A Description of the Texas A&M University Electric Grid Test Case Repository for Power System Studies

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***Abstract*—A repository of diverse electric grid test cases, varying in size and characteristics, has been developed for application in power system studies. The purpose of this repository is to provide public access to realistic electric grid models of varying sizes to help facilitate research and education. This repository is regularly updated with new test cases or modifications of existing ones as a result of continuing research. This paper outlines the necessity for this repository, details the electric grids it contains, and provides explanations for the types of cases, highlighting their relevance to different applications.**

***Index Terms*—Synthetic power grids, realistic test cases, electric grids test case repository, large-scale electric grid models.**

I. Introduction

The power grid network is rapidly evolving and moving away from the historically conventional manner of operation. These changes are not only due to an increase in load but also due to the growth of technology in domains such as electric vehicles, batteries, bitcoin mining, renewable generation, and increased inverter-based resources. Apart from these man-made developments, natural events are also stressing the power grid. To prepare against these events and ensure reliable power grid operation, it is crucial now to study the power grid under different scenarios.

Therefore, there is a need for power grid models and data to perform these analyses and studies. Many countries consider their power grid infrastructure as critical and do not disclose its data publicly [1], [2]. For research and development purposes, there is a need to make electric grid models available. Some early transmission [3] and distribution [4] models were made available in the IEEE common data format, which led to the development of seminal works in power flow and stability studies. Over time, several test electric grid models (such as [5]) have been developed by the power system community.

The IEEE PES task force created a library of power grid models for the purpose of benchmarking AC optimal power flow algorithms developed by the power system research community [6]. Pacific Northwest National Laboratory created open-source transmission and distribution power grid models called "Sustainable Data Evolution Technology (SDET)" [7]. The authors in [8] provide a nice comprehensive survey of existing synthetic networks created using different approaches and their choice of metrics.

Although there have been significant developments in synthetic or test electric grid data and efforts have been made to establish an online repository for fictitious electric grid data [9]–[11], there are not many descriptions of existing repositories. GridBright, Inc. has created a global grid data online repository of several publicly available power grid models [9] named bettergrids.org. In this repository, contributors voluntarily upload power grid models. These models are only updated when the contributors who uploaded them choose to do so. Additionally, models are only available in the formats selected by the contributor. However, there are numerous simulation software programs, each with varying levels of popularity. Making one model available in multiple formats would greatly facilitate research.

Thus, there is an unrealized need for an electric grid repository that contains test cases of varying sizes in multiple formats and is regularly updated. The effectiveness of such repository is based on its regular updates with relevant data and incorporation of findings from new research. This paper describes the Electric Grid Test Case Repository at [12]. The synthetic power grid models available at this repository can be used to understand and address the challenges seen in today's power grid, serving both research and education purposes. The size of the test cases ranges from 9 buses to 82,000 buses. The test cases include the original smaller test cases developed by the power system community and larger test cases developed at Texas A&M University.

II. The Repository

The repository description can be split into two main sections. The initial section delves into the specifics of each test case set, providing technical details and the rationale behind their creation. The next section elaborates on the different formats in which these cases are available.

A. *Electric Grid Models*

1. Literature-Based Power Flow Test Cases

This section consists of cases that develop on the very first few synthetic power network test cases for power flow studies.

Prior to the comfort of swift digital data exchange, power flow data was exchanged on tapes or by using punched cards due to early computing limitations. At that time, the power network was growing, and due to the interest of different study groups in running power flow, there was a need to standardize the data in a common data format. The working group of the Power Systems Engineering Committee created a common data format for ease of exchange of information [13]. This certainly made the development of test cases easier, beginning with the need to replicate issues in power systems.

A portion of the American Electric Power network in the United States was anonymized to remove CEII data and was made available (at [3]) specifically for power flow studies as a public test case in the IEEE Common Data Format. These range from 14-bus to 300-bus systems. The IEEE 14, 30, and 57-bus cases do not have any line limits, whereas the IEEE 118 bus case (first used in [14]) has entirely made-up line limits. The IEEE 300 bus case was developed by the IEEE Test Systems Task Force, converted to the IEEE common data format, and made available at [3].

The IEEE 24 Bus, originally known as the RTS-79 test case, was the first version of the Reliability Test System (RTS) developed by the Reliability Test System Task Force of the Applications of Probability Methods Subcommittee of the Power System Engineering Committee. This was a single-area power grid model. An improvement of this model, the IEEE RTS-96, was developed with the objective of creating a multi-area test power system to account for impacts of interregional power flows [15].

The WSCC 9-bus test case provides a simplified model of the Western System Coordinating Council (WSCC), condensed into a system with nine buses and three generators. It operates at base KV levels of 13.8 kV, 16.5 kV, 18 kV, and 230 kV. Due to its limited number of voltage control devices, this test case is relatively easy to manage. The two-area system test case, derived from [16], is utilized for exploring dynamic stability, power interchange, oscillation damping, and similar studies. This system comprises 11(4) buses(generators) and is divided into two areas linked by weak tie lines.

All cases in this section are AC power flow cases with feasible solutions. The cases are made available in formats described in section II-B in the repository. Similarly, the power flow data for the Polish grid for winter 2003-2004 off-peak conditions was made available by Dr. Korab in the Matpower format [5]. It contains 400kV, 220kV, and 110kV voltage networks. This network was modified to have fictitious geographical coordinates for high-voltage substations. Machine models were added to simulate the dynamic behavior of the system to disturbances [17]. The updated case with power flow feasibility and dynamics is available in the repository.

2. Small Signal Stability Test Cases

With the goal of studying wide-area oscillations in interconnected power grids, the IEEE Task Force on Benchmark Systems for Stability Controls benchmarked 6 multi-machine systems for dynamic studies of the power grid [18]. These networks range from 6(3) to 68(16) buses(generators) and were created to study specific power system dynamics problems. The power grid cases include the 3-machine infinite bus (3MIB) system, the Brazilian 7-bus equivalent, the 2-area, 4-generator system [19], the 39-bus NETS [20], the Australian 14-generator equivalent, and the New England 68-bus system.

The damping control issues addressed in these systems vary. The 3MIB and 2-area,-generator system focus on damping various modes, including intra-plant, local, and inter-area. The Brazilian 7-bus equivalent deals with poor controllability challenges due to zeroes near critical electromechanical modes. The 39-bus NETS case emphasizes the coordination of multiple stabilizers for damping within a control area. The Australian 14-generator equivalent and the New England 68-bus system both address simultaneous damping of local and inter-area modes, with the Australian 14-generator equivalent also considering small- and large-disturbance analyses for multiple operating conditions, and the New England 68-bus system coordinating multiple stabilizers to dampen multiple modes.

3. Datasets for ARPA-E GridData Program

Under the Generating Realistic Information for the Development of Distribution and Transmission Algorithms (GRID DATA) program by ARPA-E [21], large-scale electric grid models with geographical information were created. These grids range from 200 buses to 70,000 buses on the footprint of Central Illinois to the entire Eastern United States. The creation and validation of these grids have been discussed in [22]–[26].

Historically, test cases for power systems (explained in the previous two subsections) were constructed with a focus on solving specific problems. In contrast, the cases developed under GridData are more generalized. Thus, these recent cases not only provide the ability to perform power flow studies and transient stability simulations ([27], [28]) but also the ability to simulate the impact of geomagnetic disturbances [29].

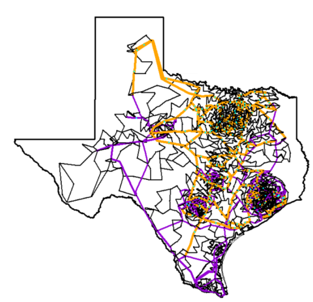

Fig. 1: ACTIVSg2000: 2000 bus power grid network on the footprint of Texas

This versatility of studies is achieved by incorporating further complexities specific to power systems into these cases. Six test cases were created under this project. The cases include generator cost models and dynamic models,

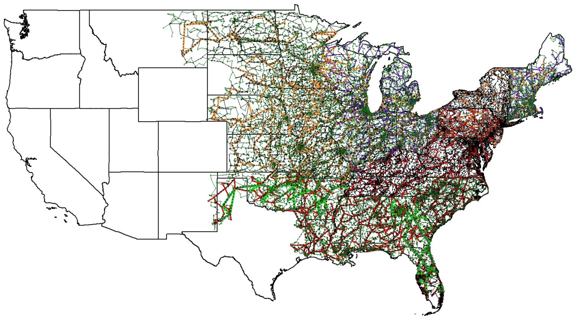

Fig. 2: ACTIVSg70k: 70,000 bus power grid network on the footprint of Eastern United States.

enabling use in optimal power flow studies [30] and transient stability studies. The publicly available test cases prior to these were smaller and lacked geographical information. To truly represent the actual grid, test cases needed to span a geography similar to actual power networks. Figure 1 shows a power grid spanning the geography of Texas, and Figure 2 shows the network on the footprint of the Eastern US.

4. Datasets from the GO Competition Challenge

ARPA-E started the Grid Optimization (GO) competition to address the challenges faced by the power grid. According to ARPA-E [31], before the GO competition, most of new research in power flow algorithms rarely advanced past the initial stages, and there were limited means to compare various optimization methods directly. Due to this, it was difficult to understand the exact strengths and weaknesses of various optimal power flow algorithms. Thus, to address the Security Constrained Optimal Power Flow (SCOPF) problem, Grid Optimization competition was started. Texas A&M University was part of the dataset creation team, and the cases created for this competition are added to this repository. [32] provides a summary of the different datasets developed under this project. Using a similar approach as the previous section, four different test cases with 617, 2k, 12k and 31k buses were created.

5. Datasets for ARPA-E PERFORM Program

The Performance-based Energy Resource Feedback Optimization and Risk Management (PERFORM) project [33] aims to create grid management systems that assess and balance risk across all grid assets (conventional and emerging intermittent sources). Incorporating increasing intermittent renewable resources calls for an economical and reliable grid that fully utilizes emerging technologies. Large-scale electric grid datasets with realistic but not real information are best to reflect different scenarios.

Under this project, a 6,700-bus grid model emulating the Electric Reliability Council of Texas (ERCOT) area and a 23,600-bus grid model representative of the US Midwest were developed. Realistic voltage levels are used for these cases to mimic actual grid problems in these footprints, including 345kV, 138kV, and 69kV for the ERCOT grid and 500kV, 345kV, 230kV, 161kV, 138kV, 115kV and 69kV for Midwest grid.

The data for generators in the synthetic models comes from the Energy Information Administration's Form EIA-860 [34], as of the end of 2019. Initially, census data was used to estimate electricity demand (load), but it has since been updated to reflect real-world consumption patterns better ([35], [36]). These detailed load profiles are used to generate time series data for a sample year, included with the grid data.

To support the development of solvable synthetic cases for alternating current power flow, voltage control devices, phase shifters, and impedance correction tools have been integrated. This integration is part of a reactive power planning strategy, ensuring the grid can effectively manage varying power flow conditions. These grids also include detailed generator models, such as improved cost curves and temporal constraints.

6. Special Cases

6.1 Combined Transmission and Natural Gas Pipeline

After the impact of winter storm Uri, it was evident that natural gas outages had a major impact on the reliability of the power grid [37]. Fictitious test cases were developed to help with studying combined electric-gas systems. The repository includes two test cases: the Travis-150, corresponding to the Austin-Travis county, and the Texas-6717, modeling the transmission network and natural gas pipeline on the footprint of Texas, US. The Travis-150 system is a 47-node synthetic natural gas test case, which includes 23 loads and 46 pipelines. The Texas combined electric-gas test case has 6717 electric buses and 2459 natural gas nodes. The development and details of these cases are provided in [38].

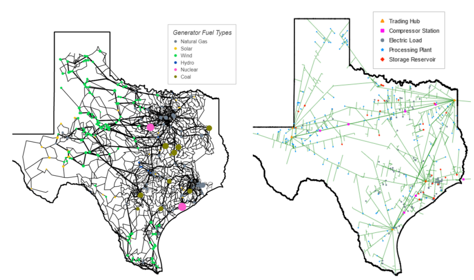

Fig. 3: Combined transmission and gas network for the Texas-7k case.

6.2 Combined Transmission and Distribution Grids

While it is useful to decouple transmission and distribution(T&D) networks for focused studies, the growing use of distributed energy resources (DERs) and electric vehicles makes it important to understand how changes in one network can affect the other. Also, since natural phenomena, such as hurricanes, can affect both transmission and distribution, there is a need to simulate both networks under different scenarios. The methodology to combine the transmission and distribution of synthetic networks with geographical information is explained in [39].

Currently, the repository contains two datasets with combined T&D networks. The first case is on the geographic footprint of Travis County in Texas, with 160 transmission system buses, 39 generator units, 132k distributed transformers, and 448 feeders. The second case is a much larger fictitious T&D network covering the entire state of Texas. The transmission network is the same as the Texas 6700 bus case, and each load in this network is mapped to distribution circuits. The generators are also mapped to the 2019 EIA-860 information. Both these datasets are available as a combination of PowerWorld and OpenDSS files. Figure 4 shows all the information mapped together where transmission lines are depicted in green for 345 kV and black for 138/69 kV, whereas distribution lines are illustrated in orange, red, purple, yellow, and pink.

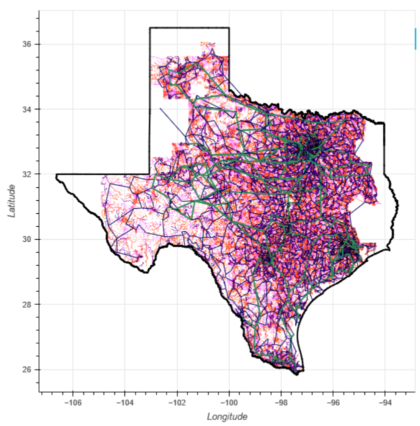

Fig. 4: Combined transmission and distribution network for the Texas-7k case.

6.3 Combined East and West US Grid

From 1967 to 1975, the North American grid functioned as a large, interconnected network [40]. Despite the challenges, interconnecting the Eastern and Western grids of North America can be beneficial. To promote research on interconnection studies and to gain insights into the dynamics of a vast network, a combined East and West synthetic test case has been developed and made available in the repository. It contains 80k buses, 12k generators, and 40k substations. Additionally, it also has generator and load dynamic models for transient stability studies. Figure 5 shows this network on the map of North America.

B. Data Format

The power system test cases are available in multiple data formats. These formats include PowerWorld Simulator and PowerWorld DS (*.pwb, *.pwd, *.tsb, *.aux), Matpower (*.m), PSSE (*.raw, *.dyr), and PSLF (*.epc, *.dyd). An additional format type is the Binary 3D Data Cube (B3D) file format, which stores two-dimensional, time-varying data like the electric or magnetic fields. This format is useful in performing geo-magnetic disturbance (GMD) analysis. Table I offers a summary of the labels assigned to each case in the repository, emphasizing that the cases contain specific model parameters necessary for conducting the relevant studies. For example, a case with TS can be used to perform dynamic studies; however, a case with only OPF can be used to run optimal power flow studies.

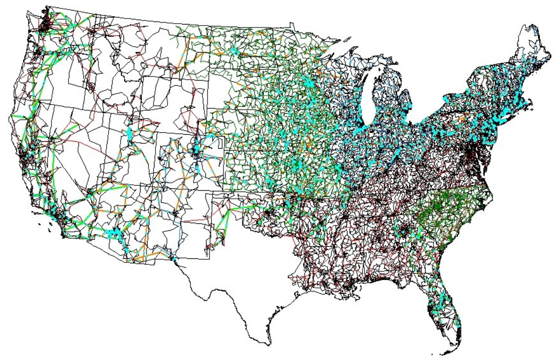

Fig. 5: ACTIVSg82k: 82,000 bus power grid network on the footprint of East and West United States.

TABLE I: Label information

Label	Application
TS	Transient Stability
GMD	Geomagnetic Distrubance
OPF	Energy Economic Study
PWDS	PowerWorld dynamic Studio Scenario
MOV	Case movies are available
PMU	Synthetic PMU data is available

III. Applications

The cases available at this repository can be applied to various studies, including power flow and dynamics, geomagnetic disturbances, extreme weather, black start restoration scenarios, transmission expansion planning, and other yet-to-be-conducted studies. Figure 6, generated from voluntary user input at the time of each case download, shows the distribution of different areas of usage. Predominantly, these cases are used for individual research, with significant application in university and educational settings, and some usage in industry research as well.

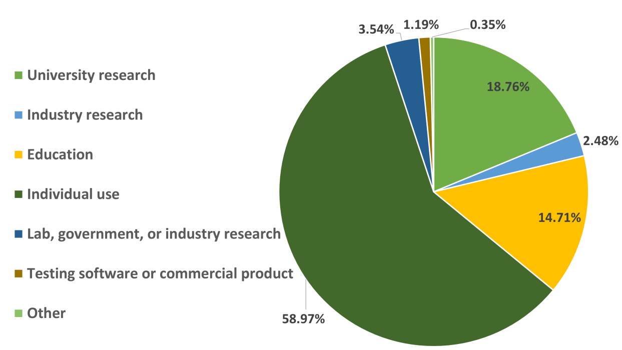

Fig. 6: Statistics of test case usage based on user input.

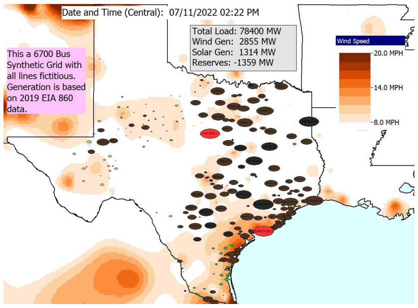

Fig. 7: A Geographic Data View [41] of ACTIVSg2000 showing the renewable and conventional generation output based on a low wind flow day.

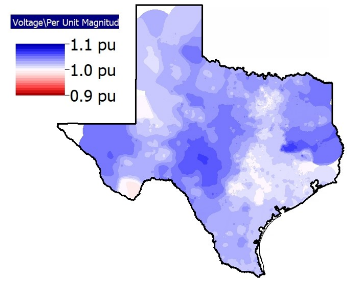

Fig. 8: Voltage contour visualization for one-time point for the year 2030.

A. Geo Magnetic Disturbance Analysis

In addition to power system complexities, the cases marked with GMD contain detailed information about transformers, such as their type (e.g., auto, Generator Step Up), winding configuration, and winding resistance. These details are essential for conducting steady-state voltage stability studies under the influence of Geomagnetically Induced Currents(GICs) [29].

B. Scenario Studies

The large-scale test cases contain fictitious geographical data for substations, which is useful for understanding the weather impacts on the grid. These studies are done by simulating different weather scenarios, such as high renewable and low load conditions or low renewable generation with high load, and several other variations. Furthermore, these cases enable the simulation of future scenarios, allowing for modifications to represent anticipated future load and generation conditions. For example, Figure 7 shows a time-step simulation output of renewable and conventional generators on the footprint of Texas on a low-wind day. The wind generation in green shows the low wind generation, while the conventional generation in black picks up the demand.

C. Education and Storytelling

Simulations based on the 37-bus and the 2000-bus cases have been developed and used for classroom assignments [42]. Engaging with large-scale grids gives students insight into the complexities of planning and operating real power grids. This includes teaching concepts such as power flow analysis, economic dispatch (including OPF, SCOPF, and LMP), contingency analysis, and transient stability analysis. [42] gives a comprehensive description of how these cases are incorporated into undergraduate laboratory assignments. A key benefit of this repository is its accessibility, allowing any instructor, anywhere in the world, to develop new assignments simulating various scenarios.

Explaining technical details to those without a background in power systems can be challenging, but using storytelling and meaningful visualizations simplifies and enhances the effectiveness of this task [43], [44]. For instance, it can help illustrate how a disturbance from generator loss spreads through the network or how reactive compensation affects voltage (Figure 8) across the grid. [45] provides an explanation of using effective storytelling for communicating power network information based on a target audience. Few visualizations and movies created using these test cases are available under the 'Visualizations' section of the repository.

IV. Conclusion

This paper offers an explanation of the electric grid test case repository, providing background on the available cases and examples of their usage. The main objective is to establish an extensive collection of electric grid test cases of different sizes with the ultimate goal of promoting innovative research in power system studies. While primarily focused on purely power systems research, these test cases also have the potential for application in interdisciplinary research areas like human factors engineering and electric-gas system studies, among other emerging fields. The vision for this repository is to be continually updated and expanded, adding to it a broader array of synthetic test cases to enhance its applicability across a wide range of research domains.

V. Acknowledgement

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