POWER SYSTEM OPERATION AND CONTROL

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Lecture Notes: 4

SEMESTER: VIII

Hydro-thermal Scheduling: Introduction, Scheduling Hydro Systems, Discrete Time Interval Method, Short Term Hydrothermal Scheduling Using $\gamma - \lambda$ Iterations, Short Term Hydro Thermal Scheduling Using Penalty Factors.

A modern power system consists of a large number of thermal andhydel plants connected at various load centers through a transmissionnetwork. An important objective in the operation of such a power system is togenerate and transmit power to meet the system load demand at minimum fuelcost by an optimal mix of various types of plants. The study of the problem ofoptimum scheduling of power generation at various plants in a power systemis of paramount importance, particularly where the hydel sources are scarceand high cost of thermal generation has to be relied upon to meet the powerdemand. The hydel resources being extremely limited, the worth of water isgreatly increased. If optimum use is made of their limited resource inconjunction with the thermal sources, huge saving in fuel and the associatedcost can be made. All hydro-systems are basically different from each other in theircharacteristics. The reason for this difference are plenty- the chief pointsbeing their natural difference in their water areas, difference between releaseelements, control constraints, non-uniform water flow etc. Sudden alterationin 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 hydroscheduling. Sometimes, water release may be dictated by treaties between thestates and due to the fishing requirements.

In certain sectors, however, the hydel source is sufficiently large,particularly in rainy seasons the inflows into the hydel reservoirs exhibits anannual cycle. Furthermore, there may be a seasonal variation in powerdemand on the system and this too exhibits an annual cycle. The optimizationinterval of one-year duration is thus a natural choice for long range optimalgeneration scheduling studies. The solution to the scheduling problem in thiscase consists of determination of water quantities to be drawn from thereservoirs for hydro generation in each sub-interval and the correspondingthermal generations to meet the load demand over each sub-interval utilizingthe entire quantity of water available for power generation during the totalinterval. The long-range scheduling (generally persisting from months to year)involves mainly the scheduling of water release. Long range scheduling alsoinvolves meteorological and statistical analysis. The benefit of this scheduling is to save the cost of generation, inaddition to meeting the agricultural and irrigational requirements. Long rangescheduling involves optimization of the operating policy in the context ofmajor unknowns such as load, hydroelectric inflows, unit availability etc.The short-range problem usually has an optimization interval of aday or a week. This period is normally divided into sub-intervals forscheduled purposes. Here, the load, water inflows and unit availabilities areassumed to be known. A set of starting conditions (i.e. reservoirs levels) beinggiven, the optimal hourly schedule can be prepared that minimizes a desiredobjective while meeting system constraints successfully. Cost optimization ofhydro stations can be achieved by assuming the water heads constants andconverting the incremental water (i.e. fuel) rate characteristics intoincremental fuel cost curves by multiplying it with cost of water per cubicmeter and applying the conventional technique of minimizing the costfunction.

HYDROTHERMAL SCHEDULING IN POWER SYSTEM

Optimal scheduling of power plant generation is the determinationof the generation for every generating unit such that the total systemgeneration cost is minimum while satisfying the system constraints. Theobjective of the hydrothermal scheduling problem is to determine the waterreleases from each reservoir of the hydro system at each stage such that theoperation cost is minimized along the planning period. The operation costincludes fuel costs for the thermal units, import costs from neighboringsystems and penalties for load shedding. The basic question in hydrothermalco-ordination is to find a trade-off between a relative gain associated withimmediate hydro generation and the expectation of future benefits comingfrom

Classification of Hydrothermal Scheduling Problem

1. Long range problem

2. Short range problem

1. **Long Range Problem**

Long range problem includes the yearly cyclic nature of reservoirwater inflows and seasonal load demand and correspondingly a schedulingperiod of one year is used. The solution of the long range problem considersthe dynamics of head variations through the water flow continuity equation.The co-ordination of the operation of hydroelectric plants involves, of course,the scheduling of water releases. The long-range hydro-scheduling probleminvolves the long-range forecasting of water availability and the scheduling ofreservoir water releases for an interval of time that depends on the reservoircapacities. Typical long-range scheduling goes anywhere from 1 week to 1year or several years. For hydro schemes with a capacity of impounding waterover several seasons, the long-range problem involves meteorological andstatistical analysis. The purpose of the long-term scheduling is to provide agood feasible solution that is close to the long-term cost minimization of thewhole 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 inflowsover the long term. Long-range scheduling involves optimizing a policy in thecontext of unknowns such as load, hydraulic inflows and unit availabilities(steam and hydro). These unknowns are treated statistically and long-rangescheduling involves optimization of statistical variables.

2. **Short Range Problem**

The load demand on the power system exhibits cyclic variation overa day or a week and the scheduling interval is either a day or a week. As thescheduling interval of short range problem is small, the solution of the shortrangeproblem can assume the head to be fairly constant. The amount of waterto be utilized for the short-range scheduling problem is known from thesolution 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 asystem to achieve minimum production cost for the given time period.The short term hydrothermal scheduling problem is classified intotwo groups

1. Fixed head hydro thermal scheduling

2. Variable head hydro thermal scheduling

PROBLEM FORMULATION

The hydrothermal scheduling problem is a power systemoptimization problem with an objective function, which is a concatenation oflinear, non-linear and dynamic network flow constraint . Since the hydro generating units have zero incremental cost, the hydrothermalscheduling problem is aspired to optimize the system thermal cost, whiletrying to maximize the hydro electric power generation. The objectivefunction and associated constraints of the hydrothermal scheduling problemare formulated as follows.

Objective Function

The objective function of the hydrothermal scheduling problem is

the minimization of the thermal power generation cost

$$F_{CTk} = \sum_{t=1}^{T} \sum_{i=1}^{n} FC_i(P_{sti}(t))$$

Constraints

(i) Power balance equation

$$D_t = \sum_{i=1}^{n} P_{sti}(t) + \sum_{j=1}^{m} P_{hyj}(t) - P_L$$

The hydro generation Phyj (t) is a function of water discharge rateand storage volume.

(ii) Thermal generation capacity

$$P_{stimin} \leq P_{sti}(t) \leq P_{stimax}$$

(iii) Hydro generation capacity

$$P_{hyjmin} \leq P_{hyj}(t) \leq P_{hyjmax}$$

(iv) Hydraulic Continuity

$$V_j(t+1) = V_j(t) + q_j(t-m) + s_j(t-m) - q_j(t) - s_j(t) + r_j(t)$$

Where m is the water delay time between reservoir j and its upstream 1 at interval t.

(v) Initial and final reservoir storage

$$V_j(0) = V_0 \; ; \; V_j(T) = V_T$$

(vi) Reservoir storage

$$V_{jmin} \leq V_j(t) \leq V_{jmax}$$

(vii) Water discharge rate

$$q_{jmin} \leq q_j(t) \leq q_{jmax}$$

(viii) Total water discharge

$$q_{jtot} = \sum_{t=1}^{T} q_i(t)$$

Where,

D_t : System load demand at interval t

$FC_i(P_{sti}(t))$: Fuel cost function of the i_{th}thermal unit

F_{CTk}: Objective function value of k_{th} individual of apopulation

n : Number of thermal generating units

m : Number of hydro generating units

Psti (t) : Thermal generation of unit i at interval t

Phyj (t) : Hydro generation of plant j at interval t

PL : Total Transmission loss

Pstimin , Pstimax: Minimum and maximum generation capacity limits of thermal unit

Phyjmin , Phyjmax: Minimum and maximum generation capacity limits of hydro unit

qj (t) : Water discharge rate of plant j at interval t

rj (t) : Inflow rate into the storage reservoir of plant j at interval t

sj (t) : Spillage of reservoir j at interval t

T : Number of hours in the study period

Vj (t) : Reservoir storage volume of plant j at interval t

V0 , VT : Initial and final reservoir storage

Short Term Hydrothermal Scheduling Using $\gamma - \lambda$ Iterations

The objective function is to minimizethe total operating cost (C- Thermal)represented by the fuel cost of thermalgeneration over the optimizationinterval (k).

$$C_{Thermal} = \mathrm{Min}\sum_{k=1}^{N_T} t_k C(P_{Tk}); \quad N_T = 96$$

where, tk is number of hours in kth time block.

Here, the problem is to schedule the power generation ofhydro-thermal units for k sub interval in order to minimize the fuel cost which is given as:

$$C(P_{Tk}) = \alpha P_{Tk}^2 + \beta P_{Tk} + \theta \quad \mathrm{Rs/hr}$$

where, α, β and q are cost coefficients of thermal plant.

Hydro Model

In hydro system, there is no fuel cost incurred in the operation of hydro units. The 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(PH) is the rate of discharge of Hydro Electric Power Plant is represented by the quadratic equation:

$$q(P_H) = aP_H^2 + bP_H + c \quad m^3/hr$$

where, a, b and c are water discharge rate coefficients of hydro plant.

Water Availability Constraint

The total water discharge is

$$q_{total} = \sum_{k=1}^{N_T} t_k q_k ; \quad k = 1,2,3,\ldots,96$$

In the current study, constant head operation is assumed and the water discharge rate, qk is assumed to be a function of the hydro generation, PHk as in

qk = qk (PHk)

where, tkis number of hours in kth time block and qk is the water discharge rate for kth time block.

Power Balance Equation

Total generated power is equal to the total demand PDK including losses PLk in each time interval. Mathematically:

$$P_{Tk} + P_{Hk} = P_{Dk} + P_{Lk} ; \quad k = 1,2,\ldots.,96$$

where, PDk is the load demand for kth sub-interval and PLk are the transmission losses for kth sub-interval. PTk and PHk are thermal and hydro power generation for kth sub-interval.The transmission loss is function of PHk and PTk.

Thermal and Hydro Power Limits

Thermal and hydro units can generate power between specified upper and lower limits:

$$P_T^{min} \le P_{Tk} \le P_T^{max} ; \quad k = 1,2,\ldots,96$$

$$P_H^{min} \le P_{Hk} \le P_H^{max} ; \quad k = 1,2,\ldots,96$$

where, PTK and PHk are Power output of the thermal and hydro generating units in MW for kthsub-interval andrepresents minimum and maximum power limits of thermal and hydro plant respectively.

Solution Technique

The augmented Lagrangian function (Wood and Wollenberg 1984) for the hydrothermal scheduling problem can be written as:

$$£ = \sum_{k=1}^{N_T} \left[t_k C(P_{Tk}) - \lambda_k (P_{Tk} + P_{Hk} - P_{Dk} - P_{Lk}) \right] + \gamma \left[\sum_{k=1}^{N_T} t_k q_k (P_{Hk}) - q_{total} \right]$$

Where,

£=Lagrange function of hydro-thermal problem=Fictitious cost of water for hydro plant= Incremental cost of received power for kth interval

The co-ordination equation from the above function can be obtained as

$$t_k . \frac{dC(P_{Tk})}{dP_{Tk}} + \lambda_k \frac{dP_{Lk}}{dP_{Tk}} = \lambda_k$$

$$\gamma . t_k . \frac{dq(P_{Hk})}{dP_{Hk}} + \lambda_k \frac{dP_{Lk}}{dP_{Hk}} = \lambda_k$$

Thus, using the above equations and given load demand profile, thermal power, hydro power, rate of water discharge in each interval the optimum cost can be calculated.

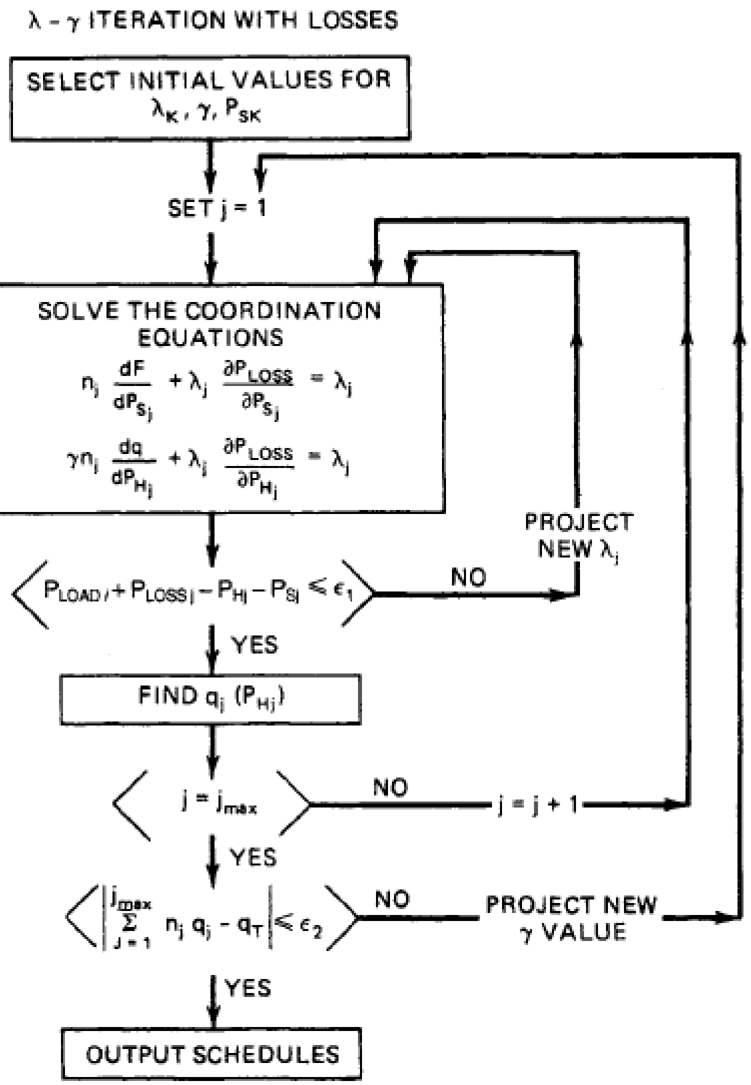

Fig. A α.- λ iteration scheme for hydrothermal scheduling

Short Term Hydro -Thermal Scheduling Using Penalty Factors

The following is an outline of a first-order gradient approach, as shown in Figure 6.7a, 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 hydroplant. Let:

j = the interval = 1, 2, 3,. . . , j,,,

6 = storage volume at the end of interval j

qj = discharge rate during interval j

rj = inflow rate into the storage reservoir during interval j

pSj = steam generation during jIh interval.

sj = spillage discharge rate during interval j

Ploss = losses, assumed here to be zero

Pioad = received power during the jthinterval (load)

PHj = hydro-generation during the jth hour

Next, we let the discharge from the hydroplant be a function of the

hydro-power output only. That is, a constant head characteristic is assumed.