



Hydro-Thermal Scheduling

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Abstract: This paper addresses a short-term scheduling of hydrothermal system by using nonlinear programming technique in conjunction with the first order gradient method. The Lagrangian is formulated by augmenting the cost function of thermal with equality constraints of hydro through Lagrange multiplier. The method is quit general and can be directly extended to a system having multi-hydro and multi-thermal plants. A problem is tested and the results shows that the proposed approach perform well for optimization of hydrothermal system. The objective of scheduling is to optimize thermal operating cost under the hydro constraints: load demand, water availability, maximum hydro generation and water discharge. Solution technology shows the formulation of equation for solving the problem. For simplicity fundamental hydrothermal system is taken into account which consists scheduling of single hydro and single thermal units fulfilling the system load demand. The algorithm is implemented in MATLAB optimization toolkit. The obtained results from both mathematical solution and MATLAB are same after single iteration. The complete solution takes 46 iterations for this short-term hydrothermal scheduling problem.

Keywords: -First order gradient, Lagrangian multiplier, MATLAB, hydrothermal, MW

I. Introduction

No state or country endowed with plenty of water sources or abundant coal and nuclear fuel. For reducing environmental pollution, thermal generation should be minimum. Hence, a mix of hydro and thermal power generation is necessary. The state that have a large hydro potential can supply excess hydro power during period of high water run-off to other states and can receive thermal power during period of low water run-off from other state. The states, which have a low hydro potential and large coal reserves, can use the small hydro power for meeting peak requirements. This makes the thermal station to operate at high load factors and to have reduced installed capacity with the result economy. In states, which have adequate hydro as well as thermal power generation capacities, power coordination to obtain a most economical operating state is essential. Maximum advantage of cheap hydro-power should be taken so that the coal reserves can be conserved and environmental pollution can be minimized. Most economical operating state of a hydro-thermal system. The hydro-thermal coordination is classified into long-term co-ordination and short term co-ordination.

II. Research Elaboration

The hydro-thermal co-ordination is of two types:-

- (i) Long-term co-ordination - Typical long term co-ordination may be extended from one week to one year or several years. The co-ordination of the operation of reservoir hydro-power plant and steam plant involve the best utilization of available water in term of the scheduling of
- (ii) Short-term co-ordination - This type of hydro-thermal scheduling is required for one day or one week, which involves the hour-by-hour scheduling of all available generation on a system to get the minimum production cost for the given time. Such type of scheduling problem, the load, hydraulic inflow, and unit availabilities are assumed to be known.

Solution technique:-

The problem is solved here using non-linear programming technique in conjunction with the first order gradient method. The Lagrangian $\mathcal{E}$ is formulated by augmenting the cost function of equation with equality constraints of equation through Lagrange multiplier (dual variable) λ_1^m , λ_2^m and λ_3^m . Thus,

$$\mathcal{E} = \sum_m [C(P_{GT}^m) - \lambda_1^m(P_{GT}^m + P_{GH}^m - P_L^m - P_D^m) + \lambda_2^m(X^m - X^{(m-1)}) - J^m + q^m]$$

$$+\lambda_3^m\{P_{GH}^m - h_0\{1 + 0.5e(X^m + X^{m-1})\}(q^m - \rho)\} \quad [2.1]$$

The dual variables are obtained by equating to zero the partial derivative of the Lagrangian with respects to the dependent variable yielding the following equation:

$$\frac{\partial \mathcal{E}}{\partial P_{GT}^m} = \frac{dC(P_{GT}^m)}{dP_{GT}^m} - \lambda_1^m \left(1 - \frac{\partial P_L^m}{\partial P_{GT}^m}\right) = 0 \quad [2.2]$$

$$\frac{\partial \mathcal{E}}{\partial P_{GH}^m} = \lambda_3^m - \lambda_1^m \left(1 - \frac{\partial P_L^m}{\partial P_{GH}^m}\right) = 0 \quad [2.3]$$

$$\left(\frac{\partial \mathcal{E}}{\partial X^m}\right) m \neq M, m \neq 0 = \lambda_2^m - \lambda_2^{m+1} - \lambda_3^m\{0.5h_0e(q^m - \rho)\} - \lambda_3^{m+1}\{0.5h_0e(q^{m+1} - \rho)\} = 0 \quad [2.4]$$

And using equation [3.3.6] in equation [3.4.1], we get

$$\left(\frac{\partial \mathcal{E}}{\partial q^1}\right) = \lambda_2^1 - \lambda_3^1 h_0\{1 + 0.5e(2X^0 + J^1 - 2q^1 + \rho)\} = 0 \quad [2.5]$$

The dual variable for any subinterval may be obtained as follows:

1. Obtained λ_1^m from equation [2.2].
2. Obtained λ_3^m from equation [2.3].
3. Obtained λ_2^1 from equation value of $\lambda_2^m (m \neq 1)$ from Eq. [2.4]

The gradient vector is given by the partial derivative of the Lagrangian with respect to the independent variables. Thus,

$$\left(\frac{\partial \mathcal{E}}{\partial q^m}\right) m \neq 1, = \lambda_2^m - \lambda_3^m h_0\{1 + 0.5e(2X^{m-1} + J^m - 2q^m + \rho)\} \quad [2.6]$$

For optimality, the gradient vector should be zero if there are no inequality constraints on the control variable.

Algorithm:-

1. Assume an initial set of independent variable $q^m (m \neq 1)$ for all subintervals except the first.
2. Obtain the value of dependent variables $X^m, P_{GH}^m, P_{GT}^m, q^m$ using equation [2.5, 2.6 and so on].
3. Obtain the dual variable $\lambda_1^m, \lambda_3^m, \lambda_2^m (m \neq 1)$ and λ_2^1 using equation [2.2-2.5].
4. Obtain the gradient vector using equation [2.6] and check if all its elements are equal to zero within a specified accuracy. If so, optimum is reached. If not go to step 5.
5. Obtain new value of control variables using the first order gradient method, i.e.

$$q_{new}^m = q_{old}^m - \alpha \left(\frac{\partial \mathcal{E}}{\partial q^m}\right); m \neq 1 \quad [2.7]$$

When α is a positive scalar. Repeat from step 2.

III. Problem

Consider the problem with load given below in table-3.1 [6] and solve schedule hour by hour for a day.

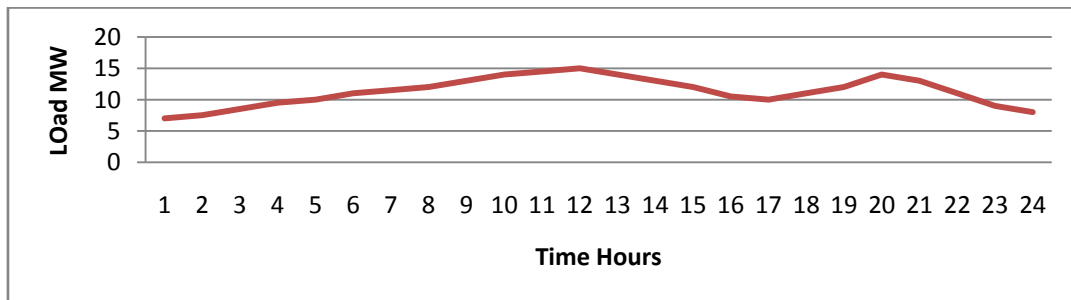


Figure 3.1 Load Demand Curve

Table- 3.1 Load demands

Hour	Load(MW)	Hour	Load(MW)
1	7	13	14
2	7.5	14	13
3	8.5	15	12
4	9.5	16	10.5
5	10	17	10
6	11	18	11
7	11.5	19	12
8	12	20	14
9	13	21	13
10	14	22	11
11	14.5	23	9
12	15	24	8

IV. Result

Result: - The problem is a short-term hydro-thermal scheduling problem in which the hydro and thermal units are scheduled hour by hour for a day (24-hour). The system load demand [6] is given in table-3.1. The problem solved here using MATLAB programming and results are provided in table-4.1

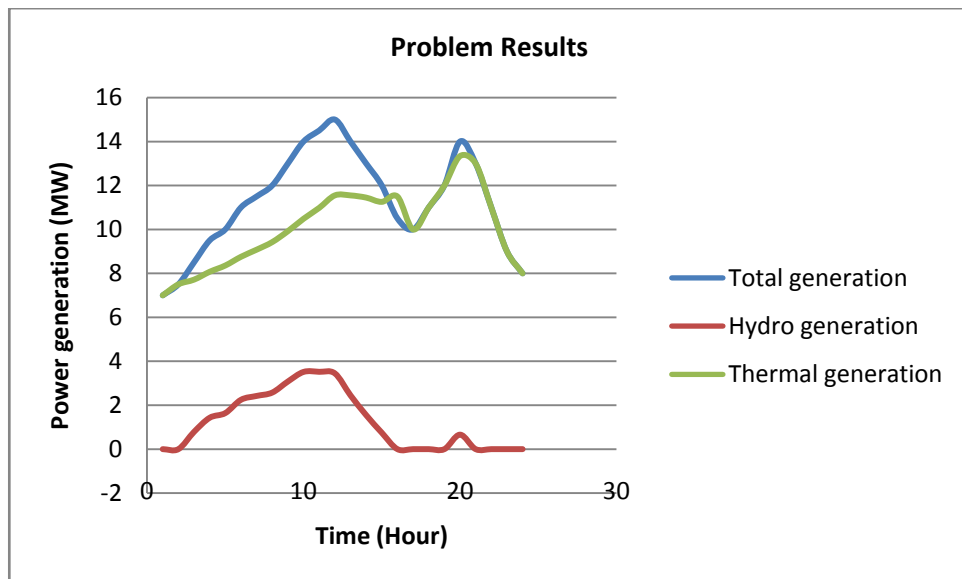


Figure 4.1 Power Generation Results

Table-4.1 MATLAB Result

S.No.	Hydro generation (P_{GH}) (MW)	Thermal generation (P_{GT}) (MW)	Total generation (Load) (MW)
1	0	7.0000	7
2	0	7.5000	7.5
3	0.7850	7.7150	8.5
4	1.4278	8.0722	9.5
5	1.6406	8.3594	10
6	2.2451	8.7549	11
7	2.4206	9.6764	11.5
8	2.5743	9.4257	12
9	3.0775	9.9225	13
10	3.5137	10.4863	14
11	3.5174	10.9826	14.5
12	3.4479	11.5521	15

13	2.4491	11.5509	14
14	1.5494	11.4506	13
15	0.7437	11.2566	12
16	0	11.5000	10.5
17	0	10.0000	10
18	0	11.0000	11
19	0	12.0000	12
20	0.6589	13.3411	14
21	0	13.0000	13
22	0	11.0000	11
23	0	9.0000	9
24	0	8.0000	8

V. CONCLUSION

A nonlinear programming technique in conjunction with the first order gradient method based approach has been proposed and demonstrated to solve the short term hydro thermal scheduling problem. Numerical result shows that highly near optimal solution can be obtained by this approach. The effectiveness of the developed program is tested for the system having one hydro and one thermal unit for 24 hour load demand. The test results on the fundamental hydrothermal generation system with one hydro unit and one thermal unit show the efficiency of our proposed formulation. Numerical results as well as Matlab results for a problem show that the proposed approach produce better schedules in term of total production cost and system constraints violations. As only objective function is relied on to guide the search towards the optimal solution in the first order gradient based algorithm. So it is possible to find more optimal solution by existing short term hydrothermal scheduling problem. So we conclude that this approach of hydrothermal scheduling method could be of help for the solution hydrothermal power generation system in the uncertain environment of the competitive electricity market.

VI. References

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