How to upgrade the European power grid to enable high penetration of wind power

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Outline

• Motivation: Growth of wind power capacity
• How much wind power can Europe produce?
• UCTE power flow scenarios
• Case study: Spain
• DC model, and why it failed
• Linear programming model
• Road to modelling the whole European network
Growth of wind power

Cumulative wind power capacity in the EU [MW]

Source: European Wind Energy Association
Wind power installed in the EU by end of 2008: 64,935 MW
Source: European Wind Energy Association
New installed power capacities in the EU in 2008

Source: European Wind Energy Association

- Wind: 8.484MW (35.6%)
- Natural gas: 6.932MW (29.1%)
- Solar (PV): 4.200MW (17.6%)
- Oil: 2.495MW (10.5%)
- Coal: 762MW (3.2%)
- Hydro: 473MW (2.0%)
- Nuclear: 60MW (0.3%)
How much wind power can Europe produce?

European Environmental Agency: “Europe's onshore and offshore wind energy potential” (technical report, June 2009). Its main conclusion is that considering

● technological development in turbine design,
● environmental constraints and
● economical competitiveness,

potentially approx. 12 200 TWh/year wind energy can be produced in 2020, which is 3 times larger than the EU's projected total energy demand.
Wind power is always changing, like weather,

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Power flow in the UCTE grid: Business as usual scenario

Power flow in the UCTE grid: Northern wind scenario

Power flow in the UCTE grid: Southern wind scenario

Case study: Spain

Share of wind power in consumption (monthly average)

Installed capacity (end of 2008): 16740 MW

Wind power record in Spain! 5 March 2009

The share of wind power exceeded 40% for several hours. The peak wind power was 11180 MW, corresponding to 69% capacity factor (the long time average capacity factor is 21-23%).

0,0%
2,0%
4,0%
6,0%
8,0%
10,0%
12,0%
14,0%
16,0%
18,0%

0,0%
2,0%
4,0%
6,0%
8,0%
10,0%
12,0%
14,0%
16,0%
18,0%

Power load
18 March 2009
source: UCTE
France-Spain border

Cross border lines maximum total capacity: 2930 MW

Source: UCTE
Power grid simulation: DC model (linearized)

Assumptions:

- Connecting lines at a node have the same voltage (U) and phase (θ)
- Along a line, phase shift Δθ << 1
- x << r for the complex resistance r+i*x

Power flow: \( P = U^2 \frac{\Delta \theta}{x} \)

Constraints: sums of power flows at nodes are zero → sparse set of linear equations for the phases.
DC model is not suitable for power line overload testing

Max. power line capacity: 55 MW

Linear programming model:
Linear programming model

Variables:

\[ I_{21} = P_2 - P_1 \]
\[ I_{31} = P_3 - P_1 \]
\[ I_{32} = P_3 - P_2 \]

Model inequalities:

minimize: \[ |I_{21}| + |I_{31}| + |I_{32}| \]
\[ |I_{21}| \leq 55 \text{ MW} \]
\[ |I_{31}| \leq 55 \text{ MW} \]
\[ |I_{32}| \leq 55 \text{ MW} \]
\[ I_{21} + I_{31} = 100 \text{ MW} \]
\[ -I_{21} + I_{32} = -70 \text{ MW} \]
\[ -I_{31} - I_{32} = -30 \text{ MW} \]
Linear programming solver

lp_solve

- Easy to formulate the problem
- Good performance compared to commercial software
- Open source, free to use

“It is much easier than Matlab, I don't have to write the many zeros into the matrix.” (Aleksandra Kanevce, Skopje)
European network modelling

- Linear programming model instead of DC model
- Goal: determine safe maximum of wind power
- Power plant types: base load plants (e.g. nuclear), conventional plants (e.g. natural gas fuelled), wind power plants
- Wind modelling: ERA-40, ERA-Interim, airport measurement data
- The system softly fails if wind power plants has to be stopped
- Hard failure: the network collapses if one line fails (N-1 criterion)
- Still work in progress
A closer look at the UCTE map