Problem Solutions

For

POWER GENERATION OPERATION AND CONTROL

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Solutions to homeworks problems

Chapter 2

Preface

We trust that these homework problem solutions will prove helpful in teaching a course with our text. If you find typographical errors please send us corrections via John Wiley.

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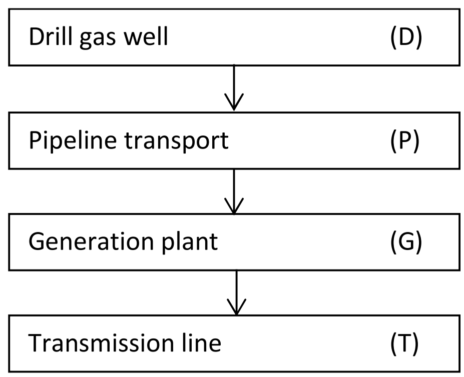
Problem 2.1 Solution

> Problem 2.1) The interested student should rewrite the equations for the vertically Integrated Utility to show that the total revenue received from all activities is equal to the sum of all input costs, plus the sum of all capacity charges. Note that total revenue equals total cost.

The profit modelling of an integrated energy company for one major city (Sydney) – including Peak and Off-peak hours:

The gas fire power generation process is divided into four steps:



The energy is transformed from gas to electricity. Between each step, there are energy efficiency losses due to various reasons. We note them as:

η_1 (from D to P), η_2 (from P to G), η_3 (from G to T).

So, $MT/\eta_3 = MG$, $MG/\eta_2 = MP$, $MP/\eta_1 = MD$

Moreover, there are other letters noted as below:

M – Energy production at each step

Co – Operation cost / unit energy production

Co' – Capital cost

Max / Min – Production maximum / minimum capacity at certain step

Pr – The price applied on the final electricity

As a result, our objective formula can be described as

$Maximize\ the\ Profit$

$= Revenue - cost$

$Revenue = Pr \times MT$

(MT means the energy production M at the end of transmission line T)

$$Cost = CoD \cdot MD + CoD' + CoP \cdot MP + CoP' + CoG \cdot MG + CoG' + CoT \cdot MT + CoT'$$

$$= CoD \cdot MT/(\eta_1 \cdot \eta_2 \cdot \eta_3) + CoP \cdot MT/(\eta_3 \cdot \eta_2) + CoG \cdot MT/\eta_3 + CoT \cdot MT \cdot$$
$$+ CoD' + CoP' + CoG' + CoT'$$

$$= MT \cdot [CoD/(\eta_1 \cdot \eta_2 \cdot \eta_3) + CoP/(\eta_3 \cdot \eta_2) + CoG/\eta_3 + CoT] + CoD' + CoP' + CoG' + CoT'$$

$$Profit = MT \cdot \{Pr - [CoD/(\eta_1 \cdot \eta_2 \cdot \eta_3) + CoP/(\eta_3 \cdot \eta_2) + CoG/\eta_3 + CoT]\} - CoD' - CoP' - CoG' - CoT'$$

All the conditions are listed below:

$\boldsymbol{\eta_1 = 97\%}$ $\boldsymbol{\eta_2 = 50\%;}$ $\boldsymbol{\eta_3 = 92\%}$

In this example, we assume there are pe*ak and off-peak hour:*

Peak hours: 6:00pm-10:00pm (4h)

Off-peak hours: Rest (20h)

The electricity consumption at peak hour is 2.5 times higher than off-peak hours,

Assume the population of the city is 6million; the annual energy consumed is 3,000,000MWh, so the overall consumption can be classified into off-peak section (2000000MWh) and peak section (1000000MWh)

The operation costs of Generation Company at peak and off-peak hour is 4 times higher (non-linear relationship), and the unit price is listed below.

The electrical price is $80/MWh off peak and $160/MWh peak

So, the value of each variable is identified as (numbers are got from 2011 annual report of various companies):

CoD: $20/MWh

CoD': $15/Customer/year – 90million/year

CoP: $1/MWh

CoP': $0.3/Customer/Year – 1.8million/year

CoG: $4/MWh off-peak and $16 peak

CoG': $4/Customer/Year – 24million/year

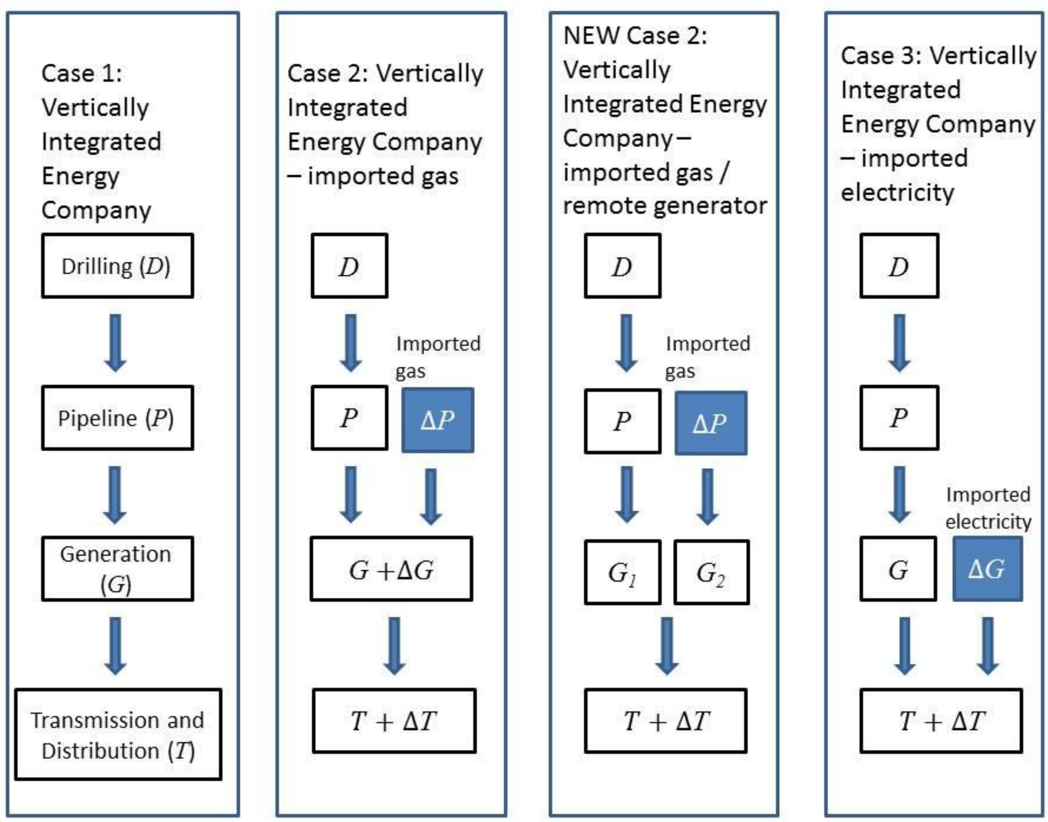
CoT: $0.12/MWh

CoT': $1.1/Customer/year – 6.6million/year

$$Profit = MT_{Off-peak} \cdot \{Pr_{Off-peak} - [CoD/(\eta_1 \cdot \eta_2 \cdot \eta_3) + CoP/(\eta_3 \cdot \eta_2) + CoG_{Off-peak}/\eta_3 + CoT]\}$$
$$+MT_{Peak} \cdot \{Pr_{Peak} - [CoD/(\eta_1 \cdot \eta_2 \cdot \eta_3) + CoP/(\eta_3 \cdot \eta_2) + CoG_{Peak}/\eta_3 + CoT]\}$$
$$-(CoD' + CoP' + CoG' + CoT')$$
$$= 2000000 \cdot \left\{80 - \left[\frac{20}{0.97 \cdot 0.5 \cdot 0.92} + \frac{1}{0.92 \cdot 0.5} + \frac{4}{0.92} + 0.12\right]\right\}$$
$$+1000000 \cdot \left\{160 - \left[\frac{20}{0.97 \cdot 0.5 \cdot 0.92} + \frac{1}{0.92 \cdot 0.5} + \frac{16}{0.92} + 0.12\right]\right\}$$
$$-(90000000 + 1800000 + 24000000 + 6600000)$$
$$= 2000000 \times (80 - 44.82 - 2.17 - 4.34 - 0.12) + 1000000 \times (240 - 44.82 - 2.17 - 17.36 - 0.12) - 122400000 = 30230000$$
$$\frac{30230000}{9000000 + 1800000 + 24000000 + 6600000} = \mathbf{24.7}\%$$

The profit would be expected to be $30230000

The Capital return rate is expected to be 24.7%



In Case 2, we discuss the scenario when the company decide to import gas from other (vertical integrated energy) company at nearby state, to minimize the high Drilling and Pipeline operation cost – *CoD* and *CoP*

We continue to use the profit equation in Case 1,

$$Profit = MT_{Off-peak} \cdot \{Pr_{Off-peak} - [CoD/(\eta_1 \cdot \eta_2 \cdot \eta_3) + CoP/(\eta_3 \cdot \eta_2) + CoG_{Off-peak}/\eta_3 + CoT]\}$$
$$+MT_{Peak} \cdot \{Pr_{Peak} - [CoD/(\eta_1 \cdot \eta_2 \cdot \eta_3) + CoP/(\eta_3 \cdot \eta_2) + CoG_{Peak}/\eta_3 + CoT]\}$$
$$-(CoD' + CoP' + CoG' + CoT')$$

$$MT_{Off-peak} = \frac{2MT}{3}$$

$$MT_{peak} = \frac{MT}{3}$$

But here, we introduce ΔG as the energy generated with the imported gas, and subsequently, the total amount of energy transported by T&D section is increased to $T + \Delta T$

We assume the other parameters are the same, the cost of importing gas is ***X***, then we are going to solve the function to evaluate at what cost level (***X***) can ensure $M(\Delta T)$ is positive (gas import is worthwhile).

The Profit equation above can be modified as:

$$Profit = \frac{2M(T+\Delta T)}{3} \cdot Pr_{Off-peak} - \frac{2MT}{3} CoD/(\eta_1 \cdot \eta_2 \cdot \eta_3) - \frac{2MT}{3} CoP/(\eta_3 \cdot \eta_2) - \frac{2MT}{3} CoG_{Off-peak}/\eta_3 - \frac{2M(T+\Delta T_1)}{3} CoT + \frac{M(T+\Delta T)}{3} \cdot Pr_{Peak} - \frac{MT}{3} CoD/(\eta_1 \cdot \eta_2 \cdot \eta_3) - \frac{MT}{3} CoP/(\eta_3 \cdot \eta_2) - \frac{M(T+\Delta T)}{3} CoG_{Peak}/\eta_3 - \frac{M(T+\Delta T)}{3} CoT - (CoD' + CoP' + CoG' + CoT') - \boldsymbol{X}(M\Delta T)$$

$$Profit = \frac{2M(T+\Delta T)}{3} \times (80 - 4.34 - 0.12) - \frac{2MT}{3} \times (44.82 + 2.17) + \frac{M(T+\Delta T)}{3} \times (160 - 17.36 - 0.12) - \frac{MT}{3} \times (44.82 + 2.17) - 122400000 - \boldsymbol{X}(M\Delta T)$$

$$Profit = \frac{2M(T+\Delta T)}{3} \times 75.54 - \frac{2MT}{3} \times 46.99 + \frac{M(T+\Delta T)}{3} \times 142.52 - \frac{MT}{3} \times 46.99 - \boldsymbol{X}(M\Delta T) - 122400000$$

Simplified

$$Profit = M(T+\Delta T) \times 50.88 + M\Delta T \times 46.99 - \boldsymbol{X}(M\Delta T) - 122400000$$

$M(T+\Delta T) = 3000000$MWh,

So, the Profit can be expressed as:

$$\underline{Profit = (46.99 - \boldsymbol{X})M\Delta T + 30320000}$$

We assume $\boldsymbol{X} = \frac{\$37.59}{MWh}(20\%\ cheaper), M(\Delta T) = 1000000MWh$

$$\underline{Profit = 9400000 + 30320000 = 39720000}$$

In NEW Case 2, similar to Case 2, this company import gas ΔT to minimize the operation cost. Moreover, this company owns a remote generator and related transmission and distribution network which is specially prepared for the extra gas.

In previous discussion, the Profit equation in Case 2 can be described as:

$$\begin{aligned} Profit = {} & \frac{2M(T+\Delta T)}{3} \cdot Pr_{Off-peak} - \frac{2MT}{3} CoD/(\eta_1 \cdot \eta_2 \cdot \eta_3) - \frac{2MT}{3} CoP/(\eta_3 \\ & \cdot \eta_2) - \frac{2M(T+\Delta T)}{3} CoG_{Off-peak}/\eta_3 - \frac{2M(T+\Delta T)}{3} CoT + \frac{M(T+\Delta T)}{3} \\ & \cdot Pr_{Peak} - \frac{MT}{3} CoD/(\eta_1 \cdot \eta_2 \cdot \eta_3) - \frac{MT}{3} CoP/(\eta_3 \cdot \eta_2) \\ & - \frac{M(T+\Delta T)}{3} CoG_{Peak}/\eta_3 - \frac{M(T+\Delta T)}{3} CoT - (CoD' + CoP' + CoG' \\ & + CoT') - \boldsymbol{X}(M\Delta T) \end{aligned}$$

Here, as to the remote generator the operation cost is higher than the major utilities: the generation cost CoG_2 is \$5/MWh off-peak hours and \$20/MWh peak hours; the T&D operation cost for this system CoT_2 is \$0.15/MWh.

Previous equation can be modified as:

$$\begin{aligned} & NEW\ Profit \\ & = \frac{2M(T+\Delta T)}{3} \cdot Pr_{Off-peak} - \frac{2MT}{3} CoD/(\eta_1 \cdot \eta_2 \cdot \eta_3) - \frac{2MT}{3} CoP/(\eta_3 \\ & \cdot \eta_2) - \frac{2MT}{3} CoG_{Off-peak}/\eta_3 - \frac{2M\Delta T}{3} CoG_{Off-peak2}/\eta_3 - \frac{2MT}{3} CoT \\ & - \frac{2M\Delta T}{3} CoT_2 + \frac{M(T+\Delta T)}{3} \cdot Pr_{Peak} - \frac{MT}{3} CoD/(\eta_1 \cdot \eta_2 \cdot \eta_3) \\ & - \frac{MT}{3} CoP/(\eta_3 \cdot \eta_2) - \frac{MT}{3} CoG_{Off-peak}/\eta_3 - \frac{M\Delta T}{3} CoG_{Peak2}/\eta_3 - \frac{MT}{3} CoT \\ & - \frac{M\Delta T}{3} CoT_2 - (CoD' + CoP' + CoG' + CoT') - \boldsymbol{X}(M\Delta T) \end{aligned}$$

$$Profit = \frac{2M(T+\Delta T)}{3} \times 80 - \frac{2MT}{3} \times (44.82 + 2.17 + 4.34 + 0.12) - \frac{2M\Delta T}{3} \times (5.43 + 0.15) + \frac{M(T+\Delta T)}{3} \times 160 - \frac{MT}{3} \times (44.82 + 2.17 + 17.36 + 0.12) - \frac{2M\Delta T}{3} \times (21.74 + 0.15) - 122400000 - \boldsymbol{X}(M\Delta T)$$

$$Profit = \frac{2M(T+\Delta T)}{3} \times 80 - \frac{2MT}{3} \times 51.45 - \frac{2M\Delta T}{3} \times 5.58 + \frac{M(T+\Delta T)}{3} \times 160 - \frac{MT}{3} \times 64.47 - \frac{M\Delta T}{3} \times 21.89 - \boldsymbol{X}(M\Delta T) - 122400000$$

$$Profit = \frac{2MT}{3} \times 28.55 + \frac{2M\Delta T}{3} \times 74.42 + \frac{MT}{3} \times 95.53 + \frac{M\Delta T}{3} \times 138.11 - \boldsymbol{X}(M\Delta T) - 122400000$$

$$Profit = MT \times 50.87 + M\Delta T \times 95.65 - \boldsymbol{X}(M\Delta T) - 122400000$$

$$Profit = M(T+\Delta T) \times 50.87 + M\Delta T \times 44.78 - \boldsymbol{X}(M\Delta T) - 122400000$$

$$= 30120000 + M\Delta T \times (44.78 - \boldsymbol{X})$$

We assume $\boldsymbol{X} = \frac{\$37.59}{MWh} (20\%\ cheaper), M(\Delta T) = 1000000MWh$

$$\underline{Profit = 7190000 + 30120000 = 37310000}$$

In Case 3, the company would like to import electricity from other energy company (peak or off-peak hour period). This decision would significantly lower the generator operation cost at the peak hour period.

We assume that, $M\Delta T$ amount of electricity will be imported and the cost of importing electricity is $\boldsymbol{X}$

$$Profit = \frac{2M(T+\Delta T)}{3} \cdot Pr_{Off-peak} - \frac{2MT}{3} CoD/(\eta_1 \cdot \eta_2 \cdot \eta_3) - \frac{2MT}{3} CoP/(\eta_3 \cdot \eta_2) - \frac{2MT}{3} CoG_{Off-peak}/\eta_3 - \frac{2M(T+\Delta T)}{3} CoT + \frac{M(T+\Delta T)}{3} \cdot Pr_{Peak} - \frac{MT}{3} CoD/(\eta_1 \cdot \eta_2 \cdot \eta_3) - \frac{MT}{3} CoP/(\eta_3 \cdot \eta_2) - \frac{MT}{3} CoG_{Peak}/\eta_3 - \frac{M(T+\Delta T)}{3} CoT - (CoD' + CoP' + CoG' + CoT') - M\Delta T \times \boldsymbol{X}$$

$$Profit = \frac{2M(T+\Delta T)}{3} \times (80 - 0.12) - \frac{2MT}{3} \times (44.82 + 2.17 + 4.34)$$

$$+\frac{M(T+\Delta T)}{3}\times(160-0.12)-\frac{MT}{3}\times(44.82+2.17+17.36)-122400000$$
$$-M\Delta T\times\boldsymbol{X}$$

$$Profit=M(T+\Delta T)\times 53.25-MT\times 42.9+M(T+\Delta T)\times 53.29-MT\times 21.45$$
$$-122400000-M\Delta T\times\boldsymbol{X}$$

$$Profit=M(T+\Delta T)\times 106.54+MT\times 64.35-122400000-M\Delta T\times\boldsymbol{X}$$
$$=3000000\times 42.16+(64.35-\boldsymbol{X})-122400000$$

$$\underline{Profit=4080000+(64.35-\boldsymbol{X})\times M\Delta T}$$

We assume $\boldsymbol{X}=\$51.48/MWh\ (20\%\ cheaper), M(\Delta T)=1000000MWh$

$\underline{Profit=4080000+12870000=16950000}$

Case 4, Hydro storage for peak and off-peak hours

In this scenario, this company is using hydro reservoir to store energy at off-peak hours and generate energy at peak hours to minimize the high load of generators at peak hours.

The operation cost of normalized off-peak hours (shoulder hours) is assumed as \$8/MWh

$$Profit=MT_{Off-peak}\cdot\{Pr_{Off-peak}-[CoD/(\eta_1\cdot\eta_2\cdot\eta_3)+CoP/(\eta_3\cdot\eta_2)+CoG_{Shoulder}/\eta_3+CoT]\}$$
$$+MT_{Peak}\cdot\{Pr_{Peak}-[CoD/(\eta_1\cdot\eta_2\cdot\eta_3)+CoP/(\eta_3\cdot\eta_2)+CoG_{Shoulder}/\eta_3+CoT]\}$$
$$-(CoD'+CoP'+CoG'+CoT')$$
$$=2000000\cdot\left\{80-\left[\frac{20}{0.97\cdot 0.5\cdot 0.92}+\frac{1}{0.92\cdot 0.5}+\frac{8}{0.92}+0.12\right]\right\}$$
$$+1000000\cdot\left\{160-\left[\frac{20}{0.97\cdot 0.5\cdot 0.92}+\frac{1}{0.92\cdot 0.5}+\frac{8}{0.92}+0.12\right]\right\}$$
$$-(90000000+1800000+24000000+6600000)$$
$$=2000000\times(80-44.82-2.17-8.68-0.12)+1000000\times(240-44.82-2.17-8.68-0.12)-122400000=110230000$$

Problem 2.2 Solution

> Problem 2.2) The interested student should identify the regulations for his country and state (province). How many regulatory bodies are overlooking the utilities? How many interconnections exist? Which fuels are used? What storage is available? How many markets exist? How are they related? How many contracts exist for the utility (GENCO, etc.) and for the customer? Are there option contracts?

USA has one federal (national) regulator, the Federal Energy Regulatory Commission (FERC). FERC has authorized the National Energy Reliability Commission (NERC) to overview and to establish the reliability standards at the national level. The Environmental Protection Agency (EPA) oversees the environmental standards including the electric utility industry. The Security and Exchange Commission and the Commodity Futures Trading Commission (CFTC) were combined with FERC for electric companies to coordinate the regulatory oversight.

Each state has a Public Utilities Commission to verse the electric utilities in the state and to coordinated activities between adjacent utilities.

Municipal utilities as well as Public Power Districts report outside the FERC/NERC/PUC oversight as these entities are publicly owned.

Most state PUCs show the major providers:

http://www.oregon.gov/energy/pages/power.aspx

However, the distinction that BPA provides transmission and energy from the US Corps of Engineers is not provided.

Problem 2.3 Solution

> Problem 2.3) What government agency analyzes and/or provides the impact of future fuel prices or energy policies?

The Energy Industry Administration (EIA) publishes a list of raw data for the energy markets, the impact of price changes, and the impact of regulatory changes.