (x,x,0,0,x,x,x), (x,x,x,x,0,x,x), (x,x,x,x,x,0,0) }.

Let S_1, S_2, ... S_7 represent the state of the loads No.1, No.2, ... No.7 respectively. Define S as:

$$\mathbf{S} = (S_1.\mathbf{OR}.S_2)\ .\mathbf{AND}.\ (S_3.\mathbf{OR}.S_4)\ .\mathbf{AND}.\ S_5\ .\mathbf{AND}.\ (S_6.\mathbf{OR}.S_7) \qquad (3\text{-}1)$$

then **S** can be used to represent the state of the auxiliary system. Here, **S** = 1 means that the system experiences no interruption while **S** = 0 means that the system experiences an interruption.

3-1-3 THE STATISTIC RELIABILITY CHARACTERISTICS OF THE SYSTEM

After the simulations, an output file is obtained. The data in the output file read as follows:

125 3347 75846.65 1
125 3568 20775.42 0
125 3568 46789.52 1

This means that in period 125, from the time (day 3347 at second 75846.65) to the time (day 3568 at second 20775.42), the system does not experience any interruption; and from the time (day 3568 at second 20775.42) to the time (day 3568 at second 46789.52), the system experiences an interruption and the interruption time is 26014.10 seconds; and at the time (day 3568 at second 46785.52), the system recovers again.

From the output file, various statistical reliability characteristics of the system can be calculated. The most important ones are the expected number of interruptions per year and the expected total duration of interruptions per simulation period. Some other important reliability parameters such as the expected number of interruptions at any year, the probability distribution of the number of interruptions and the probability distribution of the duration of an interruption can be calculated too.

3-2 The Application of the REANIPOS Program to the Reliability Analysis of the Auxiliary Electrical System

The REANIPOS program was specially developed for the reliability analysis of industrial power systems. The program can only give the simulation results of the reliability behaviour of the loads themselves, it can not directly give the simulation results of the reliability behaviour of the whole system . In order to use the program to simulate the reliability behaviour of a whole auxiliary electrical system, some modifications have to be performed.

Firstly, an extra branch is added to the electrical network. This branch is not a real branch in the network, it is only a fake branch added to the network for statistical purpose. The state of the fake branch is used to represent the state of the whole system. In order to simulate the real situation of the reliability behaviour of the system, the fake branch should not influence the reliability behaviour of the system nor the electrical behaviour of the system.

As shown in Figure 3.3, the additional fake branch consists of two sections: a circuit breaker B and a load L. The branch is connected between ground and a busbar. The busbar should be such a busbar that if the busbar is short circuited or disconnected from the network, the auxiliary electrical system experiences an interruption. Otherwise, the reliability of the load L can not represent the reliability of the system. For example, the short circuit or the disconnection of the busbar leads the load L to an interruption but it does not lead the system to an interruption, so the number of interruptions of the load L may be bigger than that of the system.

Both the circuit breaker B and the load L are assumed to be 100% reliable components. They experience neither failure nor short circuit. Therefore, they do not lead to any failure of the system; it means that they do not change anything in the reliability behaviour of the system.

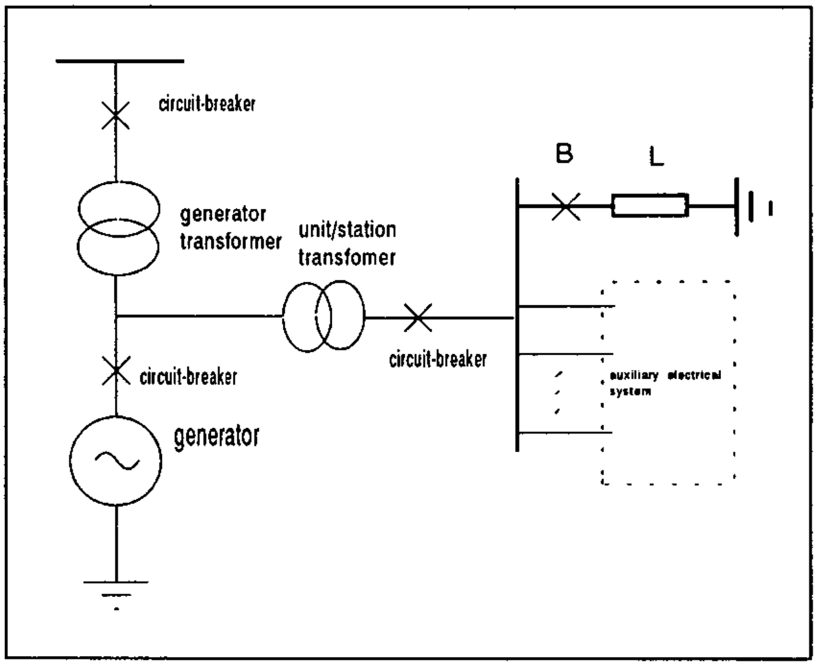

Figure 3.4 The application of REANIPOS in the reliability analysis of auxiliary electrical system.

The impedance of the load L is assumed very big, therefore, the current that flows through the load is very small. It is assumed that the current is too small to change any current in the network, which means that the fake branch almost does not have any influence to the electrical behaviour of the system. Meanwhile, the impedance of the circuit breaker B is assumed very small, therefore, when the breaker is closed, the voltage at the node of the load L is equal to the voltage of the busbar that the fake branch is connected to.

As shown above, the fake branch with the circuit breaker B and the load L does change neither the reliability behaviour of the system nor the electrical behaviour of the system.

The dependent connection model in the REANIPOS program (see [3],section 3.10) makes it possible that the reliability of the load L represents the reliability of the whole system.

The fake branch is assumed to be a dependent connection. The disconnection and insertion of the fake branch are dependent on the other load branches.

For the example in 3-1-2, the interruption set of system states is shown as follows(x represents either state 1 or state 0):

{ (0,0,x,x,x,x,x), (x,x,0,0,x,x,x), (x,x,x,x,0,x,x), (x,x,x,x,x,0,0) }.

The interruption set is used to determine if the system experiences an interruption at a certain time. If the state of the system at an event falls in the interruption set, the system experiences an interruption, otherwise, it experiences no interruption at the event.

Actually the state set { (0,0,x,x,x,x,x) } represents the states that lead to the interruption of the system due to the interruptions of load No.1 and No.2; it means the interruption of both load No.1 and No.2 leads the system to an interruption regardless of the state of other loads.

The above function can be fulfilled by the dependent connection model and the fake load branch. The disconnection of the load L from the network means the state of the system is 0, it also means that the system experiences an interruption.

Let 1, 2, ... , 7 stand for the branch numbers of load No.1, No.2, ... , No.7 respectively, then the following function

```
{   IF
        ( branch 1 disconnected for longer than time 1 )  AND
        ( branch 2 disconnected for longer than time 2 )
    THEN
        The fake branch is removed from the network.

    IF
        one of branch 1 and branch 2 is inserted,
    THEN
        the fake branch is inserted again.
    }
```

means that the interruption of both branch 1 and branch 2 leads the fake load to an interruption regardless of the state of other loads. Therefore, the above function equals to the function of the interruption set (0, 0, x, x, x, x, x) and the interruption of the load L due to the interruption of load No.1 and No.2 can represent the interruption of the system due to the interruption of those two loads.

In the same way, the interruption of the load L due to the failure of load No.3 and No.4 can represent the interruption of the system due to the interruption of those two loads, which can be performed by the following function:

```
{   IF
        ( branch 3 disconnected for longer than time 3 )  AND
        ( branch 4 disconnected for longer than time 4 )
    THEN
```

The fake branch is removed from the network.

IF
one of branch 3 and branch 4 is inserted,
THEN
the fake branch is inserted again.
}.

The interruption of the load L due to the failure of the load No.5 can represent the interruption of the system due to the same load, which is performed by the following function:

{ IF
(branch 5 disconnected for longer than time 5)
THEN
The fake branch is removed from the network.

IF
branch 5 is inserted,
THEN
the fake branch is inserted again.
}.

The interruption of the load L due to the failure of the load No.6 and No.7 can represent the interruption of the system due to those two loads, which can be performed by the following function:

{ IF
(branch 6 disconnected for longer than time 6) AND
(branch 7 disconnected for longer than time 7)
THEN
The fake branch is removed from the network.

IF
one of branch 6 and branch 7 is inserted,
THEN
the fake branch is inserted again.
}.

As shown above,the interruptions of the load L can represent the interruptions of the system with the help of the dependent model in REANIPOS.

3-3 An Example

3-3-1 DESCRIPTION OF THE SYSTEM

The auxiliary electric system under study is shown in Figure 3.3 (see page 11). The system includes seven loads, five of them are motors and the other two are loads such as computers and instruments. Motor 1 and motor 2 are for high pressured oil system. and one is redundant. Motor 3 and motor 4 are for circulating fans for combustion air and one is redundant. Motor 5 is for cooling water with a big upstream pond and cooperates with other motors to support the water of the pond. If the forced outage of the motor lasts less than 3 days, this does not lead to an interruption of the system at all. If the forced outage lasts more than 3 days, it leads the system to an interruption. Load 6 and load 7 are for computers and other equipment, one is redundant too.

For this investigation we assume that all connections including load connections are protected by means of differential relays. Over current time relays serve as back-up for differential relays.

3-3-2 THE RELIABILITY DATA OF THE COMPONENTS OF THE SYSTEM

The main components of the auxiliary electrical system are power transformers, buses, cables, breakers, fuses and motors. The reliability data of the components used in reliability studies are very different from study to study. The reliability data of the components from surveys are also very different from case to case.

For MV/MV transformers, the expected time to failure (ETTF) used in reliability studies varies from a few years to a few hundreds years. The expected repair time varies from a few hours to hundreds of hours. The reliability data for 33kV/11kV transformers used by Dialynas and Allan[11] [12] in their studies are:

ETTF = 500 years, repair time = 343 hours.

The reliability data for 33kV/11kV transformer used by McNab [13] are:

ETTF = 40 years, repair time = 14 hours.

Allan and Inga-Rojas [14] used ETTF = 9 years for transformers in their distribution system reliability analysis.

After an extensive literature search for the failure data of components in distribution power systems Bollen [8] presents his suggested values for ETTF of components in distribution power systems. The following are some of his suggested values:

MV/LV transformers	500 - 1000 years
MV/MV transformers	75 - 100 years
MV and LV circuit breakers	1000 - 5000 years
electronic relay systems	10 - 30 years
fuses	1000 - 5000 years
busbars(one section)	500 - 2000 years
cables	500 - 2000 years
large motors	15 - 30 years.

In the example presented in this report, the Weibull distribution is used for the failure of components while the normal distribution is used for the repair time. According to the consultation with engineers in a research company and information from various publications, the reliability data used in the example simulation are shown in the Table 3.1. The data include the characteristic life time (CLT), the shape factor of the Weibull distribution, the mean time to repair(MTTR), the standard deviation of the repair distribution, and the minimum time to repair.

Table 3.1 The reliability data used in the example

component	CLT (years)	shape factor	MTTR (days)	standard deviation (days)	min repair time (days)
23/6.6 transformer	20	2	2	1	0.2
6.6/0.38 transformer	50	1	1	0.5	0.1
cable	500	1	0.2	0.2	0.1
bus	500	1	1	0.5	0.2
relay	30	1	0.2	0.2	0.1
motor	10	2	1	1	0.2
380v load	30	2	0.2	0.2	0.1

3-3-3 ANALYSIS OF THE RESULTS OF THE EXAMPLE

The length of the simulation is 30 years. Some different simulations are performed in order to understand the differences between the various conditions. The simulations are listed as follows:

Simulation 1:
Only failures and repairs of transformers,buses and cables are taken into account.

Simulation 2:
Failures and repairs of the loads of the system such as motors and 380V loads are taken into account as well as those of transformers,buses and cables.

Simulation 3:
Failures and repairs of all components in the system including relays, loads, transformers, buses and cables are taken into account. Preventive maintenance is not performed.

Simulation 4:
Failures and repairs of all components are taken into account and preventive maintenance of relays is performed once per five years.

Some results of the simulations are shown in Figure 3.5 to Figure 3.8 and Table 3.2.

Figure 3.5 shows the expected number of interruptions per year for simulation 1 and for simulation 2. The results show clearly that the reliability of the loads themselves in the auxiliary electrical system is very important to the reliability of the system.

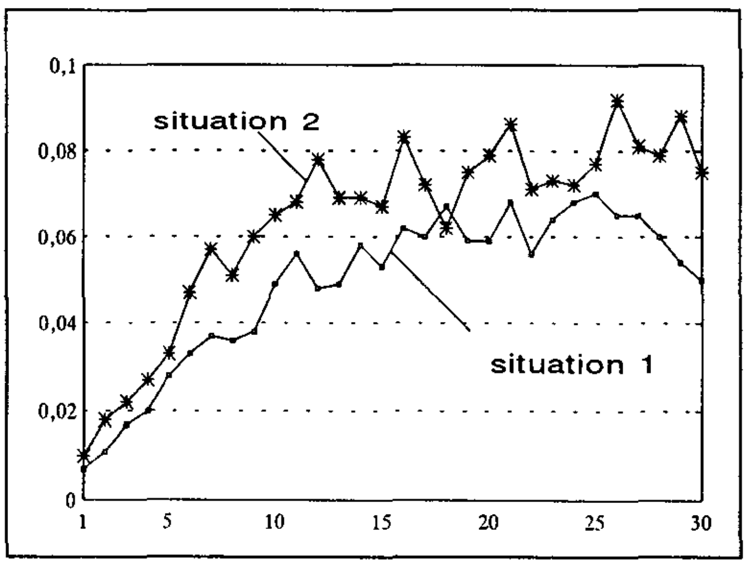

Figure 3.5 The influence of the failures of the motors & 380 V loads on the expected number of interruptions per year.

In order to get reasonable reliability indices of an auxiliary system, the failures and repairs of the motors and other appliances should therefore be taken into account.

Figure 3.6 shows the influence of the failures of relays on the reliability of the auxiliary systems. The expected number of interruptions of simulation 3 (with relays failures) is almost three times that of simulation 2 (without relays failures). The redundancy of the system has such a great influence that if the relay system works well, most short circuits in the system do not lead to an interruption of the system. For example, a single short circuit in motor 1 to 4, in 6.6/0.38 transformers , in 380V buses, in load 6 or in load 7 does not lead to an interruption of the system at all if the relay system works well. Figure 3.6 shows the importance of the reliability of the relay system to the reliability of the auxiliary electrical system.

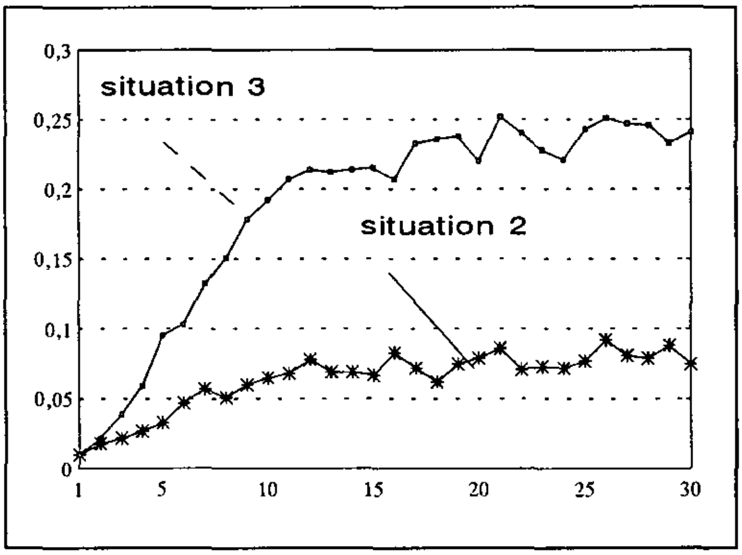

Figure 3.6 The influence of relays failures on the expected number of interruptions per year

Figure 3.7 shows the comparison of the expected number of interruptions per year of simulation 3 (no preventive maintenance of the relay system) and that of simulation 4 (with preventive maintenance of the relay system once per five years). The figure shows the importance of preventive maintenance of the relay system.

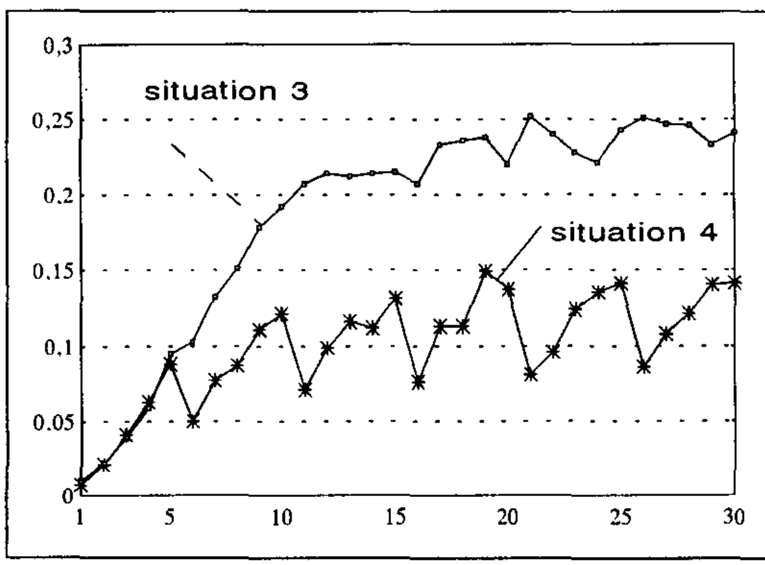

Figure 3.7 The influence of preventive maintenance of relays on the expected number of interruptions per year.

Figure 3.8 shows the probabilitydistributions of the duration of interruptions for different simulations. The distributions are very similar. The mean durations per interruption are 39.29, 42.30 and 42.09 in hours respectively for simulation 2, 3 and 4.

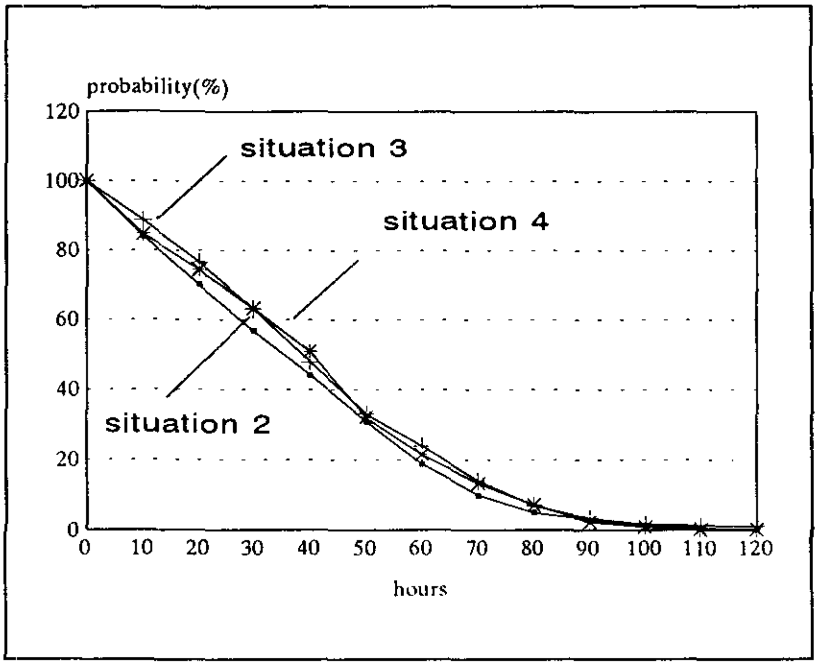

Figure 3.8 Probability distributions of the duration of interruptions.

The summarized results of the four simulations are shown in Table 3.2. The results include the expected number of interruptions of the system per period (30 years), the expected total duration of interruptions of the system per period and the expected average duration of per interruption for above 4 simulations.

The table shows that failures of the relay system play a key role in the reliability of the auxiliary electrical system. If the relay system is assumed to be 100% reliable (simulation 2), the expected number of the interruptions of the system per period is only 1.90. If the failures of the relays are taken into account (simulation 3), the expected number of the interruptions per period is 5.58, much bigger than that of the simulation 2.

The table also shows that failures of loads of the system should taken into account in the reliability of the auxiliary electrical system. Failurs of the loads increased the expected number of interruptions per period from 1.47 to 1.90.

The table shows that preventive maintenance of the relay system is very important for the auxiliary electrical system to improve its reliability. Preventive maintenance of relays once per five years decreased the expected number of interruptions per period from 5.58 to 2.95.

Table 3.2 The summarized simulation results
EN -- The expected number of interruptions per period
ED -- The expected total duration of interruptions per period.
EA -- The expected average duration of an interruption.

Simulation No.	1	2	3	4
EN (times)	1.47	1.90	5.58	2.95
ED (hours)	70.22	74.65	236.06	124.18
EA (hours)	47.2	39.3	42.3	42.1

3-4 Conclusions

In the reliability analysis of auxiliary systems presented in this chapter, the reliability indices are calculated by means of combining the Monte Carlo simulation and an electrical network model. The voltage profiles at the load nodes(such as motors and other appliances) are used to determine the states of the loads and the states of all loads combined are used to determine the state of the system. The reliability indices of a system are calculated from the statistics of the states of the system.

As an example, the reliability analysis of an auxiliary electrical system is performed. The simulation results of the example show that the reliability analysis of an auxiliary electrical system should take into account the failure of the loads themselves and the failures of relays as well as the preventive maintenance of the relay system.

4 RELIABILITY ANALYSIS OF GENERATING UNITS

4-1 Reliability Behaviour Simulation of the Mechanical Sub-system of Generating Units

As shown in Figure 1.1 (see page 2), the mechanical sub-system of a thermal generating unit consists of three main components: a boiler, a turbine and a generator. The failure of anyone of the three components leads to the failure of the generating unit. Therefore, the three components work in series in the aspect of reliability, which is shown in Figure 4.1. The reliability of the connection from the point A to the point B in the figure is used to represent the reliability of the mechanical sub-system of a generating unit. The point A is connected with the point B means that the subsystem works well and the generating unit does not experience any interruption due to the subsystem; the point A is disconnected from the point B means that the subsystem fails and the generating unit does experience an interruption due to the failure of the subsystem.

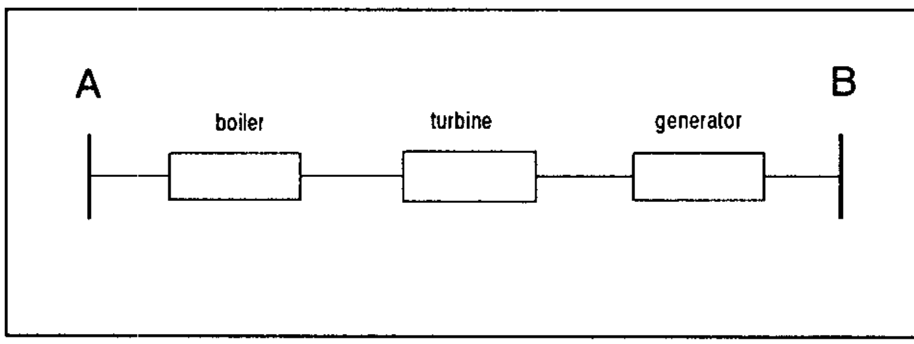

Figure 4.1 Mechanical components work in series in the aspect of reliability of the generating unit.

In Figure 4.1, the removal of a component from the connection represents the failure of the component while the insertion of a component to the connection means the finish of repair of the component. The removal of any component from the connection leads to the disconnection of the point A from the point B. Only when all components work well, the point A is connected with the point B.

In order to simulate the reliability behaviour of the mechanical subsystem with the help of the REANIPOS program, the connection between point A and point B is added to the electrical network as an electrical branch of the network. The point B is connected to ground of the network while the point A is connected to the generator node. As shown in Figure 4.2, the branch consists of three sections:

section 1, section 2, and section 3. All of the three sections are assumed as very big impedance sections, therefore, the current through the branch is very small. Meanwhile, the sections are assumed to experience no short circuit. Because of the above assumption, the insertion or removal of the branch does not influence the electrical behaviour of the system.

The failure and repair distributions of section 1 are assumed to be the same as those of the boiler, so the reliability behaviour of the section can be used to represent that of the boiler. The failure and repair distributions of section 2 are assumed to be the same as those of the turbine, so the reliability behaviour of the section 3 can be used to represent that of the turbine. The failure and repair distributions of section 3 are assumed to be the same as those of the generator (mechanical), so the reliability behaviour of the section can be used to represent that of the generator(mechanical).

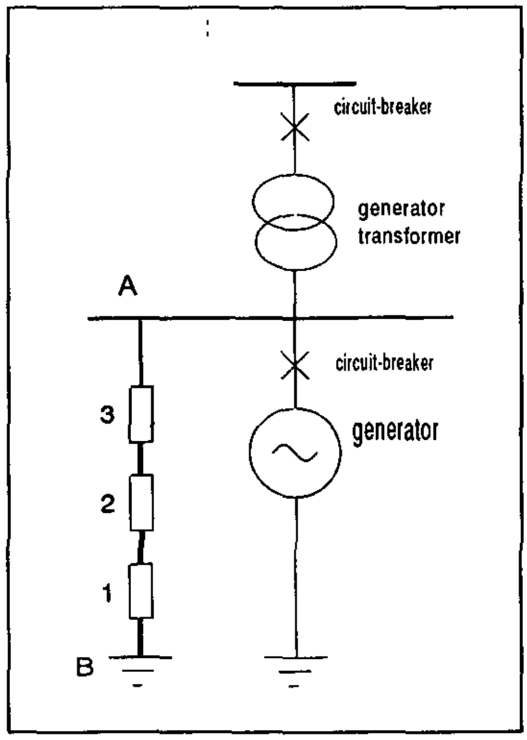

Figure 4.2 Reliability behaviour simulation of the mechanical subsystem of generating units.

Using the above assumptions, the reliability behaviour of a section in the branch AB represents that of a component in the mechanical subsystem, so the reliability behaviour of the branch AB can be used to represent the reliability behaviour of the mechanical subsystem.

4-2 Reliability Behaviour Simulation of Generating Units

In order to use REANIPOS to simulate the reliability behaviour of a whole generating unit, an additional load branch is added to the electrical network of the generating unit (see Figure 4.3). This additional load branch has the similar characteristics as the fake branch shown in 3-2. The branch consists of two sections; one is a breaker and another is a load. The branch is connected between ground and a busbar which should be such a busbar that if the busbar is short circuited or disconnected from the network, the generating unit experiences a forced outage. Both the breaker and the load are assumed to be 100% reliable components and the impedance of the load is assumed to be very big while the impedance of the breaker is assumed to be very small. According to the above assumption, the additional load branch does change neither the reliability behaviour nor the electrical behaviour of the generating unit on the basis of the same reasons shown in 3-2.

The dependent connection model in the REANIPOS program is used to make it possible that the reliability of the additional load represents the reliability of the generating unit. The additional load branch is assumed to be a dependent connection. The disconnection and insertion of the branch are dependent on the state of the subsystems and components of the generating unit.

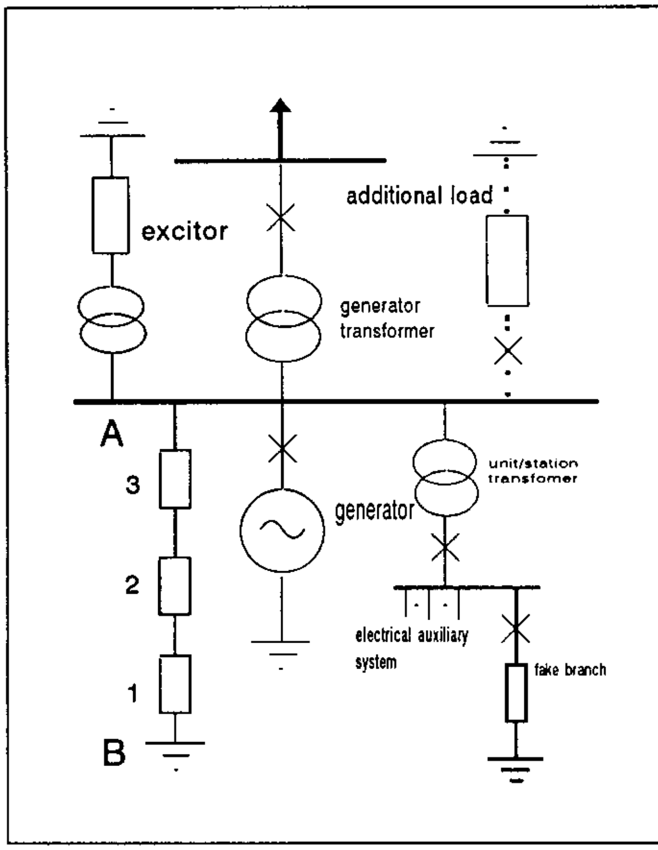

Figure 4.3 Reliability behaviour Simulation of generating units.

For the generating unit shown in Figure 4.3, the forced outages are contributed by its mechanical subsystem, auxiliary electrical system, generator transformer, generator (electrical) and excitor system.

As shown in the Figure 4.1, the reliability behaviour of the branch AB represents that of the mechanical subsystem, so according to the dependent model, the forced outage of the generating unit due to the failure of its mechanical subsystem can be represented by the interruption of the additional load due to the failure of the branch AB , which is performed by the following function:

{ IF
(branch AB is disconnected for longer than a certain time)
THEN
(the additional load branch is removed from the network).
IF
(branch AB is inserted)
THEN
(the additional load branch is inserted again).
}

As shown in section 3-2, the failure of the fake load L is used to represent the failure of the auxiliary electrical system, so the interruption of the additional load due to the failure of the fake branch can be used to represent the forced outage of the generating unit due to the interruption of the auxiliary system, which is performed by the following function:

{ IF
(the fake branch is disconnected for longer than a certain time)
THEN
(the additional load branch is removed from the network).
IF
(the fake branch is inserted)
THEN
(the additional load branch is inserted again).
}.

In the same way, the interruption of the additional load due to the failure of the generator transformer can represent the forced outage of the generating unit due to the failure of the transformer, which is performed by the following function:

{ IF
(the generator transformer branch is disconnected for longer than a certain time)
THEN
(the additional load branch is removed from the network).
IF
(the generator transformer branch is inserted)
THEN
(the additional load branch is inserted again).
}.

The interruption of the additional load due to the failure of the generator excitor can represent the forced outage of the generating unit due to the failure of the excitor system, which is performed by the following function:

{ IF
(the generator excitor branch is disconnected for longer than a certain time)
THEN
(the additional load branch is removed from the network).
IF
(the generator excitor branch is inserted)
THEN
(the additional load branch is inserted again).}.

As shown above, the interruptions of the additional load branch can represent the forced outages of the generating unit with the help of the dependent model in the REANIPOS program.

4-3 An Example of Reliability Analysis of Generating units

4-3-1 DESCRIPTION OF THE GENERATING UNIT

The electrical network of the generating unit under study is shown in Figure 4.4. The network includes an auxiliary electrical system, a generator, a generator transformer and an excitor branch (excitor and its transformer).

The failure of any subsystem such as the mechanical subsystem, the auxiliary electrical system and the generator transformer leads the generating unit to a forced-outage.

All connections in the network are protected by means of differential relays. Over current relays serve as back-up for the differential relays.

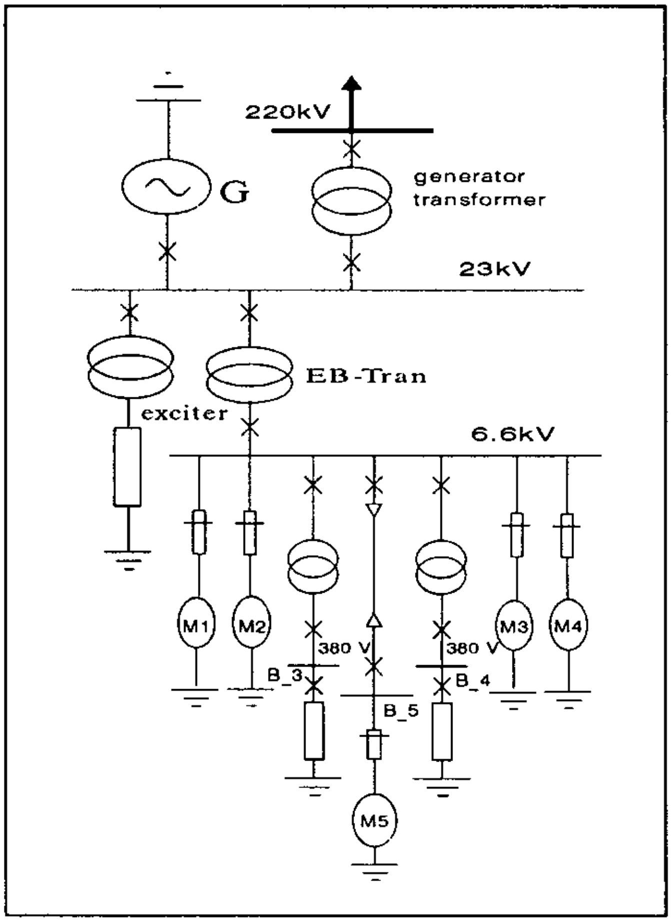

Figure 4.4 The electrical network of a generating unit.

In the example, the Weibull distribution is used to decribe the failure of the components; the normal distributions is used to describe the repair times of the components . The reliability data of the components of the generating unit used in the example are listed in Table 4.1. The data are obtained from a serarch of the literature or from an educated guess. The data types include the characteristic life time of the Weibull distribution(CLT), the shape factor of the Weibull distribution, the mean time to repair(MTTR), the standard deviation of the repair distribution, and the minimum time to repair.

Table 4.1 The reliability data of the components.

component	CLT (years)	shape factor	MTTR (days)	standard deviation (days)	min repair time (days)
boiler	30	3	10	5	2
turbine	40	3	10	5	2
generator(mechanical)	50	3	10	5	2
generator(electrical)	50	2	3	2	1
generator transformer	30	2	3	2	1
excitor system	50	2	3	2	1
23/6.6 transformer	20	2	2	1	0.2
6.6/0.38 transformer	50	1	1	0.5	0.1
cable	500	1	0.2	0.2	0.1
bus	500	1	1	0.5	0.2
relay	30	1	0.2	0.2	0.1
motor	10	2	1	1	0.2
380v load	30	2	0.2	0.2	0.1

4-3-2 ANALYSIS OF THE RESULTS OF THE RELIABILITY ANALYSIS OF THE GENERATING UNIT

The auxiliary electrical system of the generating unit studied in this chapter is the same system presented in 3-3. In 3-3-3, four simulations were performed in order to understand the differences between the various conditions, but in the example presented in this chapter, as far as the auxiliary electrical system is concerned, only the condition for simulation 4 is taken into account; it means that for the auxiliary electrical system, "failures and repairs of all components of the auxiliary system including relays, loads, transformers, buses and cables are taken into account and preventive maintenance of relays is performed once per five years".

The length of the simulations is 30 years. Some different simulations are performed in order to understand the differences between the various conditions. For all simulations listed below, preventive maintenance of relays is performed once per five years. The simulations are listed as follows:

Simulation 1:

Failures and repairs of all electrical components of the generating unit such as transformers, generator(electrical), buses, excitor system and auxiliary system are taken into account; failures and repairs of the mechanical components of the generating unit are not taken into account; preventive maintenance of the generating unit is not performed.

Simulation 2:

Failures and repairs of all electrical components of the generating unit such as transformers, generator(electrical), buses, excitor system and auxiliary system are taken into account; failures and repairs of the mechanical components of the generating unit are not taken into account; preventive maintenance of all electrical components of the generating unit is performed once per five years.

Simulation 3:

Failures and repairs of all components of the generating unit including the electrical components and the mechanical components such as boiler, turbine and generator(mechanical) are taken into account; preventive maintenance of the generating unit is not performed.

Simulation 4:

Failures and repairs of all components of the generating unit including the electrical components and the mechanical components such as boiler, turbine and generator(mechanical) are taken into account. preventive maintenance of all components of the generating unit including mechanical components is performed once per five years.

Simulation 5:

Failures and repairs of all components of the generating unit including the electrical components and the mechanical components such as boiler, turbine and generator(mechanical) are taken into account; preventive maintenance of all components of the generating unit including mechanical components is performed once per ten years.

The simulation period is 30 years, some results of simulations are shown in Figure 4.5 to Figure 4.8 and Table 4.2.

Figure 4.5 shows the expected number of forced outages of the generating unit per year for simulation 1 and that for simulation 2. In the figure the number of forced outages per year for simulation 1 is much more than that for simulation 2 except in the first five years. The only difference between simulation 1 and simulation 2 is the preventive maintenance of the generating unit. This means that preventive maintenance of all electrical equipment of the generating unit such as generator transformer, excitor system, auxiliary electrical system and generator is performed once per five years for simulation 2 while only preventive maintenance of relays is performed for simulation 1.

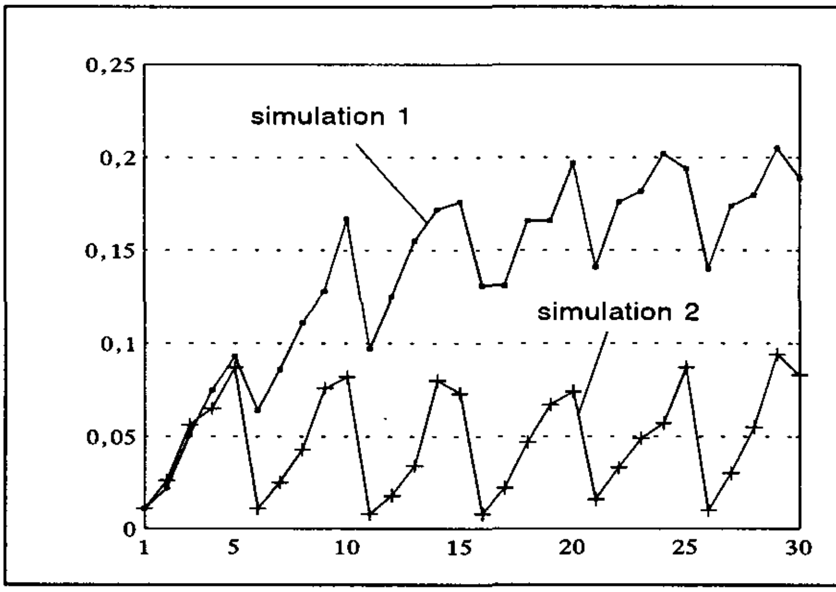

Figure 4.5 The influence of the preventive maintenance on the expected number of forced outages of the generating unit per year (no failures of mechanical components) .

The results show clearly that preventive maintenance of the generating unit is very important to decrease the number of forced outages of the generating unit.

Figure 4.6 shows the expected number of forced outages of the generating unit per year for simulation 3 and that for simulation 4 and simulation 5. In the figure, the number of forced outages per year for simulation 3 is much more than those for simulation 4 and simulation 5 except in the first five years. The expected number of forced outages per year for simulation 5 is quite bigger than that for simulation 4. The difference among simulation 3 , simulation 4 and simulation 5 is that preventive maintenance of all equipment of the generating unit including mechanical components is performed once per five years for simulation 4, once per ten years for simulation 5 while no preventive maintenance is performed for simulation 3. Figure 4.6 also shows clearly that preventive maintenance of the generating unit is very important to decrease the number of forced outages of the generating unit.

The difference between the number of forced outages for simulation 3 and that for simulation 4 (see Figure 4.6) is even much more than the difference of the number of forced outages for simulation 1 from that for simulation 2 (see Figure 4.5).

This is caused by the failure distributions of the mechanical components. In simulation 3 and simulation 4, the failures and repairs of the mechanical components are taken into account. As shown in Table 4.2, the shape factor of the Weibull distribution for failure of mechanical components is 3 while that for failure of electrical components is not more than 2; it means that the mechanical components are ageing faster than the electrical components.

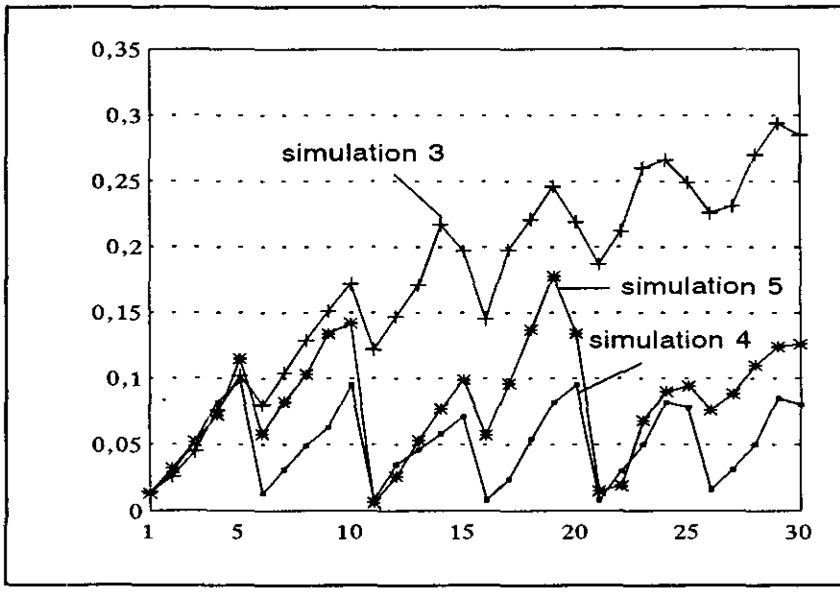

Figure 4.6 The influence of the preventive maintenance on the expected number of forced outage of the generating unit per year (with failures and repairs of mechanical components) .

Figure 4.7 shows the expected number of forced outages of the generating unit per year for simulation 1 and that for simulation 3. In the figure, the number of forced outages per year for simulation 3 is more than that for simulation 1. The difference between simulation 1 and simulation 3 is that in simulation 3, the

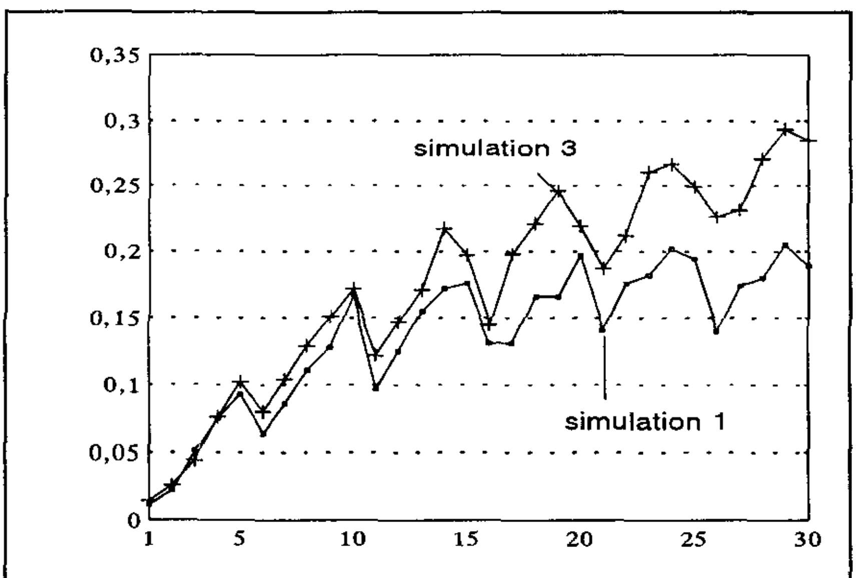

Figure 4.7 The influence of the mechanical components on the expected number of forced outage of the generating unit per year (1).

failures and repairs of the mechanical components are taken into account. The results shows the influence of the failures and repairs of the mechanical components on the reliability of the generating unit.

Figure 4.8 shows the expected number of forced outages of the generating unit per year for simulation 2 and that for simulation 4. In the Figure, the number of forced outages per year for simulation 2 is not very different from that for simulation 4. The difference between simulation 2 and simulation 4 is that in simulation 4, the failures and repairs of the mechanical components are taken into account. The results show that the failures and repairs of the mechanical components are not very important for the reliability of the generating unit when preventive maintenance is performed once per five years. This can be explained by the failure distribution of the mechanical components. As shown in Table 4.1, the shape factor of the Weibull distribution for the failure of mechanical components is 3. In the first five years the possibility of the failure of the mechanical components is relatively small; then a preventive maintenance is performed and the reliability characteristic of the mechanical components becomes as good as new. Then in the next five years the possibility of failure of the mechanical failure is still relatively small.

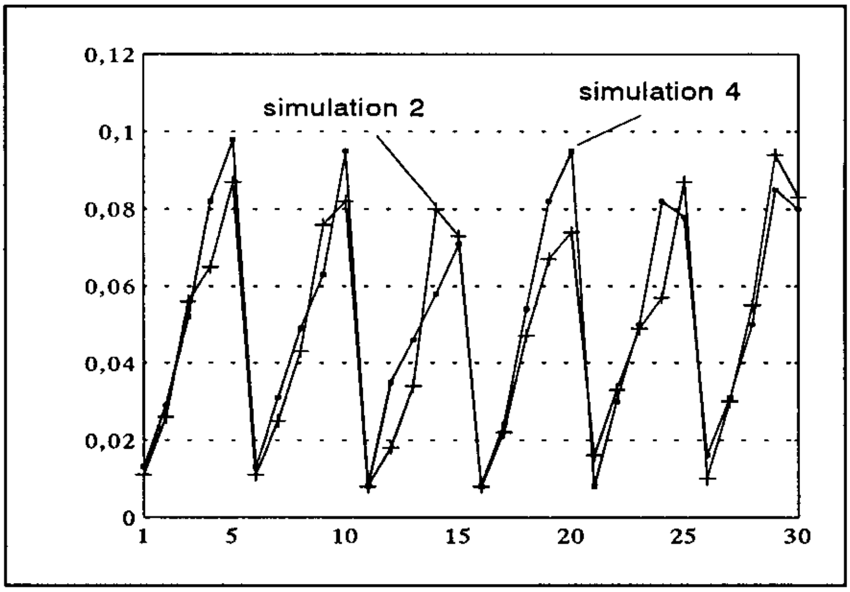

Figure 4.8 The influence of the mechanical components on the expected number of forced outage of the generating unit per year (2).

Table 4.2 shows the summarized simulation results for the example. The results include the expected number of forced outages of the generating unit per simulation period (30 years), the expected total duration of the forced outages of the generating unit, and the expected average duration of a forced outage for the five simulations.

The results show clearly that preventive maintenance of the generating unit is very important for the generating unit to improve its reliability. Preventive maintenance of the generating unit once per five years (simulation 2 and simulation 4) decreased the expected number of forced outages of the generating unit to about two third of the value for simulation 1. For simulation 1 and simulation 2, preventive maintenance of the generating unit decreased the expected number of forced outages from 4.11 to 1.42. For simulation 3 and 4, preventive maintenance decreased the expected number of the forced outages from 5.24 to 1.52.

The table shows that the expected number of forced outages for simulation 5 (2.48) is significantly bigger than that for simulation 4. The difference between simulation 4 and simulation 5 is only that preventive maintenance of the generating unit is performed once per five years for simulation 4 but once per ten years for simulation 5. In the aspect of the reliability preventive maintenance once per five years is much better than once per ten years. In the real situation, the economy should be taken into account in order to decide on the period for preventive maintenance.

For the example presented in this chapter the table shows that failure of mechanical components of the generating unit is important when no preventive maintenance is performed. Failure of mechanical components increases the expected number of forced outages by 1.13 (from 4.11 to 5.24). But if preventive maintenance is performed once per five years, failure of mechanical components is not very important. Failure of mechanical components only increases the expected number of forced outages by 0.10 (from 1.42 to 1.52).

The table shows that the expected average duration of a forced outage for simulation 3 is 100.19 hours; it is much bigger than those for the other four simulations. The reason is that the contribution of the failure of the mechanical components to the expected number of forced outages is much bigger for simulation 3 than for the other simulations. The repair time of the mechanical components is much longer than that of the electrical components (see table 4.1).

Table 4.2 The summarized simulation results of the reliability of the generating unit.

Simulation No.	1	2	3	4	5
EN (times)	4.11	1.42	5.24	1.52	2.48
ED (hours)	229.56	57.63	524.98	74.46	150.88
EA (hours)	55.85	40.58	100.19	48.99	60.84

EN —— The expected number of forced outage of the generating unit per period
ED —— The expected total duration of forced outages per period.
EA —— The expected average duration of one forced outage.

4-4 Conclusions

In the reliability analysis of generating units presented in this chapter, the reliability indices of the complete generating unit are calculated by means of the REANIPOS program. Not only the failures and repairs of the electrical components of the generating unit but also those of the mechanical components of the units have been taken into account.

An example of the reliability analysis of a generating unit is presented in this chapter. In order to understand the influence of preventive maintenance and the failures of the mechanical components five simulations bave been performed. From the results of the example,the following conclusions can be drawn:

(1). preventive maintenance is essential to improve the reliability of the generating unit.

(2). failure of mechanical components of the generating unit is important for the reliability when no preventive maintenance is performed.

(3). failure of mechanical components does not play an important role in the reliability when preventive maintenace is performed once per five years.

(4). in the aspect of reliability preventive maintenance of the generating unit should performed once per five years instead of once per ten years.

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APPENDIX 1 SOME COMMENTS ON THE REANIPOS PROGRAM

1. Consider for instance the system shown in Figure A.1. Due to some failures, the relay system removes the branch AB but the REANIPOS program does not show that the branch BC and bus B are disconnected from the system. The branch BC and bus B are apparantly still connected to the network. Of course the branch BC and bus B should be disconnected from the network due to the removal of the branch AB; this is a very curious mistake of the REANIPOS program.

In the program, neither branch nor bus may be disconnected from the network due to the removal of other branch or bus. It does not reflect the real electrical behaviour of the system.

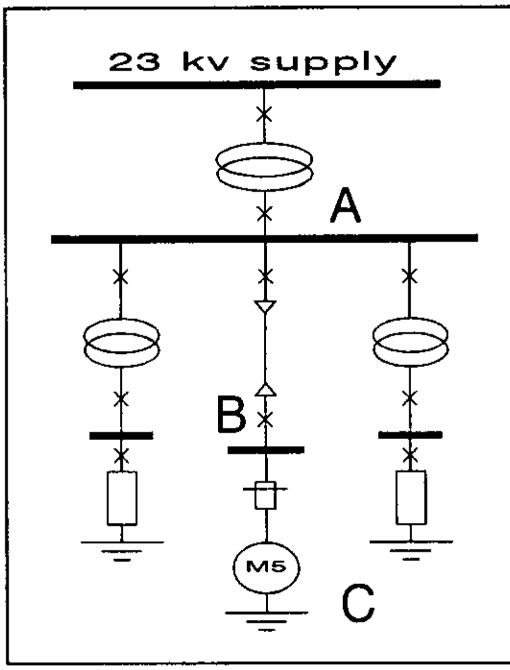

Figure A.1 Branch BC and bus B are not disconnected due to the removal of branch AB in the program.

2. If there are any spaces at the end of any input data line, the REANIPOS program does not work and the computer will be dead. No error information is given.

For example,

```
... ... ... ...
4 0 3 '380v---2' 250.00 180.00 '380v---2' 250.00 180.00 NESC SHRT 0 FAIL 0 MAIN 0 ASGDNEW[CR]
5 0 4 '380v---3' 280.00 190.00 '380v---3' 280.00 190.00 NESC SHRT 1 FAIL 0 MAIN 0 ASGDNEW [CR]
6 1 2 '--------' 390.00 600.00 '--------' 390.00 600.00 NESC SHRT 2 FAIL 0 MAIN 0 ASGDNEW[CR]
... ... ... ...
```

In the above example, [CR] represents the key 'enter'. In a DOS editor or the REANEDIT, [CR] is not shown on the screen. In the second line of the example (branch 5), before [CR] was entered, a space was entered by accident. On the screen, nothing is different, no space is shown.

With an input file like above, the REANIPOS program does not work at all. If users try to run REANIPOS with an input file like this, the computer will be surely dead. Even REANEDIT does not work either. If one tries to load an input file like this with REANEDIT, the computer will be surely dead.

One way to resolve the problem is to change the read part of the REANIPOS program, another way is to warn the users to be very careful on this problem. If the computer is dead due to trying to run REANIPOS or to load an input file with REANEDIT, one should first check if there are any spaces at the end of all data lines. One way to check spaces at the end of lines is to use the key "END" on every line in a DOS editor.

3. With an input file that has more than 2 maintenance blocks, the REANIPOS program possibly makes the computer dead after the program finishes part of its simulation.

For example, when the total number of simulation is chosen to be 1112, the program sometimes finishes 131 simulations and then the computer is dead.

4. The format of the connection dependency data block (see [3], page 42) reads as fellows

<branch#> / <branch1#> <day1#> <sec1#> { / <branch2#> <day2#> <sec2#> }[CR]

In a dependency data block, the data <sec1#> { <sec2#> } are not allowed to be zero. Otherwise, the program does not consider <branch#> as a dependent branch. It means that the data line does not define a dependent branch.

APPENDIX 2 AN INPUT FILE FOR THE EXAMPLE SYSTEM PRESENTED IN § 3-3

```
*Simulation_Name
SIMULATION-4
*RandomNumber
1
*Frequency
50.00
*BasePower
440000000
*BaseVoltage
23000
*Lifetime(days)
10950
*Accuracy
ABS
2.00
*Branch_Data
1  0  1  'generato' 0.00100  0.38900  'generato' 0.00100  0.38900  GEN  1  SHRT 0  FAIL 0  MAIN 0  ASGDNEW
2  0  2  'motor--1' 1311.200 812.5010 'motor--1' 1311.200 812.5000 NSEC  SHRT 0  FAIL 0  MAIN 0  ASGDNEW
                         / 'fuse---1' 0.00000  0.00100  NSEC  SHRT 1  FAIL 0  MAIN 0  ASGDNEW
3  0  2  'motor--3' 211.6300 102.5010 'motor--3' 211.6300 102.5000 NSEC  SHRT 0  FAIL 0  MAIN 0  ASGDNEW
                         / 'fuse---3' 0.00000  0.00100  NSEC  SHRT 2  FAIL 0  MAIN 0  ASGDNEW
4  0  3  '380v---1' 250.0010 180.0020 '380v---1' 250.0000 180.0000 NSEC  SHRT 0  FAIL 0  MAIN 0  ASGDNEW
                         / '--------' 0.00100  0.00200  NSEC  SHRT 3  FAIL 0  MAIN 0  ASGDNEW
5  0  4  '380v---2' 250.0010 180.0020 '380v---2' 250.0000 180.0000 NSEC  SHRT 0  FAIL 0  MAIN 0  ASGDNEW
                         / '--------' 0.00100  0.00200  NSEC  SHRT 4  FAIL 0  MAIN 0  ASGDNEW
6  0  5  'motor--5' 195.5000 188.5010 'motor--5' 195.5000 188.5000 NSEC  SHRT 0  FAIL 0  MAIN 0  ASGDNEW
                         / 'fuse---5' 0.00000  0.00100  NSEC  SHRT 5  FAIL 0  MAIN 0  ASGDNEW
7  1  2  'eb-tranf' 0.33700  3.61400  'eb-tranf' 0.33700  3.61400  NSEC  SHRT 6  FAIL 0  MAIN 0  ASGDNEW
8  2  3  'tr-380v1' 1.30000  14.98800 'tr-380v1' 1.30000  14.98800 NSEC  SHRT 7  FAIL 0  MAIN 0  ASGDNEW
9  2  4  'tr-380v2' 1.30000  14.98800 'tr-380v2' 1.30000  14.98800 NSEC  SHRT 8  FAIL 0  MAIN 0  ASGDNEW
10 2  5  'transmis' 2.23500  1.40000  'transmis' 2.23500  1.40000  NSEC  SHRT 9  FAIL 0  MAIN 0  ASGDNEW
11 0  2  'motor--2' 1311.200 812.5010 'motor--2' 1311.200 812.5000 NSEC  SHRT 0  FAIL 0  MAIN 0  ASGDNEW
                         / 'fuse---2' 0.00000  0.00100  NSEC  SHRT 10 FAIL 0  MAIN 0  ASGDNEW
12 0  2  'motor--4' 211.6300 102.5100 'motor--4' 211.6300 102.5000 NSEC  SHRT 0  FAIL 0  MAIN 0  ASGDNEW
                         / 'fuse---4' 0.00000  0.01000  NSEC  SHRT 11 FAIL 0  MAIN 0  ASGDNEW
13 1  6  'false-br' 20.00000 20.00000 '--------' 20.00000 20.00000 NSEC  SHRT 0  FAIL 0  MAIN 0  ASGDNEW
14 0  6  'false-lo' 30000.00 60010.00 'total-re' 30000.00 60000.00 LOAD 1  SHRT 0  FAIL 0  MAIN 0  ASGDNEW
                         / '--------' 0.00000  10.00000 NSEC  SHRT 0  FAIL 0  MAIN 0  ASGDNEW
*Rail_Data
1  'busbar-1' SHRT 12 FAIL 0  MAIN 0  ASGDNEW
2  'busbar-2' SHRT 13 FAIL 0  MAIN 0  ASGDNEW
3  'busbar-3' SHRT 14 FAIL 0  MAIN 0  ASGDNEW
4  'busbar-4' SHRT 15 FAIL 0  MAIN 0  ASGDNEW
5  'busbar-5' SHRT 16 FAIL 0  MAIN 0  ASGDNEW
6  'f-busbar' SHRT 0  FAIL 0  MAIN 0  ASGDNEW
*Load_Data
1  SPYK 0.21  0.40  0.40  0.70  0.50  0.90  COST  20.0 1.00
*Generator_Data
```

```
1 1.273    14.13
*ATS/Swit._Data
*ShortCirc_Data
1 FAIL 1 PRIREL 1 0.200 DIST 1 BACREL 12 2.500 DIST 1
2 FAIL 2 PRIREL 2 0.200 DIST 1 BACREL 12 2.500 DIST 1
3 FAIL 3 PRIREL 3 0.200 DIST 1 BACREL 13 1.500 DIST 1 BACREL 12 2.500 DIST 1
4 FAIL 4 PRIREL 4 0.200 DIST 1 BACREL 14 1.500 DIST 1 BACREL 12 2.500 DIST 1
5 FAIL 5 PRIREL 5 0.200 DIST 1 BACREL 15 1.500 DIST 1 BACREL 12 2.500 DIST 1
6 FAIL 6 PRIREL 6 0.200 DIST 1 BACREL 16 2.500 DIST 1
7 FAIL 7 PRIREL 7 0.200 DIST 1 BACREL 12 2.500 DIST 1
8 FAIL 8 PRIREL 8 0.200 DIST 1 BACREL 12 2.500 DIST 1
9 FAIL 9 PRIREL 9 0.200 DIST 1 BACREL 12 2.500 DIST 1
10 FAIL 10 PRIREL 10 0.200 DIST 1 BACREL 12 2.500 DIST 1
11 FAIL 11 PRIREL 11 0.200 DIST 1 BACREL 12 2.500 DIST 1
12 FAIL 12 PRIREL 17 0.200 DIST 1 BACREL 18 2.500 DIST 1
13 FAIL 13 PRIREL 6 0.200 DIST 1 BACREL 16 2.500 DIST 1
14 FAIL 14 PRIREL 7 0.200 DIST 1 BACREL 12 2.500 DIST 1
15 FAIL 15 PRIREL 8 0.200 DIST 1 BACREL 12 2.500 DIST 1
16 FAIL 16 PRIREL 9 0.200 DIST 1 BACREL 12 2.500 DIST 1
*Relays_Defin
1  FAIL 0  FAIL 17  MAIN 1  ASGDNEW  BRAN 2
2  FAIL 0  FAIL 18  MAIN 1  ASGDNEW  BRAN 3
3  FAIL 0  FAIL 19  MAIN 1  ASGDNEW  BRAN 4
4  FAIL 0  FAIL 20  MAIN 1  ASGDNEW  BRAN 5
5  FAIL 0  FAIL 21  MAIN 1  ASGDNEW  BRAN 6
6  FAIL 0  FAIL 22  MAIN 1  ASGDNEW  BRAN 7
7  FAIL 0  FAIL 23  MAIN 1  ASGDNEW  BRAN 8
8  FAIL 0  FAIL 24  MAIN 1  ASGDNEW  BRAN 9
9  FAIL 0  FAIL 25  MAIN 1  ASGDNEW  BRAN 10
10  FAIL 0  FAIL 26  MAIN 1  ASGDNEW  BRAN 11
11  FAIL 0  FAIL 27  MAIN 1  ASGDNEW  BRAN 12
12  FAIL 0  FAIL 0  MAIN 1  ASGDNEW  BRAN 7
13  FAIL 0  FAIL 28  MAIN 1  ASGDNEW  BRAN 8
14  FAIL 0  FAIL 29  MAIN 1  ASGDNEW  BRAN 9
15  FAIL 0  FAIL 30  MAIN 1  ASGDNEW  BRAN 10
16  FAIL 0  FAIL 0  MAIN 1  ASGDNEW  BRAN 1
17  FAIL 0  FAIL 31  MAIN 1  ASGDNEW  BRAN 1
18  FAIL 0  FAIL 0  MAIN 1  ASGDNEW  BRAN 1
*Failure_Data
1  DIST 2  REP DIST 3  ASGDNEW
2  DIST 2  REP DIST 3  ASGDNEW
3  DIST 4  REP DIST 5  ASGDNEW
4  DIST 4  REP DIST 5  ASGDNEW
5  DIST 2  REP DIST 3  ASGDNEW
6  DIST 6  REP DIST 7  ASGDNEW
7  DIST 8  REP DIST 9  ASGDNEW
8  DIST 8  REP DIST 9  ASGDNEW
9  DIST 10  REP DIST 11  ASGDNEW
10  DIST 2  REP DIST 3  ASGDNEW
11  DIST 2  REP DIST 3  ASGDNEW
12  DIST 12  REP DIST 13  ASGDNEW
13  DIST 12  REP DIST 13  ASGDNEW
14  DIST 12  REP DIST 13  ASGDNEW
15  DIST 12  REP DIST 13  ASGDNEW
16  DIST 12  REP DIST 13  ASGDNEW
17  DIST 14  REP DIST 15  ASGDNEW
18  DIST 14  REP DIST 15  ASGDNEW
19  DIST 14  REP DIST 15  ASGDNEW
20  DIST 14  REP DIST 15  ASGDNEW
21  DIST 14  REP DIST 15  ASGDNEW
22  DIST 14  REP DIST 15  ASGDNEW
```

```
23  DIST 14  REP DIST 15  ASGDNEW
24  DIST 14  REP DIST 15  ASGDNEW
25  DIST 14  REP DIST 15  ASGDNEW
26  DIST 14  REP DIST 15  ASGDNEW
27  DIST 14  REP DIST 15  ASGDNEW
28  DIST 14  REP DIST 15  ASGDNEW
29  DIST 14  REP DIST 15  ASGDNEW
30  DIST 14  REP DIST 15  ASGDNEW
31  DIST 14  REP DIST 15  ASGDNEW
*Maintenance
1  DIST 16 DIST 17 MTYPE0
*Distributions
1   CHAN 100.00
2   WEIB  3650.00    2.000    0.000
3   NORM     2.000    1.000    0.200
4   WEIB 10950.00    2.000    0.000
5   NORM     0.200    0.200    0.100
6   WEIB  7300.00    2.000    0.000
7   NORM     2.000    1.000    0.200
8   WEIB 18250.00    1.000    0.000
9   NORM     1.000    0.500    0.100
10  WEIB 182500.0    1.000    0.500
11  NORM    0.200    0.200    0.100
12  WEIB 182500.0    1.000    0.000
13  NORM    1.00     0.500    0.200
14  WEIB 10950.00    1.000    0.000
15  NORM    0.200    0.200    0.100
16  UNIF  1800.00    1825.00
17  UNIF    0.50      1.00
*Depend_Branch
13 / 2 0.0 1.00 / 11 0.0 1.00
13 / 3 0.0 1.00 / 12 0.0 1.00
13 / 4 0.0 1.00 / 5  0.0 1.00
13 / 6 3.0 3600.00
13 / 8 0.0 0.1  / 9  0.0 1.00
13 / 10 3.0 3600.0
13 / 7  0.0 0.1
13 / 1  0.0 0.1
*CommonModeFail
.END
```

APPENDIX 3 AN INPUT FILE FOR THE EXAMPLE GENERATING UNIT PRESENTED IN § 4-3

```
*Simulation_Name
EPON-UNIT-2
*RandomNumber
1
*Frequency
50.00
*BasePower
440000000
*BaseVoltage
23000
*Lifetime(days)
10950
*Accuracy
ABS
3.00
*Branch_Data
1  0  1  'generato' 0.00100 0.38900 'generato' 0.00100 0.38900 GEN 1 SHRT 1 FAIL 0 MAIN 1 ASGDNEW
2  0  6  'MAIN-BUS' 0.00050 0.18000 'MAIN-BUS' 0.00050 0.18000 GEN 2 SHRT 0 FAIL 0 MAIN 1 ASGDNEW
3  0  1  'EXCITERT' 16.00000 157.0000 'EXCITER ' 15.40000 150.4000 NSEC SHRT 0 FAIL 0 MAIN 1 ASGDNEW
                          / 'EX-TRANF' 0.60000 6.60000 NSEC SHRT 4 FAIL 0 MAIN 1 ASGDNEW
4  0  2  'MOTOR--1' 1311.200 812.5010 'MOTOR--1' 1311.200 812.5000 NSEC SHRT 0 FAIL 0 MAIN 1 ASGDNEW
                          / 'FUSE---1' 0.00000 0.00100 NSEC SHRT 5 FAIL 0 MAIN 1 ASGDNEW
5  0  2  'MOTOR--3' 211.6300 102.5010 'MOTOR--3' 211.6300 102.5000 NSEC SHRT 0 FAIL 0 MAIN 1 ASGDNEW
                          / 'FUSE---3' 0.00000 0.00100 NSEC SHRT 6 FAIL 0 MAIN 1 ASGDNEW
6  0  3  '380vbus1' 250.0010 180.0020 '380VBUS1' 250.0000 180.0000 NSEC SHRT 0 FAIL 0 MAIN 1 ASGDNEW
                          / '        ' 0.00100 0.00200 NSEC SHRT 7 FAIL 0 MAIN 1 ASGDNEW
7  0  4  '380vbus2' 250.0010 180.0020 '380VBUS2' 250.0000 180.0000 NSEC SHRT 0 FAIL 0 MAIN 1 ASGDNEW
                          / '        ' 0.00100 0.00200 NSEC SHRT 8 FAIL 0 MAIN 1 ASGDNEW
8  0  5  'MOTOR--5' 195.5000 188.5010 'MOTOR--5' 195.5000 188.5000 NSEC SHRT 0 FAIL 0 MAIN 1 ASGDNEW
                          / 'FUSE---5' 0.00000 0.00100 NSEC SHRT 9 FAIL 0 MAIN 1 ASGDNEW
9  1  2  'EB-TRAFO' 0.33700 3.61400 'EB-TRAFO' 0.33700 3.61400 NSEC SHRT 10 FAIL 0 MAIN 1 ASGDNEW
10 2  3  'TR-380V1' 1.30000 14.98800 'TR-380V1' 1.30000 14.98800 NSEC SHRT 11 FAIL 0 MAIN 1 ASGDNEW
11 2  4  'TR-380V2' 1.30000 14.98800 'TR-380V2' 1.30000 14.98800 NSEC SHRT 12 FAIL 0 MAIN 1 ASGDNEW
12 2  5  'TRANSMIS' 2.23500 1.40000 'TRANSMIS' 2.23500 1.40000 NSEC SHRT 13 FAIL 0 MAIN 1 ASGDNEW
13 1  6  'gen-traf' 0.00200 0.13000 'gen-traf' 0.00200 0.13000 NSEC SHRT 3 FAIL 0 MAIN 1 ASGDNEW
14 0  2  'Motor--2' 1311.200 812.5010 'MOTOR--2' 1311.200 812.5000 NSEC SHRT 0 FAIL 0 MAIN 1 ASGDNEW
                          / 'FUSE---2' 0.00000 0.00100 NSEC SHRT 14 FAIL 0 MAIN 1 ASGDNEW
15 0  2  'Motor--4' 211.6300 102.5100 'MOTOR--4' 211.6300 102.5000 NSEC SHRT 0 FAIL 0 MAIN 1 ASGDNEW
                          / 'FUSE---4' 0.00000 0.01000 NSEC SHRT 15 FAIL 0 MAIN 1 ASGDNEW
16 1  7  'FALSE-BR' 20.00000 20.00000 '        ' 20.00000 20.00000 NSEC SHRT 0 FAIL 0 MAIN 1 ASGDNEW
17 0  7  'False-LO' 30000.00 60010.00 'TOTAL-RE' 30000.00 60000.00 LOAD 1 SHRT 0 FAIL 0 MAIN 0 ASGDNEW
                          / '        ' 0.00000 10.00000 NSEC SHRT 0 FAIL 0 MAIN 0 ASGDNEW
18 0  1  'mechanic' 30000.00 60000.00 'BOILER  ' 10000.00 20000.00 NESC SHRT 0 FAIL 37 MAIN 1 ASGDNEW
                          / 'TURBINE ' 10000.00 20000.00 NESC SHRT 0 FAIL 38 MAIN 1 ASGDNEW
                          / 'G-MECHAN' 10000.00 20000.00 NESC SHRT 0 FAIL 39 MAIN 1 ASGDNEW
*Rail_Data
1  'busbar-1' SHRT 16 FAIL 0 MAIN 0 ASGDNEW
2  'busbar-2' SHRT 17 FAIL 0 MAIN 0 ASGDNEW
3  'busbar-3' SHRT 18 FAIL 0 MAIN 0 ASGDNEW
```

```
4  'busbar-4' SHRT 19 FAIL 0  MAIN 0  ASGDNEW
5  'busbar-5' SHRT 2  FAIL 0  MAIN 0  ASGDNEW
6  'mainbus ' SHRT 0  FAIL 0  MAIN 0  ASGDNEW
7  'F-BUSBAR' SHRT 0  FAIL 0  MAIN 0  ASGDNEW
*Load_Data
1  SPYK 0.21  0.40  0.40  0.70  0.50  0.90  COST  20.0 1.00
*Generator_Data
1  1.273   14.13
2  1.050   -5.00
*ATS/Swit._Data
*ShortCirc_Data
1 FAIL 1 PRIREL 1 0.200 DIST 1 BACREL 2 1.500 DIST 1
2 FAIL 2 PRIREL 6 0.200 DIST 1 BACREL 8 2.500 DIST 1
     / BACREL 10 2.700 DIST 1
3 FAIL 3 PRIREL 3 0.200 DIST 1 BACREL 4 1.500 DIST 1
4 FAIL 4 PRIREL 1 0.200 DIST 1 BACREL 2 1.500 DIST 1
       PRIREL 5 0.200 DIST 1 BACREL 4 1.500 DIST 1
5 FAIL 5 PRIREL 7 0.200 DIST 1 BACREL 8 2.500 DIST 1
     / BACREL 10 2.700 DIST 1
6 FAIL 6 PRIREL 9 0.200 DIST 1 BACREL 8 2.500 DIST 1
     / BACREL 10 2.700 DIST 1
7 FAIL 7 PRIREL 11 0.200 DIST 1 BACREL 12 1.500 DIST 1 BACREL 8 2.500 DIST 1
                    / / BACREL 10 2.700 DIST 1
8 FAIL 8 PRIREL 13 0.200 DIST 1 BACREL 14 1.500 DIST 1 BACREL 8 2.500 DIST 1
                    / / BACREL 10 2.700 DIST 1
9 FAIL 9 PRIREL 15 0.200 DIST 1 BACREL 16 1.500 DIST 1 BACREL 8 2.500 DIST 1
                    / / BACREL 10 2.700 DIST 1
10 FAIL 10 PRIREL 17 0.200 DIST 1 BACREL 4 1.500 DIST 1
        PRIREL 1 0.200 DIST 1 BACREL 2 1.500 DIST 1
11 FAIL 11 PRIREL 18 0.200 DIST 1 BACREL 8 2.500 DIST 1
      / BACREL 10 2.700 DIST 1
12 FAIL 12 PRIREL 19 0.200 DIST 1 BACREL 8 2.500 DIST 1
      / BACREL 10 2.700 DIST 1
13 FAIL 13 PRIREL 6 0.200 DIST 1 BACREL 8 2.500 DIST 1
      / BACREL 10 2.700 DIST 1
14 FAIL 14 PRIREL 20 0.200 DIST 1 BACREL 8 2.500 DIST 1
      / BACREL 10 2.700 DIST 1
15 FAIL 15 PRIREL 21 0.200 DIST 1 BACREL 8 2.500 DIST 1
      / BACREL 10 2.700 DIST 1
16 FAIL 16 PRIREL 1 0.200 DIST 1 BACREL 2 1.500 DIST 1
        PRIREL 3 0.200 DIST 1 BACREL 4 1.500 DIST 1
17 FAIL 17 PRIREL 17 0.200 DIST 1 BACREL 4 1.500 DIST 1
        PRIREL 1 0.200 DIST 1 BACREL 2 1.500 DIST 1
18 FAIL 18 PRIREL 18 0.200 DIST 1 BACREL 8 2.500 DIST 1
      / BACREL 10 2.700 DIST 1
19 FAIL 19 PRIREL 19 0.200 DIST 1 BACREL 8 2.500 DIST 1
      / BACREL 10 2.700 DIST 1
*Relays_Defin
1  FAIL 0  FAIL 20  MAIN 1  ASGDNEW  BRAN 1
2  FAIL 0  FAIL 0   MAIN 1  ASGDNEW  BRAN 1
3  FAIL 0  FAIL 21  MAIN 1  ASGDNEW  BRAN 13 2
4  FAIL 0  FAIL 0   MAIN 1  ASGDNEW  BRAN 13 2
5  FAIL 0  FAIL 22  MAIN 1  ASGDNEW  BRAN 3
6  FAIL 0  FAIL 23  MAIN 1  ASGDNEW  BRAN 12
7  FAIL 0  FAIL 24  MAIN 1  ASGDNEW  BRAN 4
8  FAIL 0  FAIL 0   MAIN 1  ASGDNEW  BRAN 9
9  FAIL 0  FAIL 25  MAIN 1  ASGDNEW  BRAN 5
10  FAIL 0  FAIL 0  MAIN 1  ASGDNEW  BRAN 1
11  FAIL 0  FAIL 26  MAIN 1  ASGDNEW  BRAN 6
12  FAIL 0  FAIL 27  MAIN 1  ASGDNEW  BRAN 10
13  FAIL 0  FAIL 28  MAIN 1  ASGDNEW  BRAN 7
```

14 FAIL 0 FAIL 29 MAIN 1 ASGDNEW BRAN 11
15 FAIL 0 FAIL 30 MAIN 1 ASGDNEW BRAN 8
16 FAIL 0 FAIL 31 MAIN 1 ASGDNEW BRAN 12
17 FAIL 0 FAIL 32 MAIN 1 ASGDNEW BRAN 9
18 FAIL 0 FAIL 33 MAIN 1 ASGDNEW BRAN 10
19 FAIL 0 FAIL 34 MAIN 1 ASGDNEW BRAN 11
20 FAIL 0 FAIL 35 MAIN 1 ASGDNEW BRAN 14
21 FAIL 0 FAIL 36 MAIN 1 ASGDNEW BRAN 15
*Failure_Data
1 DIST 2 REP DIST 3 ASGDNEW
2 DIST 4 REP DIST 5 ASGDNEW
3 DIST 6 REP DIST 7 ASGDNEW
4 DIST 8 REP DIST 9 ASGDNEW
5 DIST 10 REP DIST 11 ASGDNEW
6 DIST 10 REP DIST 11 ASGDNEW
7 DIST 12 REP DIST 13 ASGDNEW
8 DIST 12 REP DIST 13 ASGDNEW
9 DIST 10 REP DIST 11 ASGDNEW
10 DIST 14 REP DIST 15 ASGDNEW
11 DIST 16 REP DIST 17 ASGDNEW
12 DIST 16 REP DIST 17 ASGDNEW
13 DIST 18 REP DIST 19 ASGDNEW
14 DIST 10 REP DIST 11 ASGDNEW
15 DIST 10 REP DIST 11 ASGDNEW
16 DIST 4 REP DIST 5 ASGDNEW
17 DIST 4 REP DIST 5 ASGDNEW
18 DIST 4 REP DIST 5 ASGDNEW
19 DIST 4 REP DIST 5 ASGDNEW
20 DIST 20 REP DIST 21 ASGDNEW
21 DIST 20 REP DIST 21 ASGDNEW
22 DIST 20 REP DIST 21 ASGDNEW
23 DIST 20 REP DIST 21 ASGDNEW
24 DIST 20 REP DIST 21 ASGDNEW
25 DIST 20 REP DIST 21 ASGDNEW
26 DIST 20 REP DIST 21 ASGDNEW
27 DIST 20 REP DIST 21 ASGDNEW
28 DIST 20 REP DIST 21 ASGDNEW
29 DIST 20 REP DIST 21 ASGDNEW
30 DIST 20 REP DIST 21 ASGDNEW
31 DIST 20 REP DIST 21 ASGDNEW
32 DIST 20 REP DIST 21 ASGDNEW
33 DIST 20 REP DIST 21 ASGDNEW
34 DIST 20 REP DIST 21 ASGDNEW
35 DIST 20 REP DIST 21 ASGDNEW
36 DIST 20 REP DIST 21 ASGDNEW
37 DIST 24 REP DIST 25 ASGDNEW
38 DIST 26 REP DIST 27 ASGDNEW
39 DIST 28 REP DIST 29 ASGDNEW
*Maintenance
1 DIST 22 DIST 23 MTYPO
*Distributions
1 CHAN 100.00
2 WEIB 18250.00 2.000 0.000
3 NORM 3.00 2.000 1.000
4 WEIB 182500.0 1.000 0.000
5 NORM 1.00 0.500 0.200
6 WEIB 10950.00 2.000 0.000
7 NORM 3.00 2.000 1.000
8 WEIB 18250.00 2.000 0.000
9 NORM 3.00 2.000 1.000
10 WEIB 3650.00 2.000 0.000

```
11 NORM    1.00    1.000   0.200
12 WEIB 10950.00   2.000   0.000
13 NORM    0.20   0.200   0.100
14 WEIB  7300.00   2.000   0.000
15 NORM    2.00   1.000   0.200
16 WEIB 18250.00   1.000   0.000
17 NORM   1.000   0.500   0.100
18 WEIB 182500.0   1.000   0.000
19 NORM   0.200   0.200   0.100
20 WEIB 10950.00   1.000   0.000
21 NORM   0.200   0.200   0.100
22 UNIF  1800.00 1810.00
23 UNIF   10.000  10.000
24 WEIB 10950.00   3.000   0.000
25 NORM   10.000   5.000   2.000
26 WEIB 14600.00   3.000   0.000
27 NORM   10.000   5.000   2.000
28 WEIB 18250.00   3.000   0.000
29 NORM   10.000   5.000   2.000
*Depend_Branch
16 / 4 0.0 1.00 / 14 0.0 1.00
16 / 5 0.0 1.00 / 15 0.0 1.00
16 / 10 0.0 1.00 / 11 0.0 1.00
16 / 6 0.0 0.10 / 7 0.0 0.10
16 / 8 3.0 3600
16 / 3 0.0 0.1
16 / 1 0.0 0.1
16 / 9 0.0 0.1
16 / 12 3.0 3600
16 / 13 0.0 0.1
16 / 18 0.0 1.0
*CommonModeFail
.END
```

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