Conclusions for Power Grid Topologies

Content Summaries

BURN [2]

- In the early days of electricity, energy systems were small and localized → Pearl Street Station in New York City
- From the late 1800s onward, a patchwork of AC and DC grids cropped up across the country → privatization!
- Todays electricity grid actually three separate grids is extraordinarily complex as a result.

50Hertz [1]

- Stromversorgung zu Beginn des 20. Jahrhunderts zunchst nur in unmittelbarer Umgebung der Stromerzeugungsstellen mglich
- berwiegend in Stadtgebieten und Ballungsrumen.
- 4040 Unternehmen mit einer installierten Leistung von insgesamt 2096 MW, d.h. durchschnittlich 500 kW je Werk
- Problem: Ausfall eines isolierten Kraftwerks, Schwankende Nachfrage oder extreme Wettersituationen

  → Versorgungssicherheit
- Nach und nach wurden einzelne Kraftwerke im Bereich der Niederspannung verbunden, so dass im lndlichen Bereich weitlufigere Netzstrukturen entstanden
- Diese wurden spter an die Mittelspannungsebene angeschlossen, um noch grere Entfernungen berbrcken zu knnen
- Problem: Zunahme Last+Erzeugung → hohe Lastflsse → hhere Spannungsabene ntig
- Um 1930 entstand die erste Verbundleitung auf Hchstspannungsebene (220 Kilovolt) fr den Stromtransport zwischen Regionalnetzen. → Reichssammelschiene
- 1951 im Zusammenschluss der Netze von elf Lndern zum europischen Verbundnetz UCPTE. Derweil begann in Deutschland der Ausbau des 380-Kilovolt-Verbundnetzes.

DDR: Zum Ende des Jahres 1975 bestand in der DDR ein Hchstspannungsnetz mit mehr als 7600 km Systemlnge, vorwiegend 220 kV. Bis zur politischen Wende im Jahr 1990 wurde das Verbundnetz der DDR auf eine Systemlnge von 4312 km in 380 kV und 6416 km in 220 kV, ausgebaut. Es bestanden 16 Umspannwerke bzw. Schaltanlagen mit einer Oberspannung von 380 kV und 39 mit 220 kV Oberspannung.

Ravn et al. [5]

- main assumption is that all demand sites and production sites have fixed locations (extra sites cannot he introduced)
- when one cable cannot be used, it should still be possible to redirect the flow through the network, such that all demand is met,
- every site should be connected to at least two other sites
- the network itself sl;ould be connect:ed, i.e., it should be possible to reach every site from every other site, only using the selected connections.
- combination of capacity constraints and connectivity constraints, and the possibility of using multiple cables
- voltage levels optimised independently → strong assumption!!
- no (technical?) requirements for inter-level connections
- all demand must be met without storage, i.e. locally, line capacities need to match demand/generation capacity
- smiulated annealing (cross-wirings) + load flow calculations in each step
- given: node location and generation/demand capacities
- different kinds of cables, power flow capacity, costs are proportional to length!
- almost impossible to tell if a network design that consists of a lot of nodes can be improved

Strano et al. [8]

- road network evolution typically governed by urbanisation
- continuous expansion and rein
- forcement of pre-existing structures
- persistent backbone of high-centrality (old) roads
- two elementary processes: densification and exploration, distinguished by edge-betweenness

- densification: low impact on centrality, no dead ends
- exploration: higher impact on centrality, dead ends
- average population per road intersection remains contant over time
- averange link length decreases over time
- road networks are planar graphs, cell area distribution follows power law
- homogenisation of cell areas, rectangles become dominant shape

Yang and H. Bell [9]

- mixed NDP : involving simultaneous choice of link addition and capacity improvement which is considered more sensible for road networks
- introduce the network reserve capacity concept for a capacity improvement plan, and raise and clarify some interesting issues relating to NDP and Braess's paradoxes
- The objective is to make an optimal investment decision in order to minimize the total travel cost in the network, while accounting for the route choice behaviour of network users
- travel costs could be equivalent to transport losses, on the one hand we have line losses, on the other hand losses at plants that cannot produce at full capacity
- economic-based objective function for optimization
- mixed network design problem involving the simultaneous choice of link addition and capacity improvement
- e.g. 4.2.1. Travel cost minimization with fixed demand
- objective function contains travel costs along all links and construction costs (alternatively, they can also be subject to an additional budget constraint)

Liu et al. [4]

- kernel density estimate of a network (nodes/links) to estimate a probable spatial density function
- one parameter, bandwidth of the kernel
- e.g. polynomial, gaussian, ...
- threshold to define cores

Rosas-Casals et al. [7]

- data of 33 EU countries
- static robustness, i.e. no load flow redistribution considered !!
- Power grids, having less skewed exponential degree distributions and often without small-world topology, parameter gamma $\neq$ mean degree
- average nearest neighbor connectivity of a node with the degree k is constant?
- networks grouped in fragile (gamma > 1.5) and robust against intentional attacks
- the application of the NX contingency-based criteria, though originally intended to avoid interruptions in power service, would difficult the islanding of disturbances
  - → the more connected an element is, the easier would be for a disturbance to reach
  - → difficulties encountered in preventing perturbations, blackouts or isolating the different power grid elements

Rosas-Casals [6]

UCTE data with coordinates: `http://www.ct.upc.edu/termodinamica/RTEdata`

- spatio-temporal evolution of french grid
- All transmission lines are assumed to be bidirectional; hence the resulting graph is undirected.
- The nodes of the network (i.e., generators, transformers, substations, and so on) are treated as identical, featureless vertices.
- All transmission lines are assumed to be identical (that is, unweighted, with no attributes associated to edges)
- Only the transmission network is considered.
- Fractal spatial distribution of nodes: power grid, being equally geographically constrained, does not follow a fractal pattern until distribution and low voltage grids are considered
- Limited node degree
- Distance-dependence cost of edges
- Trivial clustering-degree correlations

Lakervi and Holmes [3]

chapter 1

p.3 LV (<1kV), MV (1-36kV), HV (36-300kV), EHV/UHV (>300kV)

p.6 DC links to former soviet union, scandinavia, UK; i.e. scandinavia is dynamically separated (still true?)

p.3 higher-voltage systems can be added as overlays when lower levels become too heavily loaded, e.g. UK supergrid 275/400 in the 50's

p.6 EHV for high power over long distances, country interconnections

p.7 EHV and HV should designed to be robust against single-circuit faults (N-1 ?)

p.7,17 MV and LV in general operated as radial systems (open loops)

p.12 length of LV line usually limited to 500m or less

p.15 HV typically build as mesh configuration

p.17 number of substations connected to feeder is function of: voltage, distance, average demand

chapter 8

p.148 HV serve as distribution layer primarily, historically they have been superseded by EHV as trasnmission grids

p.149 main role to supply HV/MV substations

p.152 placement of HV/MV substations as close as possible to centre of high load-density area !

chapter 9

p.166 MV grids exist bcauseit's convenient for industrial loads and lines are MUCH cheaper then HV lines, other wise HV could directly supply LV ...

p.176 almost always operated radially, although mesh could lead to lower voltage drops and losses, but control would be more complicated

p.181 in urban areas, MV cables commonly buried along roads -¿ street network

chapter 10

p.192 radial design -¿ only a single in-feed

p.194 average load density in cities can exceed 100 MW/km^2, rural just 10 kW/km^2

p.202 in urban areas, LV grids are often close enough to be interconnected, still commonly operated as radial

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