I

"DEVELOPMENT OF MAINTENANCE SCHEDULES FOR NATIONAL ELECTRIC POWER AUTHORITY GENERATING FACILITIES"

BY

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B.ENG.(ABU)

A thesis submitted to the Department of Electrical Engineering, Ahmadu Bello University, Zaria (Nigeria) in partial fulfillment of the requirements for the award of the degree of

MASTER OF SCIENCE (ELECTRICAL)

IN

POWER & MACHINES

DECEMBER, 1988

DEDICATION

To the entire Family of

Late ALH. MUSA GUMEL

(M.O.O.N.)

D E C L A R A T I O N

I hereby declare that this thesis has been composed by myself and that it is a record of my own research work. It is also believed to be a pioneering study of its kind to be accepted for higher degree. All quotations are distinguished by quotation marks and the sources of information are specifically acknowledged by means of references.

MUSA MUSA GUMEL



.....

SUPERVISOR: DR. U.O. ALIYU

DEC., 1988

CERTIFICATION

This thesis entitled: DEVELOPMENT OF MAINTENANCE SCHEDULES FOR NATIONAL ELECTRIC POWER AUTHORITY(NEPA) GENERATING FACILITIES BY MUSA MUSA GUMEL meets the regulations governing the award of the Degree of Master of Science (M.Sc) of Ahmadu Bello University and is approved for its contribution to knowledge.

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A C K N O W L E D E M E N T

All praise be to Allah the sustainer of the worlds, may His peace and blessings be upon our prophet Muhammed.

The Author wishes to express his profound gratitude and appreciation to his main supervisor Dr. U.O. Aliyu for his continuous guidance during the course of this study and reviewing all parts of the manuscripts; and also to his subsidiary supervisor Dr. B. G. Ishaku.

I am greatly indebted to Engr. Isa Musa, the present Managing Director of Rural Electricity Board of Kano State, a Brother, for his moral, material andfinancial support; and his bossom friend A.A. Sadiq for a similar gesture.

Material and moral support by my head of department Arc. Ahmed Shamsuna and all his staff of Nigerian Telecommunications Limited are gratefully acknowledged.

My acknowledgement also goes to Engr. F.A. Shomolu of NEPA who by the aid of his staff enabled my acquiring the relevant data for this study.

Thanks are also due to all friends who contributed in one way or another to make this thesis a success.

ABSTRACT

This dissertation is primarily concerned with the generating plant maintenance scheduling problem of an electric utility in a developing environment as typified by the generating facilities of National Electric Power Authority (NEPA). The importance of this study lies in the fact that system reliability and operating cost of such electric utility are significantly affected by the adhoc maintenance philosophy adopted. There is the need to evolve an efficient maintenance policy aimed at optimizing system reliability and security.

In this research effort, therefore, the maintenance scheduling problem has been recognised as an optmization problem with several constraints. Although the mathematical formulation is not altogether new, its application via existing optimizing algorithms to solve specific maintenance scheduling problem often requires some innovative assumptions to be made in order to generate realistic maintenance schedules. Herein, the Engineering assumptions and approximations made with respect to the maintenance problem at hand simplified **the** optimization problem proposed and led to the development of versatile software program.

This technique has been applied to twenty eight generating units of NEPA, based on a scheduling horizon of one year and a maintenance period of one month. Several case studies were ran and the results obtained have been presented and fully discussed.

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This dissertation is primarily concerned with the generating plant maintenance scheduling problem of an electric utility in a developing environment as typified by the generating facilities of National Electric Power Authority (NEPA). The importance of this study lies in the fact that system reliability and operating cost of such electric utility are significantly affected by the adhoc maintenance philosophy adopted. There is the need to evolve an efficient maintenance policy aimed at optimizing system reliability and security.

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$f^{c}_{(.)}$: Expected production cost

$f^{m}_{(.)}$: Expected maintenance cost

$f^{r}(.)$: Expected cost of reliability

$\forall$: for all

$u_i(t)$: Decision (control variable for unit i at stage t)

$x_i(i)$: State variable for unit i

$\underline{x}$ (t): State vector

$= [\, x_1\,(t),\ x_2\,(t),\ \ldots\ldots x_i(t),\ldots\ldots X_N\,(t)\,]^{!}$

$\underline{U}$ (t): Decision vector

$= [\, U_1\,(t),\ U_2\,(t),\ \ldots\ldots U_i\,(t),\ldots\ldots U_N(t)\,]^{!}$

R_m: Reserve margin

Y: Outage megawatts associated with the entry

Y -CP: is the additional outage in the remainder of the system necessary to make a $\underline{Y}$ MW outage or greater with CP already on forced outage. if $\underline{Y - CP}$ is negative assume the table entry is 1.0.

CHAPTER 1

GENERAL INTRODUCTION

1.1 MOTIVATION

It is a known fact that scheduling the maintenance for an individual utility company is a formidable problem. This arises because as power system generating facilities become larger and more complex, the need for rigorous control and monitoring of maintenance of the generating facilities increases. The reliability of operation, production costs and capital expenditures are affected by the methods used to schedule the maintenance. It could then be rightly expected that most power companies spend millions of naira annually to carry out planned maintenance of their generating facilities and other major system components. An electric utility with fossil fuel fired generating capacity of 20,000 MW, for example will spend in the neighbourhood of ₦31 million [1] annually for plant maintenance.

The rationale behind preventive maintenance, otherwise known as scheduled outages of all generating equipment is to reduce the chances of unplanned capacity outages, thereby improving the overall availability of such units throughout their entire working life. The scheduling maintenance policies of established electric utilities in developedcountries are so implemented in order to achieve the desired reliability at minimum cost. On the other hand, electric utilities of most developing countries are characterized by poor maintenance procedures that in turn adversely affect the average life span of major system components and quality of supply.

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For example, intermittent power disruptions as well as frequent load sheddings characterizing the Nigerian National grid are clear indications that the National Electric Power Authority (NEPA), is facing the problem of maintenance of its generating facilities and other key system components.

From the preliminary investigations carried out, NEPA, a utility of over 5,000 MW; has not embraced modern techniques of maintenance scheduling. The standard practice is for each unit to be taken out of service once or twice annually so that reliability and security of the supply system as perceived by various consumers are not jeopardized. The non-adherence of NEPA to this standard practice, among other reasons, is suspected to be responsible for the catastrophic failure of many of its generating facilities. To arrest this trend, through effective maintenance policy for NEPA generating facilities is the main objective of this study.

Although several algorithms have been proposed for automatic unit maintenance scheduling [4,5] the technique adopted in this dissertation attempts to equalize system reserve thereby levelizing the risks over the various maintenance periods. Practical applications of the algorithm evolved are demonstrated by analysing data acquired from NEPA, and hence the development of maintenance schedules for the utility.

1.2 LITERATURE REVIEW

In solving practical problems with several feasible solutions, there is need for an objective function to be maximized in order to arrive at an optimal solution [2]. Generally speaking, there are two desired objectives in the operation of an electric power system. These involve minimization of the total costs to the utility and maximization of the system reliability. More often, reliability index is specified

apriori as a constraint which the system must strive to meet at all times.

Two types of costs are of importance when the objective is to minimize the overall operating cost. The first is the maintenance cost and the second is the production cost. Production cost has been used by some authors [3,4] as an objective function, to schedule maintenance of thermal power systems. Except for long range planning purposes [2], short term production cost based on maintenance strategies requires many approximations and tedious simulations and therefore less attractive in the absence of reliable data base.

Reliability oriented methods fall under one of two categories: deterministic and stochastic. Deterministic reliability objectives strive to levelize the capacity of reserves in one way or another [5]. It has been recognised [6,7], that this objective does not levelize system reliability as long as the uncertainties in demand and generating unit availabilities are ignored. Stochastic methods subsequently introduced include load uncertainties and generating forced outages. Garver [6], used the idea of load carrying-capability to include unit forced outages. It should be noticed that most stochastic approaches incorporate practical approximations of some kind to reduce computational efforts. Consequently, the solutions obtained are usually sub-optimal.

Integer programming has been proposed by a number of authors to solve maintenance scheduling problems [5,8]. The difficulties associated with this approach are two fold. Firstly, the approach cannot consider the uncertainties involved, and secondly (for sizeable problems) it sometimes exceeds the available computer memory. To alleviate these problems, branch and bounds approaches have been implemented by some researchers [9].

In theory, dynamic programming is most suitable to the solution of maintenance problem because it is a sequential decision process problem. However, the problem of large data manipulation [15], limits the application of this method.

Many authors have published results reporting some computational experience [11,13,15] based on a handful computer programs developed. In this research work, the maintenance scheduling technique adopted has resulted in the modification of an existing model computer program [11] to schedule the maintenance problem at hand. The availability of data requirements of this technique favoured its adoption.

THESIS OUTLINE

This dissertation is divided into six chapters, of which general introduction of the thesis is provided in chapter 1. Covered in chapter 2 is the survey of maintenance scheduling methods, and chapter 3 an overview of NEPA generating facilities & maintenance management. The actual formulation and development of maintenance schedules are presented in chapter 4. While the discussion of results is treated in chapter 5, and drawn in chapter 6 are the general conclusion & recommendations.

List of references is given at the end of the thesis. Included thereafter, are three appendices. Appendix I contains the listing of the input data. Computer program listing and sample results are contained in appendix II. Finally, appendix III contains the capacity outage probability table.

CHAPTER 2

A SURVEY OF MAINTENANCE SCHEDULING METHODS

2.1 INTRODUCTION:

The object of this chapter is to survey some methods which have been successfully used to schedule plant maintenance. It is intended to provide broad overview of the scheduling problem and the usefullness of automated techniques for improving maintenance scheduling. Before the survey however, the terminologies often used in the formulation of the scheduling problem are briefly defined. The relative merits of alternate approaches to the problem are fully discussed.

2.2 TERMINOLOGY:

Unit: This term, as used in this dissertation refers to any device for which an outage results in a loss of generating reserves. The term includes generators, boilers, auxiliary equipment and tie lines [13].

Reserve Loss: A reserve loss is generally associated with each unit or device. This value in megawatts, is the decrease in reserves during maintenance.

Gross Reserve: [Weekly] The gross reserve in megawatts for a given week is the total installed generating capacity available during the week less the peak load forecast for the week.

Net Reserve: [Weekly] The net reserve in megawatts for a given week is the gross reserve for the week less the total reserve lost because of the maintenance scheduled for that week.

Net Reserve: [Minimum] The minimum net reserve is the lowest of all the weekly net reserves over the year.

Crew: A crew is a pool of manpower assigned to each unit or device for maintenance activity. For example, a single crew may be responsible for maintaining all the units in a given plant.

Maintenance Outage: Generally speaking, an outage is the taking of a unit out of service for maintenance.

Firm Maintenance: This term describes an occurrence of an outage which has already taken place or is prescheduled to begin on a specified week. [A general model would include a variable number of firm outages followed by a variable number of flexible outages].

Flexible Maintenance: This term refers to the occurrences of an outage which are to be scheduled sequentially following the firm outages.

Resource: A resource is a general term applied to a pool of manpower, equipment or other quantity which is in limited supply during each week and is shared by two or more outages. Examples include heavy cranes, major units in a system etc.

Independent Variables: The independent variables in the problem are the starting dates of each of the flexible outages.

Objective Function: The objective is to set the starting dates so that the minimum net reserve over the entire year is maximized. This is to spread the outages over the year so that when peak load and capacity out for maintenance are subtracted from the installed capacity for each week, the remaining reserve is about equal for each week throughout the year.

Forced Outage: A forced outage is one which requires the turbo generator/or boiler to be taken out of service at once or as soon as possible. This includes the removing of equipment from service during off-peak period and cases where damage occurs during shutdown and start up.

Time Exposed To Forced Outage: The time on forced outage plus the service time [time in operation].

Forced Outage Rate: The forced outage rate of a unit is the ratio of forced outage time and time exposed to the forced outage.

Objective: The objective of a maintenance scheduling is to have a "reliable" system with minimum operating costs to the utility [indirectly to the consumer] [13].

2.3 SCHEDULING MAINTENANCE METHODS

Sequel to the recognition of maintenance scheduling problem as one of optimization problems with serveral feasible solutions, various methods as proposed by some authors have been successfully used to schedule plant maintenance. One of the authors [15] described the scheduling problem as a diagrammed "multi-stage" decision "tree" problem as illustrated in figure 1. The decision tree model describes the scheduling process as a sequential series of yes-no decision. Each unit is either in service or out for maintenance during any week. Decisions are made sequentially in the following order:

[Week 1, Unit 1], [Week 1, Unit 2] .... [Week 1, Last Unit]

[Week 2, Unit 1], ... [week 2, Last Unit]

.....

[Last Week, Unit 1] ..... [Last Week, Last Unit]

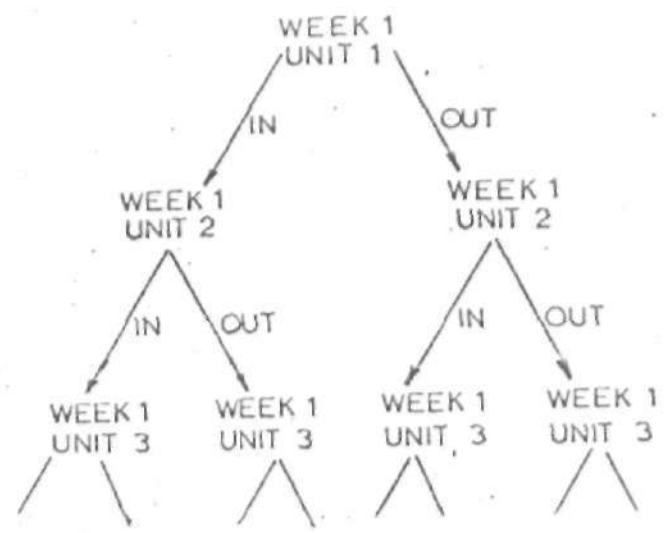


Figure 1. Decision tree showing the scheduling problem as a multi-stage decision process.

Each possible complete set of yes-no decisions represents a different schedule. One by one the infeasible ones can be eliminated from the set of all schedules by application of the problem constraints. This is a slow process as each branch of the decision tree must be considered individually. Even when all feasible schedules are known, each must be tested individually against the objective function to determine the optimal schedules. Prior to the wide spread use of digital computers for automated scheduling of maintenance, this tedious task was accomplished by hand calculation, clever techniques were developed which enabled schedulars to arrange an acceptable schedule. Usually, any feasible schedule was acceptable though sub-optimal.

The line of reasoning of minimizing fuel cost over the year by maximizing the total megawatt hour utilization of most efficient units, and minimizing the total megawatt hour utilization of least efficient units, led to the assumption that equalizing net reserves over the schedule period also corresponds, approximately to minimizing total fuel costs. It was concluded that the objective would be the maximization of the minimum net reserves over the year [15]. Details vary from one method to another. The scheduling techniques which rely on this assumption are nevertheless sub-optimal. A basic advantage of these sub-optimal techniques is that they require minimum of plant data to obtain a feasible schedule which is reasonably close to optimum.

2.4 SCHEDULING OPTIMIZATION FOR ECONOMY AND SECURITY

The shortcomings of the sub-optimal techniques prompted much work in the area of scheduling optimization. The desirability of incorporating mathematical rigour into maintenance scheduling algorithms has long been identified [15]. Only recently have Dopazo & Merill successfully developed an algorithm which does so economically [7].

The maintenance scheduling is formulated as 0 - 1 integer linear programming optimization problem. The general form is: Find the n-vector $\vec{X}^*$ which minimizes the scalar cost function.

$$Z = \vec{C}^t\vec{X} \quad \ldots\ldots\ldots\ldots\ldots\ldots(2.1)$$

Subject to the constraints

$$\bar{A}\,\vec{X} \leqslant \vec{b} \quad \ldots\ldots\ldots\ldots\ldots\ldots(2.2)$$

or equivalently

$$\vec{Y} = \vec{b} - \bar{A}\vec{X} \geqslant \vec{0} \quad \ldots\ldots\ldots(2.3)$$

and

$$X_i = 0 \text{ or } 1,\ i = 1, 2, \ldots\ldots\ldots(2.4)$$

Any n-vector $\vec{X}$ which satisfies equation 2.4 is a solution to the problem. A feasible solution is a solution $\vec{X}$ which satisfies a set of constraints [7]. A feasible n-vector $\vec{X}$ is optimal if and only if $\vec{C}^t\,\vec{X}^* \leqslant \vec{C}^t\vec{X}$ for all feasible $\vec{X}$.

Each independent variable X_i is associated with beginning maintenance on some unit j during some week k. Hence $X_i = 1$ if and only if maintenance on unit j is scheduled to begin during week k. The starting times for maintenance on each unit are the unknowns to be solved for.

The cost function represents the criterion of optimality. A great advantage of the integer program formulation is that it will accept a variety of cost functions while the remainder of the program input data are unaffected. Many cost functions may be formulated as desired by the maintenance engineer. However, cost functions of Naira costs/benefits incurred by advancing or delaying maintenance must be developed from actual reported data for each unit in the system.

Assuming that maintenance on a particular unit must be accomplished once annually, figure 2 displays the capital investment of maintenance expended over twelve months period. There is also a cost associated with maintaining a unit too early: as some of the twelve months of operation purchased the last time the unit was maintained will be lost.

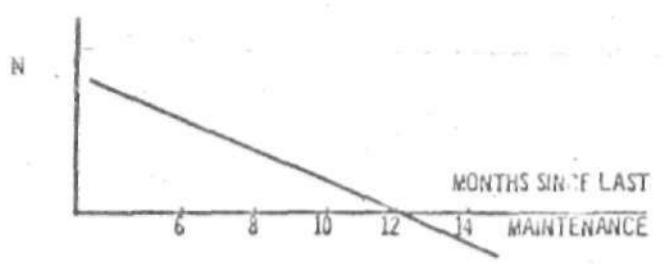


Figure 2. Undepreciated maintenance investment lost by maintaining a unit too early.

Projected maintenance costs rise dramatically as illustrated in figure 3. when maintenance is delayed too long. Accelerated deterioration of neglected machinery makes maintenance more expensive when it is finally performed.

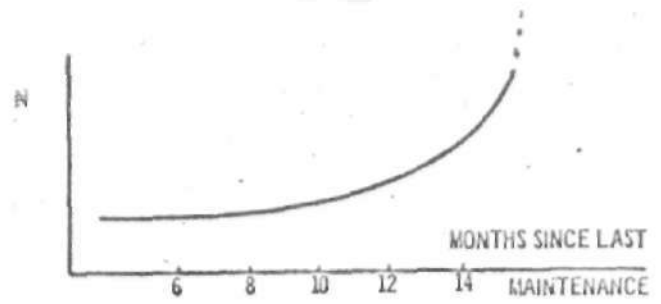


Figure 3. Expected out-of-pocket maintenance cost in terms of time since previous maintenance.

The optimum time to begin maintenance is clearly the minimum of the curve in figure 4. which was obtained by summing figures 2 & 3. Such "total maintenance cost" curves as figure 4 could be developed for each unit of a system. The sum of the cost curves for all units gives an overall cost function which when minimized, provides the least cost schedule for the system as a whole [7]

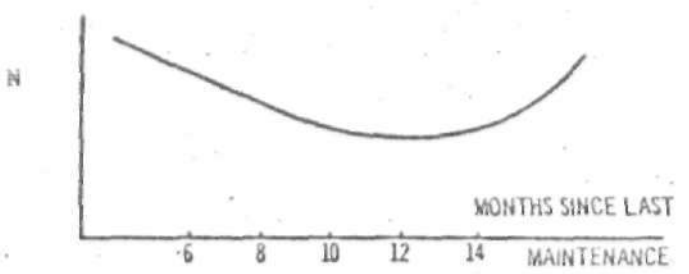


Figure 4. Total maintenance cost in terms of time since previous maintenance

In addition to the conventional constraints described earlier, certain major constraints are implicitly imbedded in the algorithm structure of the integer program formulation and are not expressed explicitly. Some of these implicit constraints are:

1. that maintenance for each unit occupies the required time duration, without interruption, in specified period;

2. that each unit must be maintained once within a year.

The cost function is transformed into powerful constraint with a ceiling. Each time a new feasible solution is found with a lower cost than the previous best solution, the ceiling is reduced so that only improving schedules are considered in the future.

The integer program is solved by an extension of implicit enumeration algorithm. Dopazo & Merill described the method as a "tree search". The decision tree is redefined as a compact decision tree in figure 5. This new model groups several decisions at each node, implicitly including the "multiple choice" constraint that maintenance on each unit can begin no more than once. The method of solution provides tests for cancelling irrelevant variables and constraints.

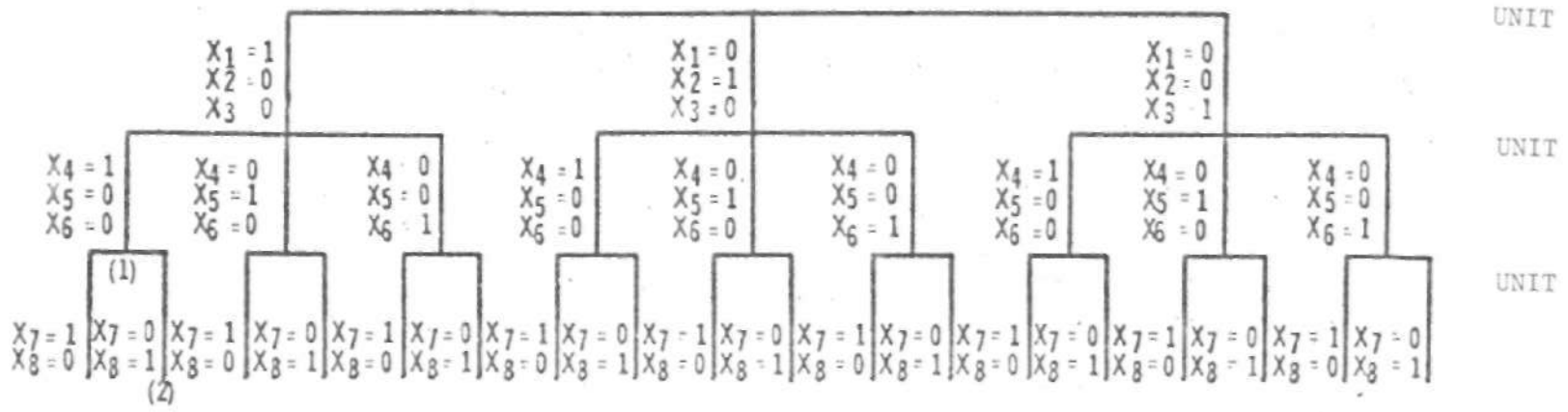


Figure 5. Compact decision tree for three unit example.

Implicit enumeration embodies several tests involving only addition and comparison operations. In terms of the compact decision tree diagram of figure 5, the algorithm starts at the top of the tree and goes down each branch in turn until it has determined that the branch has no feasible solution. This is called Fathoming. When a branch has been fathomed, the algorithm steps back up the tree until a branch is found that has not been fathomed. When all branches have been fathomed, the process is completed. The tests and exploitation of the unique problem structure insure that most solutions are enumerated implicitly (7). This is the key to speed and economy without compromising mathematical rigour as in the case of the integer programming approach. The mathematical rigour has an apparent disadvantage of requiring large amount of statistical and histor plant data.

Given adequate input data, the 0 - 1 integer programming method significantly reduces the number of operations that would otherwis be required under straight implicit enumeration. Consequently, the computer execution time for scheduling programs employing this algorithm as opposed to others considered in this thesis is greatly reduced and thus practical for frequent use.

CHAPTER 3

OVERVIEW OF NEPA GENERATING FACILITIES & MAINTENANCE MANAGEMENT

3.1 INTRODUCTION

Highlighted in the preceeding chapter were the various methodologies of tackling maintenance scheduling problems, the common terminologies used in addressing the problems, merits and demerits of those methodologies as well as their practicability. In this chapter, attention is focussed on the existing generating facilities of NEPA in order to gain sufficient insight into their maintenance management problems.

3.2 GENERATING FACILITIES

The Nigerian National grid is fed from a generation mix of thermal and hydro capacities. The total installed and committed capacity of all NEPA generating stations to date stand at about 5,400 MW. The hydro stations sited on Nigerian river system constitute a sizeable percentage of the presently installed generating plants. Broadly speaking, they are characterized by variation in water inflow patterns which in turn determine the energy contributions of the hydro power stations to the grid energy demand. To take advantage of the country's fossil fuel reserves, steam power stations located at Sapele & Egbin [near Lagos] have also contributed towards meeting the ever increasing power demand of the country.

The rest of the plants are composed of gas turbine power plants in which NEPA Operators have acquired in-depth experience. For the purpose of identification designations - HG. ST and GT for the hydro, steam and gas turbines respectively are assigned to the various unit types; and each unit is prefixed by the first alphabet of its station name.

TABLE I

NEPA COMMITTED GENERATING STATIONS

POWER STATION	TYPE	UNITS INSTALLED	UNITS IN OPERATION *	UNIT CAPACITY (MW)	PERCENTAGE GENERATING MIX
KAINJI	HYDRO	2	2	120	36.2
"	"	4	3	80	
"	"	2	1	100	
JEBBA	"	6	4	96	
EGBIN	STEAM	6	5	220	37.7
SAPELE	"	6	2	116	
"	GAS	4	1	75	26.1
AFAM 1	"	1	1	10	
"	"	2	2	18	
AFAM II	"	4	3	24	
AFAM III	"	4	3	27	
AFAM IV	"	6	2	75	
DELTA III	"	12	7	20	
DELTA IV	"	2	1	36	
IJORA	"	4	1	20	

* AS AT JANUARY 1988

Table 1 gives a summary of all NEPA installed generating stations as at January 1988 with the corresponding generating mix percentages indicated. The various generating stations are briefly discussed in what follows to highlight their state of health.

3.2.1 THE HYDRO POWER STATION

There are three existing hydro power stations of the Authority as follows:

[i] Kainji the first established hydro power station with installed generating capacity of 760 MW;

[ii] The Jebba hydro power station, being the second, has an installed generating capacity of 576 MW; and

[iii] The shiroro hydro station with total installed capacity of 600 MW.

While the Kainji and the Jebba Stations are currently being run, the Shiroro station is yet to be commissioned. Additional information concerning the hydro generating units are contained in Table II. and the individual status of each unit is given in Table III.

TABLE II

HYDRO GENERATING PLANT CAPACITIES

LOCATION	UNITS INSTALLED	NO. OF UNITS HEALTHY	DAMAGED	TOTAL CAPACITY [MW] INSTALLED	AVAILABLE
KAINJI	4	3	1	320	240
- do -	2	1	1	200	100
- do -	2	2	-	240	240
JEBBA	6	4	2	576	384

TABLE III

STATUS OF THE HYDRO GENERATING UNITS

STATION	UNIT	CAPACITY (MW)	COMMENTS
KAINJI	KHG5	80	In operation
	KHG6	"	-do-
	KHG7	"	-do-
	KHG8	"	Stator winding insulation failure since 1984**
	KHG9	100	In operation
	KHG10	"	Generator hydraulic system failure*
	KHG11	120	In operation
	KHG12	"	-do-
JEBBA	JHG1	96	Technical problem not specified*
	JHG2	"	Excitation problem*
	JHG3	"	In operation
	JHG4	"	-do-
	JHG5	"	-do-
	JHG6	"	-do-

** Catastrophic failure

* As at January 1988

3.2.2 THE STEAM POWER STATIONS

The Sapele steam power station pioneered the nations experience of running modern steam turbines. It has an installed generating capacity of 696 MW. The Egbin power station is another recently commissioned steam power plant with a total installed capacity of 1320 MW when fully operational. Tables IV & V give detailed breakdown of the generating units and their status respectively.

TABLE IV

STEAM GENERATING PLANT CAPACITIES

LOCATION	UNITS INSTALLED	NO. OF UNITS HEALTHY	DAMAGED	TOTAL CAPACITY [MW] INSTALLED	AVAILABLE
SAPELE	6	2	4	696	232
EGBIN	6	6*	-	1320	1100

*One unit yet to be commissioned.

TABLE V

STATUS OF THE STEAM GENERATING UNITS

STATIONS	UNIT	CAPACITY (MW)	COMMENTS
SAPELE	SST1	116	Awaiting overhaul
	SST2	"	Failure of low pressure turbine blade
	SST3	"	In operation
	SST4	"	- do -
	SST5	"	Burnt unit transformer
	SST6	"	Generator cooling water leakage
EGBIN	EST1	220	In operation
	EST2	"	- do -
	EST3	"	- do -
	EST4	"	- do -
	EST5	"	- do -
	EST6	"	Not Commissioned

3.2.3 THE GAS POWER STATIONS

These stations are composed of Sapele station with 300 MW generating capacity; Afam I, Afam II, Afam III and Afam IV all of total installed capacity of 700 MW; Delta III & Delta IV of 312 MW installed capacity and the Ijora power station with 80 MW generating capacity. In a similar manner, details of the gas power plants and individual unit status are contained in Tables VI & VII respectively.

TABLE VI

GAS GENERATING PLANT CAPACITIES

LOCATION	UNITS INSTALLED	NO. OF UNITS HEALTHY	DAMAGED	TOTAL CAPACITY [MW] INSTALLED	AVAILABLE
SAPELE	4	1	3	300	75
AFAM I	1	1	-	10	10
- do -	2	2	-	36	36
AFAM II	4	3	1	96	75
AFAM III	4	3	1	108	81
AFAM IV	6	2	4	450	150
DELTA III	12	7	5	240	140
DELTA IV	2	1	1	72	36
IJORE	4	1	3	80	20

TABLE VII

STATUS OF THE GAS GENERATING UNITS

STATION	UNIT	CAPACITY (MW)	COMMENTS
SAPELE	SGT1	75	In operation
	SGT2	"	Major overhaul
	SGT3	"	In operation
	SGT4	"	Awaiting arrival of heat shield spare part
AFAM I	AGT1	10	In operation
	AGT2	18	- do -
	AGT3	"	- do -
AFAM II	AGT4	24	- do -
	AGT5	"	- do -
	AGT6	"	- do -
	AGT7	"	No spare for repair work
AFAM III	AGT8	27	In operation
	AGT9	"	- do -
	AGT10	"	- do -
	AGT11	"	- do -
AFAM IV	AGT12	75	Motoring system defect
	AGT13	"	In operation
	AGT14	"	- do -
	AGT15	"	- do -
	AGT16	"	Starting equipment problem
	AGT17	"	Damaged turbine inner casing

DELTA III	DGT1	20	Awaiting rehabilitation
	DGT2	"	Vibration problem
	DGT3	"	Failure due to fire
	DGT4	"	Rehabilitation in progress*
	DGT5	"	- do -
	DGT6	"	In operation
	DGT7	"	- do -
	DGT8	"	- do -
	DGT9	"	- do -
	DGT10	"	- do -
	DGT11	"	- do -
	DGT12	"	- do -
DELTA IV	DGT13	36	In operation
	DGT14	"	Awaiting rehabilitation
IJORA	IGT3	20	Unit transformer explosion
	IGT4	"	Rehabilitation in progress
	IGT5	"	In operation
	IGT6	"	High turbine vibration

* As at January 1988

3.2.4 COMPARISON OF POWER STATION PERFORMANCES

In order to compare and contrast the relative performances as at January 1988 on Individual Power Station bases and among the different power generating options (i.e Hydro, Steam and Gas Turbines), percentages of capacities available to be put on-line and those off-line due to one failure or another of power stations are computed. The results are shown in Tables VIII & IX.

TABLE VIII

SUMMARY OF RESULTS OF GENERATING CAPACITIES STATUS IN PERCENTAGES (INDIVIDUAL STATION CONSIDERED)

STATION	TYPE	CAPACITY TO BE PUT ON-LINE (%)	CAPACITY OFF-LINE DUE TO FAILURE (%)
KAINJI	HYDRO	76	24
JEBBA	"	66	34
SAPELE	STEAM	33	67
EGBIN	"	83	17
SAPELE	GAS	25	75
AFAM	"	50	50
DELTA	"	56	44
IJORA	"	25	75

TABLE IX

SUMMARY OF RESULTS OF GENERATING CAPACITIES
STATUS IN PERCENTAGES (GENERATING TYPE CONSIDERED)

GENERATING STATION TYPE	CAPACITY AVAILABLE TO BE PUT ON -LINE (%)	CAPACITY OFF-LINE DUE TO FAILURE (%)
HYDRO	72	28
STEAM	66	34
GAS	41	59

ELECTRIC POWER SYSTEM MANAGEMENT

Modern Electric Power Stations, Electric high voltage lines and substations are highly complex due to extensive interconnections and thus require close coordination of all links in the process to ensure continuous supply of power to various consumers. A breakdown in any unit engaged in the production or transmission of electric energy may disturb the normal operation of an entire power station and result in interruption of supply to a great many users [19].

As previously mentioned the reliable and economic operation of a power system depends on the proper operation and maintenance of the various thermal and hydro power stations, substations, transmission lines and cable circuits.

Insuring the foregoing objective requires efficient management normally achieved through the following:

(i) Constant surveillance or where feasible, periodic control of the operation and maintenance of the equipment installed in the power stations and substations;

(ii) Timely (in accordance with a well planned programme) and efficient routine repair, general overhaul, and preventive maintenance, inspection and testing of equipment at generating, transmission and distribution levels;

(iii) Production support services, comprising the testing laboratories, well equipped repair workshops, etc., and bulk purchasing and stores department to ensure continuous supply of fuel, insulating and lubricating oils, spare parts and a whole variety of materials needed for day-to-day operation of the system;

(iv) Adequate transport facilities to facilitate continuous maintenance inspection of the entire length of transmission line from tower to tower and checking for broken insulators, broken conductor stands, sinking water foundation, loose bolts etc., if possible ground patrol may need to be complimented by aerial inspections with the aid of a helicopter;

(v) Department with computing facilities for analysing and condensing the operating experience of the system as a whole and its separate units, developing organizational and technical methods aimed at raising the operation, reliability and efficiency of the equipment and circuits, ensuring financial and budget control, and selecting and training the staff;

(vi) Development of competent group of technical crew and administrative staff responsible for the various departments and all phases of activity of the system. It is worthwhile to mention at this juncture that power supply quality, reliability and security will be compromised if any electric utility suffers from management whether of technical or administrative nature.

3.4 ORGANISATIONAL STRUCTURE OF NEPA POWER STATIONS

The operational requirements at each NEPA power station are met through a number of so-called production departments. The general organisational structure of a typical NEPA Power Station management can be gained from the block diagram given in figure 6. The function of each unit is summarised below.

3.4.1 THE DIRECTOR

Coordinates the overall activities of the station through the respective departmental heads.

3.4.2 MAINTENANCE DEPARTMENT

This department comprises three sections namely: the Electrical, Mechanical and Instrumentation sections. They are directly responsible for the generators, the electrical and mechanical equipment of the station, indoor and outdoor substations, the control boards, station batteries and their charging units, the station power and lighting circuits, the crane electrical equipment, the insulating oil handling facilities, the compressor units serving air blast circuit breakers, the electrolysis plant supplying hydrogen for the generator cooling systems, the station telecommunications facilities, the telemetering and supervisory control equipment, the protective relay and electrical automatic control systems and electrical instruments.

3.4.3 OPERATIONS DEPARTMENT

Manned by shifting operators, on 24-hour basis, who are charged to operate the equipment continuously or periodically and to watch over its normal operation. By virtue of their intimate knowledge of various operational conditions, the shifting operators decide on when it is ripe for a planned outage (repair or maintenance).

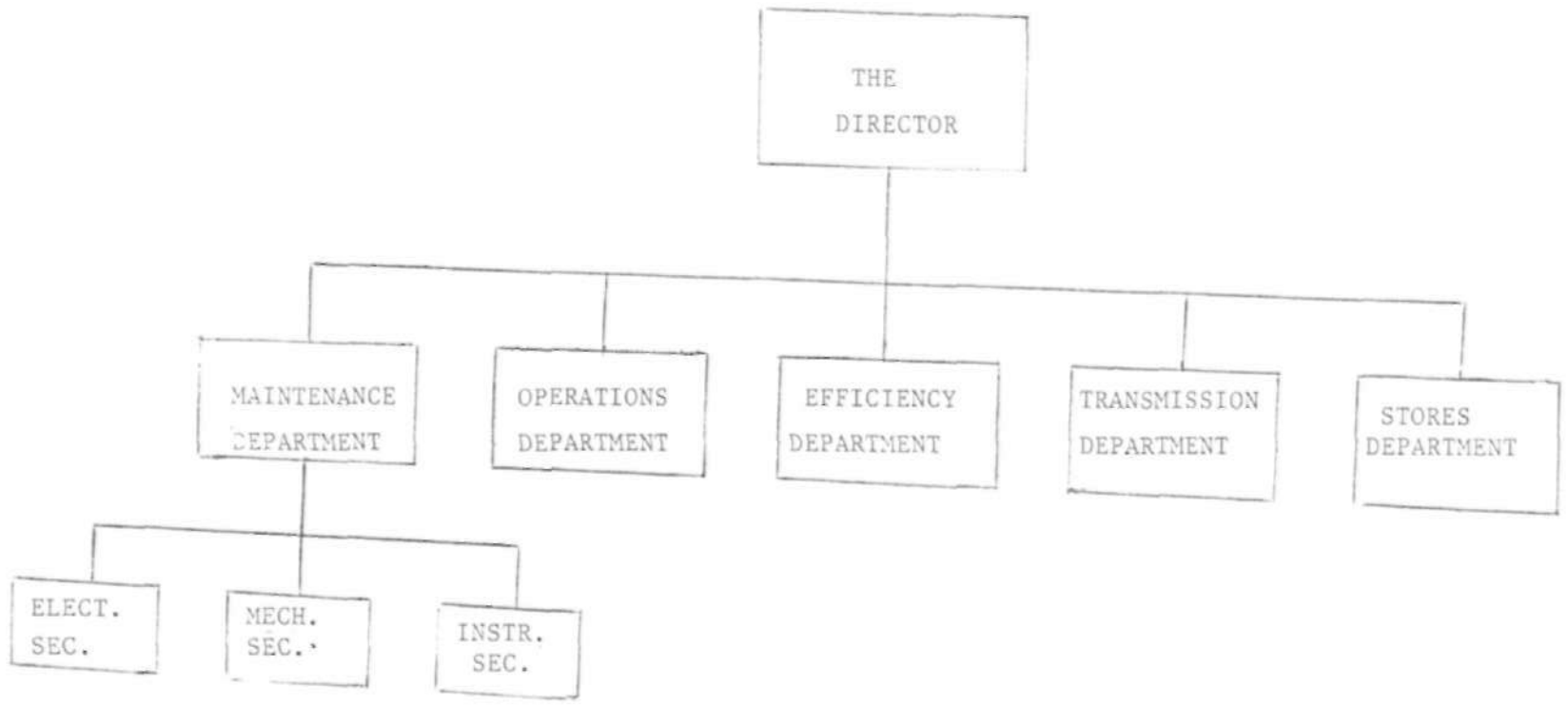


Fig. 6.Organizational Structure of NEPA Power Station.

3.4.4 EFFICIENCY DEPARTMENT

This is a newly created department charged with the proper co-ordination of all technical activities and any other relevant information for analysing with the aim of raising the operation, reliability and efficiency of the power station and hence the system in general.

3.4.5 TRANSMISSION DEPARTMENT

The duty of this department is not only ensuring putting the generated power on line but involves regular checkings and inspections of transmission lines within the power station vicinity. The results of these inspections may be compiled and used as a basis on which preventive maintenance of the transmission lines is programmed.

3.4.6 STORES DEPARTMENT

One of the responsibilities of this department is to supply spare parts to any user department of section on request. It is also given the authority of local purchasing of spare parts available in the country for replenishing its store houses. Advising the Authority in advance on major spare parts that need to be procured from foreign countries is another significant duty of this department. The adverse economic condition of the country not only brings about delays in delivery of overseas orders for spare parts but imposes some limits on the amount of technical equipment that can be procured.

3.5 MAINTENANCE PRACTICE

On any system, consideration must be given to the fact that any element of the system may be out of service due to forced outage, planned maintenance or development work.

It is desirable that the outage should not cause interruption of power supply to consumers. To achieve this, the mode of supply must provide for, at least, a single outage contingency.

In all NEPA power stations, maintenance activities are generally initiated by shifting operators, be it forced or planned outage. With their sound knowledge of the functioning of the generating equipment, they decide on planned outage. To achieve this, ledger cards are filled with the necessary information that calls for the outage and passed on to the maintenance section. Ofcourse, this is done in advance so that the maintenance section gets prepared for the activity with all necessary resources. Clearance for the outage must, however, be obtained from the headquarters via the Central Control Unit at Oshogbo. The control centre must be aware of the outage and its possible duration to ensure proper control on the system.

Each individual power station has its maintenance crew permanently stationed there because of their initial training to man those types of units installed right from the station commissioning. However, maintenance crew of any station may be called upon to another when the need arises. Similarly, major reinforcement of resource may be sent from one station to another, these may include among other things heavy cranes required for some outages. It should be noted that clearance from the headquarters is necessary before any major maintenance is embarked upon. In the event of a breakdown in a major power station, maintenance crew and resource pooled from other stations expedite the restoration of that station.

Figure 7 describes the communication link of the maintenance activity.

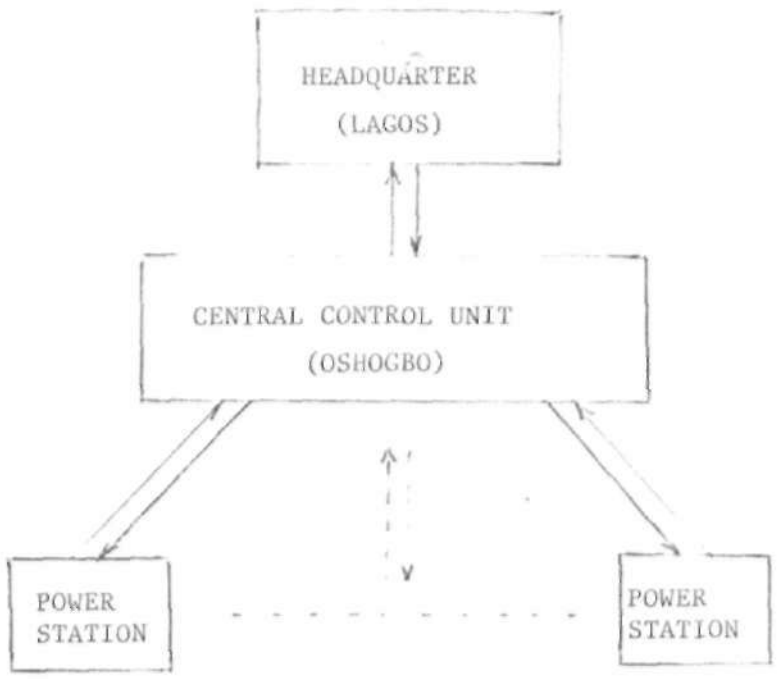


Fig.7 Communication link of Maintenance Activity

The maintenance practice of NEPA generating facilities could be described as being 'adhoc' due to the following reasons:

(i) Lack of proper coordination especially if there are mutiple requests;

(ii) Overly delayed maintenance of generating facilities (responsible for major failure experienced in one of the Kainji Units);

(iii) Material constraints (lack of enough spare parts and resource).

(iv) Non-optimal resource utilization due to decentralization of maintenance crew.

Although the problems facing NEPA are complex and multi-dimensional, the maintenance aspect of the problem can be improved upon. In the next chapter, practical and easily implementable maintenance schedules are developed.

CHAPTER 4

FORMULATION AND DEVELOPMENT OF MAINTENANCE SCHEDULES

4.1 INTRODUCTION

The main concern of this chapter is to set forth a rigorous formulation of maintenance scheduling problem. Subject to certain limitations and assumptions, easily implementable maintenance schedules for the generating facilities of NEPA are then evolved. The goal of paramount importance is to maximize the reserve margin as much as possible for such a supply system in order to reduce generation crisis often experienced.

4.2 FORMULATION OF THE SCHEDULING PROBLEM

Maintenance scheduling is generally treated as one of optimization with constraints [14]. There are basically three components of the problem definition. The first is the selection of the independent or decision variables. Next is the specification of the objective function, that is the quantity to be maximized or minimized as a function of the decision variables. The third component is the designation of constraints or limits on the values of the decision variables.

In most cases the decision variables are chosen to be the starting times for maintenance on each unit. It will hold good if the following data are specified.

1. Weekly gross reserve (MW) over the year;
2. The number of maintenance outages to be scheduled during the year;
3. The loss of reserve (in MW or reliability units) and duration in (weeks) for each outage [15]; and
4. Total maintenance cost in terms of time since previous maintenance for each unit [7].

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Objective function can be variously chosen to

1. Optimize reliability criterion [5];
2. Minimize total maintenance cost;
3. Revise the schedule while minimizing changes from the existing schedules; or
4. Levelize net reserve.

The desirability of each objective function would depend on the immediate needs of the utility company management.

Constraints, the external limits imposed on the decision variables, are usually known in advance. The resources available to perform maintenance are never infinite. Typically, a utility has a fixed number of maintenance crews or a limited man power pool for each Craft or Union. There are definite bounds on megawatt capacity available for purchase to sustain minimum net reserve during maintenance outages. The time blocks which outage are safely allowable are usually of limited duration. Non-availability of necessary materials or replacement of parts can also restrict maintenance work during certain periods. Each constraint is usually reduced to an algebraic expression before it becomes part of the data input to automated scheduling process.

The solution of the scheduling problem results in a schedule. A feasible solution (schedule) is one which satisfies all constraints [22]. An obvious optimization technique is to generate all alternative schedules, discard those which violatethe constraints, then select the best schedule from the set of feasible ones remaining.

4.3 OPTIMAL MAINTENANCE SCHEDULING: MATHEMATICAL FORMULATION

A combination of the reliability and system production & maintenance costs form the basis of this formulation. It is assumed that in this formulation when maintenance on a unit starts, it will continue for the duration of the maintenance, thus implying fixed maintenance duration. The problem is formulated as a forward dynamic programming [12].

The general expression for the objective function for stage cost at t is given by:

$$F = \sum_{t=1}^{T} f\left(\underline{x}(t)\,\underline{U}(t), d(t)\right) \qquad \ldots\ldots\ldots\ldots\ldots (4.1)$$

where

$$f\left(\underline{x}(t), \underline{U}(t), d(t)\right) = \gamma_c f^c\left(\underline{x}(t), \underline{U}(t), d(t)\right) + \gamma_m f^m\left(\underline{x}(t), \underline{U}(t), d(t)\right) + \gamma_r f^r\left(\underline{x}(t), \underline{U}(t), d(t)\right) \qquad \ldots\ldots\ldots\ldots\ldots (4.2)$$

and

γ_c : weighting coefficient for production cost

γ_m : " " " maintenance cost

γ_r : " " " reliability cost

The coefficients are to be judiciously selected in accordance with the available data of the system under consideration.

The various constraints can be expressed mathematically as follows:

1. Initial and final conditions:

$\underline{x}_1$ = known vector f (x (1))

$$x\ (T+1) = \begin{bmatrix} D_1 \\ \cdot \\ \cdot \\ \cdot \\ D_N \end{bmatrix}$$

2. State equations:

$$x_i(t) + U_i(t) = x_i\ (t+1) \quad \forall\ i \in N \qquad \ldots\ldots\ldots\ldots\ (4.3)$$

where $U_i\ (t) = \begin{cases} 1 & \text{if unit is on maintenace} \\ 0 & \text{otherwise} \end{cases}$

3. Maintenance period:

$$U_i\ (t) = \begin{cases} 0 \text{ for } t < E_i \text{ if } t > L_i + D_i \\ 0,1 \text{ for } E_i \leqslant t \leqslant D_i \quad \forall\ i \in N \end{cases}$$

$\ldots\ldots\ldots\ldots\ (4.4)$

4. Crew constraint:

$$\sum_{i=1}^{N} P_i \cdot U_i\ (t) \leqslant P_T;\ E_i \leqslant t \leqslant D_i \quad \forall\ i \in N$$

$\ldots\ldots\ (4.5)$

5. Resource constraints:

$$\sum_{i=1}^{N} U_i(t) \cdot M_{k_{l_i}} \quad MA_k(t) \qquad k = 1 \ldots K \qquad \ldots\ldots\ldots (4.6)$$

where

l_i = lth stage of maintenance for unit i (integer)

$= U_i(t) * (x_i(t) + 1)$

MA_k = k^{th} resource available during stage t

$M_{k_{l_i}}$ = Amount of resource k which unit i needs for its lth maintenance stage.

K = Number of resources.

6. Reliability constraint:

A minimum level of reliability for each stage should be maintained. This takes the following form

$R_{m_t} = (\underline{x}(t), \underline{U}(t), d(t))$ acceptable R_m

$\ldots\ldots\ldots\ldots (4.7)$

The optimization problem can, therefore, be stated as follows:

Minimize the cost function subject to the various constraints. The above mathematical formulation is applicable to all maintenance scheduling problems. A feasible solution to the constrained optimization problem will yield an optimal solution subject, ofcourse, to the required data base.

In order to apply the same formulation to an electric utility system characterized by inadequate data base, certain practical assumptions are necessary.

4.4 MODIFIED APPROACH OF THE FORMULATION TO NEPA GENERATING FACILITIES

Outright application of the mathematical formulation to the system under consideration may not be possible due to inadequate data base. The data readily available include:

1. Monthly peak loads for a year,
2. Monthly available hydro for the same year;
3. Forced outage rates for the units; and
4. The number of the units to be scheduled for maintenance

Since the production and maintenance cost are very difficult to obtain, certain intuitive modifications need to be made to take care of these data, although this may result in a sub-optimal solution. The first approximation made is to assume that the weighting coefficients for both production and maintenance costs are zero, thus yielding only reliability based objective function. In order to minimize the violation of certain constraints such as those imposed by crew and resource requirements, the often assumed period of maintenance is herein doubled, that is from two weeks to one month. It is of paramount importance here to note that spare parts as a principal component of the resource requirement are the hardest constraints whose effects are severely felt by electric utilities in most developing countries. Whilst this technical contraint is recognised, for the purpose of this research effort, it is assumed that the necessary spare parts are procured well in advance.

This, in effect, implies sound management policy.

The various assumptions and approximations made are based on the engineering knowledge of the system under consideration. It is however, intuitively clear that the modified formulation is an attempt to realise this rigorous mathematical formulation. i.e to generate realistic schedules for NEPA generating facilities, reserve levelization is finally adopted as an objective function. This is not a serious departure from the mathematical formulation because its reliability cost function is now based on maximization of reserve margin.

The most attractive feature of this modified formulation is that the maintenance scheduling problem of the hydro-thermal units reduces to two independent sub problems as follows:

1. The hydro units are strictly scheduled for maintenance during periods of low water inflow as dictated by the uniqueness of the system being investigated.

2. The thermal units are,on the otherhand,flexibly scheduled to maximize reserve margin, which in turn minimizes level of risk.

Based on the foregoing discussions on the modified problem formulation, a suitable software program has been developed to provide maintenance schedules for NEPA generating stations. The Key features of the software program are discussed in the subsequent sections.

4.5 MAINTENANCE SCHEDULING PROGRAM DEVELOPMENT

The software developed is a computer program that prepares a power system maintenance schedule for up to twelve periods, assuming that each generating unit requires one full period for maintenance

(one month), although larger or shorter periods of maintenance for a group of units can be simulated by increasing or decreasing the number of units in the input data, so that the product of the number of units and maintenance time per unit are approximately the same [11].

4.5.1 DESCRIPTION OF THE COMPUTER PROGRAM

The algorithm used by the program allocates the maintenance of a given unit in a period where the "maintainance space" is maximum (in absolute terms or relative to peak load or both in sequence, according to the input option used.) taking into account any previous scheduling of maintenance of other units.

The "maintenance space" or reserve available in each maintenance period is calculated by taking the total thermal capacity of the system (assumed to be constant over the total scheduling period) adding the available hydroelectric capacity and subtracting the predicted load demand.

As a unit is scheduled for maintenance in a period, the available reserve in that period is reduced by the capacity of the unit being removed from the system. The program also permits forcing the maintenance of a given unit in a desired period. If this option is chosen for some units they will be scheduled in the desired periods.

Scheduling the remaining units can be performed in a decreasing order of capacity starting with the largest unscheduled unit according to the scheduling option chosen. This will result in a more or less uniform net reserve capacities in all the periods.

4.5.2 GENERAL PROGRAM ORGANIZATION

Figure 8. shows the flow chart of the computer program and a listing of the program is contained in appendix II.

The input data required by the program are: the total number of maintenance periods; the total thermal capacity of the system; the scheduling option required, the total hydroelectric capacity available in each period; the peak loads of the periods, and the specifications for each power plant to be scheduled. The maintenance data for NEPA system are shown in Table X.

With the data read in, the program calls subroutine ORDER which simply reorders the power plant by decreasing capacity, placing first the largest unit for which forced maintenance has been specified followed by the second largest one and so on until all plants with forced maintenance have been considered. The non-forced maintenance units are ordered in a similar fashion; so that the last plant in the list is the lowest capacity unit which does not have forced maintenance.

4.6 COMPARISON OF SCHEDULES' RISKS

Having generated a number of feasible schedules, there is then the need to select better ones among the lot. This could be achieved with what is known to be the "Capacity outage table". This table answers the question "What is the probability of having a certain number of megawatts or more on forced outage?"

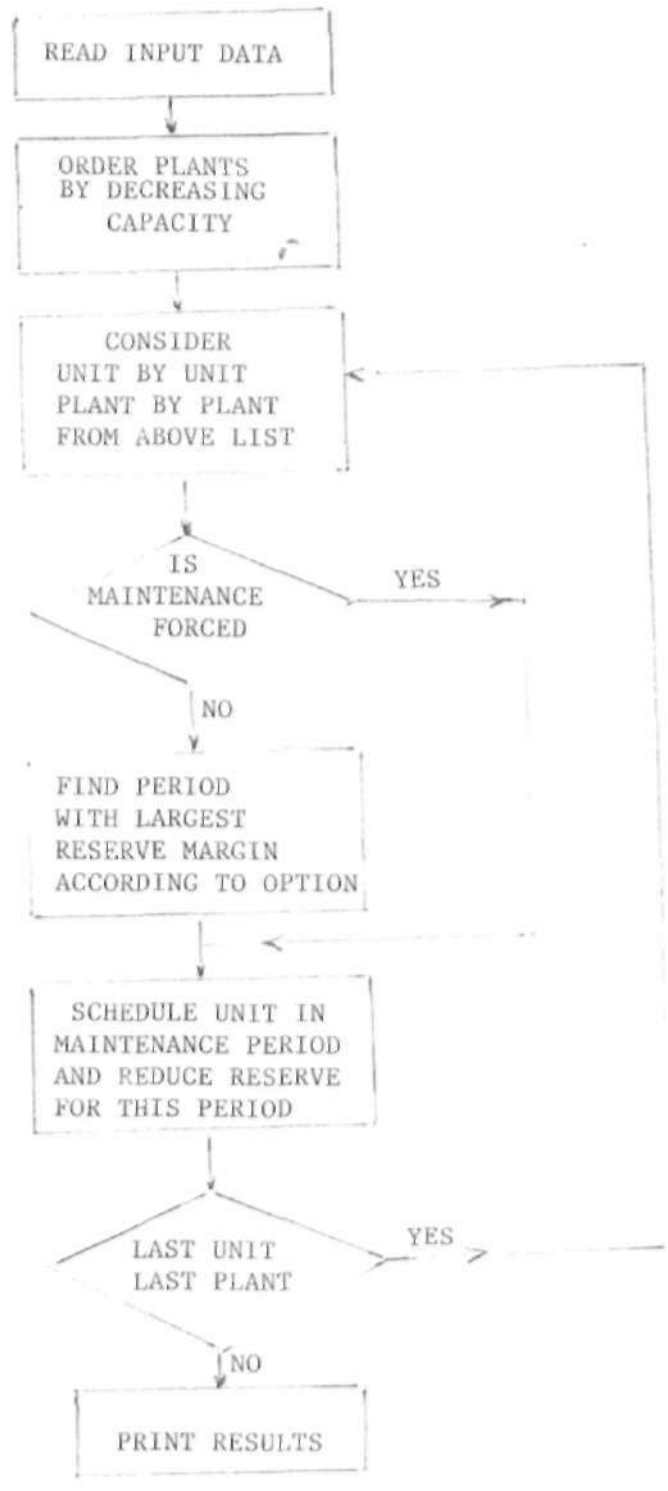


Figure 8. Flow Chart for the Computer program

TABLE X. MAINTENANCE DATA OF NEPA SYSTEM

System peak demand:	variable (see appendix I)
Total available installed thermal capacity:	2026 MW
Available hydro capacity:	variable (see appendix I)
Number of generating units to be scheduled for maintenance:	28
Net capacity of smallest thermal unit:	10 MW
Net capacity of smallest hydro unit:	80 MW
Unit time period:	1 month
Planning interval:	12 months
Number of planned outage per unit:	1
Planned fixed maintenance outage durations:	2 months
Number of maintenance crews :	1/station

The calculation of the outage table begins with the selection of a number of megawatts between each entry in the table, called the step size [6]. All unit ratings are expressed as multiples of this step size as they are entered into the table. Step size of 20 MW is selected for our analysis and hence all the units are expressed as multiples of this size. A table contained in appendix III gives a summary of NEPA generating units as multiples step size and their corresponding forced outage rates.

The capacity outage table is initialised to 1.0 in the first entry (associated with zero capacity or greater on outage) and 0.0 in all other entries, this is vividly shown in table XI.

TABLE XI

CAPACITY OUTAGE PROBABILITY TABLE

0 MW CAPACITY SYSTEM

OUTAGE (MW)	PROBABILITY OF OUTAGE OR GREATER
0	1.0
20	0.0
40	0.0

The formula [6] for each new entry in the table is given as:

$$\text{New Entry at } \underline{Y} \text{ MW} = (1-\text{FOR})(\text{Old Entry at } \underline{Y} \text{ MW}) + \text{FOR (Old Entry at } \underline{Y-CP} \text{ MW)} \quad \ldots\ldots\ldots\ldots (4.8)$$

Using equation 4.8 to add a 20 MW unit to the previous table of 0 MW capacity system results in Table XII., as a 20 MW capacity system.

TABLE XII

CAPACITY OUTAGE PROBABILITY TABLE

20 MW CAPACITY SYSTEM

OUTAGE (MW)	PROBABILITY OF OUTAGE OR GREATER
0	1.0
20	0.3
40	0.0

The above table may be interpreted to mean that there is a certainty of 20 MW being in or out, i.e the 0. MW, 1.0 entry. There is 0.3 probability of 20 or more MW out; there is no probability of 40 MW or more out.

The illustrated recursive method above was applied to each subsequent unit to be added until all the twenty eight units of NEPA (to be scheduled for maintenance) were exhausted. This led to the realization of the complete capacity outage table of the system in question. The listing of the 30th and last convolved capacity outage table is in appendix III.

Several maintenance schedules were generated for the utility by running the computer program on several cases of study with the acquired data from NEPA as contained in appendix I and results of some selected few would be amply discussed in the next chapter.

CHAPTER 5

SIMULATION RESULTS AND DISCUSSIONS

5.1 INTRODUCTION:

The preceeding chapters were principally concerned with the methodologies of maintenance scheduling as well as a review of NEPA generating facilities, management structure, maintenance problem formulation and hence the development of schedules.

In this chapter some of the various schedules developed are presented and amply discussed. The criteria by which better schedules are selected from the view point of reliability are also presented.

5.2 GENERAL COMMENTS ON PRESENTATION OF RESULTS

With the supply Authority's generation mix and several units, numbers were assigned to each unit for identification during the course of running the program. In all cases studied, the hydro and steam power stations i.e Kainji, Jebba, Egbin and Sapele generating units were assigned twice the normal period of maintenance for reasons discussed in chapter 4. The maintenance space for each gas-turbine was also assumed to be one month. All hydro units were forced to be maintained during periods of low water level as the associated dams are seasonal regulated types. Three hydrological conditions: ideal, average and worst were simulated for each case study.

The computer print out for each case considered in the same run gives a summary of available thermal and hydro capacities, with maximum load and maintenance space for each period described. This is followed by maintenance schedule for the units and the resulting reserve margins according to the selected option.

The computations of reserve surplus and reserve deficiency were carried out periodically. Using a schedule for instance, capacities of units to be on line during a period of maintenance were multiplied by their respective forced outage rates and summed up. This quantity was then added to the available hydro of that period to obtain the available capacity.

5.3 CASE STUDY I

Taking into consideration the three hydrological conditions under this case study, three input data with available hydro capacities as variables were run with input data option to print schedules relative to the peak loads. The resulting schedules are portrayed by the print-outs contained in appendix II.

The average levelized reserves of the three hydrological conditions were found to be 792 MW, 558 MW and 313 MW respectively. The slight variations of the reserves for each schedule could be seen by plots of histograms of figures 9 - 11. Maintaining spaces making up the reserve capacities and maintenance reserve are also indicated. summary of results of the maintenance schedules are listed in tables XIII - XV. In addition the computed reserve results are shown in tables XVI - XVIII.

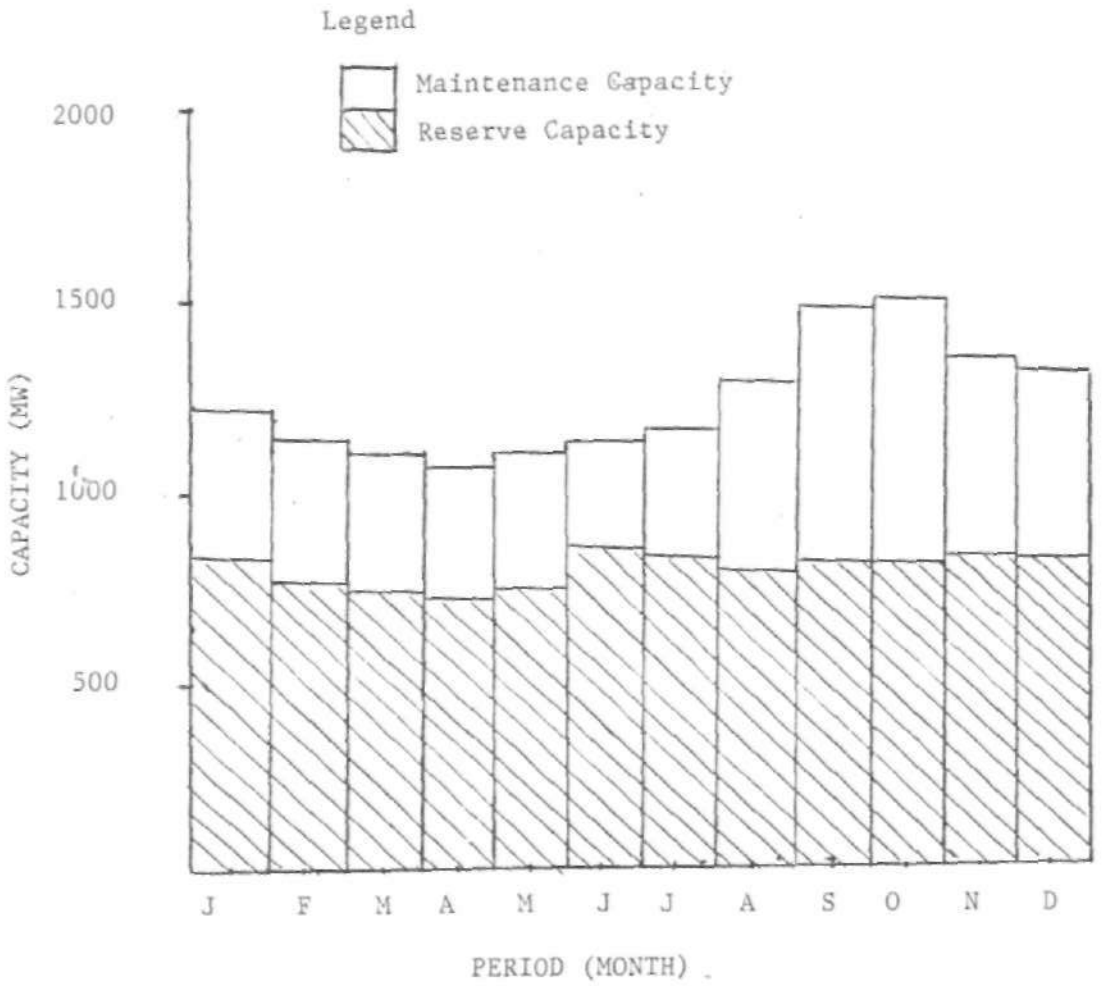


Fig.9 Case 1. Ideal Hydro. Condition

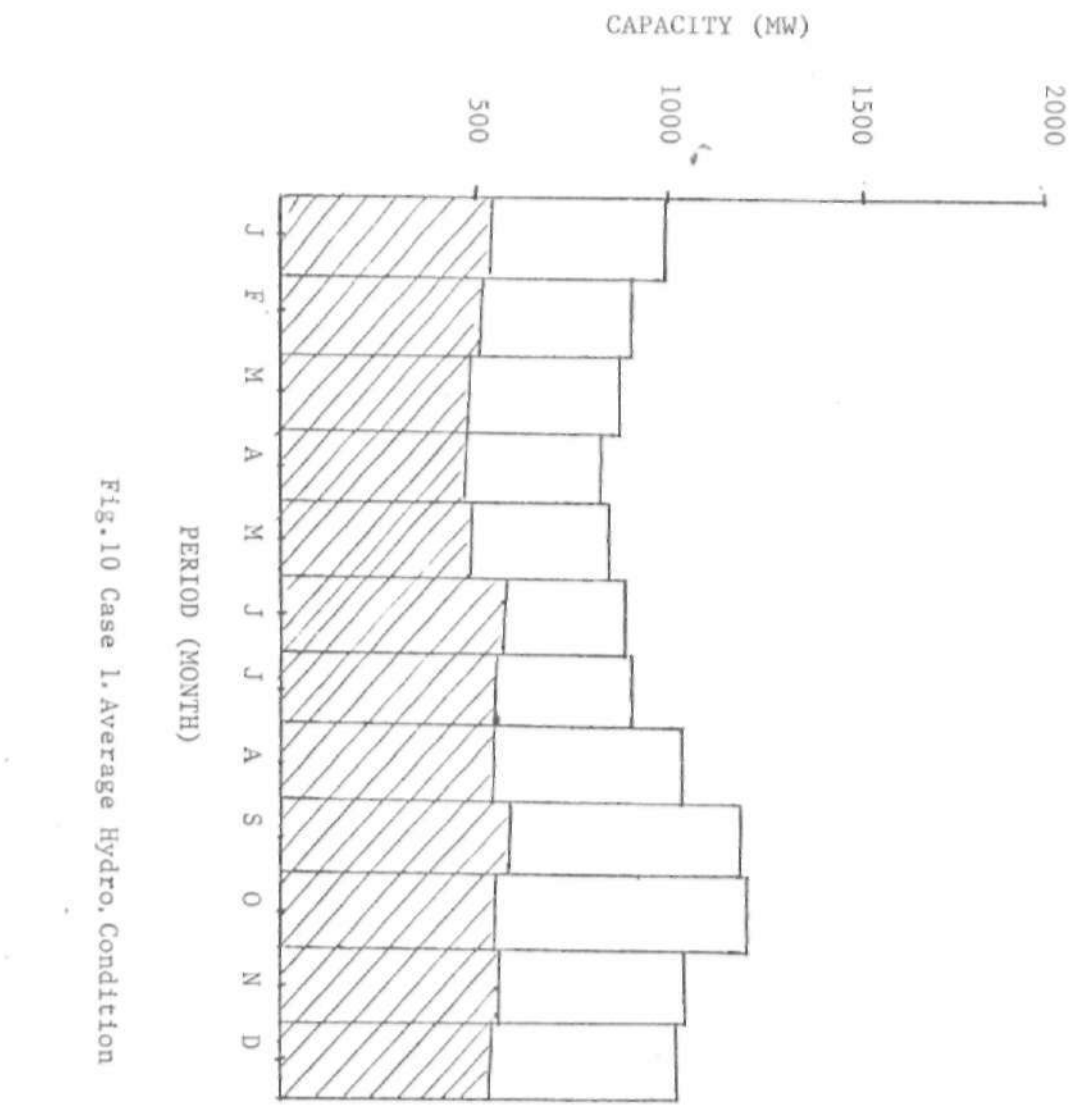


Fig.10 Case 1. Average Hydro. Condition

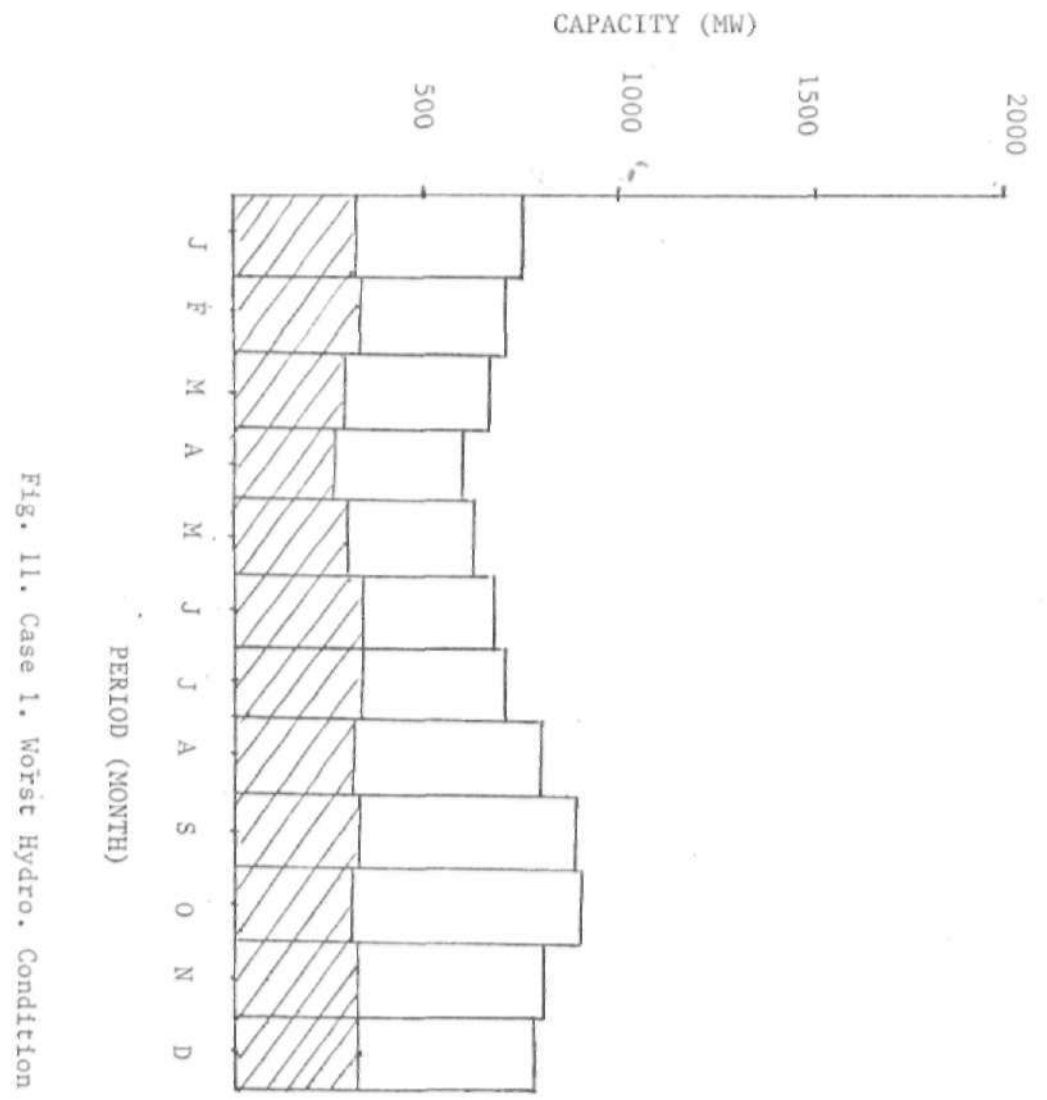


Fig. 11. Case 1. Worst Hydro. Condition

TABLE XIII. SUMMARY OF RESULTS OF MAINTENANCE SCHEDULES
CASE STUDY I. IN IDEAL HYDROLOGICAL CONDITION

JANUARY	FEBRUARY	MARCH
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
1232 MW	1152 MW	1113 MW
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
EST5, SST4, DGT13,	JHG3, JHG4, JHG5 & JHG6	JHG3, JHG4, JHG5 & JHG6.
DGT5, & IGT4.	RESERVE CAPACITY	RESERVE CAPACITY
RESERVE CAPACITY	768 MW.	729 MW.
820 MW.		

APRIL	MAY	JUNE
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
1053 MW	1079 MW.	1128 MW.
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
KHG11, KHG12 & KHG9.	KHG11, KHG12 & KHG9.	KHG5, KHG6, KHG7, AGT4, DGT6 & IGT5.
RESERVE CAPACITY	RESERVE CAPACITY	RESERVE CAPACITY
713 MW.	739 MW.	844 MW.

JULY	AUGUST	SEPTEMBER
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
1135 MW.	1282 MW	1466 MW.
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
KGH5, KGH6, KGH7,	EST1, EST2, AGT8,	EST1, EST2, SST3,
AG75, OGT7 & AGT2.	DGT8, DGT9 & AGT1.	AGT13, DGT10 & AGT1.
RESERVE CAPACITY	RESERVE CAPACITY	RESERVE CAPACITY
833 MW.	735 MW.	805 MW.

OCTOBER	NOVEMBER	DECEMBER
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
1474 MW.	1321 MW.	1296 MW.
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
EST3, EST4, SST3,	EST3, EST4, AGT9,	EST5, SST4, SGT3,
AGT14, AGT6 & AGT3.	DGT11, & AGT3.	AGT11, DGT12 & IGT5.
RESERVE CAPACITY	RESERVE CAPACITY	RESERVE CAPACITY
801 MW.	834 MW.	814 MW.

TABLE XIV. SUMMARY OF RESULTS OF MAINTENANCE SCHEDULES
CASE STUDY I. IN AVERAGE HYDROLOGICAL CONDITION

JANUARY	FEBRUARY	MARCH
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
997 MW.	9932 MW.	893 MW.
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
EST5, SST4, DGT13,	JHG3, JHG4, JHG5 &	JHG3, JHG4, JHG5 &
AGT4, IGT5 & AGT2.	JHG6.	JHG6.
RESERVE CAPACITY	RESERVE CAPACITY	RESERVE CAPACITY
581 MW.	768 MW.	509 MW.

APRIL	MAY	JUNE
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
833 MW.	859 MW.	908 MW.
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
KHG11, KHG12 & KHG9.	KHG11, KHG12 & KHG9.	KGH5, KGH6, KGH7, AGT8, DGT5 & DGT6.
RESERVE CAPACITY	RESERVE CAPACITY	RESERVE CAPACITY
493 MW.	519 MW.	601 MW.

JULY	AUGUST	SEPTEMBER
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
915 MW.	1052 MW.	121 MW.
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
KHG5, KHG6, KHG7	EST1, EST2, AGT10,	EST1, EST2, SST3,
AGT9, AGT4 & AGT1.	& DGT7	AGT13, AGT2 & DGT8.
RESERVE CAPACITY	RESERVE CAPACITY	RESERVE CAPACITY
594 MW.	565 MW.	562 MW.

OCTOBER	NOVEMBER	DECEMBER
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
1219 MW.	1061 MW.	1046 MW.
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
EST3, EST4, SST3,	EST3, EST4, DGT11 &	EST5, SST4, SGT3,
AGT14, DGT9 & DGT10.	IGT5.	AGT6, DGT12 & AGT3.
RESERVE CAPACITY	RESERVE CAPACITY	RESERVE CAPACITY
568 MW.	581 MW.	573 MW.

TABLE XV. SUMMARY OF RESULTS OF MAINTENANCE SCHEDULES
CASE STUDY I. IN WORST HYDROLOGICAL CONDITION

JANUARY	FEBRUARY	MARCH
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
762 MW.	710 MW.	671 MW.
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
EST5, SST4, DGT13,	JHG3, JHG4, JHG5	JHG3, JHG4, JHG5
AGT8, AGT4 & IGT5.	& JHG6.	& JHG6.
RESERVE CAPCITY	RESERVE CAPACITY	RESERVE CAPACITY
319 MW.	326 MW.	287 MW.

APRIL	MAY	JUNE
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
611 MW.	637 MW.	686 MW.
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
KHG11, KHG12, & KHG9.	KHG11, KHG12 & KHG9.	KHG5, KHG6, KHG7, AGT13, DGT5 & IGT5.
RESERVE CAPACITY	RESERVE CAPACITY	RESERVE CAPACITY
271 MW.	297 MW.	331 MW.

JULY	AUGUST	SEPTEMBER
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
693 MW.	820 MW.	896 MW.
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
KHG5, KHG6, KHG7,	EST1, EST2, AGT9,	EST1, EST2, SST3,
AGT14, AGT5 & DGT6.	AGT6 & DGT7.	DGT8, DGT9 & AGT2.
RESERVE CAPACITY	RESERVE CAPACITY	RESERVE CAPACITY
334 MW.	309 MW.	320 MW.

OCTOBER	NOVEMBER	DECEMBER
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
904 MW.	801 MW.	796 MW.
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
EST3, EST4, SST3,	EST3, EST4, DGT11	EST5, SST4, SGT3,
DGT10 & AGT1.	& AGT2.	AGT11, DGT12 & AGT3.
RESERVE CAPACITY	RESERVE CAPACITY	RESERVE CAPACITY
318 MW.	323 MW.	320 MW.

TABLE XVI. DEVELOPMENT OF NEPA AVAILABLE CAPACITY AND RESERVE [SURPLUS/DEFICIENCY] FOR MAINTENANCE PERIODS
CASE STUDY I, IDEAL HYDRO. CONDITION

PERIOD	AVAILABLE CAPACITY [MW]	PEAK DEMAND [MW]	RESERVE SURPLUS [MW]
JANUARY	2168	1734	434
FEBRUARY	2064	1756	308
MARCH	2064	1795	269
APRIL	2108	1855	253
MAY	2108	1829	279
JUNE	2163	1780	383
JULY	2162	1773	389
AUGUST	2060	1666	394
SEPTEMBER	2160	1700	460
OCTOBER	2152	1692	460
NOVEMBER	2186	1745	441
DECEMBER	2180	1730	450

TABLE XVII. DEVELOPMENT OF NEPA AVAILABLE CAPACITY AND RESERVE [SURPLUS/DEFICIENCY] FOR THE MAINTENANCE PERIODS
CASE STUDY I. AVERAGE HYDRO. CONDITION

PERIOD	AVAILABLE CAPACITY [MW]	PEAK DEMAND [MW]	RESERVE SURPLUS [MW]
JANUARY	1933	1734	199
FEBRUARY	1844	1756	88
MARCH	1844	1795	49
APRIL	1888	1855	33
MAY	1888	1829	59
JUNE	1943	1780	163
JULY	1942	1773	169
AUGUST	1830	1666	164
SEPTEMBER	1875	1700	175
OCTOBER	1867	1692	175
NOVEMBER	1926	1745	181
DECEMBER	1930	1730	200

TABLE XVIII. DEVELOPMENT OF NEPA AVAILABLE CAPACITY AND RESERVE [SURPLUS/DEFICIENCY] FOR THE MAINTENANCE PERIODS
CASE STUDY I. WORST HYDRO. CONDITION

PERIOD	AVAILABLE CAPACITY [MW]	PEAK DEMAND [MW]	EQUIVALENT RESERVE DEFICIENCY [MW]
JANUARY	1698	1734	-36
FEBRUARY	1624	1756	-132
MARCH	1621	1795	-171
APRIL	1668	1855	-187
MAY	1668	1829	-161
JUNE	1723	1780	-57
JULY	1722	1773	-51
AUGUST	1599	1666	-67
SEPTEMBER	1590	1700	-110
OCTOBER	1582	1692	-110
NOVEMBER	1666	1745	-79
DECEMBER	1680	1730	-50

5.4 CASE STUDY II

In this case study, the three hydrological conditions were simulated, again the option for the program was to print schedules relative to peak loads. Samples of print-out results of this case study are also contained in appendix II.

Reserve levelization was similarly achieved for the various conditions of hydro. The averages of the reserves stood to be the same with that of case study I. This was essentially because the systems capacity remained the same but only the transpositioning of the units was affected during the course of re-scheduling. The slight variations of the reserves were plotted in figures 12 - 14. The summary of results of this case study are shown in tables XIX - XXI while the computed equivalent reserve margin of this case study are contained in tables XXII - XXIV.

5.5 CASE STUDY III

Here again, simulation of the three hydrological conditions with aforementioned print-out option were of priority. Hydro units transpositioning remained to be the basic difference between all the input data for the three case studies. All the hydro units were forced to be maintained during periods of low water level, and the rest of the units were scheduled freely by the program. The print-outs for this case study are contained in appendix II.

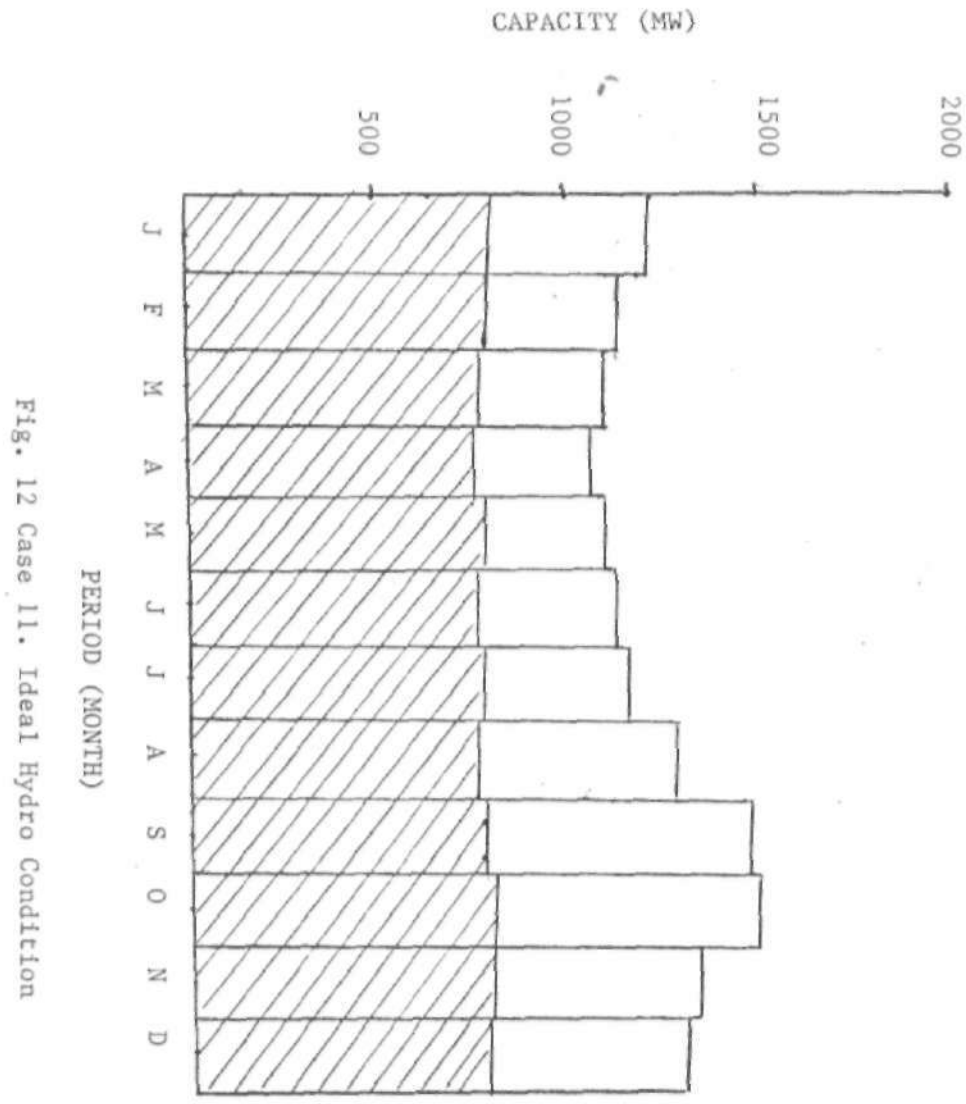


Fig. 12 Case 11. Ideal Hydro Condition

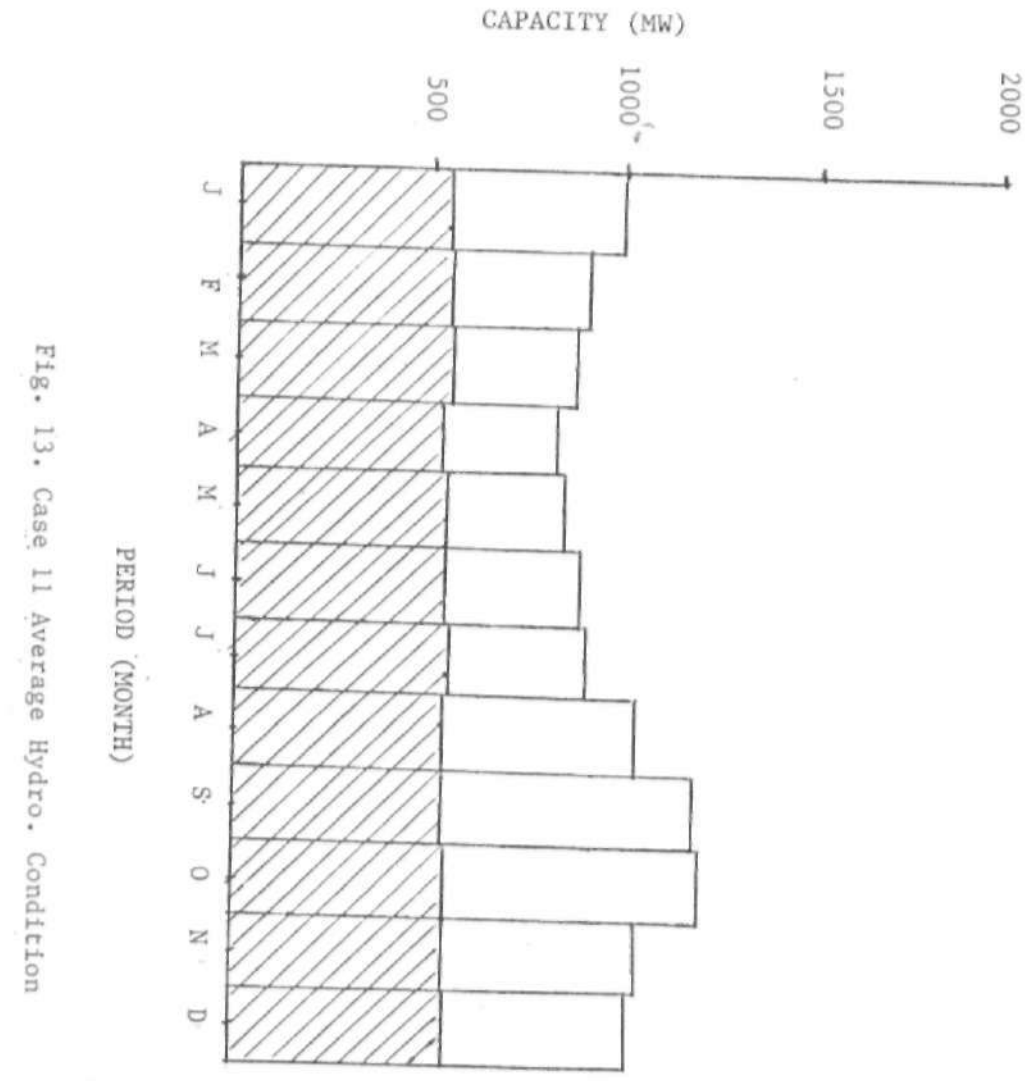


Fig. 13. Case 11 Average Hydro. Condition

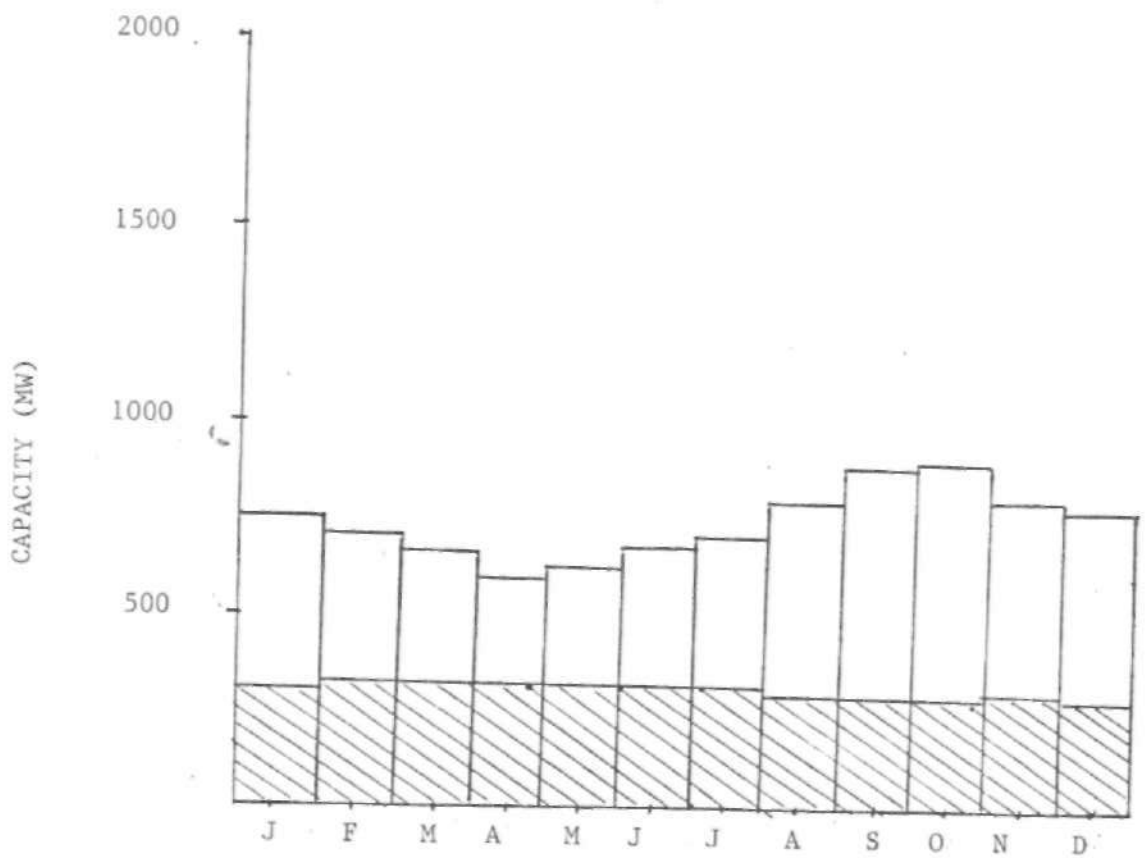


Fig. 14 Case 11 Worst Hydro. Condition

TABLE XIX. SUMMARY OF RESULTS OF MAINTENANCE SCHEDULES
CASE STUDY II. IN IDEAL HYROLOGICAL CONDITION

JANUARY	FEBRUARY	MARCH
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
1232 MW.	1152 MW.	1113 MW.
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
EST5, SST4, DGT13,	KHG11, KHG12, KHG5,	KHG11, KHG12 &
AGT4, DGT5 & AGT1.	AGT2 & AGT3.	KHG5
RESERVE CAPACITY 806 MW	RESERVE CAPACITY 814MW	RESERVE CAPACITY 793MW
APRIL	**MAY**	**JUNE**
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
1053 MW.	1079 MW.	1128 MW.
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
KHG9, JHG3 & JHG4	KHG9, JHG3 & JHG4	JHG5, JHG6, KH66 & KHG7.
RESERVE CAPACITY	RESERVE CAPACITY	RESERVE CAPACITY
761 MW	787 MW.	776 MW.
JULY	**AUGUST**	**SEPTEMBER**
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
1135 MW.	1282 MW.	1466 MW
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
JHG5, JHG6, KHG6	EST1, EST2, AGT8,	EST1, EST2, SST3,
& KHG7.	DGT5, DGT6 & IGT5.	AGT13, DGT7 & DGT8.
RESERVE CAPACITY	RESERVE CAPACITY	RESERVE CAPACITY
783 MW.	775 MW.	795 MW.
OCTOBER	**NOVEMBER**	**DECEMBER**
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
1474 MW.	1321 MW.	1296 MW.
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
EST3, EST4, SST3,	EST3, EST4, AGT10,	EST5, SST4, SGT3,
AGT14, AGT5, DGT9 & AGT2	DGT10 & DGT11.	AGT11, AGT6 & DGT12.
RESERVE CAPACITY	RESERVE CAPACITY	RESERVE CAPACITY
781 MW.	814 MW.	814 MW.

TABLE XX. SUMMARY OF RESULTS OF MAINTENANCE SCHEDULES
CASE STUDY II. IN AVERAGE HYDROLOGICAL CONDITION

JANUARY	FEBRUARY	MARCH
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
997 MW.	932 MW.	893 MW
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
EST5, SST4, DGT13,	KHG11, KHG12, KHG5,	KHG11, KHG12, KHG5
AGT8, DGT5 & AGT2.	DGT6, DGT7 & AGT3.	& IGT5.
RESERVE CAPACITY	RESERVE CAPACITY	RESERVE CAPACITY
560 MW.	572 MW.	573 MW.
APRIL	**MAY**	**JUNE**
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
833 MW.	859 MW.	908 MW.
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
KHG9, JHG3 & JHG4	KHG9, JHG3 & JHG4.	JHG5, JHG6, KHG6&KHG7.
RESERVE CAPACITY	RESERVE CAPACITY	RESERVE CAPACITY
54 MW.	567 MW.	556 MW.
JULY	**AUGUST**	**SEPTEMBER**
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
315 MW.	1052 MW.	1211 MW.
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
JHG5, JHG6, KHG6	EST1, EST2, AGT9,	EST1, EST2, SST3,
& KHG7.	AGT4 & IGT5.	AGT13, DGT8 & AGT1.
RESERVE CAPACITY	RESERVE CAPACITY	RESERVE CAPACITY
563 MW.	541 MW.	550 MW.
OCTOBER	**NOVEMBER**	**DECEMBER**
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
1219 MW.	1061 MW.	1046 MW.
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
EST3, EST4, SST3,	EST3, EST4, AGT5,	EST5, SST4, SST3,
AGT14, DGT9 & DGT10.	DGT11, & AGT3.	AGT11, AGT6 & DGT12.
RESERVE CAPACITY	RESERVE CAPACITY	RESERVE CAPACITY
548 MW.	559 MW.	564 MW.

TABLE XXI. SUMMARY OF RESULTS OF MAINTENANCE SCHEDULES
CASE STUDY II. IN WORST HYDROLOGICAL CONDITION

JANUARY	FEBRUARY	MARCH
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
762 MW.	710 MW.	671 MW.
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
EST5, SST4, AGT13,	KHG11, KHG12, KHG5,	KHG11, KHG12, KHG5,
AGT4 & IGT5	AGT8, AGT9 & DGT5.	DGT6 & AGT1.
RESERVE CAPACITY	RESERVE CAPACITY	RESERVE CAPACITY
307 MW.	316 MW.	321 MW.

APRIL	MAY	JUNE
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
611 MW.	637 MW.	686 MW.
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
KHG9, JHG3 & JHG4	KHG9, JHG3, JHG4, DGT7 & AGT2.	JHG5, JHG6, KHG6 KHG7 & AGT3.
RESERVE CAPACITY	RESERVE CAPACITY	RESERVE CAPACITY
319 MW.	325 MW.	316 MW.

JULY	AUGUST	SEPTEMBER
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
693 MW.	820 MW.	896 MW.
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
JHG5, JHG6, KHG6,	EST1, EST2, AGT14,	EST1, EST2, SST3,
KHG7 & DGT8.	AGT10 & IGT5,	OGT9, DGT10 & AGT2.
RESERVE CAPACITY	RESERVE CAPACITY	RESERVE CAPACITY
321 MW.	305 MW.	300 MW.

OCTOBER	NOVEMBER	DECEMBER
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
904 MW.	801 MW.	796 MW.
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
EST3, EST4, SST3,	EST3, EST4, AGT11,	EST5, SST4, SGT3,
AGT5 & DGT11.	& DGT12.	DGT13, AGT6 & AGT3.
RESERVE CAPACITY	RESERVE CAPACITY	RESERVE CAPACITY
304 MW.	314 MW.	307 MW.

TABLE XXII. DEVELOPMENT OF NEPA AVAILABLE CAPACITY AND RESERVE [SURPLUS/DEFICIENCY] FOR THE MAINTENANCE PERIODS
CASE STUDY II. IDEAL HYDRO. CONDITION

PERIOD	AVAILABLE CAPACITY [MW]	PEAK DEMAND [MW]	RESERVE SURPLUS [MW]
JANUARY	2159	1734	425
FEBRUARY	2103	1756	347
MARCH	2128	1795	333
APRIL	2156	1855	301
MAY	2156	1829	327
JUNE	2096	1780	316
JULY	2096	1773	323
AUGUST	2067	1666	401
SEPTEMBER	2146	1700	446
OCTOBER	2138	1692	446
NOVEMBER	2199	1745	454
DECEMBER	2178	1730	448

TABLE XXIII. DEVELOPMENT OF NEPA AVAILABLE CAPACITY AND RESERVE [SURPLUS/DEFICIENCY] FOR THE MAINTENANCE PERIODS CASE STUDY II. AVERAGE HYDRO. CONDITION

PERIOD	AVAILABLE CAPACITY [MW]	PEAK DEMAND [MW]	RESERVE SURPLUS [MW]
JANUARY	1924	1734	190
FEBRUARY	1883	1756	127
MARCH	1908	1795	113
APRIL	1836	1855	81
MAY	1936	1829	107
JUNE	1876	1780	96
JULY	1876	1773	103
AUGUST	1837	1666	171
SEPTEMBER	1861	1700	161
OCTOBER	1853	1692	161
NOVEMBER	1939	1745	194
DECEMBER	1928	1730	198

TABLE XXIV. DEVELOPMENT OF NEPA AVAILABLE CAPACITY AND RESERVE [SURPLUS/DEFICIENCY] FOR THE MAINTENANCE PERIODS CASE STUDY II. WORST HYDRO. CONDITION

PERIOD	AVAILABLE CAPACITY [MW]	PEAK DEMAND [MW]	EQUIVALENT RESERVE DEFICIENCY [MW]
JANUARY	1689	1734	-45
FEBRUARY	1663	1756	-93
MARCH	1688	1795	-107
APRIL	1716	1855	0139
MAY	1716	1829	-113
JUNE	!656	1780	-124
JULY	1656	1773	-117
AUGUST	1607	1666	-59
SEPTEMBER	1576	1700	-124
OCTOBER	1568	1692	-124
NOVEMBER	1679	1745	-66
DECEMBER	1678	1730	-52

Level reserves were obtained, as the system remained unchanged units transpositioning apart, the reserve averages stood to be the same as with former case study. Plotted in figures 15 - 17 were the reserves, maintenance spaces and maintenance reserves versus periods of scheduling. As usual, summary of results are presented in tables XXV - XXVII and equivalent reserve margins in tables XXVIII - XXX.

5.6 SELECTION OF A SCHEDULE

The twelve interval schedules developed satisfied the traditional method of scheduling maintenance with level of reserves. To select a better schedule from the ones developed, reliability considerations incorporated in the capacity outage table have to be employed. This table is used to compute the interval risk.

Interval risk is defined as the sum of capacity outage probabilities associated with the reserves within the interval [6]. These probabilities could be deduced directly from the computed capacity outage probability table. The risk involvements of all schedules being discussed were determined as shown in tables XXXI - XXXIII. A cursory glance at the table [XXXIV] of comparison of schedules interval risk, depicts the fact that schedules of the third case study proved to be more reliable by virture of having least interval risks under all the hydrological conditions. This is justified by reason of closeness of all level reserves of the schedules. Schedules of the first case study are the most unreliable due to their associated high risk involvements.

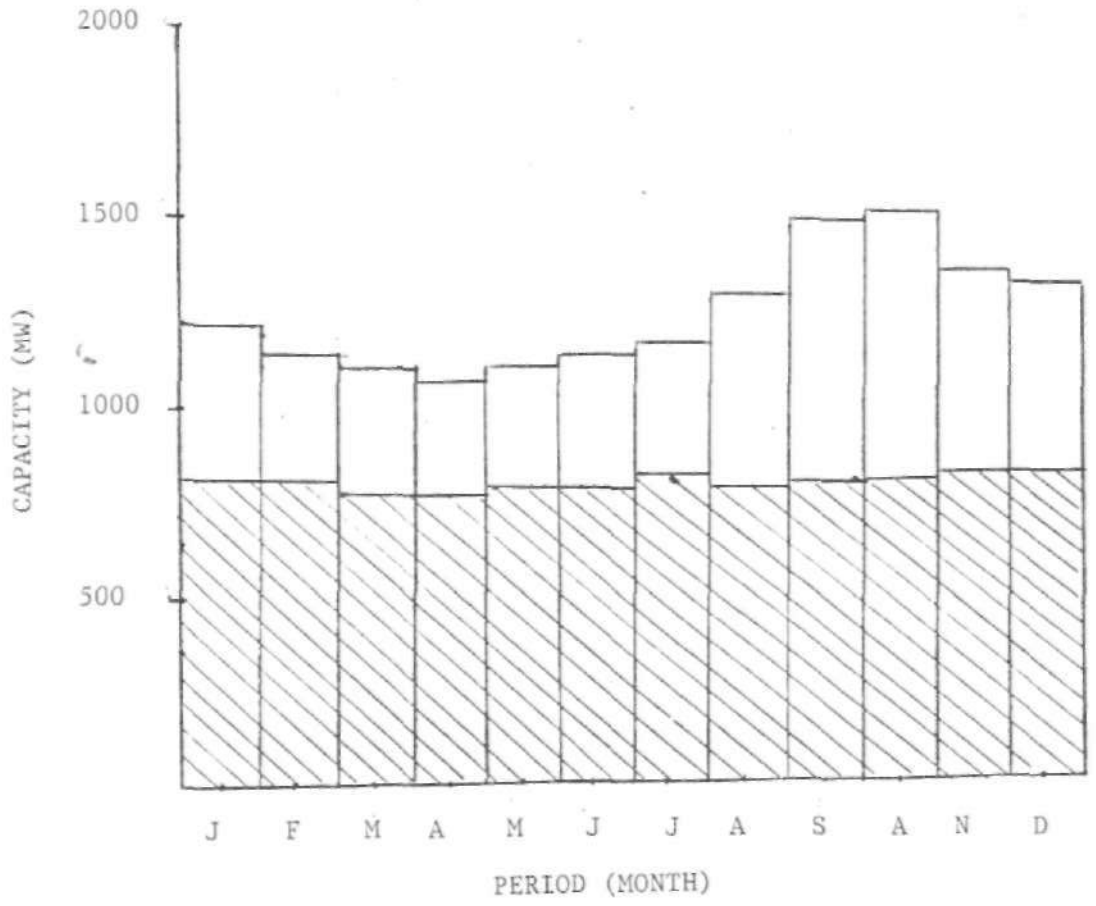


Fig. 15. Case 111 Ideal Hydro. Condition

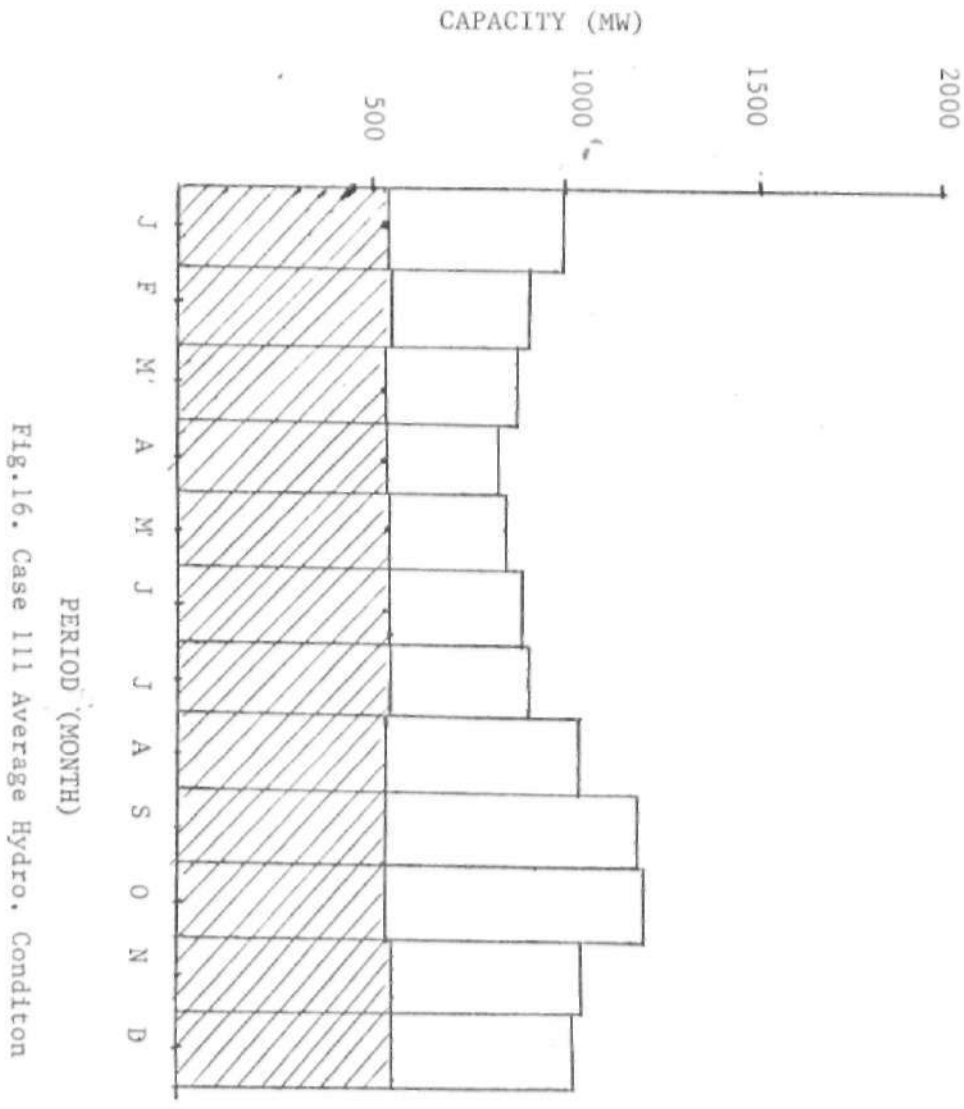


Fig.16. Case 111 Average Hydro, Conditon

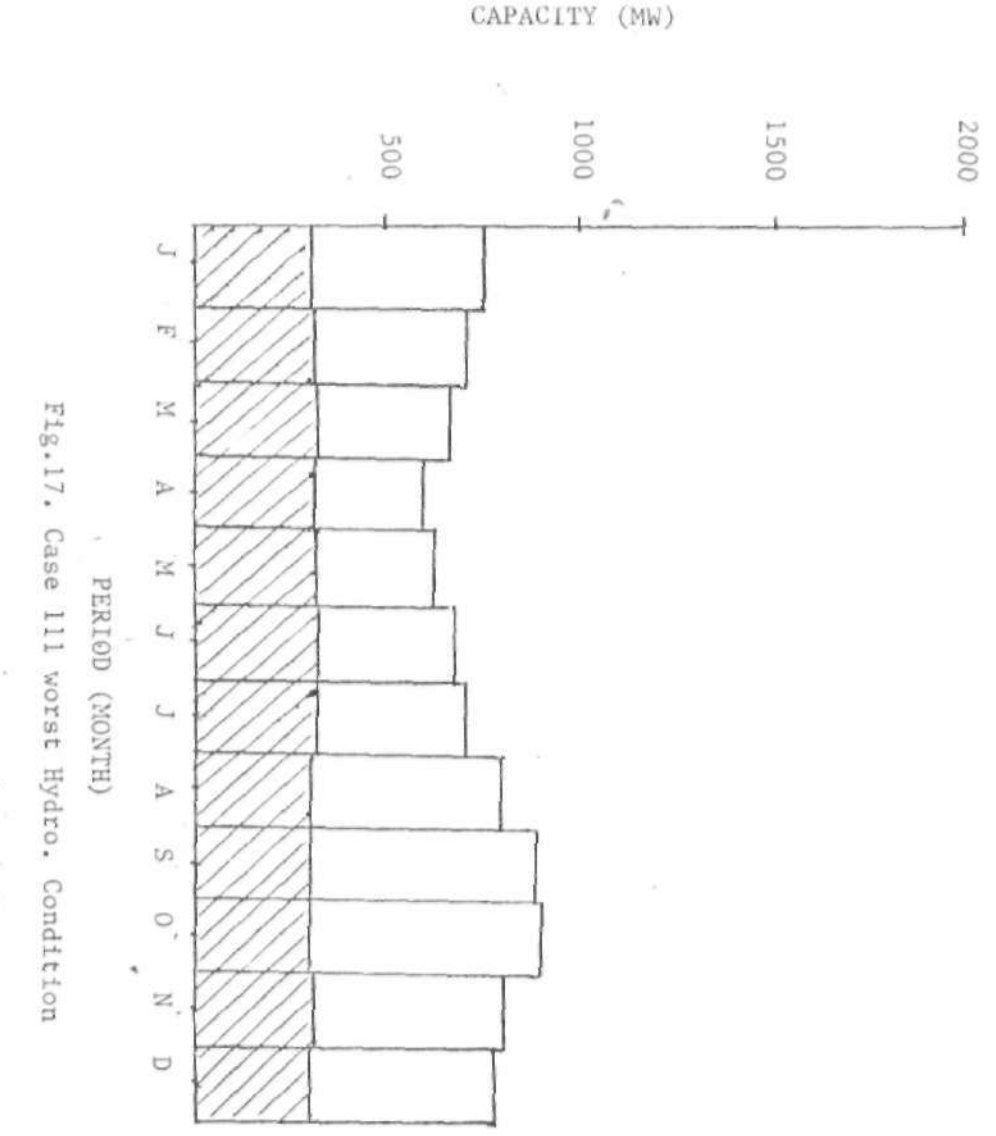


Fig.17. Case 111 worst Hydro. Condition

TABLE XXV. SUMMARY OF RESULTS OF MAINTENANCE SCHEDULES
CASE STUDY II. IN IDEAL HYDROLOGICAL CONDITION

JANUARY	FEBRUARY	MARCH
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
1232 MW.	1152 MW.	1113 MW.
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
EST5, SST4, DGT13,	KHG9, KHG5, KHG6,	KHG9, KHG5, KHG6 &
AGT4, DGT5 & AGT2	KHG7 & AGT3.	KHG7.
RESERVE CAPACITY	RESERVE CAPACITY	RESERVE CAPACITY
798 MW.	812 MW.	773 MW.

APRIL	MAY	JUNE
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
1053 MW.	1079 MW.	1128 MW.
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTEAINED
JHG3, JHG4 & JHG5.	JHG3, JHG4 & JHG5.	KHG11, KHG12 & JHG6.
RESERVE CAPACITY	RESERVE CAPACITY	RESERVE CAPACITY
765 MW.	791 MW.	792 MW.

JULY	AUGUST	SEPTEMBER
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
1135 MW.	1282 MW.	1466 MW.
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
KHG11, KHG12 & JHG6.	EST1, EST2, AGT8,	EST1, EST2, SST3
	DGT5, IGT5 & DGT6.	AGT13, DGT7 & DGT8.
RESERVE CAPACITY	RESERVE CAPACITY	RESERVE CAPACITY
799 MW.	775 MW.	795 MW.

OCTOBER	NOVEMBER	DECEMBER
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
1474 MW.	1321 MW.	1296 MW.
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
EST3, EST4, SST3,	EST3, EST4, AGT9	EST5, SST4, SGT3, AGT10
AGT14, AGT5, DGT9&AGT3.	DGT10, DGT11 & AGT1.	AGT6, DGT12 & AGT.2
RESERVE CAPACITY	RESERVE CAPACITY	RESERVE CAPACITY
781 MW.	814 MW.	804 MW.

TABLE XXVI. SUMMARY OF RESULTS OF MAINTENANCE SCHEDULES
CASE STUDY III. IN AVERAGE HYDROLOGICAL CONDITION

JANUARY	FEBRUARY	MARCH
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
997 MW.	932 MW.	893 MW.
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
EST5, SST4, DGT13,	KHG9, KHG5, KHG6,	KHG9, KHG5, KHG6,
AGT8, DGT5 & IGT4.	KHG7, DGT6, DGT7.	& KHG7.
RESERVE CAPACITY	RESERVE CAPACITY	RESERVE CAPACITY
558 MW.	572 MW.	553 MW.
APRIL	**MAY**	**JUNE**
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
833 MW.	859 MW.	908 MW.
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
JHG3, JHG4 & JHG5	JHG3, JHG4, JHG5,	KHG11, KHG12, JHG6
	& AGT2.	& IGT5.
RESERVE CAPACITY	RESERVE CAPACITY	RESERVE CAPACITY
545 MW.	571 MW.	572 MW.
JULY	**AUGUST**	**SEPTEMBER**
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
915 MW.	1052 MW.	1219 MW.
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE AMINTAINED
KHG11, KHG12, JHG6,	EST1, EST2, AGT9,	EST1, EST2, SST3,
& AGT1.	AGT4 & DGT8.	AGT13, DGT9 & AGT2.
RESERVE CAPACITY	RESERVE CAPACITY	RESERVE CAPACITY
569 MW.	541 MW.	542 MW.
OCTOBER	**NOVEMBER**	**DECEMBER**
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
1219 MW.	1061 MW.	1046 MW.
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
EST3, EST2, SST3,	EST3, EST4, AGT5,	EST5, SST4, SGT3,
AGT14, DGT10 & IGT4.	DGT11, & AGT2.	AGT10, AGT6 & DGT12.
RESERVE CAPACITY	RESERVE CAPACITY	RESERVE CAPACITY
548 MW.	559 MW.	564 MW.

TABLE XXVII. SUMMARY OF RESULTS OF MAINTENANCE SCHEDULES
CASE STUDY III. IN WORST HYDROLOGICAL CONDITION

JANUARY	FEBRUARY	MARCH
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
762 MW.	710 MW.	671 MW.
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
EST5, SST4, AGT13,	KHG11, KHG12, KHG5,	KHG11, KHG12, KHG5,
AGT4 & IGT4.	AGT8, AGT9 & DGT5.	& DGT6 & AGT1.
RESERVE CAPACITY	RESERVE CAPACITY	RESERVE CAPACITY
307 MW.	316 MW.	321 MW.

APRIL	MAY	JUNE
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
611 MW.	637 MW.	686 MW.
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
KHG9, JHG3 & JHG4.	KHG9, JHG3, JHG4,	JHG5, JHG6, KHG6,
	DGT7 & AGT2.	KHG7 & AGT3.
RESERVE CAPACITY	RESERVE CAPACITY	RESERVE CAPACITY
319 MW.	325 MW.	316 MW.

JULY	AUGUST	SEPTEMBER
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
693 MW.	820 MW.	896 MW.
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
JHG5, JHG6, KHG6,	EST1, EST2, AGT13,	EST1, EST2, SST3,
KHG7 & DGT8.	AGT8 & DGT9.	IGT5, DGT10 & AGT2
RESERVE CAPACITY	RESERVE CAPACITY	RESERVE CAPACITY
321 MW.	305 MW.	300 MW.

OCTOBER	NOVEMBER	DECEMBER
MAINTENANCE SPACE	MAINTENANCE SPACE	MAINTENANCE SPACE
904 MW.	801 MW.	796 MW.
UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED	UNITS TO BE MAINTAINED
EST3, EST4, SST3,	EST3, EST4, AGT10	EST5, SST4, SGT3
AGT5 & DGT11.	& DGT12.	DGT13, AGT6 & AGT3.
RESERVE CAPACITY	RESERVE CAPACITY	RESERVE CAPACITY
304 MW.	314 MW.	307 MW.

TABLE XXVIII. DEVELOPMENT OF NEPA AVAILABLE CAPACITY AND RESERVE [SURPLUS/DEFICIENCY] FOR THE MAINTENANCE PERIODS CASE STUDY III. IDEAL HYDRO. CONDITION

PERIOD	AVAILABLE CAPACITY [MW]	PEAK DEMAND [MW]	RESERVE SURPLUS [MW]
JANUARY	2153	1734	419
FEBRUARY	2095	1756	339
MARCH	2108	1795	313
APRIL	2160	1855	305
MAY	2160	1829	331
JUNE	2112	1780	332
JULY	2112	1773	339
AUGUST	2067	1666	401
SEPTEMBER	2153	1700	453
OCTOBER	2138	1692	446
NOVEMBER	2178	1745	433
DECEMBER	2171	1730	441

TABLE XXIX. DEVELOPMENT OF NEPA AVAILABLE CAPACITY AND RESERVE [SURPLUS/DEFICIENCY] FOR THE MAINTENANCE PERIODS CASE STUDY III. AVERAGE HYDRO. CONDITION

PERIOD	AVAILABLE CAPACITY [MW]	PEAK DEMAND [MW]	RESERVE SURPLUS [MW]
JANUARY	1918	1734	184
FEBRUARY	1875	1756	119
MARCH	1888	1795	93
APRIL	1940	1855	85
MAY	1940	1829	111
JUNE	1829	1780	112
JULY	1829	1773	119
AUGUST	1837	1666	171
SEPTEMBER	1868	1700	168
OCTOBER	1853	1692	161
NOVEMBER	1918	1745	173
DECEMBER	1921	1730	191

TABLE XXX. DEVELOPMENT OF NEPA AVAILABLE CAPACITY AND RESERVE [SURPLUS/DEFICIENCY] FOR THE MAINTENANCE PERIODS
CASE STUDY III. WORST HYDRO. CONDITION

PERIOD	AVAILABLE CAPACITY [MW]	PEAK DEMAND [MW]	EQUIVALENT RESERVE DEFICIENCY [MW]
JANUARY	1683	1734	-51
FEBRUARY	1655	1756	-101
MARCH	1668	1795	-127
APRIL	1720	1855	-135
MAY	1720	1829	-109
JUNE	1672	1780	-108
JULY	1672	1773	-101
AUGUST	1607	1666	-59
SEPTEMBER	1583	1700	-117
OCTOBER	1568	1692	-124
NOVEMBER	1658	1745	-87
DECEMBER	1671	1730	-59

TABLE XXXI.

RESERVE CAPACITIES/RISKS

CASE STUDY I.

PERIOD	IDEAL HYDRO. COND.		AVERAGE HYDRO. COND.		WORST HYDRO. COND.	
	RESERVE	RISK	RESERVE	RISK	RESERVE	RISK
JAN.	820	.03146	581	.18141	319	.60856
FEB.	768	.05121	548	.23367	326	.60856
MAR.	729	.06989	509	.28138	287	.68139
APR.	713	.06989	493	.28138	271	.68139
MAY	739	.05998	519	.25368	297	.64615
JUN.	844	.02655	601	.16113	331	.64615
JUL.	833	.02655	594	.16113	334	.56981
AUG.	795	.03713	565	.20289	309	.64615
SEPT.	805	.03713	562	.20289	320	.60856
OCT.	801	.03713	568	.20289	318	.60856
NOV.	834	.02655	581	.18141	323	.60856
DEC.	818	.03146	573	.18141	320	.60856

TABLE XXXII

RESERVE CAPACITIES/RISKS

CASE STUDY II.

PERIOD	IDEAL HYDRO. COND.		AVERAGE HYDRO. COND.		WORST HYDRO. COND.	
	RESERVE	RISK	RESERVE	RISK	RESERVE	RISK
JAN.	806	.03713	560	.20289	307	.64615
FEB.	814	.03146	572	.18141	316	.60856
MAR.	739	.05998	573	.18141	321	.60856
APR.	761	.05121	541	.23367	319	60.856
MAY	787	.04345	567	.20289	325	.60856
JUN.	776	.04345	556	.20289	316	.60856
JUL.	783	.04345	563	.20289	321	.60856
AUG.	775	.04345	541	.23367	305	.64615
SEPT.	795	.03713	550	.23367	300	.64615
OCT.	781	.04345	548	.23367	304	.64615
NOV.	814	.03146	559	.20289	314	.60856
DEC.	814	.03146	564	.20389	307	.64615

TABLE XXXIII.
RESERVE CAPACITIES/RISKS
CASE STUDY III

PERIOD	IDEAL HYDRO. COND.		AVERAGE HYDRO. COND.		WORST HYDRO. COND.	
	RESERVE	RISK	RESERVE	RISK	RESERVE	RISK
JAN.	798	.04345	558	.20289	307	.64615
FEB.	812	.03146	572	.18141	316	.60856
MAR.	773	.04345	553	.20289	321	.60856
APR.	765	.05121	545	.23367	319	.60856
MAY.	791	.03713	571	.18141	325	.60856
JUN.	792	.03713	572	.18141	316	.60856
JUL.	799	.03713	569	.20289	321	.60856
AUG.	775	.04345	541	.23267	305	.64615
SEPT.	795	.03713	542	.23367	300	.64615
OCT.	781	.04345	548	.23367	304	.64615
NOV.	814	.03146	564	.20289	314	.60856
DEC.	804	.03713	564	.20289	307	.64615

TABLE XXXIV.

COMPARISON OF SCHEDULES INTERVAL RISKS

CASE STUDY	DYDRO. CONDITION	INTERVAL RISK [DAYS/YEAR]
I	IDEAL	0.50493
	AVERAGE	2.52527
	WORST	7.5224
II	IDEAL	0.49708
	AVERAGE	2.51484
	WORST	7.49067
III	IDEAL	0.47358
	AVERAGE	2.49336
	WORST	7.49067

5.7 UNIT MAINTENANCE SCHEDULE

A further breakdown of the actual maintenance schedules could be developed to provide a maintenance schedule for individual units at each power station. This brings to the open a clear picture of the continuous nature of units maintenance especially those with double periods of maintenance. Considering the schedule print-out of case study I [of ideal hydro condition] for instance, maintenance schedules for Egbin & Sapele units were developed as shown in tabels XXXV and XXXVI.

TABLE XXXV

EGBIN MAINTENANCE SCHEDULE

EGBIN STATION	MAINTENANCE PERIODS					
	AUG	SEP	OCT	NOV	DEC	JAN
EST 1						
EST 2						
EST 3						
EST 4						
EST 5						

TABLE XXXVI

SAPELE MAINTENANCE SCHEDULE

SAPELE STEAM	MAINTENANCE PERIODS				
	SEP	OCT	NOV	DEC	JAN
SST 3	———	———			
SST 4				———	———

CHAPTER 6

CONCLUSIONS & RECOMMENDATIONS

6.1 INTRODUCTION

A practical technique developed for maintenance scheduling has been applied to NEPA generating facilities. The results of several case studies based on real data obtained from the utility have been presented and discussed.

6.2 CONCLUSIONS

This research effort has endeavoured to develop maintenance schedules for twenty eight hydro-thermal units feeding the Nigerian National Grid. To the best of the authors knowledge, this is perhaps the first attempt to research into the maintenance problem facing the supply authority and will therefore, form basis for further investigations.

Although the mathematical formulation developed in this thesis is very comprehensive, the available data base led to the making of some engineering approximations and assumptions which in turn, permitted the development of an automated computer software for the maintenance problem at hand.

The program so developed has the capability of preparing power system maintenance schedules for up to twelve periods. The objective function is principally aimed at levelizing the reserve margin throughout the year. The extension of this technique to accommodate the revision of schedules in response to forced outages, strikes and other unexpected contingencies can easily be realised. Of the results presented and

discussed, having considered all the hydrological conditions, case study III has been found to have the least risk involvements as presented in table XXXIV.

This study has also brought into focus, the catastrophic failure suffered by some key generating facilities of NEPA, suspected to be due to non-adherence of the established practice of maintenance. It has also been observed that lack of spare parts (resource constraint) has led to the shutdown of some gas-turbines of Afam and steam units at Sapele. As at January 1988, the percentage failure rates of Hydro, steam and Gas (generating types) are 28%, 34% & 59% respectively.

6.3 RECOMMENDATIONS

A substantial percentage of NEPA revenue is known to be spent on maintenance of the installed facilities each year. This problem is further compounded by the present economic condition with respect to the procurement of the necessary spare parts from external sources. It is therefore envisaged that scheduling generating units'maintenance in the face of these trends will become increasingly difficult and an important problem to NEPA The following recommendations are therefore offered.

1. Stream-lining or standardizing of generating equipment which will in turn enhance bulk purchase of spare parts.

2. Effective stock control in the stores department to ensure timely and adequate supply of resource.

3. Implementation of the maintenance schedules centrally coordinated by the control unit at Oshogbo.

Finally, future work towards the improvement of the practical maintenance schedules obtained should be the incorporation of the production and maintenance costs in the analysis. This will lead to the actual implementation of the mathematical formulation whose objective function is based on maintenance, production and reliability costs, thus yielding much better schedules.

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APPENDICES

APPENDIX I

INPUT DATA LISTING

TABLE I

INPUT DATA TO RUN THE PROGRAM FOR CASE STUDY I

(IDEAL HYDRO-CONDITION)

12	2026	R									
940	882	882	882	882	882	882	922	1140	1140	1040	1000
1734	1756	1795	1855	1829	1780	1773	1666	1700	1692	1745	1730
10	220	0	1								
2	120	4	2								
2	120	5	2								
4	116	0	3								
1	100	4	2								
1	100	5	2								
4	96	2	4								
4	96	3	4								
3	80	6	2								
3	80	7	2								
1	75	0	5								
2	75	0	6								
1	36	0	7								
3	27	0	8								
3	24	0	9								
7	20	0	10								
2	20	0	11								
2	18	0	12								
1	10	0	12								

TABLE II

INPUT DATA TO RUN THE PROGRAM FOR CASE STUDY I
AVERAGE HYDRO. CONDITION

12	2026	R									
705	662	662	662	662	662	662	692	885	885	780	750
1734	1756	1795	1855	1829	1780	1773	1666	1700	1692	1745	1730
10	220	0	1								
2	120	4	2								
2	120	5	2								
4	116	0	3								
1	100	4	2								
1	100	5	2								
4	96	2	4								
4	96	3	4								
3	80	6	2								
3	80	7	2								
1	75	0	5								
2	75	0	6								
1	36	0	7								
3	27	0	8								
3	24	0	9								
7	20	0	10								
2	20	0	11								
2	18	0	12								
1	10	0	12								

TABLE III

INPUT DATA TO RUN THE PROGRAM FOR CASE STUDY I

WORST HYDRO-CONDITION

12	2026	R									
470	440	440	440	440	440	440	460	570	570	520	500
1734	1756	1795	1855	1829	1780	1773	1666	1700	1692	1745	1730
10	220	0	1								
2	120	4	2								
2	120	5	2								
4	116	0	3								
1	100	4	2								
1	100	5	2								
4	96	2	4								
4	96	3	4								
3	80	6	2								
3	80	7	2								
1	75	0	5								
2	75	0	6								
1	36	0	7								
3	27	0	8								
3	24	0	9								
7	20	0	10								
2	20	0	11								
2	18	0	12								
1	10	0	12								

TABLE IV

INPUT DATA TO RUN THE PROGRAM FOR CASE STUDY II

IDEAL HYDRO CONDITION

12	2026	R									
940	882	882	882	882	882	882	922	1140	1140	1040	1000
1734	1756	1795	1855	1829	1780	1773	1666	1700	1692	1745	1730
10	220	0	1								
2	120	2	2								
2	120	3	4								
4	116	0	3								
1	100	4	2								
1	100	5	2								
2	96	4	4								
2	96	5	4								
2	96	6	4								
2	96	7	4								
1	80	2	2								
1	80	3	2								
2	80	6	2								
2	80	7	2								
1	75	0	5								
2	75	0	6								
1	36	0	7								
3	27	0	8								
3	24	0	9								
7	20	0	10								
2	20	0	11								
2	18	0	12								
1	10	0	12								

TABLE V

INPUT DATA TO RUN THE PROGRAM FOR CASE STUDY II
AVERAGE HYDRO. CONDITION

```
12    2026    R
705   662   662   662   662   662   662   692   885   885   780   750
1734  1756  1795  1855  1829  1780  1773  1666  1700  1692  1745  1730
10    220   0     1
2     120   2     2
2     120   3     4
4     116   0     3
1     100   4     2
1     100   5     2
2     96    4     4
2     96    5     4
2     96    6     4
2     96    7     4
1     80    2     2
1     80    3     2
2     80    6     2
2     80    7     2
1     75    0     5
2     75    0     6
1     36    0     7
3     27    0     8
3     24    0     9
7     20    0     10
2     20    0     11
2     18    0     12
1     10    0     12
```

TABLE VI

INPUT DATA TO RUN THE PROGRAM FOR CASE STUDY II
WORST HYDRO. CONDITION

12	2026	R									
470	440	440	440	440	440	440	460	570	570	520	500
1734	1756	1795	1855	1829	1780	1773	1666	1700	1692	1745	1730
10	220	0	1								
2	120	2	2								
2	120	3	4								
4	116	0	3								
1	100	4	2								
1	100	5	2								
2	96	4	4								
2	96	5	4								
2	96	6	4								
2	96	7	4								
1	80	2	2								
1	80	3	2								
2	80	6	2								
2	80	7	2								
1	75	0	5								
2	75	0	6								
1	36	0	7								
3	27	0	8								
3	24	0	9								
7	20	0	10								
2	20	0	11								
2	18	0	12								
1	10	0	12								

TABLE VII

INPUT DATA TO RUN THE PROGRAM FOR CASE STUDY III

IDEAL HYDRO. CONDITION

12	2026	R									
940	882	882	882	882	882	882	922	1140	1140	1040	1000
1734	1756	1795	1855	1829	1780	1773	1666	1700	1692	1745	1730
10	220	0	1								
2	120	6	2								
2	120	7	2								
4	116	0	3								
1	100	2	2								
1	100	3	2								
3	96	4	4								
3	96	5	4								
1	96	6	4								
1	96	7	4								
3	80	2	2								
3	80	3	2								
1	75	0	5								
2	75	0	6								
1	36	0	7								
3	27	0	8								
3	24	0	9								
7	20	0	10								
2	20	0	11								
2	18	0	12								
1	10	0	12								

TABLE VIII

INPUT DATA TO RUN THE PROGRAM FOR CASE STUDY III

AVERAGE HYDRO. CONDITION

12	2026	R									
705	662	662	662	662	662	662	692	885	885	780	750
1734	1756	1795	1855	1829	1780	1773	1666	1700	1692	1745	1730
10	220	0	1								
2	120	6	2								
2	120	7	2								
4	116	0	3								
1	100	2	2								
1	100	3	2								
3	96	4	4								
3	96	5	4								
1	96	6	4								
1	96	7	4								
3	80	2	2								
3	80	3	2								
1	75	0	5								
2	75	0	6								
1	36	0	7								
3	27	0	8								
3	24	0	9								
7	20	0	10								
2	20	0	11								
2	18	0	12								
1	10	0	12								

TABLE IX

INPUT DATA TO RUN THE PROGRAM FOR CASE STUDY III

WORST HYDRO CONDITION

12	2026	R									
470	440	440	440	440	440	440	460	570	570	520	500
1734	1756	1795	1855	1829	1780	1773	1666	1700	1692	1645	1730
10	220	0	1								
2	120	6	2								
2	120	7	2								
4	116	0	3								
1	100	2	2								
1	100	3	2								
3	96	4	4								
3	96	5	4								
1	96	6	4								
1	96	7	4								
3	80	2	2								
3	80	3	2								
1	75	0	5								
2	75	0	6								
1	36	0	7								
3	27	0	8								
3	24	0	9								
7	20	0	10								
2	20	0	11								
2	18	0	12								
1	10	0	12								

APPENDIX II

COMPUTER OUTPUT LISTING

```
      1.      PROGRAM MAIN(INPUT,OUTPUT,TAPE5=DATA,TAPE6=OUTPUT)
      2.      IMPLICIT INTEGER(A-Z)
      3.      DIMENSION THERM(12),HYDRO(12),PEAK(12),SPACE(12),RESERV(12),
     *INPUT(2,4),SCHED(15,3,2),NFULL(12)

      4.      DATA STAR,BLANK,PLUS,BOTH/'*','  ','+','B'/
C             INPUT # OF PERIODS AND TOTAL THERMAL CAPACITY(MW).
      5.      READ(5,2)NPERIOD,THERM,OPTION
      6.      IF(NPERIOD).GT.21)NPERIOD=21
C             INPUT HYDRO CAPACITY(MW) FOR EACH PERIOD.
C             INPUT PEAK DEMAND(MW) FOR EACH PERIOD.
      7.      READ(5,1)(HYDRO(I),I=1,NPERIOD)
      8.      READ(5,1)(PEAK(I),I=1,NPERIOD)
C             INPUT UNITS FOR SCHEDULING
      9.      N=0
     10.      DO 10 I=1,2
     11.      READ(5,1)(INPUT(N,I),I=1,6)
     12.      IF(INPUT(N,1).EQ.0)GO TO 20

     13.      NPLANT=N-1
C             ORDER UNITS FOR SCHEDULING IN DECREASING CAPACITY.
C             FORCED MAINTENANCE UNITS AT THE BEGINNING.
C             ORDER UNITS BY DECREASING CAPACITY.
     14.      CALL ORDER(INPUT,1,NPLANT,2)
C             ORDER UNITS BY DECREASING FORCED MAINTENANCE PERIOD.
C             NON-FORCED UNITS AT THE END.
     15.      CALL ORDER(INPUT,1,NPLANT,3)
C             CALCULATE MAINTENANCE SPACE.
     16.      DO 60 I=1,NPERIOD
     17.      NFULL(I)=0
     18.      THERM(I)=THERM

     19.      SPACE(I)=THERM+HYDRO(I)-PEAK(I)
     20.      RESERV(I)=SPACE(I)
     21.      CONTINUE
C             SCHEDULE MAINTENANCE . FORCED UNITS FIRST. THEN MATCH THE
C             LARGEST REMAINING UNIT WITH THE LARGEST RESERVE.
     22.      DO 130 I=1,NPLANT
     23.      UNITS=INPUT(I,1)
     24.      DO 24 J=1,UNITS
     25.      IF(INPUT(I,3)).GT.0)GO TO 71
C             MAINTENANCE FORCED.
     26.      NPER=INPUT(I,3)
     27.      NPER=NPER+1
     28.      GO TO 230

C             MAINTENANCE FOR GOOD. FIND LARGEST RESERVE.
     29.      MAX=0
     30.      IPLACE=0
     31.      ICHR=BLANK
     32.      DO 120 J=1,PERIOD
     33.      IF(OPTION.EQ.0)GO TO 111
     34.      IF(RESERV(J).LE.MAXRES)GO TO 120
     35.      IF(FLOAT(RESERV(J))/FLOAT(PEAK(J)).GT.
     *FLOAT(MAXRES)/FLOAT(PEAK(IPLACE)))GO TO 120
     36.      MAXRES=RESERV(J)
     37.      IPLACE=J
     38.      CONTINUE
C             INSERT UNIT INTO SCHEDULE.

     39.      NFULL(IPLACE)=NFULL(IPLACE)+1
     41.      N=NFULL(IPLACE)
     41.      SCHED(IPLACE,1,N)=INPUT(I,2)
     42.      SCHED(IPLACE,2,N)=INPUT(I,4)
     44.      RESERV(IPLACE)=RESERV(IPLACE)-INPUT(I,2)
     45.      IF(RESERV(IPLACE).GT.0)GO TO 120
     46.      CONTINUE
C             IF(ERRLAM=NO,COMPLETE,PRINT RESULTS.
     47.      IF(OPTION.EQ.0)GO TO 170

     48.      WRITE(6,3)
     49.      WRITE(6,3)
     50.      WRITE(6,4)(I,I=1,NPERIOD)
     51.      WRITE(6,5)(SPACE(I),I=1,NPERIOD)
     52.      WRITE(6,6)(RESERV(I),I=1,NPERIOD)
     53.      DO 160 I=1,NPLANT
     54.      WRITE(6,7)(SCHED(I,1,J),J=1,NFULL(I))
     55.      WRITE(6,8)(SCHED(I,2,J),J=1,NFULL(I))
     56.      MAX=0
     57.      DO 200 I=1,PERIOD
     58.      IF(NFULL(I).GT.MAX)GO TO 190
     59.      GO TO 200
     60.      MAX=NFULL(I)
     61.      CONTINUE
```

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CASE STUDY I RESULTS

PERIOD	1	2	3	4	5	6	7	8	9	10	11	12
THERMAL	2220	2220	2220	2220	2220	2220	2220	2220	2220	2220	2220	2220
HYDRO.	853	852	852	802	802	932	832	922	1241	1241	1141	1171
PEAK	1754	1756	1799	1809	1849	1780	1773	1806	1761	1694	1749	1731
MAINTENANCE SPACE	1234	1252	1223	1153	1179	1268	1280	1236	1460	1474	1361	1236
SCHEDULE												
MW	220	96	96	120	120	96	96	220	220	220	220	220
TYPE	1	4	4	2	2	2	2	1	1	1	1	1
TYPE	249	96	96	242	120	96	96	241	241	241	241	116
MW	30	96	96	120	120	96	96	27	216	110	27	79
TYPE	7	4	4	2	2	2	2	6	3	3	5	5
MW	20	96	96	0	0	24	24	0	75	75	0	27
TYPE	10	4	4	0	0	9	9	10	6	6	10	6
TYPE	11	2	2	2	2	11	11	11	11	11	2	11
MW	0	0	0	0	0	24	24	0	0	0	0	0
TYPE	0	0	0	0	0	11	12	12	12	12	0	11
RESERVE	822	760	723	723	709	944	832	732	655	661	814	818

BASED ON MAXIMUM RECEIVE RESERVE.

PERIOD	1	2	3	4	5	6	7	8	9	10	11	12
THERMAL	2126	2126	2126	2826	2826	2826	2826	2826	2826	2826	2826	2826
HYDRO*	745	662	662	662	662	662	662	662	865	865	765	765
PEAK	2734	2756	2788	2856	2809	2788	2773	2666	2711	2692	2745	2731
MAINTANENCE SPACE	997	982	893	883	859	918	918	1192	1211	1219	1161	1046
SCHEDULE												
MW	229	96	96	125	125	96	96	229	229	229	245	229
TYPE	2	* 4	* 4	* 2	* 2	* 4	* 4	2	2	2	1	2
MW	116	96	96	125	125	87	87	229	229	229	229	116
TYPE	3	* 4	* 4	* 2	* 2	* 2	* 2	1	1	1	1	3
MW	36	96	96	125	125	87	87	87	116	116	87	75
TYPE	7	* 4	* 4	* 2	* 2	* 2	* 2	8	3	3	10	5
MW	24	96	96	87	87	87	87	26	75	75	25	24
TYPE	9	* 4	* 4	* 3	* 3	* 3	* 3	11	6	6	11	9
MW	25	87	87	87	87	87	26	26	87	87	21	21
TYPE	11	* 3	* 3	* 3	* 3	* 3	* 3	9	* 3	12	11	* 3	11
MW	13	87	87	87	87	87	29	29	87	26	26	87	18
TYPE	12	* 3	* 3	* 3	* 3	* 3	* 3	10	12	* 3	10	10	* 3	12
MW	0	0	87	87	87	87	87	10	87	87	87	87	87	87
TYPE	* 3	* 3	* 3	* 3	* 3	* 3	* 3	12	* 3	* 3	* 3	* 3	* 3	* 3
RESERVE	561	548	509	443	529	561	536	565	562	568	581	573

* INDICATES UNITS WITH FORCED MAINTENANCE.

1:LOJA 1 (THERMAL)
2:KAINJI (HYDRO)
3:SAPELE (THERMAL)
4:SAPELE (GAS)
5:DELTA (GAS)
6:AFAM3 (GAS)
7:AFAM2 (GAS)
8:DELTA (GAS)
9:IJORA(THERMAL)
10:AFAM1 (GAS)

MAINTENANCE SCHEDULE

BASED ON MAXIMUM RELATIVE RESERVE.

PERIOD	1	2	3	4	5	6	7	8	9	10	11	12
THERMAL	2126	2126	2126	2126	2126	2126	2126	2126	2126	2126	2126	2126
HYDRO.	670	641	643	641	643	643	641	463	575	573	523	524
PEAK	1734	1756	1735	1658	1649	1781	1773	1666	1711	1692	1745	1736
MAINTANENCE												
GPA [C]	762	717	671	611	637	955	643	453	596	914	881	796
SCHEDULE												
MW	220	96	96	196	120	80	80	220	220	220	220	116
TYPE	3 *	4 *	4 *	2 *	2 *	2 *	2	1	1	1	1	3
MW	96	96	96	196	120	80	80	27	116	116	20	76
TYPE	7 *	4 *	4 *	1 *	2 *	2 *	2	6	9	3	14	5
MW	27	96	96	1	1	75	75	24	3	21	18	27
TYPE	8 *	4 *	4 *	1 *	1	6	6	9	12	11	12	8
MW	43	0	0	0	0	22	45	22	22	22	0	41
MW	20	0	0	0	0	20	20	0	18	0	0	18
TYPE	11 *	0 *	0 *	0 *	0	11	11 *	0	12 *	0 *	0	12
RESERVE	329	709	307	272	297	541	374	319	325	314	323	320

* SHUT DATES UNITS WITH FORCED MAINTANENCE.

1-BIG 4 (STEAM)
2-ROBIE (HYDRO)
3-CAPELL (STEAM)
4-BURRA (HYDRO)
5-CAPELL (GAS)
6-MFNA (GAS)
7-REMBA (GAS)
8-CF302 (GAS)
9-HILTAS (GAS)
10-[illegible] (THERMAL)
11-AFGAL (GAS)

CASE STUDY II RESULTS

MAINTENANCE SCHEDULE
BASED ON MAXIMUM RELATIVE RESERVE*

PERIOD	1	2	3	4	5	6	7	8	9	10	11	12
THERMAL HYDRO	6959	6882	6882	6882	6882	6882	6882	6882	6882	6882	6882	6882
PEAK	1734	1706	1705	1685	1629	1736	1873	1656	1702	1652	1745	1731
MAINTANENCE SPACE	1252	1252	1123	1093	1179	1126	1235	1282	1466	1474	1321	1236
SCHEDULE												
TYPE	11	12	12	12	12	7	7	11	11	11	11	11
MW	110	120	120	90	90	90	90	210	220	220	220	110
TYPE	3	2	1	4	4	4	4	1	1	2	1	3
MW	80	60	60	90	90	60	60	170	110	140	70	70
TYPE	4	5	6	5	5	6	6	3	3	3	3	4
MW	40	20	0	0	0	0	0	40	70	70	20	20
TYPE	9	10	1	1	1	1	2	2	10	0	0	10
MW	20	20	0	0	0	0	0	20	20	20	0	20
TYPE	12	11	11	11	11	11	11	11	11	11	11	11
TYPE	5	5	5	5	5	5	5	5	5	12	5	5
RESERVE	0.0	014	795	701	767	776	795	779	795	701	814	814

* INDICATES UNITS WITH FORCED MAINTENANCE.

1=EQUIV (THERMAL)
2=SHAWINIGAN (HYDRO)
3=JOHNSON (HYDRO)
4=BRYCE (GAS)
5=DELTA (GAS)
6=ALPHA (GAS)
7=OMEGA (GAS)
8=DELTA (GAS)
9=JOHNSON (THERMAL)
10=ARIEL (GAS)

MAINTENANCE SCHEDULE
BASED ON MAXIMUM RELIVE RESERVE.

PERIOD	1	2	3	4	5	6	7	8	9	10	11	12
THERMAL	2626	2626	2626	2626	2626	2626	2626	2626	2626	2626	2626	2626
HYDRO.	715	662	662	662	662	662	662	662	865	865	767	751
PEAK	1734	1796	1796	1796	1829	1780	1773	1966	1710	1692	1745	1731
MAINTENANCE SPACE	907	932	892	852	859	908	915	1202	1211	1209	1161	1146
SCHEDULE												
MW	22	17	17	17	21	36	36	24	22	224	223	224
TYPE	1 *	2 *	2 *	2 *	2 *	4 *	4	1	1	1	1	1
MW	116	121	123	36	36	36	36	224	224	224	224	116
TYPE	5 *	2 *	2 *	4 *	4 *	4 *	4	2	2	2	1	2
MW	56	61	61	36	36	32	64	47	116	116	24	75
TYPE	7 *	2 *	2 *	4 *	4 *	2 *	2	8	3	3	9	5
MW	27	21	22	5	4	3	6	24	75	75	20	27
TYPE	3	11	11 *	1 *	1 *	2 *	2	9	6	6	12	8
MW	29	29	2	5	8	8	6	22	29	29	18	29
TYPE	12	12 *	1 *	1 *	1 *	1 *	1 *	1 *	12	12 *	2	11
MW	18	18	3	6	3	3	6	6	18	21	6	21
RESERVE	561	572	573	541	567	556	563	541	556	543	559	554

* INDICATES UNITS WITH FORCED MAINTENANCE.
1=COAL I (THERMAL)
2=COAL II (HYDRO)
3=COAL III (STEAM)
4=OIL I (HYDRO)
5=OIL II (GAS)
6=OIL III (GAS)
7=OIL IV (GAS)
8=NUC I (GAS)
9=NUC II (GAS)
10=OIL V (THERMAL)
11=NUC III (GAS)

MAINTENANCE SCHEDULE
BASED ON MAXIMUM RELATIVE RESERVE

PERIOD	1	2	3	4	5	6	7	8	9	10	11	12
THERMAL GEN MW	2120	2120	2125	2120	2120	2020	2120	2120	2020	2020	2125	2020
	47%	46%	44%	44%	44%	44%	44%	40%	57%	57%	52%	57%
PEAK	1734	1756	1735	1230	1929	1731	1773	1666	1711	1652	1745	1731
MAINTENANCE												
PAGE	762	7-	67*	6	637	9 6	633	62[illegible]	596	4 4	6[illegible]1	796
SCHEDULE												
TYPE	22	*22	*22	*2	*2	* 2	* 2	22	22	22	22	22
MW	116	12	122	5	36	36	36	22	22	22	22	116
TYPE	3	*2	*2	*1	*4	*4	*4	2	1	1	3	3
MW	75	0	0	36	36	0	0	75	116	116	47	75
TYPE	0	*2	*2	*4	*4	*2	*2	0	3	3	0	0
MW	24	27	2	2	2	2	2	27	24	24	2	36
TYPE	3	3	1	1	1	*2	*2	0	1	3	3	7
MW	20	27	12	0	18	18	20	2	24	24	1	24
TYPE	11	0	12	1	1	12	12	11	11	11	1 0	9
TYPE	1	12	1	1	1	1	1	12	1	1	1	12
RESERVE	3.7	316	321	3.9	325	316	322	3 9	311	314	314	317

* INDICATES UNITS WITH FORCED MAINTENANCE.
1-OIL (TURBINE)
2-OIL (STEAM)

3-SAMPLE (GT A)
4-[illegible] (HYDRO)
5-SAMPLE (GAS)
6-[illegible] (GAS)
7-[illegible] (GAS)
8-[illegible] (GAS)
9-[illegible] (GAS)
10-[illegible] (GAS)
11-[illegible] (THERMAL)
12-[illegible] (GAS)

CASE STUDY III RESULTS

MAINTENANCE SCHEDULE

BASED ON MAXIMUM RELATIVE RESERVE.

PERIOD	1	2	3	4	5	6	7	8	9	10	11	12
THERMAL HYDRO.	2,00 940	1,80 882	2,00 882	1,80 882	2,00 882	2,00 882	2,00 882	1,80 922	2,00 2141	2,00 2140	2,00 1643	2,00 1631
PEAK	1734	1756	1795	1830	1829	1766	1773	1836	1746	1832	1745	1731
SPARE	1532	1152	1123	1080	1179	1128	1135	1282	1466	1474	1361	1296
SCHEDULE												
MW	42	210	1	30	90	120	120	240	220	220	240	200
TYPE	1	2	2	4	4	2	2	1	1	1	1	1
MW	119	42	42	30	98	210	120	240	220	220	220	110
TYPE	3	2	2	4	4	2	2	1	1	1	1	3
MW	98	42	42	98	98	98	98	42	140	140	42	70
TYPE	7	2	2	4	4	4	4	6	3	3	6	5
MW	24	42	42	-	-	-	1	42	70	70	42	28
TYPE	9	2	2	1	1	1	8	12	6	6	13	8
MW	28	14	7	7	7	7	7	28	28	28	28	28
TYPE	12	12	1	1	1	1	1	11	10	9	11	9
MW	4	0	0	0	0	0	0	0	0	14	4	14
TYPE	4	0	0	0	0	0	0	0	0	12	8	12
RESERVE	798	812	773	765	791	792	793	775	795	791	814	834

UNITS WITH FORCED MAINTENANCE.

1-[illegible] (THERMAL)
5-[illegible] (OTHER)
4-[illegible] (HYDRO)

6-[illegible] (GAS)
7-[illegible] (GAS)
8-[illegible] (GAS)
11-[illegible] (GAS)
12-[illegible] (GAS)

BASED ON MAINTENANCE,RESERVE,RESERVE.

PERIOD	1	2	3	4	5	6	7	8	9	10	11	12
THERMAL	2026	2026	2026	2026	2026	2026	2026	2026	2026	2026	2026	2026
HYDRO.	7_5	662	662	662	662	662	662	698	885	885	783	791
PEAK	1734	1756	1795	1835	1879	1781	1773	1666	1781	1692	1745	1736
MAINTANENCE SPACE	997	932	893	853	859	948	965	1252	1211	1219	1661	1346
SCHEDULE												
MW	22₁	*18₂	*18₂	* 9₄	* 9₄	*12₂	*12₂	22₁	22₁	22₁	22₁	22₁
TYPE	110	66	66	36	36	120	120	220	220	220	220	110
	3	* 2	* 2	* 4	* 4	* 2	* 2	1	1	1	1	3
MW	30	6	6	9	9	30	30	47	115	113	69	75
TYPE	7	* 2	* 2	* 4	* 4	* 4	* 4	6	5	3	9	6
MW	27	66	63	9	18	20	18	24	75	75	20	27
TYPE	8	* 2	* 2	* 2	12	11	12	9	6	6	10	8
MW	20	20	9	6	6	9	9	6	18	20	6	20
TYPE	10	10	* 3	* 2	* 6	* 6	* 6	10	10	10	12	9
MW	66	20	9	6	6	9	9	6	18	20	6	20
TYPE	11	11	* 3	* 2	* 6	* 6	* 6	12	11	* 3	* 3	10
RESERVE	558	572	553	548	574	572	569	541	542	548	559	564

* INDICATES UNITS WITH FORCED MAINTANENCE.
1-EGDIN (THERMAL)

5-KATRIJ (HYDRO)
3-SAPLLC (STEAM)
4-JENDA (HYDRO)
6-SAPLLC (GAS)
7-DELTA4 (GAS)
8-AFAM3 (GAS)
9-AFAM2 (GAS)
11-DELTA3 (GAS)
12-AFAM1 (THERMAL) (GAS)

MAINTANENCE SCHEDULE

BASED ON MAXIMUM RELATIVE RESERVE.

PERIOD	1	2	3	4	5	6	7	8	9	10	11	12
THERMAL	2126	2126	2126	2126	2126	2126	2126	2126	2126	2126	2126	2126
HYDRO.	470	440	440	440	440	440	440	400	570	670	520	540
PEAK	1734	1756	1705	1705	1629	1791	1773	1686	1701	1692	1745	1731
MAINTANENCE SPACE	762	722	671	621	637	586	633	822	995	974	881	796
SCHEDULE												
MW	22	123	123	12	141	96	96	220	220	220	220	220
TYPE	1	2	2	2	2	4	4	1	1	1	1	1
MW	116	123	123	96	96	96	96	220	220	220	220	116
TYPE	3	2	2	4	4	4	4	1	1	1	1	3
MW	75	61	61	96	96	61	31	75	116	116	27	75
TYPE	6	2	2	4	4	2	2	6	3	3	6	5
MW	23	47	23	15	15	47	23	47	23	23	15	39
TYPE	11	8	12	1	1	12	11	11	11	10	8	9
MW	0	20	0	0	0	0	0	0	10	0	0	10
TYPE	1	12	1	1	1	1	1	1	12	1	1	12
RESERVE	317	319	321	319	325	316	321	349	347	314	314	337

* INDICATES UNITS WITH FORCED MAINTENANCE.

1-EQUIV. (THERMAL)
2-RADIUS (HYDRO)
3-CAPACITY (STEAM)
4-DEBRA (HYDRO)
5-REPLACE (GAS)

7-DELTA (GAS)
8-ADAM (GAS)
9-ADAM (GAS)
11-DUCTAPE (GAS)
12-ADAM (GAS)

APPENDIX III

CAPACITY OUTAGE TABLE

NEPA 28 UNITS TO SCHEDULE FOR
MAINTENANCE

RATING (MW)	FORCED OUTAGE RATE
20 x 17	0.3
40 x 1	"
80 x 3	"
120 x 2	0.15
220 x 5	"

TABLE XXX

CAPACITY OUTAGE PROBABILITY TABLE
1960 MW CAPACITY SYSTEM

OUTAGE MW	PROBABILITY OF OUTAGE OF GREATER		
0	.85(1.0)	+ .15(1.0)	= 1.0
20	.85(.99979)	+ .15(1.0)	= 0.99982
40	.85(.99825)	+ .15(1.0)	= 0.99851
60	.85(.99289)	+ .15(1.0)	= 0.99396
80	.85(.98113)	+ .15(1.0)	= 0.98396
100	.85(.96158)	+ .15(1.0)	= 0.96734
120	.85(.93595)	+ .15(1.0)	= 0.94556
140	.85(.90558)	+ .15(1.0)	= 0.91974
160	.85(.87149)	+ .15(1.0)	= 0.89077
180	.85(.83152)	+ .15(1.0)	= 0.85679
200	.85(.78884)	+ .15(1.0)	= 0.82056
220	.85(.74344)	+ .15(1.0)	= 0.78192
240	.85(.70402)	+ .15(.99979)	=0.74839
260	.85(.66485)	+ .15(.99825)	=0.71486
280	85(.62642)	+ .15(.99289)	=0.68139
300	.85(.58704)	+ .15(.98113)	=0.64615
320	.85(.54626)	+ .15(.96158)	=0.60856
340	.85(.5052)	+ .15(.93595)	=0.56981
360	.85(.466)	+ .15(.90558)	=0.53194
380	.85(42739)	+ .15(.87149)	=0.49401
400	.85(.38815)	+ .15(.83152)	=0.45466
420	.85(.34939)	+ .15(.78884)	=0.41531
440	.85(.31089)	+ .15(.74344)	=0.37577

460	.85(.27852)	+ .15(70402)	= 0.34235
480	.85(.24814)	+ .15(.66485)	= 0.31065
500	.85(.22049)	+ .15(.62642)	= 0.28138
520	.85(.19485)	+ .15(.58704)	= 0.25368
540	.85(.17131)	+ .15(.54626)	= 0.23367
560	.85(.14954)	+ .15(.5052)	= 0.20289
580	.85(.13119)	+ .15(.466)	= 0.18141
600	.85(.11414)	+ .15(.42739)	= 0.16113
620	.85(.09871)	+ .15(.38815)	= 0.14213
640	.85(.08456)	+ .15(.34949)	= 0.12428
660	.85(.07111)	+ .15(.31089)	= 0.10708
680	.85(.06087)	+ .15(.27852)	= 0.09352
700	.85(.05145)	+ .15(.24814)	= 0.08095
720	.85(.04331)	+ .15(.22049)	= 0.06989
740	.85(.03618)	+ .15(.19485)	= 0.05998
760	.85(.03001)	+ .15(.17131)	= 0.05121
780	.85(.02473)	+ .15(.14954)	= 0.04345
800	.85(.02053)	+ .15(.13119)	= 0.03713
820	.85(.01687)	+ .15(.11414)	= 0.03146
840	.85(.01381)	+ .15(.09871)	= 0.02655
860	.85(.01121)	+ .15(.08456)	= 0.02221
880	.85(.00878)	+ .15(.07111)	= 0.01813
900	.85(.00724)	+ .15(.06087)	= 0.01528
920	.85(.00582)	+ .15(.05145)	= 0.01266
940	.85(.00482)	+ .15(.04331)	= 0.01042
960	.85(.00365)	+ .15(.03618)	= 0.00853
980	.85(.00285)	+ .15(.03001)	= 0.00692
1000	.85(.00221)	+ .15(.02473)	= 0.00559

1020	.85(.00171)	+	.15(.02053)	= 0.00453
1040	.85(.00132)	+	.15(.01687)	= 0.00365
1060	.85(.00101)	+	.15(.01381)	= 0.00293
1080	.85(.00076)	+	.15(.01121)	= 0.00232
1100	.85(.00054)	+	.15(.00878)	= 0.00178
1120	.85(.00043)	+	.15(.00724)	= 0.00145
1140	.85(.00032)	+	.15(.00582)	= 0.00112
1160	.85(.00024)	+	.15(.00462)	= 0.00088
1180	.85(.00018)	+	.15(.00365)	= 0.0007
1200	.85(.00013)	+	.15(.00285)	= 0.00054
1220	.85(.00009)	+	.15(.00221)	= 0.00041
1240	.85(.00006)	+	.15(.00171)	= 0.00031
1260	.85(.00004)	+	.15(.00132)	= 0.00023
1280	.85(.00003)	+	.15(.00101)	= 0.00018
1300	.85(.00002)	+	.15(.00076)	= 0.00013
1320	.85(.00001)	+	.15(.00054)	= 0.00009
1340	.85(.00001)	+	.15(.00043)	= 0.00007
1360	.85(.00001)	+	.15(.00032)	= 0.00006
1380	.85(0.0)	+	.15(.00024)	= 0.00004
1400	.85(0.0)	+	.15(.00018)	= 0.00003
1420	.85(0.0)	+	.15(.00013)	= 0.00002
1440	.85(0.0)	+	.15(.00009)	= 0.00001
1460	.85(0.0)	+	.15(.00006)	= 0.00001
1480	.85(0.0)	+	.15(.00004)	= 0.00001
1500	.85(0.0)	+	.15(.00003)	= 0.0

1520	.85(0.0)	+.15(.00002)	= 0.0
1540	.85(0.0)	+.15(.00001	= 0.0
1560	.85(0.0)	+.15(.00001)	= 0.0
1580	.85(0.0)	+.15(.00001)	= 0.0
1600	.85(0.0)	+.15(0.0)	= 0.0
1620	.85(0.0)	+.15(0.0)	= 0.0
1640	.85(0.0)	+.15(0.0)	= 0.0
1660	.85(0.0)	+.15(0.0)	= 0.0
1680	.85(0.0)	+.15(0.0)	= 0.0
1700	.85(0.0)	+.15(0.0)	= 0.0
1720	.85(0.0)	+.15(0.0)	= 0.0
1740	.85(0.0)	+.15(0.0)	= 0.0
1760	.85(0.0)	+.15(0.0)	= 0.0
1780	.85(0.0)	+.15(0.0)	= 0.0
1800	.85(0.0)	+.15(0.0)	= 0.0
1820	.85(0.0)	+.15(0.0)	= 0.0
1840	.85(0.0)	+.15(0.0)	= 0.0
1860	.85(0.0)	+.15(0.0)	= 0.0
1880	.85(0.0)	+.15(0.0)	= 0.0
1900	.85(0.0)	+.15(0.0)	= 0.0
1920	.85(0.0)	+.15(0.0)	= 0.0
1940	.85(0.0)	+.15(0.0)	= 0.0
1960	.85(0.0)	+.15(0.0)	= 0.0
1980	.85(0.0)	+.15(0.0)	= 0.0