OPTIMUM HYDRO-THERMAL GENERATION SCHEDULE

A DISSERTATION

Submitted in partial fulfilment of the requirements
for the award of the degree
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MASTER OF ENGINEERING
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By

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CERTIFICATE

Certified that the dissertation entitled "OPTIMUM HYDRO-THERMAL GENERATION SCHEDULE" which is being submitted by Mr. UMESH NARAIN KHANNA in partial fulfilment of the requirements for the award of the Degree of MASTER OF ENGINEERING in ELECTRICAL ENGINEERING (SYSTEMS ENGINEERING & OPERATION RESEARCH) of the UNIVERSITY OF ROORKEE, ROORKEE (U.P.) is the record of student's own work carried out by him under my supervision and guidance. The matter embodied in this Dissertation has not been submitted for the award of any other degree or diploma.

It is further certified that he has worked for a period of six months from January 1982 to July 1982 for preparing this dissertation at this University.

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

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A B S T R A C T

The hydrothermal generation scheduling problem either of long range, medium range or short range nature is basically a nonlinear programming problem with a non-linear objective function and a mixture of linear and non-linear constraints. The present work presents a nonlinear programming technique called flexible tolerance algorithim which is a direct optimization method. It is used for solving hydrothermal generation scheduling problem of both deterministic and stochastic nature. The flexible tolerance algorithim (18) improves the value of the objective function by using information provided by feasible points, as well as certain and non-feasible points termed near feasible points. The near feasibility limits are gradually made more restrictive as the search proceeds towards the solution of the problem until in the limit only optimal and feasible vectors are found.

A deterministic system model is first presented which takes into account spilling, bounds on all the physical variables and a nonlinear function relating head to reservoir storage. The model expressed is more realistic than the existing ones. The model is further improved to take into account stochastic demand using chance constraint

programming and a case study has been worked out. The algorithim and the computor code, is found to be capable to treat efficiently more complex problems, on the basis of deduced results.

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- AN INTRODUCTION

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AN INTRODUCTION

In recent years there has been a substantial increase both in the size and complexity of power system. This period has also been characterised for an increase in primary costs of energy and differential rise in the cost of different fuel types. Further, the consistently increasing demand made it necessary to plan the expansion of existing generating units or to install new sources of generation. Many of the newer sources are quite differ nt (such as pumped hydro and nuclear power plants) from the conventional Thermal or Reservoir type Hydro Plants.

The increasing utilization of interchange energy has effectively provided another new type of source. The programme of interchanging power with these alternative sources is thus becoming more difficult, not only because of the larger number of plants, but also because of the more complex characteristics of the new plants.

These factors, when taken together, create the need for a more systematic approach to the determination of generation schedule for the units (plants) to be committed to service.

The present day power systems, which normally consist of a large number of steam and hydro generating plants connected to various load centres by a complex interconnected transmission network.

The negligible marginal cost of hydroelectric generation makes the hydrothermal power system optimisation a problem of how to use, in a given period of time, the water availability for hydroelectric generation to reduce thermal production in order to keep thermal generation cost at a minimum. The basic question for the decision maker is to find a trade off between a relative gain associated with immediate hydroelectric generation and the expectation of future benefits coming from storage, as measured in terms of the thermal generation cost.

The water available for generation, in a hydroelectric system is governed by the capacity of the reservoir and the prespecified with-drawal from the reservoirs for meeting the agricultural, navigational and other interstate requirements. The solution to the problem of hydrothermal generation scheduling in a given interval of time consists of determination of a plan for withdrawal of water from the reservoirs for power generation and the determination of the corresponding thermal power generation, so as to minimise the total thermal fuel cost over the specified period while meeting the total power demand on the system and satisfying the constraints on storage discharge and generating capacities of various units.

The cyclic nature of water flow and load demand as well as the validity of the model assumption, suggests splitting the problem into long range, medium range, and short range problems. For the long range problems, the period can be one year (water flow cycle) or more than that. It is only possible to estimate river flow and the system load by making use of probability theories, making the problem more difficult. Moreover, it is essential to take, water head variation affecting the hydro generation efficiency, into consideration.

In amedium range problem the period over which the study is done extends from one month to a year. The otpmization is done for each week or month over the entire period as the case may be. Fairly good power demand and water inflow estimations can be made for each interval of study over the entire period using the data from past experience. However, incorporation of probalistic features will make the problem more realistic.

For short period mhp optimization, normally complete knowledge of reservoir inflows and system load are generally assumed for the period of one day or one week. These, however, would not appear to be a reasonable assumptions, especially in the case of load demand which presents significant random variations even in short time periods. Another assumption made in short term scheduling problem is constant water head which is correct only in the absence of reservoirs with high relationship between inflow and capacity.

Most of the hydrostations are situated far away from the load centre. This is due to several reasons, the most important being the availability of water. Thus mostly hydrostations are not load oriented. This causes considerable transmission loss, which, if not accounted for, effects the optimum scheduling of generation. Thus, it is in of immense importance to consider the transmission losses while scheduling the generation.

A thermal plant, forming a component of thermal subsystem, usually consists of large number of units. The start up and shut down costs, the forced outage and maintenance costs of these thermal units vary and hence the sharing of power between the units for optimum generating schedule (from the economy point of view) depends upon the units brought on line in the order of merit for sharing the load. The decision to bring into operation which unit at what time is known as unit committment problem and is again a problem to be considered in the scheduling process. However, it is tactically assumed that a suitable unit committment schedule is being followed at the thermal plants and the generation scheduling problem is given all priorities and concentration.

Further, if the hydro subsystem consists of cascaded type plants then the discharge of water from one plant affects the generation (head) of other plants down stream. Hence generation scheduling of power in such a system becomes more complex than the system withindependent reservoirs. Moreover if such cascaded plants are located plants are located at an appreciable distance then the time lag in the water discharge from upstream and the inflow to the down stream has also to be taken into consideration.

In formulating the generation scheduling problem, the principle of 'Trivial too many and vital few' is kept in mind. To start with, a simple but healthy formulation is done incorporating nonlinear cost and generation function and also the influence of transmission loss. The presented formulation is better than the existing ones because of (a) the incorporation of the various desirable features viz. nonlinear cost and generation function, transmission losses and stochastic demand, (b) the formulation is very easy to follow also. The solution technique used is a direct method. As compared to the existing algorithims, this algorithim is faster in convergence and can efficiently handle the large size systems also with the same computational efficiency. The algorithim further guarantees a global or near global solution.

Problem attempted successfully in this study comes under the head of mid range problems. Both stochastic and deterministic cases are dealt with. The study starts with the survey of the problem shapes and solution techniques already existing. These are detailed in the next chapter (Chapter 2). In chapter 3 various features of the hydro and the thermal generation units and their separate and combined operation are explored starting from the elementary level, analysing each component of the problem and finally characterising the main problem. Chapter 4 focuses upon the solution technique used and the developed algorithm, step by step. Chapter 5 concentrates upon the problem formulation for both cases, deterministic and stochastic and contains the data for these problems. Chapter 6 includes the results and a discussion taking each solution one by one. Seven and the final chapter is devoted to conclusion derived from the results. In the end an appendix is given containing Computer Programme for subroutine prob. used to insert the problem in the main programme, in both deterministic and stochastic case. A general subroutine prob. for inserting a N hydro and N thermal system problem is given alongwith the main programme.

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CHAPTER - 2

HYDROTHERMAL GENERATION SCHEDULING - A SURVEY

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PROBLEM SHAPES AND SOLUTION TECHNIQUES

The problem of hydrothermal generation scheduling and the idea of their economic operation started from the time two or more units were committed to take on the load of a power system whose total capacities exceeded the generation required.

The classical tool for handling the generation scheduling problem is the equal incremental dispatch and loss treatment by means of loss formula and their implementation for on line control. Interestingly enough, it is still found to be one of the most effective techniques in use.

In the early 60s, carpentier of electric de France, putforth the pioneering work in the mathematical formulation of economic generation scheduling. He treated the scheduling problem as P & Q scheduling. Chief motivation behind his work was the hope that by his method additional saving would be realised which would be beyond that obtained through the classical method. The solution of carpentier's formulation is a nonlinear optimisation which has been the subject of much study till date.

The reliability of a power system is an additional and important feature that has come to the fore in the last decade. It has a profound influence on the net loaded etc.; (2) best point loading, where units are successively loaded to their lowest heat rate point beginning with the most efficient unit, and working down to the least efficient unit. Only in the early 30s it was recognized that the incremental method or equal incremental method yielded the most economic results. By 1931 the idea had crystalised sufficiently and it was understood that as a fundamental principle the incremental costs of all units should be equal, for economic operation, a fact which is appreciated even to day. However, the only variables considered in this approach were the unit powers and the influence of the transmission network was ignored. The demerits of this equal incremental method were the computational complexities, computation time and the complexities due to random variation of loads.

These were reduced by the development of the station loading slide rule developed for the consolidated Edison system Corporation U.K. in 1938. In 1939 the effect of loss was recognised and a form for considering them in terms of incremental efficiency terms was introduced by Stinberg and Smith. This was quite similar to the penalty form (dF/dP.PF=1), used to this day but applied to a single transmission line. The manual calculating process was slow and cumbersome. By economic scheduling problem as a whole. As a practice, the security of a system is assessed by determining the impact of a line on a generation outage. Linear influence coefficient are used for this purpose. The incorporation of security constraints as apart of economic dispatch, whose solution would thus yield results which satisfy security constraints, is still a developmental area.

Optimal generation scheduling is a computational process wherein the total generation required is allocated amongst the generating units available, so that the constraints imposed are satisfied and the energy requirements in terms of MJ/HR or Currency/Hr are minimised. Optimal dispatch assumes that units that are to take on load are committed and that no load running costs are incurred irrespective of whether or not they are assigned to take on extra generation.

Economic scheduling dates back to early 20's or even earlier when the power engineers concerned themselves with properly dividing the system load among the generating units, in order to achieve generation economy. Prior to 1930, the most used methods were (1) the base load method; where the most efficient unit is loaded to its maximum capability, then the second most efficient unit is loaded etc.; (2) best point loading, where units are successively loaded to their lowest heat rate point beginning with the most efficient unit, and working down to the least efficient unit. Only in the early 30s it was recognised that the incremental method or equal incremental method yielded the most economic results. By 1931 the idea had crystalised sufficiently and it was under stood that as a fundamental principle the incremental costs of all units should be equal, for economic operation, a fact which is appreciated even to day. However, the only variables considered in this approach were the unit powers and the influence of the transmission network was ignored. The demerits of this equal incremental method were the computational complexities, computation time and the complexities due to random variation of loads.

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By 1940 the loss formula was primarily used in construction of average loss charts. A method of properly combining the incremental fuel cost with that of transmission losses was obviously needed. The challenge of refining and giving practicability to the loss formula was taken up by Kirchmayer. His efforts resulted in much improved loss formula calculating procedures (1).

Later, in computer codes, Kirchmayer further successfully drived the classic coordination equation

$$\frac{dF_n}{dP_n} + \lambda \frac{\partial P_L}{\partial P_n} = \lambda \qquad n=1,2,\ldots \qquad (2.1)$$

These theoretical developments lead to the development of analog computer solution procedures for properly executing the coordination equations in a dispatching environment. A transmission loss penalty factor computer was deviced by 1954(5) and was used in conjunction with an incremental loading slide rule for producing daily generation schedules in a load dispatching office. Later on, in 1955, an electronic differential analyser was developed for use in economic scheduling for off line or on line use. The use of digital computers for obtaining loading schedules, a taste of the future things to come, was also investigated in 1954 and is in use to this day.

In 1952, Kron deviced a method for finding the total incremental losses of interconnected systems using the B matrices of individual companies (3, 2). Kirchmayer extended the derivation of the coordination equation to the multi area case(7). The major difference between the single area and the multi area case is that in the multi area case, each area's optimum interchange, or excess (except one) has to be determined. The total fuel input is thus

$$F_t = \sum_A F_A(P_A) + \sum_B F_B(P_B) + \dots \qquad (2.2)$$

$F_i(P_i)$ denotes the total fuel cost in area i. The single area constraint

$$\phi(P_i) = P_R + P_L - P_1 - P_2 = 0 \qquad .. \quad (2.3)$$

where P_1, P_2 = loading of machines 1 and 2 respectively, has become

$$\phi_i(P_i) = P_{Ri} + P_{Li} + P_{oi} - P_{Gi} = 0 \qquad .. \quad (2.4)$$

For area i, where P_{oi} denotes the area interchange or excess represented by the summation of area A's ties

$$P_{oi} = \sum_i P_{TIES} \qquad .. \quad (2.5)$$

Using the Lagrange technique, the constraints were augmented in the objective functions. Happ and his associates analysed the networks to devise a more exact network representation programme (10-13) and a unique tie model called the inter area matrix (in 1975. This model was usedmainly for multi area scheduling.

S.Narita*(16) presented a model for hydro-thermal generation scheduling. The nonlinear features of the power generation and generation cost are incorporated in themodel. B_{mn} matrix ~~is/frm~~ accounted for transmission losses. The problem is dealt as a variation problem. Water storage, which fluctuate in time wit the reservoir water in flow and the water discharge, are considered as a state variables of the system. The total thermal generation cost over the specified period is minimised after setting the control variable 'water discharge' at its maximum. Sample examples are solved using the Pontryagin 's maximising principle of optimal control. R.P.Agarwal et al.(25) formulated the problem which was quite similar to the Narita's model. However, they solved the problem for abigger size of hydro-thermal system. Discrete time formulation of the problem ~~xxxxx~~ was employed. Method of local variations was used for the solution.

Rees and Larson(22) developed an algorithm and computer code, using the dynamic programming successive approximation algorithm, for the optimisation of power generation schedules for utilities participating in a coordination agreement. The power sources considered were : (1) Hydro (2) Thermal (3) Pump storage units (4) Diversity interchange contracts with out side utilities. The proposed computer code were suggested for three optimisation.

1. Monthly optimisation over one year.
2. Daily optimisation over one month.
3. Hourly optimisation,over 48 hours.

S.K.Agarwal(23) presented an algorithm based on first order gradient technique in conjuction with a non-linear programming technique for a long range hydrothermal generation scheduling problem. The system variables were in discrete form. The stochastic nature, described on the previous data, of the water inflows and demand, was taken into consideration. Thus, it described a formulation quite close to the real world problem. Using the algorithm a 2 hydro and 2 thermal problem was dealt with.

An entirely new technique (27) for the solution of hydrothermal generation scheduling problem was developed. It is a direct method which treated the constraints as limiting surfaces or subspaces and thus automatically restricted the solution within the limiting subspaces.

Bounds on storage, discharge and generating capacities were considered. The objective function was constructed to minimise the thermal generation cost. The model included the influence of transmission losses with deterministic features of demand and inflows.

The stochastic feature of power demand, reservoir inflows and the outages of generating units have attracted increasingly more attention of researchers , as the time advanced and demand increased. In response to this another model (24) incorporating stochastic features was developed minimising the system energy production costs over a given period. For solution explicit stochastic dynamic programming technique was used to deal with the n stage stochastic return function, the random inflows to the reservoirs and the bounded nature of the system constraints. Although aggregation of the reservoir and the hydro plant subsystem through though reduced the dimensionality of the problem, it made the model less realistic. Important features like scheduled down time for various unitb maintenance activities, the predicted partial and total forced outages and the stochastic river inflows to the reservoirs made the model healthy.

However, this increased the computational complexity for a large system and long range problem. Quintana in another model (30) presented a formulation for economic dispatch of amulti area system, with constraints on line flows and spinning reserves. Theproblem was formulated as a linear optimisation problem. The solution technique applied was the Dantzig Wolfe Decomposition Principle.

Pioneering work was done by S.Vemuri, Ĉuk (31) et al. in the area of sensitivity analysis of optimum operation of hydrothermal system. Short term hydrothermal optimisation has been solved. The sensitivity analysis for correcting the optimum schedule for small order changes in the system input and forecast parameters had been done. The sensitivity of the cost function to small order variations was investigated.

The commonly used solution techniques for the optimal load scheduling problem have been first variational method, second dynamic programming, third Pontryagin's maximum principle and general mathematical programming techniques. The basic difficulty that remains is to harmonise accurate modelling with the ability of solving large scale real systems. The practiced manupulation, to aggregate the hydro-electric system in composite reservoirs(20,21) or thermal system in concentrated thermal units (16), though reduces problem dimension and thus makes the existing technique usable, but is an undesirable simplifications.

The method of local variations needs a discrete time description of the system. It (25) consists of determining an optimal trajectory by successively correcting an initial trial trajectory, achieving in the process an improvement in the objective function in each correction of the trajectory such that the cost index is decreases from iteration to iteration till a satisfactory convergence to an optimal trajectory is obtained.

The major difficulty in adopting the calculus of variation approach for a hydrothermal system is that all the system variables must be made time dependent. For a typical hydrothermal electric system this leads to a complicated expression subjected to, many nonlinear constraints. Further, the solution cannot be strictly global optimal.

The dynamic programming is a widely used tool for the solution of hydrothermal generation scheduling. It has also been used for long range problems (8,24). The problem is dealt as a multistage decision process.

Dynamic programming approach restricts the size of the problem to be solved as it has the curse of dimensionality, thus requiring considerably more CPU time and memory space. This undesirable feature makes it formidable to use dynamic programming or variations of dynamic programming.

Pontryagin's maximum principle is an approach practised by many researchers (15,16). This method however, is computationally simple for a small size system but is applied to a loss less system consisting of an equivalent thermal plant with several reservoirs. Unfortunately in this case the convergence is not fast due to specified final storage being taken as the regorous or hard constraint for obtaining the solution.

Nonlinear programming techniques have started attracting more attention since last few years. In a model (23) then nonlinear programming technique of conjugate gradient method has been used for hydrothermal generation scheduling. Here Lagrangian multipliers take care of the equality constraints and Powell's penalty function is used for the inequality constraints. This increases the complexity of the problem and the computations to be carried out. However, it proves to be a better technique than other because of the saving in the C.P.U time, while handling a very accurate model. The solution gives nearly globaly optimal results. The same technique has been utilised for the large scale nonlinear optimisation of the energy capability for hydroelectric system.

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CHAPTER - 3

CHARACTERISTIC OF GENERATING PLANTS, AND OPTIMAL OPERATION CONCEPT

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STEAM PLANTS

From the point of view of economic operation of the steam plants it becomes necessary to properly characterised them. For this characterisation many terms are need to be introduced. For the purpose, simplified performance curves of typical turbine generator boiler unit are shown in Figs. 3.1, 3.2, and 3.3. In Fig.3.1 the fuel input in BTU/hour is the dependent variable while the power output is the independent variable. Corresponding heat rate in BTU/KW-hr defined as the ratio of input to the output is shown in Fig.3.2. The incremental fuel rate is equal to the ratio of small change in input to the corresponding output (= input/ output). As the differential quantities become smaller and smaller (incremental fuel rate = d(input)/d(output)), the units associated with the incremental fuel rate are(BTU/KW-hr) same as that of heat rate. The incremental fuel cost is equal to the product of the incremental fuel rate in BTU/KW-hr and the fuel cost in currency/10^6 BTU, expressed in RUPEES/MW-hr.

The incremental production cost of a given thermal system constitute of two parts (1) incremental fuel cost (2) incremental cost of such items as labour, supplies, maintenance and water etc. For a real world analysis it is essential to incorporate this 2nd part of incremental cost as well, however no hard and fast rule or method exists

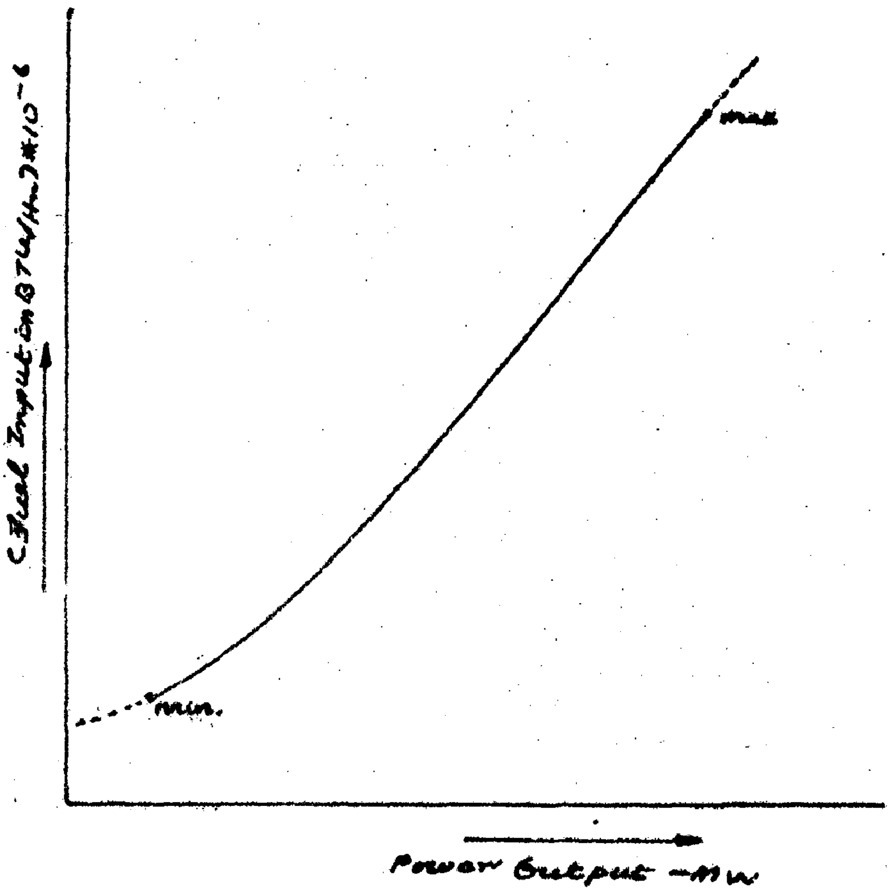


Fig 3.1 Power Output

(6)

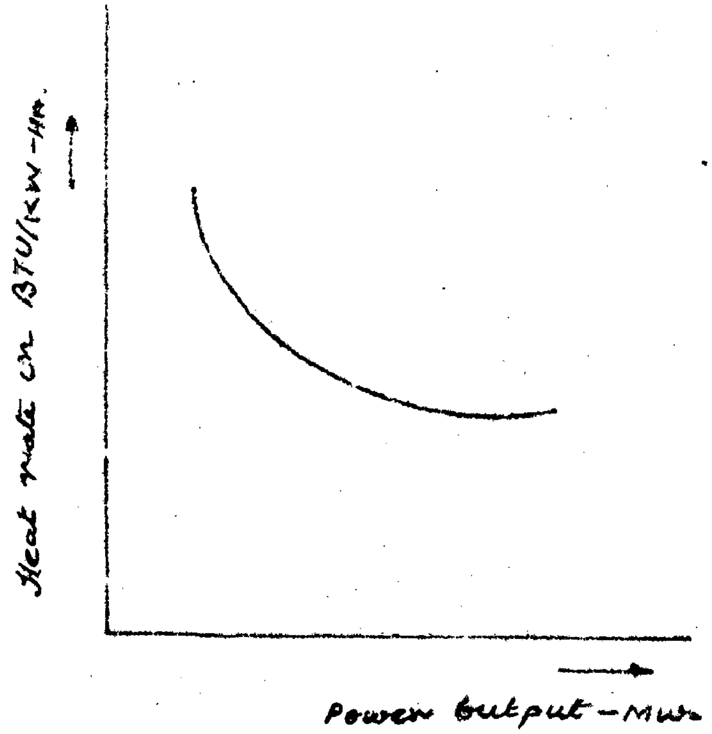


Fig 3·2 Heat Rate Characteristics (6)

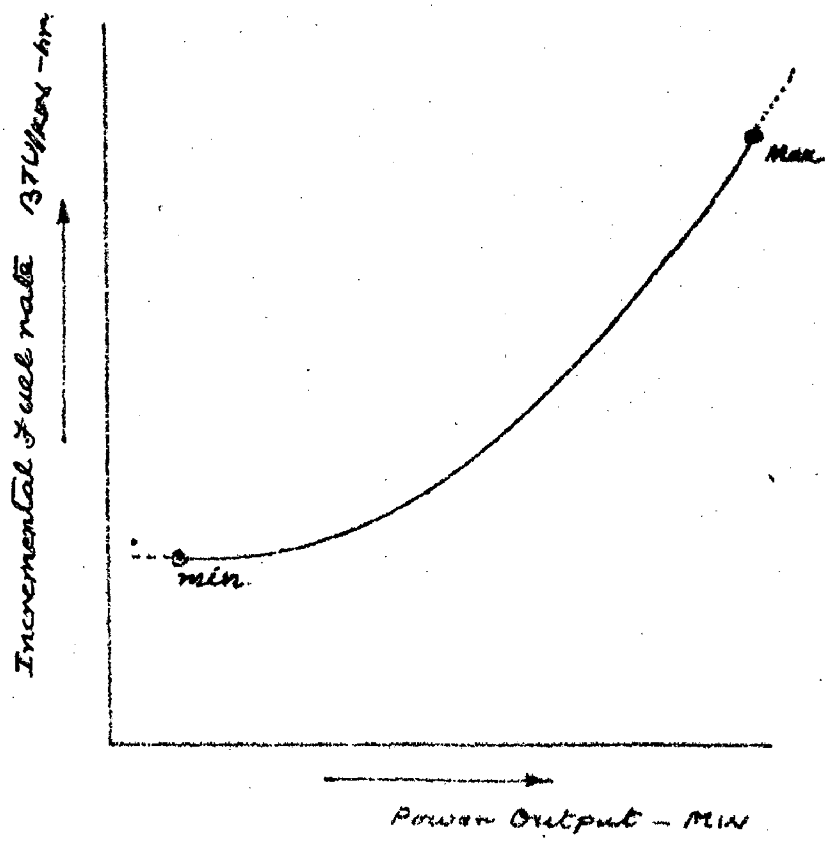


Fig. 3·3 Incremental Fuel rate Curve (6) there for taking them into account. Arbitary methods available suggest to take into account these incremental cost as a certain percentage of the fuel cost.

Optimum Scheduling of Generation :

(a) Neglecting transmission losses.

IN_n = input to n^{th} unit in Rs./hr.

IN_t = total input to the system in Rs./hr.

Then,

$$IN_t = \sum_n IN_n$$

It is desired to schedule the generation such that

$$IN_t = \text{minimum} \qquad .. \qquad (5.1)$$

Subject to

$$\sum_n PT_n = P_D = \text{received load} \qquad .. \qquad (5.2)$$

where, PT_n = output of the n^{th} unit

P_D = received load

5.1 is achieved satisfying 5.2 when

$$\frac{dIN_n}{dPT_n} = \lambda \qquad .. \qquad (5.3)$$

where, dIN_n/dPT_n = incremental production cost of unit n in Rs./mw-hr.

λ = incremental cost of received power in Rs./mw-hr

The value of λ must be chosen such that

$$\sum_{n} PG_n = P_D \qquad .. \qquad (3.3)$$

In words the minimum operation cost for a given demand is achieved when all generating units are operated at the same incremental production cost. Equation 3.3 shows that the total generation is directly proportional to .

(b) Including transmission losses.

In the case of large integrated power systems operations, it is of immense importance to find optimum generation schedule taking into consideration the effects of both incremental production cost and incremental transmission losses. Thus, to combine incremental production cost and transmission losses it becomes necessary to express the incremental transmission losses as charges at a rate equal to the incremental cost of power received.

The minimum input in Rs/hr for a prescribed received load is obtained by solving the following simultaneous equations :

$$\frac{dIH_n}{dPG_n} + \quad \frac{\partial P_L}{\partial PG_n} = \qquad .. \qquad (3.4)$$

or, $$\frac{dIF_n}{dPT_n} + \frac{\partial P_L}{\partial PT_n} = 1 \qquad .. \qquad (3.5)$$

P_L = total transmission losses

$dP_L/\partial PT_n$ = incremental transmission loss at n^{th} plant in Mw/Mw.

λ = incremental cost of power received in Rs/mw-hr

In general the incremental transmission loss can be expressed as

$$\frac{dP_L}{\partial PT_n} = \sum_n 2B_{mn} PT_n \qquad .. \qquad (3.6)$$

B_{mn} = transmission loss formula constant matrix.

The incremental production cost of a given plant over a limited range is

$$\frac{dIF_n}{dPT_n} = IF_{nn} PT_n + f_n \qquad .. \qquad (3.7)$$

IF_{nn} = slope of incremental production cost curve

f_n = intercept of incremental production cost curve

Then the general simultaneous e.g. becomes

$$F_{nn}PT_n + f_n + \lambda \sum 2B_{mn} PT_m = \lambda \qquad .. \qquad (3.8)$$

Solution for different total loads are obtained by varying the magnitude of λ .

In the improved formulation the bounds on the generating capacities are also included. The optimal scheduling of power in this case is only a static optimization problem. The optimal operation depends only on the conditions that exist from instant to instant, the objective being minimization of instantaneous fuel cost which is a function of type, size andloading of the thermal units subjected to the equality constraints of the power systems demand as well as the/inequality constraints of the power system equipment ratings. In such a case the instantaneous economy in scheduling of power generation guarantees long range economy. The optimal scheduling can be very easily obtained by the solution of the classic coordination equation, with the set of equality and inequality constraints being taken care off simultaneously.

The cost function which is optimised for economical generation scheduling of the thermal units is of the form

$$F(P_i) = a_1 P_i + a_2 P_i^2 + a_3 P_i^3 + \ldots a_n P_n^n \quad .. \quad (3.9)$$

which is afunction of order n. The value of the weighting function falls as the order rises. If taken in it's purest form the solution process of the model generated becomes very complex to solve, even with a very efficient method. It is an appreciable good and acceptable practice yielding most satisfactory results to consider a quadratic cost function of the form

$$F(P_i) = a_1 P_i + a_2 P_i^2 \quad .. \quad (3.10)$$

In case the formulation is confined to linear programming the cost function which is to be taken should be linear in nature. This can be achieved only after few weak assumptions, vis. the differential cost which has a parabolic sort of nature is accounted by the second order and higher order terms, is taken as a constant. So lineari-sing means taking this cost characteristic to be of constant nature. The Cost function in this case becomes

$$F(P_i) = a_i P_i + K \qquad K \text{ is the constant} \quad .. \qquad (3.11)$$

Such formulation though simplifies the solution process but no guarantee for getting an optimal solution can be given.

Transmission Loss, Its Influences and Formula :

In the initial stages the generation scheduling application were restricted to small interconnected systems. The solutions for such systems, derived using the coordination equation without including transmission losses concept were quite satisfactory. As the system size increased with the simultaneous rise in the interconnected network size, it became impossible to get a optimal solution without considering transmission losses in the interchange of power. Thus, when the transmission losses are a factor, a system is operated at a minimum cost when incremental cost of delivered energy is the same from all plants.

A transmission loss formula expressing the total transmission losses in terms of the power delivered by the thermal plants was first presented by E.E. George in 1943. The suggested formula was of the following form -

P_L = sum of transmission losses

$$= B_{11}P_1^2 + B_{22}P_2^2 + \ldots \quad B_{nn}P_n^2 + 2B_{12}P_1P_2 + 2B_{13}P_1P_3$$

$$+ 2B_{23}P_2P_3 + \ldots\ldots 2B_{mn}P_mP_n \qquad \ldots \qquad (3.12)$$

$$= \sum_m \sum_n P_m B_{mn} P_n$$

P_n, P_m = source loadings

B_{mn} = transmission loss formula coefficients.

The determination of the B_{mn} coefficients was based on the tedious and time consuming procedure. After the advent of the network analyser, and its application to determine a similar loss formula as suggested by Ward and Associates in 1950, the process of computing B_{mn} coefficient became easy. Later on as the size of the system increased the arithmatic calculations became prohibitably large. Till the introduction of digital computer many researchers presented a method better than the other. The shape of the loss formula remained the same, however, computational tactics kept on improving.

In matrix form -

$$P_L = P^T B P \quad .. \quad (3.13)$$

P is a n x 1 matrix

B is a n x n matrix

The revenue to be gained by properly billing for losses involved during interconnection transaction may be a very large sum. Transmission loss considerations have often proved to be important in the planning of future systems in p rticular regard to location of plants and planning the construction of transmission lines.

The basic assumptions underlying the formulation of the loss formula are :

1) Each load current remains a constant complex ratio of the total load current irrespective of the load level.

2) The VAR or WATT ratio of all generators and of the ties remain constant.

3) The deviation of generator voltages and angles from those incorporated in the loss formula are small.

Digital computer were increasingly used (for the purpose of determination of loss formula coefficient. A very popular method of calculating loss coefficients was developed based on Kron's work reported in a series of papers (   ) titled 'Tensorial analysis of integrated transmission system', the first two parts considered losses in asingle area and the latter two parts considered losses in inter-connected areas.

As dictated by the afore mentioned assumption the loss formula is found to be of the form -

$$P_L = \sum_m \sum_n P_m B_{mn} P_n \qquad .. \qquad (3.14)$$

If such loads (Aluminium or Paper Mills) come on the system which do not vary over the daily load cycle in the same manner as the rest of the system loads then these non-conforming loads may be properly included in the loss formula. The loads at each bus may be devided into a constant component and a component that maintains a constant ratio to the total load. The constant component of load are treated asnegative generation in the loss formula. The loss formula then takes the form :

$$P_L = P_m B_{mn} P_n + B_{no} P_n + B_{oo} \qquad .. \qquad (3.15)$$

where, $B_{no} = 2P_j B_{nj}$

$B_{00} = P_j \cdot P_{jk} \cdot P_k$

P_j, P_k = constant mw components of loads

D_{nj} = mutual loss formula coefficients between constant components of loads and generators.

B_{jk} = self and mutual loss formula coefficient for constant component of loads.

The B coefficient loss formula provides a fast means for calculating incremental losses without the need for direct network solutions. Thus, transmission losses can be coordinated into cosnomic scheduling problem without large overheads in computer time storage.

HYDRO PLANTS

Falling water powered the machines and mankind long before coal, oil, gas or uranium ever did. From the begining grist mills and saw mills clustered around the falls on rivers and streams. By the end of 18th century electricity generating stations had joined the mills. In the western countries by early 19th century huge hydroelectric projects were instituted to harnessthe tremendous potential of the large rivers. But by the end of 40s large central steam plants fired by coal, oil and gas began to turn out cheaper power.

Although large hydro projects were still economical, suitable places to build new projects of large size were becoming increasingly scarce. Meanwhile, smaller hydroplants became less economical to run.

To-day the price of power from coal, oil, gas and uranium is climbing steadily, reflecting sharp increase in the cost of fuel, capital equipment, operation, maintenance ane environmental protection. Other alternative power sources, such as solar and wind, are promising but need much more research and development before they can be economical. So, in need of near term, reasonably priced energy solutions is again turning to hydro.

Hydro has much to recommend it in terms of capital, operating and maintenance costs, fuel, technology and environmental considerations. The falling water that powers hydroelectric plants is essentially free, resistant to inflation and available to some extent at many places. New engineering developments, buttressed by further research, are advancing hydro from a mature technology to tough competitive status required to-day.

Despite topographic and hydrologic variations from one hydro site to an other, the basic of all hydro plants are the same. Water is collected in a pond on reservoir behind a dam, then conveyed through tunnels or penstocks to turbines. The falling water spins the turbine, which in turn drive the power house generators. The result is electricity. The energy potential at each installation depends on two main factors the head (difference in elevation between reservoir andtail water) and the quantity of water released through the turbine.

Pumped hydro, is an energy storage technique rather than a primary energy resource, as in conventional hydro. Less costly off peak electricity, powers a pump turbine to move water from a lower to an upper reservoir, separated by 300 to 1200 ft. When electricity demand peaks, the water in the upper reservoir is let down thro gh the turbines to the lower reservoir, thereby generating electricity at lower overall cost than many other peaking options.

The general expression for the power generated by a hydro unit is given by

$$PH = wQH/75 \qquad .. \qquad (5.16)$$

w = density kg/m^3

Q = discharge in m^3/sec

H = head in meters

PH = hydro energy generated in H.P.

The density w remains almost constant and the same for each station is 1000 kg/m^3, so

$$PH = 1000\ QH/75\ \text{H.P.} \quad .. \quad (3.17)$$

Again the discharge Q is a controlling factor. The head is a function of discharge and the inflows and can be expressed as a function of these in the following form -

$$H_i = f(Q,X) = H_{io}(1 + C_i\ X_i) \quad .. \quad (3.18)$$

Here, H_{io} is the basehead. C_i is the correction factor used for taking into account the storage variations due to rainfall and evopration. The rainfall is accounted by a negative discharge whose value is equal to the expected value of rainfall during any period. This value is computed from the available past history. Similarly the evopration losses in the reservoirs are assumed to be functions of the temperature and the water surface area. The expected value of the temperature for each interval is obtained and factors are found for each interval which when multiplied by storage take into account these effects so the power equation becomes -

$$PH_i = 1000QH_{io}(1+C_iX_i)/75 \quad \text{H.P.} \quad .. \quad (3.19)$$

If the PH_i generated in a period is to be found then the mean storage has to be taken into the account thus,

$$X_i = \tfrac{1}{2}(X_i(N) + X_i(N-1)) \quad .. \quad (3.20)$$

The state equation describing the hydro system dynamics is

$$X_i(k+1) = X_i(k) + J_i(k) - U_i(k) \quad .. \quad (3.21)$$

K is to denote the period.

In generalised form this equation can be expressed as for N^{th} period as below -

$$X_i(N) = X_{io} + \sum_{k=1}^{N-1} J_i(k) - U_i(k) \quad .. \quad (3.22)$$

Thus the power generated in H.P. is

$$PH_i = 1000\, Q\phi H_{io}\, (1 + C_i/2(2X_{io} + \sum_{k=1}^{N-2} J_i(k) - U_i(k))$$

$$+ J_i(k-1) - U_i(k-1))/75 = PH.HP \quad .. \quad (3.23)$$

and in mw units is

$$PH_i = PH.HP \times 746 \times 1000/1000/1000 \quad .. \quad (3.24)$$

$$= 75/100,000 \times PH.HP \quad .. \quad (3.25)$$

In case of hydro system consisting of number of plants of diverse nature and with reservoirs of different sizes and hydrologic characteristics, the economic scheduling of power becomes a relatively complex problem. Since the incremental cost of hydro generation is negligible, the objective of economic scheduling in this case will be maximising hydro energy that can be produced. It is well known that the load demand varies seasonally and peak occurs in mid winter. This results in the need for appreciable storage draw-down to meet the system load requirements and providing the space for ~~spring~~ Monsoon floods flowing into the reservoirs. Drawdown too early in the season can cause a considerable loss of energy because all subsequent flows are used at reduced head. On the other hand, failure to drawdown sufficiently results in spillage of water which otherwise could have been used for power generation. Thus, the economic scheduling of power in this case depends upon the water usage policy over the entire operating period. The maximum economy can only the obtained by the planned usage of water over the entire operating period under consideration.

Further the hydrosystem may be consisting of a number of cascaded system besides the independent type reservoir system. In such cases, as mentioned earlier, the release of water from the up stream plants affects the storage, head and hence generation of the down stream plants.

Hence optimal generation scheduling in this case becomes more complex than that in case of systems with independent reservoirs. This complexity is further enhanced if the cascaded plants have sufficient distance between them i.e. capacitance causing delay or time lag.

What-so-ever hydro's advantages - its resistance to inflation, its independence from rising fuel costs, its relative freedom from pollution, its renewability, its availability andits proven technology - are compelling, especially to electric utilities restricted in their energy alternative. And as the price of energy from oil, gas, coal, and uranium rises, the falling water that powered the mankind from its earliest days makes more and more sense.

HYDROTHERMAL SYSTEM

Where on one hand the negligible generation cost feature, of a hydro system pledges strongly for it's maximum utilization the stochastic features viz., inflows, head, storage etc. making it less and less reliable restricts its use to a certain limit only. This apart, most of the hydro stations are situated far away from theload centre. This is due to several reasons, the most important being the availability of water. Thus, most of the hydro stations are not load oriented. This resulting in considerable loss of energy in transmission, as transmission losses. On the contrary the steam plants, using coal as fuel which is available in abundance, their load oriented location (in most of the cases) and large size of generating units makes them more reliable as compared to hydro plants. But steam plants as a matter of fact has a very high generation cost because of fuel and other overhead secondary (differential charges, labour, maintenance, supplies etc) charges.

A wise decision is to combine the good feature of the two alternatives and eliminating the undesired ones using the good ones of the other. This concept and the features mentioned in the above para recommended the decision maker to use the hydro thermal generation facility. In an inter-connected hydrothermal system the basic question is to find a trade off between a relative gain associated with immediate hydroelectric generation and the expectation of future benefits among from storage, all measured in terms of thermal fuel economy. Thus the problem becomes a dynamic optimisation problem.

The time period, in which the distinct cycles viz. load and river inflows and seasonal demands repeat, are a day and an year respectively. It will therefore be convenient, and also necessary because of available information about the system to split the generation scheduling problem, into a long term problem , spreading over a span of a year or more than that, a mid range problem extending from a month to a year and a short range term problem spreading over a few or a week.

In the long and mid range scheduling considering optimisation over a period of one year or more, the inflows into hydro reservoirs and power demand on the system due to its seasonal variation is taken as a cyclic process repeating every period. It is essential in such a case to predict the load demand and reservoir inflows using statistical methods. Thus, the stochastic formulation is essential. The objective in this case is to minimize the expected values of the cost of thermal generation in the entire period of study with an extra emphasis to reduce the risk of over flow of the reservoirs . Because of the stochastic nature of the problem it is approached in one of the following direction :

1. Characterize the random nature of the water inflow and demand by specific p.d.f. and then represent the problem by some stochastic models or

2. Develop a model that uses deterministic hydrology and demand making use of short term predictions based on historical data.

The short range problem, on the other hand, attempts to minimise the overall cost of generation over a day/week. The effect of variation in the head of the reservoir may not be crucial. A more exact representation to account the transmission losses is however very essential so as to meet the given load pattern at all the instants, for optimum system security.

C H A P T E R – 4

PROBLEM FORMULATION

** **

DETERMINISTIC CASE :

The problem of optimal scheduling of power station can be stated as follows :

Given theinitial and final storages of the hydro reservoirs and load demand curve over a period, it is required to find the rates of water discharge and the required thermal generation over theprescribed period such that –

1) Load demand at every instant is satisfied.
2) Cost of fuel over the entire period is minimum.
3) Ratesof water discharge, storage at any instant and the thermal generation do not violate their minimum or maximum limits.

Considering a hydrothermal system which has N reservoir type plants and R thermal plants connected through an arbitary transmission system. Load demand and water inflow into the reservoirs are assumed to be deterministic. The problem, optimisation of the annual cost of thermal generation with full utilisation of available water, can be visualised as a P stage decision process by subdividing the year into P subintervals.

First the thermal system is considered. The thermal generation of i^{th} thermal plant in k^{th} period is $PT_i(k)$ and the cost associated with this generation is given by

$$F(PT_i(k)) = a_i PT_i(k) + b_i PT_i^2(k) \quad .. \quad (4.1a)$$

now if the period of study is divided in P interval,

$F(PT_i(k)) = a_i PT_i(k) + b_i PT_i^2(k)$ denotes the cost of thermal generation at i^{th} plant in k^{th} period. Thus, the sum of thermal generation cost for R plants in k^{th} period is

$$F(PT_i(k)) = \sum_{i=1}^{R} \left(a_i PT_i(k) + b_i PT_i^2(k) \right) \quad .. \quad (4.1b)$$

again for P intervals i.e. for the total period

$$F = \sum_{k=1}^{P} \sum_{i=1}^{R} \left(a_i PT_i(k) + b_i PT_i^2(k) \right) \quad .. \quad (4.1c)$$

As defined earlier, the objective of the study is to minimise the thermal generation cost. Therefore, the objective function is minimise $F = \sum_{k=1}^{P} \sum_{i=1}^{R} (a_i PT_i(k) + b_i PT_i^2(k))$ (4.1)

which is a nonlinear function. Each of the thermal plants have a maximum generation capacity. Again each of them have a lower bound also on the generation. So

$$PT_i^{min} \quad PT_i(k) \quad PT_i^{max} \qquad .. \qquad (4.2)$$

$k = 1, \ldots P$

$i = 1 \ldots R$

Giving P° R+2 constraints.

Hydro system, on the other hand, have bounds on storage capacity, discharge rate and generation capacity.

The hydro generation for i^{th} plant in k^{th} period, $PH_i(k)$, is a function of both the discharge through the turbines, and the head. It may be assumed that the head varies exponentially as a function of reservoir storage. Using this assumption the hydro plant generation $PH_i(k)$, is again a nonlinear function :

$$PH_i(k) = Q_i(k)\, H_i^{max} \left(1-\beta\left(e^{-\alpha x_i(k-1)} - e^{-\beta x_i^{max}}\right)\right) \qquad (4.3)$$

α and β are real +ve ~~constraintsx~~ constants.

This gives satisfactory hydro generation estimation and is also very realistic. The dynamic feature of the hydro system is expressed by the following expression in terms of storage, ~~inflowsxxxxxx~~ inflows and discharge.

$$X_i(N) = X_i(0) + \sum_{k=1}^{N-1} \left(J_i(k) - Q_i(k)\right) \qquad .. \qquad (4.4)$$

The above expression gives the hydro storage for i^{th} hydro plant in n^{th} period.

The bounds on the storage $X_i(k)$ for i^{th} hydro plant in k^{th} period are

$$X_i^{min} \leq X_i(k) \leq X_i^{max} \quad .. \quad (4.5)$$

$i = 1, \ldots N$

$k = 1, \ldots P$

Giving $N \cdot P \cdot 2$ inequality constraints.

Bounds on discharge $Q_i(k)$, for i^{th} hydro plant in k^{th} period are

$$Q_i^{min} \leq Q_i(k) \leq Q_i^{max} \quad .. \quad (4.6)$$

$i = 1, \ldots N$

$k = 1, \ldots P$

Giving $N \cdot P \cdot 2$ constraints.

Bounds on the hydro generation for i^{th} plant in k^{th} period are

$$PH_i^{min} \leq PH_i(k) \leq PH_i^{max} \quad .. \quad (4.7)$$

$i = 1, \ldots N$

$k = 1, \ldots P$

Giving in all $N \cdot P \cdot 2$ constraints.

Further, the variable $q_i(k)$ which accounts for the spilling for i^{th} hydro plant in k^{th} period is to be considered since spilling is always a non negative quantity. Therefore,

$$q_i(k) \geqslant 0 \qquad \text{..} \qquad (4.8)$$

It has been assumed that an excess energy $E_i(k)$ from i^{th} plant in k^{th} period could have been produced using the spilling water. Thus it would not make sense to allow spilling unless both the reservoir storage and the discharge through the turbines are at their respective maximum values. This is accounted for by the following non-equalities.

$$\left(Q_i^{max} - Q_i(k)\right) q_i(k) = 0 \quad i=1, \text{ to } H, \; k=1 \text{ to } P$$

$$\left(X_i^{max} - X_i(k)\right) q_i(k) = 0 \quad i=1, \text{ to } H, \; k=1 \text{ to } P \qquad (4.9)$$

Thus giving H*P*2 equality constraints.

In modern power station reservoir the probability of spilling is made negligibly low at the designing stage only. However, even if some leakage/seepage is there it is found to be negligible as compared to the discharge. Therefore, these equality constraints can easily be dropped without affecting the optimal solution at all, if needed.

Considering the factor of the power demand as the scheduling is done for each interval over the entire period of study, the combined hydro and thermal generation should meet the demand. Thus,

$$\sum_{i=1}^{H} PH_i(k) + \sum_{j=1}^{R} PT_j(k) = PD(k) \quad .. \quad (4.10)$$

Further, in interconnected systems, the transfer of power from one point to another causes sufficient transmission losses. These must also be accounted for in the demand equation.

$$PLOSS(k) = \sum_{i=1}^{H+R} \sum_{j=1}^{H+R} P_i(k)\, B_{ij}\, P_j(k) \quad .. \quad (4.11)$$

$k = 1, \ldots P$

$P_i(k) = PH_i(k), \quad (i=1 \ldots H)$

$P_i(k) = PT_j(k), \quad (i=H+1 \ldots H+R), \quad (j=1 \ldots R)$

B_{ij} is the transmission loss coefficient matrix as explained earlier.

Combining loss with the demand/generation equation, we get

$$\sum_{i=1}^{H} PH_i(k) + \sum_{j=1}^{R} PT_j(k) - PLOSS(k) = PD(k) \quad .. \quad (4.12)$$

$k = 1 \ldots P$

Giving P equality constraints.

Had at any instant, if the reservoir has an approximately uniform cross sectional area, is given by

$$H_i(k) = H_i0\ (1+C_iX_i(k)) \qquad .. \qquad (4.13)$$

For i^{th} plant and k^{th} interval.

In order to make the problem solution easy while giving full regard to vital features and keeping the formulation also close to real world problem, the nonlinearities, the bounds and the equalities are necessarily taken into account so the total mathematical model of the hydro thermal scheduling problem can be summarized as one including equation 4.1, 4.2, 4.5, 4.6 , 4.7, 4.8, 4.9, 4.12 and the dynamic equation of the hydro system.

Thus, in all, there are (H*P*8+P*R*2) inequality constraints and P equality constraints.

Using this deterministic model a 1 hydro and 1 thermal problem for a period of one year, divided in six intervals, where first interval starts from the month of July, is solved.

The data of the problem is given below:

max. water storage	$= X_1^{max}$ (m^3/sec)	= 70.0
min. water storage	$= X_2^{min}$ (m^3/sec)	= 0.0
basic water load	$= H_0$(mt)	= 20.0
max. water head	$= H_0^{max}$(m)	= 28.0

max. water discharge = $Q_{max}(m^3/sec)$ = 150.0

min. water discharge = $Q_{min}(m^3/sec)$ = 2.0

non effective discharge = $q_o(m^3/sec)$ = 2.0

max. hydraulic output = PH_1^{max} (mw) = 35.0

min. hydraulic output = PH_1^{min}(mw) = 0.0

max. thermal output = PT_1^{max}(mw) = 58.0

min. thermal output = PT_1^{max}(mw) = 0.0

For all intervals water inflow = J (m^3/sec) = 100.0

loss formula coeff. = $B_{11}(1/mw)^2$ = 0.0005

$B_{22}(1/mw)^2$ = 0.0005

$B_{21} = B_{12}$ $(1/mw)^2$ = 0.0

thermal fuel cost coeff. a_1 = 2.5

b_1 = 0.05

Period = I II... VI
Demand = 35, 35, 35, 30, 30, 30 in mw

For the solution of this nonlinear programming problem, the computer programme developed for the previously explained flexible tolerance algorithm, isused. The programme and the subroutine problem developed for incorting this problem in the program is given in the Appendix (Ap-1 and Ap-2 respectively).

Another general purpose subroutine problem is developed for inserting a N hydro andR thermal system generation schedulin for P periods. This is given in Appendix (Ap-3).

STOCHASTIC CASE :

The hydrothermal generation scheduling problem, which, as detailed earlier, is basically stochastic in nature because of the probabilistic features (random nature) of demand coming on the system and inflows to the reservoirs. For short range scheduling problem, the problem can easily be discretised and very good estimates of the demand and inflows can be madeusing the forecast information from data gathered in thepast. As the time range of the problem increases, it becomes undesirable to rely on such data.

In medium range and long range scheduling problem, so long the increasing complexity does not become unmanageable, it is desirable to include the probablistic features of demand atleast and further that of the inflows to the reservoirs.

Many approaches are existing in which this scheduling problem's probabilistic features have been included.

Many of them have the limitation on size of the system to be dealt or the nonlinear cost of generation function have been undesirably made linear or the method is too complex taxing the computational efficiency.

Following is a formulation for a stochastic problem dealing with a system of H hydro and R thermal system for P periods, taking into account the probabilistic features of demands. As willb be seen, the formulation is basically similar in nature to that of for deterministic case (dealt with inprevious section) leaving the demand constraint.

Chance constraint programming method is used to incorporate probabilistic demand feature. Using this method the problem can be redefined as -

$$\text{minimise } f(PT_i) = \sum_{k=1}^{P} \sum_{i=1}^{R} \left(a_i PT_i(k) + b_i PT_i^2(k)\right) \qquad (4.14)$$

subject to :

$$P_r\left(\left(PH_i(k) + PT_i(k) - PLOSS(k)\right) \leq PD(k)\right) \quad p_m \qquad (4.15)$$

which can be stated in words as 'the probability that the random variable (which in this case is supposed to follow normal distribution) of demand PD(k) will be greater than or equal to the power available ($PH_i(k) + PT_j(k) - PLOSS(k)$), PA(k) for k^{th} period is less than or equal to p_m ($p_m = 0.01$ for this case), so rewriting the expression -

$$P_r(PA(k) \leqslant PD(k)) \leqslant p_m \quad .. \quad (4.16)$$

since PD(k) follow normal distribution on each interval with a mean and variance of $\overline{PD}(k)$ and $\sigma D^2(k)$ respectively.

Thus standardising the random available for standard normal distribution (mean 1 and variance 0)

$$P_r((PA(k)-\overline{PD}(k))/\sqrt{\sigma D^2(k)} \leqslant (PD(k)-(\overline{PD}(k))/\sqrt{\sigma D^2(k)}) \leqslant p_m \quad (4.17)$$

Further $Z_{PA}(k) = *_x(PA(k)- \overline{PD}(k))/\sqrt{\sigma D^2(k)}$ and

$$Z_D(k) = (PD(k)-\overline{PD}(k))/\sqrt{\sigma D^2(k)}$$

So the equation (4.17) reduces to

$$P_r(Z_{PA} \leqslant Z_D) \leqslant p_m \quad .. \quad (4.18)$$

$$P_r(Z_D \geqslant Z_{PA}) \leqslant p_m \quad .. \quad (4.19)$$

or, $1-P_r(Z_D \leqslant Z_{PA}) \leqslant p_m \quad .. \quad (4.20)$

or, $P_r(Z_D \leqslant Z_{PA}) \geqslant 1-p_m \quad .. \quad (4.21)$

Now say E_1 is the standard normal variate for which

$$\phi_m(E_{1}) = (1-p_m) \quad .. \quad (4.22)$$

Thus,

$$\text{or} \quad \phi(Z_{PA}) \geq \phi(E_m) \qquad \cdots \qquad (4.23)$$

$$\text{or} \quad Z_{PA} \geq E_m \qquad \cdots \qquad (4.24)$$

$$\text{or,} \quad \frac{\sum_{j=1}^{R} PT + \sum_{i=1}^{H} PH - PLOSS(k) - \overline{PD}(k)}{\sqrt{var(P_D)}} \geq E_m(k) \qquad (4.25)$$

$$\text{or,} \quad \sum_{j=1}^{R} PT + \sum_{i=1}^{H} PH - PLOSS(k) - \overline{PD}(k) \geq E_m(k).\sqrt{ED^2(k)} \qquad (4.26)$$

$$\text{or,} \quad \sum_{j=1}^{R} PT_j + \sum_{i=1}^{H} PH_i(k)\ PLOSS(k) - \overline{PD}(k) \geq E_m(k)\sqrt{ED^2(k)} \qquad (4.27)$$

Hence the equality constraint for demandbos now bocome the inequality constraint of the following form

$$\sum_{j=1}^{R} PT_j(k) + \sum_{i=1}^{H} PH_i(k) - PLOSS(k) - \overline{PD}(k) - E_m(k)\sqrt{ED^2(k)} \geq 0 \qquad (4.28)$$

$k = 1,\ldots,P$

Giving P inequality constraints.

Thus the formulation for stochastic case can be summarized as below (all variable denote the same quantity they did in previous section).

$$\min F(PT_i) = \sum_{k=1}^{P} \sum_{i=1}^{N} \left(a_i PT_i(k) + b_i PT_i^2(k) \right) \quad .. \quad (4.29)$$

subject to

$$\sum_{j=1}^{P} PT_j(k) + \sum_{i=1}^{H} PH_i(k) - PLOSS(k) - \overline{PD}(k) - E_n(k) / \overline{ED^2(k)} \geq 0$$

$$k = 1,\ldots P \quad .. \quad (4.30)$$

$$PT_i^{min} \leq PT_i(k) \leq PT_i^{max} \quad .. \quad (4.31)$$

$$k = 1,\ldots P$$

$$i = 1,\ldots N$$

$$X_i^{min} \leq X_i(k) \leq X_i^{max} \quad .. \quad (4.32)$$

$$k = 1,\ldots P$$

$$i = 1,\ldots H$$

$$Q_i^{min} \leq Q_i(k) \leq Q_i^{max} \quad .. \quad (4.33)$$

$$k = 1,\ldots P$$

$$i = 1,\ldots H$$

$$PH_i^{min} \leq PH_i(k) \leq PH_i^{max} \quad .. \quad (4.34)$$

$$k = 1,\ldots P$$

$$i = 1,\ldots H$$

$$q_i(k) \geq 0 \quad .. \quad .. \quad (4.35)$$

$$i = 1,\ldots H$$

$$k = 1,\ldots P$$

$$\left(Q_i^{max} - Q_i(k)\right) q_i(k) = 0 \qquad .. \qquad (4.36)$$

$$\left(X_i^{max} - X_i(k)\right) q_i(k) = 0 \qquad .. \qquad (4.37)$$

$$i = 1,\ldots N \;, \quad k=1,\ldots P$$

With the expressions for dynamic equation and power equation of the hydro systems -

$$X_i(K) = X_i(o) + \sum_{k=1}^{K-1} \left(J_i(k) - Q_i(k)\right) \qquad .. \qquad (4.38)$$

and

$$H_i(k) = Q_i(k)\, H_i^{max} \left(1-p\left(e^{-x_i(k-1)} - e^{-x_i^{max}}\right)\right) \qquad (4.39)$$

In this case there are in all (N*P*8 + P*R*2 + P) constraints of inequality type. There are in all (N*P + R*P) independent variables.

Using this formulation for stochastic generation scheduling a 1 hydro and 1 thermal system for a period of a year starting from the month of July, divided in six intervals is dealt with. The data for this problem is the same as that of the problem dealt in deterministic case in the last section leaving the demand. Demand, which follows the normal distribution, is given below for each interval, with mean and variance of demand as given below :

Interval	K	1	2	3	4	5	6
Mean	PD	35	35	35	50	30	30
Variance	ED^2	3.5	3.5	3.5	3.5	3.5	3.5

Again computer programme for floxible tolerance algorithm is used for its solution, fetching a satisfcotory solution, The subroutine problem for this problem, developed for inserting the proble in main package, is given in Ap-1 and Ap-4 sections of Appendix, respectively

** **

CHAPTER - 5

SOLUTION TECHNIQUE & ALGORITHM

**

SOLUTION TECHNIQUE (22A)

The general NLP problem is found to be of the form

$$\min : f(x) \quad \bar{X} \in E^n$$

$$\text{subject to} : \quad h_i(\bar{x}) = 0 \qquad i=1,\ldots,m$$

$$G_i(\bar{x}) \geqslant 0 \qquad i=m+1,\ldots,P$$

where $f(x)$, $h_i(x)$, and $G_i(x)$ may be linear and/or non linear functions. In many nonlinear programming methods a considerable portion of the computation time is spent on satisfying rather rigorous feasibility requirements. The flexible tolerance algorithim (OR 1969, DM Himmelblau Vol 17)(18 on the other hand improves the value of the objective function by using information provided by feasible points, as well as certain nonfeasible points termed near feasible points. The near feasibility limits are gradually made more restrictive as the search proceeds towards the solution of the programming problem, until in the limit only feasible $\bar{X}$ vector in (5.1) are accepted. As a result of this basic strategy the NLP problem of (5.1) can be expressed as

$$\min : f(\bar{x}) \quad \bar{X} \in E^n \qquad \ldots \qquad (5.2)$$

$$\text{subject to} : \quad \phi(k) - T(\bar{x}) \geqslant 0$$

where, $\phi(k)$ is the value of the flexible tolerance criterion for feasibility on the k^{th} stage of search, and $T(\bar{x})$ is a positive functional of all the equality and/or inequality constraints of problem in (5.1) used as a measure of the extent of constraint voilation.

<u>Definition of tolerance constraint voilation – and the concept of near feasibility tolerance criterion ϕ :</u>

The tolerance criterion ϕ is selected to be a +ve decreasing function of the vertices of the flexible polyhedron in E^n; $\phi^{(k)} = \phi^{(k)}(x_1^{(k)}, x_2^{(k)}, \ldots, x_{r+1}^{(k)}, x_{r+2}^{(k)})$.
The function ϕ acts as a tolerance criterion for constraint voilation through out the entire search, and also serves as a criterion for termination of search. The definition of ϕ incorporated in the algorithm is

$$\phi^k = \min \left\{ \phi^{(k-1)}, \frac{m+1}{r+1} \sum_{i=1}^{r+1} \| x_i^k - x_{r+2}^k \| \right\} \quad \phi^{(0)} = 2(m+1)t \qquad .. \quad (5.3)$$

where, t = size of initial polyhedron

m = number of equality constraints

$x_i^{(k)}$ = ith vertex of polyhedron in E^n

r = $(n-m)$ = number of degrees of freedom of $f(x)$ in problem (5.1)

$x_{r+2}^{(k)}$ = vertex corresponding to centroid with $n = r$

K = 0,1... is an index referring to number of completed stages of search.

$\phi^{(k-1)}$ = value of tolerance criterion on (k-1) st stage of search.

Let the second term in the braces in equation (5.3) be denoted by $\theta^{(k)}$.

$$\theta^{(k)} = \frac{n+1}{r+1} \sum_{i=1}^{r+1} \| X_i^{(k)} - X_{r+2}^{(k)} \| = \frac{n+1}{r+1} \left\{ \sum_{i=1}^{r+1} \sum_{j=1}^{n} (X_{ij}^{(k)} - X_{r+2,j}^{(k)})^2 \right\}^{\frac{1}{2}} \quad .. \quad (5.4)$$

where $X_{ij}^{(k)}$, $j=1,\ldots,n$, are the coordinates of the ith vertex of the flexible polyhedron in E^n. Observe that $\theta^{(k)}$ represents the average distance from each $X_i^{(k)}$, $i=1,\ldots,r+1$ to the centroid $X_{r+2}^{(k)}$ of the polyhedron in E^n. It is obvious that the value of θ will depend on the size of the polyhedron in E^n, which may remain unchanged, expand on contract, depending on which operation is used to carryout the transition from $X_i^{(k)}$ to $X_i^{(k+1)}$. Thus $\phi^{(k)}$ behaves as a +ve decreasing function of X, although $\theta^{(k)}$ may increase or decrease during the progress of the search, and as the solution of the problem is approached, both $\theta^{(k)}$ and $\phi^{(k)}$ approach zero.

$$\phi^{(o)} \geqslant \phi^{(1)} \geqslant \ldots \geqslant \phi^{(k)} \geqslant 0 \quad .. \quad (5.5)$$

<u>The criterion for constraint violation $T(X)$</u>

Consider now a functional of the equality and inequality constraints of (5.1)

$$T(\bar{X}) = + \left[\sum_{i=1}^{m} h_i^2(\bar{X}) + \sum_{i=m+1}^{p} u_i g_i^2(\bar{X}) \right]^{\frac{1}{2}} \quad .. \quad (5.6)$$

where u_i is the weighting function such that $u_i = 0$ for $g_i(\bar{X}) \geq 0$ and $u_i = 1$ for $g_i(\bar{X}) < 0$. Therefore $T(\bar{X})$ is defined as the +ve square root of the sum of the squared values of all the violated equality and/or inequality constrain s of problem (5.1). $T(\bar{X}) \geq 0$ for all $\bar{X} \in E^n$, in particular, if $\sum_{i=1}^{m} h_i^2(x)$ is convex and the $g_i(\bar{X})$, $i = m+1, \ldots, P$ are concave functions, then $T(\bar{X})$ is a convex function with a global minimum for all feasible $\bar{X}$ vectors; i.e. for any $\bar{X} / h_i(\bar{X}) = 0$, $g_i(\bar{X}) \geq 0$ for $i = 1, \ldots P$. Also, $T(\bar{X}) \geq 0$ for all $\bar{X}$ vectors that are nonfeasible. For $\bar{X}^{(k)} \in E^n$, the value of $T(\bar{X})$ evaluated at $\bar{X}^{(k)}$ using (5.6) can be used to distinguish between feasible and nonfeasible points. If $T(\bar{X}^{(k)}) = 0$, $\bar{X}^{(k)}$ is feasible; if $T(\bar{X}^{(k)}) > 0$, $\bar{X}^{(k)}$ is nonfeasible. On the other hand, a small value of $T(\bar{X}^{(k)})$ implies that $\bar{X}^{(k)}$ is relatively near to the feasible region, and alarge value for $T(\bar{X}^{(k)})$ implies that $X^{(k)}$ is relatively far from the feasible region.

The concept of near feasibility

Near feasible $\bar{X}$ vectors are those points in E^n that are not feasible, but nevertheless almost feasible, in the sense given below. To establish a clear cut distinction between feasible, near feasible, and nonfeasible points, let $\emptyset^{(k)}$ be the value of $\emptyset$ on the k^{th} stage of the optimization search and let $\overline{X}^{(k)}$ be any vector in E^n. The $\overline{X}^{(k)}$ vector is said to be

1. Feasible, if $T(\overline{X}^{(k)}) = 0$
2. Near-feasible, if $0 \leq T(\overline{X}^{(k)}) \leq \emptyset^{(k)}$
3. Nonfeasible, if $T(\overline{X}^{(k)}) > \emptyset^{(k)}$

Thus the region of near-feasibility is defined as

$$\emptyset^{(k)} - T(x) \geqslant 0 \qquad .. \qquad (5.7)$$

On any transition from $\overline{X}^{(k)}$ to $\overline{X}^{(k+1)}$, the move is said to be feasible if $T(\overline{X}^{(k+1)}) = 0$, near feasible if $0 \leq T(\overline{X}^{(k+1)}) \leq \emptyset^{(k)}$, and nonfeasible if $T(\overline{X}^{(k+1)}) > \emptyset^{(k)}$. It is important to note that the value of $\emptyset$ on the (k+1)th stage of the search is determined only after $\overline{X}^{(k+1)}$ has been located as either a feasible or near-feasible point.

Procedure for finding feasible or near feasible points :

The procedure for obtaining either a feasible or a nearfeasible point can be summarised as follows:

1. Let $\overline{X}^{(o)} = \overline{X}_i^{(k)}$ be a nonfeasible point in E^n and $\emptyset^{(k)}$ be the value of the tolerance criterion determined from (5.5) on the k^{th} stage of the search procedure. Let $t = 0.05 * \emptyset^{(k)}$ be the size of the initial polyhedron for the minimisation of $T(\overline{x})$ starting from $\overline{X}^{(o)}$.

Next let $\bar{X}^{(o)} = \bar{X}_i^{(k)}$ be a nonfeasible point in E^n. To initial the search to reduce the value of $T(\bar{x})$ (n+1) initial vertices $\bar{X}_i^{(o)}$, i=1... (n+1), that may or may not form a regular polyhedron in E^n, must are required. The (n+1) vertices should be chosen in such a way that any subset of n vectors is linearly independent. For all practical purposes it is most convenient to build a regular polyhedron using $\bar{X}^{(o)}$ as the base point. The (n+1) vertices of the initial polyhydron in E^n are found from

$$\bar{X}_i^{(o)} = \bar{X}^{(o)} + D_i \qquad i=1,\ldots,n+1 \qquad .. \qquad (5.8)$$

where D_i is a column vector, in which the components are, the elements of the i^{th} column of the n x (n+1) matrix, D.

The search path followed depends upon the size and orientation of the initial polyhedron, when the size of the initial polyhedron is small compared with the size of the feasible region, the search path is nearly independent of the orientation of the initial polyhydron. For small values of t, the search path follows the direction of steepest descent with respect to the function $T(\bar{x})$ fairly closely, at least during the early stages of the search.

In this algorithm the size of the initial polyhddron for the minimisation of $T(\bar{x})$ at each stage k is calculated from the empirical relation.

$$t = 0.05\, \phi^{(k)} \qquad .. \qquad (5.9)$$

where $\phi^{(k)}$ is the value of the tolerance criterion on the k^{th} stage as computed from (5.3). The size of the polyhedron used to minimize $f(\bar{x})$ is fixed at an initial size at the start of the search for the minimum of $f(\bar{x})$, and is reduced only as the $\bar{X}$ vectors fail to improve $f(\bar{x})$.

From equation (5.6), compute $T(x)$ at each one of the $(n+1)$ vertexes, that is, $T(\bar{X}_i^{(o)})$, $i=1,\ldots,n+1$.

2. With $\alpha=1$, $\beta = 0.5$, and $\gamma = 2$, minimize $T(x)$. At the end of each stage s, compare the smallest value of $T(\hat{X}_i^{(s)})$ for $i = 1,\ldots, n+1$, that is $T(\hat{X}_i^{(s)})$, with the value of $\phi^{(k)}$.

3. If $T(X_i^{(s)}) \ngtr \phi^{(k)}$, either a feasible or near-feasible point has been determined. If $T(X_i^{(s)}) > 0$, replace the nonfeasible point $\bar{X}_i^{(k)}$ by $\bar{X}_i^{(s)}$ so that $\hat{X}_i^{(k)} = \hat{X}_i^{(s)}$ is either feasible or near-feasible and terminate the minimization of $T(\bar{x})$. If $T(\hat{X}_i^{(s)}) = 0$ and $s = 0$, go to step 7 below.

4. If $T(X_i^{(s)}) > \phi^{(k)}$, compute

$$\Delta^{(s)} = \frac{1}{n+1}\left[\sum_{i=1}^{n+1} \left\{ -T(X_{n+2}^{(s)}) + T(X_i^{(s)}) \right\}^2 \right]^{\frac{1}{2}} \quad .. \quad (5.10)$$

where $T(X_{n+2}^{(s)})$ is the value of $T(\bar{x})$ at the centroid of the polyhedron on the s^{th} stage of the minimization of $T(x)$.

5. If $\Lambda^{(s)} > 10^{-7}$, return to step 2 and proceed with the minimization of $T(x)$ on to the $(s + 1)$ st stage.

6. If $\Lambda^{(s)} \geq 10^{-7}$, the flexible polyhedron is about to collapse into apoint without a feasible or a near-feasible point having been found. The procedure may encounter difficulties when $\Lambda^{(s)} \leq 10^{-7}$ if a large number of nonlinear equality and inequality constraints are involved in the definition of $T(\bar{x})$ at the vertices $\bar{X}_i^{(s)}$ because $\Lambda^{(s)} \leq 10^{-7}$. Under such conditions $T(\bar{x})$ turns out to be quite a complex function in the nonfeasible region. Let $\hat{X}_1^{(s)}$ be the vertex correspondingto the lowest value of $T(\bar{x})$. Instead of terminating the search at $\hat{X}_1^{(s)}$ without being able to find a feasible or near-feasible point, the algorithm then the searches along each one of the directions parallel to the coordinate axis of X to determine the minimum of $T(\bar{x})$ as follows.

Let $\bar{X}_j$, $j=1,\ldots,n$, be the minima of $T(\hat{x})$ along each respective direction parallel to the coordinate axis of $\bar{X}_j$. From $\hat{X}_1^{(s)}$, determine $\bar{X}_1^*$ so that $T(\bar{x})$ is minimum in the direction parallel to the coordinate of $\bar{X}_1$, from $\bar{X}_1^*$ determine $\bar{X}_2^*$, and so on, until all $\hat{X}_j^*$ for $j=1,\ldots,n$, are determined. The technique used consists in determining the interval l_o that contains the minimum of $T(\bar{x})$ in the direction under consideration. Then a unidimensional search is carried out by golden searchmethod until the size of the interval that contains

$\hat{X}_j^*$ is reduced to less than 1 percent of the value of $\phi^{(k)}$. The purpose of carrying out the unidimensional searches is to locate a new point away from $\hat{X}_1^{(o)}$ and then repeat the search, starting from step 1, with a larger initial polyhedron.

At the end of each unidimensional search in the direction parallel to the coordinate axis, a test is executed to determine if the new value of $T(\hat{X}_j^*) \leq \phi^{(k)}$, in which case $\bar{X}_i^{(k)}$ is replaced by $\hat{X}_j^*$ and the minimization of $T(\bar{x})$ is terminated. If after searching in all coordinate directions a feasible or a near-feasible point still has not beenfound, the algorithm returns to step 1 and repeats the search, once again starting with $\hat{X}_n^*$, that is, the point at which $T(\bar{x})$ is a minimum in the direction parallel to the nth coordinate axis. If the procedure steps 1 through 6 fails to find a feasible or a near-feasible point three times in a row, the minimization is terminated as a failure.

7. If $T(\hat{X}_1^{(o)}) = T(\bar{X}_i^{(k)}) = 0$, before returning to the minimization of $f(\bar{x})$, the interpolation [illegible] is carried out to make certain that $\bar{X}_i^{(k)} = \hat{X}_1^{(o)}$ is not far from the boundaries of the constraints that were violated just prior to obtaining $\hat{X}_1^{(o)}$.

<u>Initiation and Terminationof Search :</u>

(n+1) vertices, where n is the total number of variables (dependent and independent) in problem (5.1), are used in the minimization of $T(\bar{x})$, whereas (r+1) vertices, $r = n-m$ is thenumber of degrees of freedom in prob. (5.1) are used in the minimization of $f(\bar{x})$. If $m = 0$, that is, problem has no equality constraints, then $r = n$ and the minimization of $f(x)$ involves the same number of degrees of freedom as does the minimization of $T(\bar{x})$.

To initiate the search for the minimization of $f(x)$ using the flexible tolerance algorithm,one needs to know an initial $x^{(o)}$, the size of the initial polyhedron t, the value of $\phi^{(o)}$, and r. In order to start the minimization of $f(x)$ with the appropriate polyhedron size, t should be selected as a function of the expected range of variation of the variables x. Usually upper and lower bounds on x are known, in which case the following equation can be used as a reasonable estimate of t.

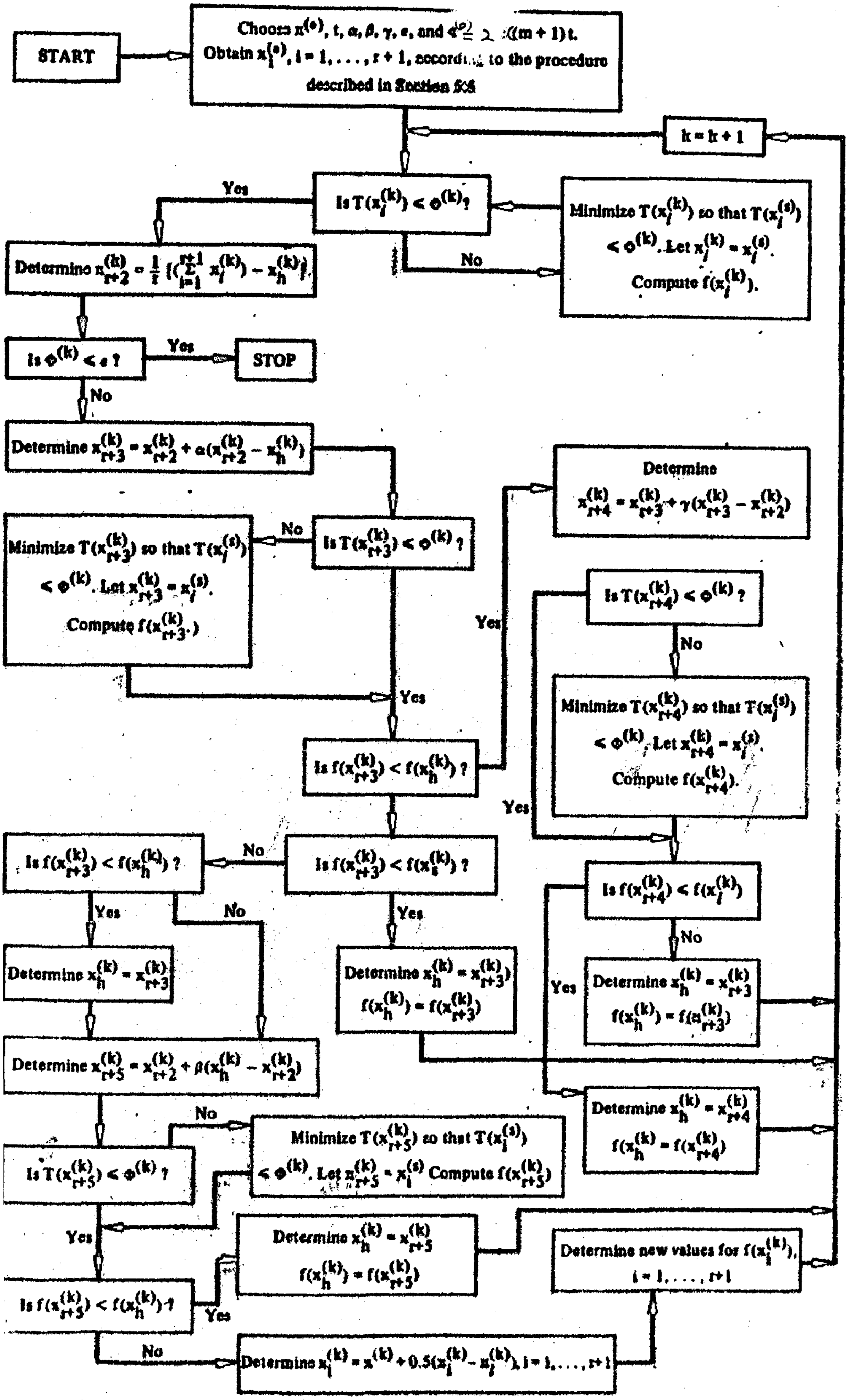
$$t = \min\left\{\left[\frac{0.2}{n}\sum_{i=1}^{n}(U_i - L_i)\right], \quad (U_1-L_1), \ldots, (U_n-L_n)\right\} \quad (5.11)$$

where $(U_i - L_i)$ is the difference between the upper and lower bounds on the variable x_i. If upper and lower bounds of x are not known, a reasonable guess for t will have to suffice.

$\hat{X}_j^*$ is reduced to less than 1 percent of the value of $\phi^{(k)}$ The purpose of carrying out the unidimensional searches is to locate a new point away from $\hat{X}_i^{(o)}$ and then repeat the search, starting from step 1, with a larger initial polyhedron.

At the end of each unidimensional search in the direction parallel to the coordinate axis, an test is executed to determine if the new value of $T(\hat{X}_j^*) \leq \phi^{(k)}$, in which case $\bar{X}_i^{(k)}$ is replaced by $\hat{X}_j^*$ and the minimization of $T(\bar{x})$ is terminated. If after searching in all coordinate directions a feasible or a near-feasible point still has not beenfound, the algorithm returns to step 1 and repeats the search, once again starting with $\hat{X}_n^*$, that is, the point at which $T(\bar{x})$ is a minimum in the direction parallel to the nth coordinate axis. If the procedure steps 1 through 6 - fails to find a feasible or a near-feasible point three times in a row, the minimization is terminated as a failure.

7. If $T(\hat{X}_i^{(o)}) = T(\bar{X}_i^{(k)}) = 0$, before returning to the minimization of $f(\bar{x})$, the interpolation [illegible] is carried out to make certain that $\bar{X}_i^{(k)} = \hat{X}_i^{(o)}$ is not far from the boundaries of the constraints that were violated just prior to obtaining $\hat{X}_i^{(o)}$.



Flow diagram of the flexible tolerance algorithm.

FIG. 5.1 (22A)

Initiation and Terminationof Search :

(n+1) vertices, where n is the total number of variables (dependent and independent) in problem (5.1), are used in the minimization of $T(\bar{x})$, whereas (r+1) vertices, $r = n-m$ is thenumber of degrees of freedom in prob. (5.1) are used in the minimization of $f(\bar{x})$. If $m = 0$, that is, problem has no equality constraints, then $r = n$ and the minimization of f(x) involves the same number of degrees of freedom as does the minimization of $T(\bar{x})$.

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$$t = \min\left\{\left[\frac{0.2}{n}\sum_{i=1}^{n}(U_i-L_i)\right],\quad (U_1-L_1),\ldots,(U_n-L_n)\right\} \qquad (5.11)$$

where (U_i-L_i) is the difference between the upper and lower bounds on the variable x_i. If upper and lower bounds of x are not known, a reasonable guess for t will have to suffice.

With the algorithm proposed in this study, nonglobal solutions are easier to avoid if the initial polyhedron is spread out widely over the topology of $f(x)$. The strategy of the algorithm does not depend on any local property of $f(x)$ nor on any combination of the properties of $f(x)$ and the constraints. In each stage of the search using the flexible tolerance algorithm, information for the next move is provided by the $(r+1)$ vertices of the polyhedron in E^n. Therefore an important advantage of the proposed algorithm is that, in the beginning of the search, a large number of vertices are widely used to obtain information about $f(x)$, enhancing the chance that some $X_i^{(k)}$ will be found that leads to a local optimum that is better than any other local optimum.

It is also advantageous to build the initial polyhedron with an $X^{(o)}$ that is feasible or near-feasible. If the initial polyhedron is built far away from the feasible region, $(r+1)$ vertices will have to be replaced by vertices closer to the feasible region.

The procedure for obtaining the vertices $X_i^{(o)}$, $i=1,\ldots,r+1$, required to start the search is as follows. From expression (5.3) compute $\phi^{(o)} = 2(n+1)t$ and compute the value of $T(x)$ at the initial vector $X^{(o)}$. If $T(X^{(o)}) \le \phi^{(o)}$ $\phi^{(o)}$, then $X^{(o)}$ is a feasible or near-feasible point and the initial vertices, $x_i^{(o)}$, i=1,... r+1, are obtained. If $T(x^{(o)}) > \phi^{(o)}$, T(x) is minimized until a feasible or near-feasible x vector is obtained, and this x vector becomes the base point for building the initial polyhedron.

The algorithm terminates under two circumstances:

1. When $\phi^{(k)} \leq \epsilon$, in which case the search is considered completed and successful.

OR

2. When a feasible or a near-feasible point cannot be obtained in which case the search is terminated and the user is instructed to choose a different starting point $x^{(o)}$ and/or a different set of parameters

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CHAPTER - 6

RESULTS & DISCUSSION

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RESULTS 1

DETERMINISTIC CASE:

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 OF H.HYDRO AND K.THERMAL GEN. SCHEDULING PROB

TERMINISTIC H=1,P=1

*****************************************

   NO. OF INDEPENDENT VARIABLES    12
   NO. OF EQUALITY CONSTRAINTS     6
   NO. OF INEQTY. CONSTTS   42
   SIZE OF INITIAL POLYHEDRON 0.17000E+02
   TH  DESIREDCONVERGENCE IS 0.10000E-04
   THE COMPTN TM IN SECS 0.00000E+00

RTING VECTER SELECTED BY USER IS
)000:+02     0.110000E+02    0.110000E+02    0.200000E+02
)000 +02     0.110000E+02    0.112000E+03    0.112000E+03
2000:+03     0.112000E+03    0.112000E+03    0.112000E+03

   THE INITIAL TOL. IS  0.23800E+03
   SUM OF VOILATED  CONSTRAINTS IS 0.99425E+01

*** **** **** **** **** **** **** **** **** ******* ****** ****** *****

   STAGE CALC. NO.=       1            TOL.CRTN.=  0.238000E+03

/E FUNC VAL. =     0.2377500E+03

EPENDENT VECTORS ARE
)0000E+02     0.1100000E+02     0.1100000E+02     0.2000000E+02
)0000E+02     0.1100000E+02     0.1120000E+03     0.1120000E+03
20000E+03     0.1120000E+03     0.1120000E+03     0.1120000E+03

ALITY CONSTRAINTS VALUES ARE
.1240E+01    -0.1911266E+01    -0.1911293E+01    -0.8050819E+01
38655E+01     0.3088629E+01

I.CONSTTS. VAL.
)0000E+03     0.1100000E+03     0.1100000E+03     0.1100000E+03
)0000E+03     0.1100000E+03     0.1800000E+02     0.1800000E+02
)0000E+02     0.1800000E+02     0.1800000E+02     0.1800000E+02
)0000E+02     0.4600000E+02     0.3400000E+02     0.2200000E+02
)0000E+02    -0.2000000E+01     0.1200000E+02     0.2400000E+02
)0000E+02     0.4800000E+02     0.6000000E+02     0.7200000E+02
)0000E+02     0.1100000E+02     0.1100000E+02     0.2000000E+02
)0000E+02     0.1100000E+02     0.3900000E+02     0.3900000E+02
)0000E+02     0.3000000E+02     0.3900000E+02     0.3900000E+02
39986E+02     0.1259988E+02     0.1259991E+02     0.1259994E+02
39995E+02     0.1259999E+02

*** **** **** **** **** **** **** **** **** ******* ****** ****** *****

   STAGE CALC. NO.=      28            TOL.CRTN.=  0.109424E+02

E FUNC VAL. =     0.1991989E+03

EPENDENT VECTORS ARE
12499E+01     0.9570215E+01     0.7975255E+01     0.2305493E+02
10603E+01     0.8557340E+01     0.1141710E+03     0.1057917E+03
11431E+03     0.1070253E+03     0.1157256E+03     0.8963068E+02

ALITY CONSTRAINTS VALUES ARE
```

```
 STAGE CALC. NO.=     56              TOL.CRTN.=  0.101651E+01

E FUNC VAL. =     0.2797424E+03

PENDENT VECTORS ARE
3551E+02     0.1295814E+02       0.1248246E+02       0.2791835E+02
4989E+01     0.1164116E+02       0.1176385E+03       0.1098619E+03
3297E+03     0.1097186E+03       0.1189168E+03       0.9191207E+02

LITY CONSTRAINTS VALUES ARE
3430E+00    -0.3947286E+00      -0.3817933E+00      -0.7683569E+00
3513E-01    -0.2131357E+00

.CONSTTS. VAL.
6385E+03     0.1078619E+03       0.1103297E+03       0.1077186E+03
9168E+03     0.8991207E+02       0.1236150E+02       0.2013810E+02
7035E+02     0.2028141E+02       0.1108316E+02       0.3808793E+02
6150E+02     0.4249960E+02       0.3016995E+02       0.2045136E+02
4520E+01     0.9622451E+01       0.1763850E+02       0.2750040E+02
3005E+02     0.4954864E+02       0.6846548E+02       0.6037755E+02
3551E+02     0.1295814E+02       0.1248246E+02       0.2791835E+02
4989E+01     0.1164116E+02       0.3806449E+02       0.3704186E+02
1754E+02     0.2208165E+02       0.4350501E+02       0.3835884E+02
7216E+02     0.1302752E+02       0.1253399E+02       0.1305623E+02
1661E+02     0.1661758E+02

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 STAGE CALC. NO.=     84              TOL.CRTN.=  0.101651E+01

E FUNC VAL. =     0.2786385E+03

PENDENT VECTORS ARE
4977E+02     0.1282420E+02       0.1230314E+02       0.2829128E+02
1527E+01     0.1150170E+02       0.1173065E+03       0.1089320E+03
0663E+03     0.1097692E+03       0.1204494E+03       0.9196410E+02

LITY CONSTRAINTS VALUES ARE
0400E-01    -0.7088627E+00      -0.4148846E+00      -0.3960145E+00
9166E+00    -0.3407627E+00

.CONSTTS. VAL.
3065E+03     0.1069320E+03       0.1110663E+03       0.1077692E+03
4494E+03     0.8996410E+02       0.1269347E+02       0.2106804E+02
3370E+02     0.2023083E+02       0.9550591E+01       0.3803590E+02
9347E+02     0.4376151E+02       0.3069521E+02       0.2092604E+02
6350E+00     0.8512533E+01       0.1730653E+02       0.2623849E+02
0479E+02     0.4907396E+02       0.6952337E+02       0.6148747E+02
4977E+02     0.1282420E+02       0.1230314E+02       0.2829128E+02
1527E+01     0.1150170E+02       0.3805023E+02       0.3717581E+02
9686E+02     0.2170872E+02       0.4396847E+02       0.3849830E+02
3855E+02     0.1321350E+02       0.1238666E+02       0.1304611E+02
1009E+02     0.1660717E+02

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 STAGE CALC. NO.=    112              TOL.CRTN.=  0.461426E+00

E FUNC VAL. =     0.2833084E+03

PENDENT VECTORS ARE
0637E+02     0.1326877E+02       0.1256450E+02       0.2871039E+02
2449E+01     0.1166278E+02       0.1173305E+03       0.1084107E+03
6177E+03     0.1094686E+03       0.1207225E+03       0.9230437E+02

LITY CONSTRAINTS VALUES ARE
2324E+00    -0.3720670E+00      -0.4898963E-01      -0.4764048E-01
8278E+00    -0.1147526E+00

.CONSTTS. VAL.
[illegible]
```

```
EPENDENT VECTORS ARE
85525E+02    0.1347161E+02    0.1249890E+02    0.2870191E+02
01055E+01    0.1163913E+02    0.1172884E+03    0.1086934E+03
37193E+03    0.1095495E+03    0.1206712E+03    0.9240847E+02

ALITY CONSTRAINTS VALUES ARE
34127E-01    -0.1166254E+00   -0.9392004E-01   -0.4005951E-01
52345E-01    -0.1176893E+00

Q.CONSTTS. VAL.
52884E+03    0.1066934E+03    0.1117193E+03    0.1075495E+03
86712E+03    0.9040847E+02    0.1271161E+02    0.2130657E+02
28074E+02    0.2045050E+02    0.9328801E+01    0.3759153E+02
71161E+02    0.4401818E+02    0.3029892E+02    0.2074942E+02
22037E-01    0.7669744E+01    0.1728839E+02    0.2598182E+02
70108E+02    0.4925058E+02    0.6992178E+02    0.6233025E+02
85525E+02    0.1347161E+02    0.1249890E+02    0.2870191E+02
01055E+01    0.1163913E+02    0.3814475E+02    0.3652839E+02
50110E+02    0.2129809E+02    0.4389895E+02    0.3836087E+02
54218E+02    0.1326121E+02    0.1225606E+02    0.1309004E+02
86571E+02    0.1651830E+02

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   STAGE CALC. NO.=    168              TOL.CRTN.=  0.967384E-01

VE FUNC VAL. =     0.2853136E+03

EPENDENT VECTORS ARE
84403E+02    0.1357651E+02    0.1252769E+02    0.2870671E+02
59485E+01    0.1170137E+02    0.1174204E+03    0.1087066E+03
37283E+03    0.1096480E+03    0.1205235E+03    0.9249687E+02

ALITY CONSTRAINTS VALUES ARE
63390E-01    -0.1056520E-01   -0.6373005E-01   -0.1612112E-01
27053E-01    -0.3882463E-01

Q.CONSTTS. VAL.
54204E+03    0.1067066E+03    0.1117283E+03    0.1076480E+03
85235E+03    0.9049687E+02    0.1257959E+02    0.2129339E+02
27172E+02    0.2035197E+02    0.9476457E+01    0.3750313E+02
57959E+02    0.4387298E+02    0.3014470E+02    0.2049667E+02
87740E-01    0.7476252E+01    0.1742041E+02    0.2612702E+02
85530E+02    0.4950333E+02    0.7002688E+02    0.6252375E+02
84403E+02    0.1357651E+02    0.1252769E+02    0.2870671E+02
59485E+01    0.1170137E+02    0.3815597E+02    0.3642349E+02
47231E+02    0.2129329E+02    0.4384052E+02    0.3829863E+02
51577E+02    0.1325857E+02    0.1225426E+02    0.1307034E+02
39527E+02    0.1650062E+02

*** **** **** **** **** **** **** **** **** ******* ****** ****** *****

   STAGE CALC. NO.=    196              TOL.CRTN.=  0.461249E-01

VE FUNC VAL. =     0.2856936E+03

EPENDENT VECTORS ARE
36450E+02    0.1355826E+02    0.1257064E+02    0.2872386E+02
78265E+01    0.1171856E+02    0.1173925E+03    0.1087276E+03
37234E+03    0.1096132E+03    0.1205332E+03    0.9250964E+02

ALITY CONSTRAINTS VALUES ARE
75141E-02    -0.2447455E-01   -0.2226431E-01   -0.6280962E-02
71978E-01    -0.1933347E-01

Q.CONSTTS. VAL.
53925E+03    0.1067276E+03    0.1117234E+03    0.1076132E+03
35332E+03    0.9050964E+02    0.1260754E+02    0.2127243E+02
27660E+02    0.2038681E+02    0.9466789E+01    0.3749036E+02
50754E+02    0.4387997E+02    0.3015657E+02    0.2054338E+02
```

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LITY CONSTRAINTS VALUES ARE
29904E-03    -0.1516958E-01    -0.1861601E-02    -0.8583326E-02
19322E-02    -0.8474188E-02

.CONSTTS. VAL.
53651E+03     0.1067531E+03     0.1117448E+03     0.1076055E+03
55344E+03     0.9052422E+02     0.1263494E+02     0.2124687E+02
55522E+02     0.2039445E+02     0.9465595E+01     0.3747578E+02
53494E+02     0.4388180E+02     0.3013702E+02     0.2053147E+02
10641E-02     0.7472853E+01     0.1736506E+02     0.2611820E+02
16298E+02     0.4946853E+02     0.7000293E+02     0.6252714E+02
17374E+02     0.1356262E+02     0.1258707E+02     0.2872303E+02
14564E+01     0.1172665E+02     0.3812626E+02     0.3643738E+02
11293E+02     0.2127697E+02     0.4379544E+02     0.3827335E+02
12684E+02     0.1324927E+02     0.1225096E+02     0.1307884E+02
19309E+02     0.1649515E+02

*** **** **** **** **** **** **** **** **** ******* ****** ****** *****

 STAGE CALC. NO.=    252                TOL.CRTN.=  0.205258E-01

E FUNC VAL. =     0.2858964E+03

PENDENT VECTORS ARE
6750E+02      0.1356687E+02     0.1257638E+02     0.2872296E+02
2154E+01      0.1173684E+02     0.1173848E+03     0.1087465E+03
7379E+03      0.1096084E+03     0.1205201E+03     0.9251285E+02

LITY CONSTRAINTS VALUES ARE
2598E-02     -0.1227224E-01    -0.1375483E-01    -0.8084822E-02
4940E-02     -0.6355625E-03

.CONSTTS. VAL.
3848E+03      0.1067465E+03     0.1117379E+03     0.1076084E+03
5201E+03      0.9051285E+02     0.1261517E+02     0.2125348E+02
6206E+02      0.2039158E+02     0.9479941E+01     0.3748715E+02
1517E+02      0.4386865E+02     0.3013071E+02     0.2052229E+02
0644E-02      0.7489386E+01     0.1738483E+02     0.2613135E+02
6929E+02      0.4947771E+02     0.6999777E+02     0.6251061E+02
6750E+02      0.1356687E+02     0.1257638E+02     0.2872296E+02
2154E+01      0.1173684E+02     0.3813250E+02     0.3643313E+02
2362E+02      0.2127704E+02     0.4379785E+02     0.3826316E+02
2289E+02      0.1325059E+02     0.1225233E+02     0.1307826E+02
9596E+02      0.1649742E+02

** **** **** **** **** **** **** **** **** ******* ****** ****** *****

 STAGE CALC. NO.=    280                TOL.CRTN.=  0.876139E-02

E FUNC VAL. =     0.2859704E+03

PENDENT VECTORS ARE
6363E+02      0.1357864E+02     0.1258307E+02     0.2872274E+02
0409E+01      0.1173499E+02     0.1173945E+03     0.1087413E+03
7546E+03      0.1096271E+03     0.1204779E+03     0.9252927E+02

LITY CONSTRAINTS VALUES ARE
5067E-02     -0.1683829E-02    -0.3885502E-02    -0.4642986E-02
7802E-02      0.7603904E-03

.CONSTTS. VAL.
3945E+03      0.1067413E+03     0.1117546E+03     0.1076271E+03
4779E+03      0.9052927E+02     0.1260548E+02     0.2125869E+02
4536E+02      0.2037287E+02     0.9522091E+01     0.3747073E+02
0548E+02      0.4386418E+02     0.3010954E+02     0.2048241E+02
0389E-02      0.7475231E+01     0.1739452E+02     0.2613582E+02
9046E+02      0.4951759E+02     0.6999550E+02     0.6252477E+02
6363E+02      0.1357864E+02     0.1258307E+02     0.2872274E+02
0409E+01      0.1173499E+02     0.3813637E+02     0.3642136E+02
1693E+02      0.2127726E+02     [illegible]       [illegible]
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).CO-STTS. VAL.

53957E+03	0.1067438E+03	0.1117536E+03	0.1076255E+03
54783E+03	0.9052872E+02	0.1260434E+02	0.2125617E+02
24642E+02	0.2037447E+02	0.9521711E+01	0.3747128E+02
50434E+02	0.4386051E+02	0.3010694E+02	0.2048141E+02
22330E-02	0.7474402E+01	0.1739566E+02	0.2613949E+02
59305E+02	0.4951859E+02	0.6999688E+02	0.6252560E+02
36340E+02	0.1357935E+02	0.1258260E+02	0.2872256E+02
79661E+01	0.1173435E+02	0.3813660E+02	0.3642065E+02
11740E+02	0.2127744E+02	0.4379034E+02	0.3826565E+02
52072E+02	0.1325113E+02	0.1224920E+02	0.1307484E+02
90432E+02	0.1649425E+02		

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STAGE CALC. NO.= 336 TOL.CRTN.= 0.419485E-02

/E FUNC VAL. = 0.2860005E+03

PENDENT VECTORS ARE

36509E+02	0.1357876E+02	0.1258700E+02	0.2872288E+02
.4382E+01	0.1173401E+02	0.1174000E+03	0.1087411E+03
37501E+03	0.1096335E+03	0.1204739E+03	0.9252390E+02

LITY CONSTRAINTS VALUES ARE

9434E-03	-0.1600110E-02	-0.8976394E-03	-0.3253099E-02
52857E-03	-0.1261104E-02		

).CONSTTS. VAL.

54000E+03	0.1067411E+03	0.1117501E+03	0.1076335E+03
54739E+03	0.9052390E+02	0.1260000E+02	0.2125887E+02
24989E+02	0.2036648E+02	0.9526062E+01	0.3747610E+02
50000E+02	0.4385888E+02	0.3010876E+02	0.2047524E+02
4626E-02	0.7477404E+01	0.1740000E+02	0.2614113E+02
9124E+02	0.4952476E+02	0.6999870E+02	0.6252260E+02
6509E+02	0.1357876E+02	0.1258700E+02	0.2872288E+02
4382E+01	0.1173401E+02	0.3813491E+02	0.3642124E+02
1300E+02	0.2127712E+02	0.4378562E+02	0.3826599E+02
1986E+02	0.1325167E+02	0.1224989E+02	0.1307324E+02
0519E+02	0.1649521E+02		

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STAGE CALC. NO.= 364 TOL.CRTN.= 0.108882E-02

E FUNC VAL. = 0.2860297E+03

PENDENT VECTORS ARE

6632E+02	0.1358034E+02	0.1258685E+02	0.2872597E+02
4174E+01	0.1173486E+02	0.1173985E+03	0.1087428E+03
7532E+03	0.1096323E+03	0.1204731E+03	0.9252484E+02

LITY CONSTRAINTS VALUES ARE

1720E-03	0.2898425E-03	-0.4287651E-03	-0.4823878E-03
3885E-03	-0.2342295E-03		

.CONSTTS. VAL.

3985E+03	0.1067428E+03	0.1117532E+03	0.1076323E+03
4731E+03	0.9052484E+02	0.1260145E+02	0.2125718E+02
4676E+02	0.2036768E+02	0.9526853E+01	0.3747516E+02
0145E+02	0.4385863E+02	0.3010539E+02	0.2047307E+02
4027E-04	0.7475080E+01	0.1739855E+02	0.2614137E+02
9461E+02	0.4952693E+02	0.7000008E+02	0.6252492E+02
6632E+02	0.1358034E+02	0.1258685E+02	0.2872597E+02
4174E+01	0.1173486E+02	0.3813368E+02	0.3641966E+02
1315E+02	0.2127403E+02	0.4378583E+02	0.3826514E+02
2015E+02	0.1325133E+02	0.1224927E+02	0.1307348E+02
0535E+02	0.1649502E+02		

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24476E+02     0.2036939E+02     0.9527708E+01     0.3747366E+02
60189E+02     0.4385826E+02     0.3010302E+02     0.2047240E+02
06262E-03     0.7473763E+01     0.1739811E+02     0.2614174E+02
89698E+02     0.4952760E+02     0.6999989E+02     0.6252623E+02
86616E+02     0.1357971E+02     0.1258667E+02     0.2872640E+02
14355E+01     0.1173435E+02     0.3813384E+02     0.3642029E+02
41333E+02     0.2127360E+02     0.4378565E+02     0.3826565E+02
52023E+02     0.1325117E+02     0.1224887E+02     0.1307382E+02
90552E+02     0.1649472E+02

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   STAGE CALC. NO.=   420            TOL.CRTN.=  0.108882E-02

/E FUNC VAL. =    0.2860265E+03

EPENDENT VECTORS ARE
36607E+02     0.1357937E+02     0.1258668E+02     0.2872650E+02
14518E+01     0.1173437E+02     0.1173978E+03     0.1087439E+03
37564E+03     0.1096298E+03     0.1204714E+03     0.9252682E+02

ALITY CONSTRAINTS VALUES ARE
43294E-03    -0.4483340E-03     0.2448913E-04    -0.4662313E-03
09110E-03    -0.3279299E-03

I.CONSTTS. VAL.
53978E+03     0.1067439E+03     0.1117564E+03     0.1076298E+03
34714E+03     0.9052682E+02     0.1260219E+02     0.2125609E+02
24357E+02     0.2037020E+02     0.9528626E+01     0.3747318E+02
60219E+02     0.4385829E+02     0.3010186E+02     0.2047206E+02
35529E-03     0.7473868E+01     0.1739781E+02     0.2614171E+02
39814E+02     0.4952794E+02     0.6999931E+02     0.6252613E+02
36607E+02     0.1357937E+02     0.1258668E+02     0.2872650E+02
4518E+01      0.1173437E+02     0.3813393E+02     0.3642063E+02
41332E+02     0.2127350E+02     0.4378548E+02     0.3826563E+02
52029E+02     0.1325111E+02     0.1224863E+02     0.1307398E+02
90570E+02     0.1649463E+02

*** **** **** **** **** **** **** **** **** ******* ****** ****** *****

   STAGE CALC. NO.=   448            TOL.CRTN.=  0.559490E-03

/E FUNC VAL. =    0.2860307E+03

EPENDENT VECTORS ARE
16684E+02     0.1357943E+02     0.1258654E+02     0.2872653E+02
4713E+01      0.1173459E+02     0.1173951E+03     0.1087448E+03
37569E+03     0.1096312E+03     0.1204722E+03     0.9252699E+02

ALITY CONSTRAINTS VALUES ARE
5337E-04     -0.2190406E-03    -0.2877414E-04    -0.1610518E-03
6291E-03     -0.7565040E-04

I.CONSTTS. VAL.
3951E+03      0.1067448E+03     0.1117569E+03     0.1076312E+03
4722E+03      0.9052699E+02     0.1260488E+02     0.2125521E+02
4312E+02      0.2036880E+02     0.9527756E+01     0.3747301E+02
0488E+02      0.4386008E+02     0.3010320E+02     0.2047201E+02
6965E-03      0.7472770E+01     0.1739512E+02     0.2613992E+02
9680E+02      0.4952799E+02     0.7000023E+02     0.6252723E+02
6684E+02      0.1357943E+02     0.1258654E+02     0.2872653E+02
4713E+01      0.1173459E+02     0.3813316E+02     0.3642057E+02
1346E+02      0.2127347E+02     0.4378529E+02     0.3826541E+02
2083E+02      0.1325094E+02     0.1224854E+02     0.1307371E+02
0553E+02      0.1649459E+02

** **** **** **** **** **** **** **** **** ******* ****** ****** *****

   STAGE CALC. NO.=   476            TOL.CRTN.=  0.559490E-03

E FUNC VAL. =    0.2860294E+03
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1166699E+02    0.1357928E+02    0.1258641E+02    0.2872642E+02
6214617E+01    0.1173448E+02    0.3813301E+02    0.3642072E+02
3741360E+02    0.2127358E+02    0.4378518E+02    0.3826552E+02
1152105E+02    0.1325088E+02    0.1224843E+02    0.1307370E+02
1090552E+02    0.1649454E+02

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     STAGE CALC. NO.=    504              TOL.CRTN.=  0.559490E-03

TIVE FUNC VAL. =     0.2860287E+03

NDEPENDENT VECTORS ARE
1186709E+02    0.1357899E+02    0.1258618E+02    0.2872676E+02
6215028E+01    0.1173404E+02    0.1173937E+03    0.1087461E+03
1137591E+03    0.1096297E+03    0.1204715E+03    0.9252913E+02

QUALITY CONSTRAINTS VALUES ARE
7041357E-04   -0.3843149E-03    0.4987698E-04   -0.2374575E-03
2350314E-03   -0.1998590E-03

NEQ.CONSTTS. VAL.
1153937E+03    0.1067461E+03    0.1117591E+03    0.1076297E+03
1184715E+03    0.9052913E+02    0.1260630E+02    0.2125386E+02
1624091E+02    0.2037033E+02    0.9528530E+01    0.3747087E+02
5260630E+02    0.4386016E+02    0.3010107E+02    0.2047140E+02
6771088E-04    0.7470811E+01    0.1739370E+02    0.2613984E+02
3989893E+02    0.4952860E+02    0.7000007E+02    0.6252919E+02
1186709E+02    0.1357899E+02    0.1258618E+02    0.2872676E+02
6215028E+01    0.1173404E+02    0.3813291E+02    0.3642101E+02
3741382E+02    0.2127324E+02    0.4378497E+02    0.3826595E+02
1152112E+02    0.1325067E+02    0.1224810E+02    0.1307401E+02
1090568E+02    0.1649417E+02

.OF CALC. STAGES=  519            CONVR.LIMIT=  0.753445E-04

TIVE FUNC VAL. =     0.2860334E+03

NDEPENDENT VECTORS ARE
1186721E+02    0.1357931E+02    0.1258622E+02    0.2872698E+02
6215261E+01    0.1173429E+02    0.1173936E+03    0.1087463E+03
1137588E+03    0.1096298E+03    0.1204715E+03    0.9252890E+02

QUALITY CONSTRAINTS VALUES ARE
2826843E-04   -0.4838966E-04    0.3548153E-04    0.1627952E-05
1195399E-04   -0.4108064E-05

NEQ.CONSTTS. VAL.
1153936E+03    0.1067463E+03    0.1117588E+03    0.1076298E+03
1184715E+03    0.9052890E+02    0.1260642E+02    0.2125374E+02
1624121E+02    0.2037018E+02    0.9528452E+01    0.3747110E+02
5260642E+02    0.4386016E+02    0.3010137E+02    0.2047155E+02
3814697E-05    0.7471108E+01    0.1739358E+02    0.2613984E+02
3989863E+02    0.4952845E+02    0.7000000E+02    0.6252890E+02
1186721E+02    0.1357931E+02    0.1258622E+02    0.2872698E+02
6215261E+01    0.1173429E+02    0.3813279E+02    0.3642069E+02
3741378E+02    0.2127302E+02    0.4378474E+02    0.3826571E+02
1152114E+02    0.1325064E+02    0.1224816E+02    0.1307398E+02
1090567E+02    0.1649421E+02

                                   THESE ARE  FINAL ANSWERS

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STOCHASTIC CASE:
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RES... ... ... GE

CASE:. ... J=1,K=1
****

... ... VA
... CO STR
... CO.SCTS
... ...
... CONVERGENCE
... SECS

... ... VECTOR ... CY
.1... +02 .1... +02
.1... +02 .14... +02
.1... +03 .112... +03

... IS
S ... CO S

**** **** **** **** **** ****

STAGE CALC. ...=

OBJECTIVE F... C VAL. = ...3332

... VECTORS ARE
..1... +02 0.1... E+0
.1... +02 0.1... E+
..1... +03 0.112... E+

THE I... CO.STS. VAL.
- .33 77... +01 -..3307766E+
..215... +0 ..1792129E+0
.... +03 ..110... E+
.... +02 ..18... E+
.... +02 0.18... E+0
.3... +02 0.220... E+0
.12 ... +02 0.24... E+0
.6... +02 0.720... E+0
.1... +02 0.2800000E+0
.3... +02 0.360... E+0
.36 ... +02 0.360... E+0
.1299991.+02 ..1259994E+0

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STAGE CALC. ...= 52

OBJECTIVE F... C VAL. = 0.38...81

THE I... VECTORS ARE
0.1657.7...E+02 0.176...E+0
.11...E+02 0.1184462E+0
.1151...E+03 0.1187326E+0

THE I... CO STS. VAL.
- ..521...E+0 -0.2.122608E+0
..632...E+03 -..1..12278E+0
..1..511...E+03 ..1167326E+0
..16...27E+02 0.2151...E+02
..2...91E+02 0.169...2078+02
..3523...30E+02 ..175..382E+02
..1330373E+02 ..22252...E+02
..55...126E+02 ..6908919E+02
... ..30605R2E+02

STOCHASTIC CASE:

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                 ^*********************************************
RESULTS OF  HYDRO THERMAL GEN. SCHEDULING PROB

CASE:STOCHASTIC H=1,K=1
                 ^*********************************************

        NO. OF INDEPENDENT VARIABLES    12
        NO. OF EQUALITY CONSTRAINTS      0
        NO. OF INEQTY. CONSTTS     46
       SIZE OF INITIAL POLYHEDRON 0.17000E+02
       THE DESIRED CONVERGENCE IS 0.10000E-03
        THE COMPT. TIME  SECS 0.00000E+00

THE STARTING VECTOR SELECTED BY USER IS
  0.14000E+02    0.14000E+02    0.14000E+02    0.24000E+02
  0.14000E+02    0.14000E+02    0.11200E+03    0.11200E+03
  0.11200E+03    0.11200E+03    0.11200E+03    0.11200E+03

       THE INITIAL TOL. IS  0.34000E+02
       SUM OF VIOLATED  CONSTRAINTS IS 0.76156E+01

**** **** **** **** **** **** **** **** **** **** ****** ****** ****** ******

      STAGE CALC. NO.=      1           TOL.CRT.=   0.340000E+02

OBJECTIVE FN. VAL. =    0.3332000E+03

THE INDEPENDENT VECTORS ARE
  0.1400000E+02    0.1400000E+02    0.1400000E+02    0.2400000E+02
  0.1400000E+02    0.1400000E+02    0.1120000E+03    0.1120000E+03
  0.1120000E+03    0.1120000E+03    0.1120000E+03    0.1120000E+03

THE INEQ.CONSTTS. VAL.
 -0.3307792E+01   -0.3307766E+01   -0.3307793E+01   -0.[illegible]E+01
  0.1692156E+01    0.1692129E+01    0.1100000E+03    0.1100000E+03
  0.1100000E+03    0.1100000E+03    0.1100000E+03    0.1100000E+03
  0.1800000E+02    0.1800000E+02    0.1800000E+02    0.1800000E+02
  0.1[illegible]E+02    0.1600000E+02    0.5800000E+02    0.[illegible]E+02
  0.3[illegible]E+02    0.2200000E+02    0.1000000E+02   -0.2000000E+01
  0.1200000E+02    0.2400000E+02    0.3600000E+02    0.4800000E+02
  0.6[illegible]E+02    0.7200000E+02    0.1400000E+02    0.1400000E+02
  0.1400000E+02    0.2800000E+02    0.1400000E+02    0.1400000E+02
  0.3600000E+02    0.3600000E+02    0.3600000E+02    0.2200000E+02
  0.3600000E+02    0.3600000E+02    0.1259998E+02    0.1259988E+02
  0.1259991E+02    0.1259994E+02    0.1259996E+02    0.1259999E+02

**** **** **** **** **** **** **** **** **** **** ****** ****** ****** ******

      STAGE CALC. NO.=     52           TOL.CRT.=   0.3116[illegible]E+01

OBJECTIVE FN. VAL. =    0.3808116E+03

THE INDEPENDENT VECTORS ARE
  0.1557[illegible]74E+02    0.1760[illegible]6[illegible]E+02    0.1731021E+02    0.3[illegible]512E+02
  0.1[illegible]E+02    0.1188462E+02    0.1133[illegible]378E+03    0.1[illegible]E+03
  0.1[illegible]511[illegible]E+03    0.1187326E+03    0.1034951E+03    0.113[illegible]579[illegible]E+03

THE INEQ.CONSTTS. VAL.
 -0.[illegible]21126[illegible]E+00   -0.2812260E+00   -0.1391240E+00   -0.7568121[illegible]E+00
  0.1[illegible]E+00   -0.1812278E+00    0.1113[illegible]37[illegible]E+03    0.1094[illegible]9[illegible]E+03
  0.1[illegible]511[illegible]E+03    0.1167326E+03    0.1014951E+03    0.111[illegible]579[illegible]E+03
  0.1[illegible]9[illegible]27[illegible]E+02    0.2155109E+02    0.1848593E+02    0.1[illegible]7[illegible]E+02
  0.2[illegible]91[illegible]E+02    0.1692207E+02    0.5[illegible]9627[illegible]E+02    0.4774736E+02
  0.3523639E+02    0.1750382E+02    0.14[illegible]8748E+02    0.9198[illegible]73[illegible]E+00
  0.1330373[illegible]E+02    0.2225264E+02    0.3376361E+02    0.5249615E+02
  0.55[illegible]3126E+02    0.6908919E+02    0.1657[illegible]74[illegible]E+02    0.17[illegible]E+02
  0.[illegible]13213E+02    0.3069582E+02    0.1466914E+02    0.11[illegible]462E+02
  0.3[illegible]202[illegible]E+02    0.3231840E+02    0.3268379E+02    0.1[illegible]39[illegible]18[illegible]E+02
  0.3[illegible]35[illegible]E+02    0.3811538E+02    0.1233911E+02    0.1321[illegible]E+02
  0.12[illegible]9771[illegible]E+02    0.1125342E+02    0.1430[illegible]952E+02    0.123[illegible]9[illegible]E+02

**** **** **** **** **** **** **** **** **** **** ****** ****** ****** ******

      STAGE CALC. NO.=    104           TOL.CRT.=   0.27659[illegible]E+00

OBJECTIVE FN. VAL. =    0.3840775E+03

THE INDEPENDENT VECTORS ARE
  0.1722[illegible]5E+02    0.1793525E+02    0.1784755E+02    0.3[illegible]62717E+02
  0.1362379E+02    0.1199193E+02    0.1120213E+03    0.1[illegible]91[illegible]15[illegible]E+03
  0.10[illegible]3864E+03    0.1224925E+03    0.1038139E+03    0.113[illegible]E+03

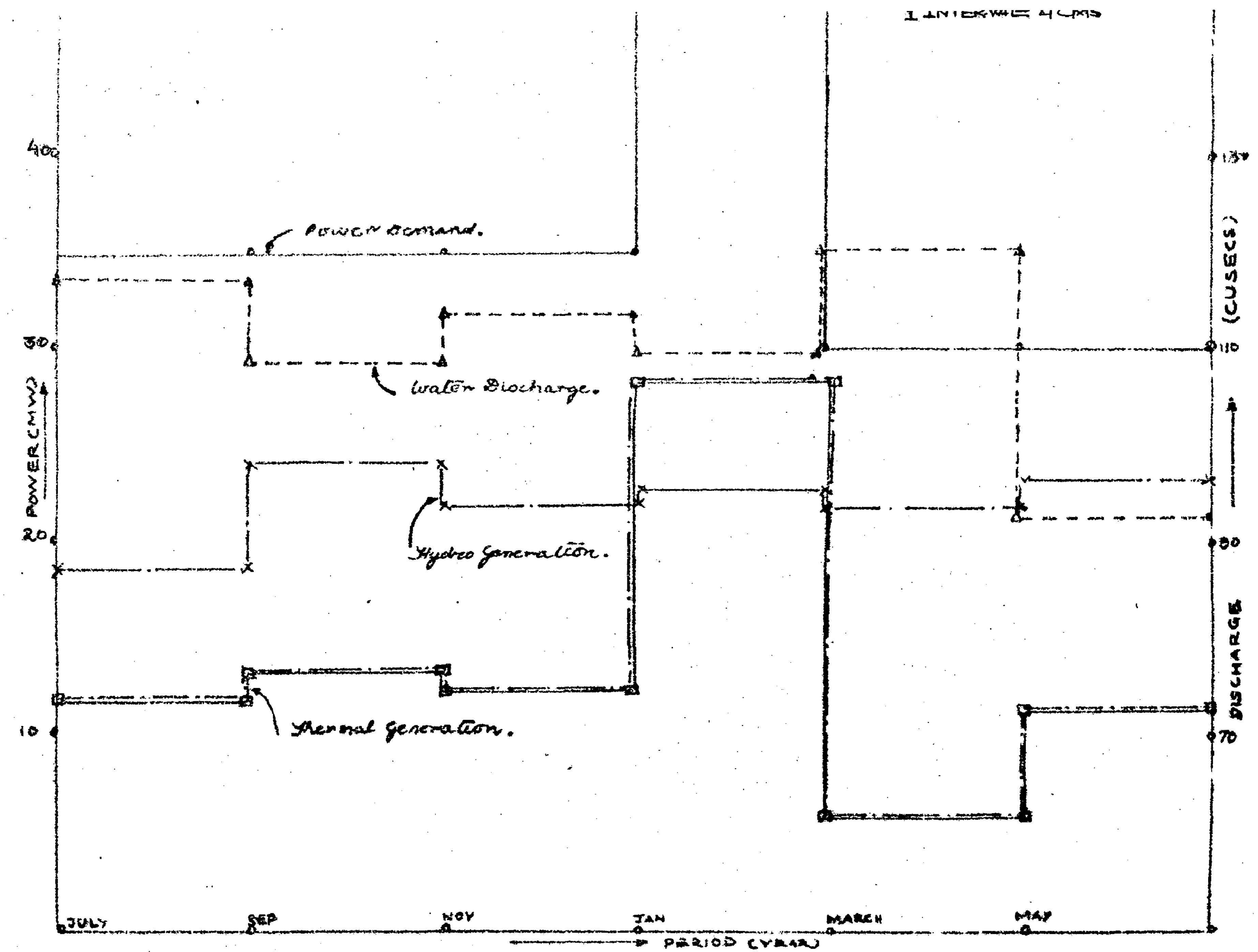
THE INEQ.CONSTTS. VAL.
 -0.129863[illegible]E+00    0.1535909E-01   -0.3616978E-01   -0.2371151E-02
```

```
-[illegible]E-01    -0.9509838E-01    0.1169213E+03    0.1571915E+03
[illegible]E+03     0.1207925E+03     0.1018139E+03    0.1116466E+03
[illegible]E+02     0.2086559E+02     0.2063156E+02    0.7507518E+01
[illegible]E+02     0.1695338E+02     0.5797470E+02    0.4676724E+02
[illegible]E+02     0.1692632E+02     0.1311241E+02    0.3772066E-01
[illegible]E+02     0.2121276E+02     0.3058129E+02    0.5307368E+02
[illegible]E+02     0.6993423E+02     0.1722105E+02    0.1793525E+02
0.17[illegible]E+02 0.3062717E+02     0.1362379E+02    0.1196193E+02
0.3277595E+02       0.3206475E+02     0.3215245E+02    0.1937283E+02
0.3517621E+02       0.3801807E+02     0.1259563E+02    0.1316159E+02
0.1312622E+02       0.1050143E+02     0.1423719E+02    0.1239066E+02
**** **** **** **** **** **** **** **** **** **** ****** ****** ****** ******
STAGE CALC.  I.=   156            COL.CRT .=   .247776E+00
OBJECTIVE FN C VAL. =   0.3834596E+03
THE I [illegible] VECTORS ARE
0.17[illegible]E+02 0.1774124E+02     0.1837508E+02    0.3127562E+02
0.137[illegible]E+02 0.1191451E+02    0.1121898E+03    0.1100372E+03
0.11[illegible]E+03 0.1237317E+03     0.1037178E+03    0.1135174E+03
T [illegible] .CO STS. VAL.
-0.2[illegible]E-01 -0.9741360E-02    -0.6996429E-02   -0.[illegible]E+00
-0.1352253E+03      -0.6970675E-01    0.1101893E+03    0.1[illegible]E+03
0.1[illegible]E+03  0.1217317E+03     0.1017178E+03    0.1115174E+03
0.178[illegible]E+02 0.1990279E+02    0.2333305E+02    0.[illegible]E+01
0.2628223E+02       0.1648264E+02     0.5791017E+02    0.7772968E+02
0.[illegible]E+02   0.1707434E+02     0.1335657E+02    -0.1[illegible]E+00
0.121[illegible]E+02 0.2222704E+02    0.2919394E+02    0.5252565E+02
0.55[illegible]E+02 0.7015079E+02     0.1729365E+02    0.1774124E+02
0.1337[illegible]E+02 0.3027582E+02   0.1378637E+02    0.1191451E+02
0.327[illegible]E+02 0.3225876E+02    0.3162992E+02    0.1972145E+02
0.3[illegible]E+02  0.3893579E+02     0.1256189E+02    0.1299224E+02
0.13[illegible]E+02 0.1025359E+02     0.1425541E+02    0.1229651E+02
**** **** **** **** **** **** **** **** **** **** ****** ****** ****** ******
STAGE CALC. I.=   208            COL.CRT.=   .798926E-03
OBJECTIVE FN C VAL. =   0.3850293E+03
THE I [illegible] VECTORS ARE
0.1738755E+02       0.1765544E+02     0.1852106E+02    0.3130548E+02
0.139113[illegible]E+02 0.1196696E+02 0.1118613E+03    0.11[illegible]E+03
0.1[illegible]E+03  0.1249659E+03     0.1037965E+03    0.1136067E+03
T [illegible] .CO STS. VAL.
-0.[illegible]E-03  -0.5895371E-03    -0.2698526E-03   -0.5595688E-03
-0.[illegible]E-03  -0.1278499E-03    0.1098013E+03    0.1[illegible]E+03
0.1[illegible]E+03  0.1220950E+03     0.1017965E+03    0.1116067E+03
0.[illegible]E+02   0.1953582E+02     0.2362737E+02    0.5924957E+01
0.262[illegible]E+02 0.1639132E+02    0.5813870E+02    0.4767452E+02
0.[illegible]E+02   0.1740684E+02     0.1361033E+02    0.[illegible]E-02
0.11[illegible]E+02 0.2232588E+02     0.2849612E+02    0.5259316E+02
0.5635957E+02       0.6994834E+02     0.1738755E+02    0.1765554E+02
0.1521[illegible]E+02 0.3[illegible]E+02 0.1391134E+02 0.1196680E+02
0.3212452E+02       0.3233446E+02     0.3147292E+02    0.1967352E+02
0.36[illegible]E+02 0.3803314E+02     0.1262769E+02    0.1290705E+02
0.137653[illegible]E+02 0.1[illegible]E+02 0.1424067E+02 0.1227825E+02
TL. [illegible] CALC. STAGES=  2[illegible]      CONV.L [illegible]=  0.798926E-03
OBJECTIVE FN C VAL. =   0.3853222E+03
THE I [illegible] VECTORS ARE
0.17[illegible]E+02 0.1768104E+02     0.1853699E+02    0.3132235E+02
0.139[illegible]E+02 0.1196682E+02    0.1118573E+03    0.11[illegible]E+03
0.1[illegible]E+03  0.1240965E+03     0.1037985E+03    0.1136089E+03
T [illegible] .CO STS. VAL.
-0.[illegible]E-01  0.1542405E-01     0.1532871E-01    0.1499882E-01
-0.[illegible]E-03  -0.1318462E-03    0.1098573E+03    0.1[illegible]E+03
0.1[illegible]E+03  0.1220965E+03     0.1017985E+03    0.1116089E+03
0.[illegible]E+02   0.1953380E+02     0.2362748E+02    0.5903491E+01
0.[illegible]E+02   0.1639112E+02     0.5814272E+02    0.4767653E+02
0.[illegible]E+02   0.1740750E+02     0.1360905E+02    0.1559393E-03
0.[illegible]E+02   0.2232376E+02     0.2849599E+02    0.5259250E+02
0.[illegible]E+02   0.[illegible]E+02 0.1738416E+02    0.1768144E+02
0.[illegible]E+02   0.3[illegible]32235E+02 0.1391982E+02 0.1196682E+02
```

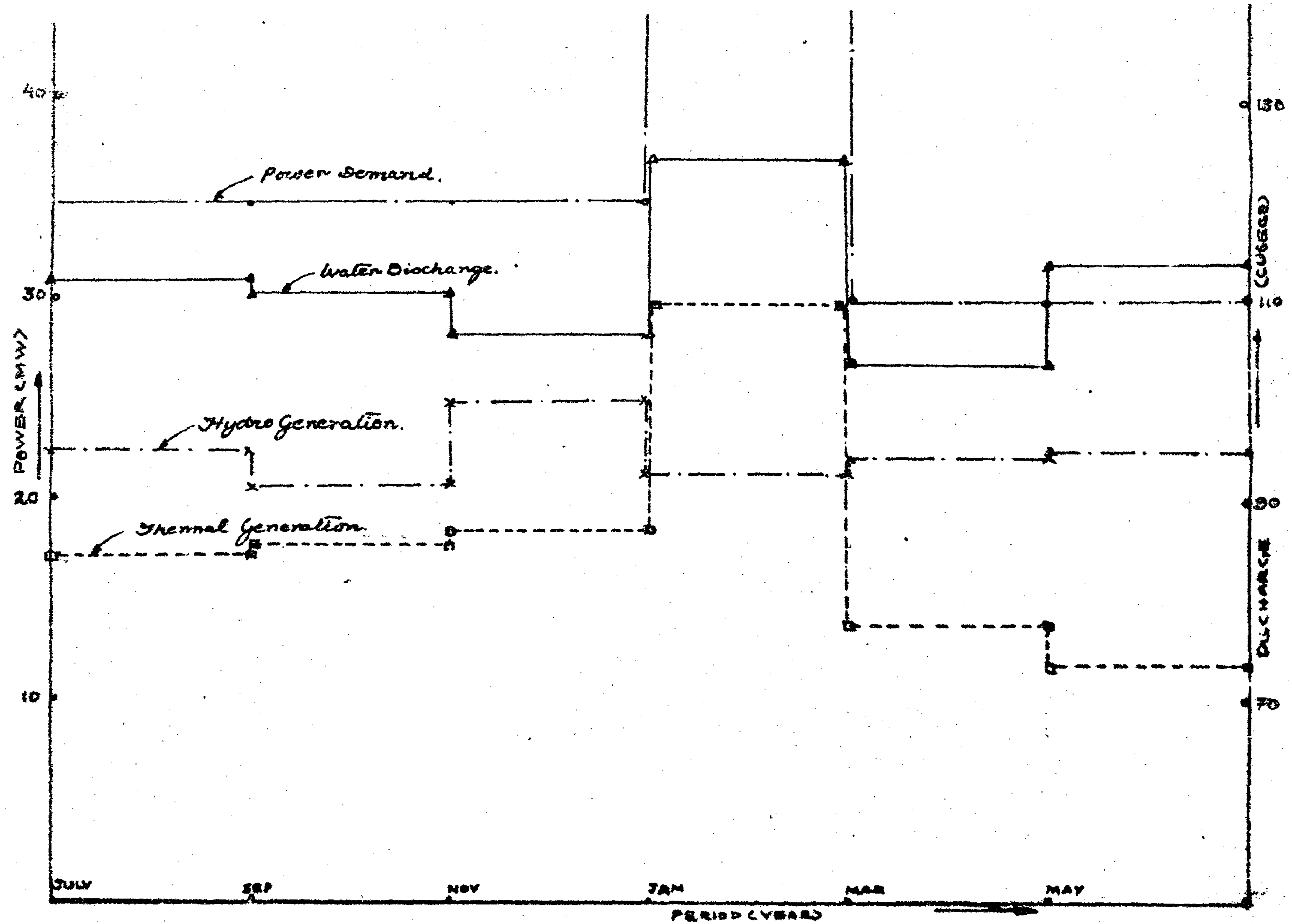
RESULTS

The initial values of the variables of interest, the number of constraints both equality and inequality and the convergence criterion chosen are printed in the computer outputs for both deterministic and stochastic case. The value of the objective function, tolerance criterion and the sum of violated constraints for the initial stage is also printed on the output. After every k stages the values of objective function, tolerance criterion, variables of interest, equality constraints and inequality constraints is calculated and printed. The value of k depends upon the number of variables and the numberof equality constraint. The output format for both deterministric and stochastic casesis the same.

As the tolerance criterion meets the predefined convergence limit, the solution converges to the optimal point. Total number of calculation stages is printed along with the final value of tolerance criterion, independent vectors (at the optimal point), t e values of the equality and inequality constraints. Finally the programme indicates the end of the solution process by typing "THESE ARE THE FINAL ANSWERS". The CPU time used for the deterministic problem is found to be 55.8 seconds. The total number of calculation stages for the deterministic case, as required



PLOTS FOR DETERMINISTIC CASE I RESULT 1



PLOTS FOR STOCHASTIC CASE 1 RESULTS

by the algorithm to converge to the optimal point, is 519. The optimal thermal generation cost given by the value of the objective function value is 286.035 units of currency. The convergence limit for the final stage is 0.75345×10^{-4}.

For the stochastic case, the CPU time required is 49.3 secs. The total number of calculation stages for this case are 203. The optimal thermal generation cost given by the value of the objective function value is 305.32 units of currency, the convergence limit at the final stage is 0.7989×10^{-3}. The values of the variables of interest are given under the head 'The Independent Vectors are ='. First six values are for thermal generation and the next six for the hydro discharge in each of the six intervals respectively.

DISCUSSION

In order to study and discuss the results obtained, plots have been drawn for deterministic as well as stochastic case. Time, as per the norm, is taken as the independent variable on the X axis and the variables viz., demand, thermal generation, hydro generation and water discharge are considered as dependent variables taken on the Y axis. To make the analysis of the results, all the variables are considered in the same plot. The period of one year, devided into six intervals, starts from the month of July, the seventh month of the year. Since the monsoon is scheduled by this month, maximum load is transferred to the hydro plants in the months of May and June (6th intervals), so that sufficient space can be created in the reservoirs to accomodate the monsoon inflows. Thus, the thermal generation in the sixth intervals remains at a low level as compared to hydro generation which meets the major part of the load. Further, in the fourth interval covering the month of January-February, the power demand peaks (50 MW). This load is shared by the hydro and thermal plants, thermal plants sharing more load. All of the inequality and equality constraints are satisfied in reasonable limits. In both the cases (a) deterministic (FIG 6.1) and (b) stochastic (FIG 6.2), the above features have been encountered. As the solution approaches the global optimal region, the improvement in the objective function becomes progressively lesser. The improvement in the satisfaction of constraints, however, continues.

For this reason, the independent variables (of interest) are varied till they reach the optimal point satisfying all the constraints and globly optimal point is reached.

The only difference in case of the stochastic case is the reasonably high increase in the value of the objective function. This is due to the security constraints on the demand taking into account the probabilistic features of the demand. These constraints are reasonably satisfied. The number of stage calculation to reach the optical point is found to be less in this case as compared to the deterministic case. This is because of the more appropriate initial values. In stochastic case more load demand is diverted towards the steam plants. This is because the steam plant have a high generation capacity, making them more reliable sources of power.

Thus, the results are found to be very satisfactory as well as realistic. The algorithm proved its high efficiency taking only 55.8 seconds of CPU time in deterministic case and 493 seconds of CPU time (on DEC 20/50 system) in the case of stochastic formulation.

CHAPTER - 7

CONCLUSION

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A detailed study of the mid range hydrothermal generation scheduling problem has been done. The system considered for the problem consists of one hydro and one thermal generation plant. In the problem formulation all the relevant features viz. nonlinear thermal generation cost function, nonlinear hydro generation function, transmission losses, constraints on spillage are incorporated. Further, the formulation is made more realistic taking into account the bounds on thermal power capacity, hydro power capacity, storage capacity, discharge capacity.

The formulation is made more realistic taking into account the random power demand. Chance constrained programming (28) approach, an efficient method to incorporate random feature of the system under consideration, is made use of for incorporating the stochastic feature of demand. This formulation is further used for solving another hydrothermal generation scheduling problem.

The flexible tolerance algorithm of nonlinear programming is used for the solution of the problems. This method is found to be fast in convergence. The results obtained are very realistic and as guaranteed by the algorithm, are optimal. The water discharge and thermal generation policies are very logical. The CPU time consumed for solution of the problem is reasonably less.

The developed package SUBROUTINE PROB, for including a N hydro and N thermal plants can further be used for solving large systems generation scheduling problem. Using the chance constrained programming the probabilistic feature of the river inflows can also be taken into account. A little modification in the subroutine prob. can extend its use for stochastic problems.

The model efficiency and closeness to real world problem recommends its use for practical purposes and for larger systems, which if practised, will result in considerable savings.

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APPENDIX

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C        **A COMPUTER CODE FOR NONLINEAR HYDROTREATER AS GENERATION SCHEDULING
C        PROBLEM -- COMPLEX*******************************************
C        NX     TOTAL NUMBER OF INDEPENDENT VARIABLES
C        NC     TOTAL NUMBER OF EQUALITY CONSTRAINTS
C        NIC    TOTAL NUMBER OF INEQUALITY CONSTRAINTS
C        SIZE   EDGE LENGHT OF THE INITIAL POLYHEDRON
C        CONVER CONVERGENCE CRITERION FOR TERMINATION OF THE SEARCH
C        ALFA   THE REFLECTION COEFFICENT
C        BETA   THE CONTRACTION COEFFICIENT
C        GAMA   THE EXPANSION COEFFICIENT
C        X(I)   THE ASSUMED VECTOR TO INITIATE THE SEARCH
C        FDIFER THE TOLERANCE CRITERION FOR CONSTRAINT VIOLATION
C        ICONT  A COUNTER TO RECORD STAGE COMPUTATIONS
C        NCONT  A COUNTER TO PRINT INFORMATION EVERY (NX+1) STAGE
C        LOW   AN INDEX TO IDENTIFY INFORMATION RELATED TO THE LOWEST
C        VALUE OF OBJ. FUNCTION IN MOST RECENT POLYHEDRON
C        LHIGH AN INDEX TO IDENTIFY INFORMATION RELATED TO LARGEST VALUE
C        OF OBJ. FUNCTION IN MOST RECENT POLYHEDRON
C        LSEC  AN INDEX TO IDENTIFY INFORMATION RELATED TO THE SECOND
C        LARGEST VALUE OF OBJ. FUNCTION IN MOST RECENT POLYHEDRON
         DIMENSION X(100),X1(100,100),X2(100,100),R(100),SUM(100),
       1 F(100),SR(100),ROLD(100),H(100)
         COMMON/A1/NX,NC,NIC,STEP,ALFA,BETA,GAMA,IN,INF,FDIFER,SEQL,K1,K2
        1K3,K4,K5,K6,K7,K8,K9,N,X1,X2,R,SUM,F,SR,ROLD,SCALE,FOLD
         COMMON/A2/LFEAS,L5,L6,L7,L8,L9,R1A,R2A,R3A
           OPEN(UNIT=2,DEVICE='DSK',FILE='INP.DAT')
         READ (2,*), NX,NC,NIC,SIZE,CONVER
         ALFA= 1.
         BETA = 0.5
         GAMA = 2.
         STEP = SIZE
         READ (2,*),(X(I),I = 1, NX)
    11   PRINT 106
         PRINT 7590
         PRINT 759
         PRINT 7591
         PRINT 7592
         PRINT 756, NX,NC,NIC,SIZE,CONVER,TIME
         K1 = NX+1
         K2 = NX+2
         K3 =NX+3
         K4 =NX+4
         K5 =  NX+5
         K6 = NC+NIC
         K7 =  NC+ 1
         K8 = NC+NIC
         K9 = K8+1
         N = NX -NC
           N1=N+1
         IF(N1.GE.3)   GO TO 50
         N1 = 3
         N = 2
    50   N2 =   N+ 2
         N3 =   N+3
         N4 =   N+4
         N5 =   N+5
```

```
      .6 =  +
      .7 =  +7
      .8 =  +
      X. =
        X  X =
      X 1 =  1
      R1A =  .5*( (5.)-1.)
      R2A =  R1 *
      R3A =  2A*
      L5 =  X + 5
      L6 =  X+6
      L7=  X+7
      L8 =  X+
      L9 =  X+
      ICO  =1
      ICO  = 1
      PRI  115
      PRI   1 , (X(J), J = 1, X)
      FDIFFE = 2.*( C+1)*STEP
      FOLD = FDIFF
      I =  1
      CALL S
      SR( 1) = SQRT(SQL)
      PRI   763,FDIFFE,SR(J1)
      IF(SR( 1).GT.FDIFFE) GO TO 341
      CALL  RITEX
      PRI 1 757
      I F =  1
      STEP = 0. 5*FDIFER
      CALL FEASBL
      PRINT 764
      PRI   116,(X2(I F,J),J= 1,NX)
      PRI   765,SR(I F)
      IF(FOLD.LT.1.0E-04) GO TO 80
341   PRI T 35
      PRI   758,ICO T, FDIFER
       CALL  RITEX
      FTER = F(K9)
C     COMPUTE CENTROID OF ALL VERTICES OF INITIAL OF  POLYHEDRON
 237  STEP1 = STEP*(SQRT(XNX + 1.) + XNX - 1.)/(X X*SQRT(2.))
      STEP2 = STEP*(SQRT(X X+1.)-1.)/(X X*SQRT(2.))
      ETA = (STEP1 + (XNX- 1.)*STEP2)/(XNX + 1.)
      DO 4 J = 1, NX
      X(J) = X(J) - ETA
    4 CONTINUE
      CALL START
      DO 9 I = 1, 1
      DO 9 J = 1, X
      X2(I,J)  = X1(I,J)
    9 CONTINUE
      DO 5 I = 1, 1
      I  = 1
      DO 5 J = 1, X
    5 X(J) = X2(I,J)
      CALL SUMR
      SR(I) = SQRT(SEQL)
```

```
      IF(S[illegible](I).[illegible] THEN) GO TO 8
      CALL [illegible]
      IF([illegible] .LT. [illegible]-04) GO TO 80
      CALL PRO[illegible]3
      F(I) = [illegible]
    5 CO[illegible]
 1000 STEP = [illegible] STEP [illegible]
      IC[illegible] = IC[illegible] +1
C     SELECT [illegible] VALUE OF OBJECTIVE FUNCTION FROM POLYHEDRON VERTI
      F[illegible] = F(1)
      L[illegible] = 1
      DO 16 I = 2, [illegible]
      IF(F(I).[illegible].F[illegible]) GO TO 16
      F[illegible] = F(I)
      L[illegible] = I
   16 CONTINUE
C     SELECT [illegible] VALUE OF OBJECTIVE FUNC FROM POLYHDRN VERTICES
   [illegible] FL=F(1)
      L[illegible] =
      DO 17 I=2,[illegible]
                 IF(FL.LT.F(I)) GO TO 17
      FL=F(I)
               L[illegible] =I
 17   CONTINUE
      DO [illegible] J=1, X
 85   X(J)=X2(L[illegible],J)
      J[illegible]
      CALL [illegible]
       S[illegible]([illegible])=SQRT(SEQL)
      IF(S[illegible](L[illegible]).GT.FDIFER) GO TO 87
      I[illegible]
      CALL FEASBL
      IF(F[illegible].LT.1.0E-04) GO TO 80
       CALL PRO[illegible]3
      F([illegible])=R(K9)
      GO T[illegible]1
 87   CONTINUE
      DO 19 J=1,[illegible]X
      SU[illegible]2=
      DO 2[illegible] I=1,[illegible]1
 2[illegible]   S[illegible]2=S[illegible]2+X2(I,J)
 19    X2([illegible]2,J)=1./X[illegible]*([illegible]2-X2(L[illegible]IGH,J))
      SU[illegible]2=
      DO 3[illegible] I=1,[illegible]1
      DO 3[illegible] J=1,[illegible]X

      S[illegible]2=S[illegible]2+(X2(I,J)-X2([illegible]2,J))**2
 30     CONTINUE
               F[illegible]IFER=([illegible]C+1)/X[illegible]1*SQRT(SU[illegible]2)
      IF(F[illegible]IFER.LT.FOLD) GO TO 98
     F[illegible] =F[illegible]
      GO T[illegible] 198
 98   F[illegible] =F[illegible]IFER
 198  CONTINUE

      F[illegible]=F([illegible])
```

```
137     C... = ...
        IF(... .LT.1.0E-*...) GO TO 37
        IF(... ...15...) GO TO 337
        ...=...5*...
337     C... = ...
        PR... 35
         ... 75...,I... ...,F...IFER
         CALL ...
37       IF(... ...  ...LT.C...VER) GO TO 81
        IF(L...IG...  ...1) GO TO 43
        FS=F(1)
         LSEC=1
         GO TO ...
43       FS =F(2)
        LS C=2
...       DO ... I=1, ...
         IF( ...IGH.... I) GO TO 18
        IF(F(I). ...FS) GO TO 18
                  FS =F(I)
        LSEC=I
18      CONTINUE
        DO 51 J=1, X
         X2( 3,J)=X2( 2,J)+ALFA*(X2(...2,J)-X2(HIGH,J))
51       X(J)=X2( 3,J)
        I = 3
        CALL S...
        SR( 3)=S...RT(SE...)
89       IF(SR( 3).LT.FDIFER) GO TO 82
         I...= 3
         CALL FEASBL
         IF(F...).LT.1.0E-04) GO TO 80
82       CALL PR...3
         F(...3)=...(X9)
         IF(F( 3).GT.F(LOW)) GO TO 84
         IF(F( 3).GT.F(LSEC)) GO TO 92
         GO TO ...
92        DO 93 J=1, X
93       X2(...IG...,J)=X2(...3,J)
        SR(...IG...)=SR(...3)
        F(...IG...)=F(...3)
        GO TO 1...
84       DO 23 J=1, X
         X2( ...,J)=X2(...3,J)+GAMMA*(X2(...3,J)-X2(...2,J))
23       X(J)=X2( ...,J)
         I = 4
        CALL S...
        SR( ...)=S...RT(SE...)
         IF(SR(...).LT.FDIFER) GO TO 25
         I...= ...
         CALL FEASBL
         IF(F...).LT.1...E-04) GO TO 80
25       CALL ...R...3
         F( ...)=R(X9)
        IF(F(LO...).LT.F( ...)) GO TO 92
        DO 26 J=1, X
```

```
26         X2(  .L. , . )=X2(N4,J)
       F(LIIG  )=F(  )
       SR(L  L..)=S  (  )
       GO  I .  1
 6.      IF(F(  J).  .F(HIGH)) GO TO 64
       DO  n    =  1,
 65      X2(.  1.  ,J)  =X2( 3,J)
 64      DO         =1, X
        X2(  ,  )=   *X2(LHIGH,J)+(1.-BETA)*X2(N2,J)
 66    X( )=X2(  ,  )
       I =
       CALL S
       SR( )=S   (SEQL)
       IF(S (  ). . .FDIFER) GO TO 67
       I  =
       CALL
       IF(F  .  . 1.0E-04) GO TO 80
  67    CALL      3
       F( 4)= ( )
       IF(F(  I  ).GT.F(N4)) GO TO 68
       DO  69 J= 1, X
       DO  69 I=, 1
 69     X2( , )= .5*(X2(I,J)+X2(L  ,J))
       DO  7   I=,  1
       DO  7   =1, X
 71     X(J)=X2(I,J)
       I =I
        CALL S  R
        SR( )=S  R (SEQL)
       IF(SR(I).LT.FDIFER) GO TO 72
       I F  =I
        CALL  E S L
        IF(  .LT.1.0E-04) GO TO 80
 72      CALL PR  3
 7.     F(L)=F( 9)
       GO  T   1
 68       DO 73 J=1, X
  73   X2( LG ,J)=X2(N4,J)
       SR(  LG )=SR(N4)
       F( HIG )=F( 4)
       GO  T   1
 81    PRI   76  ,ICO T,FDIFER
      CALL  RI  X
        PRI  7 755,FI  
        PRI  T 7 1
 80     P     7      ,ICO T,FDIFER
       CALL   I  X
       PRINT 762
       PRI   7621
 1      FOR AT(3I5,F10.5,E10.3)
2        FOR  (8F10.5)
 35      FOR   (/,2X,'**** **** **** **** **** **** **** **** ****
    1**** ****** ****** ****** ****** ')
 100     FOR AT (1H1,//)
7530 FOR AT(/,' *****************************************************')
115      FOR AT(//,' THE STARTING VECTOR SELECTED BY USER IS ' )
```

```
OR.FOR   F R...  /.5A(621) /A1    17-JUN-82          12:05    PAGE 1-5

 116    FOR AT(...15.6)
 755    FORMAT(//,' THE COMPUTATION TIME IN SECS. =' E12.5)
 756    FORMAT(//,10X,' NO. OF INDEPENDENT VARIABLES' I5,/,10X
    1   ,' NO. OF INEQUALITY CONSTRAINTS '15,/,10X,' NO. OF EQUIY. CONSTRS
    2   I5,/,10X,'SIZE OF INITIAL POLYHEDRON' E12.5,/,10X,'THE DESIRE
    3CONVERG. ... IS' F12.5,/,10X,' THE COMPUT TIME IN SECS'  5E12.5)
 757    FOR A (//,' THE INITIAL X VECTOR DOES NOT SATISFY THE TOL. CRI
    ITERIO '  )
 758    FOR   (/,10X,' STAGE CALC. NO.= ' I5,10X,' TOL.CRIT.=' E14.6)
 759    FORMAT(/,' RESULTS OF R.HYDRO AND R.THERMAL GEN. SCHEDULING PROB
 7591   FOR A (/,' CASE:DETER INISTIC A=1,K=1')
 7592   FOR A (/,' **********************************************')
 760    FOR A (//' TI...G.OF CALC. STAGES='I5,10X' CONVR.CRITC='E14.6)
 761      F    (//,35X,' THESE ARE NOT FINAL ANSWERS ' )
 762      F R A (//,35X,' THESE ARE  FINAL ANSWERS' )
 763    FOR A (//10X' THE INITIAL TOL. IS 'E12.5,/10X' SUM OF VOILATED
    1   CONSTRAINTS IS'  E12.5)
 764    FOR A (//' THE VECTOR FOUND BY PROG. WHICH SATISFY THE.TOL.IS')
 765    FOR A (/,' SUM OF VOILATED CONSTRAINTS=' E17.7 )
 7521 FOR A (/,'*****************************************************')
 9999    STOP
         END


LOCALS

216)
+0      ..C      +1      .IC     +2      STEP    +3      ALFA    +4
+5      GA  A    +6      I.      +7      I.P     +10     FOIFER  +11
+12     K1       +13     K2      +14     K3      +15     K4      +16
+17     K6       +20     K7      +21     K8      +22     K9      +23
+24     X1       +170    X2      +23610  R       +47230  SU.     +4737.
+47540  SR       +47704  ROLP    +50050  SCALE   +50214  FOLD    +50215

)
+0      L5       +1      L6      +2      L7      +3      L8      +4
+5      R1A      +6      R2A     +7      R3A     +10

A  S CALLED

 RITEX   FEASBL   PROB3   STANI   SUMR

A   ARRAYS ( "*" NO EXPLICIT DEFINITION - "%" NOT REFERENCED )

1       *STEP1   2      * .7     3      *F.L     4      *. 1     5
6       .S0032   7      * C      10     *XX X    11     .S0031   12
13      *ETA     14     %.       15     * .6     15     *X 1     16
17      * 5      20     *J       21     .S0007   22     .S0006   23
24      .S0004   25     *X       26     .S0003   27     .S0002   30
31      .S0001   32     .S0000   33     *LHIG.   34     *SIZE    35
36      .S0016   37     *TI  E   40     .S0015   41     .S0014   42
43      .S0013   44     * 3      45     .S0012   46     *FH      47
50      .S0011   51     *LO      52     .S0010   53     *STEP2   54
```

```
55        *[illegible] 2   5[illegible]     *I         57     *ICO[illegible]F  60     *[illegible]d     61
62         .S[illegible]26 [illegible]3       .S0025 64      .S0024 65     *[illegible]2     66
67         .S[illegible]22 7[illegible]       .S0021 71
```

IE[illegible]

[illegible]45

[[illegible] ERRORS [illegible]CTED]

```
        SU ROUTI   REASON
C*****SUR   REASON  INITIALIZES THE SU  OF THE SUM VALUES OF THE VOLCANO
C       CO SUBRI TS
        DI E SIO  X(100),X1(100,100),X2(100,100),R(100),SU (100),
     1F(100), ROLD(100),R1(100),R2(100),R3(100),FLG(100),I(100),
     2SR(100)
 100       FOR AT(8E16.6)
       CO  O /A1/ X, C, IC,STEP,DU 1,DU 2,DU 3,I ,I  ,FOIFER,S   ,K1,
     1K2,K3,K4,K5,K6,K7,K8,K9,X,X1,X2,R,SU ,F,SR,ROLD,SCALE,FOLD
       CO   O /A2/LREAS,L5,L6,L7,L8,L9,R1A,R2A,R3A
        AL  A=1.
        BE  A=0.5
        GA  A=2.
         X  X= X
        IC  I=
        LC EK=
         ICHEK=(
  25    CALL START
         DO 3 I=1,K1
        DO 4 J=1, X
  4     X(J)=X1 (I,J)
        I =I
        CALL SU
  3     CO TI UE
  28     SU  =SU (1)
        I DEX=1
        DO 7 I=2,K1
        IF(SU (I).LE.SU  ) GO TO 7
                SU  =SU (I)
        I DEX=I
  7     CO TI UE
        SU L=SU (1)
        KOU T=1
        DO 8 I=2,K1
        IF(SU L.LE.SU (I)) GO TO 8
        SU  =SU (I)
        KOU T=I
  8             CO TI UE
        DO 9 J=1, X
        SU 2=0.
         DO 10 I=1,K1
  10     SU 2=SU 2+X1(I,J)
       X1(K2,J)=1./X X*(SU 2-X1(I DEX,J))
         X1(K3,J)=2.*X1(K2,J)-X1(I DEX,J)
  9     X(J)=X1(K3,J)
         I =K3
         CALL SU R
      IF (SU (K3).GT.SU  ) GO TO 11
        IF (I DEX.EQ.1) GO TO 38
        SU S =SU (1)
        GO TO 39
  38    SU S= SU (2)
  39    DO 12 I=1,K1
        IF((I DEX-I).EQ.0) GO TO 12
        IF(SU (I).LE.SU S) GO TO 12
        SU S=SU (I)
```

```
12    C   L
      IF (S  (K3).GT.SU S) GO TO 13
      G    1
11      5  =1, X
      X1( ,  )=X1(K2,J)+2.*(X1(K3,J)-X1(K2,J))
15     X(J)=X (X , )
      I =
      CALL S
      IF(   ( ).GT.S  L) GO TO 16
      G    1
13    I (   ( 3).GT.S   ) G  TO 17
          =  , X
16    X1(    X,  )=X1(K3,J)
17        =1, X
      X1(  ,  )=0.5*X1(I DEX,J)+0.5*X1(K2,J)
19    X(J)= 1( 4,J)
      I =
      CALL S
      IF(S   .GT.SU (K4)) GO TO 6
      DO 2   =1, X
          20    I=1,K1
20    X1( ,  )= .5*(X1(I,J)+X1(KOUNT,J))
      D  2   I=1,K1
      D  3   =1, X
30    X(J)=X (I,J)
      I =1
      CALL S
29    CO TI UE
5     SU  =S  (1)
      K  =1
      DO 23 I=2,K1
      IF(S   .GT.SU (I)) GO TO 23
      S  =S  (I)
             KOU T=I
23    CO TI UE
      SR(I  )=SQRT(SU (KOU T))
      DO 27 J=1, X
27    X(J)=X1(K OU T,J)
      G    26
6     D  31 J=1,NX
31    X1(I   X,J)=X1(K4,J)
      S  (   EX)=SU (K4)
      GO T  5
16       21 J=1, X
      X1(I   X,J)=X1(K4,J)
21    X(J)=X1(I DEX,J)
      S   (I  EX)=S  (K4)
      SR(I  )=SQRT(S  (K4))
      GO T  26
14       22 J=1, X
      X1(I   X,J)=X1(K3,J)
22    X(J)=X1(I DEX,J)
      SU (I  EX)=S  (K3)
      SR(I  )=SQRT(S  (K3))
26    IC   =IC  T+1
      D  35 J=1, X
```

```
36        X2(I[illegible],[illegible])=X([illegible])
         IF(IC[illegible].[illegible].[illegible]1) [illegible] 50
         IC[illegible]=[illegible]
          DO 24 J=1,[illegible]
 24       X(J)=X1([illegible],[illegible])
         I[illegible]=K2
         CALL S[illegible]
         DIFER=[illegible]
         DO 57 I=1,[illegible]1
 57       DIFER=DI[illegible]R+(S[illegible] (I)-S[illegible] (K2))**2
         DIFER =1./([illegible])*S[illegible]RT(DIFER)
          IF(DIF[illegible].[illegible].1.[illegible]-7) GO TO 5[illegible]
 51        I[illegible] =K1
         STEP=2[illegible].*F[illegible]
         CALL S[illegible]
         SR(I[illegible])=[illegible]T(S[illegible])
                  [illegible] 52 J= 1, X
 52       X1(K1,J)=X(J)
         DO 53 J=1, X
         FACTOR=1.
         X(J)=X1(K1,J)+FACTOR*STEP
         X1(L9,J)=X(J)
         I[illegible]=L[illegible]
         CALL S[illegible]
                   X(J)=X1(K1,J)-FACTOR*STEP
         X1(L5,J)=X(J)
         I[illegible] =L5
         CALL S[illegible]
 56       IF(S[illegible] (L9).[illegible].S[illegible](K1)) GO TO 54
        IF(S[illegible] (L5).[illegible].S[illegible] (K1)) GO TO 55
        GO TO 97
 54        X1(L5,J)=X1(K1,J)
        S[illegible](L5)=S[illegible] (K1)
        X1(K1,J)=X1([illegible],J)
        SU[illegible](K1)=S[illegible] (L9)
        FACTOR=[illegible]+1.
        X(J)=X1(K1,J)+FACTOR*STEP
        IN=[illegible]9
        CAL[illegible]
        GO TO 5[illegible]
 55        X1(L[illegible],J)=X1(K1,J)
        S[illegible](L[illegible])=S[illegible] (K1)
        X1(K1,J)=X1(L5,J)
        S[illegible](K1)=S[illegible] (L5)
        FAC[illegible]=FAC[illegible]+1.
        X(J)=X1(K1,J)-FACTOR*STEP
         I[illegible]=L5
        CAL[illegible]
        GO TO 56
 97     H(J)=X1([illegible],J)-X1(L5,J)
        X1(L6,J)=X1(L5,J)+H(J)*R1A
        X(J)=X1([illegible],[illegible])
        I =[illegible]6
        CAL[illegible]
        X1([illegible]7,J)=X1(L5,J)+H(J)*R2A
        X(J)=X1(L7,J)
```

```
      I[illegible]=[illegible]7
      CAL[illegible]
      IF(S[illegible](L6).[illegible].S[illegible](L7)) GO TO 68
      X1(L8,J)=X1(L5,J)+(1.-R3A)*H(J)
      X1(L5,J)=X1(L7,J)
      X(J)=X1([illegible],J)
      I[illegible]=[illegible]
      CAL[illegible]
      IF(S[illegible]([illegible]) .G[illegible].S[illegible](L6)) GO TO 76
      X1(L5,J)=X1(L6,J)
      S[illegible](L5)=S[illegible](L6)
      GO TO 75
 76   X1(L9,J)=X1(L[illegible],J)
      S[illegible](L9)=S[illegible](L[illegible])
      GO TO 75
 68   X1(L9,J)=X1(L5,J)
      X1(L8,J)=X1(L5,J)+R3A*H(J)
      X(J)=X1(L[illegible],J)
      I[illegible]=L[illegible]
      CAL[illegible]
      STE[illegible]=[illegible]
      S[illegible](L[illegible])=S[illegible](L[illegible])
      IF(S[illegible](L7).GT.S[illegible](L8)) GO TO 71
      X1(L5,J)=X1(L8,J)
      S[illegible](L5)=S[illegible](L[illegible])
      GO TO 75
 71     X1(L[illegible],J)=X1(L7,J)
      S[illegible](L[illegible])=S[illegible](L7)
 75   IF(ABS(X1(L9,J)-X1(L5,J)).GT.0.01*FDIFER) GO TO 97
      X1([illegible],J)=X1(L7,J)
        X(J)=X1(L7,J)
      S[illegible](K1)=S[illegible](L5)
      SR(I[illegible])=S[illegible]RT(S[illegible](K1))
      IF(SR(I[illegible]).LT.F[illegible]IFER) GO TO 760
 53   CONTI[illegible]
      IC[illegible]=IC[illegible]+1
      STEP=[illegible]
      IF(IC[illegible].[illegible].2) GO TO 25
      F[illegible]L[illegible]=1.0E-12
      PRI[illegible]T 553
      PRI[illegible]T [illegible]5[illegible]
      PRI[illegible]T 551,(X(J), J=1,[illegible]X)
      PRI[illegible]T 552,F[illegible]IFER,SR(I[illegible])
      GO TO 4[illegible]
 760  DO 761 J=1,[illegible]X
      X2(I[illegible],J)=X1([illegible],J)
 761  X(J)=X1([illegible],J)
 50    IF(SR(I[illegible]).GT.F[illegible]IFER) GO TO 28
      IF(SR(I[illegible]).[illegible]) GO TO 35
      CALL P[illegible]3
      F[illegible]1=X(39)
      DO 139 J=1,[illegible]X
 139  X(J)=X2(I[illegible],J)
      CALL P[illegible]2
      DO [illegible] J=K7,K8
 40   R1(J)=X(J)
```

```
      DO 41 J=1, X
41    X(J)=X1(  ,J)
      CALL PE  2
      DO 42 J= 7, N
42    R3(J)=R(J)
      DO 43 J=1, X
      E(J)= X1(  ,J)- X2(I F,J)
43     X(J)=X2(I F,J)+ .5* (J)
      CALL P  2
      FLG(1)= .
      FLG(2)= .
      FLG(3)= .
      DO 44 J=K7,
      IF(R3(J).GE. .) GO TO 44
      FLG(1)=FLG(1)+R1(J)*R1(J)
      FLG(2)=FLG(2)+ (J)*R(J)
      FLG(3)=FLG(3)+R3( )*R3(J)
44    CONTINUE
      SR(I F)=S R (FLG(1))
      IF(SR(I F).LT.F IFER) GO TO 35
      ALFA1=FLG(1)-2.*FLG(2)+FLG(3)
      BETA1=3.*FLG(1)-4.*FLG(2)+FLG(3)
      RATIO=BETA1/( .*ALFA1)
      DO 45 J=1, X
45    X(J)=X2(I F,J)+ (J)*RATIO
      IN=IN
        CALL S  R
      SR(I F)=S R(S  L)
      IF(SR(I F).LT.F IFER) GO TO 465
      DO 49 I=1,2
      DO 48 J=1, X
48    X(J)=X(J)- .05*E(J)
      CALL S  R
      SR(I F)=S R (S  L)
      IF(SR(I F).LT.F IFER) GO TO 465
 49   CONTI
465   CALL P  3
      IF(R1  .GE. R(K9)) GO TO 46
      SR(I F)= .
      GO TO 35
 46   DO 47 J=1, X
 47   X2(I F,J)=X(J)
 35   CONTI
      DO 335 J=1, X
335   X(J)=X2(I F,J)
850   FOR AT(//' IT IS  OT POSSIBLE TO SATISFY THE VOILATED CONSTRTS SET
     1  FR  S IS VECT. THE SEARCH WILL BE TER TD.'/'PL. CHOOSE A  E
     2STARTING VECTOR A D RESTART SOLU.')
851    FOR AT(//,'THE STARTING VECT. FOR WHICH THE CONSTRTS,COULD NOT
     3  BE S  FIED IS'/,(8E16.6))
852   FOR A (//,'   TOL. CRIT.=' E14.6,20X, 'SQR OF CONST SQRD IS='
     2 E16.6)
853   FOR  (//, '* * * * * SUB. FEASBL FAILS TO FIND A FEASBLE PT*')
      RETURN
      END
```

BLOCKS

216)									
+0	AC	+1	IC	+2	STEP	+3	DUAL	+4	
+5	DU 3	+6	I	+7	INF	+10	FOIFER	+11	
+12	K1	+13	K2	+14	K3	+15	K4	+16	
+17	K6	+20	K7	+21	K8	+22	K9	+23	
+24	X1	+17	X2	+23610	R	+47230	SU	+4737	
+4754	SR	+477 +	ROLD	+50050	SCALE	+50214	FUUD	+5021	

)									
+0	L5	+1	L6	+2	L7	+3	L8	+4	
+5	R1A	+6	R2A	+7	R3A	+10			

AND CALLED

SQRT. ABS. PROG3 START SUBR

AND ARRAYS ("*" NO EXPLICIT DEFINITION - "%" NOT REFERENCED)

1	*ICONS	2	.S0037	3	.S0036	4	*ALFA1	5	
6	.S0034	7	.S0033	10	*BETA	11	.S0032	12	
13	.S0031	14	.S0030	15	H	16	*GAMA	162	
163	.S0044	164	.S0043	165	.S0042	166	*ALFA	167	
170	.S0045	171	R3	172	*INDEX	336	*SUMH	337	
340	*FLAG	341	.S0007	342	.S0006	343	.S0005	344	
345	*FACTOR	346	.S0003	347	%R2		.S0002	350	
351	.S0000	352	*SIZE	353	.S0017	354	.S0016	355	
356	.S0015	357	*DIFER	360	.S0014	361	R1	362	
526	.S0012	527	.S0011	530	.S0010	531	*SUMS	532	
533	*I	534	*ICONT	535	*SUMG	536	.S0027	537	
540	.S0026	541	.S0025	542	FLG	543	.S0024	707	
710	.S0022	711	*ECHEK	712	.S0021	713			

IES

1030 .0 1031

[NO ERRORS DETECTED]

```
      SUBROUTINE  LANC
      DIMENSION   (50,50)
      DIMENSION   X(100),X1(100,100),X2(100,100),R(100),SU(100),F(100),
     1  ROLD(100),SR(100)
      COMMON /  /  X, C,  IC,STEP,ALFA,BETA,GAMA,I ,I F,FDIFER,SEQ,K1,K2
     1K3,K4,  ,  ,K7,K8,K9,X,X1,X2,R,SU ,F,SR,ROLD,SCALE,FOLD
      COMMON / / L5,L5,L6,L7,L8,L9,R1A,R2A,R3A
      V = X
      STEP1=   /(V *SQRT(2.))*(SQRT(V +1.)+V -1.)
      STEP2=   /(V *SQRT(2.))*(SQRT(V +1.)-1.)
      DO 1 J=1, X
 1    A(1,J)= .
      DO 2 I=2, 1
      DO 4 J=1, X
 4    A(I,J)=STEP2
      L=I-1
 2    CONTINUE
      DO 3 I=1, 1
      DO 3 J=1, X
 3    X1(I,J)=X(J)+A(I,J)
      RETURN
      END
```

BLOCKS

216)									
+0	NC	+1	NIC	+2	STEP	+3	ALFA	+4	
+5	GAMA	+6	I	+7	IOF	+10	FDIFER	+11	
+12	K1	+13	K2	+14	K3	+15	K4	+16	
+17	K6	+20	K7	+21	K8	+22	K9	+23	
+24	X1	+170	X2	+23610	R	+47230	SU	+47374	
+47540	SR	+47704	ROLD	+50050	SCALE	+50214	FOLD	+50215	
)									
+0	L5	+1	L6	+2	L7	+3	L8	+4	
+5	R1A	+6	R2A	+7	R3A	+10			

NOT CALLED

AND ARRAYS ("*" NO EXPLICIT DEFINITION - "%" NOT REFERENCED)

	*	2	*J	3	.S0004 4	.S0003 5	
5	.S 2 4712		.S0001 4713		.S0006 4714	*STEP2	4715
4716	*I	4717					

1E[illegible]

172[illegible] .9[illegible] 721

[illegible] ERRORS [illegible]

```
        SUB     II      X
        DI    SI   X(   ),X1(100,100),X2(100,100),R(100),SU (100),F(100),
     1  R   ( ),  (1 2)
        C   / /   ,  C, IC,STEP,ALFA,BETA,GA A,I ,INF,FOIFER,   ,K1,K2
     1K3,  ,  ,  ,K7,K8,K9,X,X1,X2,R,SU ,F,SR,ROLD,SCALE,F
        C  / 2/    ,L5,L6,L7,L8,L9,K1A,K2A,R3A
        CAL
        PRI  1,  ( )
 1      FOR  (/,'      TIVE   .C VAL. =' E17.7)
        PRI    ,( ( ), J=1, X)
 2      FOR   (/, '    I DEPENDENT VECTORS ARE ' /(4E17.7))

        IF( C.   ) GO TO 6
        CAL
        PRI   3,  (R(J), J=1,  C)
 3      FOR  (/, '  THE EQUALITY CO STRAI TS VALUES ARE'  /(4E17.7))
 6      IF(  C.  )  GO TO 5
        CAL      2
        PRI  4 ,( (J), J=K7,K8)
 4      FOR  (/,'  E I EQ.CO STS. VAL.' /(4E17.7))
 5      RET R
        E
```

BLOCKS

2 15)

+	C	+1	IC	+2	STEP	+3	ALFA	+4	
+5	GA	+6	IN	+7	INF	+10	FOIFER	+11	
+12	K1	+13	K2	+14	K3	+15	K4	+16	
+17	K6	+20	K7	+21	K8	+22	K9	+23	
+24	X1	+17	X2	+23610	R	+47230	SUM	+47374	
+47540	SR	+47704	ROLD	+50050	SCALE	+50214	FOLD	+50215	

)

+	L5	+1	L6	+2	L7	+3	L8	+4
+5	R1A	+6	R2A	+7	R3A	+10		

CALLED

PRO 1   PRO 3

AND ARRAYS ("*" NO EXPLICIT DEFINITION - "%" NOT REFERENCED)

1   .S 2 2   .S0001 3   .S000 4

[illegible]

[illegible]

[ERRORS DETECTED]

```
DX.... R ...    .5 (..1) /..    17-..-82        11:..    PAG. 1

        S...    ..    ..
        DI.E.S...  ..(1  .),X1(1.0,1.0),X2(100,100),R(100),S.  (100),F(100),
       1  ... (1. .),S  (1..)
        C.  .. / 1/ .,  ., IC,STEP,ALFA,BETA,GA.A,I.,I.F,FDIFER,SF..,.1,..
       1K3,..,..,..,.7,..,.9,.,X1,X2,R,SU .,F,SK,ROLD,SCAL.,F...
        C..     /..../.  ..  .,L5,L6,L7,L8,L9,R1A,R2A,R3A
        S. (. .)= .
        CA.. ..   .
        S...= .
        I. (  ...  . ) G.   . 4
        D. 1  .=  7, .
        IF(.(.).G. .) .. TO 1
        SE..=.. ..+.(.)*R(J)
 1      C.. ..
 4      IF( .. . .) G  .. 3
        CAL. .. .
        D. 2 .=1, C
 2      SE..=.. ..+.(.)*R(J)
 3      S. (I )=S. .
 5      RE.. .
        E.D
```

```
L.OCKS

2.6)
+.       .C         +.       .IC       +2       STEP      +3       ALFA      +4
+5       GA..       +6       I.        +7       I.F       +10      FDIFER    +11
+12      K1         +13      K2        +14      K3        +15      K4        +16
+17      K.         +2.      K7        +21      K8        +22      K9        +23
+24      X1         +17.     X2        +23610   R         +47230   SU.       +4737.
+47540   SK         +.7704   ROLD      +50050   SCALE     +50214   FOLD      +50215

.)
+.       L5         +1       L6        +2       L7        +3       L8        +4
+5       R1A        +.       R2A       +7       R3A       +10

... CALLE.

PR. .1

A.. ARRAYS ( "*"   . EXPLICIT DEFI.ITION - "%" NOT REFERENCE.) )

1        .S.. 1 2          .S000 3

IF.

4

[ ... ERRORS DETECTED ]
```

AP – 2   DITERMINISTIC CASE


```
      SUBROUTINE PROB1
       DIMENSION X(100),X1(100,100),X2(100,100),R(100),SUM(100),F(100),
     1 RO[illegible](100),SR(100)
       COMMON /A1/ X, C, IC,STEP,ALFA,BETA,GAMMA,L[illegible],IGF,FDIFER,S[illegible],K1,K2
     1K3,K4,K5,K6,K7,K8,K9,X,X1,X2,R,SUM,F,SR,ROLD,SCALE,FOLD
       COMMON /A2/LE[illegible]S,L5,L6,L7,L8,L9,R1A,R2A,R3A
C     E[illegible]ITY CONSTRAINTS
      R(1)=X(1)+0.2*(1+(.5E-7)*(240-X(7)))*X(7)*(1-.0001*
     1 (1+(.5E-7)*(240-X(7)))*X(7))-X(1)*X(1)*.0005-35
      R(2)=X(2)+0.2*(1+.5*(1.E-7)*(440-2*X(7)-X(8)))*X(8)*(1-
     1 .[illegible]1*(1+0.5*(1.E-7)*(440-2*X(7)-X(8)))*X(8))-X(2)*X(
     1 2)*.0005-35
      R(3)=X(3)+(1-.0001*(1+0.5*(1.E-7)*(640-2*X(7)-2*X(8)-X(9)))
     1*X(9))*0.2*(1+0.5*(1.E-7)*(640-2*X(7)-2*X(8)-X(9)))
     2*X(9)-X(3)*X(3)*0.0005-35
      R(4)=X(4)+(1-.0001*(1+0.5*(1.E-7)*(840-2*X(7)-2*X(8)-2*X(9)-
     1X(10)))*X(10))*0.2*(1+0.5*(1.E-7)*(840-2*X(7)-2*X(8)-2*X(9)
     2-X(10)))*X(10)-X(4)*X(4)*0.0005-50
      R(5)=X(5)+(1-.0001*(1+0.5*(1.E-7)*(1040-2*X(7)-2*X(8)-2*X(9)
     1-2*X(10)-X(11)))*X(11))*0.2*(1+0.5*(1.E-7)*(1040-2*X(7)
     2-2*X(8)-2*X(9)-2*X(10)-X(11)))*X(11)-X(5)*X(5)*0.0005-30
      R(6)=X(6)+(1-.0001*(1+0.5*(1.E-7)*(1240-2*X(7)-2*X(8)-2*X(9)
     1-2*X(10)-2*X(11)-X(12)))*X(12))*0.2*(1+0.5*(1.E-7)*(1240
     2-2*X(7)-2*X(8)-2*X(9)-2*X(10)-2*X(11)-X(12)))*X(12)-X(6)*X(6)
     3*.0005-30
      RETURN
      END
```

LOCAS

```
216)
+0       C       +1       NIC      +2       STEP     +3       ALFA     +4
+5       GAMMA   +6       I[illegible]       +7       IGF      +10      FDIFER   +11
+12      K1      +13      K2       +14      K3       +15      K4       +16
+17      K6      +20      K7       +21      K8       +22      K9       +23
+24      X1      +170     X2       +23610   R        +47230   SUM      +47374
+47540   SR      +47704   ROLD     +50050   SCALE    +50214   FOLD     +50215

)
+0       L5      +1       L6       +2       L7       +3       L8       +4
+5       R1A     +6       R2A      +7       R3A      +10
```

[illegible] CALLED

[illegible] ARRAYS ("*" NO EXPLICIT DEFINITION - "%" NOT REFERENCED)

[illegible]K.CGR FORTRAN V.5(621) /KI 17-JUL-82 12:[illegible]5 PAGE 1-1

END

[NO ERRORS DETECTED]

```
      S[illegible]
C     [illegible]
      DIMENSION X(1[illegible]),X1(100,100),X2(100,100),R(100),SU(100),F(100),
     1 [illegible](1[illegible])
      COMMON /[illegible]/ X,[illegible]C,[illegible]C,STEP,ALFA,BETA,GAMMA,[illegible],[illegible]F,FDIFER,[illegible],K1,K2
     1K3,[illegible],L5,[illegible],[illegible],K9,[illegible],X1,X2,R,SU[illegible],F,SR,RHO[illegible],SCALE,F[illegible]
      COMMON /[illegible]/[illegible],L5,L6,L7,L8,L9,K1A,K2A,K3A
      R(7)=X(7)-2
      R(8)=X(8)-2
      R(9)=X(9)-2
      R(10)=X(10)-2
      R(11)=X(11)-2
      R(12)=X(12)-2
      R(13)=130-X(7)
      R(14)=130-X(8)
      R(15)=130-X(9)
      R(16)=130-X(10)
      R(17)=130-X(11)
      R(18)=130-X(12)
      R(19)=170-X(7)
      R(20)=270-X(7)-X(8)
      R(21)=370-X(7)-X(8)-X(9)
      R(22)=470-X(7)-X(8)-X(9)-X(10)
      R(23)=570-X(7)-X(8)-X(9)-X(10)-X(11)
      R(24)=670-X(7)-X(8)-X(9)-X(10)-X(11)-X(12)
      R(25)=X(7)-100
      R(26)=X(7)+X(8)-200
      R(27)=X(7)+X(8)+X(9)-300
      R(28)=X(7)+X(8)+X(9)+X(10)-400
      R(29)=X(7)+X(8)+X(9)+X(10)+X(11)-500
      R(30)=X(7)+X(8)+X(9)+X(10)+X(11)+X(12)-600
      R(31)=X(1)
      R(32)=X(2)
      R(33)=X(3)
      R(34)=X(4)
      R(35)=X(5)
      R(36)=X(6)
      R(37)=50-X(1)
      R(38)=50-X(2)
      R(39)=50-X(3)
      R(40)=50-X(4)
      R(41)=50-X(5)
      R(42)=50-X(6)
      R(48)=35-.2*(1+(1.E-07)*(1240-2*X(7)-2*X(8)-2*X(9)-2*X(10)
     1 -2*X(11)-X(12))/2.)*X(12)
      R(47)=35-.2*(1+(1.E-07)*(1040-2*X(7)-2*X(8)-2*X(9)-2*X(10)
     1 -X(11))/2.)*X(11)
      R(46)=35-.2*(1+(1.E-07)*(840-2*X(7)-2*X(8)-2*X(9)-X(10)
     1 )/2.)*X(10)
      R(45)=35-.2*(1+(1.E-07)*(640-X(7)*2-X(8)*2-X(9))/2)*X(9)
      R(44)=35-.2*(1+(1.E-07)*(440-2*X(7)-X(8))/2)*X(8)
      R(43)=35-.2*(1+(1.E-07)*(240-X(7))/2)*X(7)
      RETURN
      END
```

```
LOCAS

71(0)
+0       IC      +1       IC      +2       STEP    +3       ALFA    +4
+5       G[illegible]    +6       I[illegible]  +7       I.F     +10      FILTER  +11
+12      K1      +13      K2      +14      K3      +15      K4      +16
+17      K6      +20      K7      +21      K8      +22      K9      +23
+24      X1      +17[illegible]   X2      +23610   R       +47230   SD[illegible]     +47374
+47540   S[illegible]      +477[illegible]   ROLD    +47705   SCALE   +47706   FOLD    +47707

)
+0       L5      +1       L6      +2       L7      +3       L8      +4
+5       R1A     +6       R2A     +7       R3A     +10

[illegible] CALLE[illegible]


[illegible] ARRAYS ( "*" [illegible] EXPLICIT DEFINITION - "%" NOT REFERENCED )


IF


[illegible] ERRORS DETECTED ]
```

```
        SUBROUTI E  RO  3
C       OBJECTIVE F  C.
      DI  NSIO  X(1  ),X1(100,100),X2(100,100),R(100),SU (100),F(100),
     1 ROLD(1  )
      CO    /A1/ X, C, IC,STEP,ALFA,BETA,GA A,I  ,INF,FDIFER,S  ,K1,K2
     1K3,K4,K5, 6,K7,K8,K9,X,X1,X2,R,SU ,F,SR,R LD,SCALE,FOLD
      CO    /A2/ E  S,L5,L6,L7,L8,L9,R1A,R2A,R3A
        R( 9)=2.5*X(1)+.05*X(1)*X(1)+2.5*X(2)+.05*X(2)*X(2)
     1  +2.5*X(3)+. 5*X(3)*X(3)+2.5*X(4)+.05*X(4)*X(4)+2.5*
     1  X(5)+. 5*X(5)*X(5)+2.5*X(6)+.05*X(6)*X(6)
        RET  N
        E  
```

LOCKS

710)									
+0	C	+1	IC	+2	STEP	+3	ALFA	+4	
+5	GA A	+6	I	+7	INF	+10	FDIFER	+11	
+12	K1	+13	K2	+14	K3	+15	K4	+16	
+17	K6	+20	K7	+21	K8	+22	K9	+23	
+24	X1	+17	X2	+23610	R	+47230	SU	+47374	
+47540	SR	+47704	ROLD	+47705	SCALE	+47706	FOLD	+47707	
)									
+0	L5	+1	L6	+2	L7	+3	L8	+4	
+5	R1A	+6	R2A	+7	R3A	+10			

A CALLED

A D ARRAYS ("*" O EXPLICIT DEFINITION - "%" NOT REFERENCED)

IES

[ ] ERRORS DETECTED]

```
      SUBROUTINE [illegible]
      DIMENSION S[illegible] X(1[illegible]),X1(100,100),X2(100,100),R(100),SU (100),F(100),
     1 R[illegible](1 ),[illegible](100)
      CO[illegible] / [illegible]/ X, C, IC,STEP,ALFA,BETA,GA[illegible]A,I[illegible],IAF,FDIFER,SE[illegible],K1,K2
     1K3,K4,K5,K6,K7,K8,K9,X,X1,X2,R,SU ,F,SR,ROLD,SCALE,FOLD
      CO[illegible] / [illegible]/L[illegible]S,L5,L6,L7,L8,L9,R1A,R2A,R3A
C     EQUALITY C[illegible]TRAINTS
      R(1)=X(1)+[illegible].2*(1+(.5E-7)*(240-X(7)))*X(7)*(1-.0001*
     1 (1+(.5E-7)*(240-X(7)))*X(7))-X(1)*X(1)*.0005-35
      R(2)=X(2)+[illegible].2*(1+.5*(1.E-7)*(440-2*X(7)-X(8)))*X(8)*(1-
     1 .[illegible]1*(1+ .5*(1.E-7)*(440-2*X(7)-X(8)))*X(8))-X(2)*X(
     1 2)*[illegible]5-3[illegible]
      R(3)=X(3)+(1-.0001*(1+0.5*(1.E-7)*(640-2*X(7)-2*X(8)-X(9)))
     1*X(9))*[illegible].2*(1+0.5*(1.E-7)*(640-2*X(7)-2*X(8)-X(9)))
     2*X(9)-X(3)*X(3)*0.0005-35
      R(4)=X(4)+(1-.0001*(1+0.5*(1.E-7)*(840-2*X(7)-2*X(8)-2*X(9)-
     1X(1 )))*X(1 ))*0.2*(1+0.5*(1.E-7)*(840-2*X(7)-2*X(8)-2*X(9)
     2-X(1 )))*X(10)-X(4)*X(4)*0.0005-50
      R(5)=X(5)+(1-.0001*(1+0.5*(1.E-7)*(1040-2*X(7)-2*X(8)-2*X(9)
     1-2*X(1 )-X(11)))*X(11))*0.2*(1+0.5*(1.E-7)*(1040-2*X(7)
     2-2*X( )-2*X(9)-2*X(10)-X(11)))*X(11)-X(5)*X(5)*0.0005-30
      R(6)=X(6)+(1-.0001*(1+0.5*(1.E-7)*(1240-2*X(7)-2*X(8)-2*X(9)
     1-2*X(1 )-2*X(11)-X(12)))*X(12))*0.2*(1+0.5*(1.E-7)*(1240
     2-2*X(7)-2*X(8)-2*X(9)-2*X(10)-2*Y(11)-X(12)))*X(12)-X(6)*X(6)
     3*.[illegible]5-3[illegible]
      RET[illegible]
      E[illegible]
```

LOCALS

216)									
+0	C	+1	IC	+2	STEP	+3	ALFA	+4	
+5	GA[illegible]	+6	I[illegible]	+7	IAF	+10	FDIFER	+11	
+12	K1	+13	K2	+14	K3	+15	K4	+16	
+17	K6	+20	K7	+21	K8	+22	K9	+23	
+24	X1	+170	X2	+23610	R	+47230	SU	+4737[illegible]	
+47540	SR	+47704	ROLD	+50050	SCALE	+50214	FOLD	+50215	
)									
+0	L5	+1	L6	+2	L7	+3	L8	+4	
+5	R1A	+6	R2A	+7	R3A	+10			

A[illegible] CALLED

A[illegible]D ARRAYS ["*" [illegible] EXPLICIT DEFINITION - "%" NOT REFERENCED]

END

[NO ERRORS [illegible]]

```
      S[illegible]
C     [illegible] ( [illegible]TS
      DI[illegible] X(1[illegible]),X1(100,100),X2(100,100),R(100),S0(100),F(100),
     1 R[illegible](1[illegible])
      C[illegible] /[illegible]/ X, C, IC,STEP,ALFA,BETA,GAMMA,J[illegible],I[illegible],FDIFER,SEGL,[illegible],K2
     1K3,[illegible],[illegible]5,[illegible],K7,K8,K9,X,X1,X2,R,S0[illegible],F,SR,ROLD,SCALE,FOLD
      C[illegible] /[illegible]2/[illegible]S,L5,L6,L7,L8,L9,R1A,R2A,R3A
       R(7)=X(7)-2
       R(8)=X(8)-2
       R(9)=X(9)-2
       R(10)=X(10)-2
       R(11)=X(11)-2
       R(12)=X(12)-2
       R(13)=13.-X(7)
       R(14)=13.-X(8)
       R(15)=13.-X(9)
       R(16)=13.-X(10)
       R(17)=13.-X(11)
       R(18)=13.-X(12)
       R(19)=17.-X(7)
       R(20)=27.-X(7)-X(8)
       R(21)=37.-X(7)-X(8)-X(9)
       R(22)=47.-X(7)-X(8)-X(9)-X(10)
       R(23)=57.-X(7)-X(8)-X(9)-X(10)-X(11)
       R(24)=67.-X(7)-X(8)-X(9)-X(10)-X(11)-X(12)
       R(25)=X(7)-100
       R(26)=X(7)+X(8)-200
       R(27)=X(7)+X(8)+X(9)-300
       R(28)=X(7)+X(8)+X(9)+X(10)-400
       R(29)=X(7)+X(8)+X(9)+X(10)+X(11)-500
       R(30)=X(7)+X(8)+X(9)+X(10)+X(11)+X(12)-600
       R(31)=X(1)
       R(32)=X(2)
       R(33)=X(3)
       R(34)=X(4)
       R(35)=X(5)
       R(36)=X(6)
       R(37)=5.-X(1)
       R(38)=5.-X(2)
       R(39)=5.-X(3)
       R(40)=5.-X(4)
       R(41)=5.-X(5)
       R(42)=5.-X(6)
       R(48)=35-.2*(1+(1.E-07)*(1240-2*X(7)-2*X(8)-2*X(9)-2*X(10)
     1 -2*X(11)-X(12))/2.)*X(12)
       R(47)=35-.2*(1+(1.E-07)*(1040-2*X(7)-2*X(8)-2*X(9)-2*X(10)
     1 -X(11))/2.)*X(11)
       R(46)=35-.2*(1+(1.E-07)*(840-2*X(7)-2*X(8)-2*X(9)-X(10)
     1 )/2.)*X(10)
       R(45)=35-0.2*(1+(1.E-07)*(640-X(7)*2-X(8)*2-X(9))/2)*X(9)
       R(44)=35-.2*(1+(1.E-07)*(440-2*X(7)-X(8))/2)*X(8)
       R(43)=35-.2*(1+(1.E-07)*(240-X(7))/2)*X(7)
       RETURN
       END
```

```
LOCKS

71()
+0       KC      +1       NIC     +2       STEP    +3       ALFA    +4
+5       G       +6       I       +7       I F     +10      FL12ER  +11
+12      K1      +13      K2      +14      K3      +15      K4      +16
+17      K6      +20      K7      +21      K8      +22      K9      +23
+24      X1      +170     X2      +23610   R       +47230   SU      +47376
+47540   S       +47704   ROLD    +47705   SCALE   +47706   FOLD    +47707

)
+0       L5      +1       L6      +2       L7      +3       L8      +4
+5       R1A     +6       R2A     +7       R3A     +10

A . CALLED

A D ARRAYS ( "*" NO EXPLICIT DEFINITION - "%" NOT REFERENCED )

IES

[ . ERRORS DETECTED ]
```

```
C            S[illegible] [illegible]3
             [illegible]C[illegible] F[illegible] C.
        DI[illegible]SI[illegible] X(1[illegible]),X1(100,100),X2(100,100),R(100),SU[illegible](100),F(100),
      1  [illegible](1[illegible])
        CO[illegible] /[illegible]/ X, C, IC,STEP,ALFA,BETA,GA A,I[illegible],L[illegible]F,FDIFER,SF[illegible],[illegible]
      1K3,[illegible]4,[illegible],[illegible]6,[illegible]7,[illegible]8,K9,X,X1,X2,R,SU ,F,SR,ROLD,SCALE,FOLD
        C[illegible]   / 2/L[illegible]S,L5,L6,L7,L8,L9,R1A,R2A,R3A
         R([illegible])=2.5*X(1)+.05*X(1)*X(1)+2.5*X(2)+.05*X(2)*X(2)
      1  +2.5*X(3)+.05*X(3)*X(3)+2.5*X(4)+.05*X(4)*X(4)+2.5*
      1  X(5)+.05*X(5)*X(5)+2.5*X(6)+.05*X(6)*X(6)
         [illegible]
```

L[illegible]C[illegible]S

```
71[illegible])
+0       C         +1        IC       +2       STEP     +3       ALFA     +4
+5       G[illegible]      +6        I[illegible]       +7       I[illegible]F      +10      FDIFER   +11
+12      K[illegible]       +13       K2       +14      K3       +15      K4       +16
+17      K[illegible]       +20       K7       +21      K8       +22      K9       +23
+24      X1       +17[illegible]      X2       +23610   R        +47230   SU[illegible]      +47374
+4754[illegible]   SR       +477[illegible]4    ROLD     +47705   SCALE    +47706   FOLD     +477[illegible]7

)
+0       L5       +1        L6       +2       L7       +3       L8       +4
+5       R1A      +6        R2A      +7       R3A      +10
```

A[illegible] CAL[illegible]

A[illegible] ARRAY: ("*" [illegible] EXPLICIT DEFINITION - "%" NOT REFERENCED)

IF[illegible]

([illegible] ERRORS DETECTED)

```
****H.HYDRO AND R.THERMAL GENERATION SCHEDULING PROBLEM FORMULATION***
      INTEGER H,R,P
      REAL JJ
      DIMENSION UMIN(25),UMAX(25),XMIN(25),XMAX(25)
      DIMENSION PTMIN(25),PTMAX(25),PHMIN(25),PHMAX(25)
      DIMENSION CC(25),HH(25),BB(25,25),ACOEF(25),BCOEF(25)
       DIMENSION PH(25,25),PLOSS(15),PD(25),XX(15,15),JJ(15,15)
      DIMENSION UU(15,15),PT(15,15),RR(500),X(400)
      COMMON /AREA1/H,R,P
      COMMON /AREA1/UMIN,UMAX,XMIN,XMAX
      COMMON /AREA1/PTMIN,PTMAX,PHMIN,PHMAX
      COMMON /AREA1/CC,HH,BB,ACOEF,BCOEF,PD,XX,JJ

      IX=P*R
      DO 5 I=1,R
      DO 5 K=1,P
 5    PT(I,K)=X((I-1)*P+K)
      DO 6 I=1,H
      DO 6 K=1,P
 6    UU(I,K)=X(IX+(I-1)*P+K)
      G=100
      CALCULATE XX(I,K)
      DO 10 K=1,P
      DO 10 I=1,H
10    XX(I,K+1)=XX(I,K)+JJ(I,K)-UU(I,K)
      CALCULATE PH(I,K)
      DO 12 I=1,H
      DO 12 K=1,P
12    PH(I,K)=HH(I)*UU(I,K)*(1.+CC(I)*(XX(I,K)+XX(I,K+1))/2.)/G
      CALCULATE PLOSS(K)
        DO 13 K=1,P
        PLOSS(K)=0.
      DO 13 I=1,H
13    PLOSS(K)=PLOSS(K)+PH(I,K)*BB(I,I)*PH(I,K)
      DO 14 K=1,P
       DO 14 J=H+1,R+H
14       PLOSS(K)=PLOSS(K)+PT(J-H,K)*PT(J-H,K)*BB(J,J)
      GO TO (80,81,82)INQ
      CALCULATE EQ.CONSTRAINTS
80    DO 15 K=1,P
      RR(K)=-PD(K)-PLOSS(K)
      DO 16 J=1,R
16    RR(K)=RR(K)+PT(J,K)
      DO 15 I=1,H
15    RR(K)=RR(K)+PH(I,K)
      RETURN
      CALCULATE INEQ.CONSTRAINTS (PROB2)
1       IH=H
 1    DO 20 K=1,P
      DO 20 I=1,IH
22       RR(P*(K+H)+I)=UMAX(I)-UU(I,K)
20    RR(K*P+I)=UU(I,K)-UMIN(I)
      CALCULATE STORAGE
      DO 30 K=1,P
      DO 30 I=1,H
      RR(P*(H+H+H+K)+I)=XMAX(I)-XX(I,K+1)
```

```
30      RR(P*(H+H+K)+I)=XX(I,K+1)-XMIN(I)
        IX=4*P*H
        IX1=IX+P*R
        DO 35 K=1,P
        DO 35 I=1,R
        RR(IX1+K*P+I)=PTMAX(I)-PT(I,K)
35      RR(IX+K*P+I)=PT(I,K)-PTMIN(I)
        IX=4*P*H+2*P*R
        IX1=IX+P*H
        DO 40 K=1,P
        DO 4) I=1,H
        RR(IX1+K*P+I)=PHMAX(I)-PH(I,K)
40      RR(IX+K*P+I)=PH(I,K)-PHMIN(I)
        RETUR
        CALCULATE OBJECTIVE FUNC.
82      IX=6*P*H+1+2*P*R+P
        RR(IX)=0
        DO 45 K=1,P
        DO 45 I=1,R
45      RR(IX)=RR(IX)+ACOEF(I)*PT(I,K)+BCOEF(I)*PT(I,K)*PT(I,K)
        RETUR
        END
```

```
OCKS

2573)
0       R       +1      P       +2      UMIN    +3      UMAX    +34
55      XMAX    +116    PTMIN   +147    PTMAX   +200    PHMIN   +231
262     CC      +313    HH      +344    BB      +375    ACOEF   +1556
1607    PD      +1640   XX      +1671   JJ      +2232

*S CALLED


ND ARRAYS [ "*" NO EXPLICIT DEFINITION - "%" NOT REFERENCED ]

        *K      2       .S0030  3       PT      4       PLOSS   345
54      UU      365     PH      726     *J      2107    .S0007  2110
111     .S0006  2112    .S0005  2113    .S0004  2114    .S0003  2115
116     .S0001  2117    .S0000  2120    *IX1    2121    .S0017  2122
123     .S0016  2743    .S0015  2744    *IH     2745    .S0014  2746
747     .S0012  2750    .S0011  2751    .S0010  2752    .10000  2753
754     .S0027  2755    RR      2756    .S0026  3742    *IX     3743
744     .S0024  3745    .S0023  3746    .S0022  3747    .S0021  3750

ES


 NO ERRORS DETECTED ]
```

```
      SUBROUTINE READ
      INTEGER H,R,P
       REAL JJ
      DIMENSION UMIN(25),UMAX(25),XMIN(25),XMAX(25)
      DIMENSION PTMIN(25),PTMAX(25),PHMIN(25),PHMAX(25)
      DIMENSION CC(25),HH(25),BB(25,25),ACOEF(25),BCOEF(25),PD(25),
     1XX(15,15),JJ(15,15)
      COMMON /AREA1/H,R,P
      COMMON /AREA1/UMIN,UMAX,XMIN,XMAX
      COMMON /AREA1/PTMIN,PTMAX,PHMIN,PHMAX
      COMMON /AREA1/CC,HH,BB,ACOEF,BCOEF,PD,XX,JJ
      OPEN (UNIT=1,FILE='UNK.DAT')
      READ (1,*) H,R,P
      READ (1,*) (UMIN(I),I=1,H)
      READ (1,*) (UMAX(I),I=1,H)
      READ (1,*) (XMIN(I),I=1,H)
      READ (1,*) (XMAX(I),I=1,H)
      READ(1,*) (PTMIN(I),I=1,R)
      READ (1,*) (PTMAX(I),I=1,R)
      READ (1,*) (PHMIN(I),I=1,H)
      READ (1,*) (PHMAX(I),I=1,H)
      READ (1,*) (CC(I),I=1,H)
      READ (1,*) (HH(I),I=1,H)
      DO 5 K=1,R+H
5     READ (1,*) (BB(I,K),I=1,R+H)
      READ (1,*) (ACOEF(I),I=1,R)
      READ (1,*) (BCOEF(I),I=1,R)
      READ (1,*) (PD(I),I=1,P)
      READ (1,*) (XX(I,1),I=1,H)
      DO 8 I=1,H
8     READ (1,*) (JJ(I,K),K=1,P)
      CLOSE (UNIT=1) .

      RETURN
      END
```

OCKS

```
2573)
0       R       +1      P       +2      UMIN    +3      UMAX    +34
65      XMAX    +116    PTMIN   +147    PTMAX   +200    PHMIN   +231
262     CC      +313    HH      +344    BB      +375    ACOEF   +1556
1607    PD      +1640   XX      +1671   JJ      +2232
```

NS CALLED

ND ARRAYS ["*" NO EXPLICIT DEFINITION - "%" NOT REFERENCED]

```
*K       2        .S0007 3        .S0006 4        .S0005 5
 .S0003 7         .S0002 10       .S0001 11       .S0000 12
```

```
7 13        .S0016 14       .S0015 15       .S0014 16       .S0013 17
2 20        .S0011 21       .S0010 22       *I     23       .S0021 24
```

ARIES

b 25

[NO ERRORS DETECTED]

```
C****1.HYDRO THERMAL GEN. SCHEDULING PRO
      SUBROUTINE PROB1
      DIMENSION X(100),X1(100,100),X2(100,100),
     1 ROLD(100),SR(100)
      COMMON/A1/JX,NC,NIC,STEP,ALFA,BETA,K1,K2,
     1K3,K4,K5,K6,K7,K8,K9,X,X1,X2,R,SUM,
      COMMON/A2/LFEAS,L5,L6,L7,L8,L9,R1A,
C     EQUALITY CONSTRAINTS
      RETURN
      END
      SUBROUTINE PROB2
C     I EQ. CONSTRAINTS
      DIMENSION X(100),X1(100,100),X2(100,100),SR(100),
     1 ROLD(100)
      COMMON/A1/JX,NC,NIC,STEP,ALFA,BETA,K1,K2,
     1K3,K4,K5,K6,K7,K8,K9,X,X1,X2,R,SUM,
      COMMON/A2/LFEAS,L5,L6,L7,L8,L9,R1A,
      R(1)=X(1)+0.2*(1+(.5E-7)*(240-X(7)
     1 (1+(.5E-7)*(240-X(7)))*X(7))-X(1)*X
      R(2)=X(2)+0.2*(1+.5*(1.E-7)*(440-2
     1 .0001*(1+0.5*(1.E-7)*(440-2*X(7)-X
     1 2)*0.0005-39.359
      R(3)=X(3)+(1-.0001*(1+0.5*(1.E-7)*
     1*X(9))*0.2*(1+0.5*(1.E-7)*(640-2*
     2*X(9)-X(3)*X(3)*0.0005-39.359
      R(4)=X(4)+(1-.0001*(1+0.5*(1.E-7)*
     1X(10)))*X(10))*0.2*(1+0.5*(1.E-7)
     2-X(10)))*X(10)-X(4)*X(4)*0.0005-3
      R(5)=X(5)+(1-.0001*(1+0.5*(1.E-7)*
     1-2*X(10)-X(11)))*X(11))*0.2*(1+0.
     2-2*X(8)-2*X(9)-2*X(10)-X(11)))*X(
      R(6)=X(6)+(1-.0001*(1+0.5*(1.E-7)*
     1-2*X(10)-2*X(11)-X(12)))*X(12))*0
     2-2*X(7)-2*X(8)-2*X(9)-2*X(10)-2*X
     3*.0005-34.359
      R(7)=X(7)-2
      R(8)=X(8)-2
      R(9)=X(9)-2
      R(10)=X(10)-2
      R(11)=X(11)-2
      R(12)=X(12)-2
      R(13)=130-X(7)
      R(14)=130-X(8)
      R(15)=130-X(9)
      R(16)=130-X(10)
      R(17)=130-X(11)
      R(18)=130-X(12)
      R(19)=170-X(7)
      R(20)=270-X(7)-X(8)
      R(21)=370-X(7)-X(8)-X(9)
      R(22)=470-X(7)-X(8)-X(9)-X(10)
      R(23)=570-X(7)-X(8)-X(9)-X(10)-X(1
      R(24)=670-X(7)-X(8)-X(9)-X(10)-X(1
      R(25)=X(7)-100
      R(26)=X(7)+X(8)-200
      R(27)=X(7)+X(8)+X(9)-300
      R(28)=X(7)+X(8)+X(9)+X(10)-400
      R(29)=X(7)+X(8)+X(9)+X(10)+X(11)-50
      R(30)=X(7)+X(8)+X(9)+X(10)+X(11)+X(
      R(31)=X(1)
      R(32)=X(2)
      R(33)=X(3)
      R(34)=X(4)
      R(35)=X(5)
      R(36)=X(6)
      R(37)=50-X(1)
      R(38)=50-X(2)
      R(39)=50-X(3)
      R(40)=50-X(4)
      R(41)=50-X(5)
```

APPENDIX
AP-4 STOCHASTIC CASE

```
C****1.HYDRO 1THERMAL GEN. SCHEDULING PROBLEM ********************
        SUBROUTINE PROB1
      DIMENSION X(100),X1(100,100),X2(100,100),R(100),SUM(100),F(100),
     1  ROLD(100),SR(100)
      COMMON/A1/NX,NC,NIC,STEP,ALFA,BETA,GAMA,IN,INF,FDIFER,SEQL,K1,K2,
     1K3,K4,K5,K6,K7,K8,K9,X,X1,X2,R,SUM,F,SR,ROLD,SCALE,FOLD
      COMMON/A2/LFEAS,L5,L6,L7,L8,L9,R1A,R2A,R3A
C     EQUALITY CONSTRAINTS
        RETURN
        END
        SUBROUTINE PROB2
C       INEQ. CONTRAINTS
      DIMENSION X(100),X1(100,100),X2(100,100),R(100),SUM(100),F(100),SR(100),
     1  ROLD(100)
      COMMON/A1/NX,NC,NIC,STEP,ALFA,BETA,GAMA,IN,INF,FDIFER,SEQL,K1,K2,
     1K3,K4,K5,K6,K7,K8,K9,X,X1,X2,R,SUM,F,SR,ROLD,SCALE,FOLD
      COMMON/A2/LFEAS,L5,L6,L7,L8,L9,R1A,R2A,R3A
        R(1)=X(1)+0.2*(1+(.5E-7)*(240-X(7)))*X(7)*(1-.0001*
     1 (1+(.5E-7)*(240-X(7)))*X(7))-X(1)*X(1)*.0005-39.359
        R(2)=X(2)+0.2*(1+.5*(1.E-7)*(440-2*X(7)-X(8)))*X(8)*(1-
     1  .0001*(1+0.5*(1.E-7)*(440-2*X(7)-X(8)))*X(8))-X(2)*X(
     1  2)*0.0005-39.359
        R(3)=X(3)+(1-.0001*(1+0.5*(1.E-7)*(640-2*X(7)-2*X(8)-X(9)))
        1*X(9))*0.2*(1+0.5*(1.E-7)*(640-2*X(7)-2*X(8)-X(9)))
        2*X(9)-X(3)*X(3)*0.0005-39.359
        R(4)=X(4)+(1-.0001*(1+0.5*(1.E-7)*(840-2*X(7)-2*X(8)-2*X(9)-
        1X(10)))*X(10))*0.2*(1+0.5*(1.E-7)*(840-2*X(7)-2*X(8)-2*X(9)
        2-X(10)))*X(10)-X(4)*X(4)*0.0005-54.359
        R(5)=X(5)+(1-.0001*(1+0.5*(1.E-7)*(1040-2*X(7)-2*X(8)-2*X(9)
        1-2*X(10)-X(11)))*X(11))*0.2*(1+0.5*(1.E-7)*(1040-2*X(7)
        2-2*X(8)-2*X(9)-2*X(10)-X(11)))*X(11)-X(5)*X(5)*0.0005-34.359
        R(6)=X(6)+(1-.0001*(1+0.5*(1.E-7)*(1240-2*X(7)-2*X(8)-2*X(9)
        1-2*X(10)-2*X(11)-X(12)))*X(12))*0.2*(1+0.5*(1.E-7)*(1240
        2-2*X(7)-2*X(8)-2*X(9)-2*X(10)-2*X(11)-X(12)))*X(12)-X(6)*X(6)
        3*.0005-34.359
        R(7)=X(7)-2
        R(8)=X(8)-2
        R(9)=X(9)-2
        R(10)=X(10)-2
        R(11)=X(11)-2
        R(12)=X(12)-2
        R(13)=130-X(7)
        R(14)=130-X(8)
        R(15)=130-X(9)
        R(16)=130-X(10)
        R(17)=130-X(11)
        R(18)=130-X(12)
        R(19)=170-X(7)
        R(20)=270-X(7)-X(8)
        R(21)=370-X(7)-X(8)-X(9)
        R(22)=470-X(7)-X(8)-X(9)-X(10)
        R(23)=570-X(7)-X(8)-X(9)-X(10)-X(11)
        R(24)=670-X(7)-X(8)-X(9)-X(10)-X(11)-X(12)
        R(25)=X(7)-100
        R(26)=X(7)+X(8)-200
        R(27)=X(7)+X(8)+X(9)-300
        R(28)=X(7)+X(8)+X(9)+X(10)-400
        R(29)=X(7)+X(8)+X(9)+X(10)+X(11)-500
        R(30)=X(7)+X(8)+X(9)+X(10)+X(11)+X(12)-600
        R(31)=X(1)
        R(32)=X(2)
        R(33)=X(3)
        R(34)=X(4)
        R(35)=X(5)
        R(36)=X(6)
        R(37)=50-X(1)
        R(38)=50-X(2)
        R(39)=50-X(3)
        R(40)=50-X(4)
        R(41)=50-X(5)
        [illegible]
```

```
      COMMON /A2/LFEAS,L5,L6,L7,L8,L9,R1A,R2A,R3A
       R(49)=2.5*X(1)+.05*X(1)*X(1)+2.5*X(2)+.05*X(2)*X(2)
     1 +2.5*X(3)+.05*X(3)*X(3)+2.5*X(4)+.05*X(4)*X(4)+2.5*
     1 X(5)+.05*X(5)*X(5)+2.5*X(6)+.05*X(6)*X(6)
       RETURN
       END
```