Otto-von-Guericke-University Magdeburg Faculty of Electrical Engineering and Information Technology Chair for Automation/Modeling

Power Systems Control and Optimization

Project 3-Report

Hydro-thermal Scheduling

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1. Introduction

In a large system, hydro and thermal power plants are integrated to meet the demand. The idea of this integrated operation is for optimal utilization of energy sources in the most economical manner to meet the load demand at all points of time.
In day to day life, hydro-thermal scheduling is an important activity for electric utilities to meet future demand. In the overall energy utility of India, more than 70% of the electricity requirements are contributed from thermal sources. Hydroelectric sources contribute a major share than any other source whereas in India utilize below 24% of hydropower sources. Despite this low share of the hydroelectric source the overall generation of the country is reduced due to more demand on-peak hours of the customers. **[1]**

In the process of electricity generation, it is very important to optimize the fuel cost. This is only achievable by taking major decisions such as varying the generating units and combining them in such a way that the summation of the supplying units can meet the energy demand at the lowest possible cost. To do this, some mathematical modules must be developed and these contain some specified technological and economical limitations. In this project, the hydrothermal scheduling problem will be solved for thermal generation units. The approach will be used to solve the problem called the Lagrange relaxation method. 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.

This is also one of the most important optimization operation problems. However, this problem is more complicated than economic load dispatch since several hydro plants are added to the system supplying electricity to load. The main task of the problem is to calculate the power output of both thermal plants and hydro plants so that only the total fuel cost of thermal plants is minimized while satisfying power balance constraints, power generation limits on thermal and hydro units, water discharge limits, and water volume limits. **[2]**

2. Mathematical Formulation

Moreover, a fast algorithm for solving the short-term hydrothermal scheduling problem in a power system consisting of cascaded plants with time delay and independent hydro plants. The operational planning of such problem is concerned with the determination of scheduling for hydro as well as thermal plants to meet the daily system demand with the objective of minimizing the total fuel cost of the thermal plants over the day subject to the relevant operating constraints associated with the thermal and hydro plants. **[3]**

$$B_1 (P_1) = 0{:}005P_1^2 + 11P_1 + 200 \quad (1)$$
$$B_2 (P_2) = 0{:}009P_2^2 + 10P_2 + 180 \quad (2)$$
$$B_3 (P_3) = 0{:}007P_3^2 + 10P_3 + 230 \quad (3)$$

In the thermal power plant will go first with the unit-2 thermal plant as it's more economical as per the load constraints. Then will turn on the 1st unit and at the end will go with 3rd unit. For the generating units, the following minimum and maximum power constraints have to be full filled.

$$50MW \le P_1 \le 200MW \quad (4)$$
$$37MW \le P_2 \le 150MW \quad (5)$$
$$45MW \le P_3 \le 180MW \quad (6)$$

Hydropower plant 1 is supplied from a reservoir V1 and supplies water to a reservoir V2, which supplies hydropower plant 2. The water out of hydropower plant 2 supplies reservoir V3, which supplies hydropower plant 3. The water volume in each reservoir should stay in its limits.
The following layout explains the Integration of the 3 Hydro power plants in cascade.

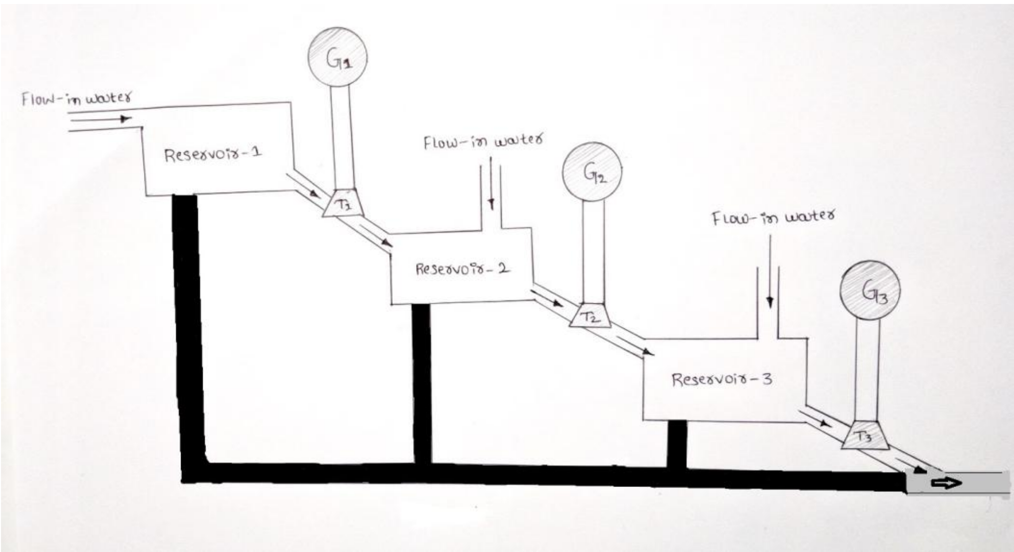


Figure (1): Layout of the reservoir connected in cascade

2.1 Hydropower constraints

The given equation (7) represents the water flow from the reservoir in all the 3 hydropower plants. The Power generation constraint of hydro plants has been represented by equation (8). It should also be noted that the Volume of the reservoirs should be in the limit as per equation (9).

$$q = 320\times10^3 + 6\times10^3 P_H + e^{0.035PH} \quad (7)$$

$$43MW \leq P_H \leq 280MW \quad (8)$$

$$7\times10^6 \leq V_i \leq 8\times10^6 \quad (9)$$

There are various constraints we must have to take care of In order to get the desire outputs effectively. **[4]**

- Physical constraints
  - Only Small variation of the water level is allowed.
  - River should be navigable at all the times so that it can maintain the flow of water (Minimum Water level).
  - No sudden changes on water release to avoid travelling Waves problems. It may cause damage of the plant.
- Mathematical Constraints
  - Flow has to remain within its limit, i.e $q \in [q_{min}, q_{max}]$
  - Limit on the maximum flow rate (q_{max}), accordingly power will generate (P_{max}).
  - Minimum flow required to generate the minimum amount of power $P_{H,min} \rightarrow P_H \in [P_{H,min}, P_{H,max}]$.
- Minimum fuel consumption problem
- Typical Constraints

Table 1: Load schedule

i	1	2	3	4	5	6	7	8	9	10	11
p_i	0.5	0.53	0.55	0.53	0:5	0.54	0.7	0.9	0.95	1.1	1.2
P(MW)	265	281	291	281	265	286	371	477	503	583	636
i	12	13	14	15	16	17	18	19	20	21	
p_i	1.4	1.7	1.65	1.5	1.3	1.0	0.9	0.8	0.5	0.54	
P(MW)	742	901	874	795	689	530	477	424	265	286	

Sample mathematical calculation of Load

At i= 1,

P (MW) = Pi×Pload, $_0$= 0.5×530= 265 MW

Where,

P= Load demand in MW

Pi= Normalized load

Pload, $_0$= Nominal load

The thermal power plants are supplying a load, where the normalized load schedule pi is given in Table 1. The nominal load is $Pload_0$ = 530MW.

The various load demand in the different span of time has been calculated and accordingly (Depending upon the requirement) the required thermal and hydropower plants should be operated to match the demand in the most economical way.

By varying the nominal load we can get the different scheduling of the plant and with that the cost of generation will also vary.

3. The Project MATLAB Code

```
clear all;

%% Simulation Parameters

T = 5;          % Time in Hrs
N = 21;         % Samples
dt = T/(N-1);   % Length of samples
t = 0:dt:T;     % vector of time
M = 6;          % Optimization variables = number of constraints =
                pg1,pg2,pg3,pgh1,pgh2,pgh3 ==6

% cost functions for thermal power plants
c(1,:) = [ 0.005 11 200 ];
c(2,:) = [ 0.009 10 180 ];
c(3,:) = [ 0.007 10 230 ];

% minimum and maximum power constraints for Thermal and hydro power plants
Pmin = [50*ones(N,1), 37*ones(N,1), 45*ones(N,1), 43*ones(N,1), 43*ones(N,1),
43*ones(N,1)];
% ones(21,1)* 50 it means 50 repeated in 21 rows and one coloumn for all i
Pmax = [200*ones(N,1), 150*ones(N,1), 180*ones(N,1), 280*ones(N,1),
280*ones(N,1), 280*ones(N,1)];

Vmin = 7e6;       % Min water volume of reservoir
Vmax = 8e6;       % Max water volume of reservoir

Pload0 = 530;     % Nominal load in MW
Pload = Pload0*[0.50  0.53  0.55  0.53  0.5  0.54  0.70  0.90  0.95  1.10 1.20
1.40  1.70  1.65  1.50  1.30  1.00  0.90  0.80  0.50 0.54];

pmin = reshape(Pmin',M*N,1);   % became (126 row,1 column)dimesnsion [
                              50;37;45;43;43;43;.....;43]
pmax = reshape(Pmax',M*N,1);   % became (126 row,1 column) dimesnsion [
                              200;150;180;280;280;.....;280]

% example below q(opt) u can understand the concept. p(6,:) represent optimum
values for Hydroelectric generation
q = @(P) 320e3 + 6e3*P(6,:)+ exp(0.035*P(6,:));

% volume formula --- reshape(p,M,N) means that from 126*1 dimension make each
row represent generation unit
V = @(p) sum(q(reshape (p,M,N)))*dt;

% nonlinear constraints water volume for each power
noncon = @(p) deal([V(p)-Vmin; Vax-V(p)], []);

Aload = kron(eye(N),ones(1,M));  % linear equality constraints
                                 pg1+pg2+pg3+ph=pload ---- [1 1 1 1 1 1]
                                 dimension 21X126
```

```matlab
%% Optimization

p0 = pmin;      %intial guess
                % performing the optimization operation to minimize cost
opt = optimset ('Algorithm', 'Interior-point', 'Display', 'iter', 'MaxIter',
1e5, 'MaxFunEvals', 1e5 );

[popt,fopt] = fmincon(@(p) costFun(p,c,M), p0, [], [], Aload, Pload', pmin,
pmax,noncon, opt);


%% Plotting
% reshaping of vector in matrix [M,N]

popt1=popt;                    % lenght of popt1 126*1
Popt = reshape(popt, M, N);    % after reshape each row represent a generation
                               unit and hydrounit 6*21 dimension
Pmint = reshape(pmin, M, N);    % same as above
Pmaxt = reshape(pmax, M, N);    % same as above

Pgen = Aload*popt;              % Aload dimension = (N*126) X popt Dimension
                              =(126*1) --> pgen dimension = (N*1)
qt = q(Popt);                  % popt= reshape(popt, M, N) this illustrate the
                                above
Vt =(qt*dt);                   % multiply each value by dt 21 values


%% subplot
 figure(1)

for i = 1:M
    subplot (3,2,i)
    plot(t,Pmint(i,:), 'r--',t,Pmaxt(i,:),'r--',t,Popt(i,:),'b'); % Popt after
                                                               reshape
    title(['P',num2str(i)]);
    xlabel('dt')
    ylabel('Power P')

end
    subplot (3, 2, 5)
    plot(t,Vmin*ones(size(t)), 'r--',t,Vmax*ones(size(t)),'r--',t,Vt,'b'); %
                                         make vmin and Vmax in the length of T

xlim([1 5])
title('V')
xlabel('dt')
ylabel('Volume V')
subplot(3,2,6)
plot(t,Pload,'rx',t,Pgen,'b')
legend('Pload', ' Pgen')
xlabel('dt')
ylabel('Power P')

end
```

CostFunction MATLAB Code

```
function y = costFun(p,c,M)   % clear for me


N = length(p)/M;          % 126/6 =21
P = reshape(p,  M,  N);     % make all values related to pg1 in one row and etc


y = 0;                      % initial cost==0

for i = 1:N


costs = c(1,1)*P(1,i).^2+c(1,2)*P(1,i)+c(1,3)+...
        c(2,1)*P(2,i).^2+c(2,2)*P(2,i)+c(2,3)+...   ( % for i=1......,21 it
                                                     has different fuel power
                                                     generation correspond to
                                                     each load i)
        c(3,1)*P(3,i).^2+c(3,3)*P(3,i)+c(3,3);

    y = y + costs;
end
```

4. Plots and explanation

Figure (2) to Figure (4) Consist of a total of 18 plots which Shows the plots of generated power P vs. time, volume of the reservoir vs. time, and the generation of power vs. load demand, for the entire given nominal load power.

In the first case, fig (2) with nominal load 530MW, the power generation and power demand is almost matched at all the points and most of the power is supplied by the hydropower plants.

In the second case, fig (3) with the nominal load 350MW, the generation is more, demand is less. At the peak point the generation is matched to the demand. This is because the most of the power stations have to be in ON state with their base load. And hence the generation is even more at some point.

In the third case, fig (4) with nominal load 730MW, the generation has matched the demand at most of the points. In this, the 1st and 2nd thermal power plant has contributed more power than its Base load at a peak time. We can see clearly in the graph.

In the volume level graph, the water level is in the limit between ($\mathbf{7\times10^6 \le Vi \le 8\times10^6}$). The usage of the water has been increasing and decreasing with the generation of power over the period of time through the Hydro power plant.

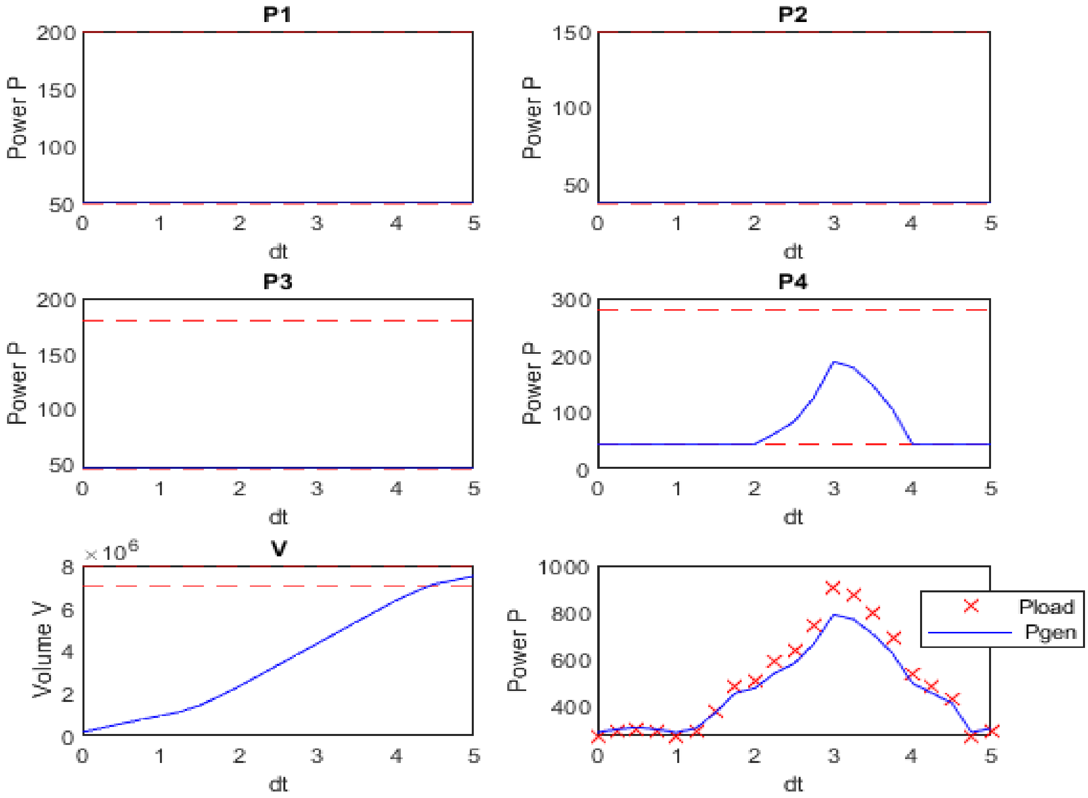


Fig. (2) Graph of different states of integreated Hydro-Thermal Power plant at nomial load 530MW.

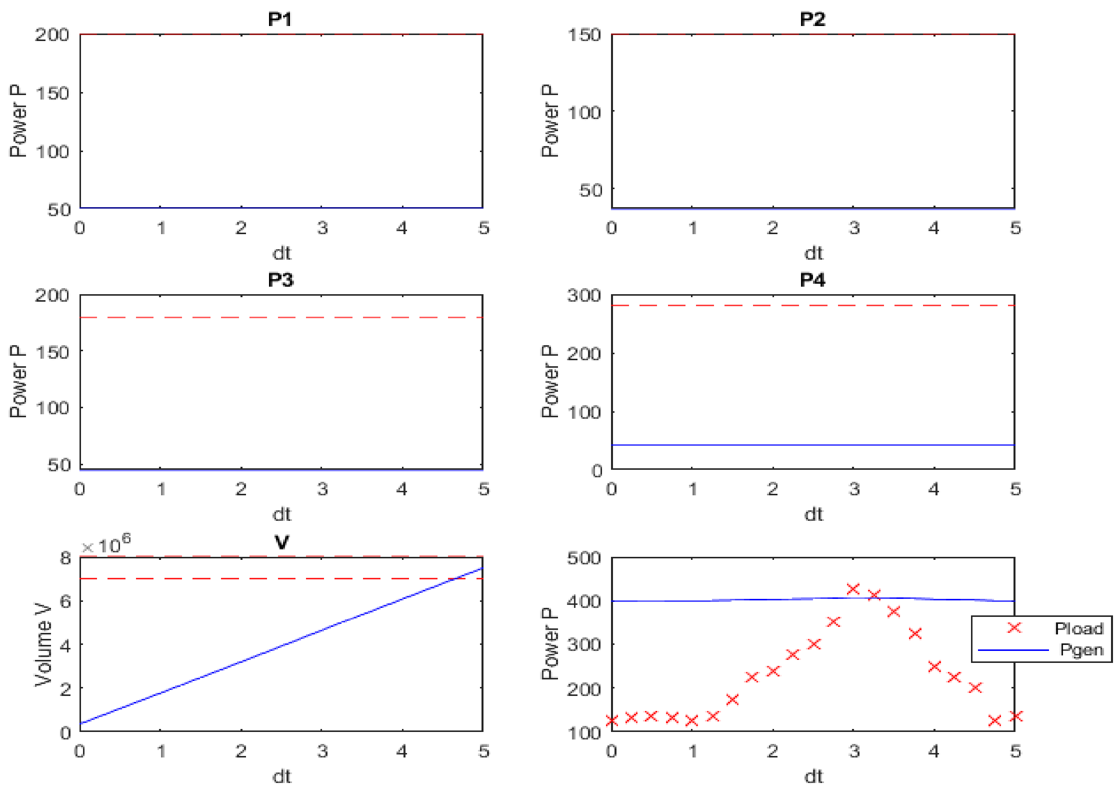
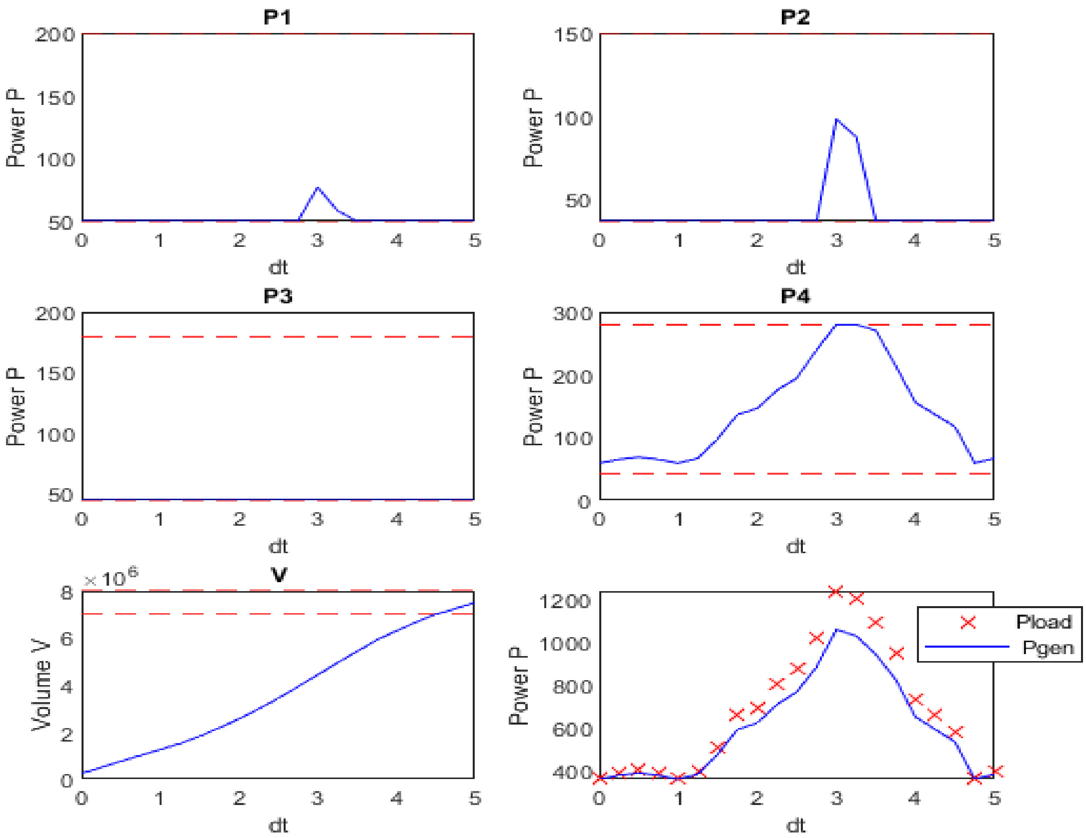


Fig.(3) Graph of different states of integreated Hydro-Thermal Power plant at nomial load 350 MW.



Fig(4) Graph of different states of integreated Hydro-Thermal Power plant at nomial load 730MW.

5. Result and discussion

Hydrothermal scheduling is an important issue in the field of power system economics. Their aim is to optimize the hourly output of power generation for different hydrothermal units for certain intervals of time to minimize the total cost of generations. And also to match the load demand to end of user.

The optimization results obtained from the simulation of the hydrothermal scheduling problems are presented in tables and plots. Tab. 1 shows the variation of power demand at nominal load 530. After the optimization and execution of the MATLAB-code (by varying the nominal load for 3 different loads demand), the various Plots have been plotted. The Integration of hydro and thermal power plants has been used as an ineffective way to match the load demand economically. This has been achieved through Matlab Simulation, and the final report has been presented.

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