Optimization problems in Smart Grids

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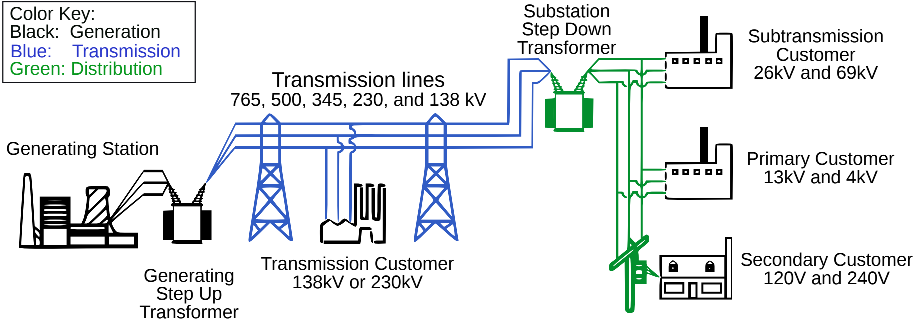
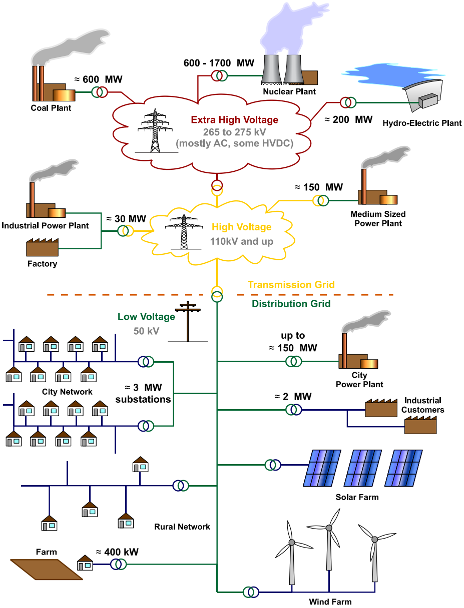
Schema of classical electrical grid



Schema with renewable energy sources



Generation energy from the Sun and wind

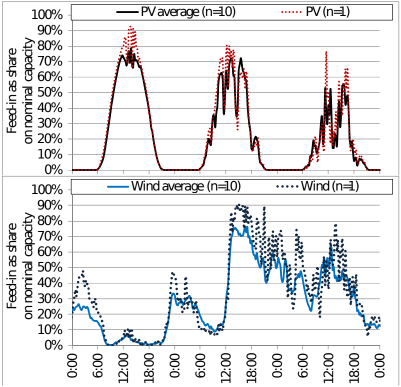


Figure: Three days in May 2011 in the Emsland, Germany

For the German low and medium voltage levels, a need for additional cables of a length of 380,000 km until 2020 with costs of more than €20 billion is estimated to avoid local problems for the voltage levels.

How to use green energy efficiently?

- Improve the legislation and regulations
- Use batteries (advanced lead-acid batteries, NaS or Li-Ion batteries or flow batteries such as Zn-Air, Zn-Br and Vanadium redox)
- Schedule domestic demands according to production

Which domestic demands can be scheduled?

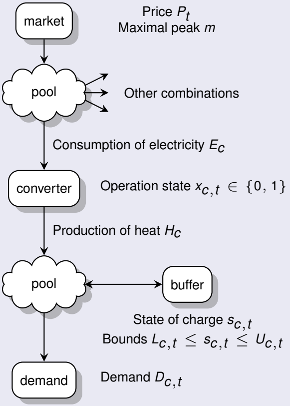
- Heating and cooling of houses
- Heating water
- Fridges and freezers
- Washing machines, driers, dishwashers
- Electrical cars

Smart Grid [European Technology Platform]

A Smart grid is an electricity network that can intelligently integrate the actions of all users connected to it - generators, consumers and those that do both in order to efficiently deliver sustainable, economic and secure electricity supplies.

Model

Schema



Problem statement

$$s_{c,t+1} = s_{c,t} + H_c x_{c,t} - D_{c,t}$$

$$L_{c,t} \leq s_{c,t} \leq U_{c,t}$$

$$x_{c,t} \in \{0, 1\}$$

Minimizing cost: minimize $\sum_t \sum_c P_t E_c x_{c,t}$

Minimizing peak: minimize m

where $m \geq \sum_c E_c x_{c,t}$

Applications

- Heating water
- House heating
- Fridges and freezers
- Energy production

Minimizing peak

Observation

Let

- $U_{c,1} = L_{c,1} = T - 1$
- $U_{c,t} = 2T - 2$ for $t \geq 2$
- $L_{c,t} = 0$ for $t \geq 2$
- $D_{c,t} = 1$
- $H_c = T$.

A scheduling of converters is feasible if and only if every converter runs exactly once.

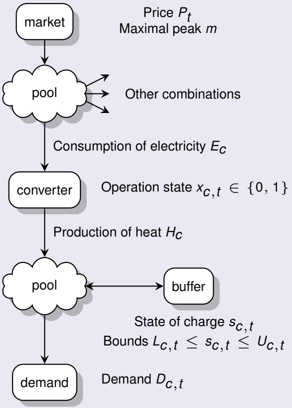
Observation

We have one-to-one correspondence between partition integers $E_1, \dots, E_N$ and scheduling converters.

Theorem

Minimizing peak is NP-complete even if $T = 2$.
Generally, minimizing peak is strongly NP-complete.

Schema



Minimizing cost

Observe, that every combination can be solved separately.

Dynamic algorithm for minimizing cost of a single combination

Let $f(t, n)$ be the minimal cost if the converter is running n times during time intervals $1, \ldots, t$. Then,

$$f(t,n) = \begin{cases} \min\{f(t-1,n), f(t-1,n-1) + P_t\} & \\ & \text{if } L_{c,t+1} \leq L_{c,1} + nH_c - \sum_{i=1}^{t} D_{c,i} \leq U_{c,t+1} \\ & \text{and } 0 \leq n \leq t \\ 0 & \text{if } t = n = 0 \\ \infty & \text{otherwise.} \end{cases}$$

The time complexity is $\mathcal{O}(T^2)$. Let R be the ratio between capacity of a buffer and production of a converter. The time complexity can also be estimated as $\mathcal{O}(RT)$.

Greedy algorithm

A greedy algorithm finds minimal cost in time $\mathcal{O}(T \log(T))$.

Minimizing peak

FPT

A dynamic algorithm finds minimal peak in time $\mathcal{O}((2R)^N \cdot T)$.

Problem

In there an algorithm for minimizing peak whose complexity is $\mathcal{O}(c^N \cdot T)$ for some constant c which is independent on R?

Minimizing peaks for converters of equal consumption is polynomial

- Scheduling problem $P_m|r_i, p_i = 1, \text{chains}|L_{\max}$ [Dror, Kubiak, Dell'Olmo]
- Network flow problem with $\mathcal{O}(NT)$ vertices

Related problems

Advanced converter

- Multiple operation states
- Multiple functions (warm water for heating and hot water for tap)
- Operation restriction (e.g. minimal running time, start up profile)
- On-line (real-time) control

MicroCHP planning problem [Bosman,Bakker,Molderink,Hurink,Smit,2010]

- MicroCHP consumes gas and produces heat and electricity
- The problem consider minimal running time, loss and wearing
- Objective is minimizing deviation from electricity profile (balancing power)
- The problem is NP-complete
- Dynamic and column degeration algorithm

Central vs. distributed control

Problems of global control in practice [Kok, 2013]

- Openness
- Privacy protection
- Scalability
- Market mechanism

Kok; Aung, Khambadkone, Srinivasan, Logenthiran; Kane, Lynch, Zimmerman; Bakker, Bosman, Huring, Molderink, Smit; etc.

Agent base control with auction mechanisms

Open question

Is there another mechanisms to control domestic demands which can work in practice?