IE453 – Energy Systems Planning

Homework 2 - Report

Group 15

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First question:

Our linear programming model to find the size of the reservoirs admitting to minimum overall cost of electricity is as follows (in the model, main energy unit is GWh and unit for the water amount is m^3);

Parameters:

Parameters

$SF = 20\ km^2$, $\gamma = 25\%$

$G_{max} = 1.2\ GW$, $\alpha = 95\%$

$h = 80m$

$C_s = 2.5\ USD/m^3$, $n = 30$ years

E_t = electricity price at period t

SR_t = solar radiation at period t

D_t = demand at period t

$i = 0.2\%$

$d = 1000\ \frac{kg}{m^3}$, $g = 9.81\ \frac{m}{s^2}$

Decision variables:

Decision Variables

$SU_{max} = SL_{max}$ = size of reservoirs

$SU_t = SL_t$ = amount of water in the reservoir at period t

$RU_t = RL_t$ = amount of water released at period t

Z_t = electricity purchased from grid at period t

$SpillU_t = SpillL_t$ = amount of water spilled at period t

P_t = pumped water at period t

$HU_t = HL_t$ = energy generated in the reservoir at period t

V_t = energy from soler farm at period t

SP_t = soler energy transferred to hydro at period t

CS_t = soler energy curtailed at period t

$$IP_t = \begin{cases} 1 & \text{if pumping mod active} \\ 0 & \text{o/w} \end{cases} \quad \text{at period } t$$

$t = 1, \ldots, 56$

LP model:

$$\min \; \frac{0.002}{1-(1.002)^{-1560}} \times 2.5 \, \frac{USD}{m^3} \, (S_{U\,max} + S_{L\,max}) + \sum_{t}^{56} Z_t \cdot E_t$$

s.t.

$$S_{U_0} = \frac{S_{U\,max}}{2}$$

$$S_{L_0} = \frac{S_{L\,max}}{2}$$

$$S_{U_t} \leq S_{U\,max} \qquad \forall t$$

$$S_{L_t} \leq S_{L\,max} \qquad \forall t$$

$$S_{U_t} = S_{U_{t-1}} + P_t - R_{U_t} - Spill_{U_t} \qquad \forall t$$

$$S_{L_t} = S_{L_{t-1}} - P_t + R_{U_t} - R_{L_t} - Spill_{L_t} \qquad \forall t$$

$$S_{U\,max} = S_{L\,max}$$

$$H_{U_t} = \left(R_{U_t} \times 80m \times 0.95 \times g \times d\right) \frac{1}{3.6 \times 10^{10}} \qquad \forall t$$

$$H_{L_t} = \left(R_{L_t} \times 80m \times 0.95 \times g \times d\right) \frac{1}{3.6 \times 10^{10}} \qquad \forall t$$

$$SR_t \times 20km^2 \times 0.25 = \vartheta_t + SP_t + CS_t \qquad \forall t$$

$$SP_t = \frac{P_t \cdot 80m \cdot g \cdot d}{0.95} \qquad \forall t$$

$$H_{U_t} \leq 1.2\,GW \times 3\,hr \qquad \forall t$$

$$H_{L_t} \leq 1.2\,GW \times 3\,hr \qquad \forall t$$

$$SP_t \leq 1.2\,GW \times 3\,hr \qquad \forall t$$

$$D_t \leq H_{U_t} + H_{L_t} + \vartheta_t + Z_t \qquad \forall t$$

$$P_t \leq I_{P_t} \cdot M \qquad \forall t$$

$$R_{U_t} \leq (1 - I_{P_t}) \cdot M \qquad \forall t$$

+ nonnegativity constraints

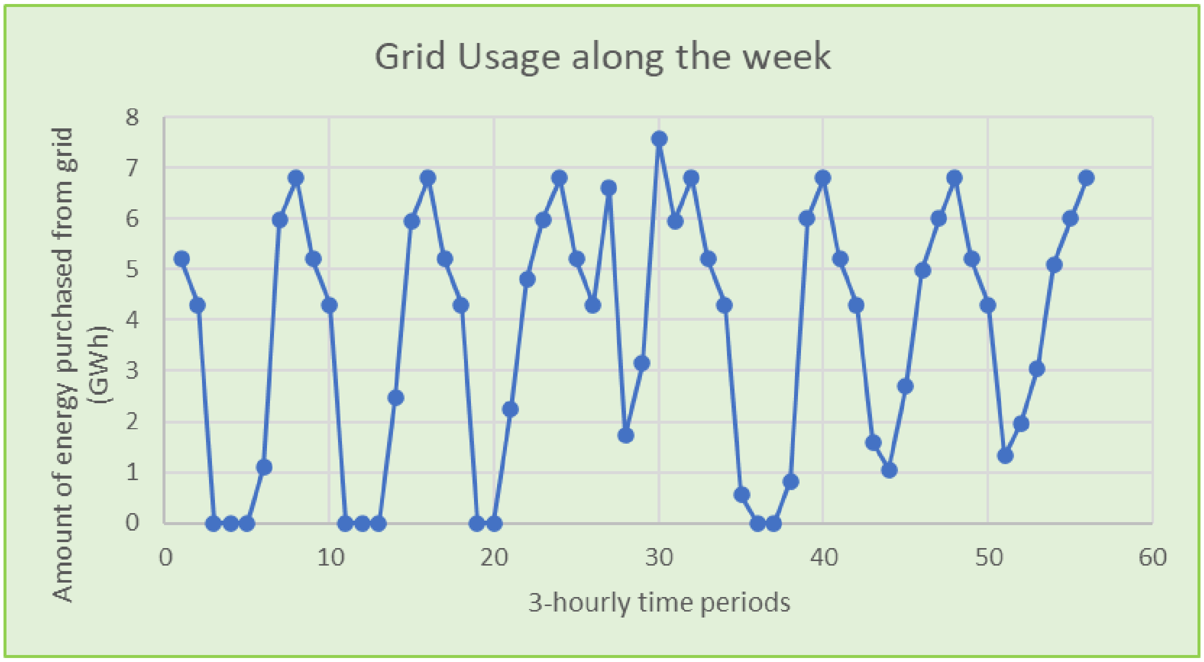
We solved our model via IBM CPLEX 12.10.

a) Overall cost of electricity is **\$56,299,274**.

b) Total grid usage is 208.745 GWh, and total demand is 700.7 GWh. That means, **29.79%** of the total demand is satisfied from the grid.

c) Size of the reservoirs is **1,386,000,000 m^3**.

d) Plot that shows the amount of energy purchased from the grid;



Second question:

In the second question we added a new decision variable and modified our objective function. Also, we made some changes in the constraint set. The new decision variable and objective function is;

G_{New} : size of the new generator

$$\min \quad 2 \cdot \left(\frac{0.002}{1-(1.002)^{-1300}} \times 5 \times 10^{8} \frac{USD}{GW} \times G_{New} \right) + \ldots$$

$\vdots$

Changes in the constraints are (where G_{new} is the size of the new generator);

$$HU_t \leq G_{New} \times 3\,hr \qquad \forall t$$

$$HL_t \leq G_{New} \times 3\,hr \qquad \forall t$$

$$SP_t \leq G_{New} \times 3\,hr \qquad \forall t$$

$$\vdots$$

When we solve the updated model, we got the following results;

a) If the overall cost of the entire system desired to be minimized, the size of the generator should be **2.3333 GW.**

b) Overall cost of the system is **\$23524506.61.** Reservoir size for both of them is **17,813 x 10^5 m^3.**

Third question:

We have to convert km^3 to m^3 because unit for the water amount was set m^3 previously. 0.01 km^3 corresponds to 10,000,000 m^3. To account for this size limitation, we simply add the following two constraints to our model;

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size_of_reservoir_upper <= 10000000;

size_of_reservoir_lower <= 10000000;
```

And we get the following results;

a) Overall cost of electricity is **\$113,782,356**.

b) Total grid usage is 550.244 GWh, and total demand is 700.7 GWh. That means, **78.52%** of the total demand is satisfied from the grid.

c) Size of the reservoirs is **10,000,000 m^3** (at maximum).

Fourth question:

When we remove the equally sized lower and upper reservoir assumption, we get the following results;

a) Overall cost of electricity is again **$113,782,356**.

b) Total grid usage is again 550.244 GWh, and total demand is 700.7 GWh. That means, **78.52%** of the total demand is satisfied from the grid.

c) Size of the reservoirs is again **10,000,000 m^3** (at maximum).

- There is no difference between the results of part 3 and part 4. In both upper and lower reservoirs, the optimal size is chosen as the maximum size, which is 10 million m^3.