Security Considerations in Transmission Planning for Creating Large Synthetic Power Grids

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***Abstract*—Synthetic power grids are test cases designed to spur innovation, as they contain no confidential energy infrastructure information and thus can be freely published. For building large and complex synthetic grids, this paper proposes a methodology to address security considerations in the transmission planning stage. The two-stage approach runs contingencies and adds lines strategically to fix violations while meeting other validation criteria. Results are shown for 10,000 and 70,000 bus cases.**

***Index Terms*—contingency analysis, power system security, synthetic power grids**

I. Introduction

Much data related to actual power systems is considered confidential energy infrastructure information (CEII), and cannot be easily shared among researchers and innovators due to legitimate security concerns. Researchers with access to such data are often subject to non-disclosure agreements to protect the CEII. However, innovation can be hindered by these restrictions, since the quality of published work cannot be cross-validated by peers if the underlying data cannot be shared.

There are some existing test cases, including standard IEEE cases, which are frequently used for published research. However, such cases are generally small and do not fully capture the complexity and difficulty that is associated with actual power system models. The motivation for building synthetic power grids is to provide the power engineering community with full-public, realistic system models. These datasets represent fictitious, designed systems which do not correspond to any actual power system but are similar to them in size and complexity. The National Academy of Engineers has recently promoted the development of synthetic power grids to open opportunities for innovation. As Section II describes, recent work has presented several methodologies for building and validating synthetic grids against actual large grids with a variety of statistical metrics. The larger size of produced synthetic grids facilitates research, demonstration, and cross-validation of results on systems similar to the actual grid.

This paper explicitly addresses single outage (N-1) security in the transmission planning stage of building large synthetic cases. While previous work has checked N-1 security of created cases, the only recourse for violations has been manual intervention, an approach that becomes less tractable as the size of the networks increase. The paper looks at the nature of these goals in the context of the network synthesis process and proposes a two-stage approach, which allows contingency conditions to be considered as the transmission line topology is formed.

II. Background

A. Synthetic Power Grids

Foundational work on the topic of synthetic grids includes investigations into the graph-theoretic structure of power networks [1]. These works show specialized properties of power networks in high clustering, small diameter, and a degree of 2-3. In [2], a large public European case is presented, which is not synthetic but represents a dc-only aggregation and approximation of the actual continental grid. Initial various approaches to building synthetic grids includes [3]-[5], which focus mainly on the topological network characteristics rather than also integrating power flow metrics. The most recent work, building on [4], has pointed to the importance of geography combined with nominal voltage level as major constraints [6]. Reference [7] confirms the importance of nominal voltage level. Power systems are not scale-free and differ from networks such as the internet and airline traffic in that there are no high-degree vertex hubs due to dominant geographic constraints.

B. Methodology for Building Large Synthetic Grids

The methodology for creating synthetic power grids employed by this paper, which builds on the approach discussed in [6], divides the process into four stages: substation planning, transmission planning, reactive power planning, and extensions. Substation planning geographically places substations on some pre-determined footprint, with load and generation from public information such as the U.S. Census Bureau population data and the U.S. Energy Information Administration form 860 generating station data. These loads

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and generators are clustered to meet validation criteria. A second clustering step determines which nominal voltage levels will be contained in each substation, and adds the buses and transformers to them [8].

The transmission planning stage, which is the focus of this paper, builds the transmission line topology to match multiple validation criteria, including topological and geometric metrics and those of a dc power flow. Dc modeling is used at this stage because the focus in placing transmission lines is the desired flow of real power, and this solution methodology does not have convergence issues.

Once the network of transmission lines is complete, the third step adds reactive power compensation to the system, leading to a good ac power flow solution, including additional voltage control devices for an acceptable voltage profile [9]. Then the fourth step builds on this base case with extensions for economic data, transient stability, geomagnetic disturbances, and time series scenarios. Extensions to synthetic power grids have been made for economics studies [10], transient stability [11], and yearly time series solutions [12]. Fig. 1 shows the example synthetic grid from [9].

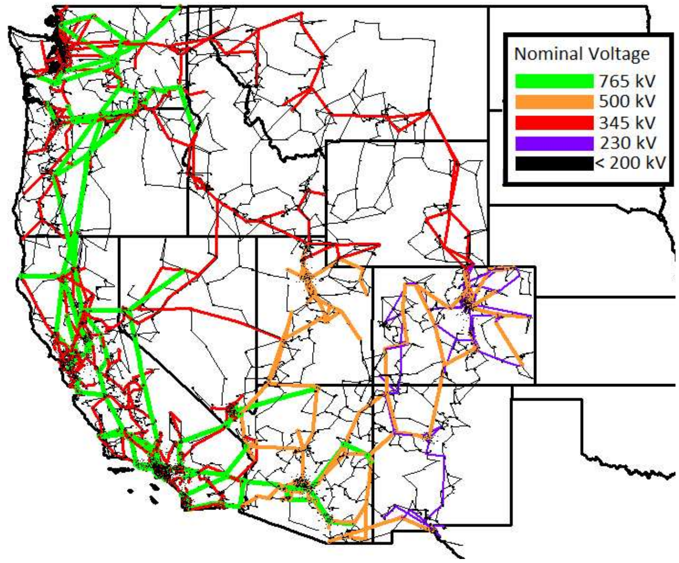

Fig. 1. The 10K synthetic grid diagram [9]. The colors indicate the voltage levels of the transmission lines

C. Transmission planning methods with security considerations

The problem of building a synthetic transmission system is related to the typical transmission network expansion problem, in that it involves the placing of transmission lines to meet certain criteria. A few references for transmission planning with security constraints are given in [13]-[16]. For large systems, the computational complexity introduced by the number of contingencies and the number of planning possibilities becomes quickly very difficult for mathematical optimization procedures. Thus the large system practical methods tend to favor heuristics which often involves considering contingency line limit violations in sequence and using sensitivity analysis to prune the planning possibilities to those which most affect the line overload actively being considered [13].

III. Security Considerations in Creating Large Synthetic Grids

A. Goals and challenges to integrating security in grid synthesis

Electric grid security to a determined contingency set is fundamental to power system planning, and a typical good starting set for analysis is N-1, that is, the outage of any single generator or branch. The North American Electric Reliability Corporation (NERC) guidelines [13] require analysis of single-element contingencies and certain multiple-element contingencies such as multiple parallel transmission lines.

The transmission planning approach used in previous work [6] in a modified form both adds and removes one or more lines at each iteration, continuing for about 4000 iterations that do a dc power flow solution, graph theoretic analysis, and comparison to the Delaunay triangulation. At each iteration the algorithm prioritizes which existing lines should be removed and which candidate lines should be added to take their place. The rapid change in topological structure makes contingency

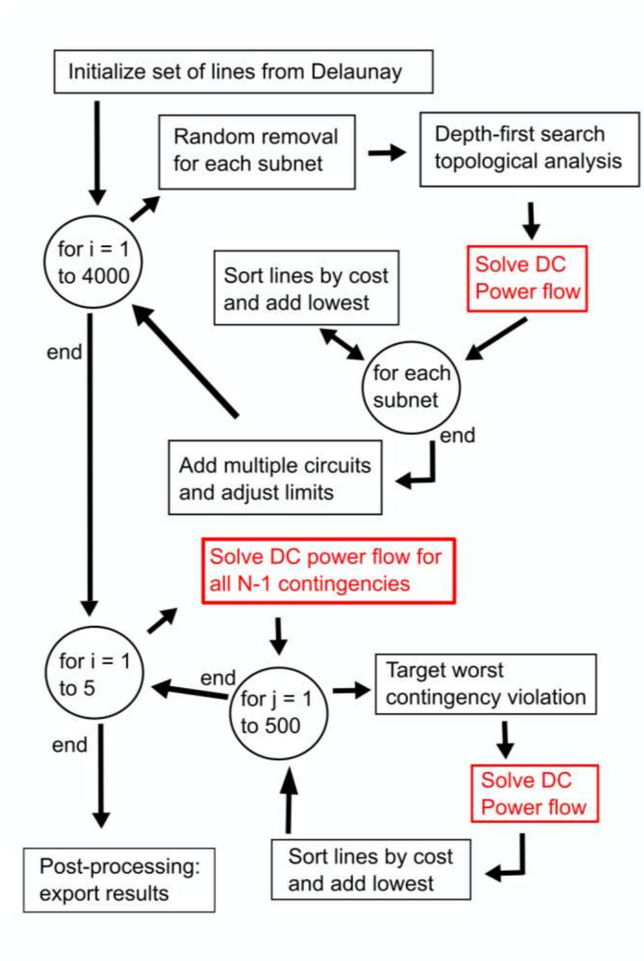

Fig. 2. Transmission planning flow chart, with second stage to address N-1 contingency violations.

Fig. 3. Decrease in contingency violations through outer loop iterations.

analysis difficult to add directly into the process. This is because contingency results are invalidated by continuous removal of lines, and the analysis becomes too computationally intensive.

B. A two-stage approach with targeted violation repair

The approach proposed by this paper is to divide the planning step into two stages, as outlined in the flow chart of Fig. 2. The first stage adds and removes lines considering the base case conditions as previously, except with fewer target lines by 5-10%, which will be added in the second stage.

That second stage as shown in Fig. 2 does not remove lines; it only adds them, targeted to solving contingency issues but still subject to the base case validation metrics. First, all contingencies are run; this process is parallelized and screens for the violating contingencies. Then the violating contingencies are run again individually, ordered by the most significant induced overload. At each iteration, a synthetic line is added.

In each iteration of the second stage, a single violating contingency is targeted for fixing. Candidate lines are selected based on topological closeness to the outaged branch and estimated increased power flow based on sensitivity to change in voltage angle across the candidate line.

$$P_{mn,est.} = \frac{1}{X_{mn}} \cdot (\Delta\theta_m - \Delta\theta_n)$$

In this equation, X_{mn} is the branch reactance, and $\Delta\theta$ is the change in bus voltage angle. The stopping criteria must avoid adding too many lines that cannot fix a contingency and decide between options at different voltage levels.

IV. Example Results

The method described here was tested on the 10,000 bus case shown in Fig. 1 and on a new 70,000 bus case built with the method of [6]. This case has over 51,000 contingencies which produced a combined 16,590 violations after the primary planning stage. The secondary planning stage, as shown in Fig. 3, targeted 500 contingencies in each iteration, but showed even greater overall improvement.

Fig. 4 shows the diagram for the 70,000 bus case, which is too large to fix the usual contingency violations by hand. These large cases have better contingency behavior when the proposed method was applied in their creation. Thus this way of handling security constraints improves the automation and validity of the process for building interconnect-sized realistic grids. All the synthetic grids are available online [17].

V. Conclusions

Synthetic grids continue to benefit the research community with public, realistic, and large test cases. This paper shows how a synthetic power grid creation algorithm can be extended to consider N-1 security conditions and reduce contingency violations in the resulting transmission system. The approach focuses on targeting contingencies individually in prioritized order, and was effective for significantly reducing the violations.

Acknowlegment

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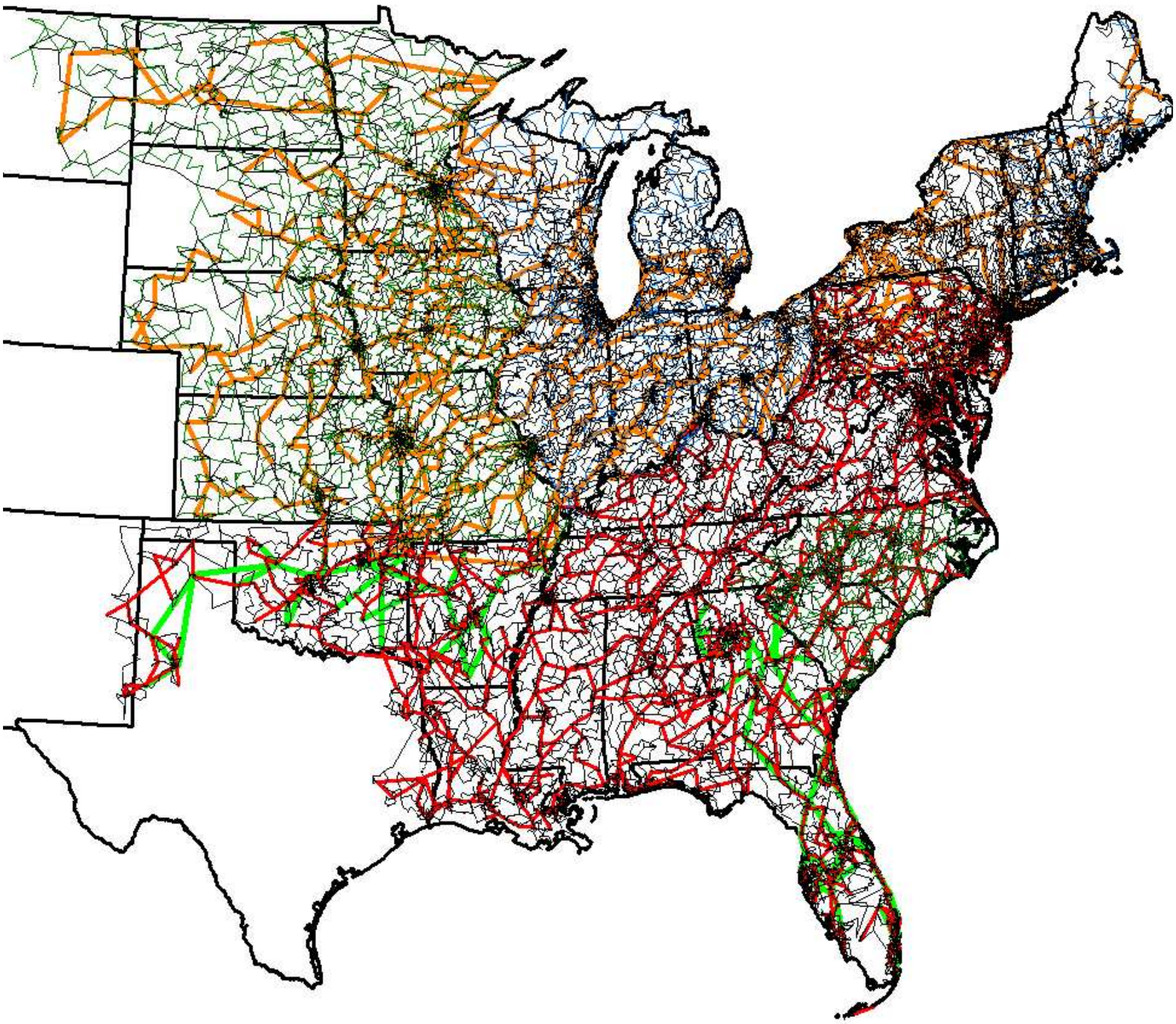

Fig. 4. Synthetic 70,000 bus case single line diagram.

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