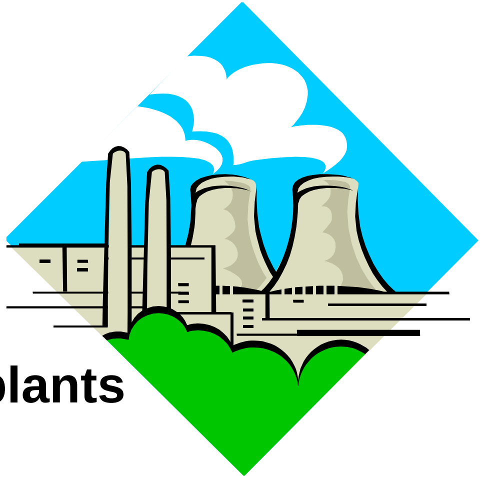
System planning 2014

Lecture 9, L9: **Short-term planning of thermal power plants**

System planning 2014

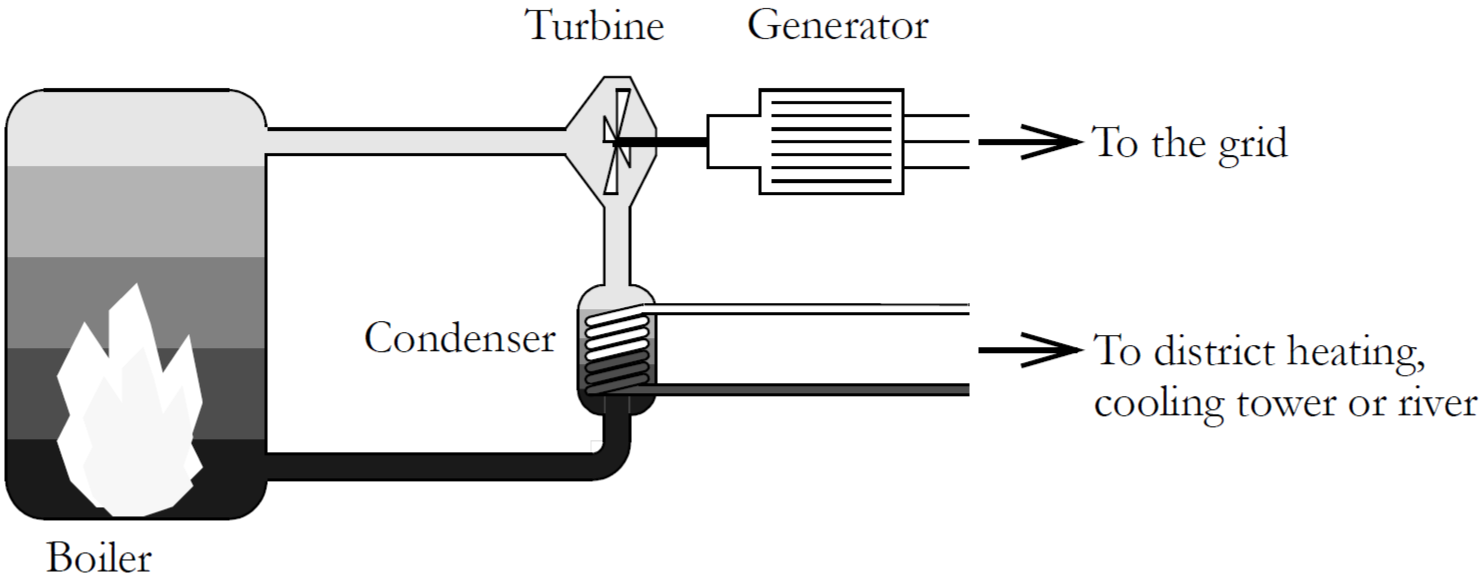


- Lecture 9, L9:
  - **Short-term planning of thermal power plants**
  - Chapters 5.3.1-5.3.3
- Content:
  - Generally about thermal power plants
  - Production costs
  - Start-up costs
  - Minimally allowed operation and stopping times
  - Constrained production changes

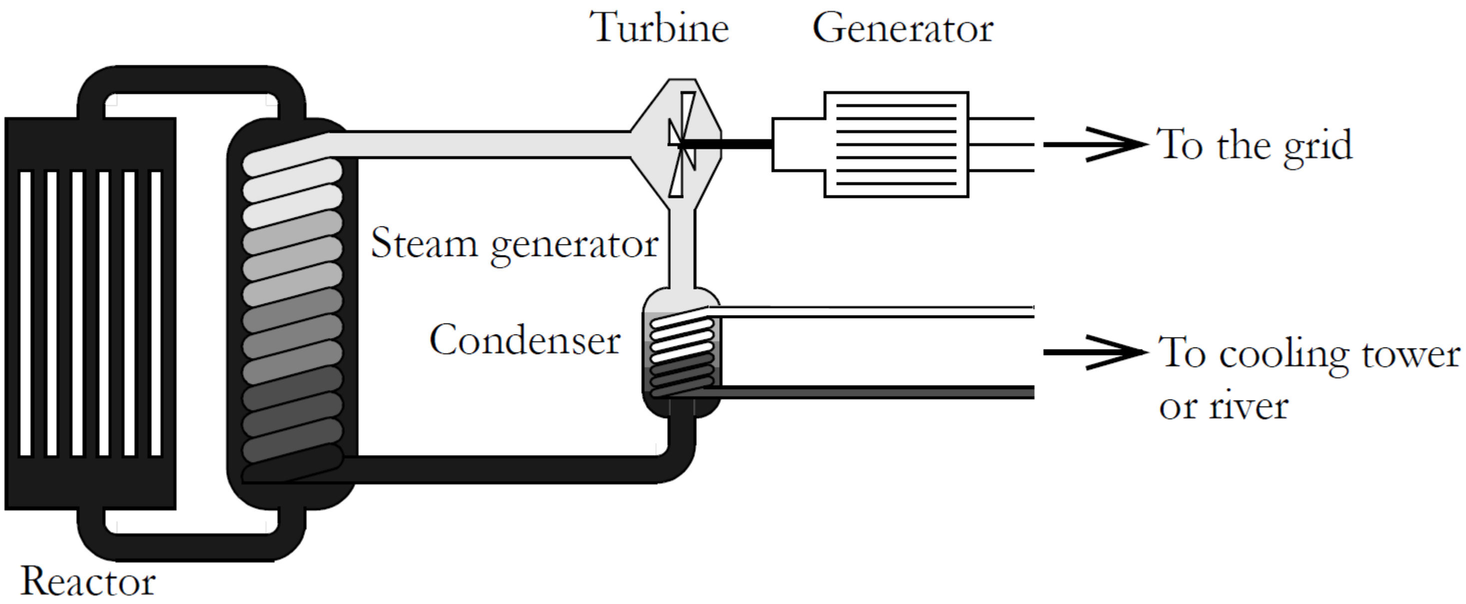
Generally about thermal power plants

- Produces electricity through combustion of fuel
  - Oil/petroleum
  - Gas
  - Coal
  - Uranium
- Larger plants, steam cycle

Generally about thermal power plants



Generally about thermal power plants



Production costs

- Fuel usage
- Efficiency not constant
  - $F(G) = \frac{G}{h\eta(G)}$
  - $F(G)$, fuel consumption, $[\frac{\text{tonne}}{\text{h}}$ or $\frac{\text{m}^3}{\text{h}}]$
  - G, electricity production $[\frac{\text{MWh}}{\text{h}}]$
  - h, heat content $[\frac{\text{MWh}}{\text{tonne}}$ or $\frac{\text{MWh}}{\text{m}^3}]$
  - $\eta(G)$, efficiency at given consumption level

Production costs

- Let φ denote the fuel price
- Production cost, $C(G) = \varphi F(G) = \varphi \frac{G}{h\eta(G)}$
- Nonlinear cost function
- Often approximated to $C(G) = \alpha + \beta G + \gamma G^2$
- We use linear approximation $C(G) = \beta G$

Operational constraints

- Changed fuel supply
  - No immediate production change (large plants)
- Operational constraints
  - Start-up times, start-up costs
  - Lowest allowed operation and stop times
  - Constrained production changes

Start-up costs (1/9)

- Operational plant, limited by installed capacity
- Offline plant, no generation
- $G_{g,t} \leq u_{g,t}\bar{G}_g$
  - $G_{g,t}$, generation, plant g, hour t
  - $u_{g,t}$, operation mode, 0 off, 1 on
  - $\bar{G}_g$, peak production, plant g

Start-up costs (2/9)

- In operation, possibly bounded from below
  - $G_{g,t} \geq u_{g,t}\underline{G}_g$
  - $\underline{G}_g$, minimal production, plant g

Start-up costs (3/9)

- Start-up thermal of plant
  - Implies fuel costs for heating-up plant
  - Certain operational temperature needed
- Fuel usage, depends om time unused
- $C_{start}(t) = C_{cold}(1 - e^{-t/\tau}) + C_{fix}$
  - $C_{start}(t)$, start-up cost t hours unused
  - C_{cold}, cost boiler at room temperature
  - τ, time constant for cooling
  - C_{fix}, time-independent start-up cost

Start-up costs (4/9)

- Can be profitable not stop combustion
- If out of production short time
- Combustion reduced to minimum, e.g. idling
- No electricity produced when idling
- $C_{start} = C_{idle}t$
- C_{idle}, hourly idling cost

Start-up costs (5/9)

- Binary variables needed considering start-up
- 1 means operational, 0 off-line
- Cost depends on stop time duration
  - Different binaries for different stop times
  - Assume two categories are enough
    - $s^{*}_{g,t}$, off-line for one hour
    - $s^{**}_{g,t}$, off-line at least two hours
    - $s^{*}_{g,t},\ s^{**}_{g,t} \in \{0,1\}$

Start-up costs (6/9)

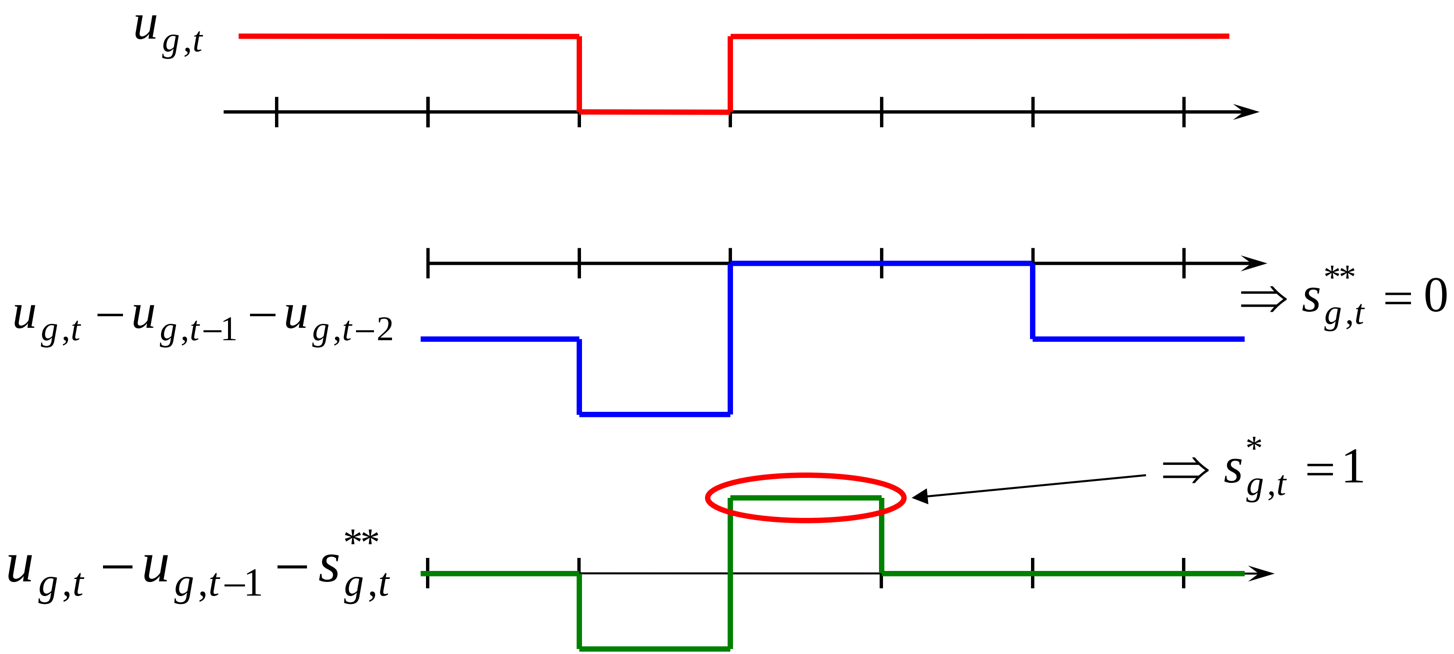
- Total start-up cost of planning period
- $\sum_{\substack{t \in T \\ g \in G}} C_g^* s_{g,t}^* + C_g^{**} s_{g,t}^{**}$
  - C_g^*, start-up cost, plant g, 1h stop
  - C_g^{**}, start-up cost, plant g, ≥2h stop
- Solver will minimize binaries
  - Constraints needed
  - Exploit abovementioned fact, greater or equal

Start-up costs (7/9)

- Necessary constraints
  - $s^{*}_{g,t} \geq u_{g,t} - u_{g,t-1} - s^{**}_{g,t}$
  - $s^{**}_{g,t} \geq u_{g,t} - u_{g,t-1} - u_{g,t-2}$

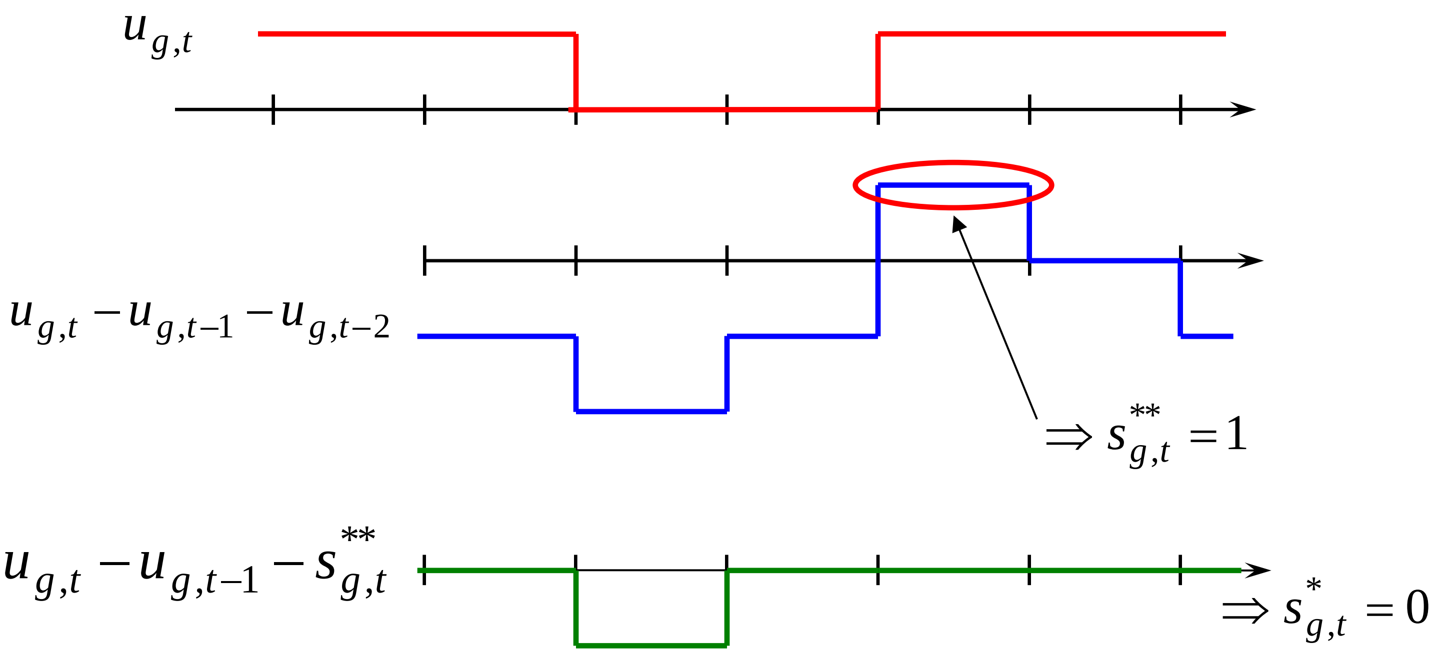
Start-up costs (8/9)

- $s^{*}_{g,t} \geq u_{g,t} - u_{g,t-1} - s^{**}_{g,t}$
- $s^{**}_{g,t} \geq u_{g,t} - u_{g,t-1} - u_{g,t-2}$



Start-up costs (9/9)

- $s^{*}_{g,t} \geq u_{g,t} - u_{g,t-1} - s^{**}_{g,t}$
- $s^{**}_{g,t} \geq u_{g,t} - u_{g,t-1} - u_{g,t-2}$



Minimal operation and stop times (1/3)

- We often use constant start-up cost
- For simplicity
- Alternative model, similar aim
  - Instead of variable start-up costs
  - Prohibit switching back and forth
- Two binary variables
  - $s_{g,t}^{+}$, indicates start-up in period before t
  - $s_{g,t}^{-}$, indicates stopping in period before t

Minimal operation and stop times (2/3)

- Total start-up and stopping cost
  - $\sum_{\substack{t \in T \\ g \in G}} C_g^+ s_{g,t}^+ + C_g^- s_{g,t}^-$
    - C_g^+, start-up cost, plant g
    - C_g^-, stopping cost, plant g
- Constraints forcing binary variables necessary
  - $u_{g,t} - u_{g,t-1} = s_{g,t}^+ - s_{g,t}^-$
  - Can find inequality alternative? KTH Social!

Minimal operation and stop times (3/3)

- Constraints, minimal operation and stop times
  - $s_{g,t}^{+} + \sum_{k=t}^{t+\underline{t}_g^{+}-1} s_{g,k}^{-} \leq 1$
  - $s_{g,t}^{-} + \sum_{k=t}^{t+\underline{t}_g^{-}-1} s_{g,k}^{+} \leq 1$
- Where
  - Minimal allowed operation time, $\underline{t}_g^{+}$, plant g
  - Minimal allowed stop time, $\underline{t}_g^{-}$, plant g

Limited production changes (1/2)

- Production cannot change instantaneously
- Necessary constraining production changes over time
  - $\bar{\Delta}_g^{G+}$, maximal production time-increment, plant g
  - $\bar{\Delta}_g^{G-}$, maximal production time-decrement, plant g
- Note! At start-up …
  - Maximal production time-increment possibly larger
  - $\overline{G}_g^1$, start-up permission threshold, plant g
- Analogously when stopping …

Limited production changes (2/2)

- Corresponding constraints
  - $G_{g,t} - G_{g,t-1} \leq \overline{\Delta}_g^{G+} + s_{g,t}^{+}\left(\overline{G}_g^{1} - \overline{\Delta}_g^{G+}\right)$, increments
  - $G_{g,t-1} - G_{g,t} \leq \overline{\Delta}_g^{G-} + s_{g,t}^{-}\left(\overline{G}_g - \overline{\Delta}_g^{G-}\right)$, decrements

Typical exam question, part 1 (1/2)

- Thermal plant Flisinge
  - Fuel costs, 200 $\frac{¤}{\mathrm{m}^3}$
  - Fuel density, 400 $\frac{\mathrm{kg}}{\mathrm{m}^3}$
  - Fuel heat content, 5 $\frac{\mathrm{MWh}}{\mathrm{ton}}$
  - Flisinge efficiency, 40 %
- Provide the production cost function

Typical exam question, part 1 (2/2)

$\left[\frac{\mathrm{MWh}}{\mathrm{h}}\right]$

- Production cost function
  - $C(G) = \varphi F(G) = \varphi \frac{G}{h\eta(G)} = 200 \cdot \frac{G}{5 \cdot \frac{400}{1000} \cdot 0.4} = 250G \; \left[\frac{\text{¤}}{\mathrm{h}}\right]$

$\left[\frac{\text{¤}}{\mathrm{m}^3}\right]$ $\left[\frac{\mathrm{MWh}}{\mathrm{tonne}}\right]$

$\left[\frac{\mathrm{kg}}{\mathrm{m}^3}\right]$

End of lecture 9

Next time **dual** variable applications & **GAMS**