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Review

A Review of Power Distribution Test Feeders in the United States and the Need for Synthetic Representative Networks

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Received: 15 October 2017; Accepted: 14 November 2017; Published: 18 November 2017

Abstract: Under the increasing penetration of distributed energy resources and new smart network technologies, distribution utilities face new challenges and opportunities to ensure reliable operations, manage service quality, and reduce operational and investment costs. Simultaneously, the research community is developing algorithms for advanced controls and distribution automation that can help to address some of these challenges. However, there is a shortage of realistic test systems that are publically available for development, testing, and evaluation of such new algorithms. Concerns around revealing critical infrastructure details and customer privacy have severely limited the number of actual networks published and that are available for testing. In recent decades, several distribution test feeders and US-featured representative networks have been published, but the scale, complexity, and control data vary widely. This paper presents a first-of-a-kind structured literature review of published distribution test networks with a special emphasis on classifying their main characteristics and identifying the types of studies for which they have been used. This both aids researchers in choosing suitable test networks for their needs and highlights the opportunities and directions for further test system development. In particular, we highlight the need for building large-scale synthetic networks to overcome the identified drawbacks of current distribution test feeders.

Keywords: distribution networks; review; state of the art; test feeders; representative networks; distributed energy resources (DERs); synthetic distribution test feeders

1. Introduction

Current distribution networks are undergoing a transformation towards the smart grid paradigm, including rapid increases in the quantity of distributed energy resources (DERs). This has prompted considerable interest from the research and vendor communities to develop innovate tools and algorithms that are adapted to smart distribution networks that provide advanced controls and distribution automation. Tools like Optimal Power Flows (OPFs), Volt/Var optimization, or advanced feeder reconfiguration, enable evaluating specific operational and planning objectives, and thereby can help utilities to implement operational strategies. Some of the objectives commonly sought in these tools are the minimization of total system costs, the minimization of network losses, the maximization of security of supply or a mixture of all these objectives [1]. Moreover, countless studies have been conducted about the impact of DERs on distribution networks in recent years. For instance,

under an active network management scheme, studies noted that DERs have the potential to reduce costs for consumers and utilities [2], highlighted the ability for coordinated controls to improve operations with high-penetration solar photovoltaic (PV) [3], explored the hosting capacity for DERs [4], and more.

However, the ability to test and analyze these trends and developments is limited by a scattered and somewhat incomplete set of public test systems. Distribution networks are sometimes considered as the critical infrastructure of a country, and detailed load/customer data prompts privacy concerns. As a result, only a very few actual networks are publically available for use as a test network. This has forced the research community to use only the available test feeders that are published in the literature so far, sometimes for purposes beyond the original intentions of the test feeder creators. For instance, in 1991, the Institute of Electrical and Electronics Engineers (IEEE) Power and Energy Society (PES) published four radial tests feeders providing references for the United States (US) distribution system for the first time. Now, 25 years after this first publication, the number of published US featured test feeders is still limited, despite significant dispersed efforts to add to the set of test feeders.

A test feeder is a distribution network model that is able to replicate the behavior of an actual distribution feeder [5]. In general, these test feeders aim to reproduce the characteristics of an actual network, including specific particularities within a specific region; this feature is called representativeness. In this case, we say that the test feeder is representative of a particular actual network located in a particular area or country. An important use of test feeders is benchmarking, allowing for researchers to evaluate the performance of their algorithms. For instance, in the OPF case, the computing time, the degree of optimality, or even a ratio between them can be used as a benchmark. With emerging widespread grid modernization efforts, testing the corresponding advanced optimization algorithms suggests a need for realistic large-scale distribution test networks. In addition to providing a valuable test platform, test networks are also essential to make consistent comparisons across different advanced algorithms.

This paper provides a comprehensive critical review of US-featured publically available test distribution networks—and their limitations—for use in evaluating and testing advanced OPF and related studies or analyzing DERs integration into smart distribution grids. This is intended to help researchers choose suitable test networks for their needs, while also highlighting opportunities and directions for further test system development. In addition, the paper includes new trends for, and emerging efforts in the creation of, large-scale synthetic distribution networks that could be provided as publically available test networks to the research community.

The paper is organized in the following manner. Section 2 develops a classification of published networks according to their origin, where each sub-section sheds light on different publicly available feeders, their summary features and intended uses. Section 2.1 analyzes the existing IEEE feeders. Section 2.2 studies the taxonomy feeders provided by the Pacific Northwest National Laboratory (PNNL). Section 2.3 examines the Electric Power Research Institute (EPRI) representative feeders. Section 2.4 inspects the prototypical feeders presented by the Pacific Gas and Electric Company (PG&E). Section 2.5 reviews other the relevant test feeders that cannot be classified into the previous sections. Section 3 analyzes the limitations found in the currently available test feeders that were discussed in the previous sections, particularly from the perspective of developing advanced algorithms for advanced controls and distribution automation. Section 4 introduces the need for large-scale synthetic networks and for tools able to generate them. Finally, Section 5 presents the conclusions.

2. Distribution Test Feeders

A distribution network consists of power infrastructures that deliver electricity from the transmission/sub-transmission circuits to the final customers as shown in Figure 1. A wide variety of metrics could be defined to exhaustively characterize a distribution network. Nevertheless, there are some key descriptive components that can provide a simplified overview of it. In this review, we have

described existing distribution test feeders using the metrics presented by respective authors or model creators in their publications, in order to be consistent with the original purposes for which these test feeders were created.

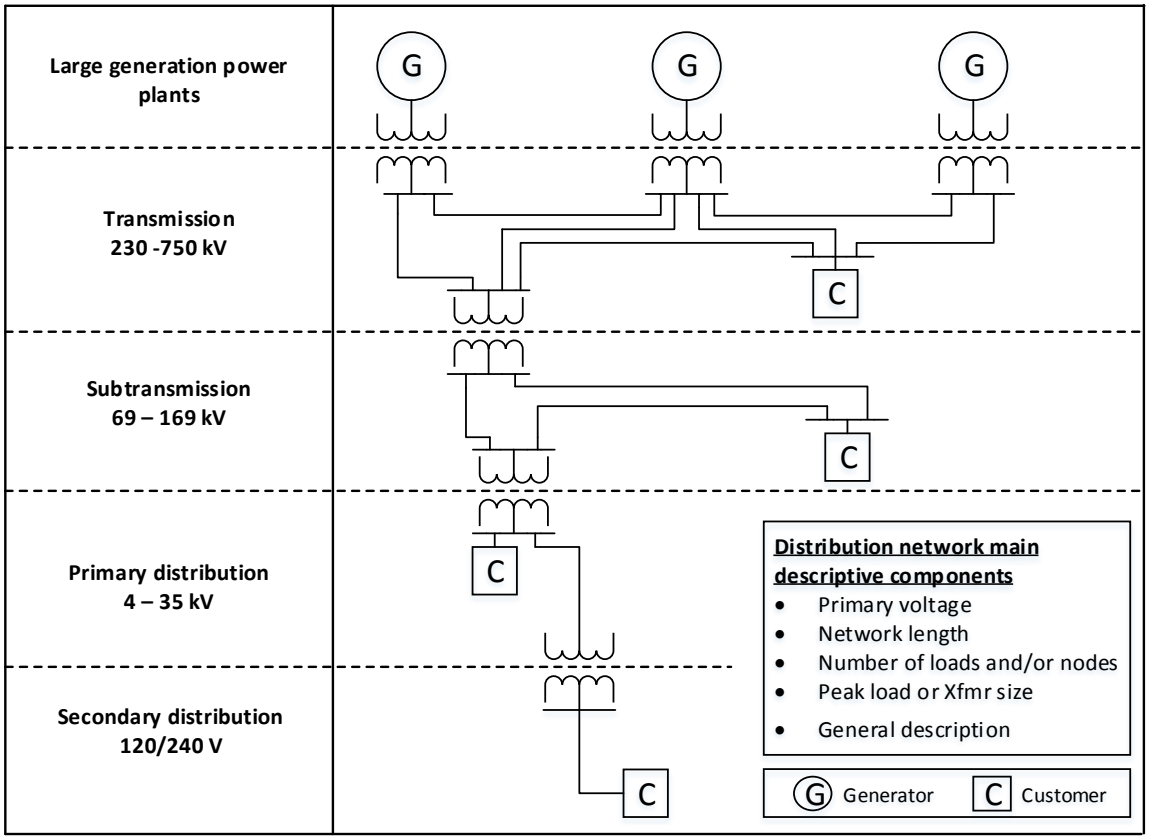

Figure 1. Power system infrastructure grouped by voltage levels.

Distribution test feeders can be built using different methods, as illustrated in Figure 2. The most straightforward one is the first method, which consists of selecting an actual feeder from a real distribution network, and anonymizing to remove private or sensitive data. The rest of the methods build synthetic networks, using real networks as the basis. The second method uses clustering techniques to group several actual networks and then stitches together pieces to build a synthetic representative test feeder for each group of actual networks. The third method builds a test feeder through manual design. This option allows for additional attention to be paid to specific network features but it is only possible with small-scale networks due to its complexity. Finally, the fourth method consists of building synthetic test networks through the use of planning tools that are designed to create realistic networks using the same technical and economic criteria that are used by distribution planners. This option allows for the design of new test networks from scratch with taylor made features. In general, the obtained test feeders should be representative of a set of real distribution networks with specific features. Representativeness is a validation criterion and therefore is not rigidly attached to any of the design methods, and it is possible to be obtained with any of the four described procedures.

In the next sections a bibliography review about the published test feeders is provided. Each section contains a brief description of the network and the most relevant publications where they are used.

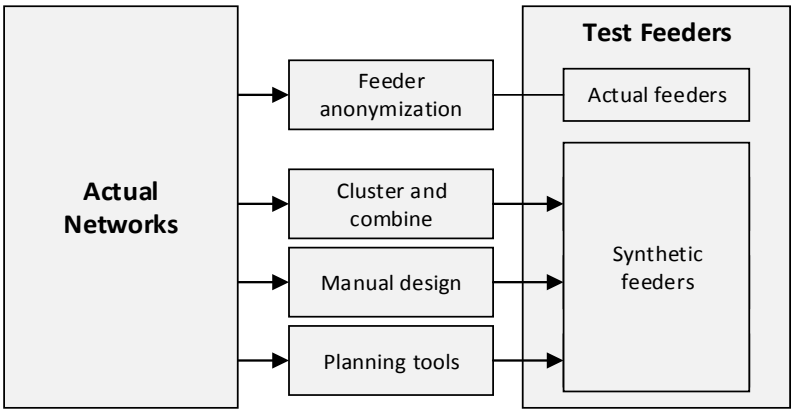

Figure 2. Test feeders building procedures.

2.1. IEEE Feeders

In 1991, the first set of four small test feeders was published [6] by the IEEE PES. Ten years later, a new test feeder was published [7] and was added to the previous set in order to provide a model of a three-phase transformer connection. In 2009, the Roadmap for the IEEE PES Test Feeder was published by the IEEE team [8]. In this paper, the direction and the requirements of the upcoming test feeders were presented, highlighting seven topics to take into account: neutral-to-earth voltage (NEV), short circuit benchmarks, distributed generation (DG) protections, large distribution system models, inverter-based DG models, comprehensive test feeders, and asymmetrical contingencies test feeders. Answering the previous needs, three new test feeders were published, a NEV test case [9], a medium-sized feeder to scale-up algorithms [10], and another with a wide variety of equipment [11]. In 2014, a new meshed low voltage test system was published [12]. The previous IEEE test feeders are presented chronologically. More information about these feeders is presented in Table 1. A recent publication [13], review the actual collection of test feeders and propose specific analytic challenges for future developments.

Table 1. Institute of Electrical and Electronics Engineers (IEEE) Test Feeders Features.

ID	Length (km)	Primary Voltage (kV)	Number of Customers/Loads	Peak load (MVA)	DG (MVA)
13 Node	2.5	4.16	9	3.6	0
123 Node	12	4.16	114	3.8	0
34 Node	94	24.9	24	1.6	0
37 Node	5.5	4.8	25	2.73	0
4 Node	1.3	12.47	1	6.3	0
NEV	1.82	12.47	1	8.9	0
8500 Node	170	12.47	1177	11.1	0
CTF	81.7	12.47/24.9	36	4.17	0.15
342 Node	15.2	13.2	624	49.4	0

2.1.1. 13 Node Test Feeder

This small and highly loaded test feeder referred in [6] includes most of the common features that are used in actual networks like voltage regulators, shunt capacitor banks, overhead and underground lines, and unbalanced loads. This feeder provides a starting point to test power-flow convergence problems for a highly unbalanced system.

2.1.2. 123 Node Test Feeder

This test feeder presented in [6] comprises of common characteristics that are installed in real networks. Several voltage drop problems are found in the feeder highlighting the necessity of voltage

management with voltage regulators and shunt capacitor banks. It includes a number of switches to enable simple testing of intrafeeder reconfiguration strategies.

2.1.3. 34 Node Test Feeder

This test feeder described in [6] is a part of a real distribution network located in Arizona. Due to the long length and the unbalanced nature of the feeder, power-flow convergence problems can be studied with this test feeder.

2.1.4. 37 Node Test Feeder

Similar to the 34 Node Test Feeder, this feeder referred in [6] was obtained from an actual distribution network, in this case in California. The three-wire delta lines configuration is not common in US distribution networks; however, this model allows for testing algorithms in this less common environment.

2.1.5. 4 Node Test Feeder

This test feeder presented in [7] was published ten years after the original IEEE test feeders. This test feeder offers a simple model for the analysis of all the available three-phase transformer connections as well as step-up and step-down operations under different scenarios of balanced and unbalanced loads.

Despite their small size, these test feeders are widely used in DERs studies [14–19] and power flow analysis [20,21] among other types of studies.

2.1.6. The Neutral-to-Earth Voltage Test Case and Distribution System Analysis

The proliferation of harmonics that are generated by residential loads is producing an increase in the NEVs. Nowadays, modeling NEV is becoming an important issue, however, it requires more detailed test networks. This test case described in [9] provides a test feeder that explicitly includes pole ground resistances and aims to understand the impact on contact voltage levels and NEV under different parameters of neutral conductor section or ground resistance. This test case is mostly used in load modeling studies [22–24] and harmonics analysis [25].

2.1.7. 8500 Node Test Feeder

This test case referred in [10] was obtained from a real US distribution network with some light changes. The objective of this test feeder is to provide a large-scale reference network that allows for researchers to test algorithms on a more realistic and larger-scale system. Bus relative coordinates are included in the feeder data. It comprises several common North American features like a deep penetration of voltage regulators, per-phase capacitor banks, low-voltage secondaries, and centered-tapped transformers. It was published in two different versions, a balanced secondary-loading version, and a more realistic one with unbalanced secondaries. The primary voltage level is 12.47 kV and the secondaries are split between 120–240 V. This test feeder is widely used in smart grid and DER integration studies [26–28].

2.1.8. Comprehensive Distribution Test Feeder (CTF)

This test feeder presented in [11] aims to present a diverse and detailed network where most of the available configurations and equipment are included. The inclusion of switching devices allows for a range of network reconfiguration possibilities. This capability, combined with several different equipment types like overhead and underground lines, dissimilar transformers, step voltage regulators, induction machines, capacitor banks, and the mixture of distributed and spot unbalanced loads, results in a remarkably complete network where many possibilities can be tested. Despite being so complete,

this test feeder has been designed for software testing issues, and outside of this application the results can be unrealistic. This test feeder is often used in smart grid analysis [29,30].

2.1.9. IEEE 342-Node Low Voltage Networked Test System (LVNTS)

This test system described in [12] contains a set of eight 13.2 kV primary feeders connected via delta/grounded-wye transformers to a low voltage meshed network in order to feed 50 MVA of unbalanced loads. The low voltage grid differentiates between the 120/208 V grid system (used in high-density areas) and the 277/480 V grid system (used in large load centers). The aim of this test system is to provide a reference for researchers whose objective is the evaluation of algorithms in non-radial distribution networks. This test system has been designed in order to deal with issues like heavily meshed systems with several parallel low voltage lines and transformers. This test feeder is mostly used in DERs studies [31], and communications planning analysis [32].

2.2. PNNL Taxonomy Feeders

The increasing penetration of smart grid technologies in the United States networks highlights the importance of the availability of test feeders that allow for studying the impact of their integration in a reliable way. Due to the large size of the country and the numerous different utilities, real networks present a wide range of differences in terms of topology and equipment used. For this reason, test feeders should reflect the differences due to parameters, such as climate region or voltage level.

In 2009, PNNL tried to answer this need with the publication of a set of 24 taxonomy radial distribution test feeders that are representative of the US continental area [33]. These synthetic distribution test feeders were developed through a clustering algorithm of 575 actual distribution feeders from 17 different utilities. To carry out this classification, the US was divided into five climate regions, where 35 relevant statistical and electrical properties were studied. A full description about the nature of each feeder is provided in the report [34], and are succinctly summarized in Table 2. This set of feeders is mostly used in DERs studies [35,36], and reliability analysis [36,37].

Table 2. Pacific Northwest National Laboratory (PNNL) Taxonomy Feeders.

ID	Primary Voltage (kV)	Peak Load (MVA)	Nodes	Description
R1-12.47-1	12.5	7152	613	Moderate suburban and rural
R1-12.47-2	12.47	2836	337	Moderate suburban and light rural
R1-12.47-3	12.47	1362	52	Small urban center
R1-12.47-4	12.47	5334	302	Heavy suburban
R1-25.00-1	24.9	2105	323	Light rural
R2-12.47-1	12.47	6046	482	Light urban
R2-12.47-2	12.47	6098	250	Moderate suburban
R2-12.47-3	12.47	1411	768	Light suburban
R2-25.00-1	24.9	17,021	317	Moderate urban
R2-35.00-1	34.5	8893	1031	Light rural
R3-12.47-1	12.47	8417	633	Heavy urban
R3-12.47-2	12.47	4322	263	Moderate urban
R3-12.47-3	12.47	7880	2000	Heavy suburban
R4-12.47-1	13.8	5530	571	Heavy urban with rural spur
R4-12.47-2	12.5	2218	263	Light suburban and moderate urban
R4-25.00-1	24.9	948	230	Light rural
R5-12.47-1	13.8	9430	265	Heavy suburban and moderate urban
R5-12.47-2	12.47	4500	311	Moderate suburban and heavy urban
R5-12.47-3	13.8	9200	1468	Moderate rural
R5-12.47-4	12.47	7700	643	Moderate suburban and urban
R5-12.47-5	12.47	8700	1075	Moderate suburban and light urban
R5-25.00-1	22.9	12,050	946	Heavy suburban and moderate urban
R5-35.00-1	34.5	11,800	338	Moderate suburban and light urban
GC-12.47-1	12.47	5200	27	Single large commercial or industrial

2.3. EPRI Representative Feeders

EPRI provides a set of six large representative feeders (J1, K1, M1, Ckt5, Ckt7, and Ckt24) obtained from real networks. Bus relative coordinates and time series data are included in all feeder´s data in order to provide more realistic cases.

Three of the feeders (J1, K1, and M1) are deeply focused on assessing the impact of different levels of distributed photovoltaic (PV) penetration. Table 3 summarizes the main parameters of these test feeders.

Table 3. The Electric Power Research Institute (EPRI) Test Feeders 1.

ID	Primary Length (km)	Primary Voltage (kV)	Number of Customers/Loads	Peak Load (MW)	DG (MW)
Feeder J1	93.3	12.47	1384	6	1.7
Feeder K1	45.1	13.2	321	6	1
Feeder M1	20.9	12.47	1470	5.5	-

2.3.1. Feeder J1

This is a real feeder located in the Northeastern United States and is referred in [38]. It is composed of residential, commercial, and light industrial customers. This feeder models 1.7 MW of customer-owned PV systems, along with voltage regulators and capacitor banks. Customers have noted overvoltage problems that are assumed to be caused by PV and a slow load tap changer (LTC). This test feeder´s goal is to find solutions in areas with overvoltage.

2.3.2. Feeder K1

This is a real feeder that is located in the Southeastern United States and is presented in [39]. It is composed of commercial and residential customers. This feeder models 1 MW of customer-owned PV systems. A substation LTC provides the voltage regulation as well as a capacitor bank that is placed mid-feeder. No voltage regulators are included. The objective of this test feeder is to test power flow solutions in environments with high penetrations of customer-owned PV without voltage regulators.

2.3.3. Feeder M1

This feeder described in [40] provides a detailed model of secondary feeders. It models reactive compensation that is offered by three-phase radio-controlled capacitor banks. The aim of this test feeder is to test capacitor bank management strategies in order to set a proper power factor.

2.3.4. Ckt 5, Ckt 7 and Ckt 24

These large-scale test networks referred in [41] allow testing power flows in smart grid environments. Table 4 summarizes the main parameters of these test feeders.

Table 4. EPRI Test Feeders 2.

ID	Primary Length (km)	Primary Voltage (kV)	Number of Customers/Loads	Xfmr Size (MVA)	Number of Feeders
Ckt 5	77.2	12.47	1379	16.31	1
Ckt 7	12.9	12.5	5694	19.32	14
Ckt 24	119.1	34.5	3885	69.37	2

These networks are mainly used in studies about high-penetration PV environments, where Volt/Var control strategies are needed to overcome overvoltage problems [42–44].

2.4. PG&E Prototypical Feeders

This set of 12 test feeders presented in [45] offers a taxonomy of the major type of networks that are observed in PG&E´s system. They are obtained through a clustering process of 2700 primary distribution feeders. Different kinds of networks, with a wide variety of sizes (from approximately 100 nodes to 2000 nodes) and customers mixes are represented in this compilation. The aim of these test feeders is to test the impact of DERs under different scenarios.

2.5. Other Test Feeders

Many other test feeders have been used in papers to study different issues, however, only a few of them are publically available for the research community. In what follows, several test feeders that have been published and cannot be classified in the previous groups are presented. Some of these feeders were intended to address the request presented in [8].

2.5.1. Benchmark Models for Low-Voltage Distribution Feeders

This test feeder described in [46] aims to reproduce the characteristics of a real and standard low voltage network. During the design process, a differentiation between residential, industrial, and commercial subnetworks has been made, adjusting equipment and features to the nature of the customer. A deep dive into the layout and geometry of the typical overhead and underground lines is also performed. This test feeder is used in network management analysis [47–49].

2.5.2. Agent-Based Distribution Test Feeder with Smart-Grid Functionality

This 13.2 kV test feeder referred in [50] is obtained from a real distribution network in Iowa where the peak power is close to 14 MVA. Customers are equipped with several smart-grid features, like rooftop PV panels, and price-responsive loads with time series data (e.g., smart air-conditioning devices and electric vehicles). The objective of this test feeder is to provide a tool that enables the analysis of wholesale electric power markets joined with the features of an actual feeder with smart-grid technologies. This test feeder is used in smart-grid studies [51] and planning process analysis [52,53].

2.5.3. Test Feeder for DG Protection Analysis

This 12.47 kV test feeder presented in [54] is extracted from an actual network with weak sub-transmission source impedance connected to a 1.65 MW wind turbine. The aim of this test feeder is to provide a benchmark that allows for testing distributed generation protection elements under four different fault scenarios. This test feeder has been used in power flow analysis [55].

3. Limitations of Previous Test Feeders

Distribution test networks, representing large regions and matching realistic utility features, become necessary for the development of advanced distribution tools, like OPFs, Volt/Var optimization, or network reconfiguration algorithms. The previously described set of test feeders presents a number of limitations that make their use for advanced distribution system applications difficult. Among these limitations we have found some common ones, such as: their small size, the lack of time series data representing demand and generation variability, the absence of representativeness, the lack of geographical coordinates for the physical layout of the network, test feeders that were created for dealing with a single technical or economic issue and do not have sufficient information necessary for other applications, or isolated feeders. In what follows, these limitations are analyzed in more detail. It is important to note that each of these features are present individually in a number of the available test feeders, however, the majority of the available test feeders only contain a small sub-set of the desired characteristics. Common limitations include:

- Smaller sizes: The size of the network is an important issue that should be considered in order to extract reliable conclusions from the studies. This paper proposes the use of the term “large-scale”

only when multiple feeders that are connected to a substation are taken into account. In most of the cases, large-scale networks capture more heterogeneity in some factors like voltage levels, equipment variety, or network configurations. This leads to more scalable and robust results and conclusions. Nevertheless, the computational time increases dramatically when the size of the problem increases. The size of the existing test feeders is generally small, the largest ones being the 8500 node test feeder and the EPRI feeders. However, these medium-size test systems are not enough to verify the performance of large-scale solutions that are provided by new algorithms.

- Lack of time series data: Time series data for demands and DERs allow for a more comprehensive analysis of network operations. For example, the integration of DERs, such as battery storage devices with time constraints for their optimal management (due to their storage capacity), makes necessary the use of time series data during the study period of interest. In these cases, the standard single-period OPF should be transformed to a multi-period optimization. Multi-period OPFs allow for solutions that consider temporal constraints from DERs, such as energy storage, electric vehicles, or demand response. For instance, the presented EPRI test feeders (Section 2.3) include time series data with different profiles for the loads.
- Lack of representativeness: The representativeness of a distribution test network is related to the specific zonal characteristics of actual networks. For instance, unlike in Europe, US primary feeders consist of three-phase and single-phase feeder sections that supply electricity in the particular coverage zones. In addition, the number of customers powered by a single medium-voltage/low-voltage distribution transformer in the United States is much smaller than in Europe, as well as the size of the transformer itself. As a consequence, in the United States, the length of low voltage networks is also shorter than in Europe. Another notable difference is the layout of the feeders. In Europe, the vast majority of feeders within urban areas are underground. However, in the United States, underground feeders are limited to some specific residential and commercial areas. In general, urban networks have higher load density than rural networks. The type of network topologies and the type of network equipment can change depending on that the geographic and development considerations of a particular region. For instance, rural networks are topologically much more radial, and the existence of loops connecting different feeders is much less frequent than in urban networks. Finally, the type of equipment that is used by utilities changes from country to country or from region to region. For instance, the presented IEEE 8500 node test feeder includes the detailed characteristics of center-tapped MV/LV distribution transformers used in the United States.
- Missing geographical coordinates: Customer coordinates are not relevant for electrical calculations; however, they give a useful topological image of the network layout. These topological issues play an important role in expansion planning and potential reconfiguration strategies in case of network failures. For instance, the IEEE 8500 node test feeder, as well as the EPRI test feeders, include the geographical coordinates of the different network nodes.
- Design and data available for only a single issue: Some of the described test feeders were designed with the objective of modeling and solving a specific technical or economic operational problem, and in general, they become unsuitable to be used in other types of problems or applications due to the lack of relevant information. One example of this case is the presented Test Feeder for DG Protection Analysis.
- Isolated feeders: Nearly all the existing distribution test systems contain only a single, isolated feeder. This effectively ignores capture voltage and other interactions between feeders that share a substation transformer and complicates testing reconfiguration using feeder-to-feeder switching commonly used for maintenance and fault recovery.

4. Need for Large-Scale Test Networks

As described above, the vast majority of the described test feeders have a variety of limitations. In particular, the research community lacks large-scale and representative test networks making it difficult to check the validity of developed algorithms and to perform reliable and scalable operational and planning studies. This is one of the reasons why public institutions are funding projects that aim to obtain a new generation of test feeders that remove current limitations while keeping the technical rigor present in some of the current test feeders is discussed in Section 2 [56].

Several planning tools that are capable of creating synthetic networks have been developed and reported in the technical literature during the last decade. These planning models are able to locate and size primary and secondary circuits, as well as distribution transformers, through mathematical programming or heuristic algorithms. Earlier efforts with mathematical programming methods like mixed integer linear programming [57] or nonlinear programming [58], are being replaced by heuristic methods like genetic algorithms [59], practical heuristic algorithms [60], or particle swarm optimization [61]. The increasing use of heuristic methods over numerical ones is driven by the computational complexity of planning entire distribution systems. The use of heuristics is particularly relevant for distribution planning because of the much larger node count when compared to transmission network planning. These past efforts have shown that heuristic methods can be dramatically faster and more robust, which becomes especially important when planning large-scale networks.

In Europe, there have been some past efforts to build "reference network models" that can automate the design and layout large-scale distribution networks [60]. Reference network models use heuristics to generate synthetic representative networks from scratch and were originally developed to overcome the information gap that was faced by regulators in assessing appropriate utility costs. Their rich modeling framework make them capable of fulfilling the criteria described in the previous sections. An overview of the main components of such a reference network model is shown in Figure 3, which highlights the various inputs and outputs that a reference network model could use for creating advanced synthetic test feeders for future use cases. However, there are major design differences between the US and Europe, making these past tools unsuitable for use in building US-style networks. Among many other differences, the US use of extensive single-phase segments considerably increases the complexity of developing a reference network model for the US.

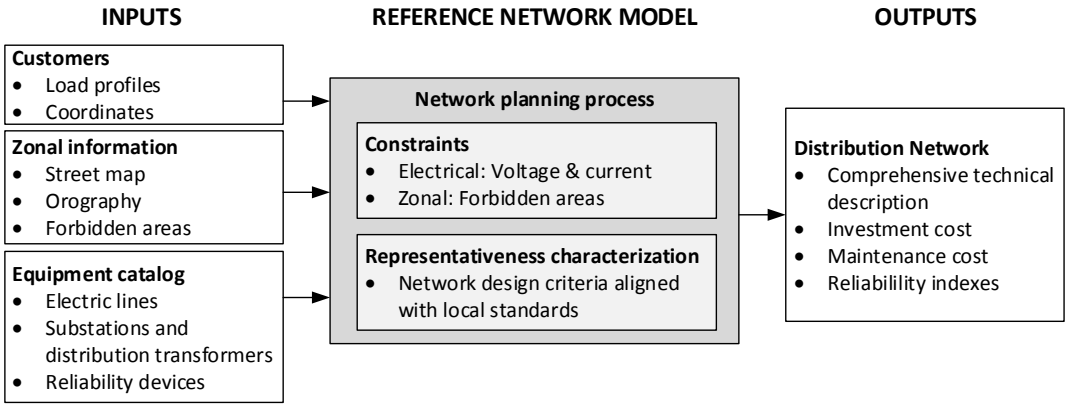

Figure 3. Components of a reference network model proposed for developing advanced, large-scale test systems.

5. Conclusions

Based on the needs of utilities and the scientific community under the new paradigm of smart distribution grids and DER integration, this paper has presented a comprehensive review of the US

distribution test feeders published over the last three decades. The paper presented a succinct analysis of all the feeders, classified them based on their origin and intended uses or applications, systematically delineated all of the limitations, and identified future research needs in this field related to test feeder generation. The first set of test feeders includes small, purely radial, and non-representative distribution networks that were effective at the time and for specific intent, but have been overused in unintended ways. However, the observed trend in the test feeders published in the last years is to build large-scale representative networks with reconfiguration capabilities and are able to model several technical and economic operational and planning issues; for instance, the ones that are associated with the integration of DERs under different future scenarios. Planning tools based on numerical and heuristic methods, such as reference network models, are opening new research areas in order to design these required large-scale realistic networks and make them suitable for validating and comparing advanced distribution system algorithms.

Acknowledgments: This work was supported by the U.S. Department of Energy under Contract No. DE-AC36-08GO28308 with Alliance for Sustainable Energy, LLC, the Manager and Operator of the National Renewable Energy Laboratory. Funding for this work was provided by Advanced Research Projects Agency-Energy (ARPA-E). The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

Author Contributions: F.E.P.M. carried out the state of the art review during his Ph.D. research. C.M.D. and T.G.S.R. supervised this work. F.E.P.M., C.M.D., T.G.S.R., B.P., B.-M.H., V.K., F.d.C.G. and B.M. contributed to the preparation of the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

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