ResearchGate

See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/282741585

A Context-free Smart Grid Model using Pretopologic Structure

Article · January 2015

DOI: 10.5220/0005409203350341

CITATIONS
6

READS
293

3 authors, including:

Guillaume Guérard
Pôle Universitaire Léonard de Vinci

30 PUBLICATIONS **150** CITATIONS

SEE PROFILE

Some of the authors of this publication are also working on these related projects:

Project Context-free Smart Grid Model View project

All content following this page was uploaded by Guillaume Guérard on 19 October 2018.

The user has requested enhancement of the downloaded file.

A Context-Free Smart Grid Model Using Pretopologic Structure

Guillaume Guérard [1], Soufian Ben Amor[1] and Alain Bui[1]
[1]*PRiSM CNRS-UMR 8144 , University of Versailles Saint-Quentin, 78000, Versailles, France*
first name.last name@prism.uvsq.fr

Keywords: Smart Grid, Complex System, Pretopology, Game theory, Multi-Agent System.

Abstract: The Power grid evolves, but its structure presents several gaps with the new numerical technologies, renewable energies and electric vehicles. The literature introduces the concept of Smart Grid, a system which takes into account the behaviour and the action of its agents. Studying the smart grid through modelling and simulation provides us with valuable results which cannot be obtained in the real world due to time and cost related constraints. Nevertheless, due to the complexity of the smart grid, achieving global optimization is not an easy task. In this paper, we propose a complex system approach to the smart grid modelling, accentuating on the representation of the structure. Thanks to this combination, the optimization can be achieved on a dynamic graph taking into account changes and network errors over time, with the ability to detect them.

1 Introduction

Our society is electrically dependent. The Power Grid supplies energy to households, businesses, and industries. Nevertheless, disturbances and blackouts are becoming common. With the pressure from ever increasing energy demand and climate change, finding new energy resources and enhancing energy efficiency have become the priority of many nations in the 21st century.

The term Smart Grid is coined by Amin in 2005 (Amin and Wollenberg, 2005). Then, the expression "Smart Grid" has expanded into different dimensions: some see it as a numerical solution for downstream counter and mostly residential customers, while others have a global vision that transcends the current structure of the energy market to generate economic, environmental, and social benefits for everyone. This article (Guérard et al., 2012) includes a survey on Smart Grid models.

Taking into account all its actors, internal and external features, the Smart Grid is defined as a complex system of subsystems (Gao et al., 2012). Before attacking optimization problems and network structure in those systems, we must understand the global and local complexity in each subsystem.

The articles (Guérard et al., 2012), (Guérard et al., 2012) refer to the literature about Smart Grid; the two articles (Ahat et al., 2013) and (Amor et al., 2014) refer to the complex system approach and the bottom-up analysis of the Smart Grid; (Guérard and Tseveendorj, 2014) exposes the mathematical approach of the Smart Grid; (Amor et al., 2014) presents the game theory used for the demand-side management.

In this paper, we focus on the dynamic structure of the Smart Grid. How to create a graph representing a dynamic structure? How to solve it? How to predict consumption and to adjust production in the future?

In the following sections, our model will be presented, especially the use of pretopology to describe a complex network. This paper is organized as the following: in the next section, complex system is introduced, theoretical approach in modelling the Smart Grid as a complex system is discussed. In Section 3, we present the details of our Smart Grid model. The Section 4 is devoted to the pretopologic approach and the feedback system is exposed in Section 5. Then, how to plan future consumption and production is described in Section 6. The section 7 is devoted to first result and future works.

2 Complex system approach

A system which consists of large populations of connected agents, or collections of interacting elements, is said to be complex if there exists an emergent global dynamic resulting from the actions of its parts rather than being imposed by a central controller. That is a self-organizing collective behaviour difficult to anticipate from the knowledge of local behavior (Boccara, 2004).

In (Segel and Cohen, 2001), the authors state that an autonomous distributed network that process information adaptively is more effective in describing the immune system and cellular metabolism. Segel and Cohens remark can be taken into account by the majority of complex systems to manage common resources, especially for the Smart Grid.

The contribution of our approach consists of considering the Smart Grid as a complex system, solving the problems at local as well as global level with coordinated methods, presented in (Ahat et al., 2013) and (Amor et al., 2014). The generality of our approach allows its applicability in various scenarios and models, that guarantees the flexibility of the exposed model. The following paragraphs summarize the proposed approach.

At first step, the system should be understood. An overview brings structural aspects, entities with goals and behaviours. These one are not randomly distributed in the system, but according to patterns, and form distinct groups with their own arrangement.

After analysing the characteristics of the system, the sub-components are defined. A sub-component has a structure, objectives and specific entities, although quantities or position in the system is variable. As a separate system, it has its own dynamics or an auto-organization. It is then possible to solve it with an appropriate optimization method. Through all the sub-component, a global behaviour emerges.

The sub-components are in interaction, then you should take into account the I-O data for each method. The stability of the model depends on local optimization, and interactions. It is necessary to optimize each part of the chain as well as a whole to stabilize the system.

To prevent system crashes, the model must have a system of communication and feedback to reach a global consensus. Moreover, the system is subjected to external pressures. Feedback between subcomponents are essential in maintaining the functionality of the complex system.

In the Smart Grid, we aim to optimize the energy distribution, it also includes the management of production, consumption and distribution of the common resource. Our optimization takes into account the resilience and reliability of the network and the research of minimum cost in a market economy (Ahat et al., 2013).

3 Overview and process

3.1 A three layered grid

The exposed model has three sub-components: the T&D, the microgrid and the local level, see figure 1.

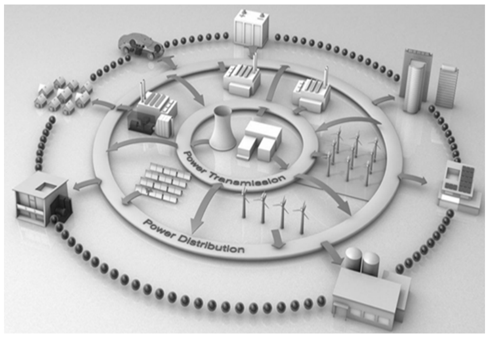

Figure 1: Smart Grid sub-components (from PowerMatrix, Siemens)

Network transmission and energy distribution network or T&D is a 2-connected structure containing electricity generators, central-type agents and grid agents, represented by the two fields around the center ring in the figure 1. Its main role is to deliver energy to consumption points.

The second level is the link between consumption and energy production, represented by the outer yellow ring. The microgrid is a broader view of local consumers, it is a tree structure representing an ecodistrict bounded by the upstream substation. Its role is to distribute energy from substation to consumers. For this, it orders or books an amount of energy from the T&D network to local consumers.

The outer ring is dotted of local levels. Those consumers are connected to a substation itself connected to the grid energy. This isolated agent, representing a residence, factory, etc., supports the consumption of energy, which is the distribution of energy among appliances under its responsibility. In other words, a local level is defined by the area under the control of a smart meter or other automation/management controller.

3.2 Algorithmics

An iteration occurs every five minutes. Once data are updated, the process is decomposed into four sequences, see figure 2. Data are synchronized in order to let time to compute and to find an equilibrium between each agent of the system (in simulation or in real network).

Sequence A: to design the intelligent aspect of the device, a priority is assigned to the devices, and

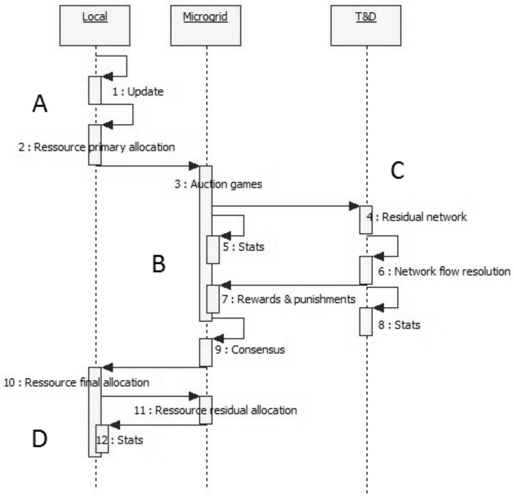

Figure 2: Sequential Scheme.

for calculating a consumption value. Indeed, we use a local knapsack problem, solved by dynamic programming after data normalization, in order to find a primary first optimal resource allocation (Ahat et al., 2013).

Sequence B: the microgrids book an amount of energy from producers to consumers using an auction (Amor et al., 2014). There are two ways to book energy: a consensus between consumers and producers, that is a unique game where microgrids and energy flows are players; and a bid system with feedback, each microgrid do a local game with producers. The problem with the first one is the complexity of the problem, impossible to resolve in a few times for large instance. The second way has the advantage of time, but do not guarantee the global optimum. In this model, the auctions will be adjusted thanks to the feedback system.

Sequence C: about the routing problem, nodal rule or Kirchhoff's circuit specifies that at any node in a circuit, the sum of currents flowing into that node is equal to the sum of the currents flowing out of that node. An electrical circuit is equal to a graph in which a junction is a node, and physical connection corresponds to an edge. Routing problem is equivalent to the known Max flow problem. Gale's theorem shows the existence of a solution in a network of offers and requests (Gale, 1957). The Max flow at Min cost problem is solved by Busacker & Gowen (Section 4.2). To recalculate the entire flow is not necessary. The residual graph removes overflows between two updates, optimizing the computation time of the optimal flow, see figure 3.

Sequence D: energy is distributed by knapsack problem, according to the last auctions. The unconsummated energy is redistributed among non-used devices at upper scale. Each device's priority is updated according to the result of the final distribution.

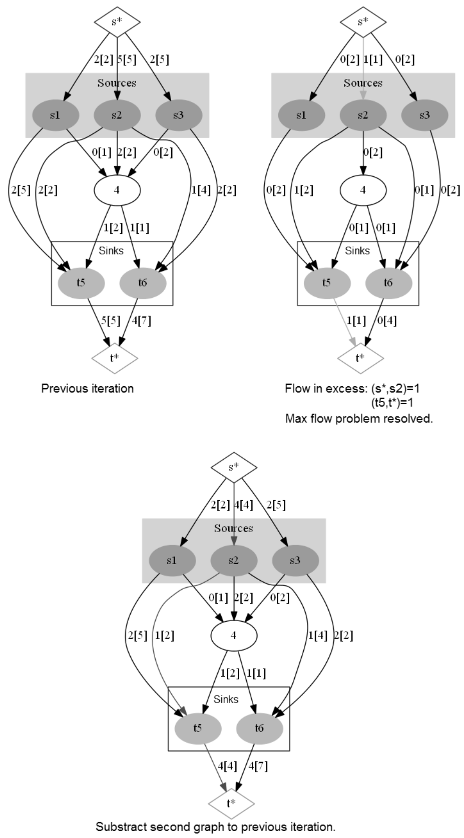

Figure 3: Updating of routing.

4 How to update the T&D structure thanks to pretopology theory

4.1 Notion of proximity

Complex systems manifested complex characteristics which are not found in simple networks, and thus called complex networks. The complex network theory has become a major interest area in complex system study and provides mathematical tools to model the structure of complex systems (Newman, 2003).

The pretopology is a mathematical theory ahead of the conventional axiomatic topology, which allows us to express the structural transformations of sets of interacting elements such as building coalitions among a population phenomenon alliance process of tolerance, acceptance and the emergence of collective behaviour. Pseudo-closure and closure are two functions used to model basic operations in complex network theory (Belmandt, 2011). The topology is a particular case of the pretopology.

The complex networks such as the Smart Grid change at each time. It is therefore important to model these functions by taking into account the dynamics. A complex network is seen as a family of pretopology on a given set as shown in the figure 4. The advantage of this theory is the separation of each criterion in a pretopologic space to simplify modelling. The overall adhesion function is defined as an aggregation of several spaces. In this manner, a modification in a space is instantaneous. The pretopologic spaces may include various types of relationships, such as metric spaces, binary spaces or valued spaces.

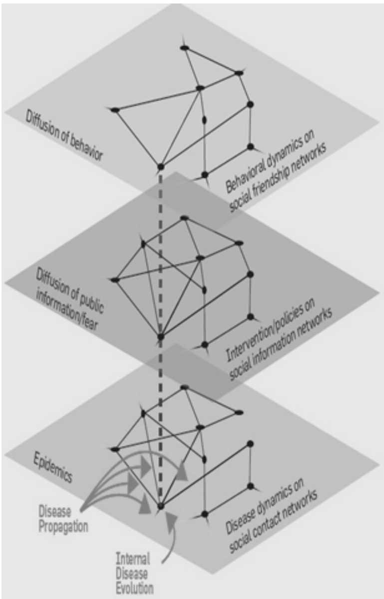

Figure 4: A family of pretopology.

The Smart Grid is a complex system, it is governed by a number of qualitative and quantitative criteria. The voltage of the power lines is an example, but it is also possible to take into account the electrical leakage based on the length of lines, installations wear, weather, etc.

Finally, pretopology is a very useful modelling tool in the context of complex systems to manage acquaintances between agents and be able to follow the dynamics of relationships between them (Petermann et al., 2012).

4.2 Routing problem

In order to define undercharged, or overcharged lines during the sequence C, a pretopologic analysis is conducted. For example, let be three pretopologic spaces a_1, a_2 and a_3. Each edge has three levels of flow corresponding to under-load, normal load and overload.

The figure 5 presents the pretopologic family. Under-load is possible on an edge if it exists in the following logical space $a_1 \cap a_2 \cap a_3$ named [1], same for overload in the logical space $(a_1 \cup a_2) \cap a_3$ named [3]. By default, any edge carries an average load named [2]. The figure 6 presents the final graph.

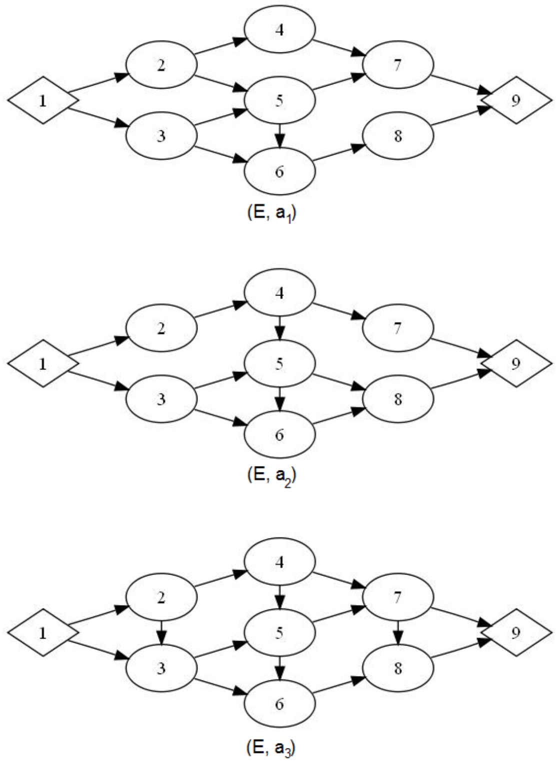

Figure 5: Pretopologic spaces.

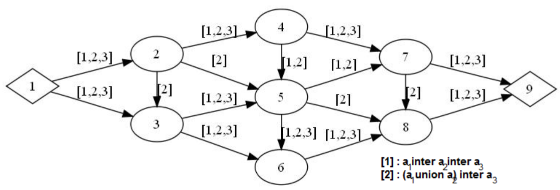

Figure 6: Network according to pretopologic spaces.

The constructed network is a fully connected graph which edge's capacity depends on pretopologic spaces. Each edge (i, j) is characterized by:

- d_{ij} the maximum capacity;

- l_{ij} the minimum capacity;
- c_{ij} the unit cost of the flow in the edge. The cost may vary in function of the total flow. Edge is duplicate with different costs related to capacity. For example, the initial cost is 1 for a flow among $[0,3]$, 3 among $[3,6]$, and 5 among $[6,8]$. Three edges rely i to j. Because the cost function is stricter increasing, this method does not perturb the algorithm of maximum flow at minimum cost only if. A path with an available capacity is called an augmenting path. At each iteration, the edge (i,j) is valued at c_{ij} if the edge (i,j) is not saturated. The edge (j,i) is valued at $-c_{ij}$ if the edge (i,j) is not empty;
- x_{ij} the flow passing through the edge.

In order to resolve this routing problem, the Busacker & Gowen algorithm is used, an example is shown in the figure 7. The idea behind the algorithm is: as long as there is a path from the source (the start node) to the sink (the end node), with an available capacity on all edges in the path, we send flow along one of these paths, filling in priority the path with the minimal cost. Then we find another path, and so on.

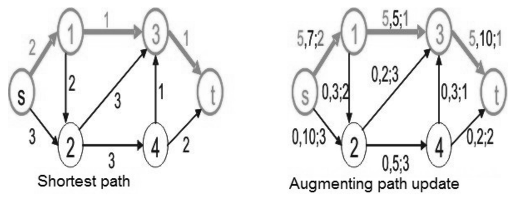

Figure 7: Busacker & Gowen algorithm.

5 Feedbacks

Various criteria and technical constraints limit the amount of energy that circulate in each edge. Production and consumption must match as best as possible.

The energy produced or the energy consumed (sequence B and C) may be different. This is a mismanagement of resources for the consumers, or mismanagement of the energy produced. The difference between the total energy and the total consumed energy (equal to Max flow) can be significant. A recognition algorithm must locate bottlenecks to perform feedback between T&D network and each microgrid. For these, two tests are used:

- The Max flow problem on the graph without capacity constraints on the edges containing the sink. The result will provide the maximum unconstrained consumption.
- The Max flow problem on the graph without capacity constraints on the edges containing the source. The result will reflect consumer demand in order to predict future production.

Management on the consumer side, called Demand Side Load Management (DSM), aims to increase the efficiency of generating by shifting consumption in low consumption period (Saad et al., 2012). Many devices can temporarily go into a standby mode (heating) or consumption can be postponed. Some devices are also able to stop using energy during operation (preemption). Approximately 50% of the consumption of residential areas can be controlled without reducing the comfort (Block et al., 2008).

To increase the effectiveness of the DSM, it is assumed that the front part of the infrastructure is a home automation and every device can be controlled separately by the user and regulation algorithms. Feedback of the sequence C on sequence B, with rewards or punishments, determines how smart meter will control automation in order to find a better auction.

The gap between the constrained solution and the two tests determined how to perform the feedback. If a microgrid can consume more than its bid, it increases the bid during the next auction. The values obtained by the graphs are used in the feedback to punish or reward and adjust the new bids. The figure 8 shows the bid and the received energy in a microgrid at each feedback (in this case, the curves are voluntarily exaggerated to see the gap between each one).

Feedback reorganizes the distribution of resources among the different microgrids. After a limited number of feedbacks, supply and demand find a consensus throughout the graph as shown in figure 8.

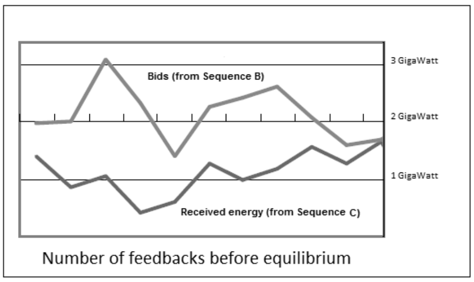

Figure 8: Equilibrium thanks to feedback in a microgrid.

The feedback seems trivial, but if we consider thousands of production and consumption places, then the problem of maximal flow has multiple valid patterns. Added to a global policy, these attempt to understand production and consumption behaviours in order to build valid patterns for future iterations.

6 Global direction

6.1 For the following iterations

When searching for the shortfall in production or consumption during the sequence C, the ideal distribution of production without consumption constraint and the ideal distribution of consumption without production are calculated (see previous section). These data allow us to understand the evolution of consumption over time. Prognostics are calculated at the end of the sequence D as follows:

1. For consumers: consumption of future consumption is the weighted average of the auction conducted. Let z_i be the bid made at the feedback $i-1$, the consumption used by prognostic is calculated as follows: $Z = 2\frac{\sum_{i=1}^{n} i * z_i}{n(n-1)}$. The latest bids have a greater impact on the prognostic.
2. For producers: prognostics are calculated like the previous one. The plants do not have the same ability to adjust production, and need a consensus among themselves. Currently the model is only supporting a single producer (with many plants). Thus, the calculation of upcoming productions does not consider the competition. We actually work to how to plan the production with many producers.

6.2 For further iterations

At long term, we must equalize the production curve of the Smart Grid. Local agents do not have an overview of the consumption (or production) curve. In order to smooth the curve, an algorithm, based on a mathematical function, guarantees the quality of the solution, or, give advice for feedback.

Bounded function cannot cross some threshold. In the case of consumption, that means the curve cannot pass under or over a fixed value. In a perfect Smart Grid, a bounded function guarantees a continuous consumption. But, in a real network, the consumption during night or day, or the sector (primary, secondary, tertiary), or the external factors, or the scale of the grid, may radically vary. To avoid incoherent behaviours due to inappropriate management policy, a function bounded on its slope must be used.

Lipschitz continuity, named after Rudolf Lipschitz, is a strong form of uniform continuity for functions. Intuitively, a Lipschitz continuous function is limited in how fast it can change: there exists a definite real number such that, for every pair of points on the graph of this function, the absolute value of the slope of the line connecting them is not greater than this real number (see figure 9). If the consumption curve is k-Lipschitz, we guarantee that the curve cannot have a peak demand (depends on the value of k).

Before each feedback between sequence B and C, we check if the result is Lipschitz continuous. If it is not, the auctions are adjusted. If it is continuous, and the solution is eligible, then the sequence D starts.

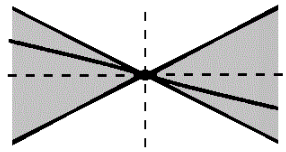
Figure 9: A Lipschitz function.

7 Future works

To validate the model, instances at local and global scale have been made. Agents data, like engine consumption or energy plants production, are implemented thanks to the french national production companies public data and energy distribution data (EDF and RTE).

In the first tests, consumption and production tend towards equilibrium. Local and renewable energies are privileged to maximize their profitability. The model limits the losses of the distance of consumption, and uses the least amount of fossil energy. It works at any scale and any agents under the condition that there exists a feasible solution.

The proposed model works for randomized or parametric Smart Grids. We actually work in the Positive Energy 2.0 project led by ALSTOM Energy Management and various companies such as Bouygues or Renault to validate the model on real projects.

The model will be compared to, electronic, automatic models and simulations. Positive Energy 2.0 project provides two microgrids (one using electronic networks and one using automatic devices), Embix provides data from several buildings and plants, and some microgrid simulations.

The analysis of the first results with public data, the project's results with private data and the economic study will form a forthcoming publication.

The model can be improved. The learning process must be developed in order to optimize the auction and the choice for utility functions. Moreover, artificial intelligence will be implemented in order to adjust each parameter in real time. The Smart Grid change over time, so the AI must find the best configuration in real time in order to keep the Smart Grid optimized and to avoid local dysfunctions.

8 Conclusion

As Smart Grid can be qualified as a complex system, classical optimization methods cannot be applied directly, due to the computational complexity for time and memory.

Integrating pretopology offers a better notion of proximity between the agents. This allows handling multiple criteria simultaneously using an aggregation. In addition, the modification of a single criterion entails that the update of the pretopology assigned and not a total restructuring of the network.

More generally, we also demonstrated how to solve optimization problems in complex systems. While applying for optimization algorithms directly in complex systems is nearly impossible, we should analyse the system and divide them into sub-systems with defined characteristics, then we should apply for specific algorithms and coordinate them using multi-agent simulation in order to achieve global optimization on a defined and dynamic network.

REFERENCES

Ahat, M., Amor, S. B., Bui, M., Bui, A., Guérard, G., and Petermann, C. (2013). Smart grid and optimization. *American Journal of Operations Research*, 3:196–206.

Amin, S. M. and Wollenberg, B. F. (2005). Toward a smart grid: power delivery for the 21st century. *Power and Energy Magazine, IEEE*, 3(5):34–41.

Amor, S. B., Bui, A., and Guerard, G. (2014). A context-free smart grid model using complex system approach. In *Distributed Simulation and Real Time Applications (DS-RT), 2014 IEEE/ACM 18th International Symposium on*, pages 147–154. IEEE.

Belmandt, Z. (2011). Basics of pretopology. *Hermann éditeur*.

Block, C., Neumann, D., and Weinhardt, C. (2008). A market mechanism for energy allocation in micro-chp grids. In *Hawaii International Conference on System Sciences, Proceedings of the 41st Annual*, pages 172–172. IEEE.

Boccara, N. (2004). *Modeling complex systems*. Springer Verlag.

Gale, D. (1957). A theorem on flows in networks. *Pacific Journal of Mathematics*, 7(2):1073–1082.

Gao, J., Xiao, Y., Liu, J., Liang, W., and Chen, C. (2012). A survey of communication/networking in smart grids. *Future Generation Computer Systems*, 28(2):391–404.

Guérard, G., Amor, S., and Bui, A. (2012). Survey on smart grid modelling. *International Journal of Systems, Control and Communications*, 4(4):262–279.

Guérard, G., Ben Amor, S., and Bui, A. (2012). A complex system approach for smart grid analysis and modeling. *International Journal of Knowledge-Based and Intelligent Engineering Systems*, 243:788–797.

Guérard, G. and Tseveendorj, I. (2014). Largest inscribed ball and minimal enclosing box for convex maximization problems. In *XII GLOBAL OPTIMIZATION WORKSHOP*, pages 61–64.

Newman, M. E. (2003). The structure and function of complex networks. *SIAM review*, 45(2):167–256.

Petermann, C., Amor, S. B., and Bui, A. (2012). A pretopological multi-agents based model for an efficient and reliable smart grid simulation. In *International Conference on Artificial Intelligence (ICAI)*.

Saad, W., Han, Z., Poor, H. V., and Basar, T. (2012). Game-theoretic methods for the smart grid: An overview of microgrid systems, demand-side management, and smart grid communications. *Signal Processing Magazine, IEEE*, 29(5):86–105.

Segel, L. and Cohen, I. (2001). *Design principles for the immune system and other distributed autonomous systems*. Oxford University Press, USA.

View publication stats