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Analysis of transmission-power-grid topology and scalability, the European case study

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Highlights

- 400 kV and 200 kV power networks are different in terms of topology.
- Number of lines, characteristic path length, and network diameter scale with size.
- Global clustering coefficient highly varies among countries.
- Global clustering coefficient presents larger values compared to random networks.

Abstract

Topological analyses are crucial when assessing network robustness or generating synthetic power grids. In the case of synthetic power grids, topological considerations may be included during the generation process or they may be used as validation criteria once synthetic networks are generated. These synthetic grids can be used as case studies only if their topology is statistically consistent with real power networks. With a view to looking into power-network topology, we analyze the topology of fifteen European transmission networks by using complex-network metrics. The study includes two voltage levels: 400 kV and 200 kV. We study these levels both independently and as a single combined grid. Degree distribution, characteristic path length, network diameter, betweenness centrality and global clustering coefficient are explored in order to understand network topology and to explain observed differences among countries. We analyze empirically whether those metrics scale or not with network size as well as the characterization of power grids as small-world networks. Our conclusions improve the current understanding of power network topology, which is essential for generating synthetic power grids and in the assessment of network robustness.

1. Introduction

Power grids are critical infrastructure for modern society since failure in their components may lead to blackouts with severe economic consequences. Although the origin of power grids was local low-voltage networks, they have evolved to extensive high-voltage networks that interconnect countries. Besides this, power grids are connected to other networks such as gas or communication networks [1], [2]. Furthermore, relatively recent developments in power systems such as the spread of flexible alternating current transmission systems (FACTS), high voltage DC lines or distributed generation, are shifting the traditional vision of power systems whilst increasing system complexity [3].

An increase in system complexity leads to more sophisticated and computational-intensive models for grid analysis, operation and control. Traditional power-system methodologies such as power-flow analyses may result in hard problems, requiring large computational resources and computing times. By using complex-network techniques, models may provide good approximations with lower computational requirements. Complex networks are systems with a large number of dynamical units that are highly interconnected among them [4]. Recent studies have started to adapt complex-network methodologies to power systems, for instance by the inclusion of power-flow analyses [5].

The combination of complex networks and power systems is mainly found in two fields of research: the generation of synthetic grids and vulnerability analysis.

Synthetic power grids are non-real-power-grid cases that are mathematically similar to real power grids from a topological and electrical point of view. The interest in synthetic power grids lies on the lack of available information about real power networks. Real cases are scarce and data is occasionally provided for projects only under strict nondisclosure agreements. Therefore, results cannot be freely distributed. Similarly, existing test cases do not always fit with the properties of real power networks or they are not endowed with node location. The location of nodes is crucial in the research into some power-system applications such as transmission expansion planning or geomagnetic disturbances [6]. By generating synthetic power grids, case