A method to determine the structural warnings of malfunction in power grid networks by use of simplicial complexes

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Abstract: Electricity is the backbone of modern society and everyday life highly depends on its uninterrupted supply. In order to make it widely accessible, it is necessary to have an infrastructure resistant to severe disruptions or unintentional islanding. This is one of the main topics of energy informatics research with a focus on overcoming the transmission system challenges, such as the absence of grid reliability, sustainability, and stability. On the other hand, another important course of energy informatics research is to observe distribution system such as volt-ampere and voltage reactivity regulation, power quality and distribution modeling, control, and visibility.

Power grid reliability research targets all challenges, limitations, and obstacles in order to create a power grid with high penetration resistance of distributed-energy generation at the distribution and transmission levels. Nonetheless, power interruptions and blackouts occur relatively often due to the equipment failures, causing the power outages. So far, primary action to alleviate this required a more redundant and costly power system. System operators and regulators propose an adequate level of grid sustainability and redundancy, keeping all costs at low level while still preventing the power interruptions.

In order to overcome the above issues, we initiate research with an aim to create strategies based on the advanced techniques of algebraic topology and topological analysis of data. For the purpose of this study, simplicial complexes are obtained from the mathematical graph of the *US Power Grid* network. The so-called clique complex is created to identify higher-order organizational structures embedded within a network that cannot be detected using just the methods of graph theory or statistical mechanics solely.

The underlying mathematical graph of the US Power Grid network consists of various kinds of nodes that come from the logical hierarchical organization of a power grid network (see Figure at the bottom). Using detected *representative* simplices in clique complex, after a few iterations, different hierarchical levels are extracted. Results show that the underlying network has hidden

embedment of the most significant representatives with higher-order aggregation than at the level of the initially obtained simplicial complex from a mathematical graph. A node that naturally originates on a lower hierarchical level can be found mixed within the same simplex with nodes that belong on a higher hierarchical level, and vice versa, presenting the potential problem, hence indicating avenues of future research.

Key words: algebraic topology, simplicial complexes, complex systems, power grid redundancy