Expert Guided Machine Learning with physical model for adaptive representation of smart grids

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Abstract

The adaptive representation of smart grids into zones is crucial for control room operators when managing the grid complexity near real time. We provide a new method for a context and task specific power grid segmentation to give a better perception of this physical world. We further show promising and new interpretable results on commonly used systems as well as on the large scale French power grid.

1 INTRODUCTION

Power grids transporting electricity across states, countries, or continents, are vital components of modern societies, playing a central economical and societal role, by supplying reliably power to industry, services, and consumers. Electricity blackouts may lead to significant losses and delay in public services and strategical industries, *de facto* freezing society. Grid operators are in charge of ensuring that a reliable supply of electricity is provided everywhere, at all times. However, their task is increasingly difficult in the digital *era* because they have to examine in real time massive amounts of data despite Artificial Intelligence's nascent developments. Power systems are in great need for innovation to cope with the increasingly complex task of satisfying electricity demand while using renewable energies and open market exchanges. Indeed, wind, solar, and the like, are not very dependable sources of energy (because they vary with the day/night cycle and weather conditions). Also, while providing opportunities, electricity markets may be plagued by speculations. This places new flexibility and reactivity requirements on the smart grids of the future. Therefore, rethinking the way we operate the grid has become a necessity.

To handle the current complexity, control room operators have built over time, and over many studies with the simulators at their disposal, their own mental representations of the grid. They actually segment the grid into static zones that are redefined every year to study the grid efficiently near real time, since it is impossible for humans to digest all the information at once on a large scale grid. They are indeed able to quickly identify remedial actions given security risks around, when a line is overloaded for instance. However we anticipate that these yearly static views will be less and less relevant in the future to operate the grid, with fuzzier electrical "frontiers". This can even occur along a course of a day within this dynamic context. Nevertheless, a zonal segmentation should still be relevant to operate the grid by efficiently representing this complexity to act on it. Offering such context awareness by augmenting their perception will help dispatchers in their decision making process. That is why an assisted segmentation built in a dynamic fashion that fits a situation is needed.

In contrast of model based methods only, that have been more extensively explored in the field of power systems for power grid segmentation on the one hand, and of new data driven methods only, that suppose a massive deployment of new ultra-fast meters on the other hand, our approach relies on machine learning coupled to model based simulators, following our previous work [1]. We propose in this paper a new method that relies on a guided systematic use of existing power grid simulators to

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teach the machine an expected system response in the context of a task. We call it "expert guided machine learning", a form of unsupervised learning with carefully generated inputs to build new representations, guided by human expertise. For more details and references, one can refer to our original paper [2].

2 METHOD

As a first step, the expert defines a task and computes an adapted representation of it in the form of an Influence Graph (IG). We further learn a higher representation of the grid by detecting communities in this complex IG.

2.1 Expert guided representation of flow affinities with model-based simulators

One task of grid operators is to make sure that no overloaded electric line, because of overheating due to the power flow going through it, leads to a cascading failure. To ensure grid stability, operators study grid states with a power flow simulator. If some overloads are found, the operator will look for remedial actions over the grid (like topological action) to relieve them. At that point, the operators needs to interpret what causes this overload and what should be a relevant zone to explore to find such a remedial action: they need to perceive what are the coherent electrical zones (communities) all over the grid when considering power flows on a given situation. To do so, one needs to measure power flow affinities to find "power flow communities", which can be done by intervening on power flows and observing the effect on other power flows. Since we have a physical simulator at our disposal to compute power flows, this is achievable given that the expert decides which simulated interventions are the most relevant to capture power flow affinities. Disconnecting a line, hence setting its power flow to zero, and observing the flow redispatch over other lines, is relevant in our case. This is an intervention operators often simulates and it has proven useful to find remedial action with an expert system [3].

Running systematically this simulated intervention for the power flow of every line on the grid enables us to build a new complex representation of the grid, specific to our task, in the form of an IG (illustrated in blue on Figure 1 a), as opposed to usual topological representation in red). Indeed the term s_{ij} of the normalized resulting IG adjacency matrix can be interpreted as the influence of flow of line i on flow on line j :

$$IG_{ij} = \frac{|PowerFlow(j)_{i_{disconnected}} - PowerFlow(j)_{originally}|}{PowerFlow(i)_{originally}} \tag{1}$$

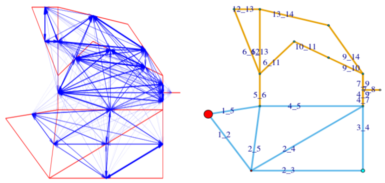
This rich task specific new representation of the grid is however difficult for human to apprehend entirely, but is suitable for community detection algorithm.

2.2 Infomap: an information theory based community detection algorithm

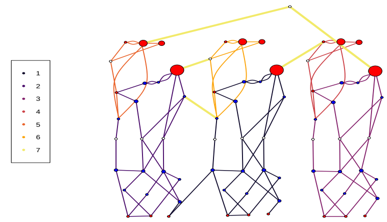
There are several algorithms for graph segmentation, known in literature as community detection algorithms and one can refer to references in our original article [2]. The algorithm known as "*Infomap*", has the advantage of being particularly suited for oriented, weighted graphs, and is able to identify flow patterns inside an IG. It is recursively hierarchical and can automatically find the proper number of hierarchical levels and clusters. It relies on Shannon's source coding theorem for information compression as well PageRank algorithm. For more details, please refer to [4]. The resulting clustering from the IG is now interpretable by human expert since it is a synthetic representation of it.

3 Results

We applied our method on grids of different sizes to test the method scalability and interpretability. The IEEE-14 commonly used system in the power system community has been used for illustration. The previously used IEEE-96 system can be considered a benchmark for such segmentations. We find similar results to other methods by segmenting identically the 3 same subgrids on Figure 1) b). We also discover an interesting new cluster, previously unclassified: a cluster grouping interconnecting



(a) On the left, our IG in blue for the IEEE 14 system, over the usual topological representation in red. On the right, the segmentation into 2 zones using InfoMap on our IG.



(b) IEEE RTS-96 system segmentation. The 7th newly discovered non-connected cluster of interconections in yellow.

Figure 1: segmentations on IEEE commonly used benchmark power systems.

line between subgrids. Even if they are not connected in the topology of the grid, which was the reason for not classifying them, they show strong mutual influences in the IG as they play a similar role for the grid.

We finally show a high level segmentation on the French power grid to demonstrate how our method scales while being able to give relevant interpretations. Indeed, our methods discover 8 clusters (the number of clusters is not an input of Infomap) for a 2012 snapshot that our operators were able to interpret since it is close and very similar to RTE historical regional segmentation in 7 regions.

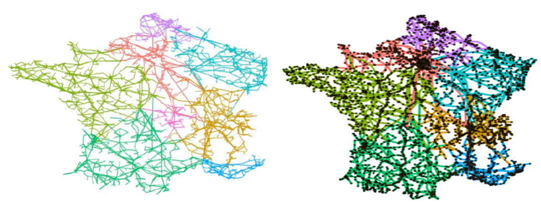


Figure 2: Comparison of a) the French power grid automatic segmentation on the left with b) historical RTE regional segmentation on the right.

4 CONCLUSIONS

In this paper we derived a new method to efficiently segment power grids. The method relies on an expert guided machine learning approach build on top of existing physical simulators. We applied it to the task of studying power flows on a grid state and the resulting synthetic segmentations led to a successful benchmarking and meaningful interpretations. In particular it highlights non-connected clusters in the grid topology illustrating the grid complexity. It also finds itself appropriate clusters on real systems. We believe that our approach could generalize to other physical systems and could be extended to create other meaningful representations for other tasks of interest. Our method could then become a building block for new contextual perceptions of physical systems. We eventually hope these shared representations between human and machines could unlock further human-machine cooperation in decision making processes.

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