The Complex Network Analysis of Power Grid: A Case Study of the Argentinian Network and its Vulnerability

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The communication, transport and energy infrastructure are essential for everyday life. The effects of damage and/or infrastructure deficits, if it happens, are far-reaching. In the case of electric supply power, the occurrence of failures can cause interruptions in the communication channels and loss of information, alterations in transport, problems with the banking circuit and the operation of the capital market, and affect the residential activity as well as manufacturing processes, mentioning these as few examples based on what has been seen in successive blackouts that took place in different parts of the world.

In this work we analyze the impact of cascade failures (which potentially produce “blackouts” (Albert et al., 2004)) in the Argentinian power grid system, from the perspective of a network theory approach that allows us to study the structural characteristics of this network and its behavior under shocks (Albert & Barabási (2002); Boccaletti (2006); Pagani & Aiello (2013)). This research tries to account for characteristics that haven’t been studied previously in the Argentinian electric power transmission system. Energy infrastructure and, in particular, the lay-out of transmission networks, can contribute to territorial cohesion and, therefore, to socio-economic development. In particular, it is interesting to study the network of connections of isolated systems that initially tried to respond to the demands of each territory of the country, according to the development of social and economic sectors that took place in each area, and on the particular geography, where the large centers of electricity consumption resulted to be far from the most important centers of generation.

The national power grid system is, in turn, segmented into three component subsectors, well differentiated in terms of the activities that concern each one (and in regulatory matters): generation, transport/transmission, and distribution. Given the regulation conditions, the macroeconomic context and the microeconomic behaviors, the sector has reached a critical state in terms of provision of electrical energy to the final user. During the last decade, the deterioration of service quality and supply interruptions (some of great magnitude) have become increasingly frequent and widespread, following multiple factors such as the growth of urban demand, some climatic phenomena and the absence of sufficient investments. These events imply economic costs that could more than compensate for the potential benefits of existing electrical infrastructure lay-out.

In this work, we are using tools and modeling techniques coming from network theory to characterize the Argentinian power grid network and understand its behavior and robustness. In particular, we want to reveal specific topological and dynamic characteristics of the network that allows us to recognize the origin of failures and help to design policy making in order to prevent future blackouts.

The networks under study correspond to the high-voltage transmission systems, which transport the electrical energy from the generators to the distribution heads (that are also denominated substations). The Argentine electrical network is studied at two geographical levels: the national system SADI[1] and the regional system GCABA[2]. First, we start with data[3] collection. Initially, the information was available in terms of geographic map formats only. These maps were digitized, from which the nodes and main connections have been extracted in stylized form. The constructed networks replicate the real power grids, see Fig. 1. We then characterized the topologies of these networks and their main descriptive statistical properties.

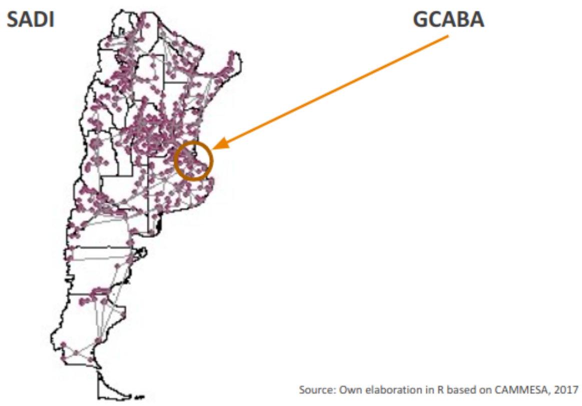

Fig. 1 Network representation of the power grids under study: SADI, GCABA.

Ensuing, we performed simulations to reveal the network robustness under shocks (disturbances due to different causes have been discussed in Crucitti et at. (2004); Kinney et al (2005); Martins et al (2016); Motter (2004); Rosas-Casals et al (2007); Saniee Monfared et al (2014)). The dynamics of the networks against exogenous shocks is simulated under two scenarios: random shocks (connections are broken at random) and directed, or preferential shocks, perturbing certain selected nodes according to different criteria of relevance. Likewise, the global state of the networks is analyzed sequentially as a greater proportion of the connections suffer failures, focusing the study on events of type "blackout" –cascade failures–, (see Fig.2 for a particular example).

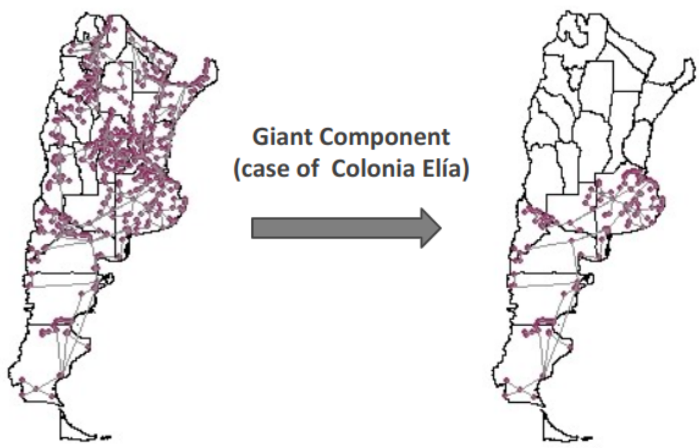

Fig. 2 FATHER'S DAY BLACKOUT
On June 16, 2019 in Argentina (Father's Day), a blackout took place that affected a big part of the country. We simulate the shock, retiring the nodes whose links were involved in the real failure, and reach similar results to the observed effects. We show the geo-representation of the giant component, once one of the nodes involved in the blackout origin is out of service.

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[1] SADI stands for the acronym in *Spanish* of Interconnection Argentinian System.

[2] GCABA stands for Autonomous City of Buenos Aires and Greater Buenos Aires.

[3] The data used consists of the geographical layout of generators and transformer stations of the electric power transmission system throughout the country, and for the GCABA power grid there is also the geographical arrangement of the distribution substations. This information is available in the Electricity Wholesale Market Management Company and in the National Ministry of Energy. First, it was necessary to transform the geographic maps into spreadsheet inputs, with tabulation according to the way in which the information is processed by the software used for network analysis in this research. Likewise, this information was enriched through exchanges with experts in the field (engineers and technicians). For the purposes of the construction and graphic presentation of the power grids, information from the IDE Conurbano of the National University of General Sarmiento, National Geographic Institute and GADM maps and data is also incorporated.

In terms of the main results, the networks present properties of small worlds (Watts (2004); Latora & Marchiori (2003)), where energy is transmitted more "quickly" but where shocks also expand more easily. In this sense, the results would indicate that the removal of random elements causes relatively minor damage to the removal of main nodes: when a minority of central nodes are out of service, a tendency to collapse of practically the entire network is observed, unlike the removal of a similar (or even higher) proportion of nodes at random, when the damage can be much less. That is, the networks under study seem to behave in a robust manner in the face of random shock while they are vulnerable to the intentional removal of central nodes (topologically defined).

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