A new modelling approach for stabilisation of smart grids

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G2Elab Grenoble

3rd INCITE Workshop
EFACEC Porto, February 2017

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

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Model description

- Investigate simplified power system models, here the SP-Model [1]:

$$
\begin{aligned}
M_i\ddot{\theta}_i + D_i\dot{\theta}_i &= P_{M,i} - \sum_j B_{ij}V_iV_j \sin\left(\theta_i - \theta_j\right) \quad i \in \mathcal{V}_G \\
D_i\dot{\theta}_i &= P_{L,i} - \sum_j B_{ij}V_iV_j \sin\left(\theta_i - \theta_j\right) \quad i \in \mathcal{V}_L
\end{aligned} \tag{1}
$$

- Synchronized if $\dot{\theta}_i = \dot{\theta}_j \forall i, j$ and the phase difference between connected nodes is bounded.
- Sophisticated conditions for existence of synchronization proposed in [2].

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Linearization and QEP

- Linearization of the full model around synchronized solution leads to:

$$\tilde{M}\ddot{\theta} + D\dot{\theta} = P - L\theta \tag{2}$$

- Can be solved by $\theta = \sum_j \psi_j \exp\left(\lambda_j t\right)$.
- Resulting in quadratic eigenvalue problem (QEP):

$$\left(\lambda^2 \tilde{M} + \lambda D + L\right)\psi = 0 \tag{3}$$

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Companion form and linearization

- To study the QEP, use a technique called linearization, leading to the companion form.
- Using $u = \lambda v$, we rewrite the QEP (3) as:

$$\lambda \underbrace{\begin{pmatrix} C & M \\ \mathbf{1} & \mathbf{0} \end{pmatrix}}_{:=A} \underbrace{\begin{pmatrix} v \\ u \end{pmatrix}}_{:=x} = \underbrace{\begin{pmatrix} -K & \mathbf{0} \\ \mathbf{0} & \mathbf{1} \end{pmatrix}}_{:=B} \begin{pmatrix} v \\ u \end{pmatrix} \tag{4}$$

- Which is a GEP for the companion matrices (A, B).

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Clustering and previous results

- Dynamical behavior can be found by eigenvalues and eigenvectors of the system.
- Nodes with identical eigenvector components for given eigenvalue will have identical behavior in this mode.
- Clustering can be observed, related to coherency of generators.
- For $D = 0$, studied in [3], main results:
  - Load nodes (where $M_i = 0$) do not influence the dynamic directly and their behavior is only affected by the neighboring generator nodes.
  - Strongly connected nodes show slow coherency in the fastest modes (smallest eigenvalues).

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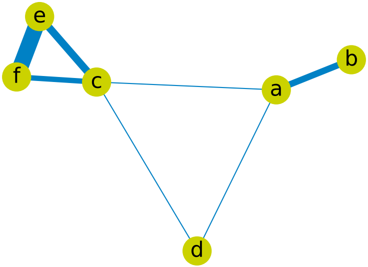
Example for clustering



λ	0.000	0.109	0.232	1.309	1.932	3.618
a	0.408	-0.460	0.198	0.758	-0.092	0.003
b	0.408	-0.563	0.322	-0.641	0.042	-0.001
c	0.408	0.336	0.089	0.063	0.837	-0.085
d	0.408	-0.137	-0.898	-0.074	-0.043	0.002
e	0.408	0.410	0.143	-0.048	-0.299	0.744
f	0.408	0.414	0.147	-0.058	-0.444	-0.663

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Computational studies

- Generalize results of [3], focus on clustering and coherency.
- Definition for cluster:
  - The eigenvector components corresponding to the nodes of C for a given mode are similar [1].
  - The subgraph induced by C on G is connected.
- Investigate various topologies and parameter sets, in the following consider IEEE 30 test case.

[1] x, y are similar iff $|x - y| \leq \left(10^{-1} + 10^{-4}\,|y|\right)$

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Clustering with respect to mode

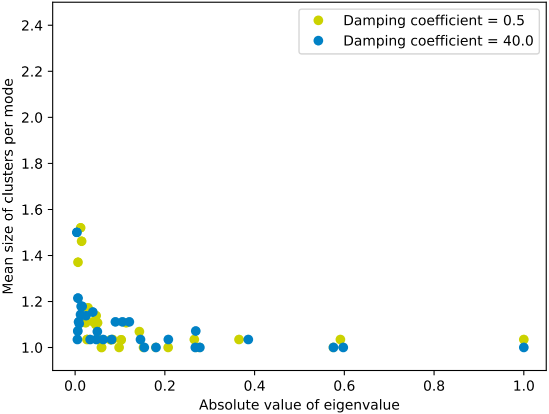

Figure: Size of clusters with respect to mode for two different damping values.

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Influence of damping coefficient

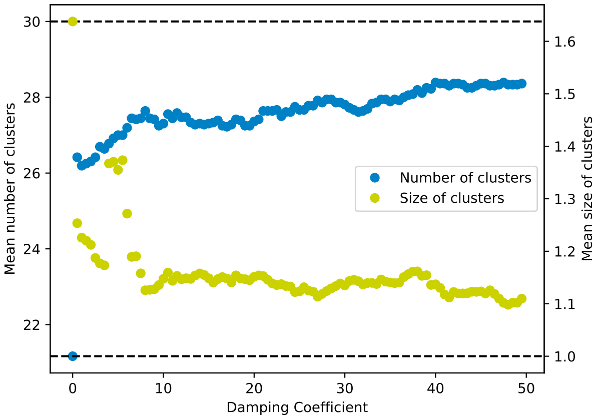

Figure: Number and size of clusters for different damping coefficients.

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Influence of coupling coefficient

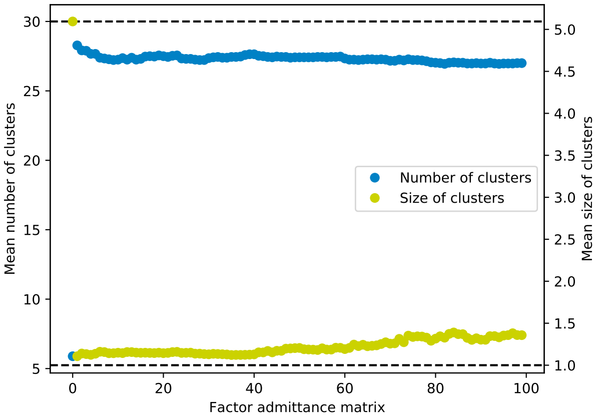

Figure: Number and size of clusters with respect to coupling strength of the network.

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Outlook - I

- Continuing investigating different IEEE and random graphs to assess how the parameters and topology influence clustering and dynamics.
- Investigate the nature and composition of clusters.
- Theoretical approach, based on [3], assess whether results are extendable by eigenvalue perturbation of original problem.

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Outlook - II

- Secondment at IREC: Try to incorporate simple control model in simplified power system model.
- Conditions to synchronize un-synchronized solutions.
- Influence of control on the stability of the synchronized solution, as studied here.

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Bibliography I

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[2] F. Dorfler, M. Chertkov, and F. Bullo. “Synchronization in Complex Oscillator Networks and Smart Grids”. In: *Proceedings of the National Academy of Sciences* 110.6 (Feb. 5, 2013), pp. 2005–2010.

[3] Babak Ayazifar. “Graph Spectra and Modal Dynamics of Oscillatory Networks”. Massachusetts Institute of Technology, 2002.

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