



GLASGOW, SCOTLAND | 12-15 JUNE 2017



## Round Table 8

**Innovative grid architectures and control strategies for 2030+ power systems**

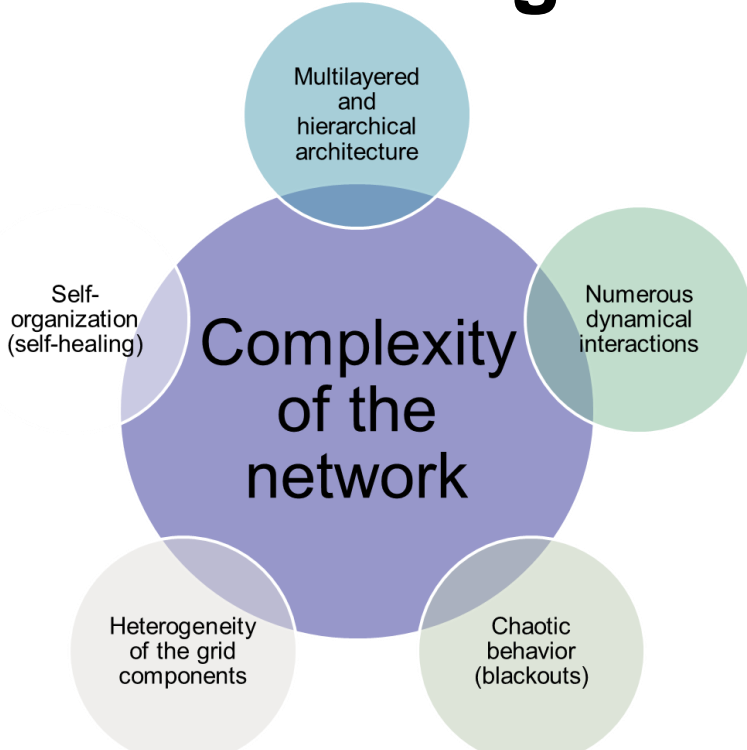
### The Fractal Grid Approach

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# Smart grids are complex systems



- **Modeling the complexity is necessary :**
  - To understand how smart grids properties emerge from their complex organization
  - To design **resilient** and **agile** architectures for the optimization of smart grid operations
- **The proposal of a framework for standardization is a key challenge**
  - To achieve interoperability



## What is « Fractal Grid »

- A French national R&D project (funded by ANR)
- **Partners** : G2Elab/INP Grenoble, MINES ParisTech / ARMINES, Université de Franche-Comté, INSA Rouen
- With the support of RTE, EDF R&D, Enedis, Schneider Electric and RATP





# What is a « fractal grid » (wikipedia)

- In [electric power distribution](#), a **fractalgrid** is a [system-of-systems](#) architecture of [distributed energy resources](#) or DERs.
- In a fractalgrid [topology](#), multiple [microgrids](#) are strategically arranged to follow a [fractal](#) or [recursive](#) pattern.
- In a fractalgrid, a microgrid may be composed of smaller microgrids or “fractal units”. In such a configuration, the network becomes one of simplified power flows and communications through distributed [substations](#).
- Implementations (US):
  - CleanSpark's FractalGrid
  - Camp Pendleton FractalGrid Demonstration (CPFD)
  - NRECA's Agile Fractal Grid



# Objectives

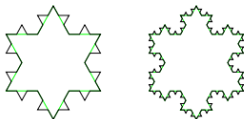
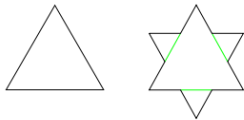
- The starting point is the use of **fractality** as a core concept to analyze, understand, design and operate the future power systems
- The project aims at providing a variety of methods and tools for multi-scale analysis and design of power systems.
- **TRL 2-3** : It brings together different research areas: power systems analysis, applied mathematics, geography, ....



# Background

- Fractal objects are **self-similar structures**, which means that at any scale, there is a smaller piece of the structure similar to the whole.
- They are characterized by the so-called **fractal dimension**, a non-integer value which shows how the fractal fills in the Euclidean space.

Koch snowflake



$$D = \frac{\log 4}{\log 3} = 1,26$$

Sierpinski triangle

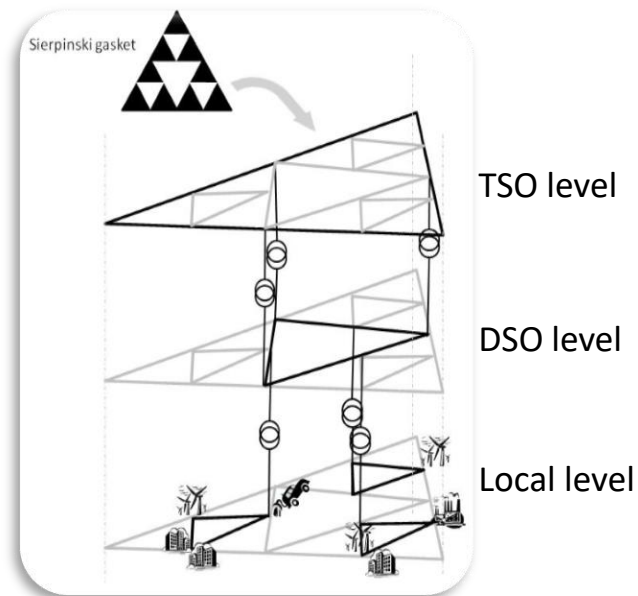


$$D = \frac{\log 3}{\log 2} = 1,58$$



# Why use fractality to analyse power systems

- Power systems are becoming more and more “fractal”: Recursive assembly of smart buildings, smart cities, micro-grids, national networks, transnational networks.
- Fractality observed in weather systems, electricity prices, electrical demand...

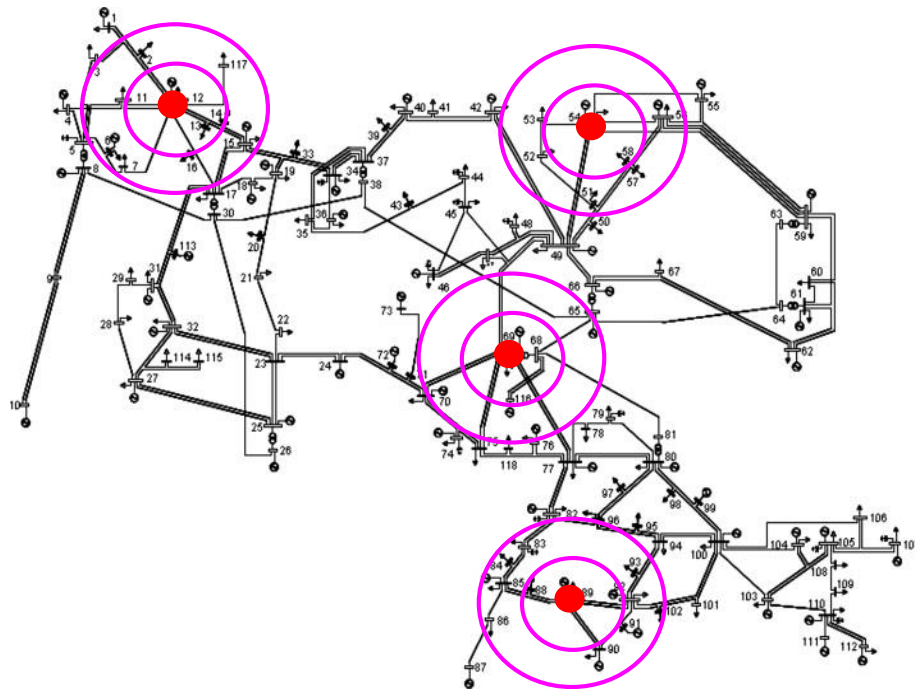






# Fractal dimensions of power systems

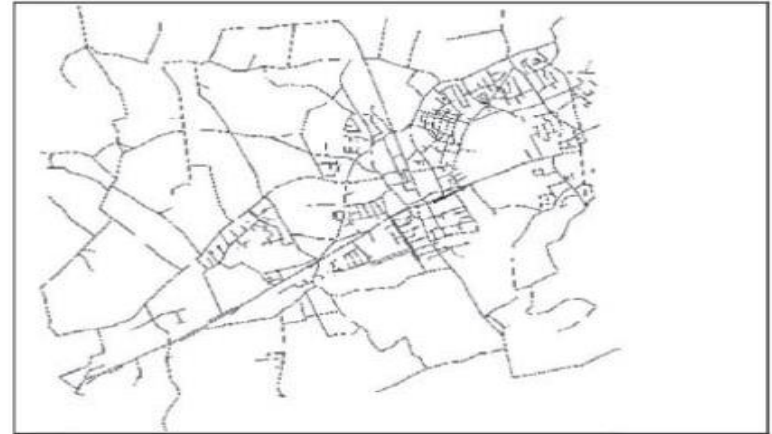
- IEEE 118-bus test network
  - Meshed transmission network
  - Fractal dimension  $D = 1.76$
  - Spectral dimension  $d_s = 1.3$
- Scale invariant over a range of observation
  - Limited range due to the finite size of the power grid
  - Complexity is reduced to a small number of dimensional parameters







# Fractal dimensions of built-up spaces

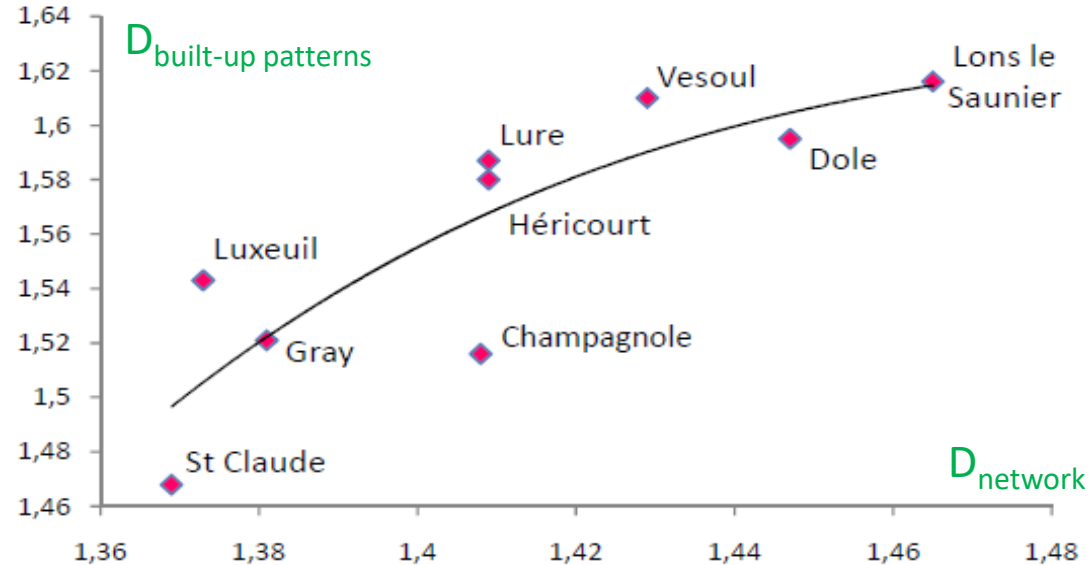


- Comparison of fractal dimensions for built-up spaces and road networks.
  - Example of Beveren (Belgium) -  $D_{surf} = 1.722$  /  $D_{netw} = 1.75$
  - Buildings are distributed rather homogeneously along the streets
  - Fractality is used to analyze the coherence between built-up spaces and road networks



# Understanding the multiscale properties of power grids

- Fractal analysis has been performed on two distribution power grids, located in the France.
- Fig.: Fractal dimensions of built-up patterns versus distribution grid for different towns





# Designing fractal architectures of power grids

- Fractality is used to design new smart grid architectures, which are driven by the assumption that a **self-similar topology can benefit the electrical system, from consumers to utilities.**
- **Green field approach** (grid planning does not consider constraints from existing buildings). **Brown field approach**

Geographical information system => A built-up area is chosen from the open-access



Distribution system operator => Network geometry, substations at the HV/MV and MV/LV grid interfaces, cables, loads and dispersed generators



A number of fractal patterns (meshed or radial) are tested and adapted to interconnect substations



The cross-scale interactions between the designed Fractal Distribution Grid and the regional grids, which are connected at the HV/MV interfaces, are studied.



# Conclusions

- **Cons** - Fractal grid requires an in-depth redesign of the grid operation (and a redesign from scratch of the grid architectures). Deployment of fractal architectures is possible only on new or rebuilt territories. Redefinition of roles of classical actors needed.
- **Pros** - Fractal grid is multilevel by nature. It enables interoperability and should lead to an "optimal" deployment of the electrical network over a given territory



## Further information

- [www.fractal-grid.eu](http://www.fractal-grid.eu)
- Paper No 1236
  - Session 5: Planning of power distribution systems
  - Block 2: Network development
  - Sub-block 1 – Innovative power distribution