UNIT-II

Hydro Thermal Scheduling

Most of the power systems are a mix of different modes of generating stations of which the thermal and hydro generating units are predominant. While in some systems hydro generation may be more than thermal generation in some other cases it may be the other way. The operating cost of thermal plants is high even though their capital cost is low.

In case of hydro electric plants, the running costs are very low, but the capital cost is high as construction of dams, canals, penstocks, surge tanks and other elements of development are involved in addition to the power house. The hydro plants can be started easily and can be assigned load in very short time. This is not so in case of thermal plants, as it requires several hours to bring the boiler, super heater, and turbine system ready to take the load allotment. For the reason mentioned, the hydro plants can handle fast changing loads effectively. The thermal plants in contrast are slow in response. For this reason, the thermal plants are more suitable to operate as base load plants, leaving hydro plants to operate as peak load plants.

However, the exact mode of operation depends upon the type of the development, and factors such as storage and pondage and the amount of water that is available is the most important consideration. A plant may be run - off river, run - off river with pondage storage or pumped storage type.

Whatever, may be the type of plant, it is necessary to utilize the total quantity of water available in hydro development so that maximum economy is achieved. The economic scheduling in the integrated operation is however, made difficult as water release policy for power is subject to a variety of constraints. There are multiple water usages which are to be satisfied. Determination of the so called pseudo - fuel cost or cost for water usage for use in conjunction with incremental water rate characteristic is a formidable exercise. Nevertheless, hydro thermal economic scheduling is possible with assumptions made wherever necessary.

In systems where there is close balance between hydro and thermal generation and in systems where the hydro capacity is only a fraction of the total capacity, it is generally desired to schedule generation such that thermal generating costs are minimized.

Short Term Hydro Thermal Scheduling

Method of Lagrange Multipliers (losses neglected)

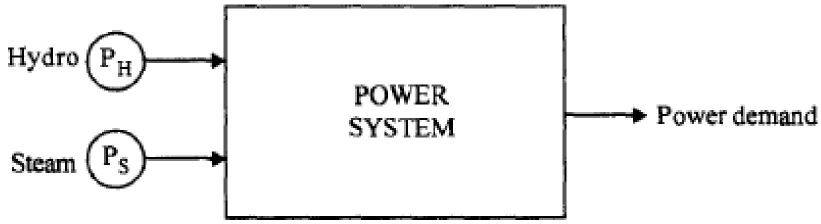

Fig. 3.16 Hydro Thermal scheduling

Let the combined operation be over a period of time T. Let this time period be divided into intervals 1, 2, ... J to suit the load curve so that

$$\sum_{j=1}^{J} n_j = T \quad .....(3.98)$$

The total volume of water available for discharge over this time period.

$$W = \sum_{j=1}^{J} n_j w_j \quad .....(3.99)$$

Where w_j is the water rate for interval j. The fuel cost required to be minimized over the time period T is given as

$$F_T = \sum_{j=1}^{J} n_j F(p_{sj}) \quad .....(3.100)$$

For load balance, the equality constraint is

$$P_{loadj} - P_{Sj} - P_{Hj} = 0 \quad j = 1, 2, ..., J \quad .....(3.101)$$

The loads are assumed to remain constant during time intervals considered. The total value of water at the beginning and at the end of the interval T, in the reservoir are Wi and W f respectively.

During this period of scheduling the head of water is assumed to remain constant.

The input - output characteristic for the equivalent hydro plant is given by

$$w = w(P_H) \quad .....(3.102)$$

The Lagrange function for minimization of eqn. (3.100) subject to the constraints (3.99) and (3.101) is

$$L = \sum_{j=1}^{J} n_j F(P_{Sj}) + \lambda_j [P_{loadj} - P_{Sj} - P_{Hj}] + \gamma \left[\sum_{j=1}^{J} nj\, w_j (P_{Hj}) - W \right] \quad .....(3.103)$$

For any specific value of j = k, the necessary conditions are

$$\frac{\partial L}{\partial P_{Sk}} = 0 \text{ and } \frac{\partial L}{\partial P_{Hk}} = 0 \quad .....(3.104)$$

giving

$$n_k \frac{dF_{Sk}}{dP_{Sk}} = \lambda_k$$

and $$\gamma n_k \frac{dw_k}{dP_{Hk}} = \lambda_k \quad .....(3.105)$$

solution to above two equations gives the economic generations at steam and hydro plants over any time interval. The incremental production cost at the steam plants must be the same as incremental production cost at the hydro plants. For simplicity n_k may be taken one unit. So that

$$\frac{dF_S}{dP_S} = \lambda$$

and $$\gamma . \frac{dw}{dP_H} = \lambda \quad .....(3.106)$$

Lagrange Multipliers Method Transmission Losses Considered

If the transmission losses are considered then the equality constraint includes P_L, the loss terms.

$$[P_{loadj} + P_{Lj} - P_{Sj} - P_{Hj}] = 0 \quad .....(3.107)$$

The Lagrange function changes now into

$$L = \sum_{j=1}^{J} n_j F(P_{Sj}) + \lambda_j (P_{loadj} - P_{Lj} - P_{Sj} - P_{Hj}) + \gamma \sum_{j=1}^{J} [n_j w_j (P_{Hj}) - W] \quad .....(3.108)$$

For any specific j = k, we obtain the optimality conditions as before;

$$\frac{\partial L}{\partial P_{Sk}} = n_k \frac{dF(P_{Sk})}{dP_{Sk}} + \lambda_k(-1) + \lambda_k \left(\frac{-\partial P_{Lk}}{\partial P_{Sk}} \right)$$

$$\frac{\partial L}{\partial P_{Hk}} = \lambda_k(-1) + \lambda_k \frac{\partial P_{Lk})}{\partial P_{Hk}} \left[+ \gamma \frac{n_k dw_k(P_{Hk})}{dP_{Hk}} \right] = 0 .$$

i.e. $$n_k \frac{dF(P_{Sk})}{dP_{Hk}} + \lambda_k \frac{\partial P_{Lk}}{\partial P_{Sk}} = \lambda_k$$

and $$\gamma n_k \frac{dw_k}{dP_{Hk}}(P_{Hk}) + \gamma_k \frac{\partial P_{Lk}}{\partial P_{Hk}} = \lambda_k$$

since k is chosen arbitrarily, and by considering the time period $n_k = 1$

The equations reduce to

$$\frac{dF(P_S)}{dP_S} + \lambda \frac{\partial P_L}{\partial P_S} = \lambda \qquad \text{.....(3.109)}$$

and $$\gamma \frac{dw(P_k)}{dP_H} + \lambda \frac{\partial P_L}{\partial P_H} = \lambda \qquad \text{.....(3.110)}$$

It can be shown that the above equations are valid for any number of steam plants n_S and for any number of hydro plants n_H.

Hence

$$\frac{dF(P_{Si})}{dP_{Si}} + \lambda \frac{\partial P_L}{\partial P_{Si}} = \lambda \text{ for } i - 1, 2, \text{ ....}, n_s \qquad \text{.....(3.111)}$$

and $$\gamma \frac{dw(P_{Hk})}{dP_{Hk}} + \lambda \frac{\partial P_L}{\partial P_{Hk}} = \lambda \text{ for } k = 1, 2, \text{ ....}, n_H \qquad \text{.....(3.112)}$$

the above equations are called coordination equations, the solution to which will give the economic schedule for P_{si} and P_{Hk}.

UNIT COMMITMENT

The topic of Unit Commitment deals with specifying the units which should be operated for a given load i.e which units should be commitment to supply a given load.

It is possible that it may be economical to decommit certain units when load is low

Constraints in Unit Commitment:-

1.Spinning Reserve

2.Minimum Up time

3.Minimum Down time

4.Crew Constraints

5.Transition Cost

6.Hydro Constraints

7.Must Run Units

8.Fuel Supply Constraints

9.Must Out Units

Unit Commitment Problems

1.OFF Line Commitment

2.ON Line Commitment

Standard prescribed methods:

i. Priority List Method

ii. Dynamic Programming Method(DP)

(Forward Dynamic Programming Method)

iii. Lagrange relaxation solution (LR)

Unit Commitment Solution Methods:-

The total number of combinations we need to try each hour is
$C(N,1)+C(N,2)+ - - - - - +C(N,N-1)+C(N,N)=2^N -1$
Where C(N,j) is the combination of N items taken j at a time.
That is

$$C(N,j)= \left[\frac{N!}{(N-j)!j!}\right]$$

$j!=1*2*3*-----*j$

For the total period of M intervals, the maximum number of possible combinations is $(2^N-1)^M$
For example ,take a 24-hour period (Eg, 24 one-hour intervals) and consider systems with 5,10,20 and 40 units.

The value of $(2^N-1)^M$ becomes the following

N	$(2^N-1)^M$
5	$6.2*10^{35}$
10	$1.73*10^{72}$
20	$3.12*10^{144}$
40	Too big

Priority List Method

The simplest unit commitment solution method consists of creating a priority list of units

Most priority-list schemes are built around a simple shut-down algorithm that might operate as follows.

1. At each hour when load is dropping, determine whether dropping the next unit on the priority list will leave sufficient generation to supply the load plus spinning-reserve requirements. If not, continue operating as is; if yes, go on to the next step.

2. Determine the number of hours, H, before the unit will be needed again. That is, assuming that the load is dropping and will then go back up some hours later.

3. If H is less than the minimum shut-down time for the unit, keep commitment as is and go to last step; if not, go to next step.

4. Calculate two costs. The first is the sum of the hourly production costs for the next H hours with the unit up. Then recalculate the same sum for the unit down and add in the start-up cost for either cooling the unit or banking it, whichever is less expensive. If there is sufficient savings from shutting down the unit, it should be shut down, otherwise keep it on.

5. Repeat this entire procedure for the next unit on the priority list. If it is also dropped, go to the next and so forth.

Dynamic-Programming Solution

This method can be used to solve problems in which many sequential decisions are required to be taken in defining the optimum operation of a system, which consist of a distinct number of stages. However it is suitable only when the decisions at the later stages do not affect the operation at the earlier stages.

Dynamic programming has many advantages over the enumeration scheme, the chief advantage being a reduction in the dimensionality of the problem.

Dynamic programming decomposes a problem into a series of smaller problems, solves the small problems, and develops an optimal solution to the original problem step-by-step. The optimal solution is developed from the sub problem recursively.

The approaches used selection techniques for choosing the most promising states from all possible states and implemented approximate economic dispatch subroutines to reduce computer running time requirement.

The imposition of a priority list arranged in order of the full-load average cost rate would result in a theoretically correct dispatch and commitment only if:

1. No load costs are zero.
2. Unit input-output characteristics are linear between zero output and full load.
3. There are no other restrictions.
4. Start-up costs are a fixed amount.

In the dynamic-programming approach that follows, we assume that:

1. A state consists of an array of units with specified units operating and
2. The start-up cost of a unit is independent of the time it has been off-line
3. There are no costs for shutting down a unit.
4. There is a strict priority order, and in each interval a specified minimum the rest off-line. (i.e., it is a fixed amount). amount of capacity must be operating.

A feasible state is one in which the committed units can supply the required load and that meets the minimum amount of capacity each period.

Procedure for preparing the UC table using the DP approach:-

Step1:- Start arbitrarily with consideration of any two units

Step2:- Arrange the combined output of the two units in the form of discrete load levels

Step3:- Determine the most economical combination of the units for all the discrete load levels. It is to be observed that at each load level, the most economic answer may be to run either a unit or both units with a certain load sharing between the two units.

Step4:- Obtain the most economical cost curve in discrete form for the two units and that can be treated at the cost curve of a single equivalent unit.

Step5:- Add the third unit and repeat the procedure to find the cost curve of the three combined units. It may be noted that this procedure, the operating combinations of the third and first and third and second units are not required to be worked out resulting in considerable saving in computation.

Step6:-Repeat the process till all available units are exhausted.

The main advantage of this DP method of approach is that having obtained the optimal way of loading 'K' units. It is quite easy to determine the optimal manner of loading (K+1) units.

Optimal Unit Commitment using Dynamic Programming method:-

The unit commitment problem is solved for the complete load cycle
The total number of units available, their individual operating cost characteristics and the load cycle on the generating stations are assumed to be known in advance.
It is assumed that the load on each unit or combination of units changes in suitably but uniform step of size $\Delta P_{D\ MW(e.g.1MW)}$.

Let a cost function $F_N(x)$ be defined

Let a cost function $F_N(x)$=The minimum cost in Rs/hour of generating x MW by N units

$F_N(y)$=The minimum cost in Rs/hour of generating y MW by the N unit

$F_{N-1}(x-y)$=the minimum cost of generating(x-y) MW by the remaining (N-1) units

The application of dynamic programming results in the following recursive relations:

$$\boxed{F_N(x) \xrightarrow{\text{min}\,y} \{f_N(Y) + f_{N-1}(x-y)}$$

Here, the value of y is varied from minimum load level in the discrete steps of ΔPD providing a set of values of the expression

$$\boxed{\{f_N(Y) + f_{N-1}(x-y)}$$

The minimum of these values is optimum value of $f_N(x)$