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Representative power distribution network: a review of available models

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ABSTRACT

In recent decades, there has been an increasing penetration of new smart grids (SG) and distributed generations (DG) that are connected to the distribution network (DN). Thus, it is critical for utilities to analyze and assess their impact on the power system networks, which often necessitates major decisions about network operation and planning. Consequently, researchers are constantly developing new and improved methods of advanced control and operation to address these challenges. Unfortunately, there are a limited number of realistic DN models that are made publicly available by the utilities for the development, testing, and evaluation of such new methods. This is mainly caused by the utilities' concerns and reluctance to reveal the public's real and “sensitive” network information. Although international standard test systems such as IEEE and CIGRE are publicly available, these test network models are customized based on the US DN and are not representative of the other networks that operate under different network settings. This paper presents a brief literature survey of existing and prominent representative DNs with a special emphasis on identifying the general description, and application, as a comparison for future development of test network in Malaysia.

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1. INTRODUCTION

Technology developments in distributed generations (DG) and smart grids (SG), both of which are typically connected to a distribution network (DN), pose significant operational challenges to power system networks of the future. Technical and economic considerations must be taken into account by the utility due to the penetration of these technologies. The objective is to guarantee timely planning and implementation of preventive measures or long-term solutions, thereby ensuring the ongoing provision of electricity by the network in a safe, secure, and cost-effective manner. To ensure the effective design and operation of distribution systems, various power system analysis methods, techniques, models, and tools have been developed. However, without proper system models, these methods are impractical. Therefore, researchers are creating representative distribution system network models, known as representative networks (RN), with parameters and characteristics resembling actual distribution systems.

One of the publicly available international standard test case models is the IEEE test network, which was first introduced and expanded in 1979 by the IEEE community [1]–[3]. IEEE test feeders are the most frequently used topologies for algorithm testing. The models can be downloaded from http://sites.ieee.org/pes-testfeeders. Likewise, CIGRE also introduced a series of benchmark networks in reference [4]–[7], and can be downloaded from eCIGRE website https://e-cigre.org/. Mostly, researchers will use this IEEE or CIGRE test network as their validation of the proposed methodology or research. For example, simulations are used to verify the performance of the proposed control approach using the IEEE 34 nodes test feeder, with one of the medium voltage (MV) nodes substituted by the radial low voltage (LV) CIGRE RN [8]. The effectiveness of the proposed approach is demonstrated through simulations conducted on distribution test systems in the following example [9]. Firstly, IEEE 13-node feeder, operating at 4.16 kV, serves as a small-scale circuit, is utilized to evaluate the standard features of distribution analysis software, and is recognized for its short line segments and high load conditions [10]. Following that, the IEEE 123-Node Feeder represents a large-scale system suitable for simulation purposes. This circuit is characterized as "well-behaved", experiencing minimal convergence challenges [10].

One problem in using these international standard test feeders is the origin of the network settings they are based upon. These IEEE and CIGRE test networks are mostly RNs of the US power distribution system, with different network settings, configurations, and characteristics. For example, the IEEE and CIGRE test networks utilize bus voltages of 120V for LV networks, while the transformer's voltage levels are dissimilar to those found in the United Kingdom (UK), European countries, or Asian countries, which use 230V for the LV network. Thus, the results obtained from IEEE and CIGRE test networks cannot accurately represent the network's actual characteristics and performance of DN for other regions. Improving the distribution system faces many challenges. DNs are often larger and more complex than transmission networks, with wide geographical coverage and numerous nodes. Hence, gathering data and conducting detailed analyses of these circuits requires significant effort. For instance, the number of metering locations and the accuracy of the measurement data accessible from DNs is limited [11]. Moreover, the topology, length of feeders, presence of voltage control devices, operational voltage levels, and other parameters across distribution feeders exhibit considerable variation. Consequently, conducting algorithm testing on a limited number of randomly selected feeders will not produce statistically significant results [12].

To tackle this, research is increasingly focused on creating representative models for DNs that closely resemble real networks worldwide. These models, known as RNs, are synthesized from statistical analyses of actual distribution feeder models provided by utilities. By analyzing data on the attributes of real operational DNs or feeders, it is possible to generate a limited set of synthetic distribution feeder models with similar foundational characteristics to those of the actual built system. Notably, these synthetic models exclude sensitive utility-specific details such as precise substation locations and names, potentially allowing for their public availability [13], [14]. However, a challenge arises when attempting to draw accurate conclusions about the system-wide network population using either samples or standard test case feeder models if the network model does not accurately represent the statistical distribution of the actual or as-built network [15]. Little is known about how power quality affects distribution feeders, which is crucial for determining proper functions based on feeder characteristics [16]. Consequently, this poses a significant barrier to strategic planning efforts. Another obstacle is the limited accessibility of comprehensive feeder datasets and as-built models within utility databases [13], [17], often due to confidentiality constraints or poor documentation [18]. Another factor to consider, as discovered is the possibility of network topology changes [19]. In such a circumstance, the methodology's accuracy will be compromised.

Thus, this study provides a brief literature review of existing and well-known representative DNs, with a focus on finding general descriptions, applications, and development methods, which represent an evaluation and testing tool for the most advanced optimal power flow and related studies for the integration of distributed energy resources (DER) into SG. In summary, it also emphasizes the development opportunity for future development of test networks in Malaysia. This arises from the need to enhance the base case feeder used in [20] into a standardized test feeder in Malaysia, leveraging the most commonly employed network in the country. This transformation is necessary because employing the base case feeder across a broad power DN can be time-consuming. While base case feeders accurately depict existing distribution infrastructure, test feeders serve as simplified models for research, analysis, or testing purposes. Frequently, these test feeders are derived from base case feeders to retain ties to real-world conditions, thus enabling focused studies or simulations. Some academics propose simplifying distribution systems through clustering analysis, grouping similar network sections to create representative feeders (RFs) for each cluster. Detailed RF analysis can then be extrapolated to the entire cluster, streamlining the network and reducing computational demands and data needs. Hence, this paper discusses RN models utilized globally and adopts techniques from various countries to enhance the standard test case feeder in Malaysia. This enables researchers to choose suitable test networks and explore new avenues for system development. In addition, the publication offers large-scale synthetic DNs for use by the research community.

2. MAJOR FINDINGS OF EXISTING REFERENCE MODEL WORLDWIDE

This section aims to lead to findings in every country's test feeder to be adapted to Malaysia's test feeder.

2.1. Existing reference model in several countries

The following subsections shall present some of the existing and prominent methods of representative DNs proposed by researchers in different countries. Nevertheless, these methods may be readily available and may not be used as a standard test network in real-life applications.

2.1.1. United States

The initial efforts to develop representative DNs in the United States (US) date back to 1985, spearheaded by Willis *et al*. [15] at Westinghouse. In this pioneering study, the classical k-means clustering algorithm was employed to synthesize 12 RNs for the US power distribution system. Each cluster contains an average feeder, with each RN representing one of these clusters. It was shown that analyzing RN can help predict how the whole distribution system works. This includes voltage drop, losses, the number of capacitors that should be used, and more. The amount of time it takes to analyze with an RN is about 100 times less than the amount of time it takes to analyze the whole system population. With an average inaccuracy of less than 5%, the findings from each RN are extrapolated to encompass the entire system, utilizing the aggregate load of all feeders within their respective clusters. However, there is no evidence that the model was made publicly available then.

The Pacific Northwest National Laboratory (PNNL) conducted a study on distribution feeders in the US, employing the k-means clustering method to create a collection of 24 prototypical feeders [13]. The PNNL model is publicly available at https://github.com/gridlab-d/Taxonomy_Feeders. This model facilitates the analysis of new SG technologies and evaluates conservation voltage reduction (CVR) across the US DN [21]. Their method differed from the one presented in [15], where they initially performed a worldwide categorization based on climate and voltage levels. A large-scale DN with millions of electrical nodes and users can be planned using a reference network model (RNM). A new RNM-US version was created to account for the fact that US networks differ significantly from European ones in design. The RNM [22] created for European distribution systems, was modified to provide realistic US DNs. However, esoteric issues such as overcoming the "wiggles" and deciding between secondary trees and primary stars have to be dealt with. While the researchers' experiences are valuable for their work, they can also serve as a valuable resource for others constructing synthetic grid models, designing power system networks, and other related endeavors in this field.

2.1.2. United Kingdom

A series of distribution RN models referred to as the "UK generic distribution system" (UKGDS) outlines 13 RF models, consisting of six extra-high-voltage and seven high-voltage designs, developed using the "decision tree" technique [23], [24]. The UKGDS models serve various purposes, including in-network pricing mechanisms, identification of efficient investment strategies, examination of network performance, assessment of demand management, analysis of energy storage, evaluation of electric vehicle (EV) impact, and more [25]–[29]. However, the details on implementing the "decision tree" approach are unavailable. While no statistical performance index was identified to validate the quality of clusters, the performance of RNs was confirmed by comparing reliability assessment outcomes conducted on the RN model against those of the actual represented network, resulting in an average discrepancy of less than 10% [23]. The model can be downloaded at https://github.com/sedg/ukgds.

Rigoni *et al.* [14] established 11 representative LV feeders for the north west of England, achieving a high level of statistical accuracy through the utilization of multiple clustering performance indexes. However, the author pointed out the previous research failed to consider the differences across clusters. For this reason, they want to experiment with various clustering algorithms and include additional parameters in their cluster definitions. However, it is unclear if the RFs generated from their work can be used on a real network.

2.1.3. European Union countries

Research work Mateo *et al.* [30] developed a comprehensive RN for the high voltage (HV) and LV network of the typical network found in European Union countries (EU) countries. The proposed methodology resulted in constructing nine RNs (three large scales and six feeder-type) that are freely accessible to researchers interested in studying European-type distribution grids. There were three large scales: urban, semi-urban, and rural. The networks are available on request at http://ses.jrc.ec.europa.eu/distribution-system-operators-observatory. The proposed methodology has proven beneficial for constructing RNs with indications that are extremely near to the actual indicators. Future research operations are expected to benefit from these networks by lowering the number of resources traditionally allocated for case study development. However, it is still not readily accessible as a standard RN.

A work by Schneider *et al*. [31] illustrates the European LV test feeder's unique analytic challenges. This feeder was created to tackle the issue of unbalanced LV feeders, which are prominent throughout Europe. The computational issues are similar to those faced by prior test feeders, except when applying Carson's equations, the correct value of 50 Hz must be employed. It is also required to run several power flow simulations when applying time-series data to end-use loads. It is possible to run these sequentially or in parallel because no state variables are dependent on the state of the prior time step. Thus, this research gap may be a good opportunity for other researchers to continue Schneider’s work. Even though distribution test systems exist, the vast majority are made up of only a small number of test feeders and networks portraying or representing the distribution system in Europe. However, there is a work by [32] that offered a real broad distribution test network that illustrated the network of a typical European town. Additionally, the test network reveals how neutral voltage impacts DNs designed in the European style. Plus, some variables that may impact DNs are currently unaccounted for and are still of great interest.

2.1.4. Australia

In Australia, nine MV and eight LV RN feeders were developed for the DN in the area of Perth for SG deployment using a reduced dataset for SG deployment [33]. The methods combine clustering and discriminant analysis techniques for optimum clustering. The main contribution of the method is that it relies upon only six variables which are highly meaningful from an engineering perspective and readily available in most distribution companies. The benefit is that the revised multivariable statistical analysis combines clustering and discriminant analysis, seeking a stable classification result with the lowest possible error rate. Based on [11] review, firstly, Li and Wolfs [34] conducted research on Australian HV networks in 2010. Then, LV networks were added to the scope of their work in 2014 using analysis of variance (ANOVA) tests to determine the appropriateness of the selected variables [35]. They claim that by simulating a small number of RFs, their method can swiftly assess the new technology's effect on a network. Schneider *et al.* [36] believe cluster analysis can be done more effectively with smaller parameters than Schneider's. They tackle the challenge from the standpoint of "technical expertise" to focus on only the most important network metrics before building clusters based on these selections. The initial essential parameters do not indicate the engineering skills they used. They just pointed out that the study's feeders are all in the same climate zone.

Compared to Schneider's 35 [36], these seven characteristics yield eight prototype feeders. The feeders are then described by Li and Wolfs [37] in a straightforward style to apply to an actual network, for example, "residential primarily utilizing overhead lines." They point out that whenever a network's feeders are proven to be statistically significant, they may be used to test a variety of SG technologies. They do not, however, apply their method to an actual network situation to assess its robustness; instead, they look at two pieces of modeling work done by others in [21], [25]. In Kiaee *et al.* [25], they used the UKGDS, so LV feeds are ignored. There appears to be more ongoing research in this area by Schneider [31] or Li and Wolfs [35].

2.1.5. Spain

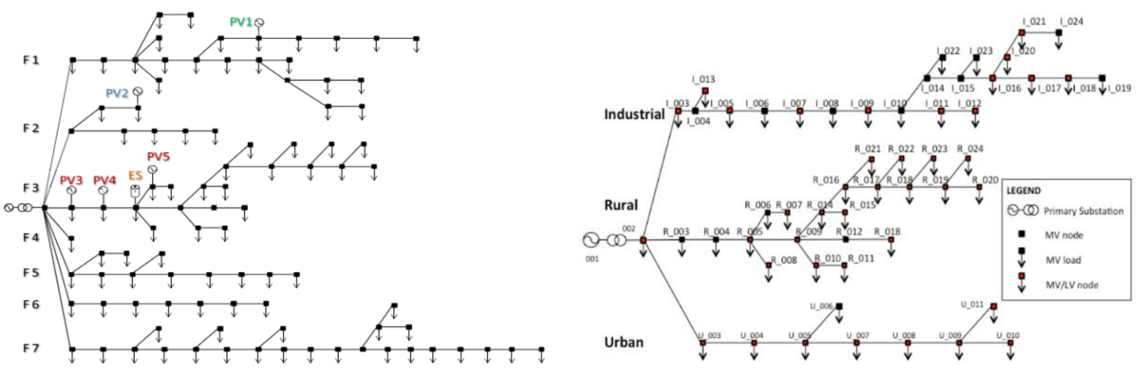
In Spain, Domingo *et al*. [22] and Pilo *et al*. [38] developed a comprehensive large-scale distribution RN model for distribution planning, integrating geographical information system (GIS) and street map data. This model serves as a robust planning tool to facilitate efficient cost distribution and incentive regulation for various DNOs operating across different regions. It employs a heuristic optimization algorithm incorporating the minimum spanning tree and branch-exchange technique. However, the project entails substantial input data requirements, such as the geo-referenced positions of every connection point, customer, and DER. Petretto *et al.* [39], the same network is used in Italy to determine the capacity of a DN to maintain grid stability. By integrating a GIS-based clustering process with a synthetic representation of HV or MV substations and their associated DNs, the research proposes a novel technique for estimating DN capacities to support grid stability. His work will be examined more in the following sub section.

Previously, Velasco *et al.* [40] demonstrated the classification procedure. A 'losses map' is created for each RF, from which Monte Carlo simulations can deduce the peak value of losses in the associated feeder for various demands of the load. This losses map has the benefit of not requiring load flow algorithms to be executed. A clustering-based methodology is offered as an energy loss tool to enhance the energy efficiency decision-making process in the extended research by a group [41]. Customized networks are used to conduct k-means clustering on a feeder. For each feeder class found, the link between the net energy imported and the lost power is determined during various situations. The data and network used in this procedure are the same as those used in the Spanish SG demonstration project's rollout (OSIRIS). Due to the unavailability of reliable sources of LV network topology information, a heuristic topology-building approach was developed by [42]. The algorithm is based on knowledge gained through the OSIRIS research project, found at www.proyecto-osiris.com. It replicates the topology of a vast Madrid DN. The underground feeders are comprised of 240 mm^2 aluminum cables.

2.1.6. Italy

Under the ATLANTIDE project in Italy, three RNs were devised to represent urban, rural, and industrial supply zones, facilitating case studies involving the integration of various emerging technologies such as DER, distributed energy storage systems (DESS), and active DN [43], [44]. However, the project did not specify the employment of specific clustering or statistical performance index methods. According to Bracale *et al.* [43], ATLANTIDE intends to develop a digital library of RNs with a comprehensive set of case studies to provide stakeholders with a helpful common benchmark for distribution system studies. Suppose future researchers want to compare different control methods, distribution schemes, or operating strategies as a way to deal with the new obstacles that DG, renewable generation and distribution storage devices will bring. In that case, they can use these network models as a reference. Meanwhile, the distribution management systems (DMS) model was created as part of the ATLANTIDE project [45]. The ATLANTIDE project will keep testing the DMS model in industrial and urban RNs to see how full active management (e.g., demand side integration, network reconfiguration, tap changer control, and EV charging aggregation.) can help businesses. The goal is to build a database of business cases. At the end of 2012, the first release of the ATLANTIDE Web Portal, as shown in Figure 1(a), included RNs that show how things have changed over time.

ATLANTIDE completed its final stages in December 2013, and its main result is publishing the networks and tools database on its website. The ATLANTIDE project website can be found at http://www.progettoatlantide.it. Combining a synthetic representation of HV and MV substations and their DNs with a GIS-based clustering tool, Petretto *et al.* [39] proposed a unique procedure for estimating DN capacities to support grid stability. An appropriate selection of RNs is combined with modeling the distribution systems. This modular strategy allows for resolving difficulties such as DN dimension and context diversity. The method suggested in this research combines a variable number of the typical example feeders, as illustrated in Figure 1(b), to depict a specific MV DN. This ATLANTIDE project is still relevant and may be used by other studies on the application of RN, such as cost evaluation. However, a more realistic grid analysis is presumably still possible because more sophisticated studies would require either processing clusters or ways for speeding up computation, maybe by using surrogate approximation models.



(a) (b)

Figure 1. RN of ATLANTIDE project in; (a) rural area [44] and (b) three common feeders including industrial, rural, and urban [39]

2.1.7. India

Network design in India is mostly influenced by client peak loads. In contrast to developed countries' robust networks, dependability and security criteria have become the primary cost determinants [18]. The procedure was implemented in a large practical network. The RN idea establishes a test mechanism for evaluating the effects of various network charging methodologies on RN costs for usage and total cost recovery for customers. This study can be extended to determine the impact on actual consumers and practical system cost recovery. Furthermore, price strategies can be devised to make the best investments and, as a result, provide the best long-term tariff for customers. In this regard, the notion of RN, developed from the fundamentals of systems that are used economically, can be applied to network pricing [46].

A good overview of earlier work in this area is given in [18], describing the methodology used, the actual computations, and the RN resultant. There was also a link between the practical limits and the assumptions made. The RN created can be used in pricing studies in the future. Two types of parameters are used for network disaggregation: structural and population, to make the classification process more logical and straightforward. The current scope of work, however, is limited to the 11 kV and 33 kV feeders, as well as the associated 33 kV, 132 kV, and 220 kV networks. Nonetheless, the feeder class can be used at any voltage level at the same time.

Efforts were made to develop RN for DN in India, aimed at network pricing and SG initiatives [18], [47], [48]. The approach adopted involves the use of a "decision tree." This methodology entails repetitive stages of disaggregating real network feeders into sub-groups based on specific "disaggregation parameters," such as peak demand, voltage level, and geographical location. While this process bears resemblance to the clustering approach, it relies on simple statistical analysis and does not necessitate complex or automated clustering algorithms as presented in [13]–[15], [22], [33], [35]. However, there is no evidence that the network model can be downloaded for public use.

2.1.8. China

An RN is also found in China [49], the benchmark system's detailed information was proposed, including system topology and typical load statistics. The benchmark is based on multiple physical MV networks in China, some of which practice renewable and DER integration. Compared to the original networks, the structure of the benchmark system was reduced to improve user-friendliness and flexibility while fully preserving the realistic nature.

According to Fan *et al*. [50] studies, the RN model plans transmission networks. They proposed an RN for transmission lines rather than distribution lines. Still, the goal is to reduce overall costs, including operating and transmission line investment costs, while improving system reliability. While in Shandong, China, numerical tests are carried out utilizing an IEEE imbalanced benchmark and a practical-scale system [51]. The suggested method's effectiveness is validated by comparisons with deterministic, stochastic, and robust distribution network reconfiguration (DNR) approaches. The two test systems' historical data, the base case three-phase load profiles and branch parameters, i.e., the IEEE 33-bus distribution system and the Shandong practical-scale system, are both available online at https://figshare.com/s/dbee74e0c09b95633edb.

2.1.9. Malaysia

A group of research works started to develop RN for the Malaysian DN, as shown in [52]–[56]. Essentially, [53] introduced a robust methodology based on statistical approaches to synthesize generic features from drastically reduced inputs to produce a collection of RNs. The 400 feeder datasets from Peninsular Malaysia's 11 kV MV network are statistically evaluated to create six RNs based on voltage transformation and geographic locations. Data stratification is used to disaggregate the MV feeder datasets. Then, for each group or cluster, a single test network is built to represent the clusters with a "near similarity" to the rest of the network characteristics in the group. The development of an RN that is much smaller than the actual network can run less time-intensive simulations and speedier decision-making [52]. The results suggest that this strategy can retrieve the most significant features of stratified datasets. The RN performances, however, were not validated. The network's performance was also analyzed in a detailed loss breakdown for each RN [52]. The characteristics examined include the number of transformers and their capacities, the number of feeders and their lengths, and the aggregated maximum demand of each substation. Both networks stratify into urban, semi-urban, and rural types, the same as the analysis made by Italian researchers in analyzing distribution system evolution through RNs by [43] and also several other researchers [53], [57].

Recent studies show that [58] utilized the Malaysian RN model with the goal of analyzing the consequences of solar PV integration into an MV network under different solar variability circumstances. The goal of this research is to measure the transformer's tap-changing operations as a result of the effect of solar intermittency on MV RNs. With the goal of reducing network losses and improving voltage profiles, three RNs, namely urban, sub-urban, and rural networks, were modelled with three voltage level transformations of 132/33/11 kV using the generic characterization and parameters of RN. However, the research is still in its infancy as the complete RN is unavailable for public access.

2.2. Summary of the existing reference model

There is a burgeoning interest in utilizing RNs as a tool for system analysis and planning. A multitude of publications on RN development, employing various methodologies and applications, have emerged from different power utilities across different countries. The application of RNs has primarily been observed in DN planning [16], cost assessment within incentive-based regulation frameworks [59], estimate losses [40], [60], [61], and, more recently, the assessment of the impact of integrating SG technologies [30], [33], [35], [47] and DER in DNs [14], [62]. Table 1 summarizes the RNs surveyed in this paper.

Table 1. Summary of RN model surveyed

References	Country of replicated network	Statistical method	Is it publicly available?	Download link
[1]–[3]	IEEE test network	Benchmark algorithm	Yes	http://sites.ieee.org/pes-testfeeders
[4]–[7], [63]	CIGRE test network	Benchmark algorithm	Yes	https://e-cigre.org/
[13], [36]	US	K-mean clustering algorithm	Yes	https://github.com/gridlab-d/Taxonomy_Feeders
[14], [23]	UK	Decision tree Clustering performance index	Yes	https://github.com/sedg/ukgds http://www.sedg.ac.uk/
[30]	EU	Open data approach	Yes	http://ses.jrc.ec.europa.eu/distribution-system-operators-observatory
[33], [35]	Australia	Clustering analysis	Unknown	-
[41], [42]	Spain	K-means algorithm Heuristic optimization algorithm	Yes	OSIRIS Project www.proyecto-osiris.com
[43], [44]	Italy	Clustering performance index	Yes	ATLANTIDE http://www.progettoatlantide.it
[18]	India	Disaggregation parameters Clustering approach	Unknown	-
[49]	China	Benchmark system	Unknown	https://figshare.com/s/dbee74e0c09b95633edb
[53]	Malaysia	Data stratification	Unknown	-

DG's penetration in the power sector is steadily increasing due to its ability to improve technical standards and provide a hopeful future for power generation in electric networks. An attempt was made in [64] to determine the efficacy of the proposed method. Then, it was put to the test on the 54-bus DN. RNMs were also employed in other research, such as in [65], for the development of large-scale MV/LV substations. Following that, the research in [66] looked into voltage stability in the context of the proliferation of variable speed drive (VSD) loads, as well as the partial voltage collapse in a DN caused by extreme PV ramps. They were shown in both a simplified and a realistic DN, such as UKGDS. This demonstrates that RN is widely employed in a variety of applications. However, there is a gap in determining which of the RN is most suited to certain applications.

China's benchmark system is based on numerous physical MV networks, some of which implement renewable and DER integration. The benchmark system's structure has been simplified to make it more user-friendly and flexible yet maintains its realistic nature. However, the network topology changes, such as cable section changes and reconfigurations under fault circumstances, must be considered. In the US, DER, like rooftop solar, EV charging, and battery storage deployment levels for residential and commercial customers, are connected to the Indiana investor-owned utilities (IOU) systems. The advantage of DER is the number of representative feeds balances the necessary amount of power flow simulations with the number of customer loads, time horizons, and DER adoption scenarios. Meanwhile, Italy's ATLANTIDE program has developed an RN for use in scenarios of DER. ATLANTIDE is developing a digital library of RNs with a complete set of case studies to give stakeholders a beneficial common benchmark for distribution system assessments. When dealing with the new challenges brought on by DG, RE generation, and storage devices for distribution, researchers can refer to these network models as a point for comparison. Nevertheless, no precise approach for grouping and calculating statistical performance index was provided in existing works.

Despite this, the development and usage of standard test systems or RN have necessitated the testing of DN's algorithms, methods of operation, and planning goals. The advent of improved metering infrastructure has led to the radical upgrade of distribution systems in various regions worldwide. One of the most effective ways to reduce power loss, improve voltage profiles, manage load congestion, and improve system quality and dependability is to reconfigure DNs. As a result, the repository can be expanded further to create a comprehensive set of DNs that span a wider range of possible network scenarios across countries. The methodological strategy for producing RNs presented here can be replicated and improved in future studies by looking at the impact of DER or SG technology on DNs. If these networks are upgraded in the future, it is conceivable to include the cost data for each piece of equipment, increasing the networks' potential use in economic research.

3. AREAS OF IMPROVEMENT

Recent researchers have developed the Malaysia RN to analyze the DN in Malaysia. It is reliable since researchers have proved that this test network has accurate data collected. However, there is still a lack of research related to the applications of DER or DG using this model. An alternative that could be adopted in Malaysia RN is optimizing the technique researchers use in other countries instead of using their RN. This is because every network has different settings and configurations, which are unsuitable to be adopted in Malaysia's DN. As for now, the data stratification technique is used instead of k-means, improved k-means, and heuristic algorithms. This is due to the researchers developing a new technique focusing on a less complex objective. Unlike other countries that focus on the k-means clustering technique, Malaysia can start using a heuristic algorithm where it can deal with large-scale clustering since it has flexibility in optimization, especially when dealing with the application of DER.

Currently, the Malaysia RN is based on data stratification, requiring less time simulation and can retrieve significant features in the clustering process. The summary of the RN development network using data stratification or clustering technique is illustrated in Figure 2. Based on the clustering technique in Figure 2, stage 1 pinpoints the crucial components of the base case feeder, such as transformers, switches, loads, generation sources, and protection devices. Next, stage 2 simplifies the feeder's topology by assigning it into several clusters while maintaining essential features like radial structure, branching, and connectivity by eliminating redundant branches, loops, or superfluous elements. In stage 3, fine-tune the parameters of the remaining components to align with the study's requirements, including scaling load and generator sizes, modifying voltage levels, adjusting equipment ratings, and simplifying control settings.

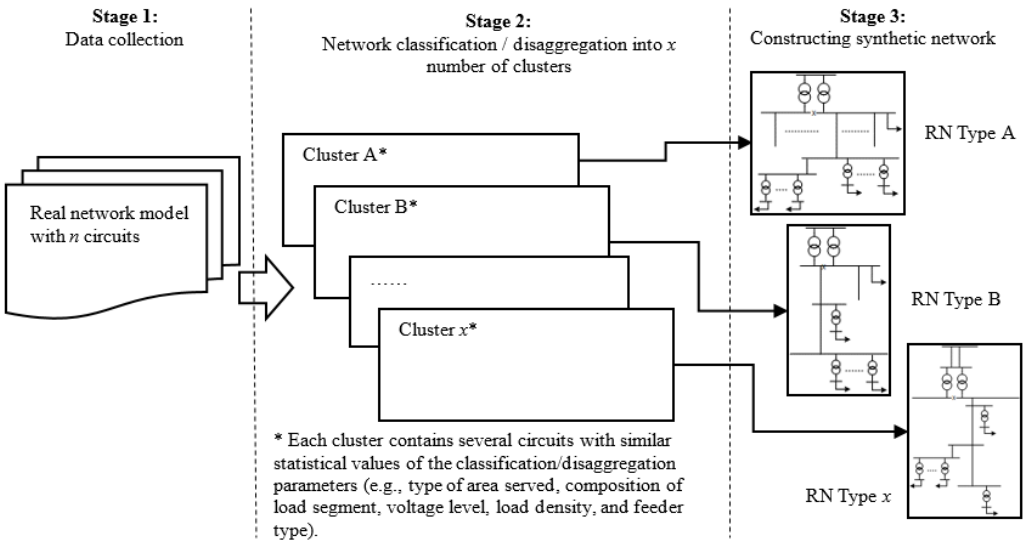


Figure 2. RN development framework from stage 1 until stage 3 (clustering technique)

Unfortunately, this technique is not yet validated; hence it is not publicly available to be used widely. Therefore, it is suggested to do validation or comparison with another test system so that researchers will fully utilize this Malaysia RN for better opportunities in the future. They are famous for their less time-consuming in nature, and since it does not disrupt the real network when researchers want to try to do some reconfiguration, it is better to use a test network. For example, in the US, Italy, and China, IEEE test feeders of various sizes are employed to assess and validate the proposed technique.

Hence, Figure 3 shows a further step that includes a validation of the test system. Stage 4 develops representative load profiles based on historical data or standard profiles, adjusting them to mirror the study area's characteristics and the relevant time frame. If the study involves the integration of DERs like solar panels or energy storage systems, incorporate these elements into the test feeder in stage 5, adapting their parameters and placements to simulate various scenarios. Stage 6 validates the simplified test feeder model against the original base case feeder to ensure fidelity in capturing desired characteristics and behaviors, comparing key performance metrics and system responses to affirm the test feeder's validity. Researchers in Malaysia can refer to Italy's ATLANTIDE program for comparison since this program supports case studies or scenarios of different emerging technologies integration. The losses in DN also can be predicted with the use of RN analysis. Dashtaki and Haghifam [67] estimate TL using load flow results of randomly constructed networks with various load sizes using a heuristic method called feeder clustering. The error rate is less than 10%. In Australia, a "losses map" is created for each RF. This losses map has the advantage of supplying the greatest losses feeder without necessitating the execution of load flow algorithms. There are many publications on RN development from various power utilities in various nations, each with its methods and applications. Accordingly, it is crucial to check that tools are compatible with the distribution system configuration.

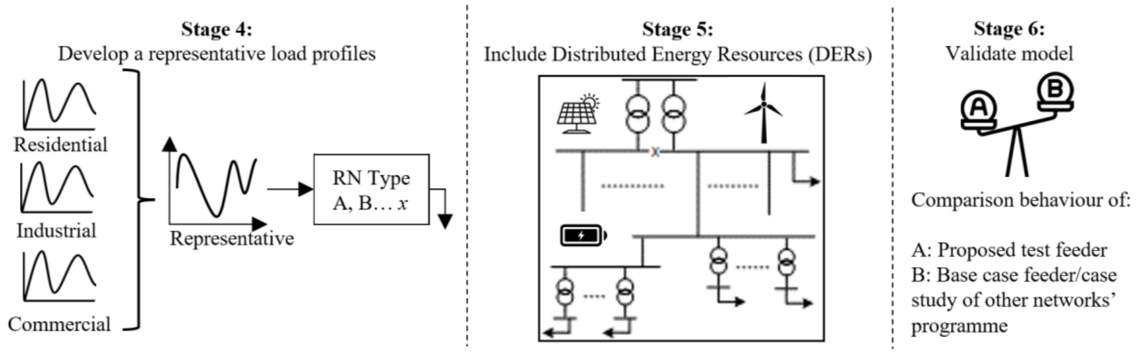


Figure 3. RN development framework from stage 4 until stage 6

In summary, it is crucial to thoroughly record all assumptions made during the conversion process, encompassing simplifications, parameter modifications, and modeling decisions. This meticulous documentation is essential for guaranteeing transparency and the ability to replicate the study's findings. By adhering to these guidelines, one can successfully enhance a base case feeder into a customized test feeder, fostering efficient and enlightening research within the domain of power distribution systems. Finally, this review paper provides a first-of-its-kind systematic literature assessment of published distribution test networks with a special emphasis on defining their primary characteristics and identifying the types of studies for which they have been utilized. In addition to helping researchers select the best test networks in Malaysia for their needs, this review paper also identifies opportunities and directions for future test systems development. In particular, the necessity of constructing large-scale synthetic networks is emphasized to circumvent the problems of the present distribution test feeders that have been identified.

4. CONCLUSION

Recent research on existing reference or RNs has provided a complete understanding of how important and useful it is for these networks to be publicly available to stimulate research interest. The findings suggest that RN is important for cost assessment, assessment of the impact of integrating SG technologies, hosting capacity studies, and many more. However, the availability of RNs in some countries is still unclear. This is because of the lack of research and studies on this topic. Consequently, it is difficult for researchers to estimate the voltage levels, losses, and so on for the enhancement of DN planning. Although there are publicly available and famous RNs such as IEEE and CIGRE, every network has different network settings and configurations. Hence, the development of RNs in each country is necessary.

This paper may help researchers across countries in using the latest RN available to this date. Also, this paper will mainly improve the test network to be used in Malaysia in the near future. RN has also been classified, and the link was provided and included in this study. Researchers can also find the research gap in each country easily. In addition, this study highlights the fact that the clustering process plays a critical role in classifying feeders. When there are more clustering techniques and a complete RN is developed, this study will facilitate an easier comparison between every RN and subsequently lead to a complete knowledge of the processes in the DN. In other words, once RN is publicly available in every country, utilities and researchers can take steps to improve DN plans, development, testing, and evaluation of such new methods. Many potential application extensions can enhance the existing DN planning, for example, considering the unbalanced characteristic of the loads, SG, and DER. Hence, there will be a lot of problems when it comes to the operation and planning of future power system networks, especially with the penetration of these technologies. This will most certainly be an intriguing future topic of research.

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