Grid model reduction

for large scale wind integration analyses

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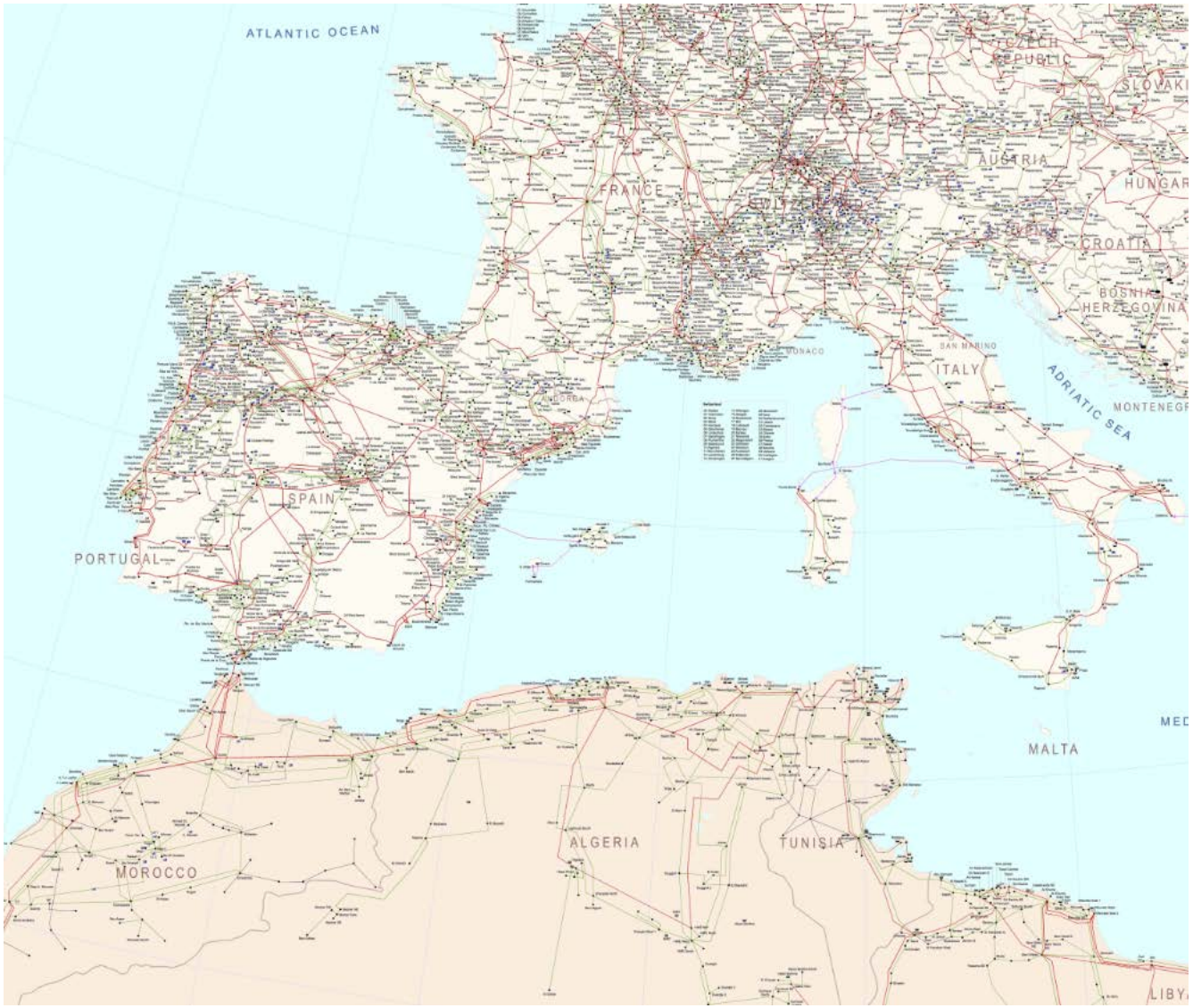
How does a large, interconnected power system cope with large amounts of renewable energy?



Electricity grid: very big system

- hard to specify a consistent **data** set
- easy to get **lost in detail**
- computationally **expensive** simulations

Use reduced models

Summary

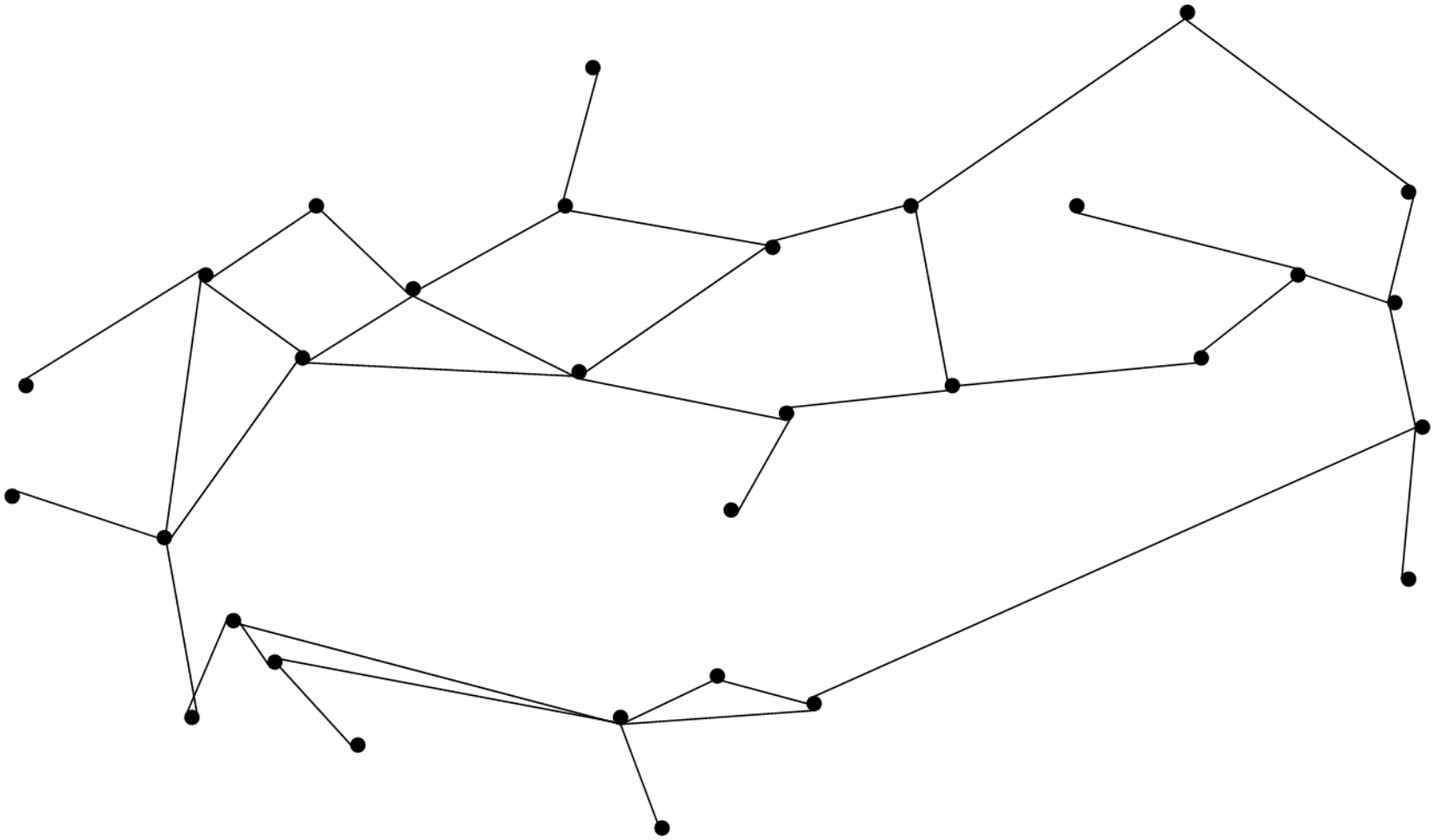
Implementation and application of a method to derive reduced, equivalent power flow models

- Reduction method
- Two examples: Norway, Morocco
- Use of reduced Morocco model

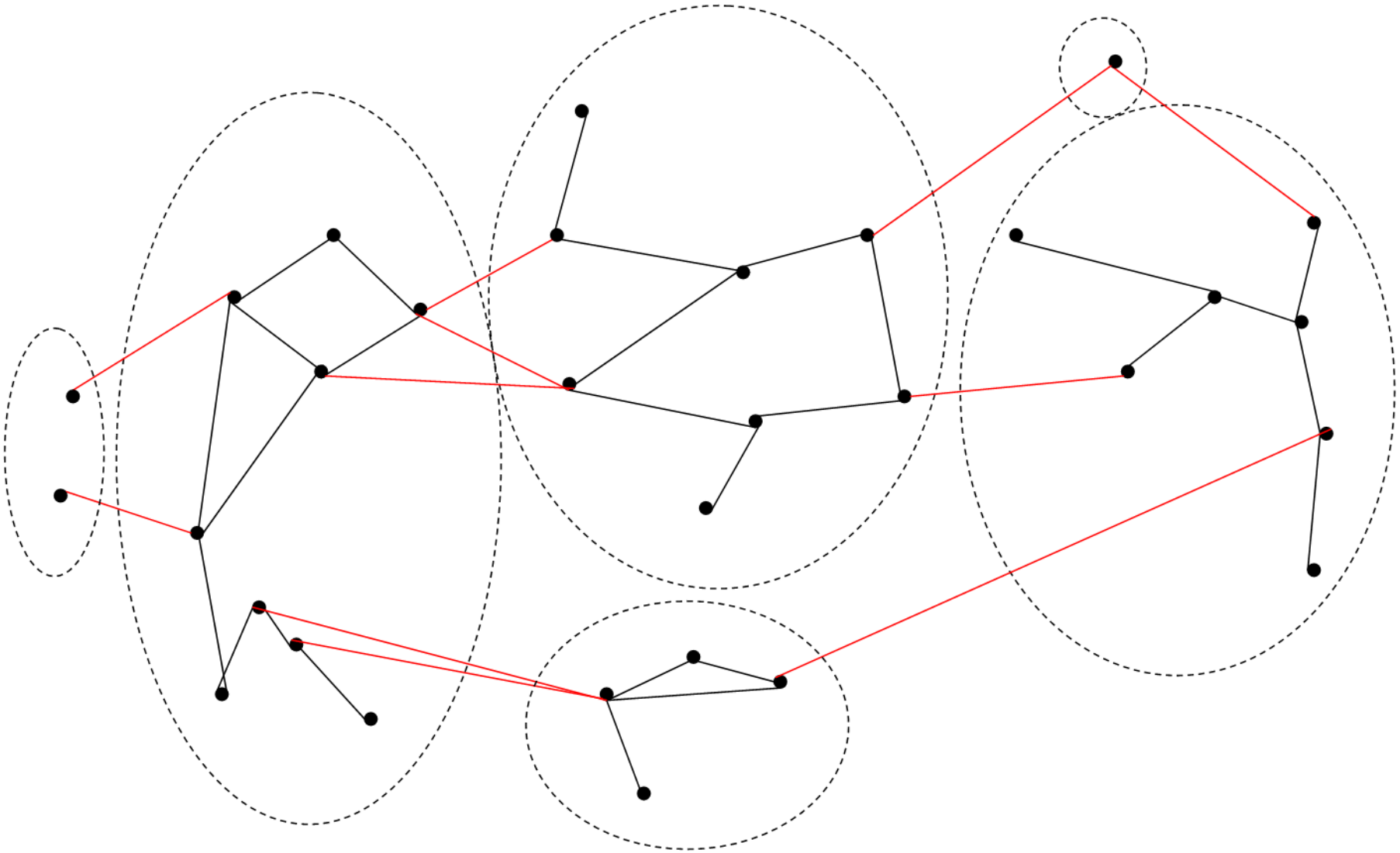
[1] X. Cheng, T. Overbye, Ptdf-based power system equivalents, Power Systems, IEEE Transactions on 20 (4) (2005) 1868–1876. doi:10.1109/TPWRS.2005.857013.

[2] D. Shi, Power system network reduction for engineering and economic analysis, Ph.D. thesis, Arizona State University, http://hdl.handle.net/2286/R.A.97598 (accessed 2014-06-24) (2012).

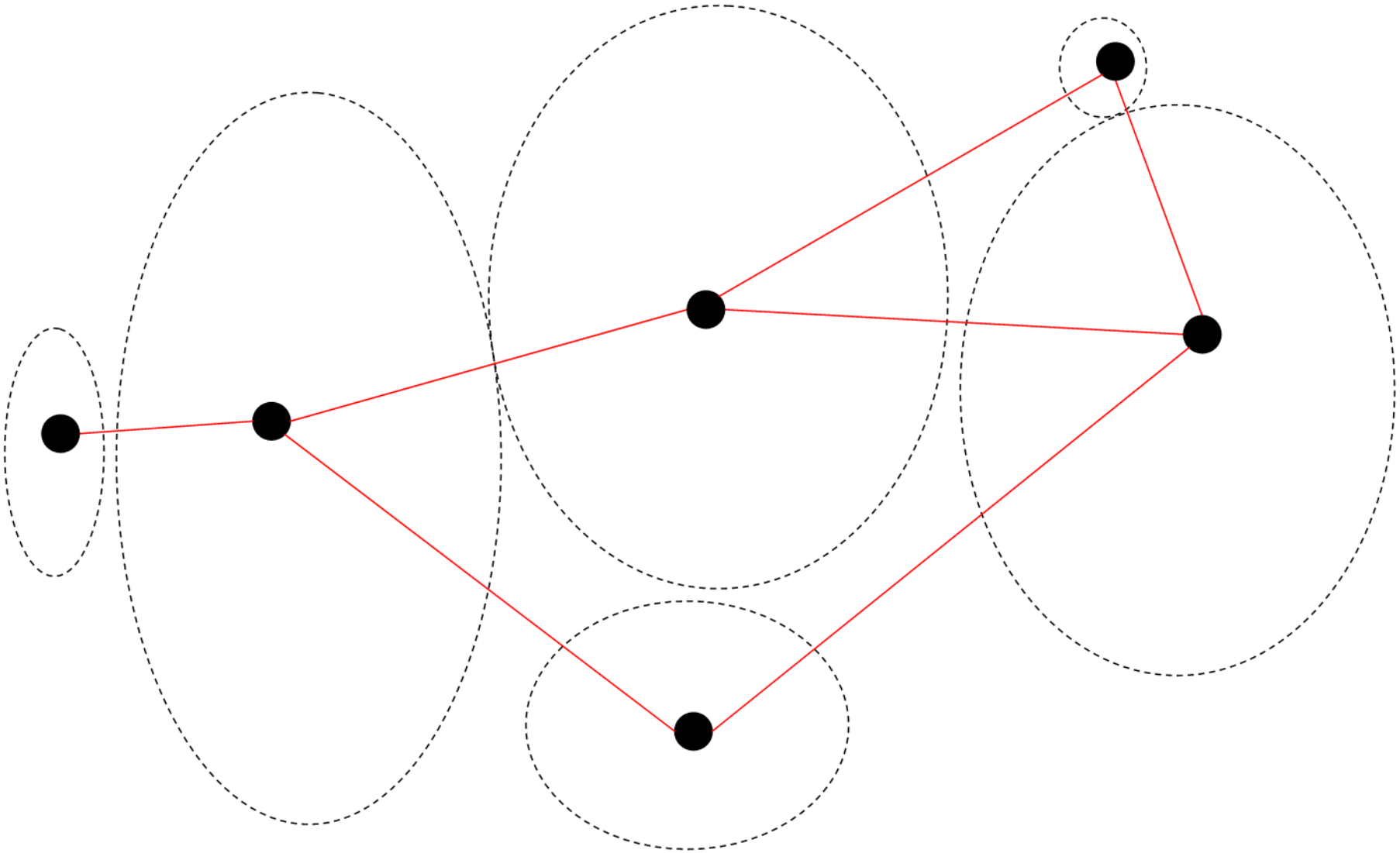
Original, detailed grid



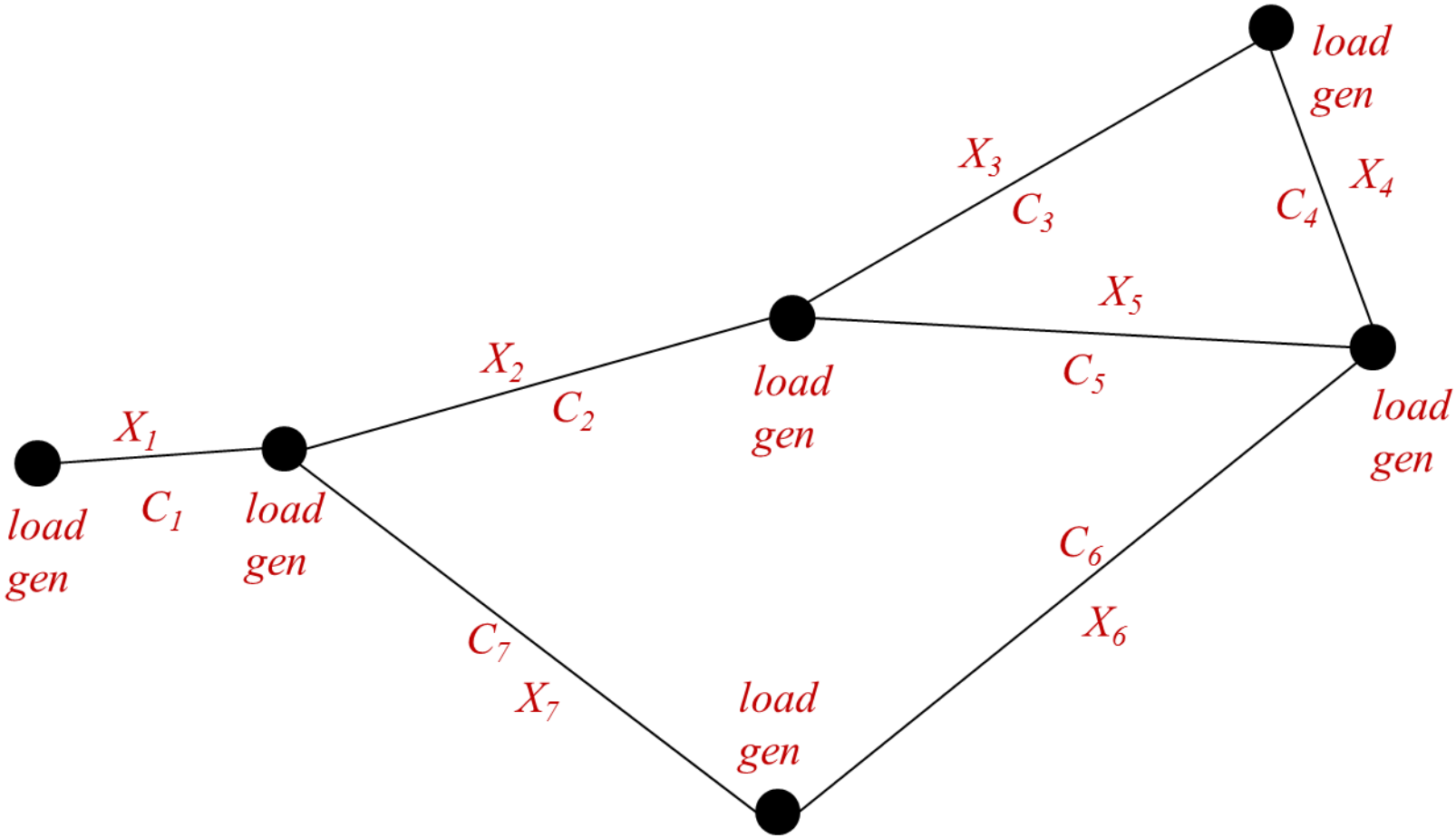
Clustering of nodes



Reduced model topology

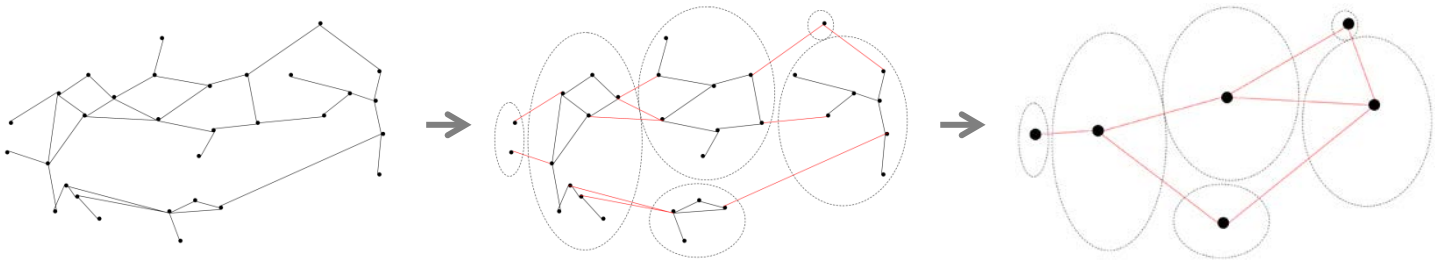


Reduced model parameters

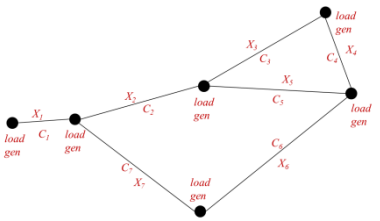


Reduced, equivalent grid

- Grid topology (nodes and connections)



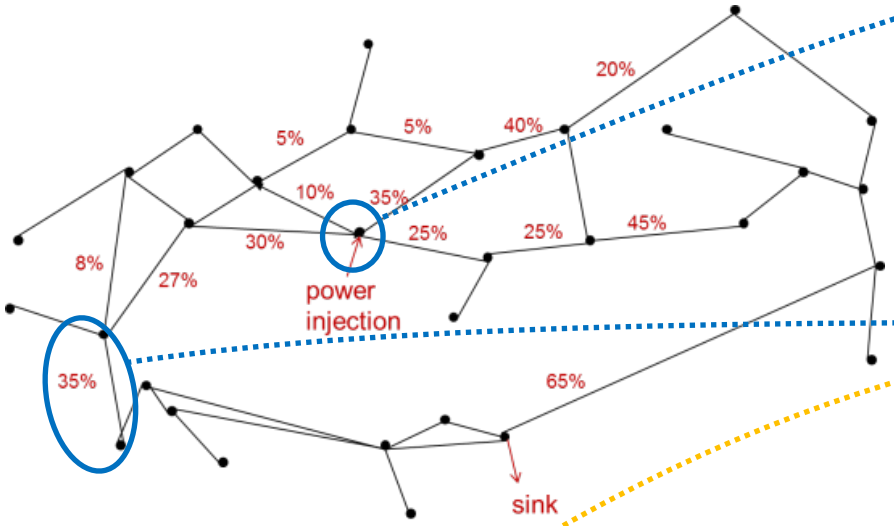
- Electrical parameters
  - Transmission capacity
  - Load and generation distribution
  - Impedance

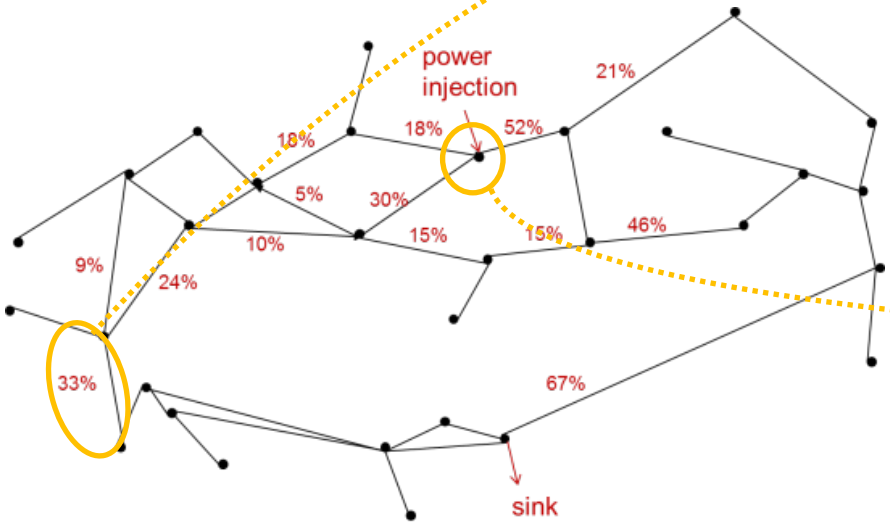


Grid topology – clustering

- Explicit clustering
- Automated clustering
  - Idea: If power injection at two nodes produce similar power flow distribution, these nodes are clustered together
  - Based on Power Transmission Distribution Factors (PTDF) and k-means clustering algorithm
  - Number of desired nodes given as input

PTDF matrix





nodes (injection point)

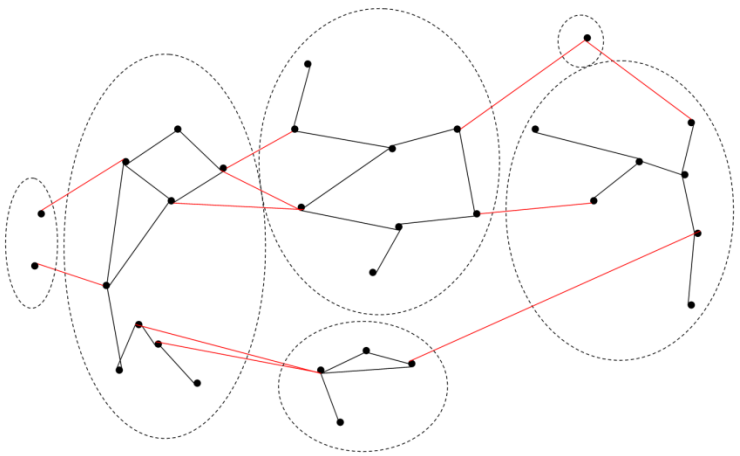
branches

0.35

0.33

Similar power flow =
similar column vectors

Capacity, generation and load



- Transmission capacity
  = sum of capacity of cluster-to-cluster connections in original model
- Load
  = sum of load within cluster
- Generation
  = sum of load within cluster
- Impedance:
  - Reduced model should exhibit **similar** power flow as original model

Equivalent impedance

Principle 1

- PTDF matrix is directly related to grid impedance (reactance)
- Equivalence between full and reduced model means
  zonal PTDF from full model = PTDF from reduced model
- Use this to derive reduced model reactance

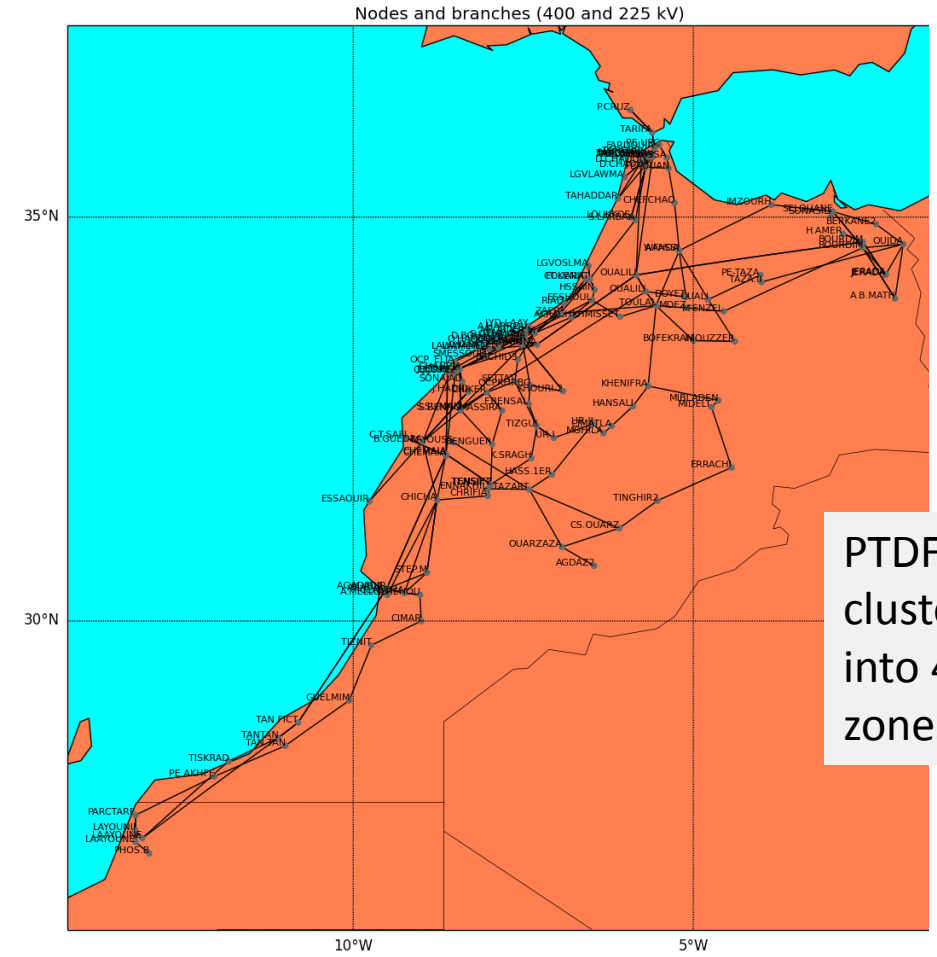
Principle 2

- A second condition is used to ensure that derived reactances have physical values:
  Voltage angle differences in reduced model = differences between average voltage angles within clusters in full model

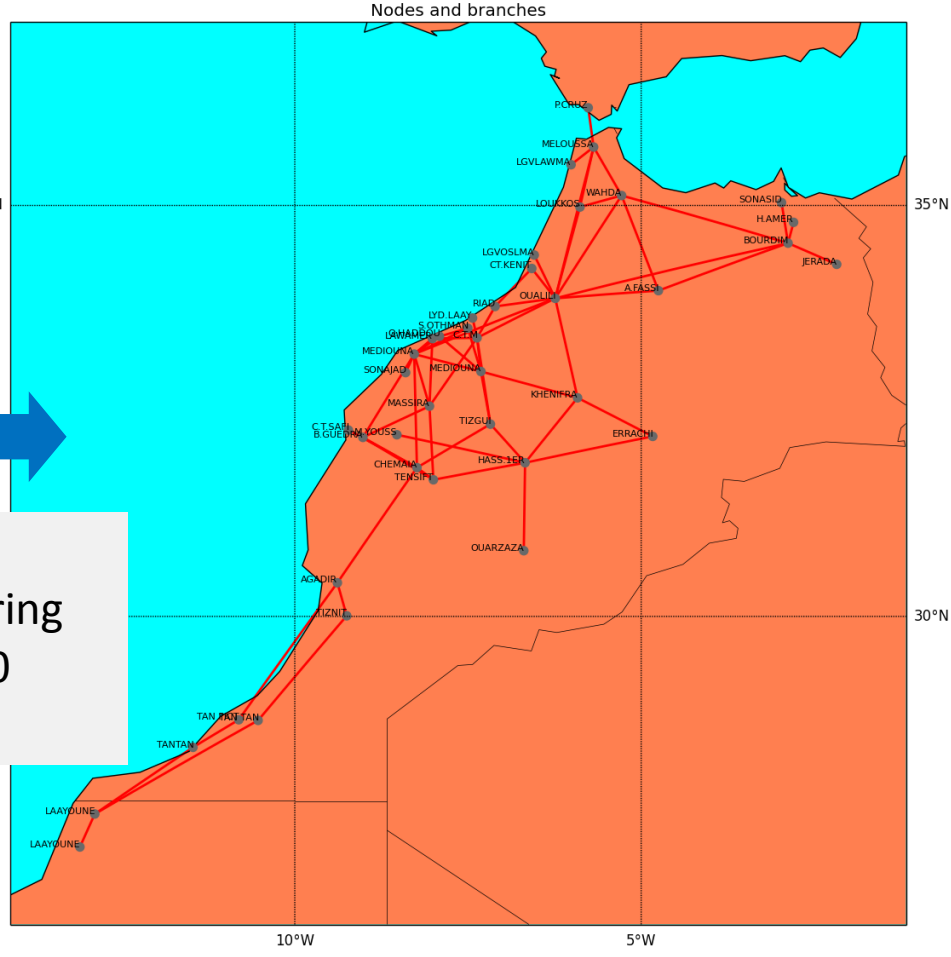
"=" equality in the sense of least error optimisation:

$$\min \{ w_1 \, |PTDF_{zonal} - PTDF_{reduced}|^2 + w_2 |angle_{zonal} - angle_{reduced}|^2 \} \quad => \quad X_{reduced}$$

Morocco



PTDF clustering into 40 zones



Full grid (≥220 kV shown): 765 nodes

Reduced 40 bus model

Comparison

Power flow

from	to	X	full model	reduced model	from	to	X	full model	reduced model
24	30	0.059	197.0	197.9	20	38	0.043	413.8	416.0
7	25	1.756	-1.5	-0.6	2	34	0.239	107.7	108.6
23	26	0.081	-186.2	-186.9	26	39	0.709	-14.8	-13.5
5	8	0.005	25.6	26.3	23	36	-0.025	124.4	293.1
0	32	-0.232	14.7	14.7	1	25	0.148	-106.8	-106.8
17	36	-0.004	-154.5	-154.5	12	37	-0.032	462.1	576.9
37	38	0.154	314.3	278.9	4	24	0.069	521.8	521.8
22	39	0.122	-109.3	-123.2	19	21	0.266	-15.8	-38.2
21	37	0.131	-166.3	-173.0	15	22	0.587	8.5	7.0
10	23	-0.004	-132.5	92.8	5	39	0.166	-162.7	-163.4
8	38	0.092	94.7	86.7	15	21	0.095	65.6	41.3
12	22	0.024	235.9	178.3	30	35	-0.030	10.5	11.2
9	39	0.112	-52.3	-52.3	2	25	0.078	-91.7	-92.6
16	38	-0.289	-35.9	-35.9	8	23	-0.632	8.5	3.9
13	23	0.009	-453.1	-491.1	20	29	0.402	46.2	44.0
3	39	-0.091	-58.1	-58.1	18	34	-0.009	93.5	92.6
0	27	-16.735	0.0	0.0	24	38	0.072	201.1	200.1
23	37	0.040	-835.3	-820.6	13	36	-0.073	99.5	160.0
33	35	0.434	-23.3	-25.7	19	36	0.076	-22.0	-97.0
18	31	56.955	-1.5	-0.6	26	36	0.161	75.2	49.4
0	28	0.121	-350.0	-350.0	30	38	-0.251	-11.3	-11.2
0	33	0.451	33.6	35.8	29	38	-0.017	-51.0	-10.0
35	38	-0.165	-19.0	-19.1	11	37	0.119	-86.5	-86.5
10	19	0.001	-118.5	-363.3	14	24	-0.021	-50.6	-50.6
12	18	0.003	302.3	302.3	0	38	0.047	177.0	173.4
33	38	0.018	-450.3	-445.7	24	35	0.050	224.5	224.6
7	31	0.025	1.5	0.6	6	12	0.088	1320.0	1320.0
13	19	0.079	-36.9	-54.9	36	38	0.431	40.9	41.0
21	36	0.064	128.6	43.5	12	15	0.013	38.1	4.7
8	39	0.169	-174.6	-161.4	21	22	0.033	-38.5	6.6
29	36	0.035	-461.5	-504.8	12	26	0.181	17.1	-6.6
10	37	0.232	-162.1	-142.5	0	35	2.222	0.9	2.3
13	37	0.240	-150.2	-154.7	15	37	0.571	-25.1	-32.8
19	37	0.049	-500.1	-665.7					

OK!

OK!

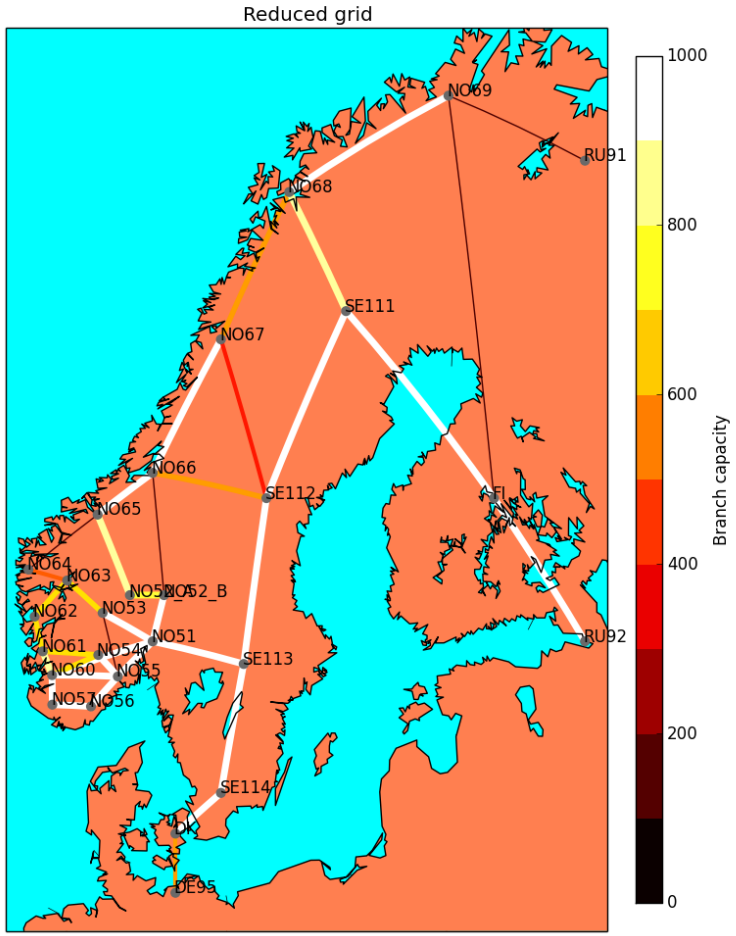
Voltage angles

zone	full model	reduced model	zone	full model	reduced model
0	-24.7	-24.2	20	-19.2	-18.7
1	-2.2	-5.0	21	-15.2	-17.2
2	2.8	0.0	22	-14.5	-17.3
3	-3.9	-5.7	23	-21.5	-22.9
4	-0.6	0.0	24	-21.3	-20.6
5	-24.3	-24.2	25	6.9	4.1
6	54.4	51.7	26	-13.1	-14.2
7	5.3	3.5	27	-1.8	-24.2
8	-24.4	-24.3	28	-0.6	0.0
9	-10.2	-12.1	29	-28.9	-28.8
10	-21.2	-23.1	30	-27.8	-27.3
11	-8.6	-10.1	31	5.3	3.5
12	-11.3	-14.9	32	-22.7	-22.3
13	-23.9	-25.5	33	-34.0	-33.5
14	-20.7	-20.1	34	-11.3	-14.9
15	-11.5	-14.9	35	-27.7	-27.1
16	-23.5	-23.0	36	-19.8	-18.8
17	-19.5	-18.5	37	-2.7	-4.2
18	-11.8	-15.4	38	-29.4	-28.9
19	-21.2	-23.0	39	-6.9	-8.7

Norway

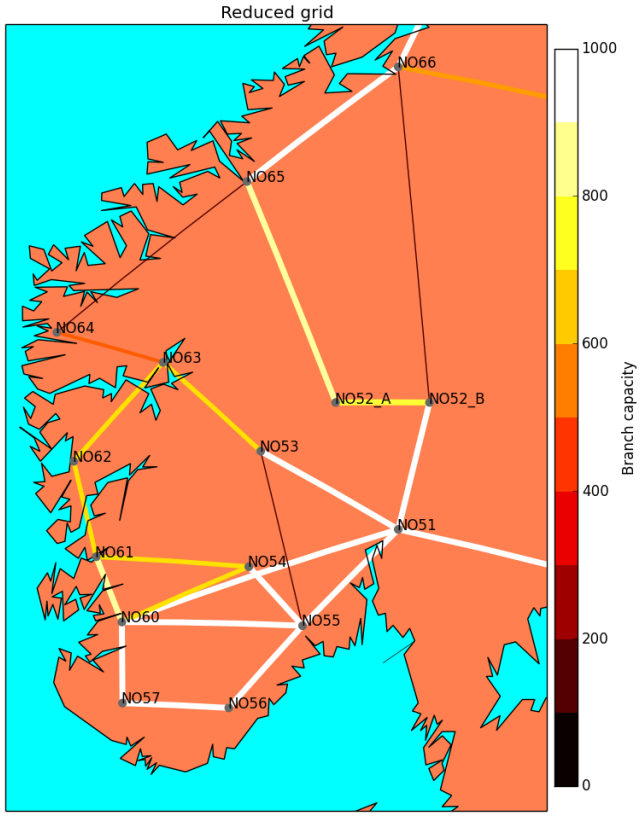
Full grid (>100 kV shown): 6133 nodes

Explicit separation into 27 zones

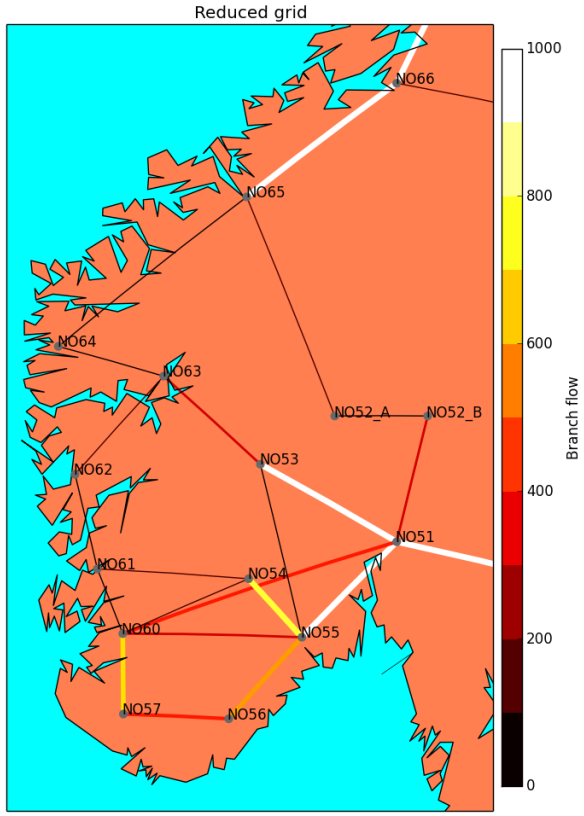


Reduced model: 27 nodes

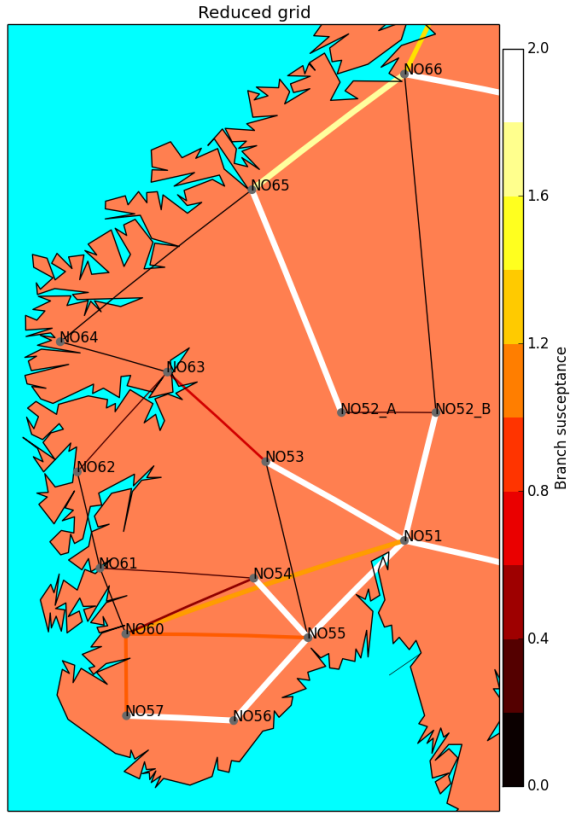
Norway – some details



Capacity



Power flow



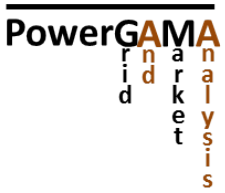
Susceptance (1/X)

Application of reduced models

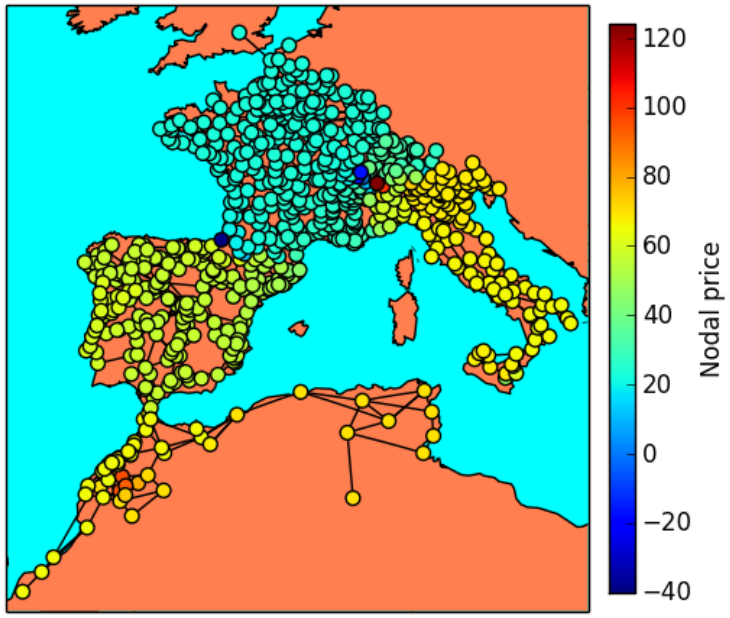
- **Idea**: Explore future scenarios of large-scale integration of renewable energy in interconnected power systems
  - Taking into account power flow constraints
  - Simplified market description
  - Simplified grid models

- Several previous studies focussing on North Sea offshore wind (TradeWind, OffshoreGrid, NOWITECH,…) using SINTEF's PSST tool

- EuroSunMed project:
  - Renewable energy in Mediterranean region
  - Open source tool PowerGAMA (https://bitbucket.org/harald_g_svendsen/powergama)

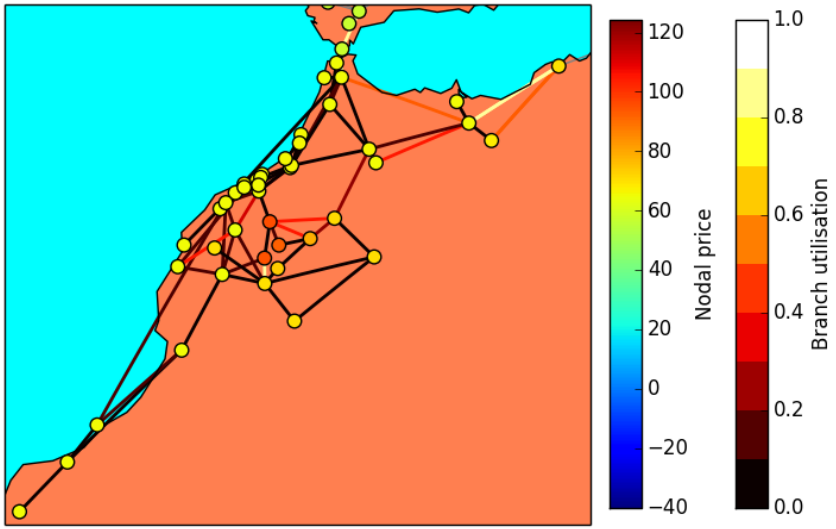


Western Mediterranean case study



An existing model of Europe has been extended to include North-Western Africa

Average nodal prices



Detail of Morocco part

Nodal prices

Branch utilisation

Conclusion

Method for automated grid model reduction implemented as Matlab (and Python) scripts, taking PSSE raw file as input

Applied to Morocco and Norway models

Reduced models are useful for power flow analyses in large systems where there is need for simplifications

Result is dependent on the specific operating state described by original full model