UNIVERSITY OF ENGINEERING AND TECHNOLOGY LAHORE

Assignment # 4

Dynamic Programming solution to Hydrothermal scheduling

Course Title: Advanced Power System Operation and Control

Course Code: EE 641

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Problem Statement

A Hydro plant must be operated in conjunction with a Steam plant to serve a time varying load P_{Load} for a 24-hour period. The day is divided into six individual periods of 4h each. The load demand for the different periods is given below:

Period j	Time Interval	P_{Load} (MW)
1	00:00-04:00	600
2	04:00-08:00	1000
3	08:00:12:00	900
4	12:00-16:00	500
5	16:00-20:00	400
6	20:00-24:00	300

Hydroelectric Plant

The minimum and maximum storage limits for the Hydro plant reservoir are given by:

$$6000\ acre.ft \leq V_S \leq 18000\ acre.ft$$

The storage volume at the start and end of the day must be 10000 acre.ft.

The water use rate of the hydroelectric plant is given by:

$$q = 260 + 10P_H \qquad 0\ MW \leq P_H \leq 200\ MW$$

$$q = 0 \qquad P_H = 0\ MW$$

Where P_H is the generated hydroelectric power and q is the water discharge rate in acre.ft/h.

$$0\ \frac{acre.ft}{h} \leq q \leq 2260\ \frac{acre.ft}{h}$$

There is no spillage and the natural inflow rate is 1000 acre.ft/h.

Steam Plant

The steam plant production cost function is:

$$F = 700 + 4.8P_s + \frac{P_s^2}{2000}\frac{\$}{h} \qquad 200\ MW \leq P_s \leq 1200\ MW$$

The marginal cost function is:

$$\frac{dF}{dP_s} = 4.8 + \frac{P_s}{1000}\ \$/MWh$$

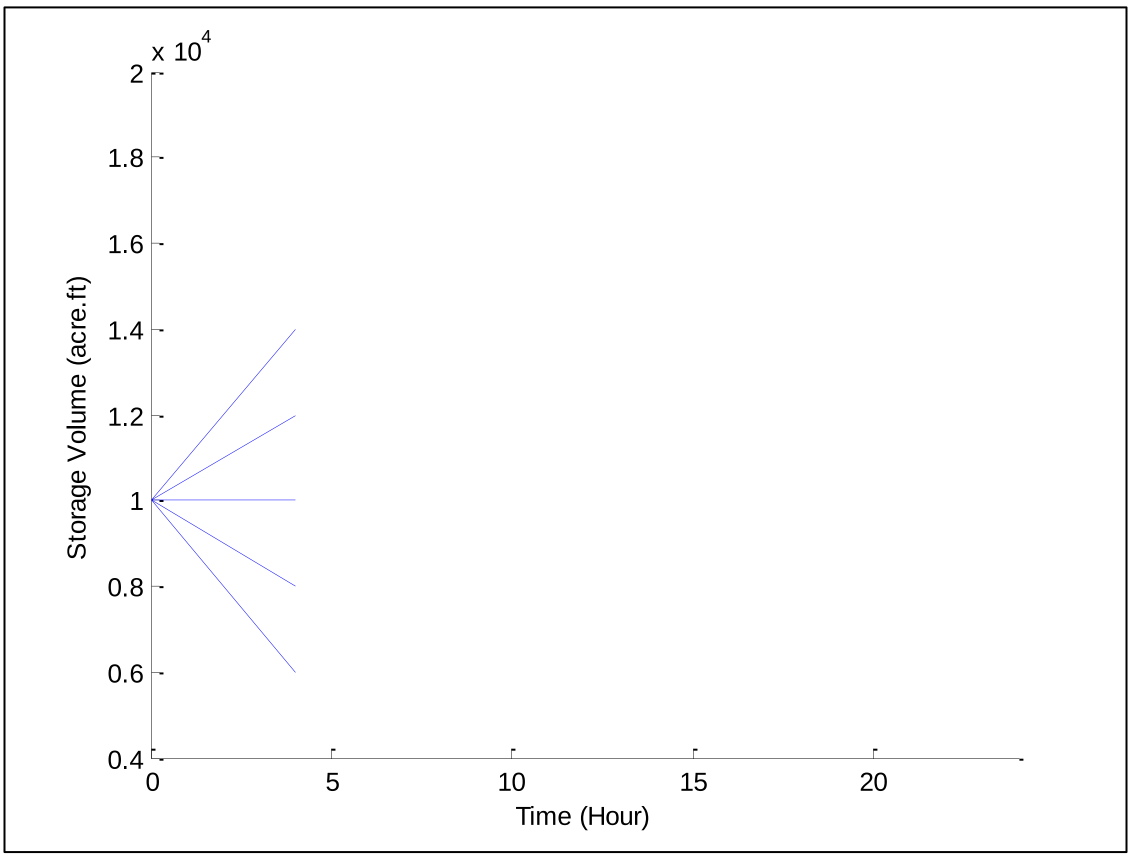
The Dynamic programming algorithm tries to schedule the two power plants optimally to meet the load demand and operational constraints for the six 4-hour time periods. It is also desired to minimize the production cost for the compound generation system.

<u>First Period</u>

The results for the first period are shown in the table below.

	j=1	$P_{Load}(1) = 600$ MW		
V_s	q (acre.ft/h)	P_H (MW)	P_s (MW)	$TC_k(j)(\$)$
14,000	0	0	600	15,040
12,000	500	24	576	14,523
10,000	1000	74	526	13,453
8,000	1500	124	476	12,392
6,000	2000	174	426	11,342

The diagram shows the initial trajectories for the dynamic programming algorithm.

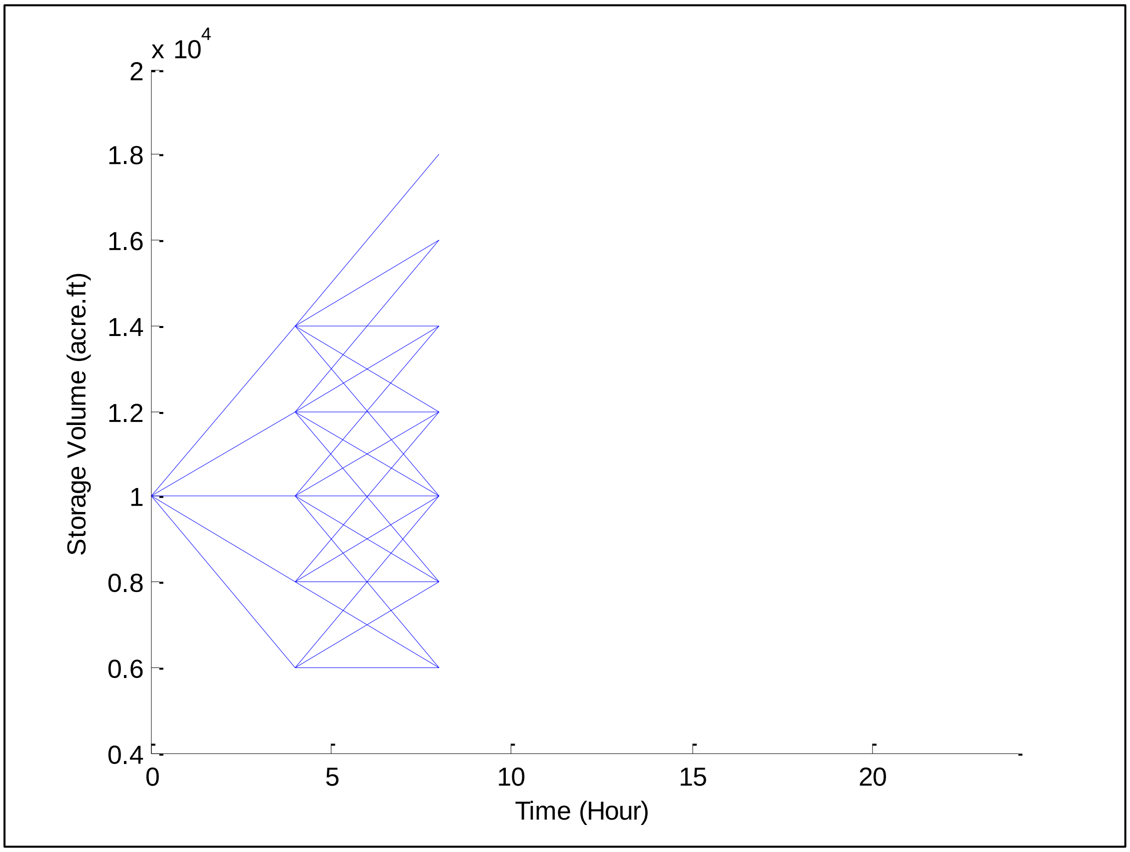


Second Period

The results for the second period are shown in the table below.

j=2			$P_{Load}(2) = 1000$ MW		
$V_{s,final}$	$V_{s,initial}$	q (acre.ft/h)	P_H (MW)	P_s (MW)	$TC_k(j)$($)
18,000	14,000	0	0	1000	39,040
16,000	14,000	500	24	976	38,484
16,000	12,000	0	0	1000	38,523
14,000	14,000	1000	74	926	37,334
14,000	12,000	500	24	976	37,967
14,000	10,000	0	0	1000	37,453
12,000	14,000	1500	124	876	36,194
12,000	12,000	1000	74	926	39,818
12,000	10,000	500	24	976	36,897
12,000	8,000	0	0	1000	36,392
10,000	14,000	2000	174	826	35,064
10,000	12,000	1500	124	876	35,677
10,000	10,000	1000	74	926	35,747
10,000	8,000	500	24	976	35,837
10,000	6,000	0	0	1000	35,342
8,000	12,000	2000	174	826	34,547
8,000	10,000	1500	124	876	34,607
8,000	8,000	1000	74	926	34,687
8,000	6,000	500	24	976	34,787
6,000	10,000	2000	174	826	33,476
6,000	8,000	1500	124	876	33,546
6,000	6,000	1000	74	926	33,636

The diagram below shows the trajectories for the second period of dynamic programming algorithm.

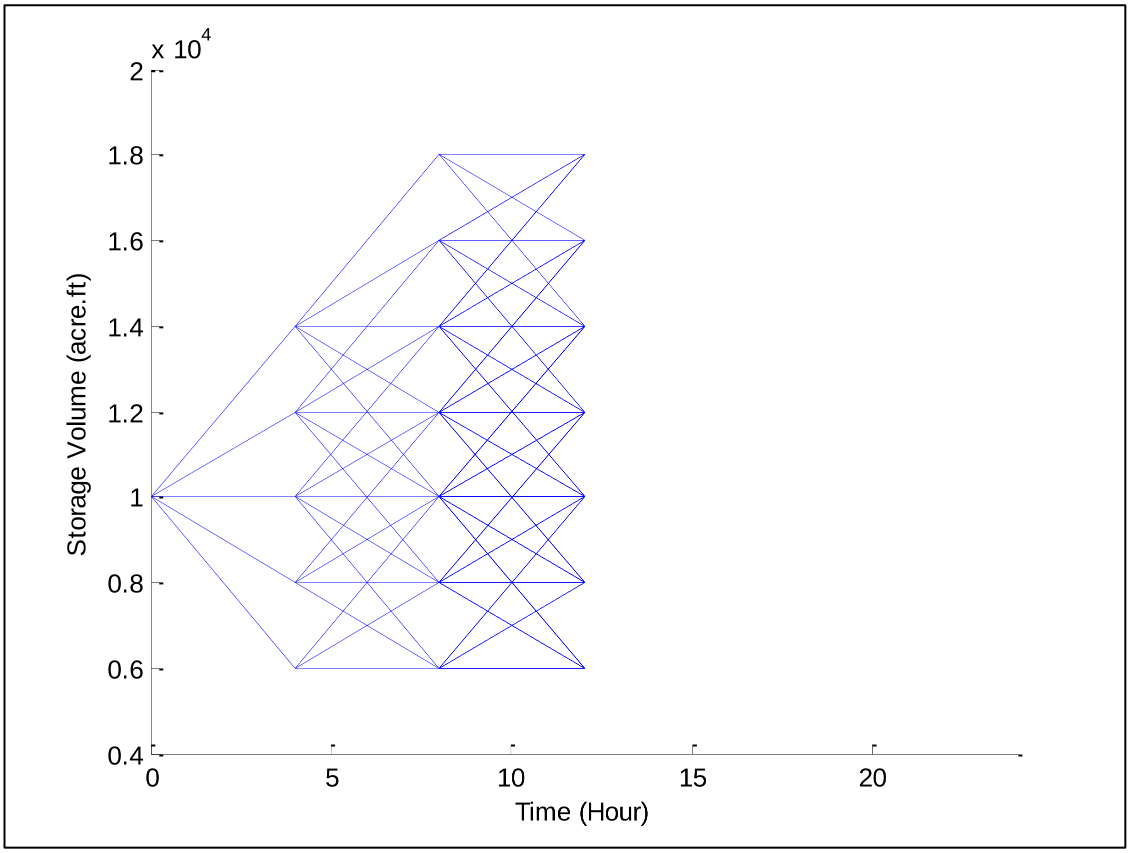


Third Period

The results for the third period are shown in the table below.

j=3			$P_{Load}(3) = 900$ MW		
$V_{s,final}$	$V_{s,initial}$	q (acre.ft/h)	P_H (MW)	P_s (MW)	$TC_k(j)(\$)$
18,000	18,000	1000	74	826	59,064
18,000	16,000	500	24	876	59,638
18,000	14,000	0	0	900	59,034
16,000	18,000	1500	124	776	57,944
16,000	16,000	1000	74	826	58,508
16,000	14,000	500	24	876	58,488
16,000	12,000	0	0	900	57,894
14,000	18,000	2000	174	726	56,833
14,000	16,000	1500	124	776	57,388
14,000	14,000	1000	74	826	57,358
14,000	12,000	500	24	876	57,348
14,000	10,000	0	0	900	56,764
12,000	16,000	2000	174	726	56,278
12,000	14,000	1500	124	776	56,238
12,000	12,000	1000	74	826	56,218
12,000	10,000	500	24	876	56,218
12,000	8,000	0	0	900	56,247
10,000	14,000	2000	174	726	55,128
10,000	12,000	1500	124	776	55,098
10,000	10,000	1000	74	826	55,088
10,000	8,000	500	24	876	55,700
10,000	6,000	0	0	900	55,176
8,000	12,000	2000	174	726	53,987
8,000	10,000	1500	124	776	53,967
8,000	8,000	1000	74	826	54,570
8,000	6,000	500	24	876	54,630
6,000	10,000	2000	174	726	52,857
6,000	8,000	1500	124	776	53,450
6,000	6,000	1000	74	826	53,500

The diagram below shows the trajectories for the third period of dynamic programming algorithm.

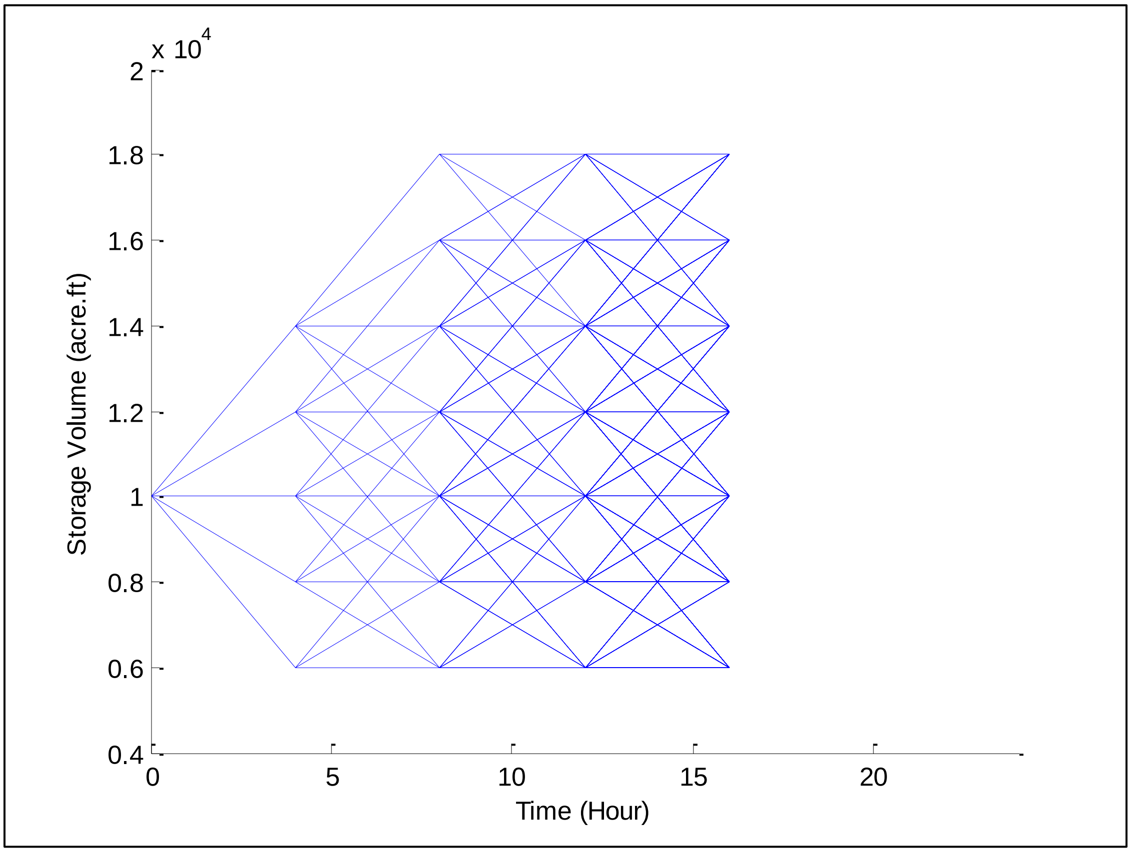


Fourth Period

The results for the fourth period are shown in the table below.

j=4			$P_{Load}(4) = 500$ MW		
$V_{s,final}$	$V_{s,initial}$	q (acre.ft/h)	P_H (MW)	P_s (MW)	$TC_k(j)$($)
18,000	18,000	1000	74	426	70,376
18,000	16,000	500	24	476	70,286
18,000	14,000	0	0	500	69,664
16,000	18,000	1500	124	376	69,336
16,000	16,000	1000	74	426	69,236
16,000	14,000	500	24	476	69,156
16,000	12,000	0	0	500	69,118
14,000	18,000	2000	174	326	68,306
14,000	16,000	1500	124	376	68,196
14,000	14,000	1000	74	426	68,106
14,000	12,000	500	24	476	68,610
14,000	10,000	0	0	500	67,988
12,000	16,000	2000	174	326	67,166
12,000	14,000	1500	124	376	67,066
12,000	12,000	1000	74	426	67,560
12,000	10,000	500	24	476	67,480
12,000	8,000	0	0	500	66,867
10,000	14,000	2000	174	326	66,036
10,000	12,000	1500	124	376	66,520
10,000	10,000	1000	74	426	66,430
10,000	8,000	500	24	476	66,360
10,000	6,000	0	0	500	65,757
8,000	12,000	2000	174	326	65,489
8,000	10,000	1500	124	376	65,389
8,000	8,000	1000	74	426	65,309
8,000	6,000	500	24	476	65,249
6,000	10,000	2000	174	326	64,359
6,000	8,000	1500	124	376	64,269
6,000	6,000	1000	74	426	64,199

The diagram below shows the trajectories for the fourth period of dynamic programming algorithm.

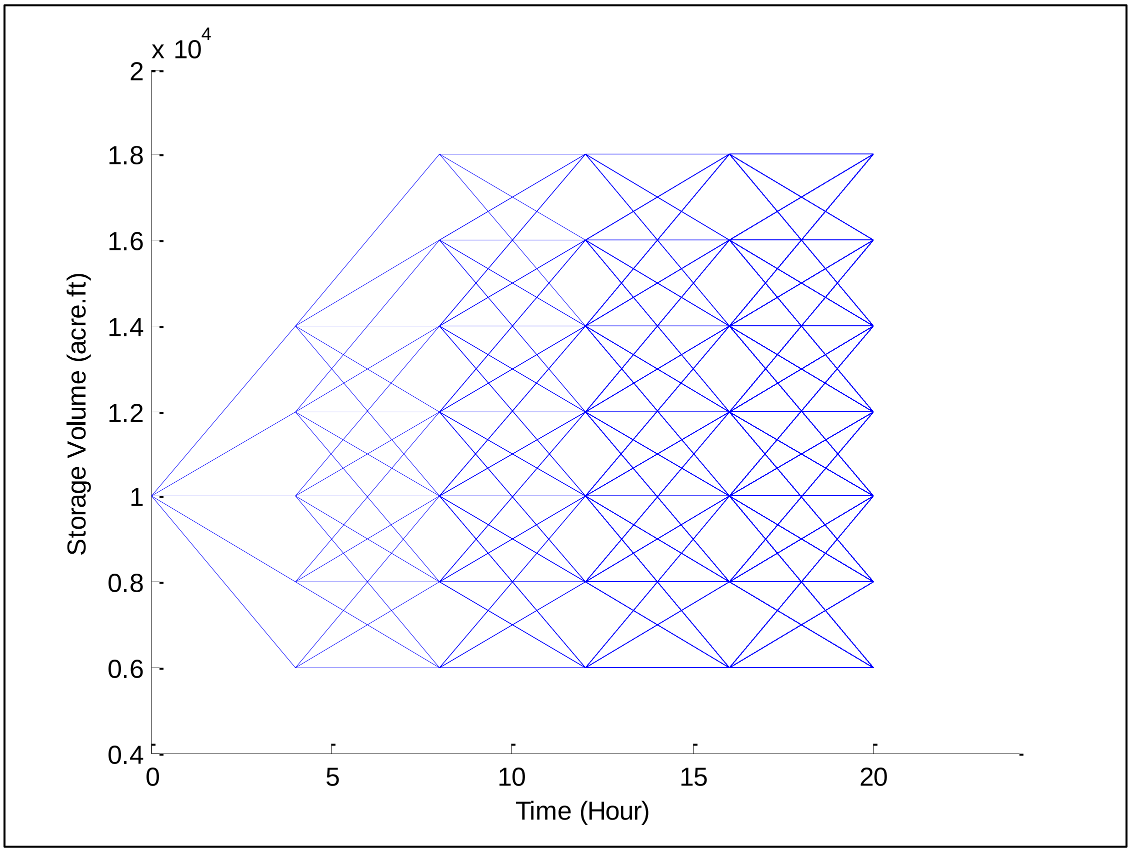


Fifth Period

The results for the fifth period are shown in the table below.

j=5			$P_{Load}(5) = 400$ MW		
$V_{s,final}$	$V_{s,initial}$	q (acre.ft/h)	P_H (MW)	P_s (MW)	$TC_k(j)$($)
18,000	18,000	1000	74	326	78,936
18,000	16,000	500	24	376	79,420
18,000	14,000	0	0	400	78,788
16,000	18,000	1500	124	276	77,915
16,000	16,000	1000	74	326	78,389
16,000	14,000	500	24	376	78,289
16,000	12,000	0	0	400	77,667
14,000	18,000	2000	174	226	76,905
14,000	16,000	1500	124	276	77,369
14,000	14,000	1000	74	326	77,259
14,000	12,000	500	24	376	77,169
14,000	10,000	0	0	400	76,557
12,000	16,000	2000	174	226	76,359
12,000	14,000	1500	124	276	76,239
12,000	12,000	1000	74	326	76,139
12,000	10,000	500	24	376	76,059
12,000	8,000	0	0	400	76,049
10,000	14,000	2000	174	226	75,229
10,000	12,000	1500	124	276	75,119
10,000	10,000	1000	74	326	75,029
10,000	8,000	500	24	376	75,551
10,000	6,000	0	0	400	74,999
8,000	12,000	2000	174	226	74,109
8,000	10,000	1500	124	276	74,009
8,000	8,000	1000	74	326	74,521
8,000	6,000	500	24	376	74,501
6,000	10,000	2000	174	226	72,998
6,000	8,000	1500	124	276	73,501
6,000	6,000	1000	74	326	73,471

The diagram below shows the trajectories for the fifth period of dynamic programming algorithm.

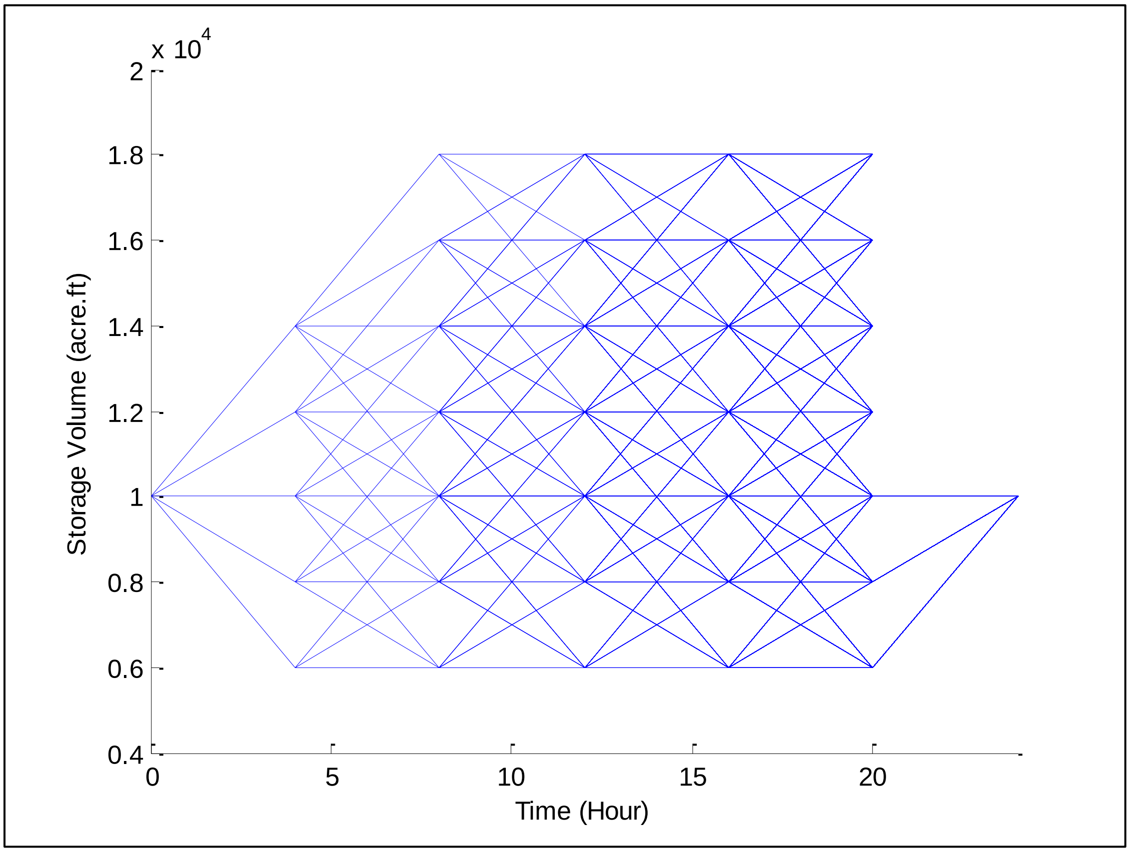


Sixth Period

The results for the sixth period are shown in the table below.

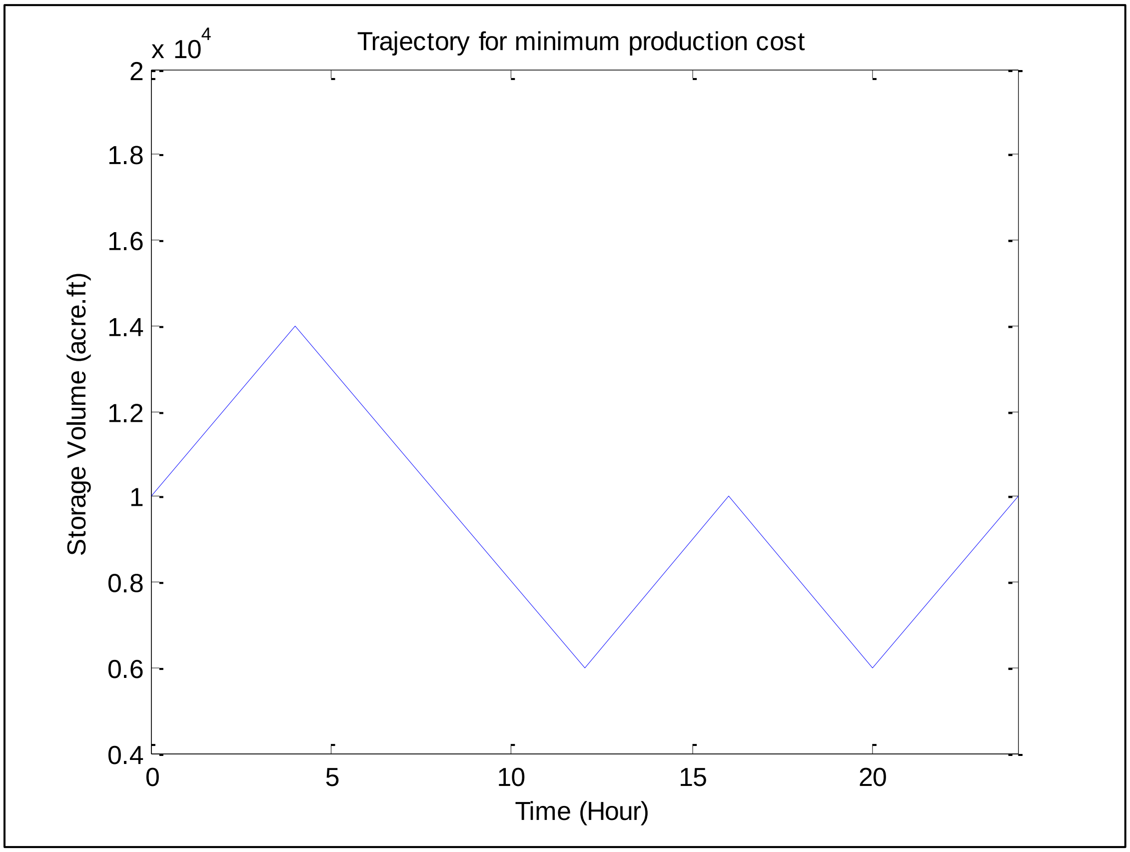
j=6			$P_{Load}(1) = 300$ MW		
$V_{s,final}$	$V_{s,initial}$	q (acre.ft/h)	P_H (MW)	P_s (MW)	$TC_k(j)(\$)$
10,000	10,000	1000	74	226	82,241
10,000	8,000	500	24	276	82,260
10,000	6,000	0	0	300	81,738

The diagram below shows the trajectories for the sixth period of dynamic programming algorithm.



Final Result

The minimum cost trajectory is shown in the figure below.



The minimum production cost for the hydrothermal power plant is $ 81,738.

MATLAB Code

```
clc;clear all;

Pload=[0 600 1000 900 500 400 300];
Vs(1,1)=10000;
Vsmin=[10 6 6 6 6 6 10]*1000;
Vsmax=[10 18 18 18 18 18 10]*1000;
clength=[1 0 0 0 0 0 0];
TCactual=ones(3000,7)*inf;
TCactual(1,1)=0;
for cindex=2:7
    for rindex=1:clength(cindex-1)
        for q=0:500:2260
            Vsnew=Vs(rindex,cindex-1)+4*1000-4*q;
            PHnew=((q-260)/10);
            if (q==0)
                    PHnew=0;
            end
            PSnew=(Pload(cindex)-PHnew);
            if
((Vsnew>=Vsmin(cindex))&&(Vsnew<=Vsmax(cindex))&&(mod(Vsnew,2000)==0)&&(PSnew
>=200)&&(PSnew<=1200))
                clength(cindex)=clength(cindex)+1;
                Vs(clength(cindex),cindex)=Vsnew;
                Vsold(clength(cindex),cindex)=Vs(rindex,cindex-1);
                PH(clength(cindex),cindex)=((q-260)/10);
                if (q==0)
                    PH(clength(cindex),cindex)=0;
                end
                PS(clength(cindex),cindex)=(Pload(cindex)-
PH(clength(cindex),cindex));
                TCactual(clength(cindex),cindex)=TCactual(rindex,cindex-
1)+4*(700+4.8*PS(clength(cindex),cindex)+(PS(clength(cindex),cindex)*PS(cleng
th(cindex),cindex))/2000);
                rindold(clength(cindex),cindex)=rindex;
            end
        end
    end
end

TC=ones(7,18,18)*inf;
for row=1:length(TCactual)
    for col=2:7
        if (TCactual(row,col)~=inf)

TC(col,Vsold(row,col)/1000,Vs(row,col)/1000)=min(TC(col,Vsold(row,col)/1000,V
s(row,col)/1000),TCactual(row,col));
        end
    end
end
hold on;
for r=1:length(Vs)
    for c=2:7
        line(([c-1 c]-1)*4,[Vsold(r,c) Vs(r,c)]);
    end
```

```
end


hold on
xlabel('Time (Hour)')
ylabel('Storage Volume (acre.ft)')
axis([0 24 4000 20000])


find=min(TCactual(:,7));
for row=1:length(TCactual)
    if (TCactual(row,7)==find)
        find=rindold(row,7);
        minTCpath(1,7)=Vs(row,7);
    end
end

for col=6:-1:1
    minTCpath(1,col)=Vs(find,col);
    find=rindold(find,col);
end

figure;
plot(0:4:24,minTCpath)
hold on
title('Trajectory for minimum production cost')
xlabel('Time (Hour)')
ylabel('Storage Volume (acre.ft)')
axis([0 24 4000 20000])
```