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Technische Universität
Cottbus - Senftenberg

Energy systems modelling

Tutorial 8 & 9

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Intertemporal dynamics

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Intertemporal dynamics - a decision made at one time step has an effect on the optimal decisions in other time steps

- Q: What are the causes of intertemporal dynamics in electricity markets?
  - Energy storages /Tutorial 6/
  - Investment decisions /Tutorial 7/
  - **Start-up constraints:**
    - **Partial-load costs**
    - **Start-up costs**

Implementing start-up constraints

- Generation capacity has to be started up to produce electricity
- Starting up capacity causes costs
  - fuel is consumed to heat power plant without electricity input
  - increased attrition due to temperature changes
- Running capacities have to produce between minimum and maximum load level
- Furthermore, operating power plants below optimal load levels (usually around max generation) causes efficiency losses (i.e. operating at higher variable costs)

Implementing start-up constraints: theoretical background [PSE2 lecture]

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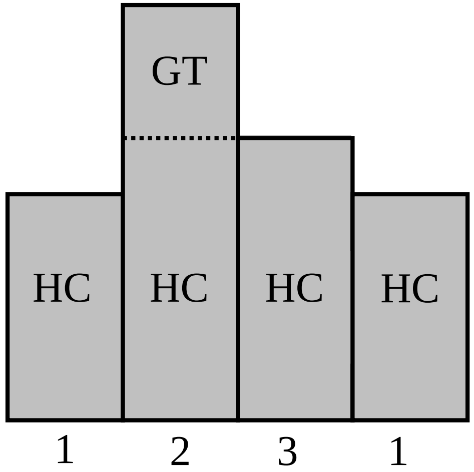
- Let‘s look at a market with three load-structures which repeat periodically
- We ‚linearize‘ the problem and assume a very small (infinitesimal) capacity of the power plant.
  I.e. each capacity that has to be started up entails start-up costs which have to be covered

Load and dispatch of p.p.

4)

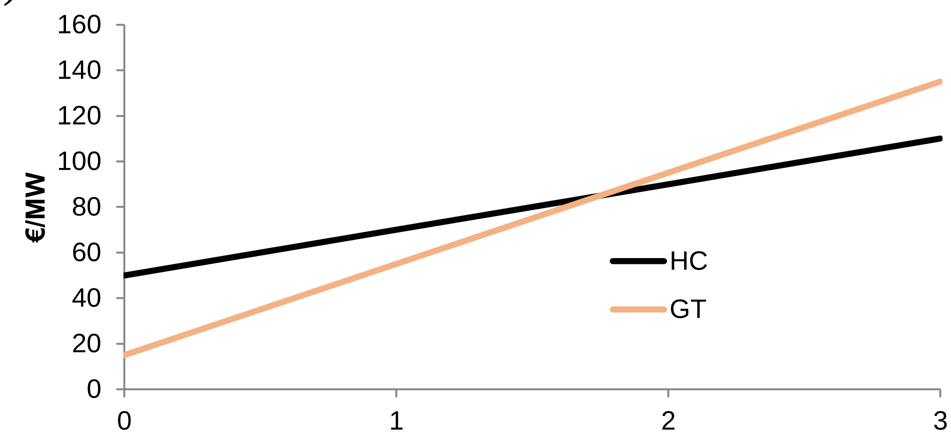


Start-up- and generation costs

2)

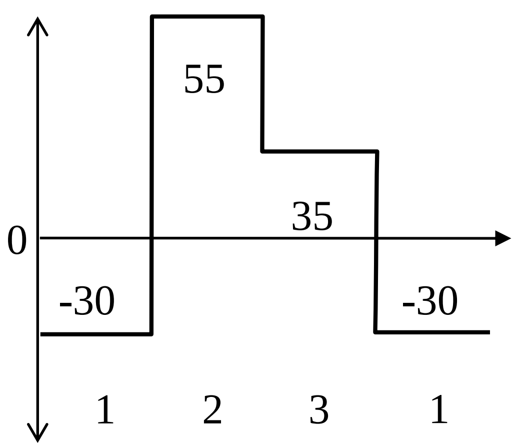
	Start-up costs [€/MW]	Variable generation costs [€/MWh]
Hard coal	50	20
Gas turbine	15	40

3)



Marginal costs of the system [€/MW]

5)



additional costs savings

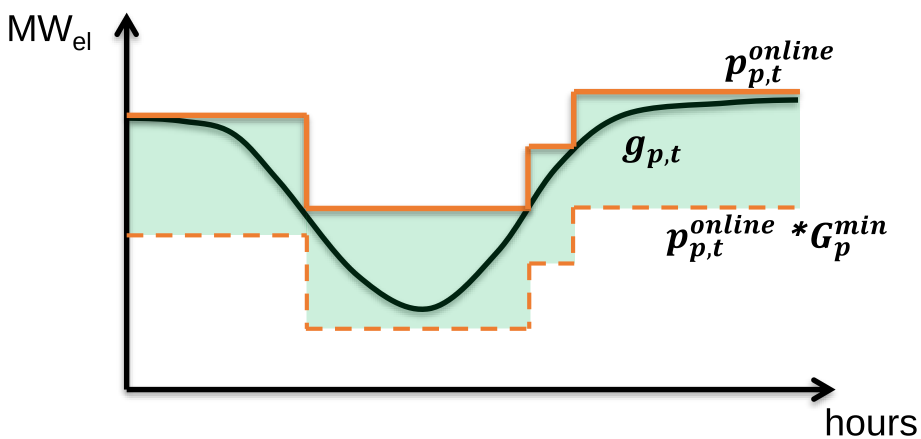
$$55 = sc_{GT} + vc_{GT} = 15 + 40$$

$$35 = sc_{HC} + 2 * vc_{HC} - (sc_{GT} + vc_{GT}) = 90 - 55$$

$$-30 = vc_{HC} - sc_{HC} = 20 - 50$$

Implementing start-up constraints: mathematical formulation

- Capacity 'online' is restricted by the installed capacity and its technical availability $$p_{p,t}^{online} \leq CAP_p * AF_{p,t} \qquad \forall p,t$$
- An upper limit for electricity generation $$g_{p,t} \leq p_{p,t}^{online} \qquad \forall p,t$$
- A lower limit for electricity generation $$p_{p,t}^{online} * G_p^{min} \leq g_{p,t} \qquad \forall p,t$$



Implementing start-up constraints: mathematical formulation

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- A start-up activity increases 'online' capacity

$$p_{p,t}^{online} - p_{p,t-1}^{online} \leq su_{p,t} \quad \forall p,t$$

Adjustments in the objective function:

Starting up capacity causes start-up costs

$$min\ tc = \sum_{p,t} VC_p^{full\ load} * g_{p,t} + \boxed{\sum_{p,t} SC_p * su_{p,t}}$$

$$\boxed{+ \sum_{p,t} \left(p_{p,t}^{online} - g_{p,t}\right) * \left(VC_p^{min\ load} - VC_p^{full\ load}\right) * \frac{g_p^{min}}{\left(1 - g_p^{min}\right)}}$$

Efficiency losses of power plants running at partial load cause higher production costs.

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1) Introduction
2) Basic theory
3) Linear problems
4) **Linear integer problems**
    1) Introduction to integer programming
    2) Application of ILP
5) Non-linear problems
6) Modelling strategic behavior

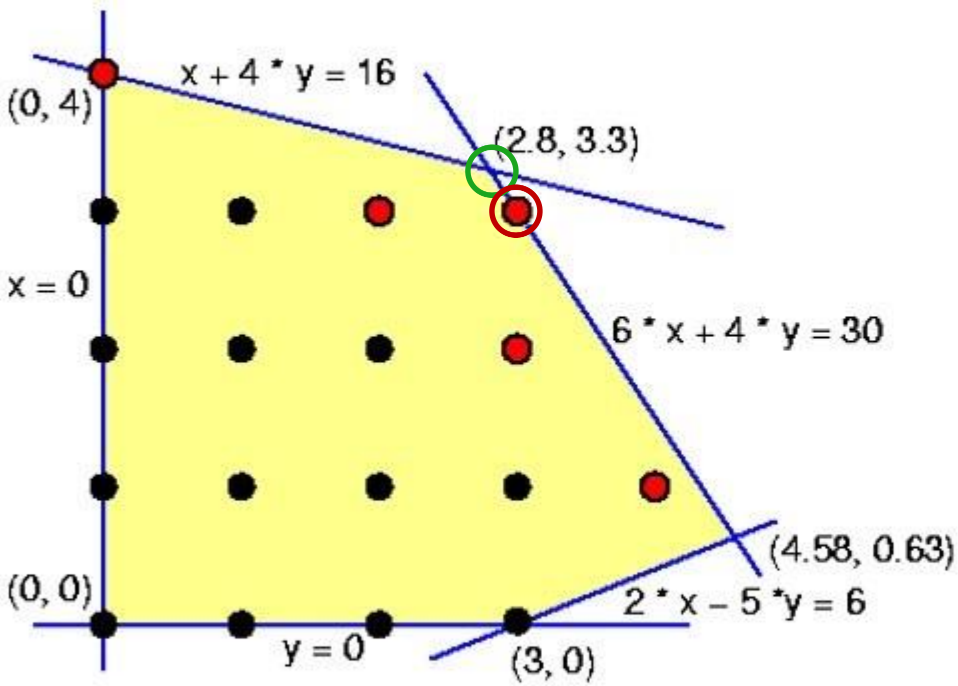
- ✓ An **integer programming** problem involves some (or all) of the variables that are restricted to be **integers**.

What are the reasons for using integer variables?

- ➢ The integers represent objects/processes that can only be integer (it is not possible to start 2.3 blocks of coal power plant).
- ➢ The integer variables may represent decisions (investment decision: "1" for "yes" and "0" for "no").

Integer programming

Solve the following integer programming example in GAMS (using IP solver) and find solution points that are shown below:



Objective: Maximization of the function **Z**

f(x,y): $Z = 6*x + 5*y$

s.t.

$x + 4*y \leq 16$
$6*x+4*y \leq 30$
$2*x-5*y \leq 6$

Optimum LP solution:

(x, y) = (2.80, 3.30)
obj = 33.30

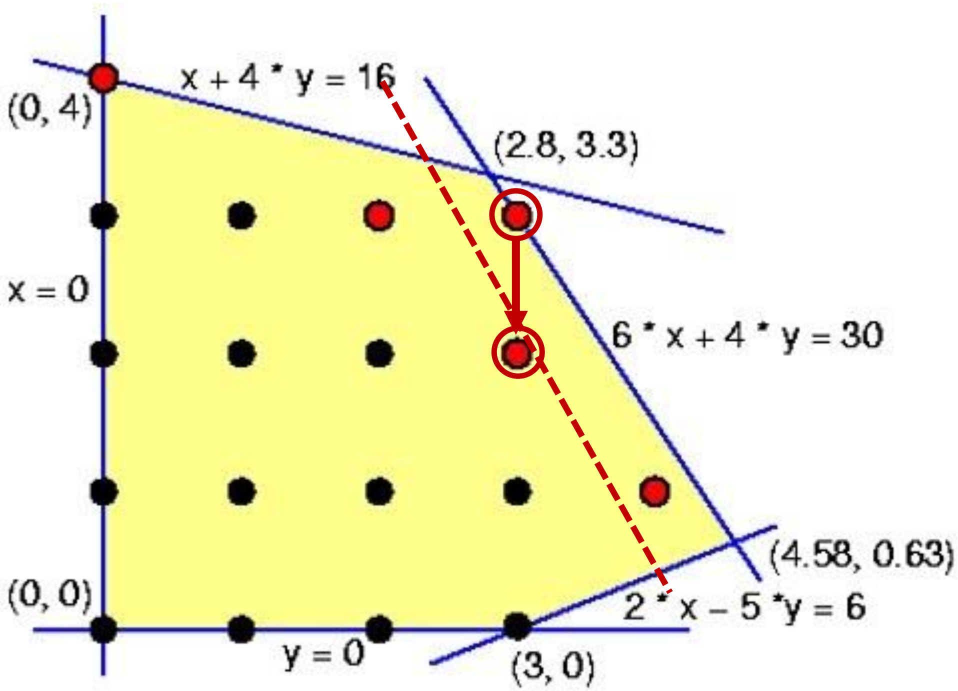
Optimum ILP solution:

(x, y) = (3, 3)
obj = 33

Image adapted from http://users.informatik.uni-halle.de/~jopsi/drand04/linear_programming.gif
GAMS code for this example will be uploaded to Moodle

Integer programming

Solve the following integer programming example in GAMS (using IP solver) and find solution points that are shown below:



Objective: Maximization of the function **Z**

f(x,y): Z = 6*x + 5*y

s.t.
x + 4*y ≤ 16
6*x+4*y ≤ 30
2*x-5*y ≤ 6

Optimum LP solution:

(x, y) = (2.80, 3.30)
obj = 33.30

Optimum ILP solution:

(x, y) = (3, 3)
obj = 33

s.t.
x + 4*y ≤ 16
7*x+4*y ≤ 30
2*x-5*y ≤ 6

Optimum LP solution:

(x, y) = (2.33, 3.42)
obj = 31.08

Optimum ILP solution:

(x, y) = (3, 2)
obj = 28

Image adapted from http://users.informatik.uni-halle.de/~jopsi/drand04/linear_programming.gif
GAMS code for this example will be uploaded to Moodle

Implementing start-up constraints with integer variables

- The single MW of capacity is physically not independent from other units
- Start-up activities can be seen as a binary decisions (0 or 1)
  - Starting up a single power plant unit (block): YES → 1
  - Starting up a single power plant unit (block): NO → 0

  Hence, start-up decisions $su_{i,t}$ are expressed as a binary variables:

  $$\boldsymbol{su_{p,t}} \in \{\mathbf{0}, \mathbf{1}\}$$

- Furthermore, it is necessary to implement a variable $down_{i,t}$ that defines the shutdown decision of a power plant block

  Shutdown decisions:

  $$\boldsymbol{down_{p,t}} \in \{\mathbf{0}, \mathbf{1}\}$$

Implementing start-up constraints with integer variables

- Adjustments in the objective function

$$min\ tc = \sum_{p,t} VC_p * g_{p,t} + \boxed{\sum_{p,t} SC_p * su_{p,t} * CAP_p * G_i^{min}}$$

$su_{p,t}$ is the start-up decision for a power plant block which has the capacity CAP_p.

- Adjustments of the constraint defining the running capacity

Generation unit is started up

$$p_{p,t}^{online} - p_{p,t-1}^{online} = \boxed{su_{p,t} * CAP_p} - \boxed{down_{p,t} * CAP_p}\ \forall p,t$$

In case of a shutdown $DOWN_{p,t}$ the full capacity cap_p has to shut down

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See you next class!