A Complex System Approach for SMART GRID Analysis and Modeling
Thesis:
Optimization in complex networks.

Problem:
Optimization of the energy distribution in Smart Grids. Production’s management, consumption and distribution of a common resource.

Multi-criteria optimization:
- Resilience
- Reliability
- Reduced costs (power flows, production, consumption)
- Regulation of power flows.
Smart Grid

The Concept

Smart Grid: a complex system

Modeling

Complex system approach for Smart Grid modeling
I. Industrial point of view
II. Scientific point of view
III. Introduction of complex systems

Needs and expectations of modern power systems
Current Energy Grid is based on the Nikola Tesla’s design in 1888.

**Smart Grid** is an electrical network integrating the *behavior* and *actions* of users (producers, consumers, both).

**Energy Grid defects:**
- **Structure**: integration of renewable energy, conservation like battery, management of digital and analog devices

- **Consumption**: congestion and T&D losses, profitability of nearby power plants, network latency.

**New Objectives and roles:**
- To *smooth* consumption curve
- To *optimize* production and consumption
- To *improve* reliability.

65% of the power consumed is used in engines operating continuously at full. This excessive consumption can be reduced by 60%.
I. Consumption and Data

Current consumption is analyzed and transformed into statistics to prevent future consumption. Consumption is in real-time but energy production is charted for a day.
II. Smart Grid Characteristics

Smart Grid has the following characteristics:

- Self-Healing
- Flexibility
- Predictively
- Interactivity
- Optimality
- Security

20% less consumption planned for 2020
Current simulations (MAS) are done on **specific and preset cases** with a limited evolution process.

**General model:**
- Three layers
- Four types of agents

**Disadvantages:**
- Computing explosion
- Storage of unhelpful data
- Specific simulation.
Smart Grid: a complex network under pressures

I. A complex network
II. Internal pressure
III. External pressure

Structural properties and environmental impact
III. Introduction on Complex System

A complex system is composed of heterogeneous entities in mutual interactions.

It adapts to internal and external pressures to maintain its functionalities.

Its behavior and evolution are not predictable. It can’t be modeled by traditional equation systems.
The system is more complex than the sum of its subsystems.

The study of a complex phenomenon requires a holistic approach and not only localized, specified (experiences).

Experience: We designed a number of rules of evolution, then the system is simulated by iterating the rules to get a structured result.
I. Electric Network

Congestion amounts to 7-10% of the invoice total annually since 2002.

» A complex network has various parts with their own structure and agents.

» Geographical distance is not proportional to the cost of the power line.

» The pretopological approach highlight the flaws of the electrical network.
I. Topology and Pretopology

**Graph theory:** Each link is a computed value and takes into account **every parameters**

\[ P(x,y) = a_1(x,y) + 3*a_2(x,y) + ... \]

**Pretopology:** Each parameter is represented in a dedicated pretopological space.
I. Congestion Management

A complex system is one whose evolution is very sensitive to small perturbations. By which the system can evolve. (G.M. Whitesides)

Percolation is a physical process described in a critical system, a transition from one state to another.

**Congestion**: The condition of a network when there is not enough capacity to support the current traffic. **Brownout**: intentional drop in voltage used for load reduction in an emergency. **Blackout**: engineered electrical power shutdown where electricity delivery is stopped for non-overlapping periods of time over geographical regions.

If 4% of supernodes are disturbed, then the whole system loses 60% of its performance.
I. Layers

A complex system is a highly structured system, which shows the structure with variations. (L. Kadanoff)

**Smart Grid model:**
- 3 layers: local, microgrid, T&D
- Cutting in function of objectives, actions and interactions between agents.

**Algorithms:**
- Network games to optimize the computation time and provide a global and local solution
- T&D network optimization with routing algorithms.

**Bottom-up/Top-down feedback:**
- Resource management
- Optimizing supply and demand
- Management of energy flows.

6% losses in the distribution network. 10% of overproduction.
I. Game Network and Global Equilibrium

A complex system has multiple interactions between many different components (D. Rind).

- Network game **normalize** the network.

- **Local Nash equilibria** vary depending on **consensus** among players.

- **Global Nash equilibrium** guarantees a solution for all players.

**Network game advantages:**
- Minimize computational costs
- Local/Global Nash equilibrium
- Used a basic game with few agents.

75% of national electricity consumption are in buildings.
Complex systems are systems in process that constantly evolve and unfold over time (W. Brian Arthur).

The network must be able to adapt in real-time to meteorology, users and any structural problems.

Mechanisms control the development, the maintenance and the evolution of the system.

Data are treated, modeled, correlated and used at the current time or in the future.

The potential energy savings may be similar to an external insulation.
I. Overview
II. Three layers

Smart Grid Model

Smart Grid Model: algorithms overview
I. Electric Network Structure
II. Local Management

1. Algorithms compare consumption predictions and the values reported by the detectors.

2. Resolution mechanisms assign a priority value to each device, weighing consumption during when solving games.

3. After the feedback, energy is attributed with low cost constraints between devices according to the priority value.
II. Microgrid Management

1. The game network gives a finer view of local clusters and their interactions.

2. Each group reduced to the basic blocks done game to « reserve » a portion of the incoming and outgoing energy (from local to T&D).

3. After feedback, the energy is redistributed between subsets. An algorithm optimizes this distribution to reduce cost and maximize the energy consume.
II. T&D Management

1. Consumption data downstream and upstream production can route the energy as a function of supply and demand.

2. In case of congestion, determined by pretopology and percolation, defects are corrected by successive feedbacks between T&D and microgrid.

3. Once a balance achieved, the statistics are updated for the following discrete time. Bottom-up and Top-down feedbacks optimize the network to achieve an overall balance.
Conclusion

**Current status:**
- State of the art on Smart Grid concepts (industrial, scientific, commercial)
- Definition of appropriate theories to solve problems related to model a Smart Grid
- Definition of the various modules and algorithms to implement.

**Future works:**
1. Implementation of algorithms
2. Checking network resiliency and efficiency
3. Implementation of the close relationship with pretopology
Quel message voulez-vous diffuser?

Smart Grid