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A linear dynamic model for microgrid voltages in presence of distributed generation

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ANALYSIS OF COMPLEX SYSTEMS

Large-scale complex systems

Complex systems

Systems comprising a large number of agents, spatially distributed, interacting one with the other.

Putting together classical models for each subsystem, usually leads to huge and useless global models, difficult to analyze and sometimes also to simulate.

Agents and interaction

Simple model are generally adopted for each agent.

The complexity of the entire system is given by the interconnection of a large number of simple systems.

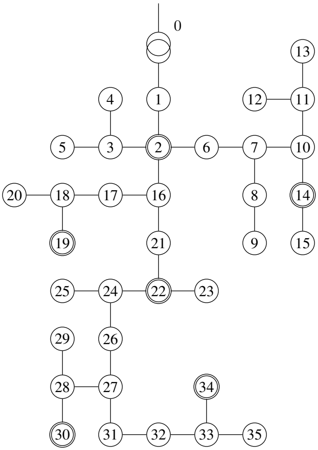
Emerging behavior

Typical result in the analysis of such systems consist in understanding how the complex behavior emerges, possibly gaining some insight about the dependance of such behavior on some characteristic parameters.

The goal is not simulating the behavior of the single agent.

MICROGRID CONTROL

Microgrid features



A microgrid is a portion of the power distribution network which is populated by a large number of microgenerators, interfaced via power inverters.

Preliminary works are exploring the possibility of controlling these devices in a synergistic way to provide ancillary services to the microgrid: voltage support, reactive power compensation,...

(Prodanovic2007, Green2007, Tedeschi2008, Tenti2010, Cagnano2011, Turitsyn2011)

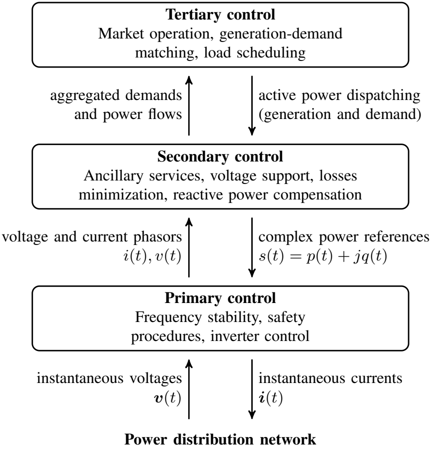
Algorithms for ancillary services

The control algorithms for ancillary services receive as

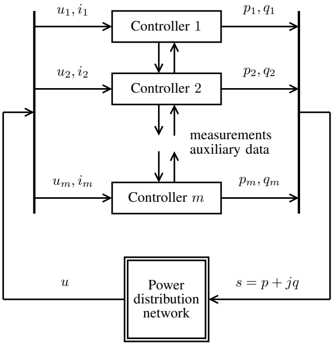
- input voltage phasor measurements from PMUs

and produce, as

- output complex power references for the inverters.



Microgrid control



These algorithms are typically distributed (each inverter decide according to local measurement and data from neighbors) and iterative (alternated execution of measurement and actuation).

It is necessary to estimate the propagation time of the control action across the microgrid: a dynamical model for the measured signals (voltages) as a function of the complex power references sent to the microgenerators.

MICROGRID DYNAMICAL MODEL

Node model

Simplified models capable of catching the relevant behaviors.

PCC – node 0

$$u_0 = U_0$$

Loads and microgenerators

Constant power devices with first order dynamics

$$\tau_v \frac{\mathrm{d} i_v}{\mathrm{d} t} = -i_v + \frac{\bar{s}_v}{\bar{u}_v}.$$

The steady state corresponds to the constant power relation

$$u_v \bar{i}_v = s_v.$$

Grid model

The interconnection between these subsystems is given by the electrical topology of the microgrid.

Let X be a matrix defined by its elements

$$X_{hk} = \sum_{e \in \mathcal{P}_h \cap \mathcal{P}_k} z_e$$

where $\mathcal{P}_h$ is the path from the PCC to node h.

Network equation

$$\begin{bmatrix} \vdots \\ u_v \\ \vdots \end{bmatrix} = X \begin{bmatrix} \vdots \\ i_v \\ \vdots \end{bmatrix} + \begin{bmatrix} \vdots \\ U_0 \\ \vdots \end{bmatrix}$$

Nonlinear complex system

Pluggin this expression for the node voltages into the model for each nodes, one gets the nonlinear dynamical system

$$\tau_v \frac{\mathrm{d} i_v}{\mathrm{d} t} = -i_v + \frac{\bar{s}_v}{1_v^T \bar{X} \bar{i} + \bar{U}_0}$$

in which the coupling between all nodes appears in $1_v^T \bar{X} \bar{i}$.

Second-order Taylor expansion for large U_0

$$\tau_v \frac{\mathrm{d} i_v}{\mathrm{d} t} = -i_v + \frac{1}{\bar{U}_0} \bar{s}_v - \frac{1}{\bar{U}_0^2} \bar{s}_v 1_v^T \bar{X} \bar{i}.$$

Approximated model

We obtained an approximate linear system of the input-output relation between complex power references s_v (input) and voltages u_v.

This result allows us to employ the tools of linear system analysis (eigenvalues, Bode plots, step response, ...) to study the dynamic behavior of such system, as a function of relevant parameters.

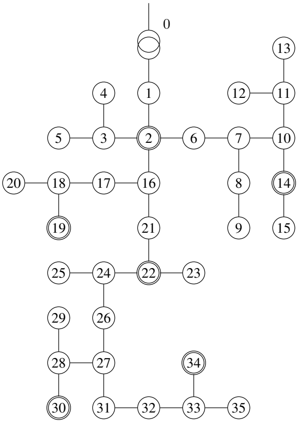
An example

System eigenvalues are

$$\Lambda = \left\{ -\frac{1}{\tau_v} \pm \frac{|s_v||X_{vv}|}{U_0 \tau_v} \right\}.$$

SIMULATIONS

IEEE37 Testbed



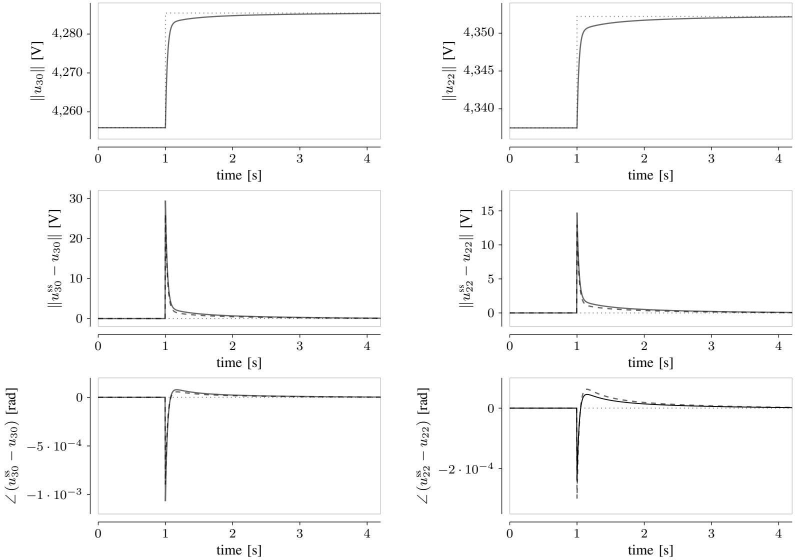
We consider the IEEE 37 testbed.

Let node 30 be a microgenerator, to which we command a step of 60 kVAR in reactive power supply.

Microgenerators are equipped with fast inverters, however slow loads are present in the microgrid.

We are interested in the settling time of voltages to their steady state in two points of the network: at the same inverter (30) and at another inverter (22).

Response to step in reactive power



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CONCLUSION

Conclusions

We focused on a specific problem: obtaining a dynamic model for the input-output relation between the complex power references commanded to the microgenerators dispersed in the microgrid, and their phasorial voltage measurements.

The obtained model has remarkable features

- it is a linear system
- network topology and parameters are recognizable in the model
- it catches the complex phenomena emerging from the interconnection of many simple systems
- it gives important insight for the design of iterative control algorithms.

Bolognani S., Cavraro G., Cerruti F., and Costabeber A. (2011).
A linear dynamic model for microgrid voltages in presence of distributed generation.
1st Intl. Workshop on Smart Grid Modeling & Simulation at SmartGridComm 2011, Brussels (B).

Thanks!

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