# Leven we in 2050 in een energie-neutrale wijk?

## Opslag van elektriciteit in de wijk: wat, waar, hoeveel?

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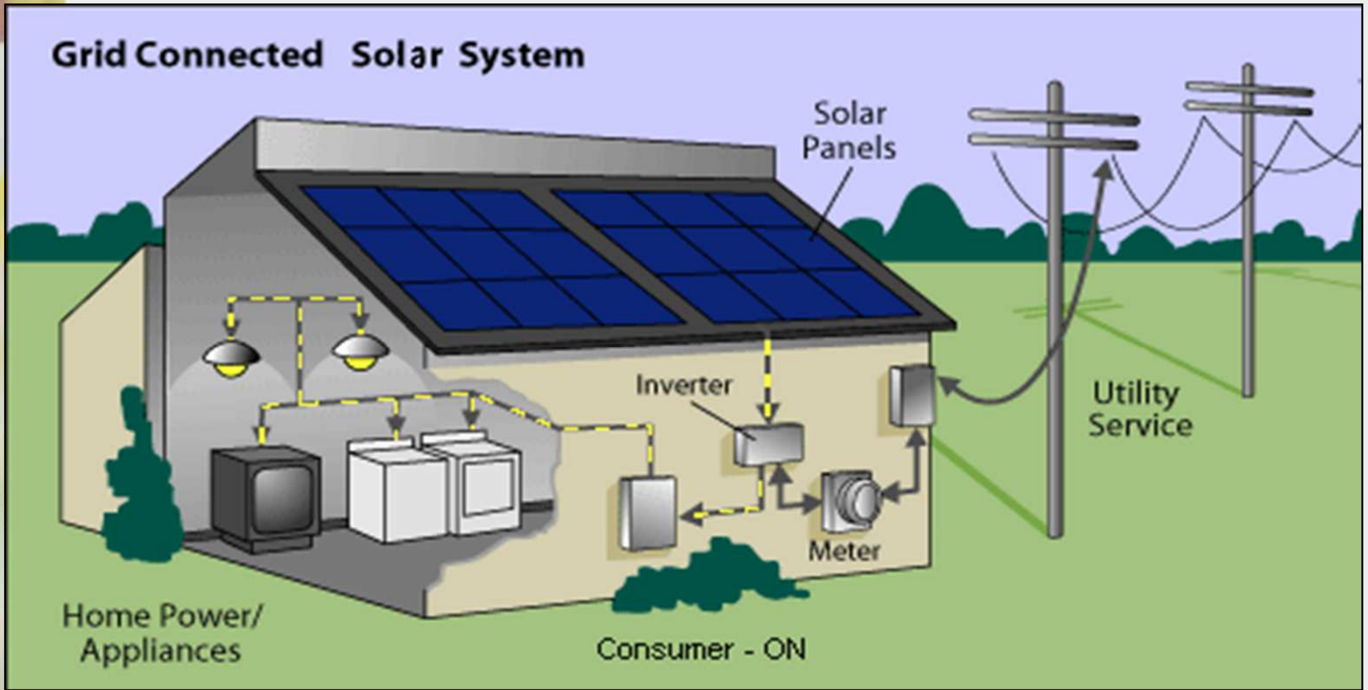
[Faculty of Science
Information and Computing Sciences]

# Even voorstellen

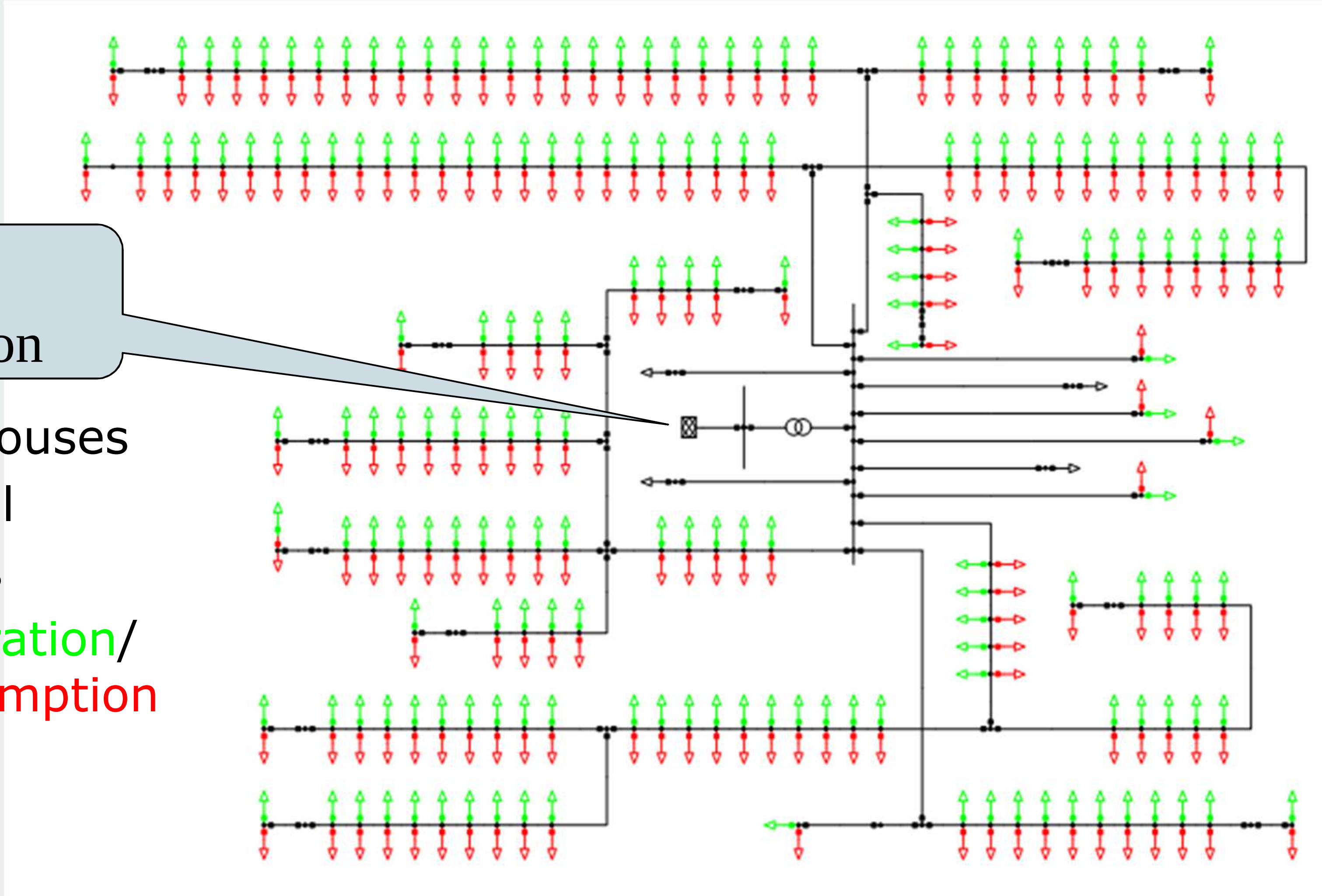
- Wiskunde (Ir) TU/e
- Promotie wiskunde TU/e:
  - Operations research, scheduling
- Nationaal Lucht- en Ruimtevaartlaboratorium:
  - modelleren, optimalisatie en simulatie Air Traffic Management (en Rekeningrijden)
- Universiteit Utrecht: Docent/onderzoeker Informatica:
  - Decision support systems
  - Advanced planning algorithms
  - Smart energy systems

# Electricity networks are changing
# Decentral generation (DG)




- Solar panels
- Wind generators
- Combined heat and power (CHP)

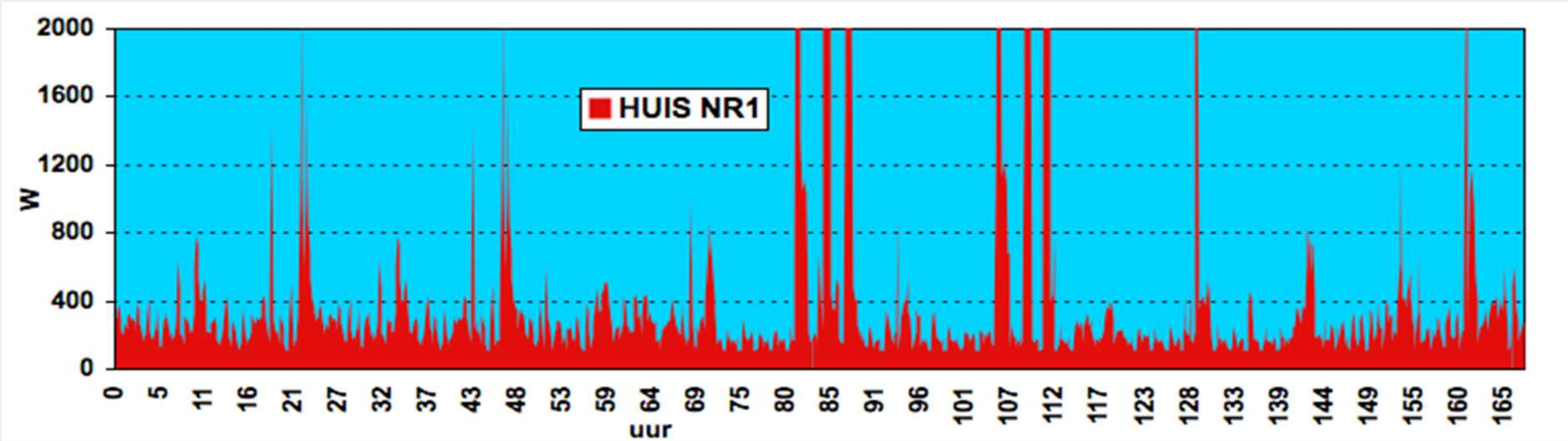
# Example low voltage Network Model

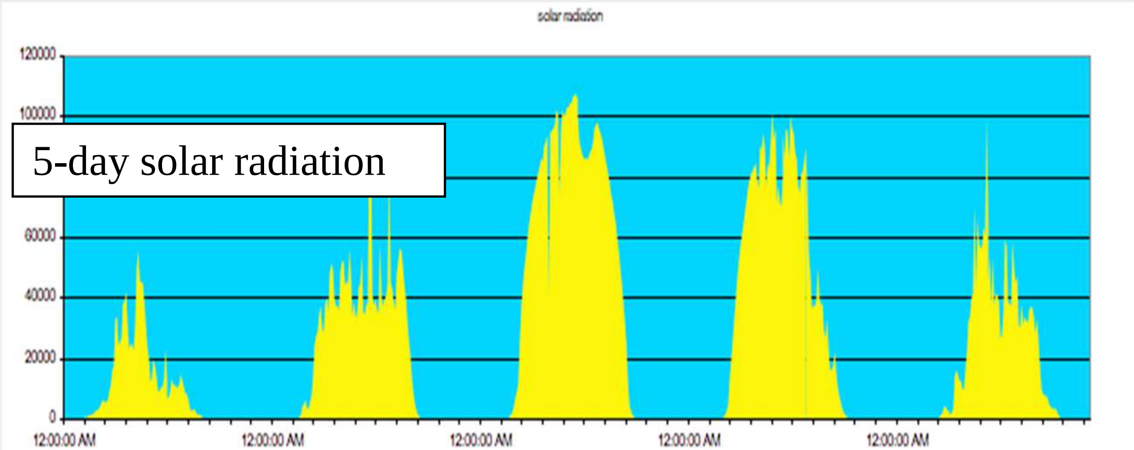



- 190 houses
- School
- Shops
- Generation/ consumption

# Consumption & generation patterns

## Individual power usage is highly variable




Solar energy may be available during hours of low consumption.

# Storage systems to match supply and demand

- Enexis Smart Storage:
  - residential area Etten-Leur (next talk)
  - Lithium-ion-accu's
- *`Een vakantie op autonome zonne-energie'*
  - Holiday parc Vesting De Bronsbergen Zutphen
  - EU project GROWDERS
  - Batteries
  - Flywheels

©Enexis


www.growders.eu

# Why storage systems

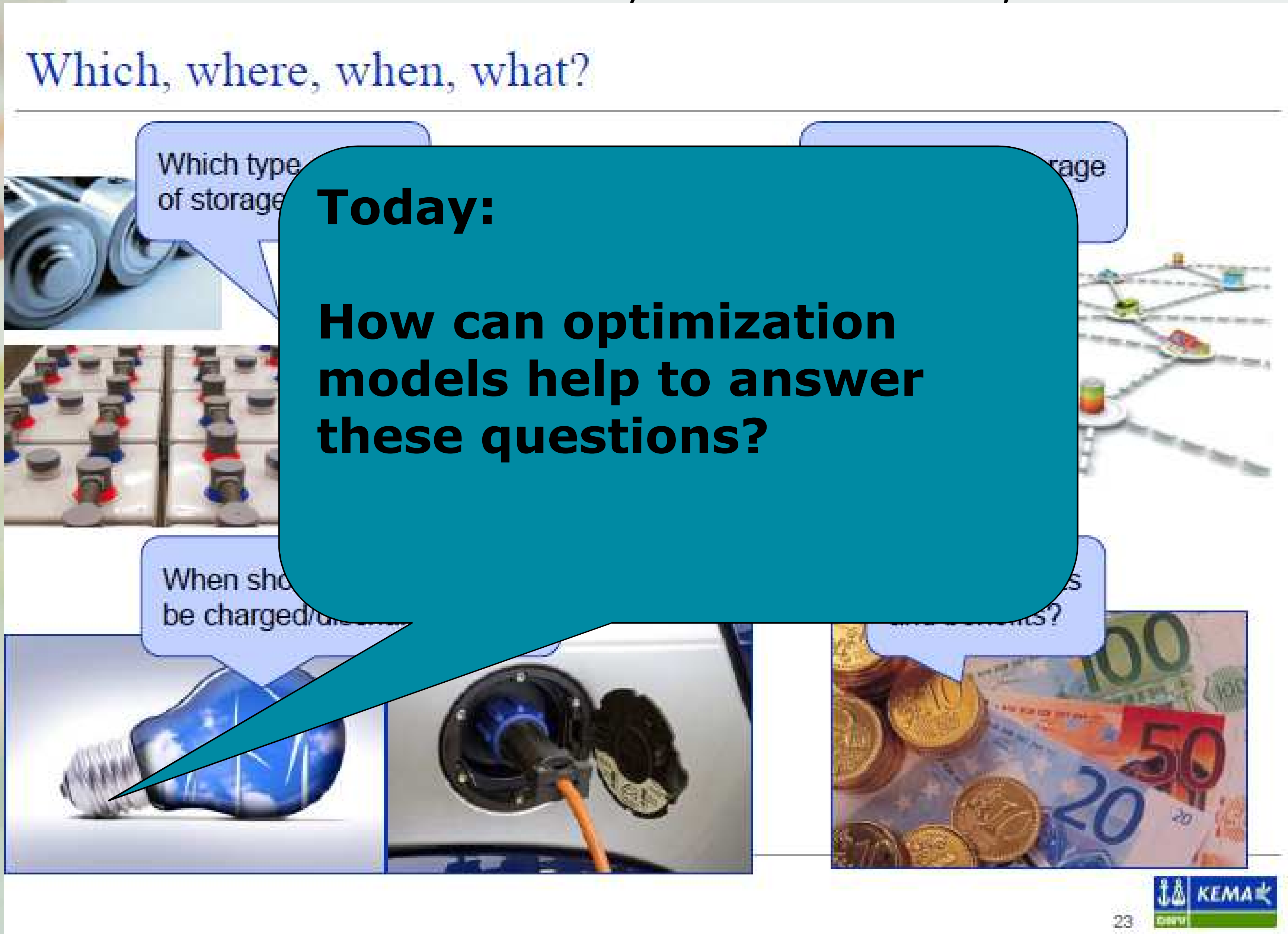
- Storing decentrally generated energy
- Prevent overloading
- Prevent voltage drops
- Power delivery in case of black-out
- Trading

$$W = V \times I$$

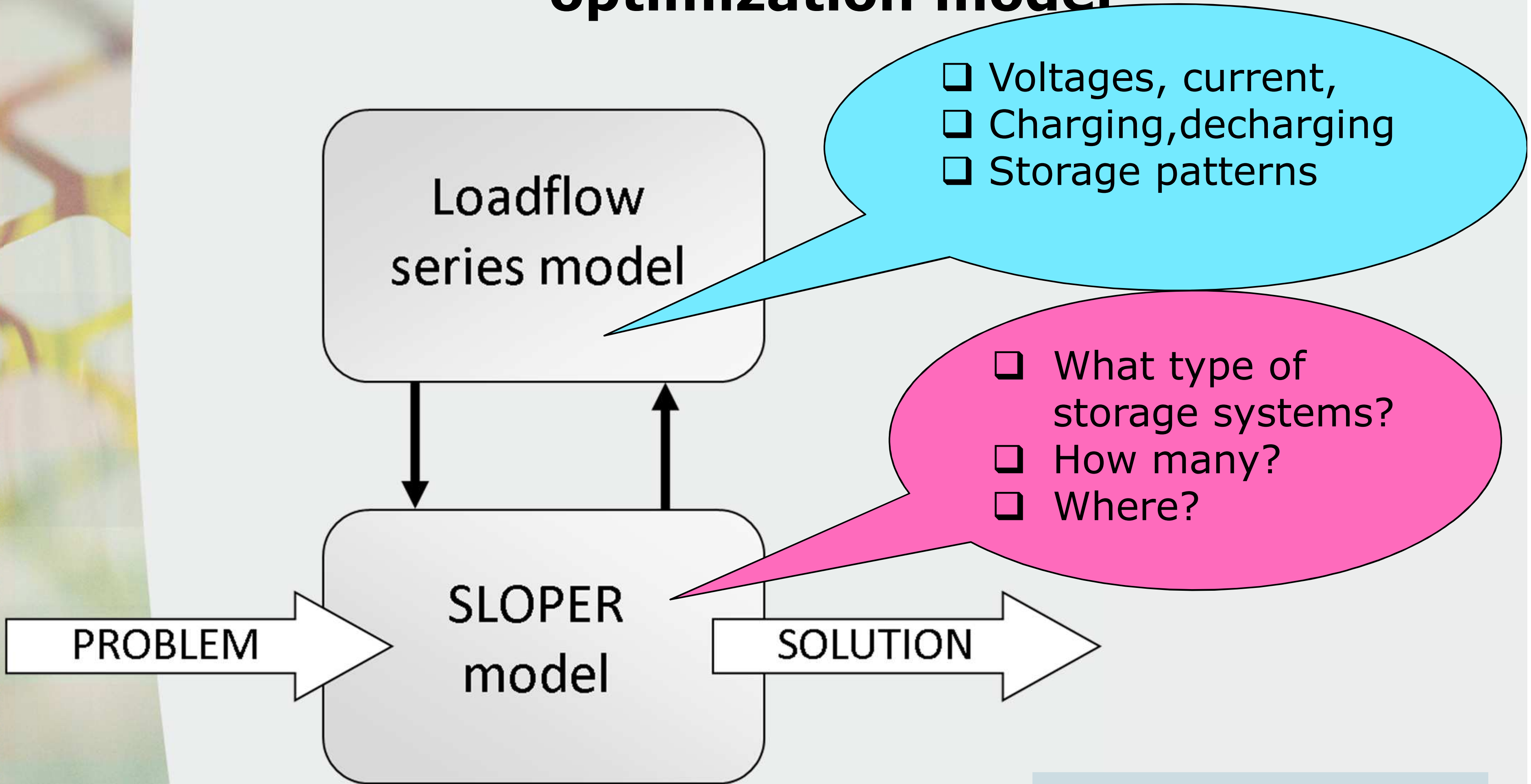
Ohm's law:

$$\Delta V = I \times R$$

**EU-2050 Power Lab 16 mei, Ir. Jillis Raadschelders, DNV KEMA:**



# How to use storage systems: layered optimization model




Decentral generation and consumption fixed!

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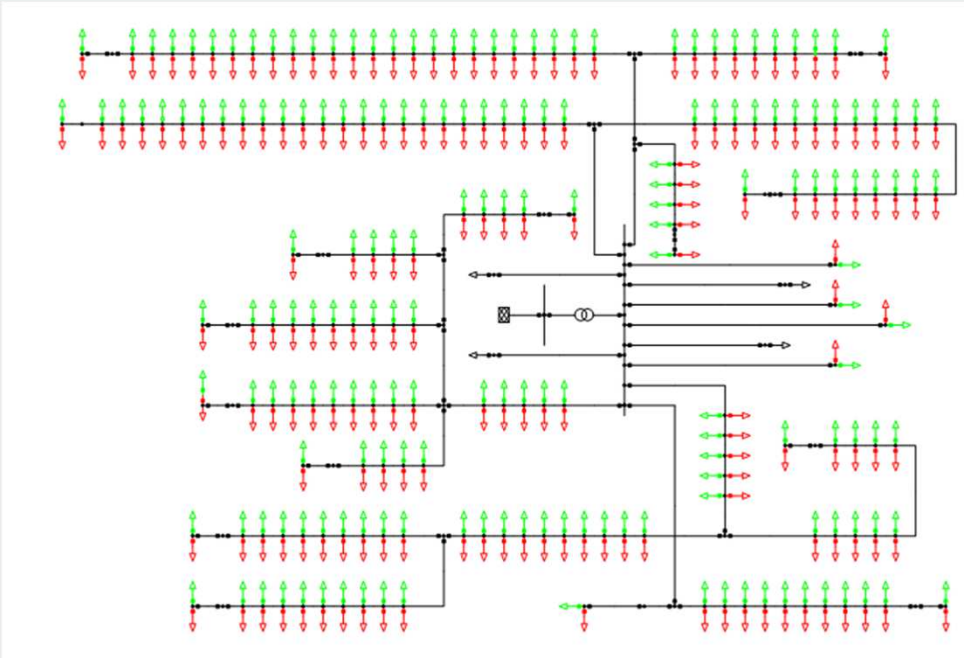
# Network model

- Nodes *V*: Users or connection points
- Edges *E*: connections between nodes
  - Directed, current flow from node *i* to *j* (upstream negative)
- Discrete set of timeframes



# Loadflow series model

- Placement of storage units is **fixed**
- Find:
  - Current on all edges in each time period
  - Voltage on all nodes in each time period
  - charging, decharging, actual storage in nodes at each time period

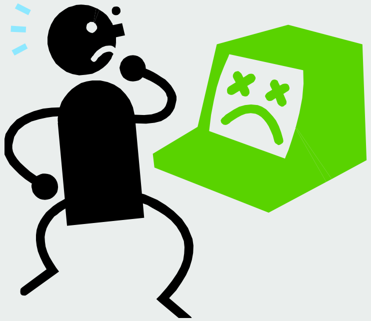
- Within constraints

- With the objective:
  - Minimize the energy taken from the grid connection multiplied by their prices i.e.

maximize being energy neutral

# Load flow series model

- 3-phase alternating current physics:
  - large computation time



- Apply DC approximation
  - Different from DC approximation found in other operations research papers.
  - Constant current production

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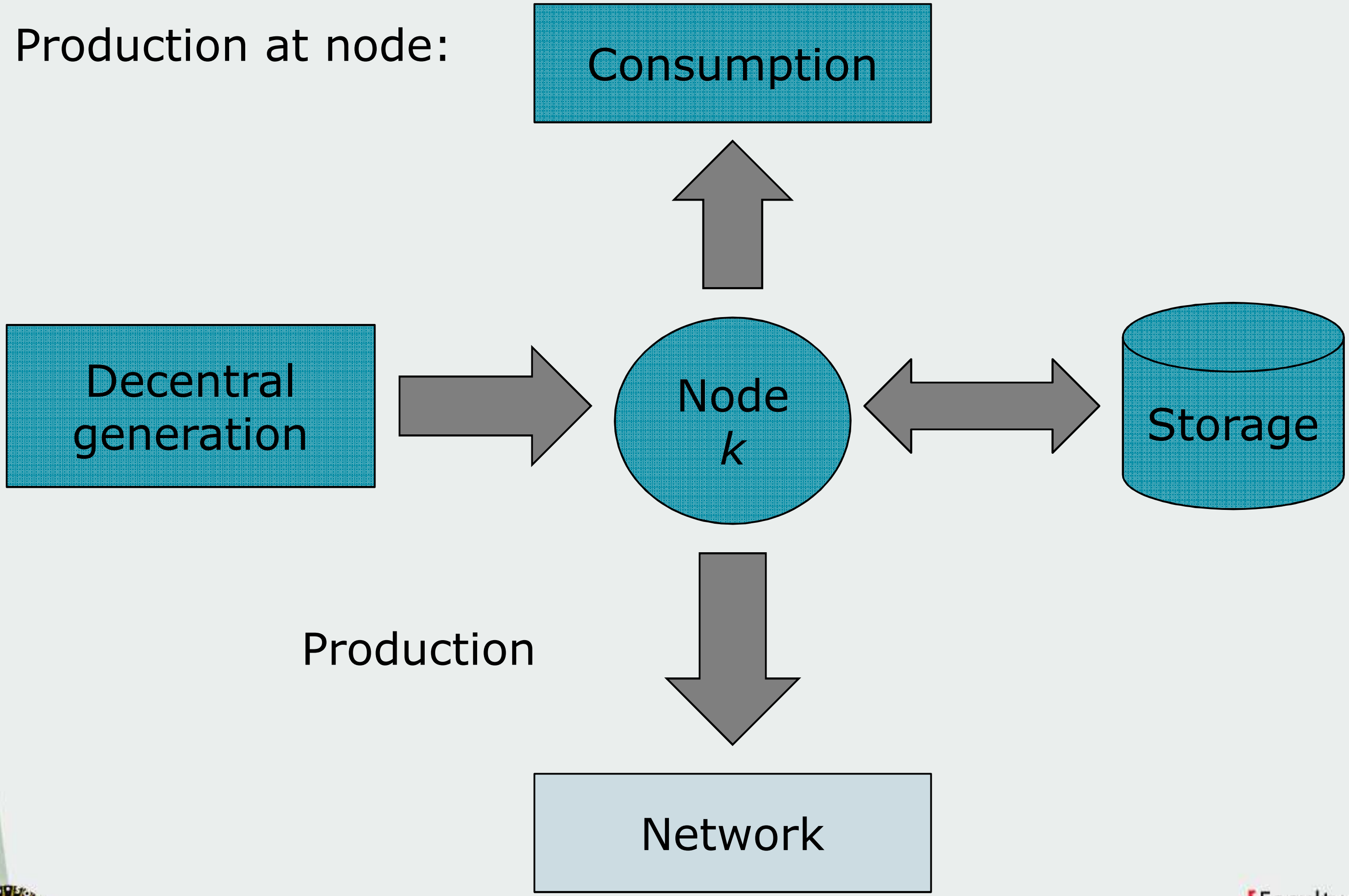
# Loadflow series model

- Production at node:



# Loadflow series model: constraints

- Kirchoff's current law:
  - The sum of the currents leaving the vertex should be equal to the total net production of current of the vertex
- Kirchoff's voltage law:
  - The net voltage drop around a loop should be zero, ensured by

# Loadflow series model: constraints

- Network operational limits on:
  - The voltages in nodes
  - The current through edges
- Inventory:
  - Inventory  balance equation:
    - In-efficiencies (losses) are included
  - Amount of energy stored is bounded
  - Power of decharging and charging is bounded
  - Amount of energy stored: beginning = end

# Loadflow series model

- Objective: Minimize the sum of
  - the energy taken from the grid connection $g_{i,t}$ $V_N$ multiplied by their prices $k_{i,t}$
  - overload penalty cost

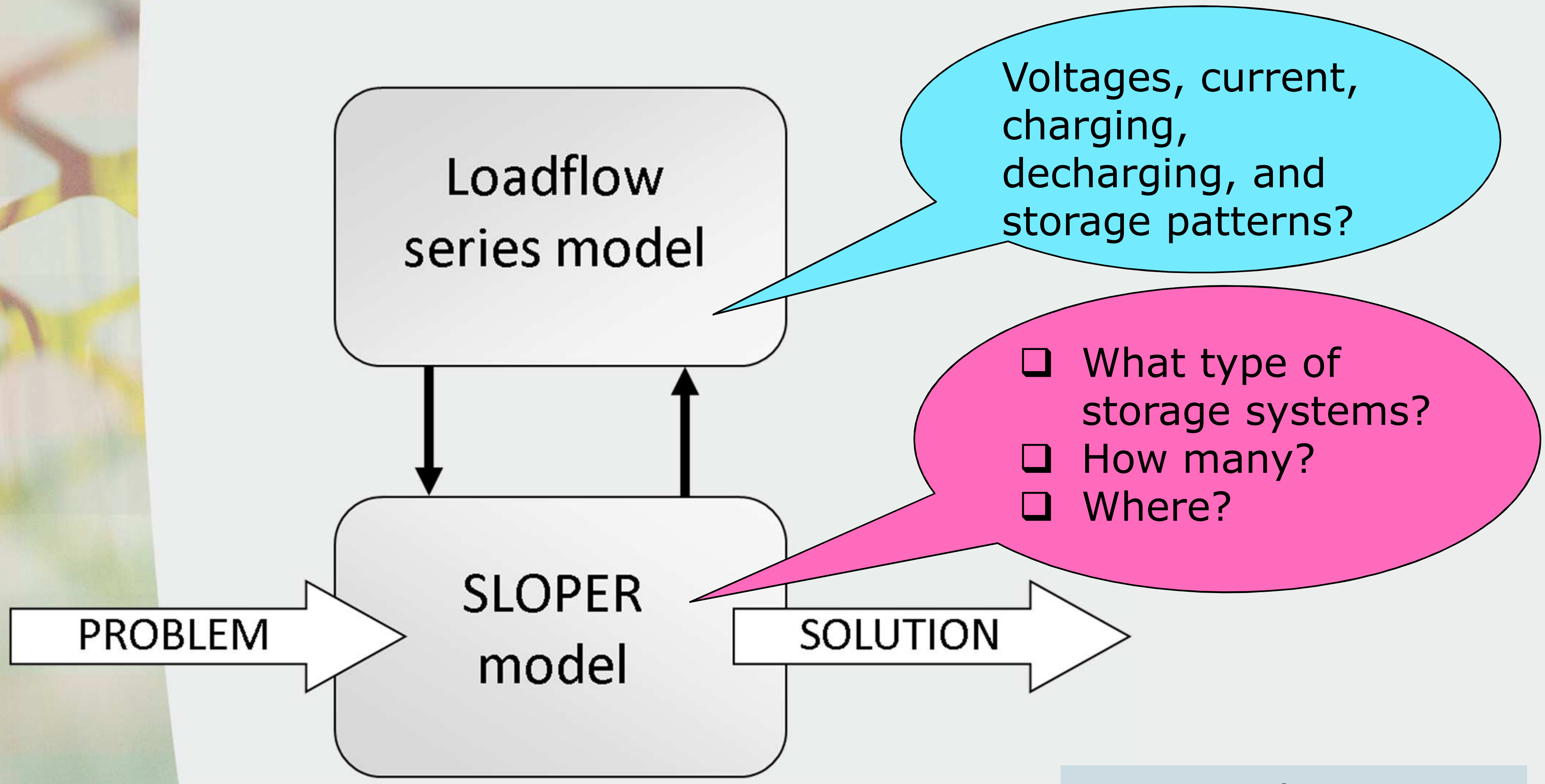
$$\min \sum_{i \in V} \sum_{t \in T} g_{i,t} \times k_{i,t} \times V_N + \sum_{(i,j) \in E} X \times x_{i,j} + \sum_{i \in V} Y \times y_i$$

maximize being energy neutral

# Loadflow series model: summary

- Find:
  - Current on all edges in each time period
  - Voltage on all nodes in each time period
  - charging, decharging, actual storage in nodes at each time period
- Within given constraints
- With the objective
- *Linear programming problem*

# Recap: decomposition model




Decentral generation and consumption fixed!

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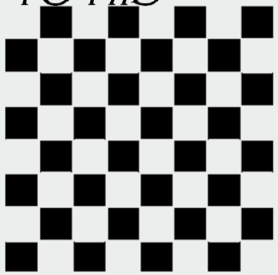
# What type of storage systems, how many, where?

- Minimize costs storage + loadflow series model results

- Combinatorial optimization problem
  - Many combinations possible

  - 2 x 2 x 2 x 2 x ……

A long time ago Sissa ben Dahir, the Grand Vizer to the Indian king, Shirham, presented his latest creation to his ruler.



It was a game called chess.

The king was so pleased, that he told Sissa that he could name his own reward.

S… …ied, "Majesty, give me the sum of 10,000 rupees;

… …heat in the following manner:

18.446.744.073.709.551.65

1 grain … …uare of the chessboard,

2 grains to pla… …e

4 grains for the third …

8 grains for the 4th square; a…

to continue in like manner,

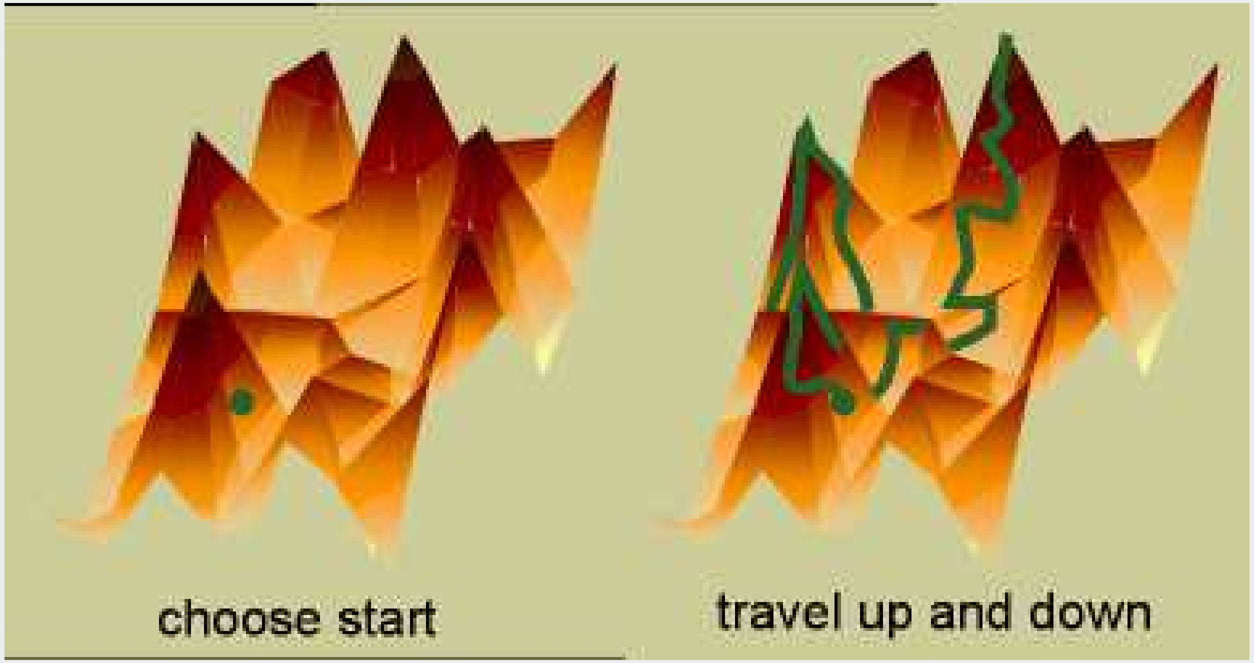
oh Mighty and Generous One, let me cover e…
squares of the board."

# Optimization of storage location

- SLOPER model:
  local search through set of possible storage locations
- To evaluate each storage location set:
  load flow series model

SLOPER **=** **S**torage **L**ocation **OP**timization **E**fficient **R**outine

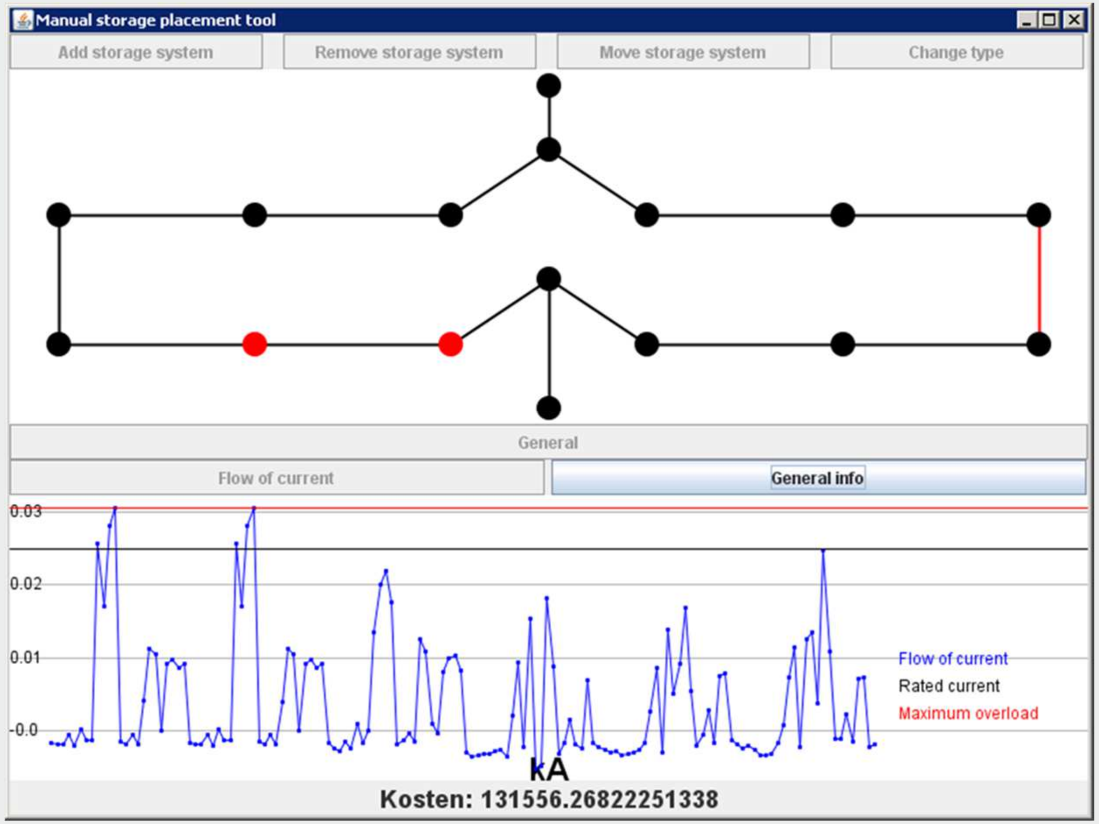
# SLOPER model: simulated annealing




http://biology.st-andrews.ac.uk/vannesmithlab/heuristic.html

# Storage placement tool

- Implementation in Java and ILOG CPLEX 12.2
- Validation with Plexos and Power-Factory:
  - Loadflow series model is reasonable approximation



# Interesting extensions

- Overload durations
- Aging effects of storage systems
- Combine with AC
- Other approximations in loadflow series model:
  - DC
  - Linearised AC
- Combine with
  - planning decentral generation
  - Optimizing topology

# References

J.M. van den Akker, S.L. Leemhuis, G.A. Bloemhof (2012). Optimizing storage placement in electricity networks. *Operations Research 2012, Energy, markets and mobility.* Hannover.

Related work:

- Maximize the amount of de-central generation within the limitations of the network

  J.M. van den Akker et al. (2010). Optimal distributed power generation under network load constraints. *Proceedings of the 72nd European Study Group Mathematics with Industry*, Amsterdam

- Optimize network topology

  A.N. Dimitriu (2012). Automatic planning tools for power system design. Master's thesis Utrecht University/DNV KEMA

# Concluding remarks

- Storage systems are important to enable energy neutral neighborhoods
- Optimization algorithms are helpful to find out which, where, how many storage systems