SHORT TERM HYDROTHERMAL SCHEDULING USING EVOLUTIONARY PROGRAMMING

Thesis submitted in partial fulfillment of the requirements for the award of degree of

Master of Engineering
in
Power Systems & Electric Drives

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CERTIFICATE

I hereby certify that the work which is being presented in the thesis entitled, "**Short Term Hydro Thermal Scheduling Using Evolutionary Programming**" in partial fulfillment of the requirements for the award of degree of Master of Engineering in Power system & electric drives submitted in Electrical & Instrumentation engineering department of Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of *Mr. Nitin Narang* and refers other researcher's works which are duly listed in the reference section.

The matter presented in this thesis has not been submitted anywhere for the award of any other degree.

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This is to certify that the above statement made by the candidate is correct and true to the best of my knowledge.

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ABSTRACT

Operation of a system having both hydro and thermal plants is far more complex as hydro plants have negligible operating cost, but are required to operate under constraints of water available for hydro generation in a given period of time. The problem of minimizing the operating cost of a hydrothermal system can be viewed as one of minimizing the fuel cost of thermal plants under the constraints of water availability (storage and inflow) for hydro generation over a given period of operation.

Earlier, a wide variety of optimization techniques have been applied to solving the Hydrothermal scheduling problems such as dynamic programming (DP), gradient search method etc. But, because of certain drawbacks, such as drastic growth of computational and dimensional requirement, insecure convergence properties, algorithmic complexity, and convergence characteristics these local optimization techniques are not suitable for such a problem. Thus, evolutionary programming has been proposed for solving the Hydrothermal scheduling problems.

The work done in this thesis presents solution to short-term hydrothermal scheduling problem. The solution approach is based on Evolutionary programming.

Evolutionary programming technique is implemented and demonstrated to solve the hydrothermal scheduling problem with quadratic thermal cost function. The advantage of the EP technique is that it is capable of determining the global or near global optimal solutions to such an optimisation problem with multiple local minima. Evolutionary programming technique provides accurate result as close to the conventional methods. EP algorithms are also capable of finding very nearly global solutions within a reasonable time.

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1.1 Overview

A modern power system consists of a large number of thermal and hydel plants connected at various load centres through a transmission network. An important objective in the operation of such a power system is to generate and transmit power to meet the system load demand at minimum fuel cost by an optimal mix of various types of plants. The study of the problem of optimum scheduling of power generation at various plants in a power system is of paramount importance, particularly where the hydel sources are scares and high cost of thermal generation has to be relied upon to meet the power demand. The hydel resources being extremely limited, the worth of water is greatly increased. If optimum use is made of their limited resource in conjunction with the thermal sources, huge saving in fuel and the associated cost can be made.

All hydro-systems are basically different from each other in their characteristics. The reason of this difference are plenty- the chief points being their natural difference in their water areas, difference between release elements, control constraints, non-uniform water flow etc. Sudden alteration in the volume of water flow due to natural constraints, occurrence of flood, draught and other natural calamities also affect the hydro scheduling. Navigational requirement of agricultural water may also govern the hydro scheduling. Sometimes, water release may be dictated by treaties between the states and due to the fishing requirements.

In certain sectors, however, the hydel source is sufficiently large, particularly in rainy season as the inflows into the hydel reservoirs exhibits an annual cyclicity. Furthermore, there may be a seasonal variation in power demand on the system, and this too exhibits an annual cylicity. The optimization interval of one year duration is thus a natural choice for long range optimal generation scheduling studies. The solution to the scheduling problem in this case consists of determination of water quantities to be drawn from the reservoirs for hydel generation in each sub-interval and the corresponding thermal generations to meet the load demand over each sub-interval utilising the entire quantity of water available for power generation during the total interval. The long range scheduling (generally persisting from months to year) involves mainly the scheduling of water release. Long range scheduling also involves metrological and statistical analysis. The benefit of this scheduling is to save the cost of generation, in addition to meeting the agricultural and irrigational requirements. Long

range scheduling involves optimisation of the operating policy in the context of major unknowns such as load, hydroelectric inflows, unit availability etc.
The short range problem usually has an optimisation interval of a day or a week. This period is normally divided in to sub-intervals for scheduled purposes. Here, the load, water inflows and unit availabilities are assumes to be known. A set of starting conditions (i.e. reservoirs levels) being given, the optimal hourly schedule can be prepared that minimises a desired objective while meeting system constraints successfully.

Cost optimization of hydro stations can be achieved by assuming the water heads constants and converting the incremental water (i.e. fuel) rate characteristics in to incremental fuel cost curves by multiplying it with cost of water per cubic meter and applying the conventional technique of minimising the cost function.

1.2 Literature Review

Hydrothermal scheduling is required in order to find the optimum allocation of hydro energy **so** that the annual operating cost of a mixed hydrothermal system is minimized. Over the last decade the hydrothermal scheduling problem has been the subject of considerable discussion in the power literature [1]-[7]. The available methods differ in the system modelling assumptions and the solution. The annual hydrothermal scheduling problem involves the minimization of the annual operating cost of a power system subject to the several equality and inequality constraints imposed by the physical laws governing the system and by the equipment ratings.

Different methods have been proposed for the solution of these problems in the past. Variational methods [8], pontryagin’s maximum principle [9], general mathematical programming [10-11] and the dynamic programming [12-14] have been used to solve the problem in different formulations. Methods based on Lagrangian multiplier and gradient search techniques [15] for finding the most economical hydrothermal generation schedule under practical constraints have been well documented. Kirchmayer [17] utilized calculus of variation for short range scheduling problem and proposed the well known coordination equations. Mixed integer programming [16] methods have been widely used to solve such scheduling problems in different formulations. Among all the methods, dynamic programming seems to be a popular approach because it is usually satisfactory to find the economic dispatch at discrete load steps rather than at continuous load levels. A serious drawback with dynamic programming, however, is that computational requirements grow drastically as the dimension of the problem increases. Beyond obtaining the optimal solution a very important consideration is the handling of unpredictable changes in natural inflows. If a schedule has to be recalculated from scratch whenever a change occurs, it is inefficient and may be impractical.

Abdul Halim and Khalid [18] linearizes the coordination equations so that the Lagrangian of the water availability constraint is determined separately from the unit generations. This water availability constraint Lagrange multiplier determines the Lagrange multiplier for the power balance constraint and hence leads to the computation of the generation of thermal and hydro units. The algorithm requires small computation resources. It has global-like convergence property so that even if the starting values are far from the solution, convergence is still achieved rapidly. Recently evolutionary algorithm has been proposed for solving scheduling problems [19-20].

The Augmented Lagrangian Relaxation (ALR) method is one of the most powerful techniques to solve the Short-Term Hydrothermal Coordination (STHC) problem. A crucial step when using the ALR method is the updating of the multipliers.

Amongst other published works the decomposition techniques by Habibollazadeh et al. [21] and the development of a computationally efficient algorithm by Carvalho et al. [22] seems to be quite promising. But the problem common to all is in convergence to a locally optimal solution. In this respect stochastic search algorithms like simulated annealing (SA) [23], genetic algorithm (GA) [24], evolutionary strategy (ES) [25] and evolutionary programming (EP) [26-31] may prove to be very efficient in solving highly nonlinear HS problems since they do not place any restriction on the shape of the cost curves and other non-linearities in model representation. Although these heuristic methods do not always guarantee the globally optimal solution, they will provide a reasonable solution (suboptimal near globally optimal) in a short CPU time.

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1.3 Objective

The main objective of the present work is:

1. To find solution of short term hydrothermal scheduling (HS) problem so that the total fuel cost is minimized while satisfying the constraints.
2. To develop and study the performances of evolutionary programs in solving HS problem.
3. Introduction of HS problem followed by a clear description of EP for solution of HS problem and finally reporting of the results.
4. To test these techniques on different problems.

1.4 Organization of Thesis

The thesis is organised into six chapters. The organisation of chapters is as follows:

The **chapter-1** summarized the overview of the problem, brief literature review, objective of work and organization of the thesis.

The **chapter-2** highlights the topic Hydrothermal Scheduling and also gives the overview of various hydro plants and classification of problem formulation and various solution approaches.

The **chapter-3** explores the structure of EP. The problem formulation using EP is discussed and the algorithm for the EP based HS problem is presented in this chapter.

The **chapter-4** represents the test system, results and discussion.

The **chapter-5** presents the conclusions drawn and also presents the scope of future work.

Chapter 2
Hydrothermal Scheduling

2.1. Introduction

Optimal scheduling of power plant generation is the determination of the generation for every generating unit such that the total system generation cost is minimum while satisfying the system constraints.

The objective of the hydrothermal scheduling problem is to determine the water releases from each reservoir of the hydro system at each stage such that the operation cost is minimized along the planning period. The operation cost includes fuel costs for the thermal units, import costs from neighbouring systems and penalties for load shedding. The basic question in hydro thermal coordination is to find a trade-off between a relative gain associated with immediate hydro generation and the expectation of future benefits coming from storage.

Two aspects make the hydrothermal scheduling a complex problem:

- The uncertainty of inflows.
- The hydraulic coupling between hydro plants.

The operation planning of hydrothermal systems is called Hydrothermal Coordination (HTC) problem. Hydrothermal coordination (HTC) problem requires solving for the thermal unit commitments and generation dispatch as well as the hydro schedules. The objective is to minimize thermal production cost subject to meeting the forecasted demand and other operating constraints. Also the hydrothermal co-ordination (HTC) problem determines the thermal unit commitments and generation dispatch, as well as the hydro schedules, to meet the forecasted demand and other operating constraints at minimum thermal production cost.

The HTC problem is usually solved by decomposition of the original problem into long, medium and short term problems each one considering the appropriate aspects for its time step and horizon of study. It is also essential to take into consideration two basic aspects of the hydro system:

a) The available water quantity (water inflows) is stochastic in nature.
b) The decision for the energy allocated to hydro units is deterministic.

Different time horizons and base times are needed for the detailed examination of each one of the above operating practices. For example, for maintenance scheduling the time horizon is the year and the base time is the week or the two week period while for the economic dispatch the time horizon is the hour and the base time is the minute. It is thus obvious that the selection of the appropriate base time for the hydrothermal scheduling problem is crucial to the formulation and solution of the problem.

2.2 Need of Hydrothermal Scheduling

The operating cost of thermal plant is very high, though their capital cost is low. On the other hand the operating cost of hydroelectric plant is low, though their capital cost is high. So it has become economical as well convenient to have both thermal and hydro plants in the same grid. The hydroelectric plant can be started quickly and it has higher reliability and greater speed of response. Hence hydroelectric plant can take up fluctuating loads. But the starting of thermal plants is slow and their speed of response is slow. Normally the thermal plant is preferred as a base load plant whereas the hydroelectric plant is run as a peak load plant.

2.3 Classification of Hydro Plants

1. Classification on the basis of type
2. Classification on the basis of location
3. Classification According to Quantity of Water Available

2.3.1 Classification on the Basis of Type-Hydro power plants on the basis of their type, are further classified as:

1. Pumped storage plants
2. Conventional plants

2. 3.1.1 Pumped Storage Plants

Pumped storage hydro plants are designed to save fuel cost by serving the peak load (a high fuel-cost load) with hydro energy and then pumping the water back up into the reservoir at light load periods (a lower cost load). These plants may involve separate pumps and turbines or more recently, reversible pump turbines.

It is associated with upper and lower reservoirs. During light load periods water is pumped from lower to the upper reservoirs using the available energy from other sources as surplus energy. During peak load the water stored in the upper reservoirs is released to generate power to save fuel cost of thermal plants. The pumped storage plant is operated until the added pumping cost exceeds the savings in thermal costs due to the peak sharing operation.

2.3.1.2 Conventional Plants

These are classified in to two different categories:

- Run-of-river plants
- Storage plants

Run-of-river plants have little storage capacity and use water as it becomes available. The water not utilized is spilled.

Storage plants are associated with reservoirs which have significant storage capacity. During periods of low power requirements, water can be stored and then released when the demand is high.

2.3.2 Classification on the Basis of Location

On the basis of their location, hydro plants are classifieds in to three different categories:

1. Hydro plants on different streams
2. Hydro plants on the same stream
3. Multi-chain hydro plants

2.3.2.1 Hydro Plants on Different Streams

The plants are located on different streams and are independent of each other.

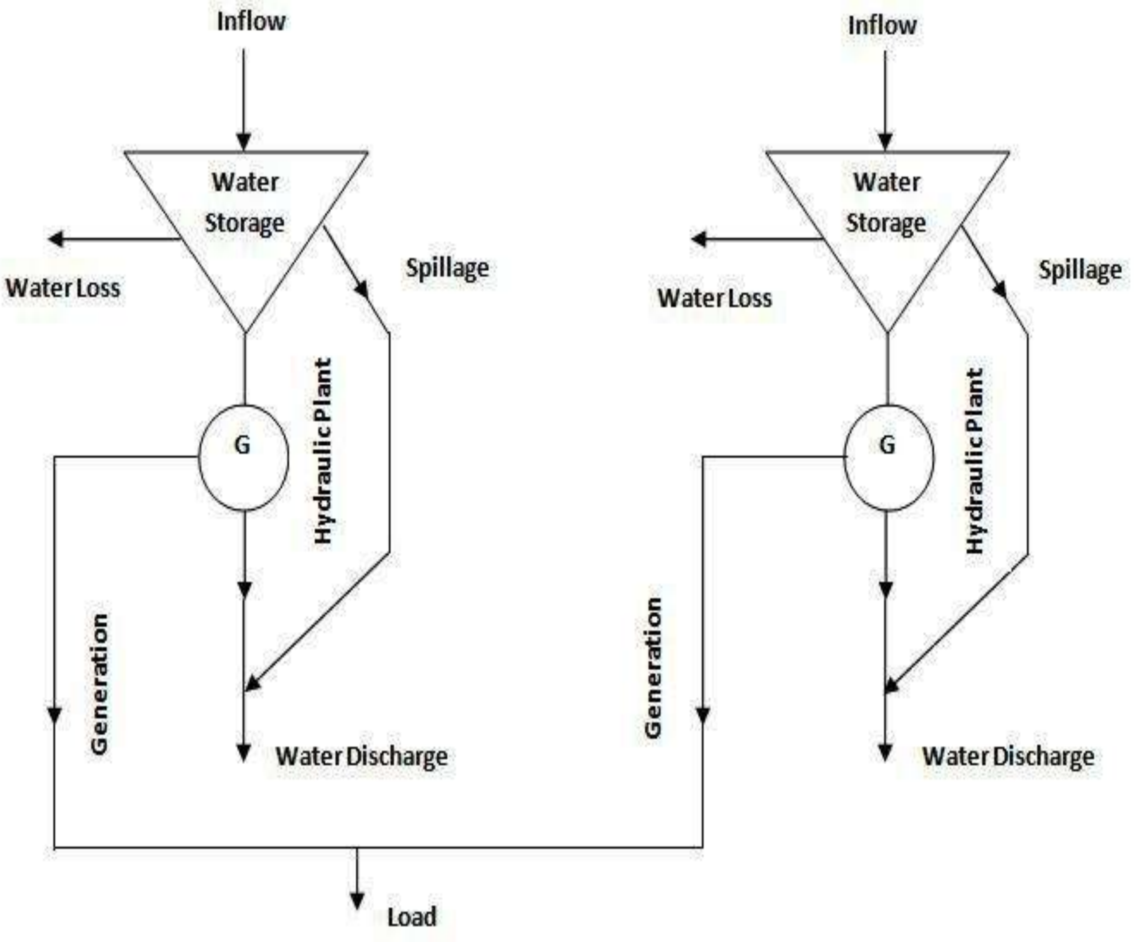

Figure 2.1 Hydro plants on different stream

2.3.2.2 Hydro Plants on the Same Stream

When hydro plants are located on the same stream, the downstream plant depends on the immediate upstream plant.

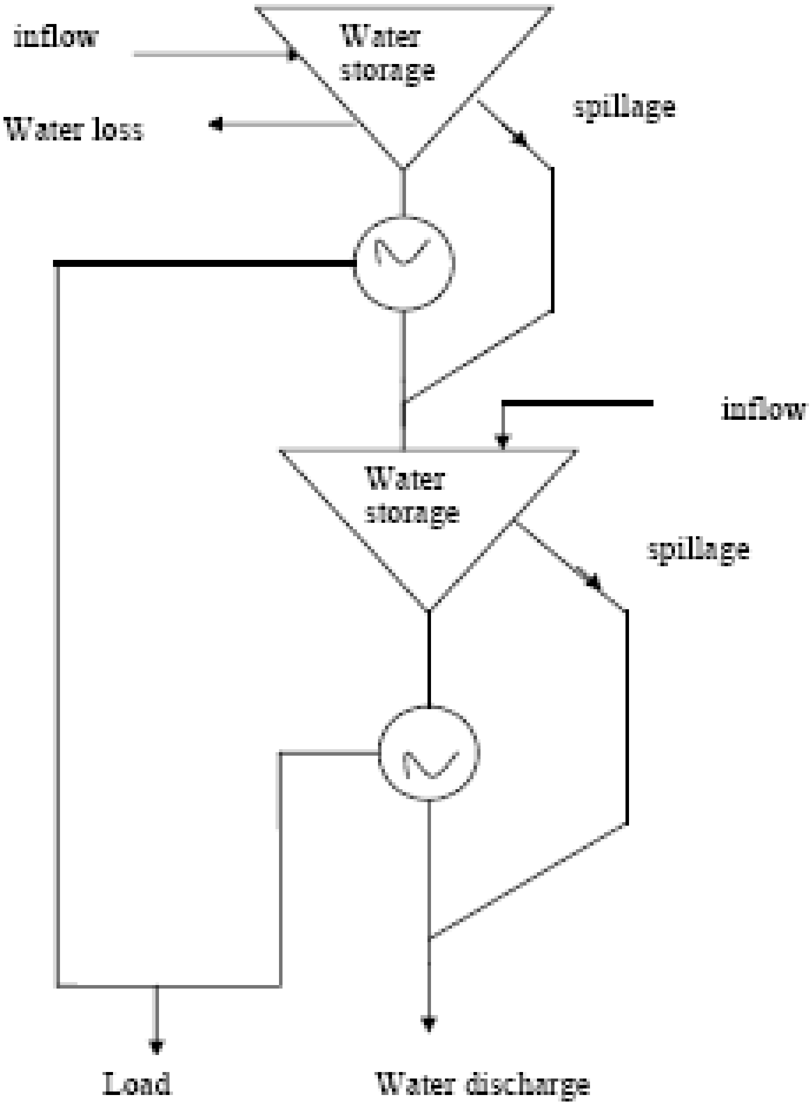

Figure 2.2 Hydro plants on same stream

2.3.2.3 Multi-Chain Hydro Plants

These hydro plants are located on different streams as well as same stream.

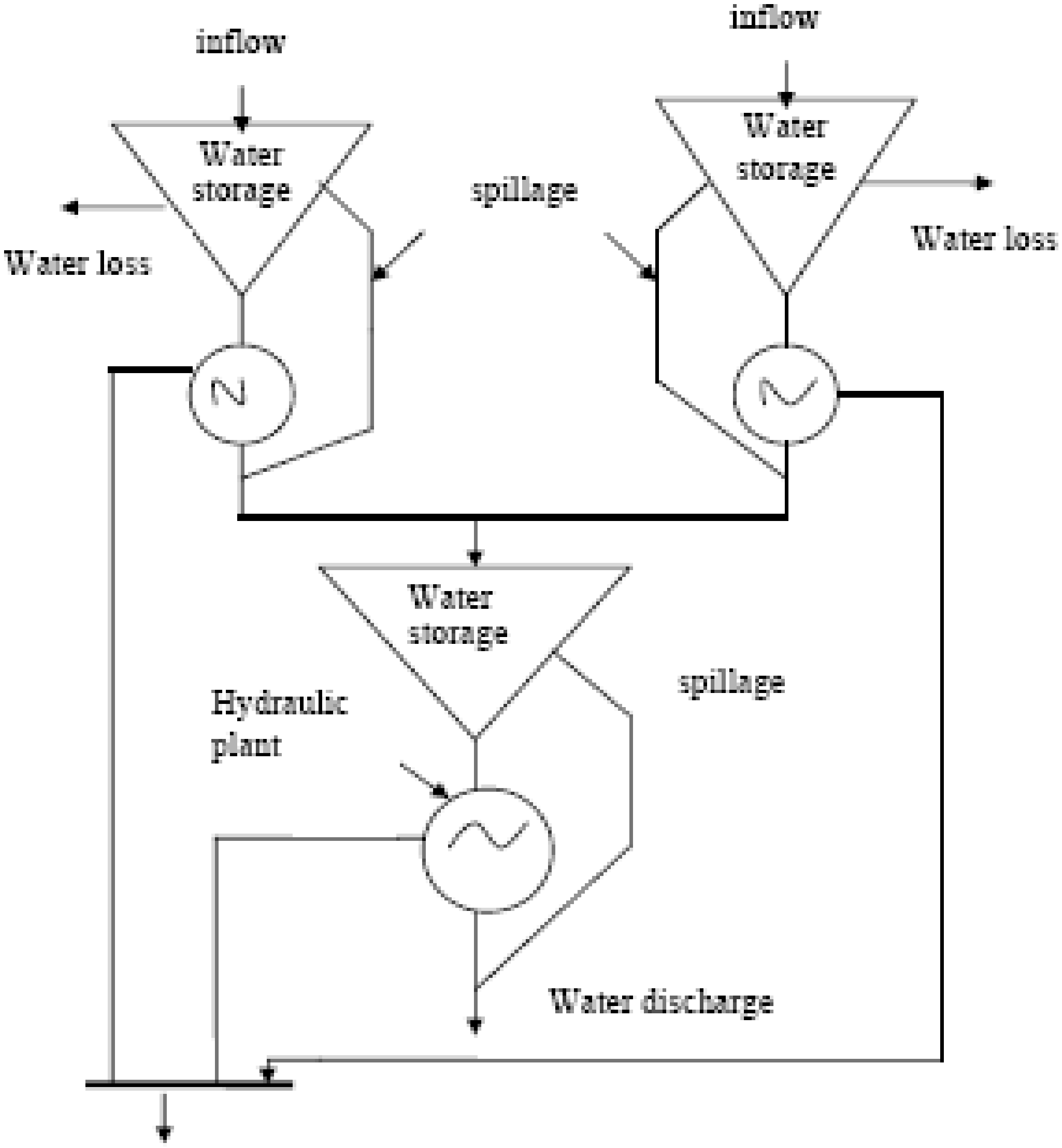

Figure 2.3 Multi chain Hydro plants

2.3.3 Classification According to Quantity of Water Available

On the basis of quantity of water available Hydro plants can be classified as:

2. 3.3.1 Run-off- River Plants without Pondage

These plants do not store water; the plant uses water as it comes. The plant can use water as and when available. Since these plants depend for their generating capacity primarily on the rate of flow of water, during rainy season high flow rate may mean some quantity of water to go as waste while during low run-off periods, due to low flow rates the generating capacity will be low.

2.3.3.2 Run-off River Plants with Pondage

In these plants pondage permits storage of water during off peak periods and use of this water during peak periods. Depending on the size of pondage provided it may be possible to cope with hour to hour fluctuations. This type of plant can be used on parts of the load curve as required, and is more useful than a plant without storage or pondage. When providing pondage tail race conditions should be such that floods do not raise tail-race water level, thus reducing the head on the plant and impairing its effectiveness. This type of plant is comparatively more reliable and its generating capacity is less dependent on available rate of flow of water.

2.3.3.3 Reservoir Plants

A reservoir plant is that which has a reservoir of such size as to permit carrying over storage from wet season to the next dry season. Water is stored behind the dam and is available to the plant with control as required. Such a plant has better capacity and can be used efficiently throughout the year. Its firm capacity can be increased and can be used either as a base load plant or as a peak load plant as required. It can also be used on any portion of the load curve as required.

2.4 Classification of Hydrothermal Scheduling Problem

1. Long range problem
2. Short range problem

2.4.1 Long Range Problem

Long range problem includes the yearly cyclic nature of reservoir water inflows and seasonal load demand and correspondingly a scheduling period of one year is used. The solution of the long range problem considers the dynamics of head variations through the water flow continuity equation.The coordination of the operation of hydroelectric plants involves, of course, the scheduling of water releases. The long-range hydro-scheduling problem involves the long-range forecasting of water availability and the scheduling of reservoir water releases (i.e., “drawdown”) for an interval of time that depends on the reservoir capacities.

Typical long-range scheduling goes anywhere from 1 week to 1 year or several years. For hydro schemes with a capacity of impounding water over several seasons, the long-range problem involves meteorological and statistical analysis. Nearer-term water inflow forecasts might be based on snow melt expectations and near-term weather forecasts. For the long-term drawdown schedule, a basic policy selection must be made. Should the water be used under the assumption that it will be replaced at a rate based on the statistically expected (i.e., mean value) rate, or should the water be released using a “worst-case” prediction. In the first instance, it may well be possible to save a great deal of electric energy production expense by displacing thermal generation with hydro-generation [32]. If, on the other hand, a worst-case policy was selected, the hydro plants would be run so as to minimize the risk of violating any of the hydrological constraints (e.g., running reservoirs too low, not having enough water to navigate a river). Conceivably, such a schedule would hold back water until it became quite likely that even worst-case rainfall (runoff, etc.) would still give ample water to meet the constraints.

Usually, long-term hydrothermal scheduling is used for breaking down the long-term problem into a number of midterm (e.g., monthly) problems. Long-term produces a near optimal cost estimation while the mid-term case can use a more detailed cost representation (short-term cases use the most detailed cost formulation).

The purpose of the long-term scheduling is to provide a good feasible solution that is close to the long-term cost minimisation of the whole system. The problem is usually very difficult to solve due to its size, the time span (up to several years) and the randomness of the water inflows over the long term [32].

Long-range scheduling involves optimizing a policy in the context of unknowns such as load, hydraulic inflows, and unit availabilities (steam and hydro). These unknowns are treated statistically, and long-range scheduling involves optimization of statistical variables.

Useful techniques include:

- Dynamic programming, where the entire long-range operation time period is simulated (e.g., 1 year) for a given set of conditions.
- Composite hydraulic simulation models, which can represent several reservoirs.
- Statistical production cost models.

2.4.2 Short Range Problem

In it, the load demand on the power system exhibits cyclic variation over a day or a week and the scheduling interval is either a day or a week. As the scheduling interval of short range problem is small, the solution of the short-range problem can assume the head to be fairly constant. The amount of water to be utilized for the short-range scheduling problem is known from the solution of the long-range scheduling problem. Short-range hydro-scheduling (1 day to 1 week) involves the hour-by-hour scheduling of all generation on a system to achieve minimum production cost for the given time period.

In such a scheduling problem, the load, hydraulic inflows, and unit availabilities are assumed known. A set of starting conditions (e.g. reservoir levels) is given, and the optimal hourly schedule that minimizes a desired objective, while meeting hydraulic steam, and electric system constraints, is sought. Part of the hydraulic constraints may involve meeting “end-point” conditions at the end of the scheduling interval in order to conform to a long-range, water-release schedule previously established

The short term hydrothermal scheduling problem is classified in to two groups

- Fixed head hydro thermal scheduling
- Variable head hydro thermal scheduling

2.5 Scheduling Problems

In the operation of a hydroelectric power system, three general categories of problems arise. These depend on the balance between the hydroelectric generation, the thermal generation, and the load.

Systems without any thermal generation are fairly rare. The economic scheduling of these systems is really a problem in scheduling water releases to satisfy all the hydraulic constraints and meet the demand for electrical energy. Techniques developed for scheduling hydrothermal systems may be used in some systems by assigning a pseudo-fuel cost to some hydroelectric plant. Then the schedule is developed by minimizing the production “cost” as in a conventional hydrothermal system. In all hydroelectric systems, the scheduling could be done by simulating the water system and developing a schedule that leaves the reservoir levels with a maximum amount of stored energy. In geographically extensive hydroelectric systems, these simulations must recognize water travel times between plants.

The largest category of hydrothermal systems includes those where there is a closer balance between the hydroelectric and thermal generation resources and those where the hydroelectric system is a small fraction of the total capacity. In these systems, the schedules are usually developed to minimize thermal generation production costs, recognizing all the diverse hydraulic constraints that may exist.

Scheduling problem consists of

- Problem characteristics.
- Problem formulation.
- Solution approach.

The objective of hydrothermal scheduling is to determine the sequence of hydro releases which will minimize the expected thermal operation cost (given by fuel cost plus penalties for rationing) along the planning horizon. This problem can be represented as a decision tree. With the help of decision tree the operator has option of using hydro today or storing the hydro energy for use in next period.

2.6 Scheduling Energy

Suppose, as in Figure**,** we have two sources of electrical energy to supply a load, one hydro and another steam. The hydro plant can supply the load by itself for a limited time.

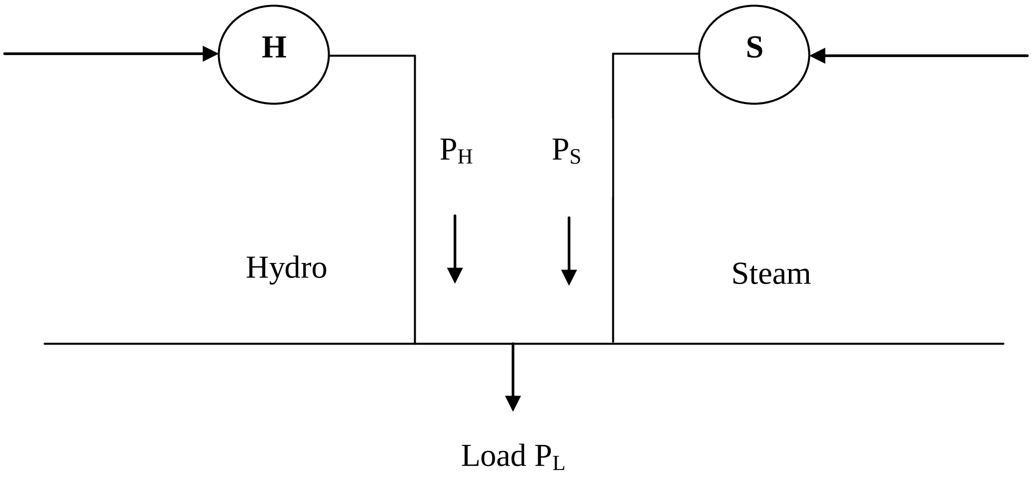

Figure 2.4 Two-unit hydrothermal systems

For any time period j**,**

$$\sum_{j=1}^{j_{max}} P_{Hj}^{max} \geq P_{loadj} \qquad (1)$$

$$j = 1 \ldots\ldots j_{max}$$

However, the energy available from the hydro plant is insufficient to meet the load

$$\sum_{j=1}^{jmax} P_{Hj}\ n_j \leq \sum_{j=1}^{j\ max} P_{loadj}\ n_j \qquad (2)$$

$$n_j = number\ of\ hours\ in\ period\ j$$

$$\sum_{j=1}^{jmax} n_j = T_{max} = total\ interval \qquad (3)$$

Use here the entire amount of energy from the hydro plant in such a way that the cost of running the steam plant is minimized. The steam-plant energy required is

$$\sum_{j=1}^{jmax} P_{loadj}\ n_j - \sum_{j=1}^{jmax} P_{Hj}\ n_j = E \qquad (4)$$

(Load energy) - (Hydro energy) = (Steam energy)

It is not require the steam unit to run for the entire interval of T_{max} hours.

Therefore

$$\sum_{j=1}^{Ns} P_{sj} n_j = E \qquad (5)$$

$$N_s = run\ period\ for\ steam\ plant$$

Then

$$\sum_{j=1}^{Ns} n_j \leq T_{max} \qquad (6)$$

The scheduling problem becomes

$$Min\ F_T = \sum_{j=1}^{Ns} F\left(P_{sj}\right) n_j \qquad (7)$$

Subject to

$$\sum_{j=1}^{Ns} P_{sj} n_j - E = 0 \qquad (8)$$

And the Lagrange function is

$$£ = \sum_{j=1}^{Ns} F(\,P_{sj}\,)\,n_j + \alpha\,(\mathrm{E} - \sum_{j=1}^{Ns} P_{sj} n_j) \qquad (9)$$

Then

$$\frac{\partial £}{\partial P_{sj}} = \frac{dF(P_{sj})}{dP_{sj}} - \alpha = 0 \qquad \text{for j} = 1 \ldots\ldots\ldots\ldots\ldots\ldots..\mathrm{N_s}$$

This means that the steam plant should be run at constant incremental cost for the entire period it is on. Let this optimum value of steam-generated power be P_s^* which is the same for all time intervals the steam unit is on. This type of schedule is shown in figure.

The total cost over the interval is

$$F_T = \sum_{j=1}^{Ns} F\,(P_s^*) n_j = F(P_s^*) \sum_{j=1}^{Ns} n_j = F(P_s^*) T_s \qquad (10)$$

Where

$$T_s = \sum_{j=1}^{Ns} n_j = the\ total\ run\ time\ for\ the\ steam\ plant$$

Let the steam-plant cost be expressed as

$$F(P_s) = A + BP_s + CP_s^2 \qquad (11)$$

Then

$$F_T = (A + BP_s + CP_s^2)T_s \qquad (12)$$

Also

$$\sum_{j=1}^{jmax} P_{sj} n_j = \sum_{j=1}^{jmax} P_s^* n_j = P_s^* T_s \qquad (13)$$

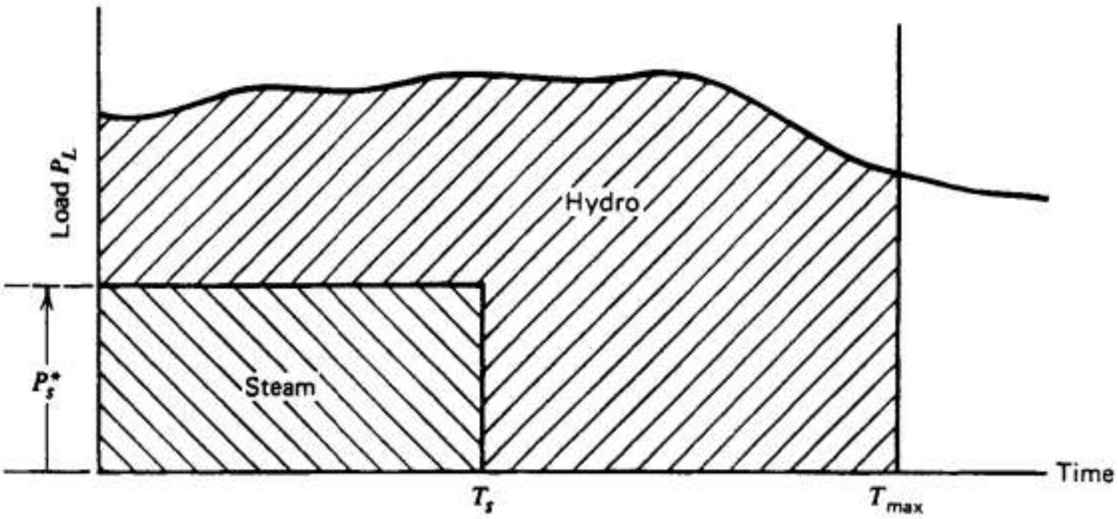

Figure 2.5 Resulting optimal hydro thermal schedule

Then

$$T_s = {}^{E}/_{P_s^*} \qquad (14)$$

And

$$F_T = (A + BP_s + CP_s^2)\, {}^{E}/_{P_s^*} \qquad (15)$$

Now we can establish the value of Ps* by minimizing F_T**:**

$$\frac{dF_T}{dP_s^*} = \frac{(AE)}{P_s^*} + CE = 0 \qquad (16)$$

Or

$$P_s^* = \sqrt{A/C} \qquad (17)$$

Which means the unit should be operated at its maximum efficiency point long enough to supply the energy needed, E**.**

Note, if

$$F(P_s) = A + BP_s + CP_s^2 = f_c \times H(P_s) \qquad (18)$$

Where *fc* is the fuel cost.
Now the heat rate is

$$\frac{H(P_s)}{P_s} = \frac{1}{f_c}\left(\frac{A}{P_s} + \mathrm{B} + \mathrm{CP_s}\right) \qquad (19)$$

And the heat rate has a minimum when

$$\frac{d}{dP_{sj}}[H(P_s)] = 0 = -\frac{A}{P_s^2} + C \qquad (20)$$

Giving best efficiency at

$$P_s = \sqrt{A/C} = P_s^* \qquad (21)$$

It is clear from the above that solution of hydrothermal scheduling problem requires solving for the thermal unit commitments and generation dispatch as well as the hydro schedules. The steam plant should be run at constant incremental cost for the entire period it is on. This optimum value of steam-generated power is P_s^* which is the same for all time intervals the steam unit is on. The best efficiency is achieved when the heat rate is minimum and it is calculated with the help of cost coefficients ‘A’ and ‘C’. Resulting optimal hydro thermal schedule shows if the thermal and hydro plants are operated with each other then it results in economy. Steam plants and hydro plants, both are used to supply base load. During peak load it is economical to use hydro plants. Hence the thermal plant is preferred as a base load plants whereas the hydroelectric plant is run as a peak load plant.

2.7 Short Term Hydrothermal Scheduling

2.7.1 Introduction

The basic idea of hydrothermal coordination is the scheduling of hydroelectric system and thermal system coordinated to meet the load demand at every interval. Hydrothermal scheduling is achieved by optimally scheduling the generation of hydrothermal system with optimal constraints fully imposed or satisfied. The systematic coordination of the operation of a system of hydroelectric generation plants is usually more complex than the scheduling of an all-thermal generation system. The reason is simple and important. That is, the hydroelectric plants may very well be coupled both electrically (i.e., the water outflow from one plant may be a very significant portion of the inflow to one or more other, downstream plants).

Optimum scheduling of power plant generation is of great importance to electric utility systems. With the insignificant marginal cost of hydroelectric power, the problem of minimizing the operational cost of a hydrothermal system essentially reduces to that of minimizing the fuel cost for thermal plants under the constraints of the water available for hydro generation in a given period of time [34].

The primary objective of short-term hydrothermal scheduling is to determine the amount of hydro- and thermal generations to meet the load demands in a schedule horizon such that the fuel cost required to run the thermal generators can be minimised. In tackling this problem, the thermal system may be represented by an equivalent thermal generator unit.

In short term hydro thermal scheduling, the load demand on the power system exhibits cyclic variation over a day or a week and the scheduling interval is either a day or a week. As the scheduling interval of short range problem is small, the solution of the short-range problem can assume the head to be fairly constant. The amount of water to be utilized for the short-range scheduling problem is known from the solution of the long-range scheduling problem. Short-range hydro-scheduling (1 day to 1 week) involves the hour-by-hour scheduling of all generation on a system to achieve minimum production cost for the given time period.

In scheduling problem, the load, hydraulic inflows, and unit availabilities are assumed. A set of starting conditions (e.g., reservoir levels) is given, and the optimal hourly schedule that minimizes a desired objective, while meeting hydraulic steam, and electric system constraints, is sought.

Part of the hydraulic constraints may involve meeting “end-point” conditions at the end of the scheduling interval in order to confirm to a long-range, water-release schedule previously established.

The short term hydrothermal scheduling problem is classified in to two groups

Fixed head hydro thermal scheduling

The head of reservoirs can be assumed fixed if the hydro plants have reservoirs of large capacity.

Variable head hydro thermal scheduling

The head of reservoir is variable if the hydro plants have reservoirs of small capacity.

2.7.2 Problem Characteristics

The objective of hydrothermal scheduling is to determine the sequence of hydro releases which will minimize the expected thermal operation cost (given by fuel cost plus penalties for rationing) along the planning horizon. This problem can be represented as a decision tree, as illustrated in below figure.

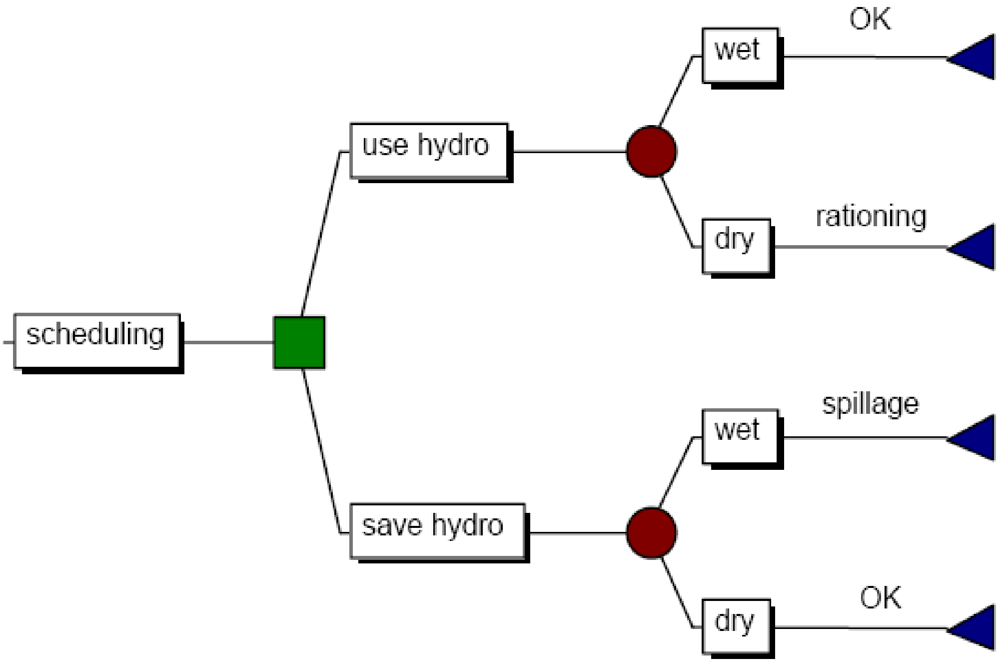

Figure 2.6 Decision process for hydrothermal systems

As seen in the figure, the operator is faced with the options of using hydro today, and therefore avoiding complementary thermal costs, or storing the hydro energy for use in the next period. If hydro energy is used today, and future inflows are high - thus allowing the recovery of reservoir storage - system operation will result to be efficient. However, if a drought occurs, it may be necessary to use more expensive thermal generation in the future, or even interrupt load supply.

If, on the other hand, storage levels are kept high through a more intensive use of thermal generation today, and high inflows occur in the future, reservoirs may spill, which is a waste of energy and, therefore, results in increased operation costs. Finally, if a dry period occurs, the storage will be used to displace expensive thermal or rationing in the future.

2.7.3 Problem Formulation

Given a power system consisting of N thermal units and M hydro units, the problem is to schedule the power generation of all units over t_k time sub -intervals in order to minimize the fuel cost. This schedule must meet given demand and pre-specified amount of water allocated at each hydro plant [35].

2.7.3.1 Thermal Model

The objective function is to minimize the total operating cost (C) represented by the fuel cost of thermal generation over the optimization interval (T).

$$C = \sum_{k=1}^{T} \sum_{i=1}^{N} t_k F_i(P_{ik}) \qquad (22)$$

Where the problem is to schedule the power generation of all units over t_k time sub-intervals in order to minimize the fuel cost which is given as :

$$F_i(P_{ik}) = a_i P_{ik}^2 + b_i P_{ik} + c_i \qquad (23)$$

$$k = 1 \dots \dots \dots T, i = 1 \dots \dots \dots .. N$$

Where a_i , b_i and c_i are cost coefficients of the i^{th} generating unit .

2.7.3.2 Hydro Model

In hydro system, there is no fuel cost incurred in the operation of hydro units.

According to Glimn-krichmayer model, discharge is a function of power output and the head. For large capacity reservoir it is practical to assume that the effective head is constant over the optimization interval. Thus q_{jk} is the rate of discharge from the j^{th} unit in the interval k and is represented by the quadratic equation:

$$q_{ik} = x_j P_{j+N,k}^2 + y_j P_{j+N,k} + z_j \qquad (24)$$

Where x_j, y_j and z_j discharge coefficients of the hydro units.

2.7.4 Constraints

2.7.4.1 Load Demand Equality Constraint

$$\sum_{\boldsymbol{i=1}}^{\mathrm{N+M}} P_{ik} = P_{dk} + P_{lossk} \qquad (25)$$

Where P_{dk} is the load demand during the k^{th} sub-interval and P_{lossk} are the transmission losses during the k^{th} interval.

2.7.4.2 Minimum and Maximum Power Generation Limits from View Point of Economy and Capacity of Generating Units

$$P_{imin} \leq P_{ik} \leq P_{imax} \qquad (26)$$

Where P_{ik} Power output of the generating units in MW during the kth interval, P_{max} is the maximum power of a generating unit in MW and P_{min} is the minimum power of a generating unit in MW.

2.7.5 Transmission Losses

The transmission losses during kth interval are given by the Kron's loss formula in terms of B- coefficients.

$$P_{lossk} = \sum_{i=1}^{N+m} \sum_{j=1}^{N+m} P_{ik} B_{ij} P_{ik} + B_{i0} P_{ik} + B_{00} \qquad (27)$$

The fixed head hydro thermal problem can be defined considering the optimization interval to meet the load demand in each interval. Each hydro plant is constrained by the amount of water available for draw-down in the interval.

2.7.6 Basic Solution Approach

2.7.6.1 Classical Method

A more general and basic short-term hydrothermal scheduling problem requires that a given amount of water be used in such a way as to minimize the cost of running the thermal units. We will use below figure in setting up this problem [34].

The problem we wish to set up is the general, short-term hydrothermal scheduling problem where the thermal system is represented by an equivalent unit, P_{sj}.

In this case, there is a single hydroelectric plant, P_{Hj}**.** We assume that the hydro plant is not sufficient to supply all the load demands during the period and that there is a maximum total volume of water that may be discharged throughout the period of T_{max} hours.

In setting up this problem and the examples that follow, we assume all spillages, S_j**,** are zero. The only other hydraulic constraint we will impose initially is that the total volume of water discharged must be exactly as defined. Therefore, the mathematical scheduling problem may be set up as follows:

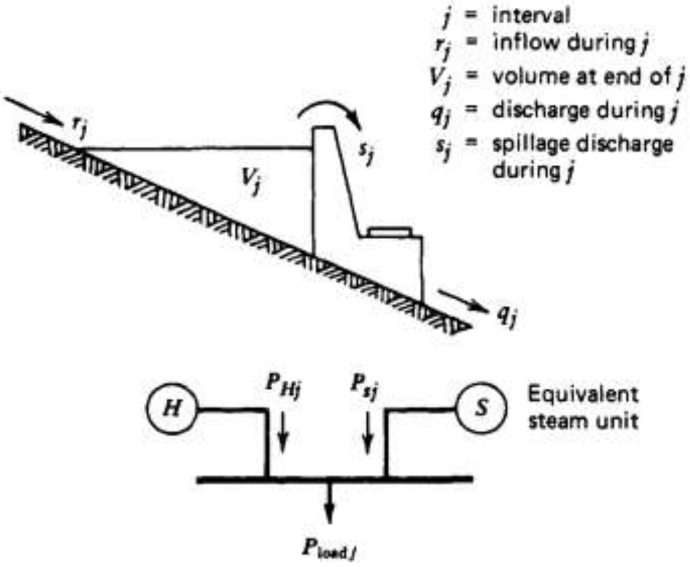

Figure 2.7 Hydrothermal system with hydraulic constraints

Problem

$$Min\ F_T = \sum_{j=1}^{jmax} n_j F_j \tag{28}$$

Subject to

$$\sum_{j=1}^{jmax} n_j q_j = q_{total} = total\ water\ discharge \tag{29}$$

$$P_{loadj} - P_{Hj} - P_{sj} = 0 \tag{30}$$

$$j = 1 \ldots \ldots ..jmax$$

Let n_j = length of j^{th} interval

$$\sum_{j=1}^{jmax} n_j = T_{max} \tag{31}$$

The loads are constant in each interval. Other constraints could be imposed, such as:

$$V_j(j = 0) = V_s \qquad starting\ volume$$

$$V_j(j = j_{max}) = V_E \qquad ending\ volume$$

$$q_{min} \le q_j \le q_{max} \qquad flow\ limits\ for\ j = 1 \ldots \ldots .j_{max}$$

Assume constant head operation and assume a q versus P characteristic is available, so that

$$q = q(P_H) \tag{32}$$

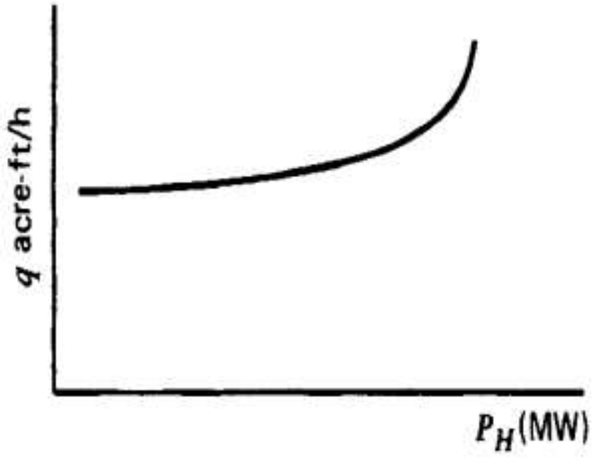

Figure 2.8 Hydroelectric unit input-output characteristic for constant head

The Lagrange function is:

$$£ = \sum_{j=1}^{Ns} F(P_{sj})\, n_j + \lambda_j\left(P_{loadj} - P_{Hj} - P_{sj} = 0\right) + \gamma\left(n_j q_j\left(P_{Hj}\right) - q_{total}\right) \tag{33}$$

and for a specific interval j = k,

$$\frac{\partial £}{\partial P_{sk}} = 0$$

$$n_j \frac{dy}{dx} = \lambda_k \tag{34}$$

And

$$\frac{\partial £}{\partial P_{Hk}} = 0$$

Gives

$$\gamma n_k \frac{dy}{dx} = \lambda_k \tag{35}$$

Suppose we add the network losses to the problem. Then at each hour,

$$P_{loadj} + P_{lossj} - P_{Hj} - P_{sj} = 0 \tag{36}$$

And the Lagrange function becomes

$$£ = \sum_{j=1}^{Ns} F(\,P_{sj}\,)\,n_j + \lambda_j\left(P_{loadj} + Ploss_j - P_{Hj} - P_{sj} \,=\, 0\,\right) + \gamma\left(\mathrm{n_j q_j}\left(\mathrm{P_{Hj}}\right) - \mathrm{q_{total}}\right)$$

(37)

With resulting coordination equations (hour k):

$$n_k \frac{dF_{sk}}{dP_{sk}} + \lambda_k \frac{\partial P_{lossk}}{\partial P_{sk}} = \lambda_k \tag{38}$$

$$\gamma\, n_k \frac{dq_{(PHk)}}{dP_{Hk}} + \lambda_k \frac{\partial P_{lossk}}{\partial P_{Hk}} = \lambda_k \tag{39}$$

Now with the help of above equations and given load demand, thermal power, hydro power, volume of water utilized and optimum cost can be calculated.

2.7.6.2 Flow Chart for Classical Method

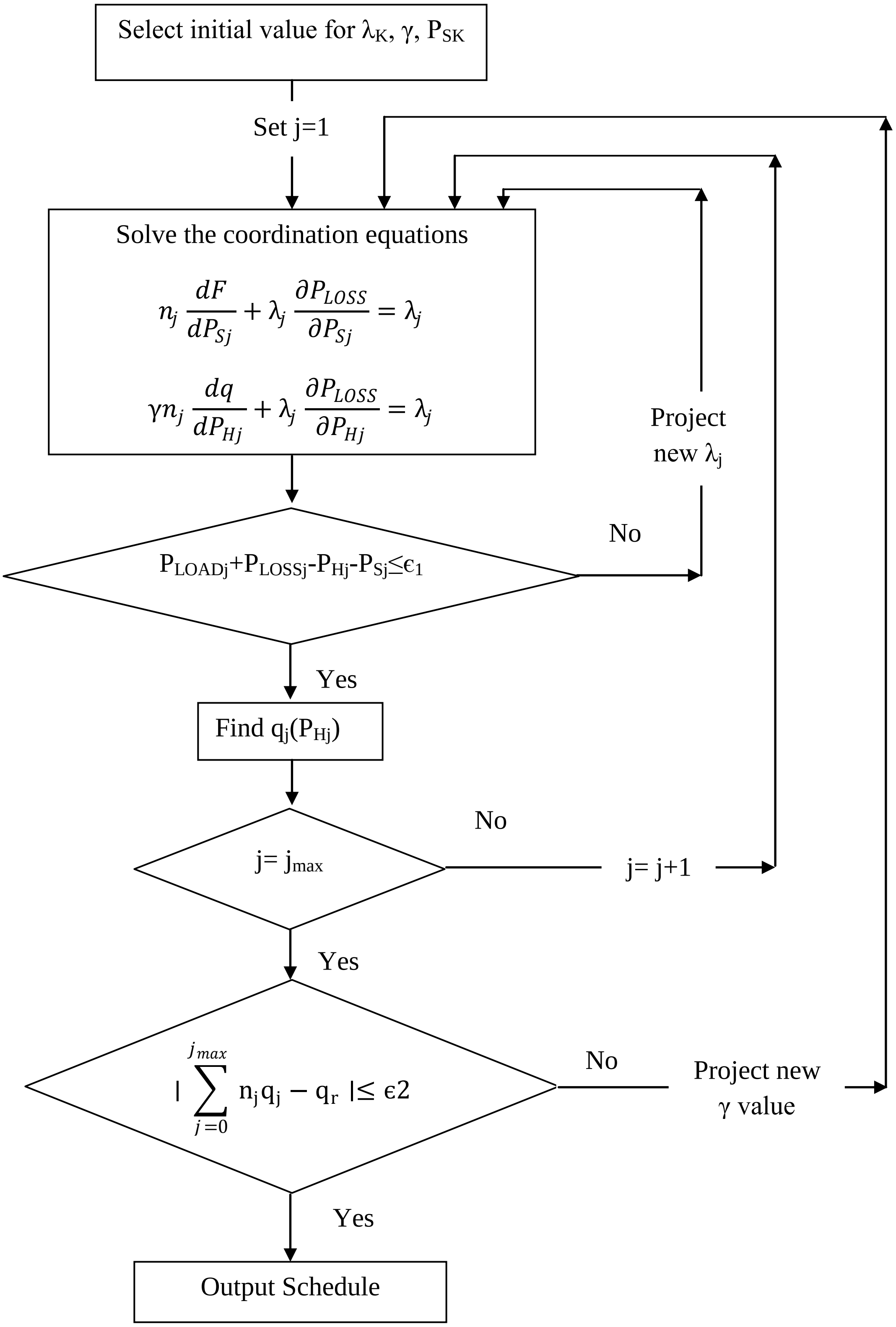

Figure 2.9 Flow chart for classical method

2.7.6.3 Algorithm for Classical Method

1. Read all the input data.
2. Calculate the initial guess value of P_{ik}, (lambda) k,V_j.
3. Consider V_j as calculated in step 2.
4. Start the iteration counter r = 1.
5. Start the hourly count k = 1.
6. Consider P_{ik} and (lamda)k.
7. Now compute new values for (lambda)k , P_{ik} , P_{jk} for given values of k.
8. Calculate total volume utilized.
9. Check for convergence.
10. If convergence is not achieved update volume and go to step 4 and increase the iteration counter and repeat.
11. Print the generation, utilized volume of water and cost.

2.7.6.4 Gradient Approach

The following is an outline of a first-order gradient approach, to the problem of finding the optimum schedule for a hydrothermal power system. We assume a single equivalent thermal unit with a convex input-output curve and a single hydro plant [34].

Let:

j = the interval = 1, 2, 3,. . . , J_{max}

v_j= storage volume at the end of interval j

q_j = discharge rate during interval j

r_j = inflow rate into the storage reservoir during interval j

P_{sj} = steam generation during *Jth* interval.

s_j = spillage discharge rate during interval j

$P_{loss\,j}$ = losses, assumed here to be zero

P_{loadj} = received power during the j_{th} interval (load)

P_{Hj} = hydro-generation during the j_{th} hour

Next, we let the discharge from the hydro plant be a function of the hydro-power output only. That is, a constant head characteristic is assumed.

Then

$$q_j\,(P_H) = q_j \tag{40}$$

so that to a first order,

$$\Delta q_j = \frac{dq_j}{dP_H} \Delta P_{Hj} \tag{41}$$

The total cost for fuel over the j = 1, 2, 3 , . . . , Jmax intervals is

$$F_T = \sum_{j=1}^{jmax} n_j F_j \left(P_{sj}\right) \tag{42}$$

The cost function may be expanded in a Taylor series to give the change in fuel cost for a change in steam-plant schedule

Considering only first order terms

$$\Delta F_T = \sum_{j=1}^{jmax} n_j F_j^{'} \left(\Delta P_{sj}\right) \tag{43}$$

In any given interval, the electrical powers must balance:

$$P_{loadj} - P_{Hj} - P_{sj} = 0 \tag{44}$$

So that

$$\Delta P_{sj} = -\frac{\Delta q_j}{\frac{dq_j}{dP_{Hj}}} \tag{45}$$

Therefore

$$\Delta F_T = \sum_{j=1}^{jmax} n_j \left[\frac{dF_j}{dP_{sj}} \Big/ \frac{dq_j}{dP_{Hj}} \right] \tag{46}$$

$$\Delta F_T = -\sum_{j=1}^{jmax} n_j \gamma_j (\Delta q_j) \tag{47}$$

Where

$$\gamma_j = \left[\frac{dF_j}{dP_{sj}} \Big/ \frac{dq_j}{dP_{Hj}} \right] \tag{48}$$

The variables γ_j are the incremental water values in the various intervals and give an indication of how to make the "moves" in the application of the first-order technique. That is, the "steepest descent" to reach minimum fuel cost(or the best period to release a unit of water) is the period with the maximum value of γ. The values of water release, Δq_j must be chosen to stay within the hydraulic constraints. These may be determined by use of the hydraulic continuity equation:

$$v_j = v_{j-1} + (r_j - q_j - s_j) n_j \tag{49}$$

We must also observe the storage limit

$$V_{min} \le V_j \le V_{max}$$

We will assume spillage is prohibited so that all $\boldsymbol{s_j} = 0$, even though there may well be circumstances where allowing $s_j > 0$ for some j might reduce the thermal system cost.

The discharge flow may be constrained both in rate and in total. That is

$$q_{min} \le q_j \le q_{max}$$

and

$$\sum_{j=1}^{jmax} n_j q_j = q_{total} \tag{50}$$

In this method, whenever a constraint is reached (that is, storage volume *is* equal to V_{min} or V_{max}) one must choose intervals in a more restricted manner.

Chapter 3
EP Based Short Term Hydrothermal Scheduling

3.1 Introduction

Evolutionary programming is based on Finite State Machine (FSM) model in its early stage, which is proposed by L. J. Fogel in 1960's when he studied the artificial intelligence. In 1990's, the evolutionary programming was developed by D. B. Fogel and was made to solve the optimal problems in real space. The evolutionary programming has been become an optimal tool and was used in many practical problems. EP is a artificial intelligence method in which an optimisation algorithm is the main engine for the process of three steps, namely, natural selection, mutation and competition. According to the problem, each step could be modified and configured in order to achieve the optimum result. Each possible solution to the problem is called an individual. In order to use EP, the mathematical model should be capable of dealing with the data type and structure of individuals.

3.2 Overview

Although evolutionary programming (EP) was first proposed as an approach to artificial intelligence, it has been recently applied with success to many numerical and combinatorial optimization problems [32].

Optimization by EP can be summarized into two major steps:

1. Mutate the solutions in the current population
2. Select the next generation from the mutated and the current solutions

These two steps can be regarded as a population-based version of the classical generate-and-test method [5], where mutation is used to generate new solutions (offspring) and selection is used to test which of the newly generated solutions should survive to the next generation. Formulating EP as a special case of the generate-and-test method establishes a bridge between EP and other search algorithms, such as evolution strategies, genetic algorithms, simulated annealing (SA), tabu search (TS), and others, and thus facilitates cross-fertilization among different research areas.

One disadvantage of EP in solving some of the multimodal optimization problems is its slow convergence to a good near-optimum.

Evolutionary programming (EP) is a stochastic optimization strategy, which places emphasis on the behavioural linkage between parents and their offspring. It is a powerful and general optimization method, which does not depend on the first and second derivatives of the objective function and the constraints of the problem.

Evolutionary programming is a probabilistic search technique, which generates the initial parent vectors distributed uniformly in intervals within the limits and obtains global optimum solution over number of iterations. The main stages of this technique are initialization, creation of off – spring vectors by mutation and competition and selection of best vectors to evaluate best fitness solution. As the history of the field suggests there are many different variants of Evolutionary Algorithms. The common underlying idea behind all these techniques is the same: given a population of individuals the environmental pressure causes natural selection (survival of the fittest) and this causes a rise in the fitness of the population. Given a quality function to be maximized we can randomly create a set of candidate solutions, i.e., elements of the function's domain, and apply the quality function as an abstract fitness measure – the higher the better. Based on this fitness, some of the better candidates are chosen to seed the next generation by applying recombination and/or mutation to them. Recombination is an operator applied to two or more selected candidates (the so-called parents) and results one or more new candidates (the children). Mutation is applied to one candidate and results in one new candidate.

Executing recombination and mutation leads to a set of new candidates (the offspring) that compete based on their fitness (and possibly age) – with the old ones for a place in the next generation. This process can be iterated until a candidate with sufficient quality (a solution) is found or a previously set computational limit is reached. In this process there are two fundamental forces that form the basis of evolutionary systems.

- Variation operator (mutation) create the necessary diversity and thereby facilitates novelty, while
- Selection acts as a force pushing quality.

The combined application of variation and selection generally leads to improving fitness values in consecutive populations. It is easy (although somewhat misleading) to see such a process as if the evolution is optimizing, or at least "approximating", by approaching optimal values closer and closer over its course. Alternatively, evolution it is often seen as a process of adaptation. From this perspective, the fitness is not seen as an objective function to be optimized, but as an expression of environmental requirements. Matching these requirements more closely implies an increased viability, reflected in a higher number of offspring. The evolutionary process makes the population adapts to the population adapt to the environment better and better. Let us note that many components of such an evolutionary process are stochastic. During selection fitter individuals have a higher chance to be selected than less fit ones, but typically even the weak individuals have a chance to become a parent or to survive. For mutation, the pieces that will be mutated within a candidate solution and the new pieces replacing them are chosen randomly. The evaluation (fitness) function represents a heuristic estimation of solution quality and the variation and the selection operators drive the search process. The most important advantage of EP is that it uses only the objective function information and hence independent of the nature of the search space such as smoothness, convexity or uni-modality, etc.

The 1966 book, "Artificial Intelligence through Simulated Evolution" by Fogel, Owens and Walsh is the landmark publication for EP applications, although many other papers appear earlier in the literature. In the book, finite state automata were evolved to predict symbol strings generated from Markov processes and non stationary time series. Such evolutionary prediction was motivated by recognition that prediction is a keystone to intelligent behaviour (defined in terms of adaptive behaviour, in that the intelligent organism must anticipate events in order to adapt behaviour in light of a goal).

3.3 Difference between EP and Classical Method

- EP has capability of converging into a global optimum. Classical methods are not guaranteed to converge to the global optimum of the general non-convex optimum problem.
- Accuracy in case of EP is less as compare to classical method.
- The search process in EP uses a population of points rather than a single point.
- Classical methods suffer from the difficulty in handling inequality constraints. Whereas EP can handle constraints easily.
- EP requires only the evaluation of the fitness function, which is formed from objective function so that every solution could be given a quality value.
- EP operates on the encoded string of the problem parameters rather than the actual parameters of the problem.

3.4 Use of Evolutionary Programming

The solution of hydrothermal coordination problem gives the schedule for economic dispatch. It is a non-linear programming problem with large number of variables and equality and inequality types of limit constraints pertaining to base case operating state. Several optimization techniques, such as linear programming, non-linear programming, quadratic programming and interior point method are used for solving the security constrained problems. The drawback of this approach is the difficulty involved in choosing proper penalty weights for different systems and different operating conditions which if not properly selected may lead to excessive oscillatory convergence.

Evolutionary programming is a probabilistic search technique, which generates the initial parent vectors distributed uniformly in intervals within the limits and obtains global optimum solution over number of iterations. Evolutionary Programming is search algorithms based on the mechanics of natural selection. The most important advantage of EP is that it uses only the objective function information and hence independent of the nature of the search space such as smoothness, etc. EP based algorithms are increasingly applied for solving power system optimization problems in recent years.

3.5 Elements of Evolutionary Programming

EP consists of a number of elements that are required for successful implementation. Evolutionary Programming requires certain steps, components, procedures or operators that must be specified. The main elements are:

1. Representation
2. fitness function
3. Population
4. Parent selection methodology
5. mutation
6. Survivor selection mechanism (replacement)
7. Initialization
8. Termination condition

To obtain a running algorithm the initialization procedure and a termination condition must be also defined .This is shown in the block diagram given below.

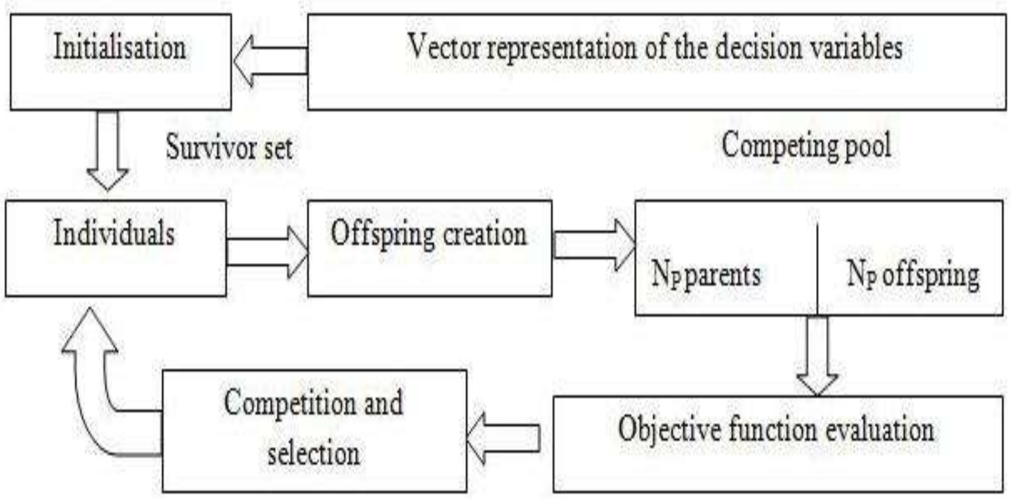

Figure 3.1 Block diagram for EP

3.5.1 Representation

This is the first design step. It amounts to specifying a mapping from the phenotypes onto a set of genotypes that are said to represent these phenotypes which means to link the" real world" to the "EA world", that is to set up a bridge between the original problem context and the problem solving space where evolution will take place. Objects forming possible solutions within the original problem context are referred to as phenotypes, their encoding, the individuals within the EA, are called genotypes. For instance, given an optimization problem on integers, the given set of integers would form the set of phenotypes. Then one could decide to represent them by their binary code, hence 18 would be seen as a phenotype and 10010 as a genotype representing it. It is necessary to understand that the phenotype space can be very different from the genotype space, and that the whole evolutionary search takes place in the genotype space. A solution of a good phenotype is obtained by decoding the best genotype after termination.

The inverse or reverse mapping from genotypes to phenotypes is usually called decoding and it is required that the representation be invertible: to each genotype there has to be at most one corresponding phenotype. The word representation can also be used in a slightly deferent sense, where the emphasis is not on the mapping itself, but on the "data structure" of the genotype space.

3.5.2 Fitness Function

Evaluation function represents the task to solve in the evolutionary context. Technically, it is a function or procedure that assigns a quality measure to genotypes. More accurately, it defines what improvement means. The role of the evaluation function is to represent the requirements to adapt to. It forms the basis for selection, and thereby it facilitates improvements.

In other words it can be said that this function is composed from a quality measure in the phenotype space and the inverse representation.

3.5.3 Population

Population means how many individuals have in it i.e. setting the population size. As opposed to variation operator, that act on one or two parent individuals, the selection operators (the parent selection and survival selection) work at population level. In general, the take the whole population into account and choices are always made relative to what we have. For instance, the best individual of the given population is chosen to be replaced by a new one. In almost all EPs applications, the population size is constant, not changing during the evolutionary search. The objective of population is to hold (the representation of) possible solutions. A population is a multiset of genotypes. The population forms the unit of evolution. Individuals are static objects not changing or adapting.

The diversity of a population is a measure of the number of different solutions present. No single measure for diversity exists; typically people might refer to the number of different fitness values present, the number of phenotypes present, or the number of different genotypes.

3.5.4 Parent Selection Methodology

Chromosomes are selected from the population to be parents. The problem is how to select these chromosomes. According to Darwin’s evolution theory the best ones should survive and create new offspring. The objective of parent selection or mating selection is to compare among the individuals based on their quality, and to allow the better individuals to become parents of the next generation. An individual is a parent if it has been selected to undergo variation in order to create offspring. Together with the survivor selection mechanism, parent selection is responsible for pushing quality improvements. Thus, high quality individuals get a higher chance to become parents than those with low quality. However, low quality individuals are often given a small, but positive chance; otherwise the whole search would become too greedy and get stuck in a local optimum.

There are many methods for selecting the best chromosomes:

1. Steady-State Selection
2. Roulette Wheel Selection
3. Rank Selection
4. Elitism

3.5.4.1 Steady-State Selection:

This is not a particular method of selecting parents. The main idea of this selection is that big part of chromosomes should survive to the next generation. EP then works in a following way. In every generations a few (good with high fitness) chromosomes are selected for creating a new offspring. Then some (bad with low fitness) chromosomes are removed and then, the new offspring is placed in their place. The rest of population survives to the new generation.

3.5.4.2 Roulette Wheel Selection:

Parents are selected according to their fitness. The better the chromosomes are, the more chances to be selected they have. Imagine a roulette wheel where are placed all chromosomes in the population, everyone has its place big accordingly to its fitness function. Then a marble is thrown there and selects the chromosome. Chromosome with bigger fitness will be selected more times.

One way to implement this selection scheme is to imagine a roulette-wheel with its circumference marked for each string proportionate to the string's fitness. The roulette-wheel is spun n times, each time selecting an instance of the string chosen by a roulette-wheel (RW) pointer. Since the circumference of the wheel is marked according to a string's fitness, this roulette-wheel mechanism is expected to make f_i / f_{av} copies of the ith string in the mating pool. The average fitness of the population is calculated as:

$$f_{av} = \frac{(\sum_{i=1}^{n} f_i)}{n} \qquad (51)$$

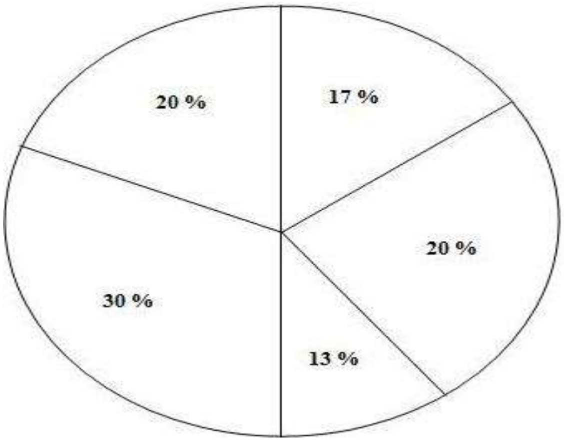

Figure 3.2 Roulette Wheel selection

Since, the third individual has a higher fitness value than any other, it is expected that the RW selection will choose the third individual more than any other individual. This roulette-wheel selection scheme can be simulated easily. Using the fitness value Fi of all the strings, the probability of selecting a string pi can be calculated. Thereafter the cumulative probability (Pi) of each string being copied can be calculated by adding the individual probabilities from the top of the list. Thus, the bottom-most string in the population should have a cumulative probability (P_n) equal to one.

3.5.4.3 Rank Selection

In the roulette wheel selection, the problem is when the fitnesses differ very much. For example, if the best chromosome fitness is 90% of all the roulette wheel then the other chromosomes will have very few chances to be selected. But, Rank selection first ranks the population and then every chromosome receives fitness from this ranking. The worst will have fitness 1, second worst will have 2 etc. and the best will have fitness N (number of chromosomes in population). After this all the chromosomes have a chance to be selected. But this method can lead to slower convergence, because the best chromosomes do not differ so much from other ones.

3.5.4.4 Elitism

Elitisms are quite different. When creating a new population by crossover and mutation, we have a big chance that we will lose the best chromosome. Elitism is the name of a method which first copies the best chromosome (or a few best chromosomes) to the new population.

3.5.5 Mutation

It is also known as background operator .It plays dominant role in the evolutionary process. It cannot be stressed too strongly that the genetic Algorithm is not a random search for a solution to a problem for highly fit individual. It consists of randomly selecting a mutation point. It is applied to one genotype and delivers a (slightly) modified mutant, the child or offspring of it. A mutation operator is always stochastic: its output- the child- depends on the outcome of a series of random choices. A problem specific heuristic operator acting on one individual could be termed as mutation. However, in general mutation is to cause a random, unbiased change.

Generate parents (x) & offspring (q).

$x = \text{lower limit} + (\text{upper limit} - \text{lower limit}) * \text{rand}$ (52)

$q' = q_1 \exp[\tau N(0,1) + \tau' N'(0,1)]$ (53)

Where $\tau = \frac{1}{\sqrt{2n}}$ and $\tau' = \frac{1}{\sqrt{2\sqrt{n}}}$

$x^{new} = x + q' N(0,1)$

3.5.6 Survivor Selection Mechanism

The role of survivor selection is to distinguish among individuals based on their quality. In that it is similar to parent selection, but it is used in different stage of evolutionary cycle. The survival selection mechanism is called after having created the offspring of the selected parents. A choice has to be made on which individuals will be allowed in the next generation. This decision is usually based on their fitness values, favouring those with higher quality. Survivor selection is also often called replacement selection or replacement strategy. In many cases, the two terms can be used interchangeably. The choice between the two is often arbitrary. The preference for using replacement can be motivated by the skewed proportion of the number of individuals in the population and the number of newly created children. In particular, if the number of children is quite small with respect to the population size e.g., 2 children and a population of 100. In this case, the survivor selection step is as simple as to choose the two old individuals that are to be deleted to make place for the new ones. In other words, it is more efficient to declare that everybody survives unless deleted and to choose whom to replace. If the proportion is not skewed like this, e.g., 500 children made from a population of 100, and then this is not an option, so using the term survivor selection is appropriate. Each individual in the competing pool is evaluated for its fitness. All individuals compete with each other for selection. The best K individuals with maximum fitness values are retained to be parents of the next generation. The process of creating off spring and selecting those with maximum fitness are repeated until there is no appreciable improvement in the maximum fitness value or it is repeated up to a pre specified number of iterations.

3.5.7 Initialization

Initialization is the first step which is applied while using Evolutionary Programming. Here, problem specific heuristics can be used in this step aiming at an initial population with higher fitness. Thus, population is selected based on certain measures. Whether this is worth the extra computational effort or not is very much depending on the application at hard. Here, an initial population of parent individuals (P_{gi} , i = 1, 2, 3 ……k) is generated randomly within a feasible range in each dimension.

3.5.8 Termination Condition

Termination means the end of the technique or application which we are using in the system. As for a suitable termination condition we can distinguish two cases. If the problem has a known optimal fitness level, probably coming from a known optimum of the given objective function, then reaching this level should be used as a stopping condition.

3.6 Basic Algorithm of Evolutionary Programming

1. The initial population (parent) is determined with the help of random number. The random number is a normally distributed random number with in a particular range.
2. Calculate the fitness of parents.
3. Make offspring with the help of parents. Calculate fitness of each offspring.
4. Combine all parent and offspring in a mating pool.
5. Start a game for competition and selection.
6. Select a competitor at random from the trial solutions. Let it is $Q_{r.}$ where
   $r = (2N_p u_2 + 1)$, N_p = Number of individuals in a population. u_1, u2 = uniform random numbers ranging over [0,1].
7. Assigns wins for each competitor as-
8. $W_n = 1$, if $u_1 <$ (fitness of Q_r)/(fitness of Q_r + fitness of Q_i).
   $W_n = 0$, otherwise.
9. Add all the wins for all the competitors.
10. Arrange in descending order all the competitors as per their wins
11. Select the top N_p among the competitor and they will be new parent.

3.7 Flowchart of Evolutionary Programming

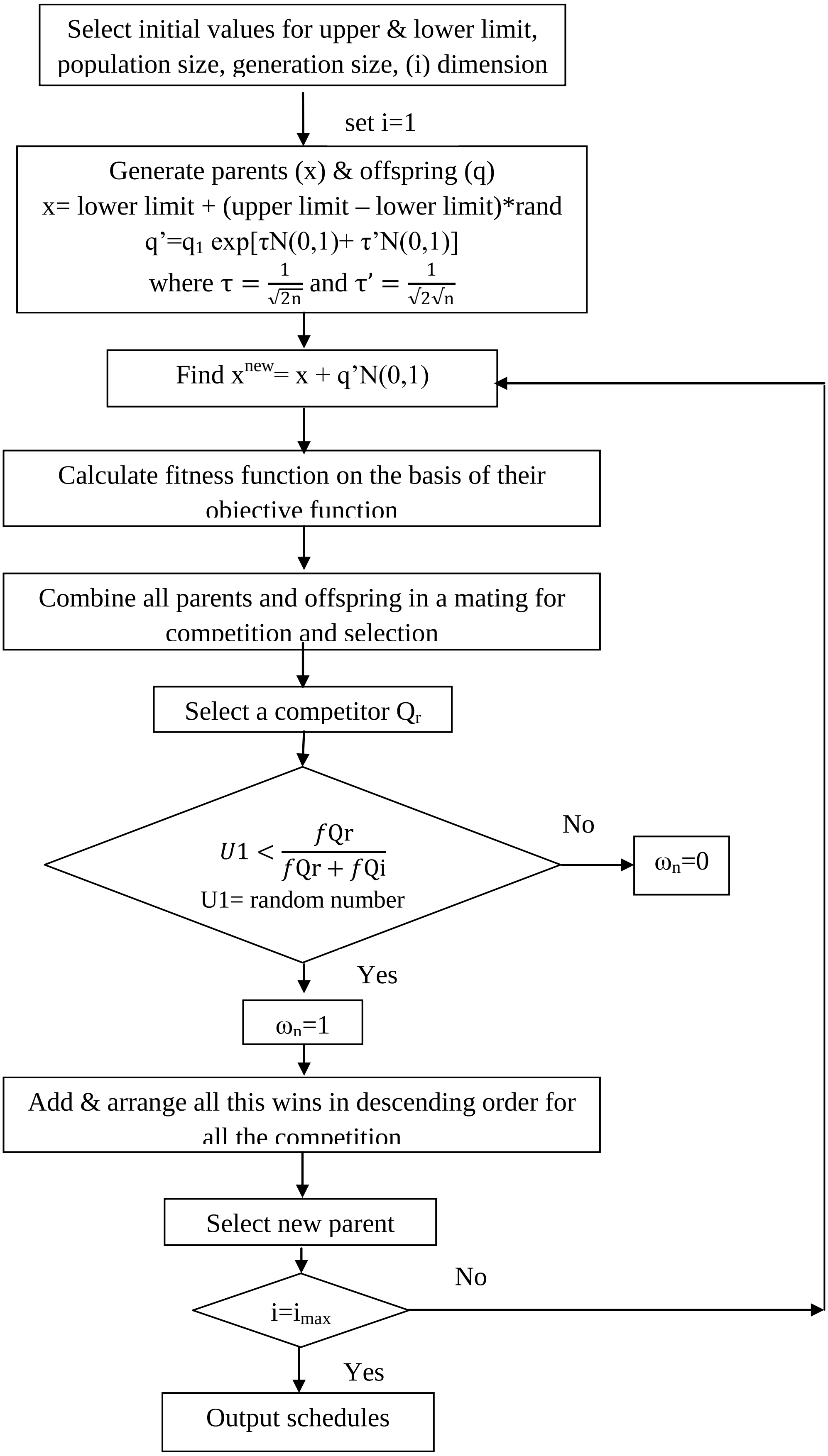

Figure 3.3 Flowchart of Evolutionary Programming

3.8 Algorithm of Evolutionary Programming for the Test Case

1. The problem variables to be determined are represented as a j-dimensional trial vector, where each vector is an individual of the population to be evolved.
2. An initial population of parent vectors Q_k for $k = 1,2....N_p$ is selected at random from a feasible range in each dimension . The distribution of these initial parent vectors is uniform.
3. An offspring is generated by from each parent with adaption of strategy parameter based on scaled cost.
4. Fitness function is evaluated for each individual of both parent and child populations.
5. A competitor is chosen randomly from the combined population of 2Np trial solutions (N_p parents and N_p' off springs) and stochastic competition is performed based on the value of fitness function where each individual in the competing pool competes against other members for survival.
6. After the competition is over, the $2N_p$ trial solutions in the competing pool are sorted according to their scores from the highest to the lowest. Thereafter the first, trial solutions are selected as the new parent vectors for the next generation.
7. If current generation is greater than or equal to the maximum generation, print the result and stop; otherwise repeat steps 3 to 6.

Chapter 4
Result and discussion

In this section, the results of Short term hydro thermal scheduling problem after the implementation of EP are discussed. The algorithms are implemented in MATLAB to solve the problem. The main objective is to minimize the cost of generation of thermal plants.

The performance is evaluated for the following case [35]-

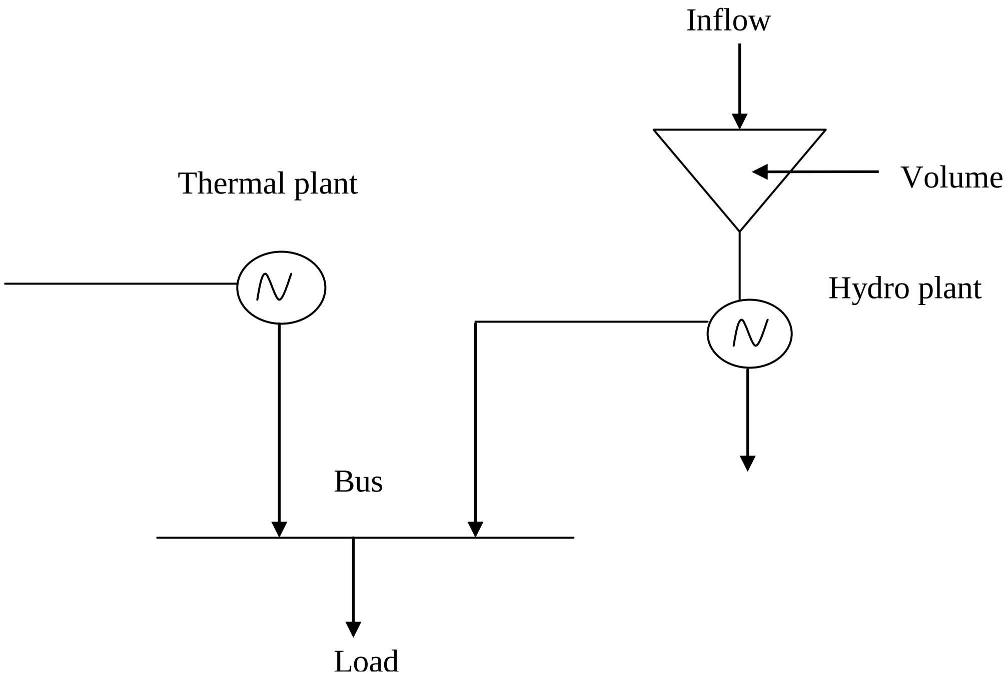

Figure 4.1 Test system

The test system consists of one thermal and one hydro generating station as shown in figure. The operating cost is given by-

$$F_1(P_{1k}) = a_1 P_{1k}^2 + b_1 P_{1k} + c_1 \qquad (54)$$

The rate of discharge of hydro generating station is given by-

$$q_{1k} = x_1 P_{2k}^2 + y_1 P_{2k} + z_1 \qquad (55)$$

The coefficients of fuel cost are given in table 4.1(a). The discharge coefficients of hydro plants are given in table 4.1(b). Maximum and minimum power limits are given in table 4.1(c). The load demands for 24-hour intervals are shown in table 4.1(d).

Unit no.	**a_1**	**b_1**	**c_1**
1	0.001991	9.606	373.7

TABLE-4.1(a) Cost coefficients

Unit no.	**x_1**	**y_1**	**z_1**
2	2.19427*10^- 4	2.5709*10^ - 4	1.742333

TABLE-4.1(b) Discharge coefficients

Limits	**Maximum**	**Minimum**
P1	500	150
P2	300	100

TABLE-4.1(c) Power generation limits

K	**Load demand (P_{DK})(MW)**
1	455.0
2	425.0
3	415.0
4	407.0
5	400.0
6	420.0
7	487.0
8	604.0
9	665.0
10	675.0
11	695.0
12	705.0
13	580.0

14	605.0
15	616.0
16	653.0
17	721.0
18	740.0
19	700.0
20	678.0
21	630.0
22	585.0
23	540.0
24	503.0

TABLE-4.1(d) Load demand

4.1 Optimum Solution for Test Case Using EP

Developed program gives the water discharge, Thermal and Hydro generations and total operating cost. The results are shown in the table given below.

K	**P_{DK} (MW)** **(Load)**	**P_{1K} (MW)** **(Thermal power)**	**P_{2K} (MW)** **(Hydro power)**
1	455.0	226.3438	228.7348
2	425.0	200.7639	224.1628
3	415.0	189.8766	225.1323
4	407.0	183.5105	223.4971
5	400.0	176.0357	223.9646
6	420.0	195.4542	224.5523
7	487.0	253.6326	233.3688
8	604.0	361.6458	242.3672
9	665.0	418.9194	246.0860
10	675.0	428.4532	246.5500
11	695.0	445.2664	249.7380
12	705.0	456.2759	248.7291
13	580.0	340.5407	239.4549
14	605.0	363.5747	241.6224
15	616.0	374.3815	241.6224
16	653.0	408.3701	244.6300
17	721.0	471.6690	249.3368
18	740.0	490.8071	249.1931
19	700.0	453.3001	246.7033
20	678.0	431.7400	246.2615
21	630.0	385.1530	244.8517
22	585.0	344.6537	240.3400
23	540.0	306.4835	233.9242
24	503.0	271.5632	231.4425

Table 4.2 Thermal and Hydro generations for the given load demand

K	**P_{DK} (MW)** **(Load)**	**q_{1K} (Mm^3/h)** **(Discharge)**	**F_K (RS/h)** **(Cost)**
1	455.0	2.6792	2645.8103
2	425.0	2.6325	2379.2227
3	415.0	2.9123	2269.4363
4	407.0	2.8922	2203.5500
5	400.0	2.9001	2126.3971
6	420.0	2.9064	2327.2939
7	487.0	2.9973	2938.1747
8	604.0	3.0935	4108.0678
9	665.0	3.1344	4747.2472
10	675.0	3.1395	4854.9135
11	695.0	3.1756	5045.6690
12	705.0	3.1637	5171.1880
13	580.0	3.0620	3875.8261
14	605.0	3.0834	4129.3820
15	616.0	3.0854	4249.0702
16	653.0	3.1183	4628.5345
17	721.0	3.1705	5347.4934
18	740.0	3.1689	5568.0081
19	700.0	3.1412	5137.2133
20	678.0	3.1363	4892.1157
21	630.0	3.1207	4368.8302
22	585.0	3.0716	3920.9467
23	540.0	2.9989	3504.7993
24	503.0	2.9772	3127.8755

Table 4.3 Hourly cost and discharge for the given load demand

For the simplification of problem the transmission losses are neglected. With the application of EP on the test case, thermal and hydro generations and hourly cost and discharge for the given load demand are obtained.

Total discharge for 24 hour load demand = 72.7603 Mm^3

Total operating cost for 24 hour load demand = Rs 93,567.0655

4.2 Optimum Solution for Test Case Using Classical Method

Developed program gives the water discharge, Thermal and Hydro generations and total operating cost. The results are shown in the table given below.

K	**P_{DK} (MW) (Load)**	**P_{1K} (MW) (Thermal power)**	**P_{2K} (MW) (Hydro power)**
1	455.0	225.3438	229.2348
2	425.0	199.9639	224.9628
3	415.0	188.8766	226.1323
4	407.0	182.3105	224.4971
5	400.0	175.1357	224.8646
6	420.0	193.9542	226.0230
7	487.0	251.5096	235.4918
8	604.0	359.6658	244.3472
9	665.0	416.4634	249.0060
10	675.0	427.1332	247.8700
11	695.0	442.1664	252.8380
12	705.0	453.3759	251.6291
13	580.0	338.1907	241.7649
14	605.0	359.4747	245.7274
15	616.0	371.8815	241.1224
16	653.0	406.2301	246.7700
17	721.0	468.5460	252.4598
18	740.0	488.5721	251.4281
19	700.0	450.8001	249.2033
20	678.0	430.5055	244.3560
21	630.0	382.8530	247.1517
22	585.0	341.2537	243.7400
23	540.0	306.4835	236.7242
24	503.0	269.2176	233.7861

Table 4.4 Thermal and Hydro generations for the given load demand

K	**P_{DK} (MW)** **(Load)**	**q_{1K} (Mm^3/h)** **(Discharge)**	**F_K (RS/h)** **(Cost)**
1	455.0	2.9543	2639.4551
2	425.0	2.9106	2374.1644
3	415.0	2.9225	2259.0762
4	407.0	2.9079	2191.1497
5	400.0	2.9096	2117.1225
6	420.0	2.9115	2311.7219
7	487.0	2.9754	2915.6460
8	604.0	3.0729	4086.2044
9	665.0	3.1145	4697.0492
10	675.0	3.1542	4839.9850
11	695.0	3.2100	5010.4130
12	705.0	3.1963	5138.0783
13	580.0	3.0870	3850.0764
14	605.0	3.1303	4084.0950
15	616.0	3.0800	4221.3407
16	653.0	3.1419	4604.5069
17	721.0	3.2057	5311.6489
18	740.0	3.1941	5542.1806
19	700.0	3.1178	4913.7483
20	678.0	3.1018	4878.1377
21	630.0	3.0926	4343.2195
22	585.0	3.0381	3883.6431
23	540.0	2.9719	3444.5010
24	503.0	2.9772	3104.1081

Table 4.5 Hourly cost and discharge for the given load demand

For the simplification of problem the transmission losses are neglected. With the application of Classical Method on the test case, thermal and hydro generations and hourly cost and discharge for the given load demand are obtained.

Total discharge for 24 hour load demand = 72.7743 Mm^3

Total operating cost for 24 hour load demand = Rs 92,791.2719

Thus it can be concluded that Evolutionary programming technique provides optimum results as close to the Classical method. Although cost obtained by Classical method is less as compare to that obtained by Evolutionary programming technique, it is better to use Evolutionary programming because Classical method can not be applied to the hydrothermal scheduling problem having prohibited zone constraints. Classical method has the major disadvantage of drastic growth of computational requirements with increasing system size.

While implementing EP there is no need of initial guess of power and water discharge. Hence it is better to use EP even it gives total operating cost more than that given by Classical method.

Chapter 5
Conclusion And Future work

5.1 Conclusion

An evolutionary programming based approach has been proposed and demonstrated to solve the short term hydrothermal scheduling problem. Numerical results show that highly near-optimal solutions can be obtained by EP. The effectiveness of the developed program is tested for the system having one hydro and one thermal unit for 24 hour load demand. The EP-based algorithm is faster in searching the optimal solution due to implicit parallelism employed in EP.

Since the encoding and decoding schemes are not needed in the proposed EP approach, a lot of computer memory and computing time can thus be saved. As only the objective function is relied on to guide the search towards the optimal solution in the EP-based algorithm, the generation models of either hydro or thermal units can be of nonlinear and non smooth functions with prohibited areas. So it is clear that with the help of EP-based algorithm it is possible to find a more nearly optimal solution to the existing hydrothermal scheduling problem.

5.2 Future Work

- An improved fast evolutionary programming (IFEP) technique that uses both Gaussian and Cauchy mutations for creation of off springs from the same parent and better ones are chosen for next generation may be used in place of EP.
- Hydro thermal scheduling problem with valve point loading can also be solved using EP. The valve point effect is modelled in two forms one is in the form of prohibited operating zones and the other is by including rectified sinusoidal component in the fuel cost function.
- Emission constrained hydro thermal scheduling problem can also be solved using EP. The amount of emission from each generator is given as a function of its output, which is the sum of a quadratic and an exponential function.

- Long-term hydrothermal scheduling problem can be solved by maximizing the profit of hydroelectric plants, based on the monthly energy requirement of the system, instead of minimizing the production cost of thermal units.
- Closed-loop and partial open-loop feedback control policies in long term hydrothermal scheduling may be used.
- One of the main hypotheses implicit in the classical composite representation is that reservoirs operate in an uniform way, that is, all of them always function at the same percentage of storage capacity. Recent studies concerning the optimal operation of reservoirs for electrical generation**,** however, have shown that the optimal operation of reservoirs is quite different, depending on their location in the cascade, since upstream reservoirs should regulate inflow through the oscillation of their reservoir storage whereas downstream reservoirs should be maintained full most of the time. These results suggest that uniform composite representations underestimate the real generation capability of hydroelectric system. Thus a non uniform composite representation of hydroelectric power systems for long-term hydrothermal generation scheduling may be used.

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